TSPS

No. 1

Recent

Developments

THE BELL SYSTEM TECHNICAL JOURNAL

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DEVOTED TO THE SCIENTIFIC AND ENGINEERING
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Traffic Service Position System No. 1
Recent Developments:

An Overview

By R. E. STAEHLER and W. S. HAYWARD, Jr.

This paper presents an overview of the Traffic Service Position System No. 1 in terms of the objectives and design philosophy of the new features that have been continuously added to the system since its initial introduction into service in the Bell System. It also serves as an introduction to the detailed technical papers that follow.

I. INTRODUCTION

Almost all of the telephones in the United States can be used to dial toll calls directly over the Direct Distance Dialing network. Nevertheless, approximately 15 percent of the total number of toll messages are placed with the assistance of toll operators. These toll calls include person-to-person, collect, credit card, hotel-originated calls, calls from coin stations, operator-dialed calls, and certain international calls. On an average business day, more than 13.1 million calls are placed through operators, and, in addition, there are over 5.2 million operator contacts for assistance and originating number identification. At year-end 1978, about 60,000 operators were employed to give this service.

1.1 Capabilities of initial design[1]

The Traffic Service Position System No. 1 (TSPS No. 1) was introduced into the field in January, 1969 (in Morristown, New Jersey) as an operator service system that could be used in conjunction with almost all Bell System local and toll switching systems to allow customers to dial their own operator-assisted calls and to relieve the operator of many tedious tasks required by cord switchboards. The basic objective of the initial system design was to automate routine

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functions so that the operator could concentrate on communicating with customers, using human judgment, and establishing calls. The features of the early installations were designed to handle basic functions for coin and non-coin calls, such as automatic call timing and recording, recording of originating directory number, and recording and transmission of customer-dialed numbers. Since TSPS employs stored program control, it was intended that additional features would be added to automate an ever-increasing number of functions as advances in technology made these technically and economically viable. Typical calls not included in the initial design were conference calls, mobile and marine calls, inward to operator calls, and special handling of hotel and motel calls.

TSPS No. 1 provides each operator with a cordless, electronic console which, through indicating lamps and pushbuttons, establishes an operator-machine interface for use in automation of routine functions. TSPS No. 1 increases the number of calls an operator can handle and also quickly makes auxiliary information available which may be needed to serve the telephone customers better.

Customers benefit from these features. Because number recording and timing calculations are performed by the computer-like system, the delay of manual operation is eliminated and calls go through faster. Calls are also billed more accurately. On coin calls, initial and overtime charge calculations are instantly available.

Operating companies benefit because they can provide operator assistance more efficiently. They can, therefore, handle increased traffic levels with the same number of operators. Furthermore, they are able to manage the work force more effectively because of the improved administrative features and to have the added flexibility to locate Operator Office Groups at convenient locations.

Operators benefit by a more attractive working environment, an equitable distribution of calls to their positions, and the satisfaction of serving their customers better.

From 1969 through 1977, five additional issues of generic programs have expanded the feature content in TSPS No. 1. There are now about 135 systems in the continental United States. Over 80 percent of Bell System customers and a large number of customers served by other companies are now served by TSPS. It is estimated that, within the next three years, the Bell System coverage will exceed 90 percent, providing almost universal availability.

1.2 Additions to capability

Since, as shown in Fig. 1, TSPS utilizes stored program control, new features have been continuously and easily introduced into the system.
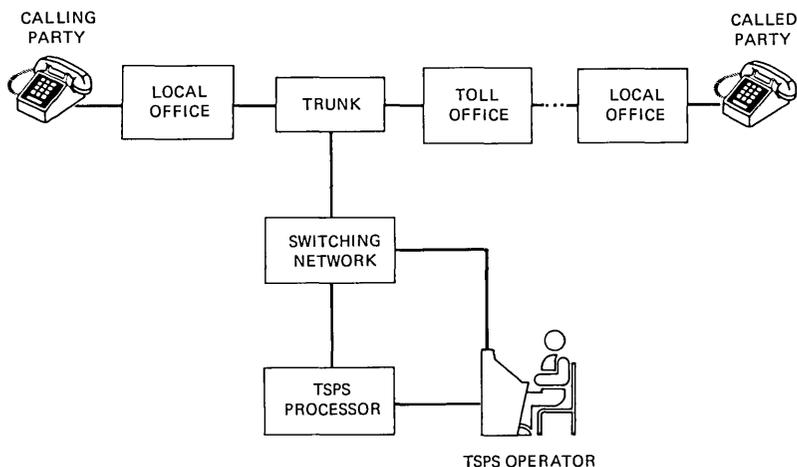
Fig. 1—Basic TSPS No. 1.

1.2.1 Hotel / motel

One of these features is the automation of hotel/motel billing. When a guest at a hotel or motel has made toll calls during his or her stay, the guest must pay the charges for these calls when checking out. These charges are now automatically computed (including taxes) for each call by TSPS. Within a few seconds, the charges are printed on a dedicated teletypewriter on the hotel/motel premises. If the hotel/motel does not have enough toll calling to justify a dedicated teletypewriter, the charges are printed at a telephone company billing center where a clerk telephones the hotel/motel and gives the charges orally—within a few minutes.

Other businesses such as convention centers, marinas, and brokerage houses may also employ this time and charge information feature to allocate telephone charges to their customers.

1.2.2 International call handling

Another of these features is the partial automation of international call handling. When a customer who is not served by an office equipped to handle International Direct Distance Dialing (IDDD) calls wishes to place an international call, he or she simply dials 0 and gives the desired international number to the TSPS operator. The operator then indicates to TSPS via key action on the console that this call is an international call and then enters the number. For a station-to-station call, the TSPS operator releases from the call, and the system automatically forwards the call to a gateway switching office, which then sends the call overseas via satellite or cable. If the call is made on a credit

card, a collect, or a person-to-person basis, the TSPS operator processes the rest of the call in the same manner as a domestic call.

In the case where a customer is served by local offices having IDDD capabilities, the customer who dials a 011 prefix followed by the country code digit and the national number will have his or her call forwarded by TSPS without the assistance of an operator. If the customer dials a 01 prefix followed by the country code and the national number, or if the customer dials 010 only, the TSPS operator will be connected to assist the customer.

1.2.3 Others

In addition, a number of other features such as time and charge quotations for non-coin (non-hotel) calls, recording of charges for directory assistance calls, and maintenance and administration improvements have been introduced into the system.

1.3 Hardware improvements

1.3.1 Semiconductor memory

The original TSPS design utilized piggyback twistor memory based on magnetic storage elements for program and call store. Advances in technology have made it possible to replace the piggyback twistor memory with a semiconductor memory resulting in major reductions in cost, space, and energy consumption.

II. MOST RECENT NEEDS

2.1 Extension to sparsely populated areas

Densely populated areas that generate a large amount of operator-assisted traffic easily justify the capital expenditures for a TSPS, but in a sparsely populated area, the toll switching center is small, and relatively few operators are needed. Savings in operating costs are not sufficient to balance the traffic-insensitive cost of the TSPS central processor. Nevertheless, the improvements provided by TSPS are extremely desirable in these sparsely populated areas. Not only can service be improved, but the difficulties of maintaining a sufficient number of operators, day and night, in small isolated teams could be eliminated.

2.1.1 Remote Trunk Arrangement[2]

To economically provide the benefits of TSPS to the sparsely populated areas, the Remote Trunk Arrangement (RTA), as shown in Fig. 2, has been developed to bring TSPS service from a distant TSPS to one of these locations.

The RTA equipment is located at a toll office in the rural area, with a concentrator network providing the talking path between the incom-

ing trunks and the TSPS operator. Data links (called peripheral control links, PCLs) connect the RTA equipment with the centrally located base TSPS processor which retains the control, logic, records, and centralized access to operators. The operator traffic from one or more RTAS is added to the traffic of a centrally located base TSPS to generate the load necessary to utilize a TSPS economically.

An improved electronic operator console (the 100C) combining training and service features has been designed to be used for both local and remote applications. This configuration is designated Position Subsystem (PSS) No. 2. The distance from the farthest RTA through the TSPS processor to the farthest Operator Office Group can total as much as 1000 miles, so that one TSPS can handle the traffic from a large geographical area.

2.1.2 Design aspects [3-5]

The articles in this issue covering the RTA design aspects include overall description, operational characteristics, transmission considerations, and hardware and software implementation.
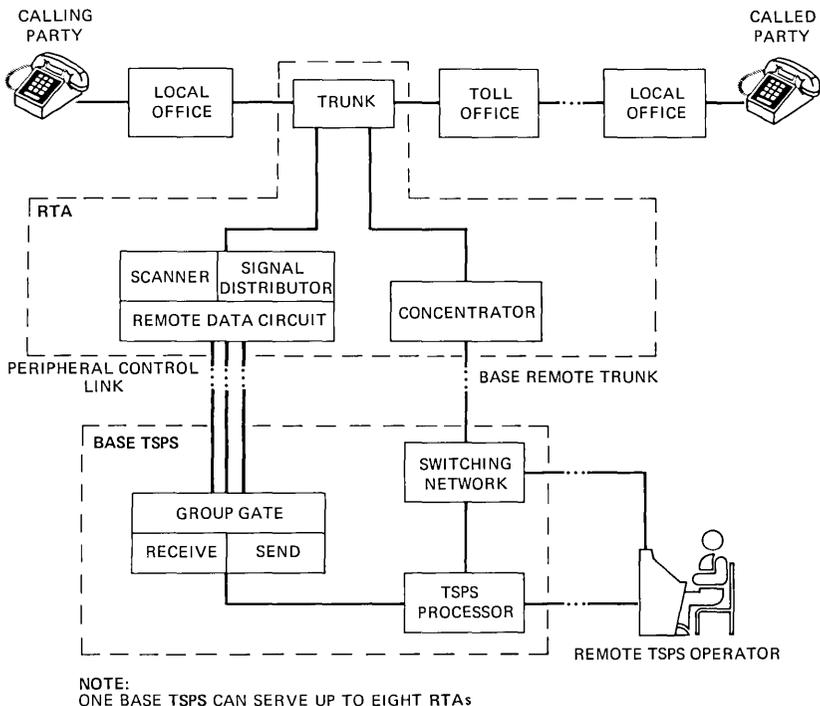
Fig. 2—Remote Trunk Arrangement.

2.2 Relieving operators of routine coin toll call functions

As advances were made in technology, it became increasingly apparent that routine coin toll call functions, such as charge quoting and coin collection, could be fully automated. Confirmation of the technical and economic viability of this approach was obtained via in-depth systems engineering studies supported by test results on laboratory feasibility models.

2.2.1 Automated Coin Toll Service

To further the benefits of TSPS, the Automated Coin Toll Service (ACTS), shown in Fig. 3, has been developed to provide TSPS with the ability to process station paid coin calls automatically, including initial period notification, overtime charge notification, and quotations on time and charges for non-coin originated calls. For communicating with the customer, additional equipment was provided with TSPS which could store digitally encoded speech segments, concatenate these speech segments into sentences, and monitor the coin deposits.

Stored program was added not only to control the new equipment in performing the coin service tasks but also for interfacing the new equipment with the existing TSPS.

2.2.2 Human factor studies[6]

The complex nature of the customer-machine interface in ACTS prompted the implementation of a three-month human factors trial in Chicago, Illinois. The trial was designed to provide ACTS-like service using TSPS operators plus a skeletonized prototype of the ACTS equipment.
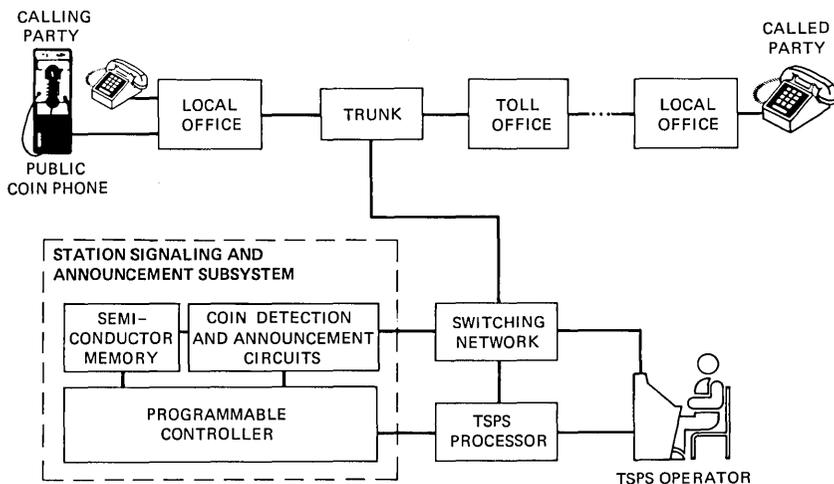
Fig. 3—Automated Coin Toll Service.
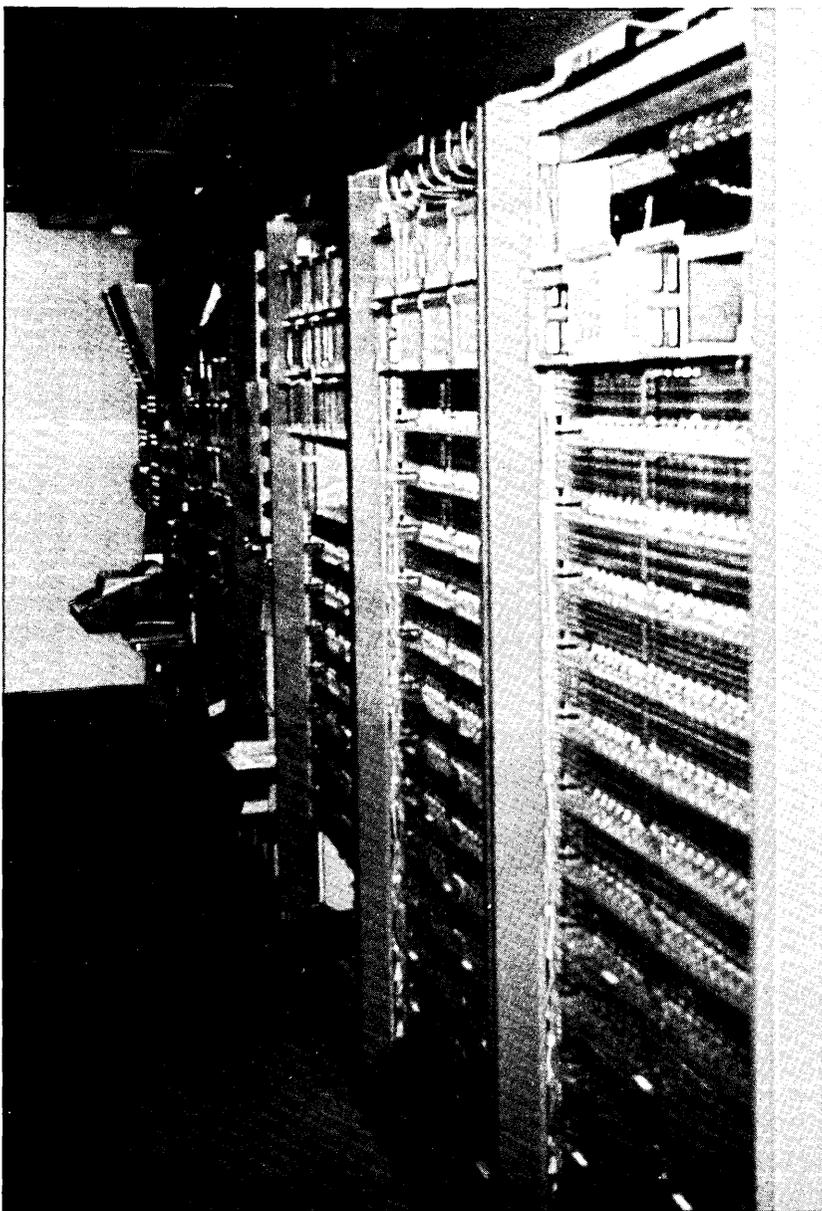
Fig. 4—Remote Trunk Arrangement in Utica, New York.

The TSPS operators were instructed to respond only to dial signals from customers and transmit the initial period length and call charges computed by TSPS to an auxiliary minicomputer via a teletypewriter. The minicomputer in turn sent instructions to the prototype ACTS

equipment to fabricate sentences (initial time interval and call charges) which were transmitted directly to the customer. The coin deposits made by customers in response to the announcements were then transmitted by the TSPS operator to the minicomputer via the teletypewriter. Subsequent prompting announcements and the timing of such announcements were controlled by the minicomputer.

The results of this trial established the basic human factors design parameters essential to the development of a system that would satisfactorily complete coin toll calls without operator assistance.

2.2.3 Design aspects

The articles in this issue covering the ACTS design aspects include details of the human factors trial, system description, operational characteristics, and hardware and software implementation.

III. STATUS

3.1 Remote Trunk Arrangement

The first RTA system was placed in service in Syracuse-Utica, New York, in May, 1976. The RTA equipment in Utica is shown in Fig. 4.

As of year-end 1978, 120 RTAs and 60 PSS No. 2s are in service, with about 20 more RTAs and 10 PSS No. 2s in various stages of installation.
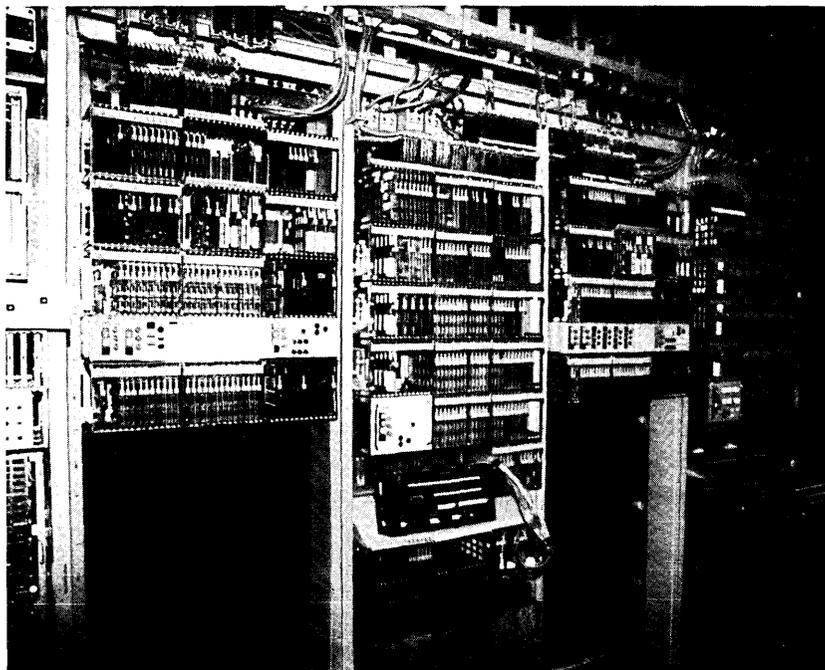
Fig. 5—Automated Coin Toll Service in Phoenix, Arizona.
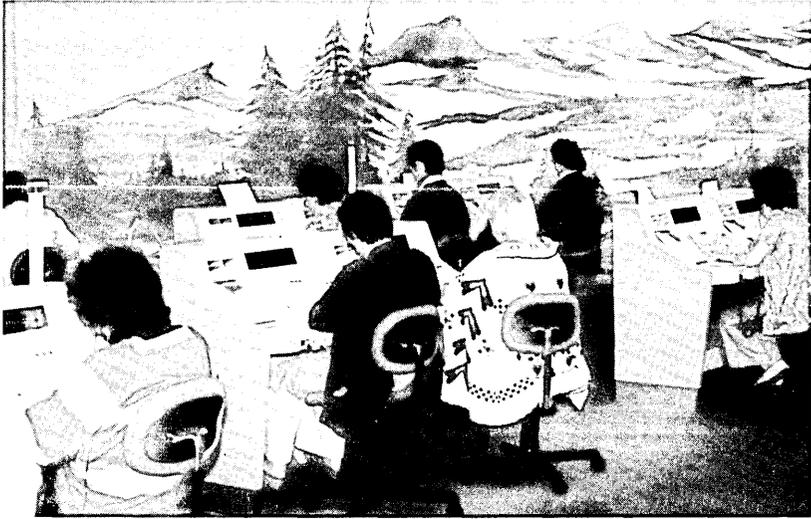
Fig. 6—An Operator Office Group in Phoenix, Arizona.

3.2 Automated Coin Toll Service

The first ACTS system was placed in service in Phoenix, Arizona, in November, 1977. The ACTS equipment in Phoenix is shown in Fig. 5.

As of year-end 1978, 3 ACTS were in service, with about 20 more in various stages of installation. By 1981, it is estimated that ACTS will be installed in all TSPS sites that have significant coin traffic, and that most of the coin paid calls in the Bell System will be handled by the ACTS equipment.

An Operator Office Group located in the suburbs of Phoenix is shown in Fig. 6.

IV. PERFORMANCE

Performance data from the RTA, PSS No. 2, and ACTS sites indicate that all design objectives have been achieved.

V. FUTURE TRENDS[13]

There are plans to exploit the stored program concept further by augmenting the operational software programs to utilize the basic ACTS equipment for handling credit card, collect, and third-number calling without operator intervention.

VI. SUMMARY

This paper has presented a general background for RTA and ACTS additions to TSPS No. 1 as an introduction to the technical papers that

follow. While all design details could not possibly be included, the papers in this issue provide a comprehensive overview of the greatly enhanced utilization of TSPS No. 1.

VII. ACKNOWLEDGMENTS

The development of these projects required the participation of hundreds of people in many organizations in Bell Laboratories, Western Electric, AT&T, and the operating companies. All the authors of this issue are indebted to these organizations for their cooperation and the team effort that culminated in the successful and on-schedule completion of these projects. The authors of this paper also wish to acknowledge the contributions of all the team members whose work is summarized here, as well as those of W. A. Depp, A. E. Spencer, Jr., M. A. Townsend, F. S. Vigilante; and J. C. Dalby, coordinating editor.

REFERENCES

1. R. J. Jaeger and A. E. Joel, Jr., "TSPS No. 1—System Organization and Objectives," B.S.T.J., *49*, No. 3 (December, 1970) No. 3, pp. 2417–2443.
2. T. F. Arnold and R. J. Jaeger, "TSPS/RTA—An Overview of the Remote Trunk Arrangement," Conference Record, *3*, International Conference on Communications ICC 75, p. 46–1.
3. S. M. Bauman, R. S. DiPietro, and R. J. Jaeger, "TSPS No. 1: Remote Trunk Arrangement—Overall Description and Operational Characteristics," B.S.T.J., this issue, pp. 1119–1135.
4. W. Brune, R. J. Piereth, and A. G. Weygand, "TSPS No. 1: Remote Trunk Arrangement Position Subsystem No. 2—Transmission and Signaling Considerations," B.S.T.J., this issue, pp. 1137–1165.
5. A. F. Bulfer, W. E. Gibbons, and J. A. Hackett, "TSPS No. 1: Remote Trunk Arrangement Hardware and Software Implementation," B.S.T.J., this issue pp. 1167–1205.
6. A. Barone-Wing, W. J. Bushnell, and E. A. Youngs, "TSPS No. 1: Automated Coin Toll Service Human Factors Consideration," B.S.T.J., this issue, pp. 1291–1305.
7. M. Berger, J. C. Dalby, E. M. Prell, and V. L. Ransom, "TSPS No. 1: Automated Coin Toll Service Overall Description and Operational Characteristics," B.S.T.J., this issue, pp. 1207–1223.
8. G. T. Clark, D. H. Larson, and K. Streisand, "TSPS No. 1: Automated Coin Toll Service Circuits and Physical Design," B.S.T.J., this issue, pp. 1225–1249.
9. R. Ahmari, J. C. Hsu, R. L. Potter, and S. C. Reed, "TSPS No. 1: Automated Coin Toll Service Software—Operational and Maintenance," B.S.T.J., this issue, pp. 1251–1290.
10. J. J. Stanaway, J. J. Victor, and R. J. Welsch, "TSPS No. 1: Software Development Tools," B.S.T.J., this issue, pp. 1307–1333.
11. J. P. Delatore, D. H. Van Haften, and L. A. Weber, "TSPS No. 1: System Verification and Evaluation Procedures," B.S.T.J., this issue, pp. 1335–1346.
12. G. Riddell, R. T. Steinbrenner, and C. R. Swanson, "TSPS No. 1: Operator Training," B.S.T.J., this issue, pp. 1347–1357.
13. E. M. Prell, V. L. Ransom, and R. E. Staehler, "The Changing Role of the Operator," International Switching Symposium, Paris, France, May, 1979.

Traffic Service Position System No. 1:

Remote Trunk Arrangement: Overall Description and Operational Characteristics

By S. M. BAUMAN, R. S. DiPIETRO, and R. J. JAEGER Jr.

This paper is an introduction to the Remote Trunk Arrangement feature of the Traffic Service Position System. The design permits the TSPS trunk circuit, which connects the subscriber to the operator, to be located in a distant, rural location. All the logic, records, control, and centralized access to the operators remains at the base unit. The Remote Trunk Arrangement is controlled over a data link and up to eight RTA subsystems can be extended from a single TSPS base unit. The addition of the RTA feature, expansion of the geographical area served by TSPS, and the necessity for handling special operator service traffic, affected several TSPS design parameters and required the addition of several new features. These supporting features and the operational characteristics and design aims of RTA are described.

I. INTRODUCTION

The Traffic Service Position System No. 1 (TSPS) helps the operator more efficiently handle toll calls such as collect, credit card, charge to third number, and coin toll calls. Key elements of the system design were to have all calls served by a single large team of operators, to divide the large team into smaller groups of a maximum of 62 operators for administrative purposes, to permit the location of the groups remote from the base unit near good labor markets, and to achieve high concentrations of traffic to fully utilize the expensive equipment needed to handle the complex, detailed toll calls.

The initial market for TSPS was in large metropolitan areas having high traffic density and high employee turnover. As the needs of the

metropolitan areas were being met, it became apparent that the benefits of TSPS would be desirable in more sparsely populated areas for two major reasons. The first was that, because of their small size— 50 position switchboards and smaller—rural operator teams are less cost effective. Moreover, there is a special need to increase efficiency in off-hours when average traffic might not require the services of a single operator. Providing the supporting personnel facilities for small groups added to the cost. The second reason for providing TSPS service in rural areas was to provide uniformity of service to all customers. An increasingly mobile population anticipates the same type of telephone service nationwide.

To provide the benefits of TSPS operation in rural areas, several approaches were investigated, including a scaled-down version of TSPS and the incorporation of TSPS features in a local switching system. The solution chosen is the Remote Trunk Arrangement (RTA). As the name implies, the design permits the TSPS trunk circuit, which provides the brief transmission bridge to the operator, to be located in a distant, rural location. All the logic, records, control, and centralized access to operators remain at the base unit. The RTA is controlled over a data link and provides all the benefits and features inherent in TSPS. Since traffic from a number of RTAS can be handled by a single base unit in addition to the traffic at the base, efficient utilization of the relatively powerful TSPS is achievable. Also, existing TSPS installations not using all the available capacity can be more fully utilized by reaching out into surrounding rural areas.

One RTA can provide up to 496 TSPS trunks which connect to the base over 64 voice circuits. Control of the RTA is over triplicated data lines. To ensure continuity of service, voice transmission and data facilities are split over diverse routings. The transmission objective of having the operator voice levels equivalent to local operator service limits the maximum allowable distance between the most remote RTA to the most distant operator to 1000 miles via the base unit. Various transmission factors establish this limit as explained in Ref. 2.

The original design of TSPS provided for remoting operator groups using a special version of T1 carrier to provide both voice and data tailored to TSPS. This arrangement has been extensively applied, but it poses a limitation to some operating companies because the maximum remoting distance is 80 miles and T carrier routes are not always available to the desired operator location. Therefore, as part of the RTA development, the data link capability for controlling the RTA was so designed that it could also control a remotely located operator group. This data link arrangement has been named the Peripheral Control Link (PCL). The voice and data circuits from the base to the operator positions can now be provided by using circuits on any standard transmission facility. Also, a new version of the TSPS console

was developed to improve the circuit control mechanisms and permit consoles to be used for both training and service. The new console is designated 100C, and the combination of the PCL with the 100C is called Position Subsystem (PSS) No. 2. Position Subsystem No. 2 can be used for both local and remote applications and supersedes the original PSS No. 1. 100C consoles can be located as far as 1000 miles from the base if no RTAS are served by the base.

Several system problems unique to the rural environment had to be solved as part of the RTA development. Closing a rural cord switchboard unit often removed the only 24-hour service unit in the area. Off-hour business service calls, repair service calls, alarms from unattended telephone offices, busy line verification calls, calls from postpay coin telephones and inward assistance calls have been traditionally handled by such switchboards. After due consideration, some of these functions are now handled by new administrative arrangements and some by new designs. A description of the RTA supporting feature designs is contained in Section III of this paper.

The RTA overall description appears in the following sections and the reader is encouraged to consult Refs. 1 and 2 for more details about the hardware and software design.

II. OVERALL DESCRIPTION OF RTA/PSS NO. 2

A simplified view of the RTA is shown in Fig. 1. The TSPS, or base unit, is shown bridging onto toll-connecting trunks between local and toll switching offices. In a similar way, the RTA bridges onto the toll-connecting trunks which home on the toll switching office serving the rural area. The RTA is controlled from the base unit by means of a data link. Voice grade connections between the RTA and the base unit allow the base unit to provide operator assistance as well as other voice frequency functions (e.g., MF digit reception and outpulsing). In this way, all traffic in the complex can be handled by a single operator team and common service circuits. Also, the substantial cost of the TSPS common control equipment is shared by all traffic in the complex.

Although Fig. 1 shows only one RTA, the system is designed to accommodate up to eight RTAs in a single complex. In this way, it has proven possible to pool the traffic of a large geographic area and in some cases to justify a TSPS/RTA complex where a single location is not a candidate for its own TSPS.

Figure 2 shows a more detailed view of RTA. The TSPS base unit is shown in the lower portion of the figure. An RTA, many miles distant, is shown at the top of the figure.

The RTA works under control of the base unit SPC processor and connects to service circuits and positions via the TSPS base unit network. At the RTA location are trunks, a switching network (the
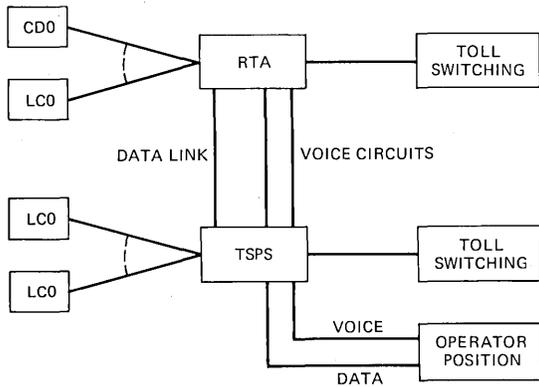
Fig. 1—Simplified diagram TSPS Remote Trunk Arrangement.
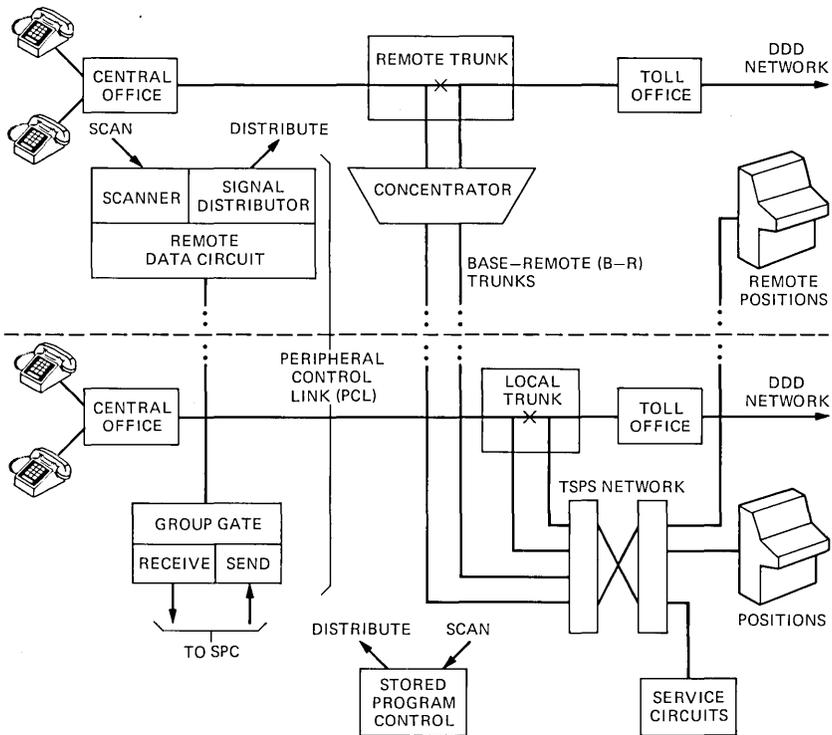
Fig. 2—Detailed diagram TSPS Remote Trunk Arrangement.

concentrator), a test frame, and scanning and signal distribution units. The RTA connects to the base unit over the Peripheral Control Link and over a number of Base-Remote (BR) trunks for voice connection to operators and service circuits.

Solid-state components are used almost exclusively for RTA circuits, and most of these consist of medium-scale TTL integrated circuits. The concentrator matrix, while controlled by integrated circuits, uses small crossbar switches. The compact physical design shown in Fig. 3 is due to this extensive use of integrated circuits. Less than one 20-ft by 20-ft building bay is required to contain an RTA of up to 496 trunks plus up to 64 base-remote trunks. Most of this space is occupied by transmission equipment and trunk frames.

The concentrator to BR trunk connections are engineered to provide a blockage of probability 0.001 to provide minimum delay in connecting operators and service circuits to calls. Since an operator is required on a connection for only a small fraction of the total call duration, a high concentration ratio can be achieved. While this ratio may vary from one site to another, 8:1 is a typical number. This is the reason for supplying a maximum of 64 base-remote trunks. One way of looking at the concentrator is that it is another stage of switching on the base network with very long links (BR trunks) between the first and second stages.

The basic traffic capabilities of TSPS remain essentially unchanged with the addition of RTA. All TSPS features are available to both TSPS
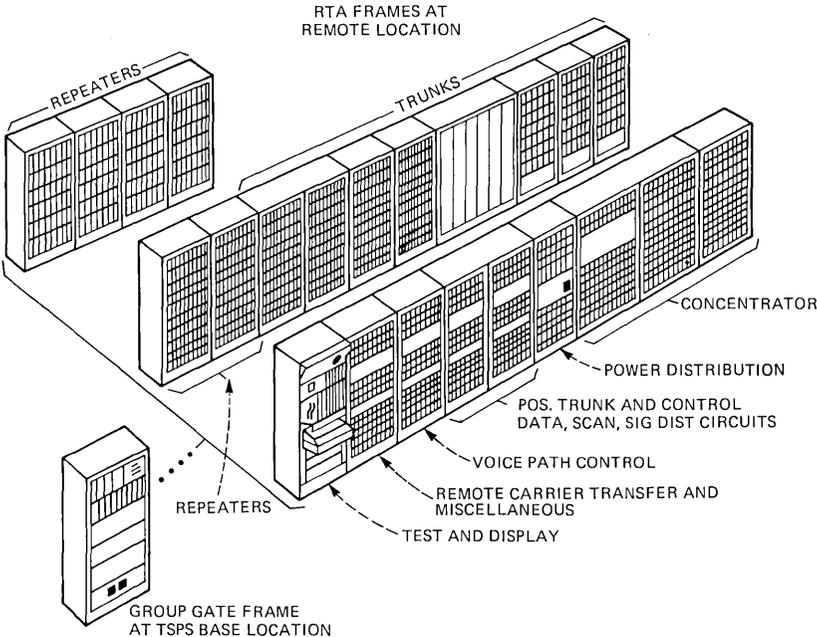
Fig. 3—RTA frames.

base unit customers and RTA customers. The customer will not be able
to detect whether service is provided directly by a base unit or through
an RTA.

2.1 Peripheral control link

The two-way data capability between the base unit and RTA is
provided by a group of elements known collectively as the Peripheral
Control Link (PCL) (Fig. 4). The PCL includes the data link itself, the
circuits which interface with the data link (group gate and remote data
circuit), and the scanning and signal distribution units. The data
facilities are standard four-wire voice channels operated full duplex
and use 2400-b/s data modems. The Group Gate and Remote Data
Circuit perform extensive error detection and provide necessary par-
allel/serial conversions. Each message over the data link is acknowl-
edged by the receiving end. Messages are retransmitted if mutilated in
the original transmission. For reliability, data facilities are provided
over two geographically independent routes. Three data lines are
provided, with one line serving as a switchable spare for two active
lines.

When used with an RTA, the PCL provides the ability to control, via
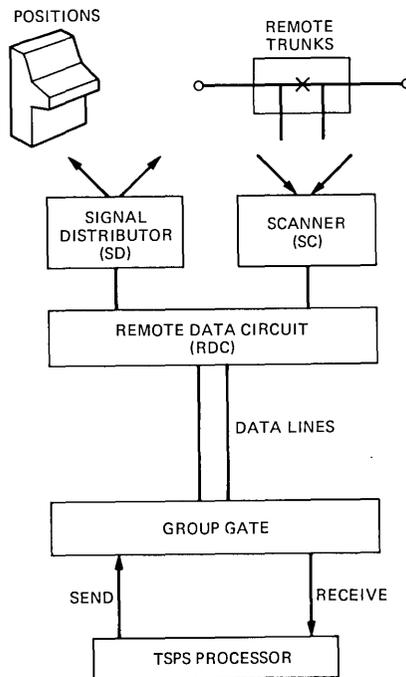
Fig. 4—Peripheral control link.

the signal distributor, the RTA trunk circuits and concentrator. By means of the scanner, the PCL can monitor trunks and report changes of state. This control and monitoring, together with the data communication function of the PCL, provides a set of general capabilities. For the PSS No. 2, the signal distributor and scanner of the PCL are used to control console lamps and detect operator keying actions.

The Position and Trunk Scanner (PTS) is located at the remote end of the PCL. Its function is to autonomously scan key reports from PSS No. 2 positions and DP pulses and supervisory state information from trunks in RTA. This information is reported to the SPC 1A over the data link. The trunks are scanned every 12.5 ms by the PTS which compares this information with last-look data in its memory. For base trunks, timing of supervisory changes of state for the purpose of detecting flashes and disconnects, and filtering out hits (a spurious change of state which must be ignored) is under program control. However, for remote trunks, since delays in transmission of successive changes of state over the data link could distort the relative timing, hit detection and filtering is done for RTA by the PTS. This is accomplished by demanding that changes in supervisory state of trunks persist for at least two successive scans before reporting them to the base unit via the PCL.

The Signal Distributor (SD), located at the remote site, is responsible, for distributing orders to remote trunks, the concentrator, test buffers, a test frame, and to 100C positions. The SD has several features designed to make efficient use of the data link. Commonly used groups of orders from the base to the remote location for control of positions are combined. Hence, one order transmitted from the base has the effect of executing many orders at the remote end. For example, there is a release order which causes all lighted lamps at a 100C position to be extinguished. This saves much data link capacity. A second design feature allows all trunks at an RTA to be initialized with one order. Since there can be as many as 496 trunks at an RTA, this could save as many as 1487 relay orders (three orders per trunk) over the data link. This feaure is used for system initialization. Customer conversations at the time of initialization must be preserved. Therefore, provisions were made in the hardware such that trunks in the talking state are not initialized.

2.2 Circuits controlled by the PCL

The RTA concentrator is controlled from the base unit by call processing software through the PCL signal distributor. The small crossbar switches are arranged in a two-stage network.

The RTA trunk circuits generally provide the same capabilities as the TSPS base unit trunk circuits. However, because they are controlled

over the data link, they differ significantly in design from base unit trunks. They have greater logic capability for sending coded flashing signals and for timing incoming flashing signals. They also have greatly augmented features for testing of the trunk units. With the use of integrated circuits and miniature relays, these complex trunks are similar in size to the functionally simpler TSPS trunks. Potential distortion of the relative timing between consecutive orders during periods of data link congestion necessitated the design of remote trunks with a unique feature. All remote trunks have the ability to generate from one to five winks from a single command. Winks of precise time duration are needed for coin station control using multiwink signaling.

As described earlier, the PCL has also been designed to function with new operator position equipment. The new 100C console contains the necessary electronics to decode information transmitted from the signal distributor, to light or extinguish the appropriate lamps, and to remember the state of all the lamps on the position. The position electronics also detects operator keying actions and provides data to the PCL scanner in appropriate form. Only a few pairs of wires are necessary to connect a position console to the PCL. Thus, the addition of positions to a position subsystem is a relatively simple matter.

The RTA/PSS No. 2 fault recognition and diagnostic programs make use of three maintenance circuits controlled by the PCL. The maintenance buffers are used to set and reset circuit states for reconfiguration and testing purposes. A Diagnostic Controller Circuit is activated over the PCL and used to execute sequences of RTA/PSS No. 2 diagnostic tests stored within its read only memory (ROM). Failing test results are reported back to the base via the PCL and formated for TTY output to the craft. The third maintenance circuit under PCL control is the Test and Display Circuit. This circuit provides the craftsforce at the remote site with a manual interface for control of trunk and position transmission test equipment. It also provides a status display of PCL and controlled circuit equipment.

2.3 Peripheral control link configurations

The RTA/PSS No. 2 system design provides for up to 15 peripheral control links to a base TSPS. There is a maximum of 8 RTA subsystems per TSPS and a maximum of 8 operator groups per TSPS.

The RTA and PSS No. 2 subsystems were each designed to operate when located at a 1000-mile maximum distance from the TSPS base unit. However, for proper transmission of voice and tones, a 1000-mile limit is applied to the sum of the farthest RTA distance to the base plus the farthest PSS No. 2 distance to the base. In other words, if a PSS No. 2 is located in a town 400 miles from the TSPS base and it is the farthest remote group, then the RTA subsystems served by the same TSPS base would have to be within a 600-mile radius of the TSPS base.

2.4 Hardware technology employed for RTA/PSS No. 2

The RTA/PSS No. 2 control circuitry design was one of the early Bell System applications of the Transistor-Transistor-Logic (TTL) integrated circuit technology. The Position and Trunk Control frame, at the remote end of the PCL, also consists of scanning circuitry using opto-isolators and diagnostic circuitry using instructions stored on existing state-of-the-art read-only-memory (ROM) devices.

The 100C positions provided with PSS No. 2 were the first large volume application of the 7-segment light-emitting diode (LED) numeric display. This new display technology was also made available for retrofit into the 100B position provided with PSS No. 1.

The RTA/PSS No. 2 features greatly extended the transmission range of TSPS. To permit such great distances between operators and customers and still maintain good voice quality required the simultaneous development of three key pieces of equipment: the Unified Telephone Circuit (4251 B network), the 1P precision hybrid, and a new three-way/four-wire bridging repeater. Each of these is discussed in Ref. 3.

The Logic Analyzer for Maintenance Planning (LAMP) was used extensively for the generation of circuit-board test-vector information provided to Western Electric. Results were also used to modify board designs to improve test access.

A minicomputer-controlled fault insertion system was developed to automate the large and repetitive task of physical fault insertion for Trouble Locating Manual (TLM) diagnostic data generation. This new system also made available timely feedback to the diagnostic designers about potential problems with diagnostic coverage and resolution.

III. RTA SUPPORTING FEATURES

The addition of the RTA feature, expansion of the geographical area served by a TSPS, and the necessity for handling special operator service traffic, affected several TSPS design parameters and required the addition of several new features. For example, with RTA, the maximum number of states and Numbering Plan Areas (NPAS) served by TSPS were increased from three to eight. In addition, the maximum number of toll switching offices with unique routing patterns serving a TSPS complex was increased from three to eight. When advancing a call to the toll network, TSPS must sometimes change the dialed or keyed digits according to a set of code conversion rules. These rules had to be changed to permit the advancement of incoming, inward, and INWATS calls through TSPS or RTA toll offices located in more than one NPA.

As mentioned in Section I, as TSPS service is extended to a wider area and TSPS capabilities are broadened to handle a wider range of call types, cordboard operations which remain solely to handle Special

Operator Services Traffic (SOST) become less and less efficient. This creates an impetus to handle more of the SOST traffic on TSPS, with the ultimate aim of eliminating the cordboard operation. Among the SOST items that were handled on cordboards, but can now be handled by TSPS, are: inward traffic and postpay coin service. In addition, small central offices connecting to TSPS require compatible trunk equipment. Multiwink coin signaling, an economically attractive method to provide coin signaling to these small offices, was also provided in TSPS/RTA.

3.1 Inward

Inward calls occur when an operator at the originating end of a call requires the assistance of an operator at the terminating end (called the inward operator) so that the latter may perform certain functions that the former cannot.

Examples of inward calls and the functions traditionally performed by the inward operator are:

(*i*) Verification—the inward operator verifies that a line is busy.

(*ii*) Calling hard to reach numbers—the inward operator tries another route for the call where previous attempts have been unsuccessful.

(*iii*) Call-back to coin stations—the call rating, computing, and recording functions are performed by the inward operator.

(*iv*) Call back (to a noncoin station) with time and charges (T&C)— the inward operator performs call rating, computing, and recording functions, and gives the T&C quote to the called party (who *originally* initiated the call).

(*v*) Call back to hotel—the inward operator performs call rating, computing and recording functions, including identification of the hotel guest, and provides the quote of charges to the hotel.

The inward feature allows a TSPS operator to act as the inward operator on an inward call. Figure 5 shows how inward calls are routed to a TSPS operator acting as the inward operator. To reach an inward operator, the originating operator, whether at a cordboard or at a TSPS position, would key forward (NPA)+(TTC)+OC, where NPA+TTC is the routine code to the Terminating Toll Center (obtained from a routing guide as a function of the NPA+NXX portion of the number to be reached by the inward operator). The numbers in parentheses (i.e., (NPA)+(TTC)) are not always present, their presence or absence being determined by the route of the call. The abbreviation OC, which stands for Operator Code, is a 3- to 5-digit number which specifies the nature of the service required from the inward operator. The Operator Codes used, together with their associated call types, are shown in Table I.

The Terminating Toll Center (TTC) recognizes inward traffic from the operator code which it receives, i.e., the OC keyed by the originating operator. Once it recognizes an inward call, the TTC will seize an inward
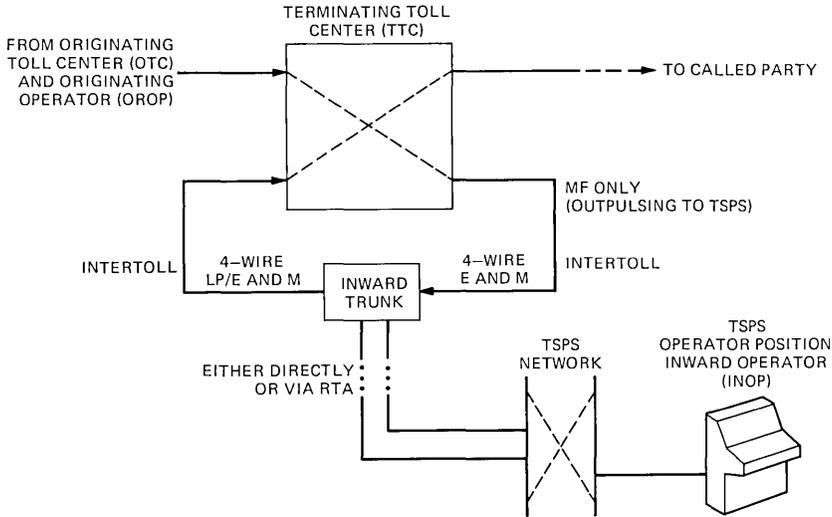
Fig. 5—Routing of inward calls to TSPS INOP and to the called party.

Table I—Operator codes and associated inward
call types [originating operator keys
(NPA)+(TTC)+Operator Code (OC)]

Operator Code	Inward Call Type
121	General inward, hard-to-reach, verification
1150(1)*	Collect or call-back to coin
1155(1)*	Time & charges (T&C) call back
1156(1)*	Hotel call back

* Additional 1 is local practice option.

trunk to the TSPS serving its toll traffic, and will outpulse the OC to that TSPS. From the OC, the TSPS determines the initial display to be given to the inward operator. The actions taken by the TSPS operator upon arrival of an inward call at the console will depend upon the nature of the inward call.

Inward trunks can be installed at RTAS as well as at a base unit. In either case, as shown in Fig 5, the inward trunk connects on its incoming side to a toll office outgoing trunk, and on its outgoing side to a toll office incoming trunk. The facilities on both sides of the inward trunk are classified as intertoll facilities for transmission purposes. Both base TSPS and RTA inward trunks are four-wire and are used with a three-way, four-wire bridging repeater. E&M signaling is used on the incoming side. The outgoing side can be arranged for either loop or E&M signaling.

Inward trunks may be organized in one trunk group for every toll

office serving the TSPS complex (base unit and RTAs). A single trunk group carrying all inward traffic routed to the TSPS or RTA through a given toll office will optimize the trunk efficiency. Alternatively, having separate trunk groups for each toll office serving the TSPS complex optimizes the grade of transmission on inward calls. Most desirable is the centralization of inward trunks at the highest class toll switch (usually the one serving the base unit) in the TSPS/RTA complex. This provides both good trunk efficiency and the ability to meet or exceed transmission performance objectives.

3.2 Postpay coin service

In postpay coin operation, the coin stations do not have coin collect and return functions. Once a coin is deposited, it is not retrievable. Therefore, collect and return signals are ineffective and are not used in postpay coin operation. Thus the trunks carrying this traffic from local offices to cordboards are simpler than those used in prepay coin operation.

Since the operator cannot return coins on a postpay coin call, a deposit for the initial period is not requested until:

(*i*) The called party answers and

(*ii*) It is determined that the correct called number has been reached.

For collection of overtime charges, there is no difference between postpay and prepay coin operation except that incorrect or questionable deposits cannot be returned.

Any of three methods may be used to bring postpay coin traffic into TSPS from a local office. Under normal conditions (no ANI failure), the first two methods result in automatic identification of postpay coin calls. The third method requires operator intervention to recognize such calls. The three methods are as follows:

(i) Dedicated Postpay Coin Trunks—The only calls routed to TSPS on such trunks are postpay coin calls.

(ii) Combined Postpay Coin-Noncoin Trunks with ANI Screening Identification—This technique is used to identify the kind of call when the local office has ANI. The technique consists of searching the coin band tables in TSPS for the received ANI number to determine whether or not that number corresponds to a coin station.

(iii) Combined Postpay Coin-Noncoin Trunks with Service Tone Identification—For such trunks, the TSPS operator can identify postpay coin calls by the presence of a service tone generated by the local office. The tone is heard shortly after the zip tone when the call is first brought the position. Absence of the service tone signifies a noncoin call.

3.3 Multiwink coin signaling

The Bell System Coin Service Improvement Committee recommended that multiwink signaling coin control be made available to provide additional coin control signals. With TSPS-RTA, BR trunk connections to coin control circuits can be eliminated with multiwink signaling, and multiwink is more economically provided than inband coin control for certain local offices.

The multiwink signaling format employs a series of one to five supervisory on-hook winks from TSPS to the local office outgoing trunks. The signals and their use are shown in Table II.

IV. ADDITIONAL TSPS FEATURES ON THE RTA GENERIC

In parallel with the RTA development, other service and maintenance features were developed. These features were made available with RTA. This section briefly describes those additional features.

4.1 Selective call screening

TSPS is required to provide for selective screening of incoming traffic that was previously handled by cord switchboards. The ability of TSPS to screen calls from various incoming trunks enables the telephone companies to offer institutions and businesses (e.g., hospitals, military installations, press and media, prisons, and university dormitories) the option of restricting the type of charging permitted for toll calls originating over some or all of their lines. Some hospitals, for example, do not want to expend the administrative effort required to collect telephone charges for toll calls from hospital patients. Hospitals could receive this kind of service from cord switchboard operators since the trunk appearance on the cordboard was labeled as hospital and the operator responded accordingly. Given the new ability for TSPS to restrict the kinds of charges allowed, the use of coinless public telephones is also made possible. Coinless public telephones can only be used to place credit card, collect, and bill-to-third-number calls. Coin-

Table II—Multiwink signaling system

Number of On-Hook Winks	Function
1	Operator release
2	Operator attached
3	Coin collect
4	Coin return
5	Ringback

less public telephones are especially attractive to operating companies' in places such as major transportation centers to reduce the number of expensive coin stations.

Another feature provided with screening is the charge quotation feature. It allows businesses (such as law firms) to get voice or automatic quotation of telephone charges on calls by account numbers similar to the TSPS hotel/motel feature.

TSPS performs the following basic functions in handling a screened call:

(*i*) TSPS determines if the line is a screened line. This is done with information present in the trunk software register indicating the trunk group as screened or by the presence of that line number in screening line number tables.

(*ii*) If the line is screened, TSPS identifies what type of screening is applicable. A table, called the screening type table, indicates the specific combinations of restrictions allowable. Each line number in the screening line number table has an index to the applicable combination of restrictions in the screening type table.

(*iii*) TSPS also validates the operator's actions. Since the screening restrictions are in memory, the acceptability of the class of billing entered by the operator is checked. If the operator enters an unacceptable class of charge, the system informs the operator by flashing the appropriate key/lamp. The operator then interacts with the customer in an effort to obtain acceptable billing.

(*iv*) Once an acceptable class of charge is entered, a unique mark is placed on the Automatic Message Accounting (AMA) tape indicating that the call was a screened call.

Any of three methods may be used to bring screened traffic into TSPS from a local office:

(*i*) Mixed traffic (combined screen/nonscreen).

(*ii*) Dedicated screened traffic.

(*iii*) ANI 7 information-digit-identified screened traffic.

In the mixed traffic case, traffic with screening conditions and traffic without screening conditions will originate over the same trunks. A search is conducted using the calling digits provided by Automatic Number Identification equipment (ANI) to determine if a screening condition exists on that particular line. If the calling number is not in the search tables, it is assumed that the line does not have a screening condition on it. If an ANI failure occurs, Operator Number Identified (ONI) digits are used for the search.

In the dedicated traffic case, a trunk group is dedicated to screened traffic. If local offices without ANI require screening, dedicated trunks must be used to deter fraud. If the trunk belongs to the dedicated screening trunk group, the calling number obtained by the operator is

checked against the screening line number tables, as in the mixed traffic case, to determine the specific restrictions.

In the case of calls from an electronic local office, an ANI 7 information digit is supplied for screened calls. The ANI information digit is denoted I in the following ANI sequence:

KP-I-7D-ST, where 7D is the 7-digit calling number.

If the ANI information digit or any part of the ANI sequence is destroyed or not received at TSPS, ONI digits are obtained and a search conducted as in the mixed traffic case. Given good ANI, the calling number is then checked against the line number table to determine the specific restrictions.

4.2 More stores/ bus (MORSTR)

More stores/bus (MORSTR) is an all-software feature which expands the Stored Program Control (SPC) No. 1A store maintenance structure to cover all expected piggyback twistor/semiconductor memory configurations. It removes the memory capacity limitation imposed by the previous maintenance software (20 stores/bus).

The maximum capacity of the SPC memory was limited by the maintenance software and by processor addressability. It was estimated that the larger TSPS systems with a combination piggyback twistor (PBT) and semiconductor memory stores would exceed the memory capacity limitation imposed by the maintenance software (20 stores/bus) upon advance to subsequent generics. The MORSTR feature was developed to provide maintenance capabilities for a maximum of 24 stores/bus. The SPC store maintenance software with MORSTR can support the various PBT/semiconductor memory combinations up to a limit imposed by the processor with the restriction that no more than 18 of the maximum 24 stores can be of the PBT type.

V. RTA CHARACTERISTICS REQUIRING SPECIAL DEVELOPMENT EMPHASIS

5.1 Necessity for more stringent transmission requirements

The original TSPS base system served by the Position Subsystem (PSS) No. 1 presented a transmission environment confined and simplified by the T1 carrier. The T1 carrier transmission limit meant that remote PSS No. 1 locations were relatively close to the toll office. With the introduction of RTA and PSS No. 2, a complex set of transmission considerations arose due to the large range of subsystem site locations allowed by the peripheral control link design. The TSPS transmission plan was revised to provide engineering and maintenance documentation for TSPS in the new RTA/PSS No. 2 environment.

5.2 Maintenance of unattended remote offices

The design intent for the RTA/PSS No. 2 feature is to provide for the primary maintenance of RTA and PSS No. 2 subsystems by a craftsforce situated at the base TSPS location. Upon identification of a fault in the remote equipment, remote site personnel would then be dispatched to replace or repair the faulty equipment. This requirement to provide base-located maintenance control reflects the general trend to more centralized maintenance in the Bell System.

Maintenance software design for the RTA/PSS No. 2 feature was strongly influenced by this trend. It was complicated by the need to provide also for those operating company situations in which more direct maintenance control was to be exercised by craftspeople situated at the remote locations.

The normal maintenance strategy associated with such items as teletypewriter interactions and visual status displays takes on an added dimension of difficulty when complicated by the introduction of multiple distant equipment sites.

More detail about the maintenance strategy chosen is provided in a subsequent article in Ref. 1.

5.3 Rapid RTA/PSS No. 2 installation buildup

The RTA and PSS No. 2 features are very attractive to operating telephone company planners because of the much increased flexibility for operator team location, the economic and service gains achieved with the replacement of small toll office cordboards, and the ability to prove in new TSPS base offices for cities of moderate size. The early demand was high, and the resulting pressures on Western Electric to supply that market were evident in the final stages of development and deployment.

Due to the efforts of many departments involved with manufacture, testing, documentation, installation, and support at the Western Electric, Columbus works and the regional offices, that heavy initial demand was satisfied. One year after the initial RTA and PSS No. 2 cutover at Utica, New York, on May 16, 1976, a dozen peripheral control links were in service and nearly one hundred had been shipped to the field. By year-end 1978, 120 RTA subsystems and 60 PSS No. 2 groups had been placed into service.

VI. ACKNOWLEDGMENTS

implemented. D. J. Eigen provided design requirements for the selective call screening feature and contributed to the software design effort. G. E. Fowler tirelessly worked to develop call-processing software and later participated with A. W. Robinson and J. J. Serinese in the field test of RTA at Syracuse and Utica, New York.

REFERENCES

1. A. F. Bulfer, W. E. Gibbons, and J. A. Hackett, "TSPS No. 1: Remote Trunk Arrangement Hardware and Software Implementation," B.S.T.J., this issue, pp.1167–1205.
2. W. Brune, R. J. Piereth, and A. G. Weygand, "TSPS No. 1: Remote Trunk Arrangement Position Subsystem No. 2 Transmission and Signaling Considerations," B.S.T.J., this issue, pp.1137–1165.
3. Ibid.

Traffic Service Position System No. 1:

Remote Trunk Arrangement and Position Subsystem No. 2: Transmission and Signaling Considerations

By W. L. BRUNE, R. J. PIERETH, and A. G. WEYGAND

(Manuscript received December 11, 1978)

Transmission and signaling implications are important for the successful introduction of the Remote Trunk Arrangement (RTA) and the Position Subsystem (PSS) No. 2 features into the Traffic Service Position System (TSPS), since both features involve the possibility of substantial distances between the TSPS operators and the customers. Consequently, a new transmission plan including objectives for inserted connection loss (ICL), received noise, balance, and operator sidetone was established and some new transmission equipment was provided. The overall objectives, general and specific considerations, maintenance facilities, signaling implications, and new transmission equipment are described. Emphasis is placed on those aspects that are novel or newly introduced as the result of RTA and PSS No. 2.

I. OVERVIEW

An RTA or PSS No. 2 being located at a remote site several hundred miles distant from the base TSPS presents an entirely new set of transmission and signaling implications. First, there is the peripheral control link or PCL, which extends the control capability of the TSPS processors to the remote locations. Then there are transmission considerations within the RTA and PSS No. 2, modifications required to PSS No. 1, the introduction of new transmission equipment, signaling ramifications, and finally the need for additional impedance balancing.

1.1 The peripheral control link (PCL)

Figure 1 shows the PCL which includes, among other components,
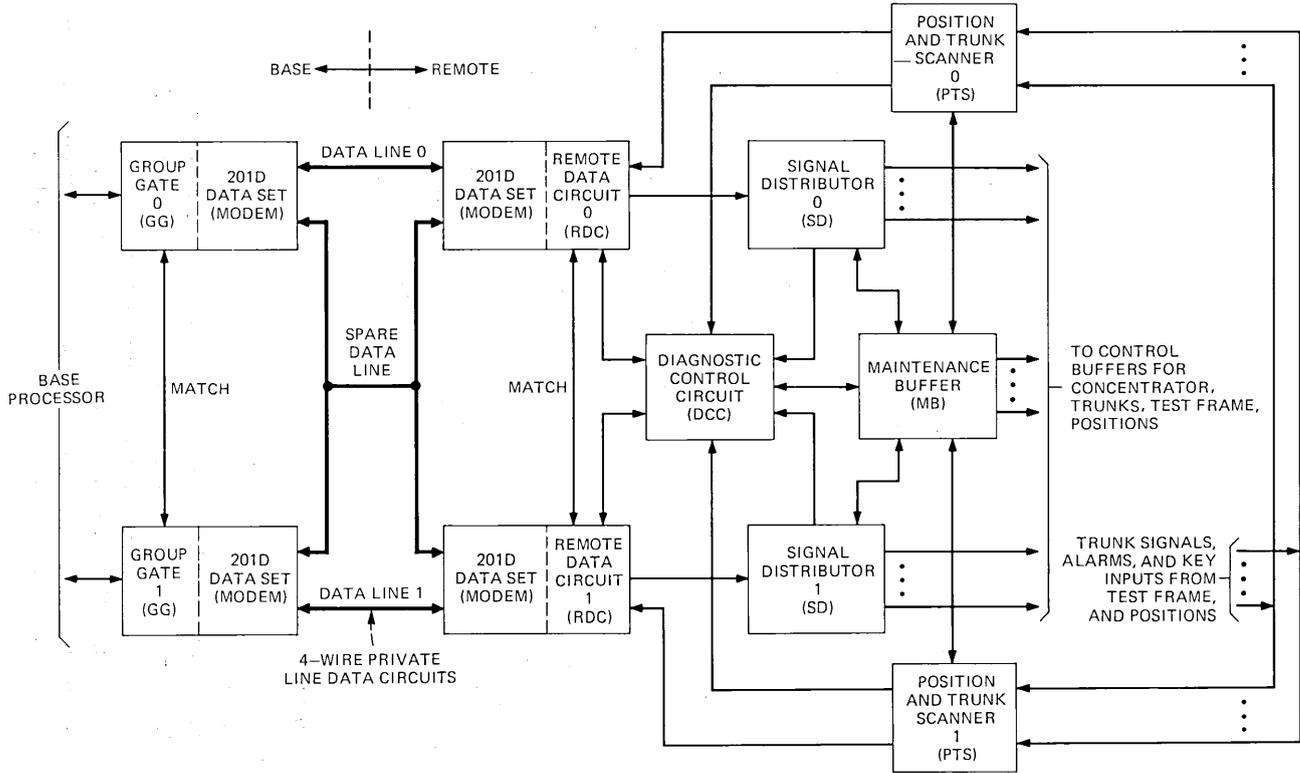
Fig. 1—Peripheral control link.

three data lines used to transmit and receive information to and from the remote sites. System requirements dictate that any standard intertoll grade transmission facilities may be used for all circuits between the base and the RTA or PSS No. 2. Hence, the data transmission circuits must also meet that constraint. Accordingly, the PCL employs 2400 baud modems with the data lines treated as unconditioned, 4-wire private line circuits. This moderate data rate coupled with distances of up to several hundred miles between modems requires that the round-trip delay time required to transmit an instruction to a remote site and receive back an acknowledgment must be limited and must be considered in the design of the data lines.

For reliability, another system requirement specifies that the transmission facilities between base and remote follow at least two diverse routes with one of the two primary data lines in each route. Since, under normal operation, data received on these lines are compared or "matched," a limit must also be placed on the delay differential; that is, on the difference between the delay times of the two routes. Both the delay differential and the round-trip delay times cannot be so restrictive, however, that they substantially restrict the choice of alternate routes between the base and the remote units or severely limit the length of the voice transmission facilities.

1.2 The remote trunk arrangement (RTA)

At the RTA, connection to a TSPS operator is made by bridging onto the toll connecting trunks (TCTs) in a manner similar to that employed at the base. This is shown in Fig. 2. Bridging 900-ohm, 2-wire trunks is accomplished by a simple tap that presents a 450-ohm impedance (two 900-ohm terminations in parallel) to the RTA network (concentrator). Bridging 4-wire trunks requires an associated 3-way, 4-wire bridging repeater which converts the 4-wire bridged tap to 2-wire and which also presents a nominal impedance of 450 ohms to the concentrator. Conversion of 4-wire circuits to 2-wire is always required, since both the RTA and the base TSPS switching networks (RTA concentrator and TSPS trunk and position link circuits) are 2-wire.

The RTA concentrator connects the bridged TCT to a base-remote (BR) trunk, typically a 4-wire intertoll grade facility up to several hundred miles long. Two-wire to 4-wire conversion at both ends of the BR trunk is accomplished by 24V4-type repeaters using a 900-ohm, 4-wire terminating set (4WTS) at the base and a high-impedance 4WTS at the RTA. Finally, the connection is completed through the base network to an operator's position, either a PSS No. 1 or a PSS No. 2.

If the performance of this connection as a function of the length of the BR and operator position trunks is examined, two types of transmission degradation are encountered. The first is echo, as detected by
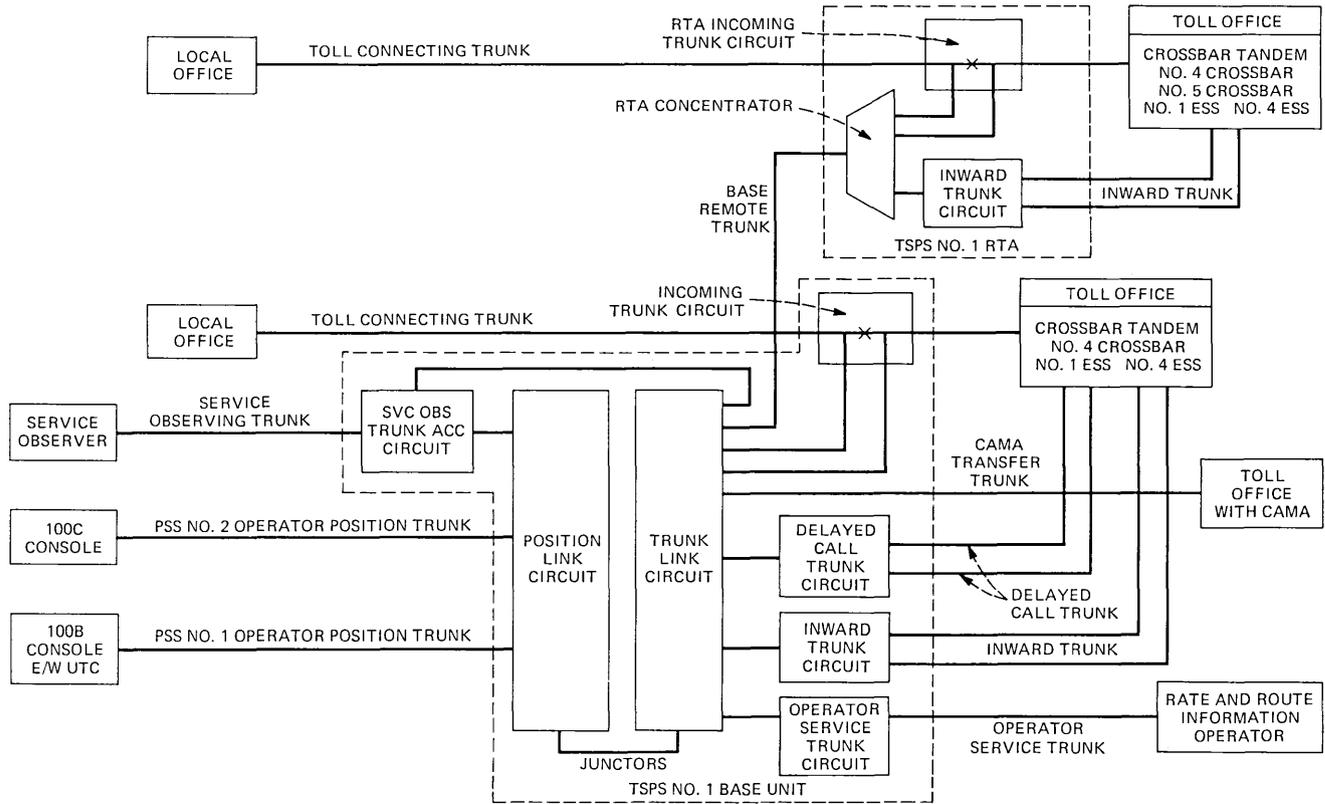
Fig. 2—TSPS No. 1—voice transmission configuration.

the customer(s) and the operator, due to the impedance mismatch at the extra switching point introduced at the RTA concentrator and accentuated by the long BR (and operator position) trunks. As discussed later, echo is controlled through impedance balancing and by a new operator's telephone circuit. The second form of transmission degradation is noise introduced by the long facilities and controlled by the use of compandors on analog facilities or by the use of digital facilities.

1.3 The position subsystem (PSS) No. 2

PSS No. 2 was devised to eliminate the constraints of the original position arrangement (PSS No. 1), which uses unique D1C channel banks and T1 carrier as the transmission facilities for remote installations, and thus is limited in range to approximately 80 miles. Conversely, PSS No. 2 may use any toll grade carrier system and is limited in range only by the noise introduced by the transmission facilities. Hence, received noise is the limiting parameter in the permissible distance between operators and RTAs when standard message grade circuits are used.

The 4-wire operator trunk circuits are connected to the TSPS switching network via 24V4 repeaters and high-impedance 4WTS in the same way as BR trunks at the RTA concentrator. This arrangement permits the PSS No. 2 circuits to be connected to the bridged base TCTS or to BR trunks. At each operator's position, new 4-wire telephone networks provide adjustable sidetone, automatic gain control (AGC), and a voice switched attenuator (VSA).

1.4 The position subsystem (PSS) No. 1

It is necessary and desirable to add RTAs to existing TSPSs which have the original position subsystem arrangements, now designated PSS No. 1. This arrangement employs the equivalent of an unbalanced 4WTS at the base unit end of the position trunks to return a fixed portion of the operator's transmitted signal which serves as sidetone to the operator. No VSA or sidetone adjustment is provided. When an RTA is added, however, the possibility of additional echo from the connection at the RTA makes this an unsuitable arrangement. Hence, the PSS No. 1 unbalanced 4WTS is replaced with a precision balanced 4WTS, and the position is equipped with the same telephone network used in the PSS No. 2. No changes are required in the PSS No. 1 when only PSS No. 2 is added to an existing system.

1.5 Transmission balance

With the introduction of RTA and PSS No. 2, the geographical extent of a single TSPS was transformed from a rather confined area around

a toll office to a system that might cover complete states or even larger areas. Under these circumstances, the distance a call must travel to the operator access point in the network may be significant compared to the length of the average customer-to-customer connection. In those cases, it becomes necessary to treat the operator connection as a toll facility. Toll facilities are characterized by trunks and switching networks which are low loss and transmission balanced and, indeed, these are exactly the requirements that have been introduced into TSPS. Transmission "balance" means matching impedances at all 2-wire to 4-wire junctions to maintain a loss design that allows accurate summation of the losses of the parts while at the same time preventing unwanted signal reflections or "echos" from mismatched junctions.

In the past, balance was not required for TSPS equipped with PSS No. 1 positions, and such systems still do not require balancing. However, whenever a TSPS is equipped with an RTA or is equipped with a PSS No. 2 in which the operator trunks exceed 200 miles in length, the entire system must be balanced.

To facilitate balancing, adjustable network build-out capacitors (NBOCs) are provided by all the 4wTSs or equivalent used in the system. Drop build-out capacitors (DBOCs) are provided or specified at the 2-wire line (or drop) anywhere there is a 4-wire/2-wire transformation on the trunk-link side of the TSPS network.

1.6 Inward trunks

With the introduction of TSPS Generic Program 7, TSPS base units and RTAs have the capability of performing some traditional inward operator functions such as general assistance, time and charges, call-back, and hotel call-back. A special 4-wire inward trunk must be used to handle inward calls. This inward trunk is composed of a toll office outgoing trunk circuit, a TSPS 4-wire bridging arrangement to provide TSPS operator access to the inward trunk, and a toll office incoming trunk circuit. These three circuits are interconnected by 4-wire facilities. An incoming call is switched by the toll office to the outgoing trunk circuit associated with an inward trunk and a TSPS operator is added to the inward trunk through the TSPS or RTA switching network. After the appropriate actions are performed by the operator, the toll office incoming trunk circuit associated with the inward trunk is switched by the toll office to the appropriate toll switching trunk, thereby extending the inward call to the desired end office. The inward trunk remains in the connection between the calling and called customers after the operator has released from the connection.

1.7 New equipment

Several new pieces of transmission-related equipment were introduced as a consequence of RTA and PSS No. 2.

A new unified operator's telephone circuit, or UTC, was designed to provide several improvements such as dual headset operation and supervisor conferencing without transmission degradation. The UTC also provides a voice-switched attenuator (VSA) to control operator talker echo return, an automatic gain control (AGC) circuit to protect the operator from high-level signals, and independent sidetone adjustment to permit meeting sidetone level objectives. Gain and line equalization adjustments are supplied to permit the UTC to properly terminate any standard transmission facility.

To eliminate unwanted echo at the point where BR or operator position trunks are bridged onto a TCT, a new precision-balanced hybrid, the type 1P 4-wire terminating set was introduced. This hybrid is characterized by a high-impedance 2-wire port (approximately 11,600 ohms) and a very high trans-hybrid loss.

Two new 3-way, 4-wire bridging repeaters were also introduced to substantially improve transmission quality when bridging 4-wire circuits. The previous bridging arrangements produced a volume contrast to both the customers and the operator between calls on 2-wire and calls on 4-wire TCTs, with the 4-wire circuits exhibiting approximately 3 to 6.5 dB greater loss, depending on the direction of transmission. The new bridges eliminate this problem and permit gain adjustment in every direction from the bridging point.

1.8 Signaling considerations

Like the base TSPS, the RTA is required to transmit and receive various types of signals. Among these are address signals (i.e., the called and calling numbers), coin control signals, ringback signals, and ringforward signals. The RTA trunk circuits allow each signal to be transmitted in at least two different ways. Unlike the base unit trunks, however, the RTA trunks are not required to generate ±130 V dc signals for coin control and ringback.

The RTA must be able to receive address signals either as dial pulses or multifrequency (MF) tones from originating local offices but is required to forward address information to the toll office only in MF form. Coin control and ringback signals toward the originating office can be either inband (MF tones) or multiple wink (MW), which consists of a specified number of timed on-hook/off-hook dc "winks." Ringforward signals may be either +130 V simplex or a single "wink."

In TSPS/RTA, as in other systems not equipped with common channel interoffice signaling (CCIS), the signals described above must be transmitted over virtually the same paths used for voice transmission. These paths include the BR trunks between the base and the RTA since all the common signaling circuits (e.g., MF receivers, MF outpulsers, coin control and ringback circuits) are located at the base. Hence, care must be exercised when engineering the transmission paths to ensure

that signaling is properly considered. Transmission level points (TLPs) must be carefully controlled to guarantee correct processing of MF signals by the various switching offices involved. MF signaling specifications call for −7dBm per tone signal power at 0- TLP (i.e., −7dBm0). Changes are being incorporated into TSPS to comply with this specification.

II. OBJECTIVES AND GENERAL CONSIDERATIONS

2.1 Voice transmission objectives

A standard TSPS/RTA connection is a 3-party call among the calling customer, the called customer, and the TSPS operator (see Fig. 3). This standard connection was considered to be the same as three 2-way connections, each of which must meet its own transmission objectives.

The transmission objective set for the 2-way customer-to-customer connection is to provide loss-noise-echo performance, which is the same as that of regular direct distance dialed (DDD) toll calls that do not have TSPS access but have the same length. This objective applies whether or not the operator is in the connection and has two corollaries, namely: (i) the toll connecting trunk (TCT) satisfies the standard DDD network transmission requirements in both the 2-way and 3-way connection, and (ii) the performance provided on calls handled by TSPS is the same as calls handled by the DDD network.

The transmission objective placed on the 2-way operator-to-calling-customer connection was that it have loss-noise-echo performance equivalent to that provided on an average short DDD toll call between 100 and 150 miles in length. This objective is satisfied by the TSPS/RTA transmission design even when there are several hundred miles between the operator position and the TSPS access point on the incoming trunks to the toll office. This performance is obtained because (i) the TSPS access point was given the same transmission level as the toll office incoming trunk which reduces the level contrast at the operator position between the received volume from the calling customer and that from the called customer, (ii) the BR trunk has zero loss to minimize volume contrast observed by the operator between calls accessed at the base unit and those accessed at an RTA, (iii) circuit noise on the trunk facilities was limited, and (iv) impedance balance was provided for all trunks to avoid echoes.

Similarly, the transmission objective for the 2-way operator-to-called customer connection was that its loss-noise-echo performance be approximately the same as that of the connection between calling customer and called customer. Two potential transmission degradations that had to be considered in meeting this objective were (i) customer and operator talker echoes as a result of the extra 2-wire switching
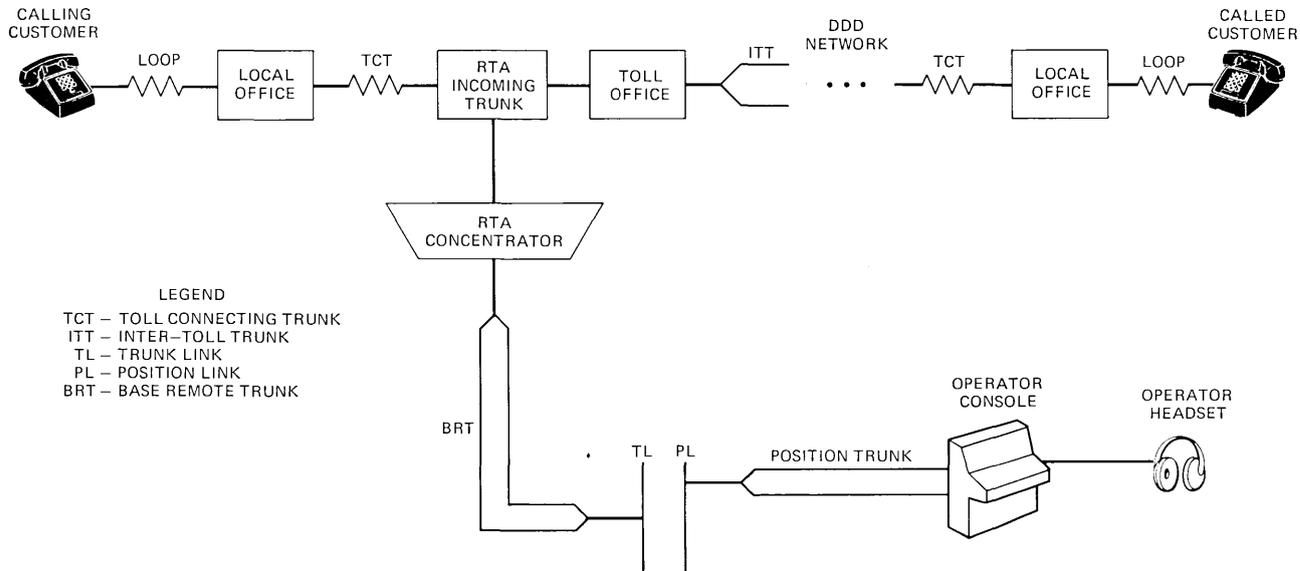
Fig. 3—Connection model of a typical call handled through TSPS via RTA.

LEGEND
TCT — TOLL CONNECTING TRUNK
ITT — INTER—TOLL TRUNK
TL — TRUNK LINK
PL — POSITION LINK
BRT — BASE REMOTE TRUNK

point at the RTA and the long BR and operator position trunks, and (ii) high noise levels in long BR and operator trunk facilities.

Transmission objectives were also imposed on operator sidetone and trunk facility noise. The operator sidetone objective was made the same as that used for subscribers, namely, an acoustical sidetone path loss of 12 ± 4 dB. Noise objectives on all TSPS associated trunks were made the same as those for the DDD network trunks which use intertoll grade carrier facilities.

2.2 Deviations from requirements

Deviations from transmission requirements were constrained because the sum of many small deviations would cause large overall loss variations between connections. Some loss considerations were:

(i) Zero loss was required between the toll office and the base unit or RTA access points on toll connecting and inward trunks. Because any variation in this loss changes the effective TSPS access point on these trunks and, consequently, increases the speech volume from one customer and decreases it from the other, a permissible maximum variation of only 0.5 dB was set. For 2-wire trunks and 2-wire toll switches, the 0 to 0.5 dB loss requirement limits the wiring gauge and length that is used between the base unit (or RTA) and its associated toll office. Four-wire access trunks were aligned to 0 dB loss without difficulty. The permissible loss variation also determined the schedule for trunk maintenance and trunk down limits.

(ii) BR trunk loss variations were stipulated to limit the volume contrast for calls between operator and customers. The permitted variation was made the same as that for intertoll trunks in the DDD network. It was recognized that these level changes also affect signaling tones since MF outpulsers are only provided at the base unit so that the MF signaling tones are transmitted to the RTA over the BR trunks.

(iii) Loss variations in operator position trunks add to the volume contrasts heard by the customers. Such trunks were given same standard loss variations as intertoll message trunks.

2.3 Transmission level points (TLP)

TSPS conforms to the standard transmission level point (TLP) plan of the Bell System, which makes the local class 5 office a 0 TLP for outgoing signals. Since the trunk loss and its control are primary requirement in TSPS, transmission level points were adjusted as required to meet (i) trunk loss requirements, (ii) loading objectives for carrier facilities, and (iii) standardized toll office transmission level points. To do this, the outgoing TLP of the TSPS was adjusted to conform with the expected received level on the toll-connecting trunk being tested. All trunks internal to the base unit and RTA are considered to be at -3 TLP.

III. VOICE TRANSMISSION CONSIDERATIONS

As discussed in Section I, TSPS Generic 7 introduced the PSS No. 2, the RTA, and inward call-handling features. As a consequence, the RTA concentrator, which is a new switch, and new types of trunks (i.e., PSS No. 2 operator position, BR, and inward trunks) were added to existing TSPS base units as shown in Fig. 2. Modifications were also made in certain existing base unit circuits to meet the TSPS voice transmission objectives discussed in Section II. Each type of trunk associated with a base unit equipped with the RTA, PSS No. 2, and inward call-handling features was designed to satisfy specific transmission requirements to meet transmission objectives. These objectives were stated in terms of loss-noise-echo performance provided to the customer(s) and to the operator on all the possible connections used in TSPS. The loss-noise performance provided on a given type of connection was controlled by setting requirements on (*i*) the inserted connection loss (ICL) and (*ii*) the noise which may be introduced by each of the various trunks in the connections. The talker echo performance provided on a given connection depends upon both the loss and the round-trip signal propagation delay of the talker echo signal path. Because the round trip propagation delay of the echo path depends markedly on the length of a given connection, the loss in the echo path is used to control the echo performance provided on a given connection. For example, in the UTC described in Section 1.7, the loss of the echo path is controlled by introducing additional loss in the receive path when the talker speaks but not in the talker's transmission path. In addition, specific balance requirements are satisfied at all junctions between 4-wire and 2-wire transmission facilities. These specific transmission requirements (i.e., ICL, noise, and balance) are considered in subsequent sections.

Whenever the RTA feature is added to an existing TSPS base unit equipped with the original PSS No. 1 operator positions, the operator position trunks are modified as follows:

(*i*) The existing operator telephone circuits are replaced by the UTC with the voice-switched-attenuator (VSA) and automatic gain control (AGC) features enabled.

(*ii*) For operator positions located remotely from the base units, the DIC channel units at the base unit end of the trunk are replaced by a new DIC channel unit which incorporates the equivalent of a 1P 4-Wire Terminating Set (4WTS).

(*iii*) For operator positions located near the base unit, the 1H 4WTS used in the 24V4 repeater at the base unit end of the trunk are replaced by the 1P 4WTS.

Whenever the RTA feature is added, the service observing circuit used in existing TSPS base units is replaced by an improved circuit.

Prior to the introduction of Generic 7, a 3-way connection among (*i*) the TSPS operator, (*ii*) a service assistance operator, and (*iii*) the customer was permitted. However, with the introduction of Generic 7, such a 3-way connection is no longer provided because of transmission loss and balance problems with the extended range TSPS system. Only a 2-way connection is provided between a TSPS operator and a service assistance operator, during which the calling customer will be put on hold. The circuit modifications outlined above were needed to meet the echo performance objectives discussed in Section 2.1.

3.1 Network arrangements

Figure 2 is a functional block diagram of the voice transmission configuration of the base unit, operator positions, and RTA, and includes the various types of trunks. Typical trunking and switching arrangements at a base unit equipped with the inward call handling, a PSS No. 2, and an RTA are shown in Fig. 4. Figure 5 illustrates the typical trunking and switching arrangements for an RTA installation.

As shown in Fig. 4, the operator position trunks of the PSS No. 2 and PSS No. 1 retrofitted with the UTC as well as the service observing trunks all have 2-wire appearances on the position link circuit of the base unit switching network. These trunks use 4-wire facilities which are converted from 4-wire to 2-wire by a bridging hybrid (i.e., a 1P 4WTS, or equivalent) at the base unit. All the types of trunks shown in Fig. 4 that have appearances on the trunk link circuit of the switching network can be connected to at least one of the three types of trunks having appearances on the position link circuit. All BR trunks use 4-wire facilities while operator service trunks and centralized automatic message accounting (CAMA) transfer trunks may use either 2-wire or 4-wire facilities. When 4-wire facilities are used, a 900-ohm 4WTS (e.g., 1M 4WTS) is used to provide the necessary conversion from 4-wire to 2-wire. All inward trunks, 4-wire TCT, delayed call trunks, and service observing trunks use 4-wire facilities with bridging access to these trunks provided by 3-way, 4-wire bridging repeaters. The equivalent of a 900-ohm 4WTS is incorporated in the bridging repeaters to provide the necessary conversion from 4 wire to 2 wire. Two-wire TCTs are bridged directly at both the RTA and base unit. This is illustrated schematically in Figs. 4 and 5.

As shown in Fig. 5, all connections through the RTA concentrator between a BR trunk and either a TCT or an inward trunk are made on a 2-wire basis. All BR trunks at the RTA use 4-wire facilities and a 1P 4WTS to provide the necessary conversion from 4-wire to 2-wire transmission. The TCT and inward trunk arrangements are essentially the same as that described above for the base unit.

SERVICE OBSERVING TRUNK CIRCUIT

SERVICE OBSERVING CONT. AND MONITORING CIRCUIT

NET

3-WAY 4-WIRE BRIDGING REPEATER

1P

24V4 RPTR

DBOC

SB CABLE

SB CABLE

D1C CHANNEL UNIT OR 24V4 RPTR

OPERATOR CUT-THRU CIRCUIT

1P

TSPS OPR

NET

SB CABLE

IDLE TERM

RETROFITTED PSS NO. 1

TSPS 2-WIRE INCOMING TRUNK CIRCUIT

LOCAL OFFICE

TOLL OFFICE

T1   T2

SB CABLE

TSPS 4-WIRE INCOMING TRUNK CIRCUIT

LOCAL OFFICE

3-WAY 4-WIRE BRIDGING REPEATER

TOLL OFFICE

T2

SB CABLE   T1   DBOC

24V4 RPTR

OPERATOR CUT-THRU CIRCUIT

1P

TSPS OPR

NET

SB CABLE

IDLE TERM

PSS NO. 2

TSPS DELAYED CALL TRUNK CIRCUIT OR INWARD TRUNK CIRCUIT

TOLL OFFICE

3-WAY 4-WIRE BRIDGING REPEATER

TOLL OFFICE

T2

SB CABLE   T2   T1   DBOC

TSPS BASE UNIT SWITCHING NETWORK

24V4 RPTR

1P

NET

SB CABLE

IDLE TERM

BALANCE TEST CIRCUIT P/O CONT., DISPLAY AND TEST CIRCUIT

BASE BR TRUNK CIRCUIT OR OPERATOR SVC TRUNK CIRCUIT

24V4 RPTR

SB CABLE

SB CABLE

SB CABLE

NET

RTA OR SVC OPR

DBOC

1M

INCOMING CAMA TRUNK CIRCUIT

24V4 RPTR

SB CABLE

NET

TOLL OFFICE WITH CAMA

DBOC

1M

POSITION LINK CIRCUIT

TRUNK LINK CIRCUIT

VOICE PATH

SB CABLE

Fig. 4—TSPS base unit trunks and switching arrangements. To simplify the sketch, the T2 port connection to the trunk link circuit of the TSPS base unit switching network is not shown.
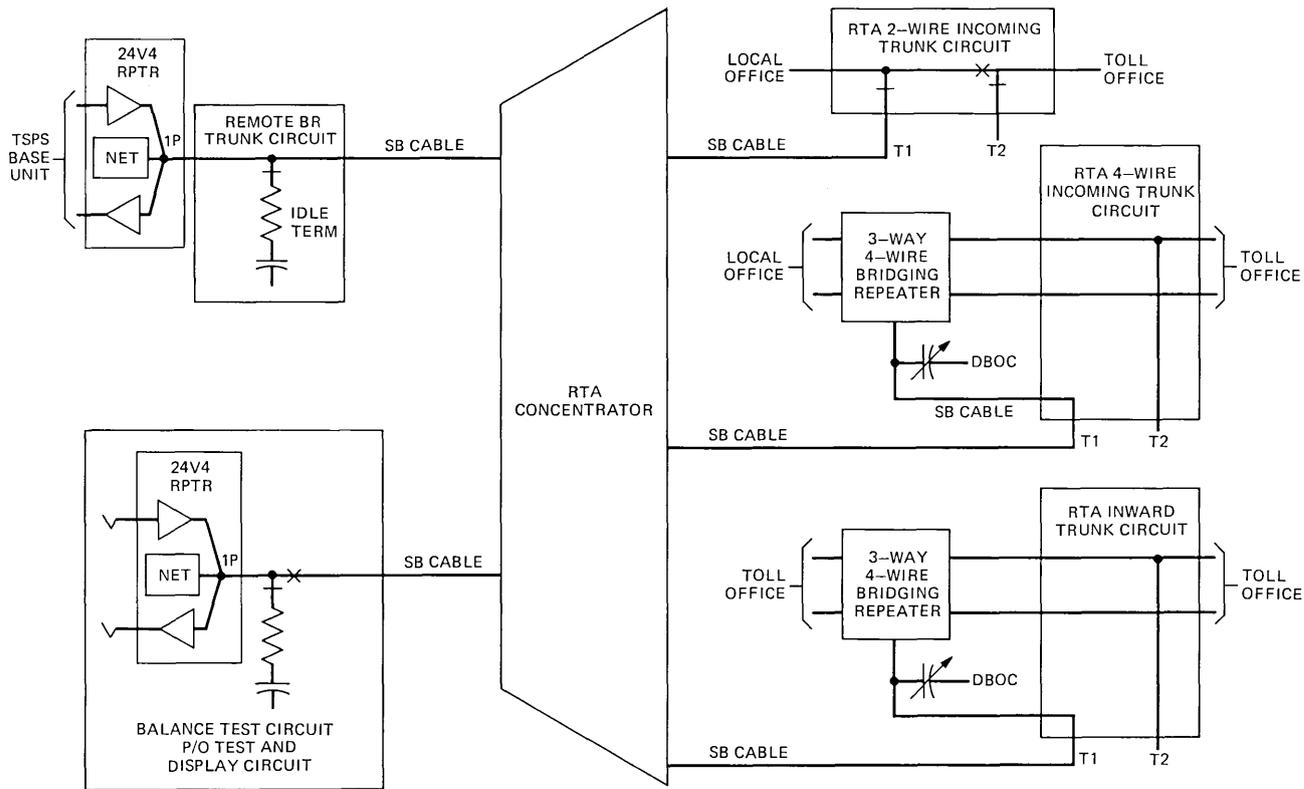
Fig. 5—RTA trunks and switching arrangements. To simplify the sketch, the T2 port connection to the RTA concentrator is not shown.

3.2 Inserted connection loss (ICL)

The ICL requirements on each of the various types of TSPS trunks shown in Fig. 2 are summarized in Table I. It should be noted that the introduction of Generic 7 has not affected the ICL requirements on those trunks which existed before its introduction. The ICL requirements on the new trunks introduced with Generic 7 are discussed next.

The ICL requirements must be the same for TCTs accessed by either a base unit or an RTA as for TCTs not accessed by TSPS to avoid any contrast in transmission performance provided to the customers between directly dialed calls and operator-assisted calls. One additional ICL requirement peculiar to TCTs provided with either base unit or RTA access is that the portion of the TCT between the TSPS bridging point and the outgoing side of the toll office switch should nominally be 0 dB with a maximum of 0.5 dB. This ICL requirement applies for both voice signals and MF signals and is needed (*i*) to equalize the transmission loss between the TSPS operator and the calling customer and between the operator and the called customer to minimize received speech volume contrast and (*ii*) to provide MF address signals to the toll office at the standard signaling power levels.

The ICL for the BR trunks is 0 dB. Since any TSPS operator can be called upon to service calls switched through either the base unit or an RTA, this requirement assures that there will be no significant volume contrast between such calls. It also ensures that the voice frequency MF signals generated at the base unit will reach the TCT bridging point at the standard power level.

The inward trunks introduced with Generic 7 may be considered as two secondary intertoll trunks in tandem, that is: (*i*) a secondary intertoll trunk from the toll office incoming to the base unit (or RTA)

Table I—Inserted connection loss requirements for TSPS trunks

Type of Trunk	ICL (dB)
1. Toll connecting trunk between TSPS No. 1 incoming trunk circuit at the TSPS base unit or RTA and the toll office	0, max. 0.5
2. PSS No. 2 operator position trunk	
a. Operator transmit direction	7
b. Operator receive direction	9
3. Retrofitted PSS No. 1 operator position trunk	
a. Operator transmit direction	7
b. Operator receive direction	9
4. Base-remote trunk	0
5. Inward trunk between TSPS No. 1 inward trunk circuit at the TSPS base unit or RTA and the toll office	0, max. 0.5
6. Delayed call trunk between TSPS No. 1 delayed call trunk circuit and toll office	0, max. 0.5
7. CAMA transfer trunk	
a. Voice path	0, max. 0.5
b. MF signaling path	0, max. 0.5
8. Operator service trunk	0, max. 0.5
9. Service observing trunk	0

for connection to an operator, and (*ii*) a secondary intertoll trunk from the base unit (or RTA) back to the toll office for connection to the desired end office. As such, each of these two sections of an inward trunk is composed of 4-wire facilities having an ICL of 0 dB nominal, with a maximum of 0.5 dB.

The ICL for the PSS No. 2 operator position trunks and for the retrofitted PSS No. 1 operator position trunks is the same. The ICL for both types of operator trunks depends on the direction of transmission. An ICL of 7 dB is used for the operator transmit direction so that the average speech power level from the TSPS operators delivered to the bridging point on the TCTs will be nominally equal to the average speech power level from the calling customers arriving at the same point. An ICL of 9 dB is used for the operator receive direction so that the preferred average speech power will be delivered to the operator when a customer's average speech level is applied to the bridging point on a TCT.

3.3 Noise

The maximum circuit noise permitted on all the various types of TSPS trunks existing before the introduction of Generic 7 was the same as on corresponding type trunks in the message network. This made it possible to use standard toll grade carrier arrangements in the makeup of the facilities for TSPS trunks whenever necessary. The noise limits on those trunks remain unchanged by the introduction of Generic 7 features, with the possible exception of the CAMA transfer trunks, which are discussed later. However, some special noise requirements for the inward, BR, and PSS No. 2 operator position trunks are introduced with Generic 7.

In the event that an inward call is extended to the desired called customer, the inward trunk remains in the overall connection between the calling and called customers after the operator releases from the connection. As discussed in Section 3.2, an inward trunk may be considered as two secondary intertoll trunks in tandem interconnected via a 3-way, 4-wire bridging repeater. To limit any degradation in the quality of the loss-noise performance provided to the calling and called customers, each of the two portions of the inward trunk are composed of low-noise 4-wire facilities such as intertoll grade T-carrier and/or 4-wire metallic facilities.

Any type or combination of types of intertoll grade voice facilities may be used in the makeup of a PSS No. 2 operator position trunks or BR trunks. The amount of noise introduced by the facilities is limited for loss-noise performance reasons. The loss-noise performance provided on customer/operator connections is adversely affected by the additional circuit noise introduced by long PSS No. 2 operator position trunks and long BR trunks.

If a PSS No. 2 is provided at a given TSPS base unit, but not an RTA, the loss-noise performance objective is met on customer/operator connections if the facility route length of analog carrier facilities used in any operator position trunk is no greater than 400 miles. This length limitation applies if the following noise maintenance limits are observed on the analog carrier facilities used in the operator position trunk:

Analog Carrier Length (route miles)	Remove From Service Limit (dBrnC0)	Maintenance Req'd Limit (dBrnC0)
0- 50	40	32
51–100	40	33
101–200	40	35
>200	44	37

If companded L-multiplex analog carrier facilities are used in the operator position trunk, the maximum facility route length may be extended to 1000 miles. It should be noted that the length of a single intertoll grade digital carrier facility (e.g., T-carrier) when used in tandem with an analog carrier facility can be ignored when applying these length restrictions. If the RTA feature is provided but not the PSS No. 2 feature, the above discussion on the makeup of PSS No. 2 operator position trunk facilities applies directly to BR trunks. If both the PSS No. 2 and RTA features are provided at a given TSPS base unit, the analog carrier facility length restrictions indicated above must be apportioned between the operator position trunks and the BR trunks. The length restrictions, of course, apply to all the diverse routes taken by the BR and operator trunks.

The introduction of RTA increases the likelihood that some of the CAMA transfer trunks to a given base unit will be long. The CAMA traffic, formerly handled by operators located near a toll office which is now being served by an RTA, will now most likely be routed over CAMA transfer trunks to the base unit for handling by TSPS operators. This, coupled with the possibility that the base unit may also be equipped with a remote PSS No. 2, places more stringent noise requirements on the CAMA transfer trunks so that their maximum circuit noise is now the same as for the BR trunks discussed above.

3.4 Transmission balance

RTA and PSS No. 2 add a new 2-wire switching point (RTA concentrator) and long lengths of facilities to the overall connection between the customers and the TSPS operator. As discussed in Section 1.5, the extra switching point introduced another potential source of talker echo whenever the trunks to be switched use 4-wire facilities. The long lengths of facilities increase the round-trip propagation delay of any

talker echo signal already existing which makes that echo more disturbing to the talker. To meet echo performance objectives on connections involving TSPS operators, balance requirements must now be placed on the various connections through the base unit and/or through the RTA when at least one of the trunks involved in the connection uses 4-wire facilities. Balance refers to matching circuit impedances to control the magnitude of the signal reflected toward the source at the junction between 4-wire and 2-wire facilities.

In general, the termination of a 4-wire facility and its conversion to a 2-wire facility is accomplished with a 4WTS, or equivalent. A 4WTS contains a balanced hybrid transformer that facilitates the transfer of signal power from the 4-wire receive path into the 2-wire facility and from the 2-wire facility into the 4-wire transmit path. However, some signal power arriving on the 4-wire receive path will be returned on the 4-wire transmit path whenever differences exist between the impedance of the 2-wire facility and the impedance of the balancing network of the 4WTS. The degree of balance between these two impedances will determine what portion of the signal power will be returned to the source.

The balancing networks used in each of the various types of 4WTSs (or equivalent) shown in Fig. 4 and 5 consist of a compromise network plus an adjustable network build-out capacitor (NBOC), which shunts the compromise network. The compromise network is designed to provide impedances over the voice frequency band of 200 to 3400 Hz that match the nominal impedance of the 2-wire circuits which may be connected to that 4WTS. The NBOC is included in the balancing

Table II—Balance requirements on the bridging hybrid at the base unit end of PSS No. 2 and retrofitted PSS No. 1 operator position trunks and the RTA end of base-remote trunks

Type of Trunk Connected to TSPS Bridging Hybrid	Echo Return Loss (dB)		Singing Return Loss (dB)	
	Median	Minimum	Median	Minimum
1. Base unit and RTA				
a. 2-wire toll connecting trunk	15	13	N.S.*	6
b. 4-wire toll connecting trunk	N.S.	19	N.S.	15
c. Inward trunk	24	21	19	16
2. Base unit				
a. Base-remote trunk	24	21	19	16
b. 4-wire delayed call trunk	24	21	19	16
c. 4-wire operator service trunk	24	21	19	16
d. 4-wire CAMA transfer trunk (voice path)	N.S.	21	N.S.	16
e. Service observing trunk	24	21	19	16

* Not specified.

Table III—Balance requirements on 4WTS, or equivalent, associated with various types of 4-wire trunks on connections to a bridging hybrid in TSPS base unit or RTA

Type of 4-Wire Trunk	Echo Return Loss (dB)		Singing Return Loss (dB)	
	Median	Minimum	Median	Minimum
1. Base unit and RTA				
a. Toll connecting trunk	N.S.*	26	N.S.	19
b. Inward trunk	N.S.	26	N.S.	19
2. Base unit				
a. Base-remote trunk	N.S.	26	N.S.	19
b. Delayed call trunk	N.S.	26	N.S.	19
c. Operator service trunk	N.S.	26	N.S.	19
d. CAMA transfer trunk (voice path)	N.S.	26	N.S.	19
3. Service observing trunk	N.S.	26	N.S.	19

* Not specified.

network to simulate the capacitance of the office cabling included between the 2-wire port of the 4WTS and the point of good impedance of the connecting circuit, which is defined as a point of fixed nominal 2-wire impedance. For example, the point of good impedance of a trunk using 4-wire facilities is the 2-wire port of a 4WTS.

The balance requirements on the 1P 4WTS (or equivalent) at the base unit end of PSS No. 2 trunks, retrofitted PSS No. 1 trunks and service observing trunks, or at the RTA end of BR trunks, vary depending upon the type of trunk connected through the base unit network or RTA concentrator to the 1P 4WTS. The balance requirements, listed in Table II as a function of trunk type, are identical regardless of whether the connections are made through the base unit or through the RTA.

The balance requirements on the 4WTS (or equivalent) associated with the various types of 4-wire trunks which can be connected through the base unit or the RTA to a 1P 4WTS are summarized in Table III. Again, balance requirements are identical for a given type of trunk switched through either the base unit or an RTA.

The balance requirements listed in Tables II and III are given in terms of echo return loss (ERL) and singing return loss (SRL) as measured at the 4WTS (or equivalent) using a return loss measuring set (RLMS). An ERL measurement is a weighted average measurement of the return losses for each frequency in the echo frequency range. An SRL measurement is the lesser of two weighted average measurements of the return losses, one measurement covering the frequencies at the lower end of the voice frequency band and the second covering frequencies at the upper end of the voice frequency band.

No resistance build-out capability is provided in the balancing networks of the various 4WTS (or equivalent) used in TSPS applications.

Therefore, to meet specific balance requirements at any given 4WTS maximum allowable lengths of office cable (26-gauge switchboard cable in both base units and RTAs) between the points of good impedance of the trunks and their 2-wire appearance on the base unit switching network or RTA concentrator have been specified. Those segments of switchboard cable in which length must be controlled are labeled "SB CABLE" in Figs. 4 and 5.

In a given base unit or RTA, the value of the NBOC in the balancing networks of all the 1P 4WTSs will be set to some compromise value such that the balance requirements are met on connections through the switching network to all possible 2-wire TCTs. To meet balance requirements when the value of the NBOC is fixed, variation in the shunt capacitances of the switchboard cables shown in Figs. 4 and 5 must be controlled. If the switchboard cabling capacitance variation is sufficiently large, balance requirements will not be met on all possible connections if the value of the NBOC is to remain single-valued.

It should be noted that the shunt capacitance of the switchboard cabling between a 1P 4WTS and the point of good impedance of any of the various trunks using 4-wire facilities shown in Figs. 4 and 5 will, in general, be much smaller than the value of the NBOC in the hybrid balancing network of the 1P 4WTS required to meet balance requirements on connections to TCTs providing 2-wire bridging access. To reduce this cabling capacitance variation, bridged capacitance is added to the shorter 2-wire switchboard cabling paths to increase their effective shunt capacitance and make them equal that of the longer 2-wire cabling paths. This is accomplished by adding a drop build-out capacitor (DBOC) in the shorter 2-wire cabling paths as indicated in Figs. 4 and 5. In some cases, the DBOC is supplied as part of the TSPS or RTA trunk circuit or as part of the 4-wire bridging repeater. In other cases, a separate DBOC is supplied and wired on a bridged basis across the 2-wire switchboard cabling path between the point of good impedance of a given trunk and its appearance on the base unit switching network or on the RTA concentrator.

Terminal balance requirements are imposed on connections in a toll office from any intertoll trunk to any TCT. When the TCT provides TSPS bridging access, the same terminal balance requirements apply. The current toll office terminal balance requirements listed in Table IV are for the most part independent of the type of toll office involved, but are dependent upon the general makeup of the TCT facilities. To meet terminal balance requirements on 2-wire TCTs providing TSPS bridging access, the maximum length and the gauge of the switchboard cabling used to interconnect the base unit or RTA incoming trunk circuit, the toll office, and the point of good impedance of the TCT facilities (e.g., 4-wire terminating set, impedance compensation network) must be controlled as a function of (i) the type of toll office, (ii) the length and

Table IV—Toll office balance requirements

1. Terminal balance
    a. 2-wire facilities with 2-dB pad (intrabuilding):
        ERL: 22 dB* median, 18 dB minimum
        SRL: 14 dB median, 10 dB minimum
    b. 2-wire facilities or 4-wire facilities with 2-wire extensions (interbuilding):
        ERL: 18 dB median, 13 dB minimum
        SRL: 10 dB median, 6 dB minimum
    c. 4-wire facilities:
        ERL: 22 dB median, 16 dB minimum
        SRL: 15 dB median, 11 dB minimum
2. Through balance
        ERL: 27 dB median, 21 dB minimum
        SRL: 20 dB median, 14 dB minimum

* 20 dB for No. 5 crossbar toll offices only when TCT provides TSPS 2-wire bridging access.

gauge of switchboard cabling internal to a 2-wire toll office, and (*iii*) the value of the NBOC of the balancing network of the intertoll hybrids in a 2-wire toll office.

The terminal balance requirements listed in Table IV also apply to connections through the toll office from any CAMA transfer trunk, TSPS inward trunk, or TSPS delayed call trunk to any TCT. The toll-office through balance requirements also listed in Table IV must be met on connections through the toll office between any TSPS inward or delayed call trunk and any intertoll trunk. These balance requirements have been imposed to limit any degradation in the quality of the echo performance provided on the overall connection resulting from the introduction of additional 2-wire switching points in the overall connection between customers. To limit degradation of the echo performance provided on the overall connection between two customers resulting from the increased round-trip propagation delay of the echo path caused by adding either a TSPS inward or a delayed call trunk in tandem with the overall connection, the maximum route length of the facilities composing each of the two portions of an inward or delayed call trunk must not exceed:

(*i*)	Metallic facilities	9 miles
(*ii*)	T-carrier facilities	50 miles
(*iii*)	T-carrier with metallic extensions	Determined by the requirement that the length of the T-carrier facilities plus 10 times the length of the metallic extension must not exceed 50 miles.

IV. ADDRESS SIGNALING AND SPECIAL SIGNALING

4.1 Signaling methods

RTA trunks utilize classical loop and E&M supervisory signaling methods. Nonsupervisory signal handling, however, is different.

Signaling between the RTA and the local or toll switching offices typically assumes one of two forms: (*i*) ac multifrequency tone bursts and (*ii*) dc pulses or "winks." When MF tones are used, the signaling is usually between the local or toll offices and the base unit with the RTA essentially transparent. This is the case for MF address signals, automatic calling number identification (ANI), and inband coin control and ringback. When dc pulsing is employed, however, signaling is restricted to the relatively short trunks between the RTA and the local and toll offices. This is the case for dc dial pulses and multiple wink (MW) coin control, ringback, and ringforward.

The RTA does not provide ±130 V dc signaling for coin control, but does provide +130 V dc simplex signaling for ringforward toward the toll office.

4.2 Dial pulse receiving

It would be nearly impossible for dc dial pulses (DP) generated at an originating office to pass through the RTA and over the extremely long BR trunks that could be encountered and still be reliably detected by a digit receiver at the base unit. An alternative way of handling DP at the RTA is required. Rather than being transmitted to the base, dial pulses received at an RTA are blocked in the trunk circuit where they are counted and encoded by the Position and Trunk Scanner (PTS) circuit in the PCL. The value of each dialed digit is then transmitted in the interdigital interval to the SPC over the PCL data links and not over the normal voice transmission facilities.

When all the called digits have been obtained, the SPC must determine if the originating office is equipped with ANI (automatic number identification). If it is, an MF receiver must be connected to the T1 port of the RTA incoming trunk via the base networks, a BR trunk, and the RTA concentrator. The trunk circuit is then directed to send an off-hook "wink" to the originating office requesting transmittal of the calling number. The MF tones then follow essentially the same path used to connect an operator to the calling customer. Hence, in the design of the toll-connecting and BR trunks, consideration must also be given to signaling.

4.3 Multifrequency receiving

If the RTA incoming trunk is identified as having MF rather than dial pulse signaling, the SPC establishes a transmission path to a base unit MF receiver in much the same manner as described above to receive the ANI digits after dial pulsing. Once a transmission path is established, the RTA is directed to signal the originating office via a 200-ms off-hook wink to start MF pulsing. After all the called number digits have been registered, the SPC must determine if the originating office

is equipped for ANI and, if so, must signal the office to forward the calling number. This is done by directing the RTA trunk to go off-hook. Thus, in the case of MF originating traffic, the signaling and the voice transmission paths are identical.

4.4 Multifrequency outpulsing

Once the called number has been registered by the SPC, it must be forwarded or outpulsed to the toll office to effect call completion. Since this is normally done at the same time that an operator is connected to the calling customer (acknowledging coin deposits, getting special billing information, etc.), a second transmission path must be established, this time via the T2 port of the incoming trunk circuit. In the case of an RTA call, the MF outpulser circuit is connected to the trunk via a BR trunk and the RTA concentrator.

MF signals transmitted from TSPS to the toll office, therefore, follow a somewhat different route than voice signals, traveling via the T2 port of the trunk circuit while voice signals use only the T1 port. In the case of the relatively simple 2-wire trunk circuits, this makes little difference (see Fig. 6). In the case of 4-wire trunk circuits, however, the MF signals do not go through and therefore do not receive the benefit of the amplifiers in the associated bridging repeaters
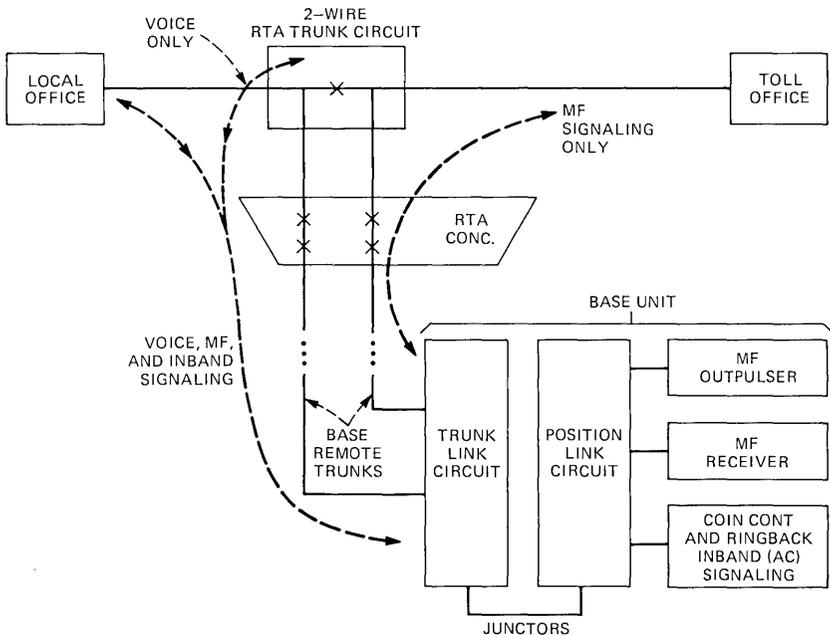
Fig. 6—MF signaling in 2-wire RTA trunk circuits.

(see Fig. 7). Thus, the 4-wire circuits require additional amplifiers to ensure that the proper ratio of MF to voice is transmitted to the toll office.

Care must also be exercised during the design of the trunk circuits and facilities to ensure that they are properly terminated at all times, particularly at the 2-wire/4-wire junctions. Improper termination of the new 1P 4-wire terminating set can lead to unintentional circuit gains or losses with resulting MF signaling difficulties.

For typical DDD calls, the TSPS must transmit the MF signals only as far as the serving toll office which, even for RTA and its toll office, is by design over trunk facilities of no more than 0.5-dB loss. With the introduction of International Direct Distance Dialing (IDDD) in Generic 5, however, TSPS must transmit MF signals to international "gateway" offices which may be more than 2000 miles away. On such calls, TSPS must first transmit a preliminary set of digits to the toll
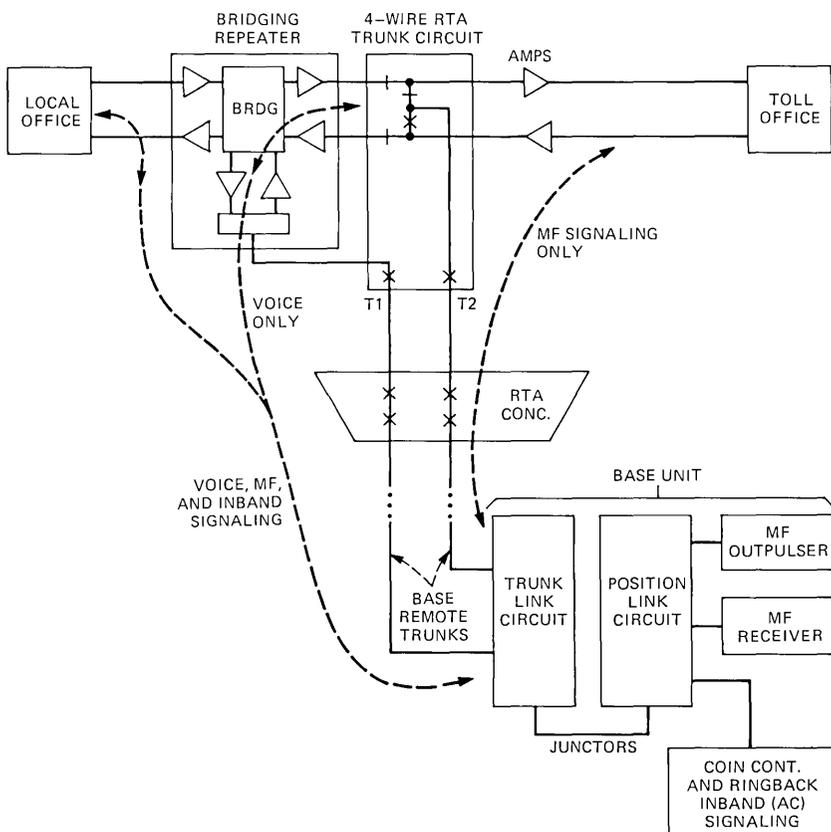
Fig. 7—MF signaling in 4-wire RTA trunk circuits.

office which will cause a connection to the gateway office to be established. Upon receipt of a signal from the gateway office, TSPS must then MF-outpulse the called number.

Transmission facilities of this length may be made up of many segments, be characterized by up to 10 dB of loss, and/or be equipped with echo suppressors. Hence, the MF signals must be transmitted from TSPS at the current standard level of −7 dBm0 per frequency to insure they are not too strong and cause facility overload, clipping, or unacceptably high crosstalk and are not too weak to be successfully received by the gateway offices.

4.5 Coin control and ringback

The RTA trunks are all equipped to provide coin control and ringback by transmitting either inband (ac) or multiple wink (dc) signals. Inband signaling requires the use of the coin control and ringback (CCR) circuit at the base unit to supply the inband frequencies. The SPC establishes a connection between the CCR and the T1 port of the RTA trunk via the base network, a BR trunk, and the RTA concentrator. The RTA trunk is then directed to transmit an alerting on-hook wink toward the local office followed by a quiet interval of 100 ms. Inband frequencies for coin collect (700/1100 Hz), coin return (1100/1700 Hz), or ringback (700/1700 Hz) are then generated by the CCR circuit.

For multiple wink signaling, the RTA trunk circuits are each equipped with an integrated circuit which when properly addressed by the PCL signal distributor circuit, will generate three winks for coin collect, four winks for coin return, or five winks for ringback. One wink and two winks, not currently used in the multiple wink signaling arrangements, are available for future use. The multiwink generator, however, does generate the one wink as an alerting signal for inband signaling and for ringforward (see Section 4.6).

Timing for the multiwink generator is derived from the 12.346-ms Position and Trunk Scanner clock in combination with an integrated circuit decade counter in each trunk circuit. Hence, the winks appear as squared waves with symmetrical 123-ms intervals.

4.6 Ringforward

The RTA trunk circuits can be arranged on an optional basis to provide either wink or simplex versions of the ringforward signal. Timing for this signal is produced by the same MW generator in the trunk circuits used for coin control and ringback. If the +130-V dc supply is connected to the trunk circuit (optional), the ringforward signal will be +130-V simplexed onto the T and R leads toward the toll office. Otherwise, the T and R leads are simply opened and a wink-type signal is sent to the toll office.

V. MAINTENANCE FACILITIES

5.1 *CDT modifications*

The control, display and test (CDT) frame at the base unit serves as the trunk test panel and also as the primary status display for the TSPS peripherals and subsystems. With the introduction of RTA and PSS No. 2, it was necessary to modify the CDT to accommodate BR trunk and PSS No. 2 position trunk testing and to add a status display for the PCL circuits and data links. A single display is provided which, under control of the SPC, can show the status of any one of the 15 PCLs possible in a given TSPS. This novel display is shown in Fig. 8.

To meet long-range Bell System objectives on test-tone power levels and to prevent crosstalk and other disruptions of carrier systems which are likely to be used for the long BR and operator position trunks, the CDT was modified to permit trunk testing at power levels 10 dB below TLP. Since the base unit, the RTA, and all trunks internal to TSPS (e.g., BR trunks) are considered to be at -3 TLP, the test tones utilized will be at -13 dBm. Coincident with this change, a system for varying the test pad (TP) values was introduced to achieve consistent values of expected measured loss (EML) when testing the difference segments of a TCT. This multilevel testing scheme is discussed later.
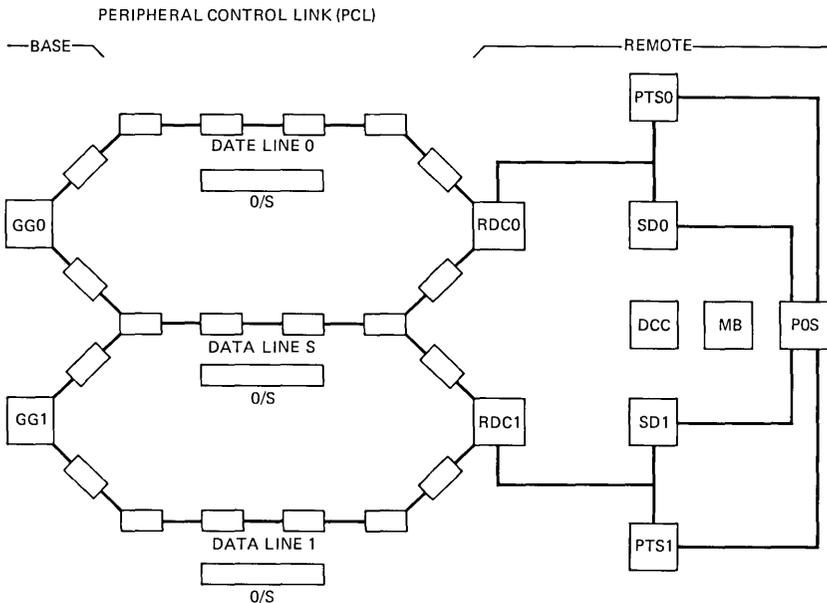

Fig. 8—Control display and test circuit frame—PCL equipment status display.

5.2 Test and display circuit

The test and display circuit (TDC), located at remote RTA and PSS No. 2 sites, provides functions similar to those of the CDT at the base unit. The TDC provides a PCL display, trunk group status indicators, carrier facility and carrier transfer circuit status lamps, and other major circuit status lamps.

A major feature of the TDC is its transmission and noise measuring circuit which is similar to the Automatic Transmission Measuring System 52A Responder. This circuit takes a "snapshot" measurement of the test tone or noise level on a trunk under test and displays the results on an LED digital display. The measured results are also passed in BCD form to the scanner circuit for transmission via the PCL to the base unit. Since the RTA and PSS No. 2 sites are likely to be unattended, this arrangement facilitates one-person testing of BR and position trunks.

On request from the CDT, the TDC is placed in a remote control mode, responding to commands from the SPC transmitted via the PCL. In this mode, the following tests can be made either semiautomatically or by automatic progression from one test to the next and for each trunk in the trunk group:

(i) Near-to-far end loss: Measurement is made by the TDC, transmitted to the base, and printed on the maintenance center TTY.

(ii) Far-to-near end loss: Measurement is made on a transmission measuring set built into the CDT.

(iii) Near-to-far end noise: Measurement is made as in test (i).

(iv) Far-to-near end noise: Measurement is made on a 3B noise measuring set built into the CDT.

In its local mode, the TDC is used to test the segments of the TCTs between the RTA and the local offices and between the RTA and the toll office. It can also be used for 2-person testing of BR or operator position trunks. As with the CDT, tests on these circuits are made at 10 dB below TLP. Test jacks are provided at the TDC to facilitate the use of portable test equipment in testing the PCL data links, TCTs, BR trunks, and the teletypewriter data channel.

5.3 Dial access test lines

A new transmission maintenance facility introduced concurrently with Generic 7 is the Dial Access Test Line circuit or DATL. The DATL circuits, located at both the RTA and the base unit, provide the equivalent of a code-100 test line (quiet termination), a code-102 test line (milliwatt 1000-Hz tone) and a code-106 test line (loop-around). These circuits permit maintenance craft at the local and toll offices to reach a TSPS test termination by simply dialing a test code, typically

959-120X for the quiet termination or 959-122X for the milliwatt tone (the "X" signifies that the last digit is immaterial).

Each DATL has two ports, each of which can supply a quiet termination or milliwatt tone. When two trunks in the same trunk group access the DATL at the same time, the SPC will automatically loop the trunks to each other through the DATL. To prevent this arrangement from being used as an unauthorized "meet me" circuit, the DATL is equipped with 60A control units which are designed to pass signals within a very narrow passband centered at 1004 Hz. If energy outside this band and above approximately −30 dBm is detected, the 60A will open the loop. The loop-around path produces an EML twice that of a 1-way connection.

5.4 Maintenance improvements

The introduction of multilevel testing at the CDT and TDC frames constitutes a noteworthy transmission maintenance improvement. In this scheme, the values of the test pad is changed depending upon the direction of the tests, that is, toward the local office, toll office, base unit (for the TDC), or RTA (for the CDT). Testing a toll-connecting trunk associated with TSPS (including RTA) may also involve testing the TCT segments. There are three possible tests: local office to toll office, local office to TSPS, and toll office to TSPS. Note that each switching center can list a given trunk with two different terminating offices, yielding the likelihood of two different EMLs for the same circuit. Test-pad switching at the CDT and TDC eliminates that condition.

Consider a TCT with ICL of 3 dB being tested between a local office and a toll office equipped with a typical 2-dB test pad. The EML at both offices would be 5 dB. However, if the same TCT circuit is tested between TSPS and the toll office when the ICL of the TCT segment is 0 dB, the toll office would now measure 2 dB. To eliminate this inconsistency, 3-dB test pad is inserted at the CDT (or TDC) to make the toll office measurement 5 dB. Similarly, if the TCT segment between the local office and the TSPS is tested, the local office would now measure 3 dB (the ICL value) or possibly 6 dB if the CDT or TDC test pad is 3 dB, as above. Instead, the CDT (TDC) test pad is switched to 2 dB, making the measurement at the local office a consistent 5 dB.

Since the TSPS base unit can be associated with more than one toll office, the CDT is equipped with test pads of 0, 2, and 3 dB to simulate the test pads found in Bell System toll offices. The TDC may have only one toll test pad value, 0, 2, or 3 dB.

VI. CONCLUSION

The introduction of RTA and PSS No. 2 with their long BR and operator position trunks required establishment of a new comprehen-

sive transmission plan. Several existing base unit circuits had to be modified or completely redesigned to meet tightened transmission standards. Equipped with the new 3-way, 4-wire bridging repeaters, unified telephone circuits, and precision 1P 4-wire terminating sets, the RTA and PSS No. 2 provide generally equivalent, if not better, transmission quality to that which previously existed in TSPS.

VII. ACKNOWLEDGMENTS

The authors wish to acknowledge the contributions of many colleagues who took part in the establishment of the transmission plan and the development of the equipment described in this article. Although they are too numerous to list completely, several deserve special mention: L. A. Ferrara for his work on the UTC: W. Fischer for trunk signaling; E. Tammaru for data link error analysis; J. J. Hibbert, S. M. Kay, and R. J. Frank for transmission planning; and various members of Department 4161 for their work and cooperation in the development of the new 4-wire bridging repeaters.

REFERENCES

1. T. F. Arnold and R. J. Jaeger, Jr., "TSPS/RTA—An Overview of the Remote Trunk Arrangement," ICC75 Conference Record, *III* (June 1975), pp. 46-1—46-4.
2. J. A. Hackett, K. A. Heller, and L. A. Rigazio, "TSPS/RTA—Reliability and Maintainability in the Hardware Design," ICC75 Conference Record, *III* (June 1975), pp. 46-5—46-10.
3. S. M. Bauman and M. F. Sikorsky, "TSPS/RTA—Call Processing," ICC75 Conference Record, *III* (June 1975), pp. 46-11—46-16.
4. W. L. Brune and R. J. Frank, "TSPS/RTA—Transmission Considerations," ICC75 Conference Record, *III* (June 1975), pp. 46-17—46-21.
5. V. L. Ransom and G. Espinosa, "TSPS/RTA—Application and Planning Information," ICC75 Conference Record, *III* (June 1975), pp. 46-22—46-25.
6. T. F. Arnold, "TSPS Goes to the Country," Bell Laboratories Record *55*, No. 6 (June 1977), pp. 147–153.
7. W. S. Hayward, Jr. and R. E. Staehler, "TSPS No. 1: An Overview," B.S.T.J., this issue pp. 1109–1118.
8. S. M. Bauman, R. S. DiPietro, and R. J. Jaeger, "TSPS No. 1: RTA Overall Description and Operational Characteristics," B.S.T.J., this issue, pp. 1119–1135.
9. A. F. Bulfer, W. E. Gibbons, and J. A. Hackett, "TSPS No. 1: RTA Hardware and Software Implementation," B.S.T.J., this issue, pp. 1167–1205.

Traffic Service Position System No. 1:

Remote Trunking Arrangement: Hardware and Software Implementation

By A. F. BULFER, W. E. GIBBONS, and J. A. HACKETT

(Manuscript received December 28, 1978)

The principal data-handling circuits used between a TSPS base location and remote sites up to 1000 miles distant are described. Included are novel operational programming and fault recognition features required by this large separation between the processor and its peripherals as well as by the uniqueness of certain remote units. The RTA's use of remotely run diagnostics and multi-unit initialization schemes for fast recovery from outages is also covered.

I. INTRODUCTION

Early in the RTA planning process, it was recognized that controlling trunks, networks, and test circuits remotely was a task similar to controlling operator positions, voice path circuits, and test circuits remotely; i.e., the RTA job would be similar, in several aspects, to the work planned for development of a new position subsystem. These configurations are shown in Fig. 1. These job similarities led to development of a set of data-handling circuits known as the Peripheral Control Link (PCL) used to link the remote hardware to the controlling processor at a TSPS base location. A Remote Trunk Arrangement (RTA) consists of a PCL, various 2-wire and 4-wire trunks at the remote site, a concentrator network to temporarily connect these remote trunks to a base-remote trunk, a maintenance buffer, and a trunk test frame. A Position Subsystem (PSS) No. 2 consists of a PCL, several operator positions, some supervisory and chief operator circuits, a voice path control frame, a maintenance buffer, and a test frame.

The PSS No. 2 is only briefly treated in this paper and is mentioned at this time to indicate another consideration in PCL design—a desire
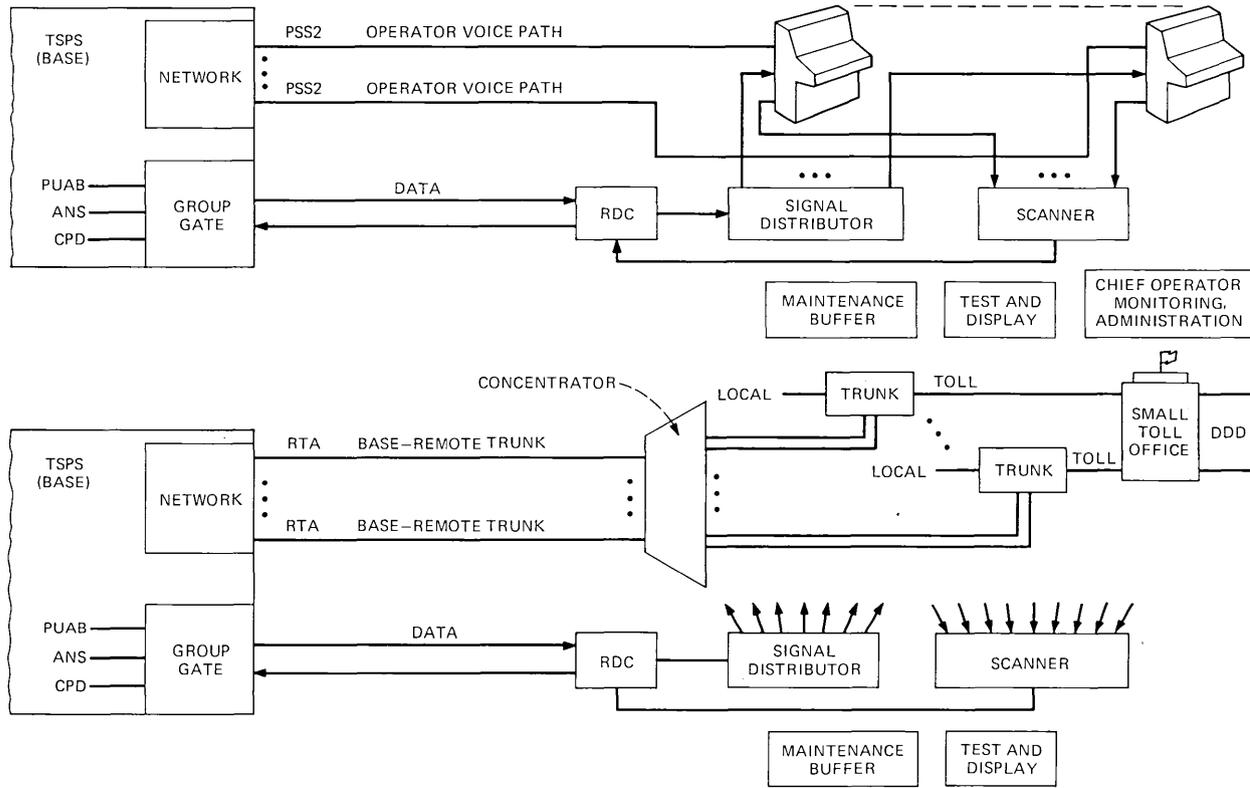
Fig. 1—RTA/PSS No. 2 common equipment.

to keep the PCL general purpose and to have its data rate high enough to handle bursts of operator activity. In both the RTA and the PSS No. 2 configurations, the remote circuits (trunks or positions) are temporarily connected to the base TSPS network in processing a call. In the RTA case, a base-remote trunk is used so that various "service" circuits at the TSPS base location (digit receivers, outpulsers, tones, announcements, etc.) can be connected to the RTA trunk as needed. In the PSS No. 2 case, operators at remote positions are temporarily connected through the base TSPS network to customers placing toll calls requiring operator assistance. The many voice circuits required in each case (up to 64 base-remote trunks or operator voice paths) utilize carrier transfer circuits and carrier failure detection circuits to permit fast, processor-controlled switching to spare carrier groups in the event of trouble. This carrier group switching is similar to that used in other switching designs and is only briefly discussed in Section 2.5.

The PCL includes a base location data conversion circuit known as a group gate, outside plant facilities, remote data circuit, signal distributor, scanner, and diagnostic control circuit. Each of these circuits consists of two identical halves and are arranged in two separate PCL halves with triplicated transmission facilities as shown in Fig. 2. A PCL half is capable of sustaining all communications and control between the Stored Program Control (SPC) and the RTA or PSS No. 2 circuits. When both PCL halves are in service, a state referred to as "duplex,"
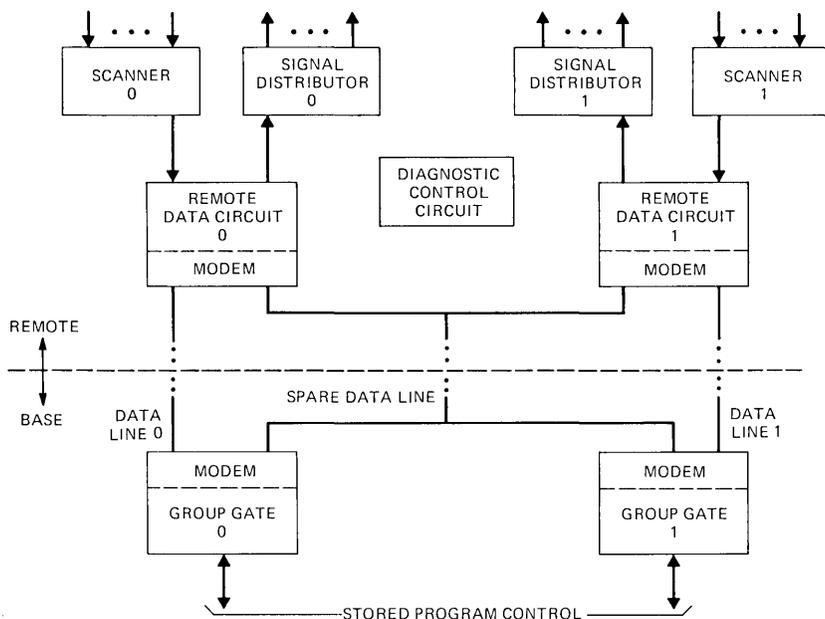
Fig. 2—Peripheral control link.

the PCL throughput remains the same, but the error detecting capabilities of the PCL are increased. Several reliability studies[1-3] have shown the transmission paths to be the weakest link and other studies have shown matching to be one of the best methods of error detection. This led to use of triplicated facilities so that duplex operation *with matching* can be continued even with a facility outage. Operation without matching is also possible so that, while error-detecting capability is lessened, complete RTA or PSS No. 2 operation can continue with two simultaneous facility outages. When a PCL half is out of service, the PCL is said to be in a simplex state.

The RTA equipment not considered part of the PCL is not duplicated. However, control of this part of the RTA is distributed over a variety of individual control devices, such as trunk buffers, concentrator controllers, and maintenance buffers. As a result, failure of any one control device affects only a small part of the RTA complex. For example, a trunk buffer failure would affect no more than 16 trunks.

II. HARDWARE AND PHYSICAL DESIGN

The principal parts of the RTA hardware are the PCL, the concentrator, and the trunks. Each of these parts is described in this section. A test frame, including a 2-way TTY for maintenance messages, is also provided and is described briefly in Section 4.5. The principal parts of the PSS No. 2 hardware are the PCL and the 100C operator positions, and the 100C positions are also described in this section.

2.1 PCL description

The PCL is a general-purpose data link designed to automatically retry failing data words so that fault recognition programs will not be utilized for minor transmission errors. Four principal checks are made on each direction of transmission: parity, cyclic code, sequence check, and matching. In general, the data to be sent are applied to both PCL halves and treated independently by each half. Then, at the far end of the PCL, the data from both halves are matched, and a control bit is examined to see which PCL half will actually execute the order. Certain combinations of matching failures, cyclic code failures, sequence failures, and parity failures still permit valid execution of the transmitted orders, and these possibilities are discussed in Section 4.1.

2.1.1 Group Gate and remote data circuit

The Group Gate (GG) connects the PCL to the address bus, answer bus, and Central Pulse Distributor (CPD) of the TSPS processor. A Group Gate frame provides up to four fully duplicated Group Gates and the common bus input/output circuits to send and receive data to all four. This common bus circuitry initially accepts a 21-bit binary

word from the address bus and passes it to all Group Gates on the frame. An enable signal from the CPD then designates which Group Gate should respond to this particular 21-bit word, i.e., there is a separate enable signal for each Group Gate on the frame. There is also a common enable designating whether this order is "odd" or "even," and circuitry at the remote end continually checks that an alternating pattern of odd and even words is received.

The Group Gate also functions as a parallel-to-serial converter (in the sending direction) and thus converts the 21-bit parallel data into a 21-bit serial bitstream. The odd/even bit mentioned above is added, and a 2-bit "start" code is also added to designate the start of a new transmission and also to designate whether the new word is a long word (*data* from the TSPS processor) or a short word (*scan complete* signal from the processor). The resulting 24-bit serial word (long word) is then passed through a cyclic code generator which appends a 5-bit cyclic code. The resulting 29-bit serial word is fed to a 2400-b/s data set which performs a digital-to-analog conversion and connects to the transmission facility. (The "short word"—an acknowledgment signal from the processor that the last transmission from the distant end was received correctly—is 11 bits long as it is passed to the data set.) In normal (duplex) operation, both halves of a Group Gate receive the 21-bit word from the address bus and generate the 29-bit analog pulse streams to the two transmission paths. However, it is also possible to split the PCL into two (simplex) halves, and in this mode each half can be sent a different order from the processor.

In the receiving direction (Fig. 3), each Group Gate half receives an analog pulse stream into the 2400-b/s data set where it is converted to a digital bitstream. This is passed to a cyclic code check circuit and a parity check circuit. A processor-controlled activity bit designates one Group Gate half as "active" and the other as "inactive." Both halves
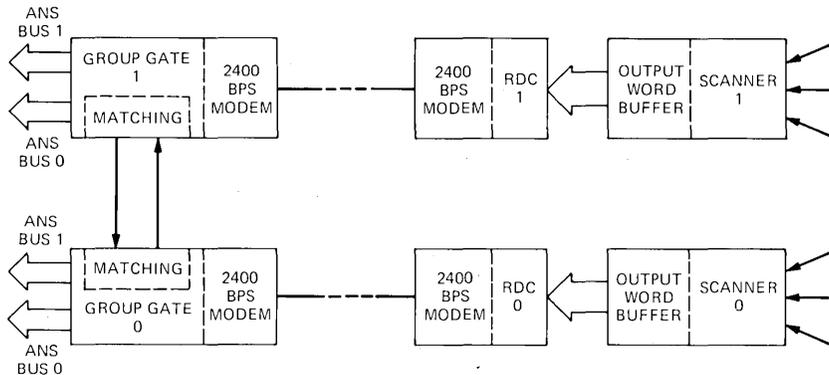

Fig. 3—PCL receive chain.

perform all the actions outlined above, but only the active half controls the matching operation. After the cyclic code and parity checks are performed, the active half moves data from both halves through a serial-mode matching circuit in the active half and determines if the match is valid or invalid. If cyclic code and parity tests have passed and matching is valid, then a signal is sent to the TSPS processor that the Group Gate has information ready to be passed on. If only the active half passed the cyclic code and parity checks and matching with the inactive half is *not* valid, then, again, the processor is signaled that information is present. A CPD pulse from the processor then causes that Group Gate to send its information on the processor answer bus.

For other combinations of invalid data and for transmission "burst" errors[2] affecting more than 1 bit and detected by the cyclic code check, a signal is sent to the remote end to retransmit the data. The processor is also informed that a retransmission or several retransmissions are taking place and, depending upon the severity of the problem, certain fault recognition routines may be executed. For example, the error activity might indicate a bad transmission facility on one PCL half, and the corrective action would be to switch to a spare transmission facility, or the error might be a simple transmission "hit" or "burst" which is cleared up by a retransmission, and no other maintenance activity is required.

The Group Gate can also receive processor data into a maintenance register which sets up any of several specialized maintenance states within a Group Gate half. For example, the cyclic code generator can be configured to purposely output bad codes so that subsequent PCL circuits can be exercised. The sending portion of a Group Gate half can also be connected back to the receiving portion of the same Group Gate half so that data from the TSPS processor can be operated upon by the Group Gate and returned to the processor as part of a diagnostic routine.

The Remote Data Circuit (RDC) is very similar to a Group Gate and, in fact, uses many of the same circuit packs designed for the Group Gate. However, it is located at the remote end of the PCL and connects to the signal distributor and the scanner. Like the Group Gate, it performs parallel-to-serial and serial-to-parallel conversions, parity checks, cyclic code generation and checking, odd/even sequence checking, and matching. The remote data handling circuits are mounted on a double-bay frame such that one side of the frame contains all the 0 half circuits and the other bay contains all the 1 half circuits. The two RDC halves, including their respective 2400-b/s data sets, each comprise one 6-in. mounting plate on the two bays of the frame. This frame, called the position and trunk control frame (for use both in PSS No. 2 and in RTA) is shown in Fig. 4.

Whenever no new data transmissions are available from either the
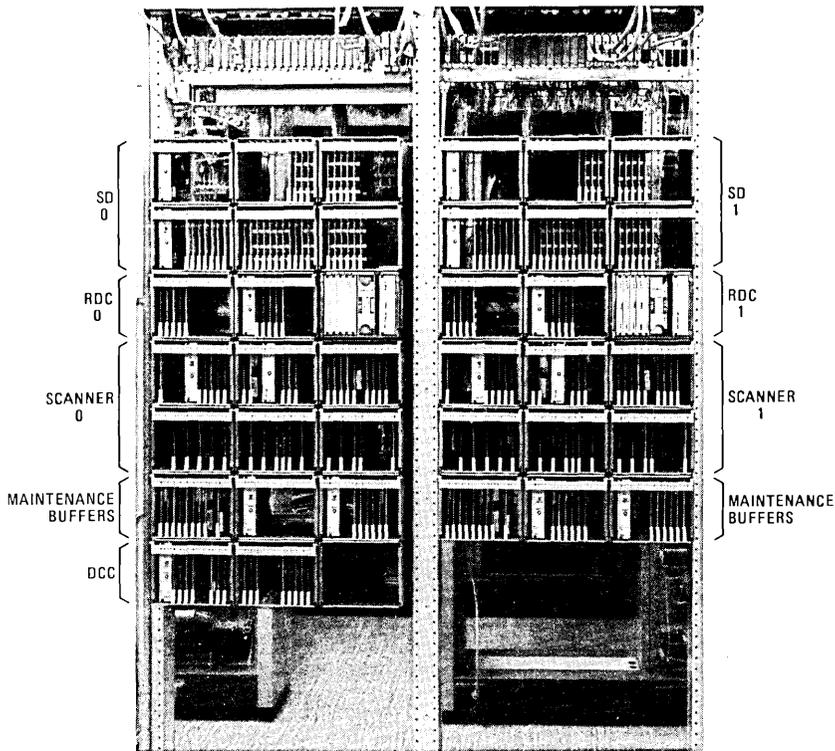
Fig. 4—Position and trunk control frame.

processor (for the Group Gate) or from the remote scanner (for the RDC), a dummy word is sent over the PCL. Thus, the PCL is sending information back and forth every 25 ms even during inactive periods. Both the Group Gate and RDC have the ability to recognize nonreceipt of such interchanges as a mechanism for identifying transmission facility troubles. In addition, the RDC, after several seconds of not receiving any words (dummy or data) from the Group Gate, will split the remote PCL end into two simplex halves. This action is based on the assumption of a trouble which has been recognized at the base (processor) location and has somehow prevented orders (to switch to simplex) from being executed at the remote location. The automatic switch to simplex operation then allows the fault recognition programs to exercise both halves and all three transmission facilities so as to find a good configuration.

2.1.2 Position and Trunk Scanner

The scanner is considered a part of the PCL, but introduces the concept of distributed control, since much of it is physically mounted on the trunk frames and 100C consoles with which it works. This

distributed concept means that only that portion required need be equipped, i.e., as a new trunk frame is added to an office, another piece of the scanner is essentially added to the scanner. This new piece of the scanner was furnished as a part of the trunk frame just added and deals with supervisory signals from those added trunks. It is then connected to the rest of the scanner which is provided as two independent halves, each reporting changes of state to the processor at the TSPS base location. At the base location (in the Group Gates, as described in Section 2.1.1), the two scanner reports are matched before actual transmission to the processor. Mismatch errors are a prime means for detecting scanner malfunctions (see Section 4.1 below).

The scanner is an autonomous circuit continually looking for transitions such as changes in trunk supervision, depression of a key on a position, or test frame and system alarms. It is driven by a clock signal obtained from the 2400-b/s data set used by the RDC and both scanners are run from a single data set clock. However, this clock signal is continually checked and both scanners will switch to the other data set (RDC) clock in case of trouble. For simplex operation, the two scanners each connect to the corresponding individual RDC clocks. Minute differences in the two RDC clocks require a period of synchronization as two simplex scanner halves are reconfigured into a single duplex system.

The scanner examines some 1300 scan points every 12.3 ms and records the state of each in Random Access Memory (RAM). In the *next* 12.3-ms cycle, the previously recorded information is known as the "Last Look" (LL). At any instant of time, the current state of a scan point on which the scanner is currently acting is known as the "Present Look" (PL). The scanner also keeps track (in RAM) of the previously *reported* state of each scan point. This is known as the "Previous State" (PS) and is the state last reported to the TSPS processor. As the scanner examines each point, it compares the PL to the LL and PS. If the PL and LL agree *and* are different from the PS, then a report is made and PS is changed to the new value. The requirement that two scans spaced 12.3 ms apart must agree allows the scanner to disregard all transient conditions producing pulses shorter than 12.3 ms and guards against line and supervisory transients being reported as valid trunk states.

Although both scanners are running on a single clock during duplex operation, there is a low probability chance that one scanner half will see a scan point transition one scan interval ahead of the other. Then, on the next scan, one scanner will make a report while the other scanner has seen the transition for the first time and will not make a report. On the third scan, the second scanner would make its report and from that point on the internal scanner states should be in

agreement. But in the meantime, a mismatch at the Group Gate may have been detected and some fault recognition activity would be triggered needlessly since the mismatch does not indicate a hard fault. To prevent this transient mismatch, a match on the present look between the scanners is performed. If a mismatch occurs at this point, then both scanners ignore the present look in this scan period. On the second scan, if the mismatch was not a hard fault, both scanners will agree and a report will be made in the normal fashion. If the mismatch persists through the second scan, both scanners are again allowed to proceed in a normal fashion but in this case a mismatch will be generated and the hard fault will be detected. A single bit per scan point is required to count the present look mismatches (PLMM) and this bit is kept in RAM along with the LL, PS, and a parity bit for RAM self-checking.

The scanner presents reports to the RDC which adds cyclic code and converts to a serial analog pulse stream. The RDC accepts the scanner reports at a maximum rate of one every 25 ms, depending upon data line activity. However, the scanner *input* rate is based on whatever activity is happening at some interval of time and could conceivably be much greater than a 25-ms rate for brief periods of time, i.e., bursts of operator activity whereby several operators simultaneously push keys or RTA trunk activity involving dial pulse reception on several trunks. Also, the 25-ms output rate may be slowed due to transmission line errors which require retransmissions. To cope with such activity, the scanner contains a 32-word output buffer so that reports can be stored temporarily until they are transmitted. Calculations indicate that, even with bursts of operator and trunk activity, a 32-word buffer will almost always guarantee that no information will be lost.[4] Exceptions can occur during severe (but very infrequent) maintenance activity, when scanner reports accumulate while fault recognition is running maintenance tests under partial outage conditions.

A feature of the scanner is its ability to count dial pulses on the incoming (local office) side of every trunk, recognize the interdigit interval, and report dialed *digits* to the TSPS processor. It also performs timing checks on initial state changes from the local office side of a trunk to recognize "false seizure" conditions so as to not report such false seizures (these can persist for up to 40 ms). These features are based on defining several possible trunk states such as initial seizure, start of open interval of a dial pulse, start of closed interval of a dial pulse, start of interdigital interval, end of pulse, end of digit, disconnect, etc. A trunk progresses from state to state by timing the number of 12.3-ms cycles in which it remains in an on-hook or off-hook condition. Thus, each time the trunk condition changes, a count of 12.3-ms cycles is started (by incrementing a 4-bit count—4 RAM bits—assigned to the

incoming side of each trunk). The actual count reached before the on-hook/off-hook condition changes determines the next state of the trunk. For example, consider a trunk receiving dial pulses which, after a few pulses of a digit, starts counting the 12.3-ms cycles of an off-hook interval. If 2 to 10 cycles are counted and then the trunk condition changes to on-hook, this is considered another pulse of the digit, and the on-hook interval is timed to confirm this. However, if 11 or more (off-hook) 12.3-ms cycles are counted, this is considered an interdigital interval and the previously counted pulses now represent the digit to be reported.

The items scanned by the scanner include trunk supervisory inputs, 100C console keys, and alarm indications from all remote circuits. The reported information consists of scan point type, unit number, and the particular status change of that unit (such as operation of the START TIMING key at a position). A parity bit and a sequence number are added by the scanner. The sequence number is a continuously incremented 2-bit binary number (0-1-2-3-0-1-· · ·) indicating the order in which reports are loaded by the scanner into its 32-word output buffer. The RDC adds a start code, a 5-bit cyclic code as described for the Group Gate in Section 2.1.1, and sends the report back to the TSPS processor. At the processor, this sequence code from the scanner is continually checked and any out-of-sequence condition is a trigger for fault recognition action. This guards against a report being lost with no indication to the processor that the lost report ever existed.

The scanner is constantly performing self-checks as it scans across certain scan points reserved for maintenance self-checks. For example, one scan point is arranged to give on-hook/off-hook sequences that should represent a certain digit count and other circuitry within the scanner checks that this count has been reached. These checks, in addition to parity checks across the RAM, influence an "all-seems-well" bit returned with each scanner report and are constantly examined by the TSPS processor. A failing "all-seems-well" bit triggers immediate fault recognition action.

2.1.3 Signal distributor

The signal distributor takes parallel information from the RDC, strips off the unit designation and unit type information (such as position number, trunk buffer number, concentrator controller number, etc.), and distributes the remaining portion of the order to the designated unit. In performing this distribution, it converts the parallel output of the RDC to a serial bipolar bitstream and adds parity and start bits. The resulting serial word is transmitted over a single pair of wires to an RTA trunk buffer, a 100C console (PSS No. 2), a concentrator controller, a maintenance buffer, or to the test frame. Thus the signal distributor communicates with 70 to 80 units of five different types.

(For a PSS No. 2, this consists of 62 positions, 5 maintenance buffers, 2 test frame buffers, and 1 self-test buffer. For an RTA, this consists of 31 trunk buffers, 5 maintenance buffers, 2 test frame buffers, 40 concentrator controllers, and 1 self-test output). The serial bit-bipolar transmission allows these units to be several hundred cable feet from the signal distributor.

After the serial word is constructed within the signal distributor and loaded into an output shift register, it is then shifted out and, at the same time, looped back into the output register. Thus, when shifting (transmission) is complete, the transmitted word is again in the output register and is rechecked bit by bit for accuracy. Both this check and a subsequent flip/flop activity check made by the receiving unit (100C console, trunk buffer, etc.) influence the check-back signal sent from the signal distributor back to the RDC, and subsequently to the SPC, as an overall check. This shifting action also allows calculation of a parity bit "on-the-fly," i.e., as the information and start bits are shifted out, parity is calculated and, if the shift register recheck passes, the correct parity bit is appended to the end of the serial transmission. Thus the parity bit can be purposely "failed" to keep the receiving unit from using questionable data.

The start code not only identifies the start of a new transmission but also identifies the *type* of unit expected to receive the new information. Each receiving unit contains a start code mask that must match the start code to accept the information bits. Each receiving unit (buffer) also generates either a "check-back" or a "buffer failure" response to the signal distributor each time it receives new information. This response is returned to the distributor over the same pair of wires used to send information to a buffer. This response, together with the signal distributor's internal checks, is used to send a check-back signal to the RDC and from there to the SPC. If the SPC fails to receive this check-back, fault recognition action is triggered, starting with a simple retry and escalating to subsystem reconfigurations if necessary.

The duplex nature of the sending portion of the PCL effectively ends at the RDC and, once RDC matching is complete, only one of the duplicated signal distributors executes the order. The distributor chosen by the RDC is changed on every order to utilize both distributors evenly. If the PCL is split into two independent halves for maintenance purposes, then maintenance orders can use one signal distributor while call processing orders use the other.

The orders to light LED numerical displays in 100C consoles place special requirements on the signal distributor. These orders are always sent as a sequence of 2 to 7 consecutive SPC orders, but only the first contains the address of the desired 100C console. The signal distributor recognizes such orders (usually called "prime" orders since they prime the distributor and the 100C console to expect a sequence) and tem-

porarily stores the position number while passing the rest of the order to the desired position. Subsequent SPC orders will contain pairs of digits to be selected on the console LED display but do not include a position number. Since only one signal distributor executed the "prime" order and remembers the position number, that one distributor handles all of the rest of the sequence and the alternating use of both signal distributors is temporarily suspended.

The "prime" order also informs the distributor as to which of several *types* of LED displays will be forthcoming; e.g., a 12-digit (including blanks) display of a called number, a 1-digit display of elapsed minutes, a 6-digit display of the time-of-day, etc. The distributor includes a 6-unit ring counter that chooses the location, within the operator's numerical display, where the pair of digits just received are to be placed. This ring counter is preloaded by the prime order to start the first pair of digits (next SPC order) in the correct position on the 100C console. The ring counter is then stepped along by each subsequent order so that it is always ready to direct the digits to the proper place. As the signal distributor forms the 23-bit serial word to the 100C console it takes the digit pair *values* from the RDC, the pair *location* from the ring counter, and the 100C *address* from its stored memory of that address, and adds a parity bit computed on-the-fly as the other information goes by.

2.1.4 Diagnostic control circuit

The diagnostic control circuit (DCC) is also considered part of the PCL as shown in Fig. 2. It allows implementation of a remotely run diagnostic concept explained in Section 4.3. The overall description, together with its control by the SPC and its considerable access to remote PCL circuits, are all included in Section 4.3 as part of the RTA maintenance plan.

2.2 Concentrator

2.2.1 Size, ratio, components

The RTA concept is to provide TSPS services for a sparsely populated area from a TSPS in a more built-up area. Therefore, many RTA installations consist of 200 to 400 trunks arranged in many small trunk groups with relatively low occupancy. Initially, only 100 to 150 trunks may be required, with growth to 300 to 400 taking place over several years. A few RTA sites will have larger trunk groups and correspondingly higher occupancy and a few will have trunks exceeding the capacity of a single RTA and use two RTAs in the same building.

Early studies of the potential RTA market and of trunk usage led to the conclusion that the base-remote trunks (from the output side of the concentrator to the controlling TSPS base installation) will be connected to a call for about one-eighth of the total holding time.[7]

Several concentration ratios were evaluated based on trunk numbers mentioned above, and the 8:1 concentrator was selected as the best compromise. The compromise was such that a slightly more expensive concentrator is initially provided but growth, on both the basic concentrator and the subsequent addition of a build-out frame, is easily accomplished. The 8:1 concentrator works well with lightly loaded offices, allows up to 496 incoming trunks, and provides for flexibility in load balancing. With a full complement of base-remote trunks (up to 64), it also works well in moderately heavily loaded offices.

The desire for a low-cost, easily-added-to, and moderately-long-holding-time switch led to use of miniature crossbar switches as the principal concentrator element. In RTA use, the select mechanism of the crossbar switches will accumulate its lifetime operations (estimated at 20 to 25 million operations) in 7 years. Ease of replacing this mechanism plus widespread operating company familiarity with such work also influenced the crossbar switch choice.

2.2.2 The logical concentrator and the physical concentrator

The logical layout of the concentrator is used to understand the connection pattern and to assign switch numbers useful to the TSPS programs controlling concentrator operations. However, the physical construction of the concentrator makes use of 20×10 crossbar switches arranged in a rather specialized way to achieve the 16 by 8 and 32 by 8 switches of the "logical" concentrator. This section explains the relationship between these two views of the concentrator.

The concentrator may be obtained in two sizes: a "small" size, able to connect up to 248 remote incoming trunks to as many as 64 base-remote trunks, and a "large" size, which can handle up to 496 remote incoming trunks. In each size, every remote trunk has full access to each of the up to 64 base-remote trunks. The term "remote trunk" is used broadly here to mean any trunk circuit which appears on the inlet side of the concentrator, while the term "remote incoming trunk" means specifically an RTA incoming trunk. A variety of possible remote trunks besides remote incoming trunks includes: hotel/motel auto-quote trunks, inward trunks, and test appearances. With the exception of test appearances, if any of these other types of remote trunks appear on the concentrator, they must replace remote incoming trunks so that the maximum number of the latter is reduced accordingly.

2.2.2.1 The Logical Concentrator. Figure 5 is a simplified depiction of the Logical Concentrator. In the small sizes, the first or trunk stage consists of thirty-two 16 by 8 three-wire crossbar switches, while the second or base-remote stage has eight 32 by 8 three-wire switches. The small Logical Concentrator thus has 512 inlets (2 for each of the 248 remote incoming trunks, 2 for test appearances, and 14 spares), 64 outlets (one for each of the 64 base-remote trunks), and 256 links (one
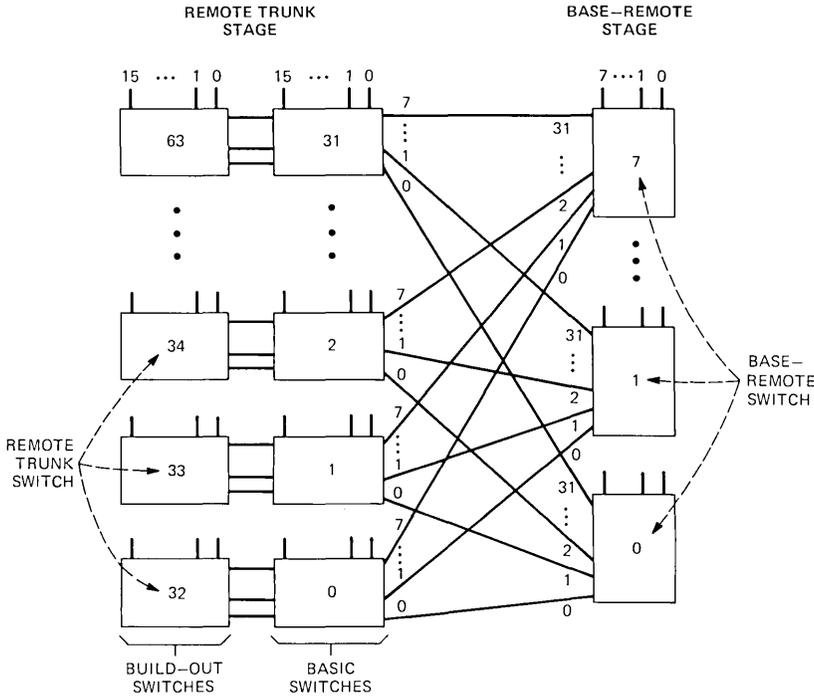
Fig. 5—The logical concentrator and its numbering.

from each of the 32 trunk stage switches to each of the 8 base-remote stage switches).

The large Logical Concentrator is obtained by adding a 16 by 8 three-wire buildout switch to each of the trunk stage switches of the small Logical Concentrator. It thus has the equivalent of thirty-two 32 by 8 trunk stage switches and eight 32 by 8 base-remote stage switches for a total of 1024 inlets (two for each of the 496 remote incoming trunks, two for test appearances, and 30 spares), 64 outlets (one per base-remote trunk), and 256 links.

It is important to note that there is only one possible path or "channel" from a *particular* remote trunk appearance to a *particular* base-remote trunk. By comparison, the base TSPS network has eight possible channels from a given inlet to a given outlet.

To make a connection in the Logical Concentrator from a particular remote trunk to a particular base-remote trunk, a *single* crosspoint is activated on the trunk stage switch containing the remote trunk and another *single* crosspoint is activated on the base-remote stage switch on which the base-remote trunk is terminated. The first crosspoint connects the remote trunk to the link going to the desired base-remote stage switch, and the second connects that link to the proper base-remote trunk.
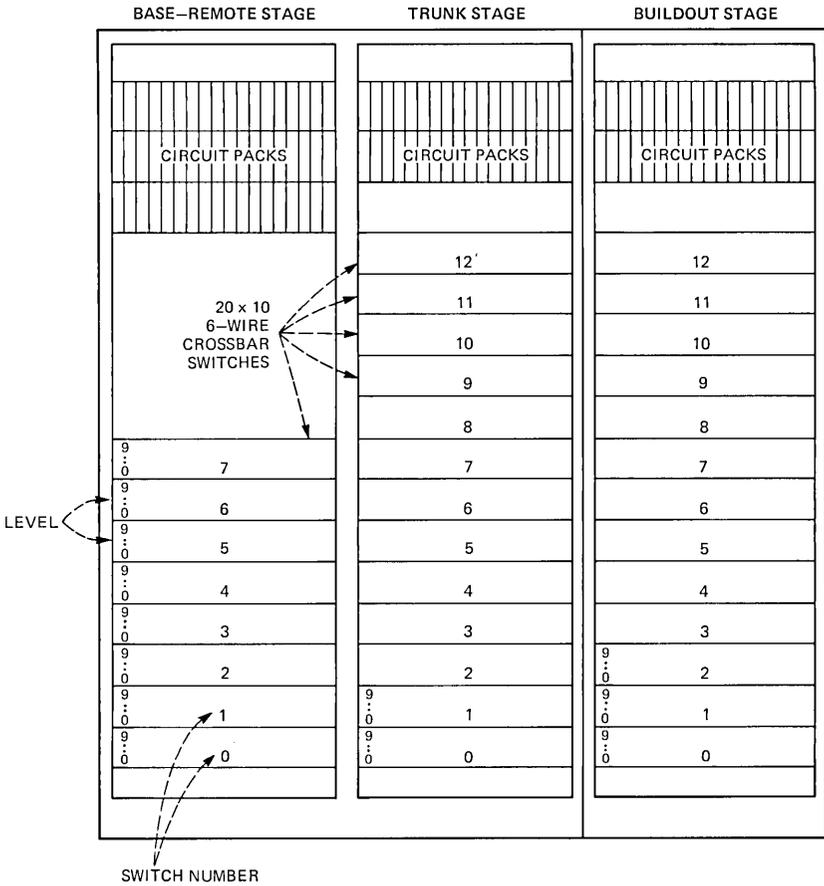
Fig. 6—The physical concentrator frames and their numbering.

2.2.2.2 The Physical Concentrator.

Because of limitations on the type of crossbar switches that are available, the actual hardware implementation of the concentrator is quite different from that described above. This hardware implementation is called the Physical Concentrator and is shown in Fig. 6. The small concentrator consists of two bays of crossbar switches. The first, or trunk stage bay, contains thirteen 20 by 10 six-wire crossbar switches, while the second or base-remote stage bay contains eight 20 by 10 six-wire crossbar switches. The large concentrator is obtained by adding a second frame, similar to the trunk stage bay above, called the buildout frame which contains thirteen 20 by 10 six-wire crossbar switches.

To make the 20 by 10 six-wire switches in the physical implementation of the RTA concentrator function logically like 16 by 8 three-wire switches, a rather complex design has evolved. The first step, that of making six-wire switches behave like three-wire switches, is per-

formed using a well-known technique[5] by which levels 0 and 1 are utilized to translate which three of the particular set of six wires are to be used. The result of this translation is that the 20 by 10 six-wire switches operate like 20 by 16 three-wire switches. These are then combined in a fairly complex way to form a unit which operates like the Logical Concentrator.

Thus, in the Physical Concentrator, to make a connection from a particular remote trunk to a particular base-remote trunk, two cross-points must be activated in the trunk stage switch on which the remote trunk is terminated and two more crosspoints must be activated in one of the base-remote stage switches to which the base-remote trunk is connected. The first of these crosspoints is located in levels 2 to 9 and connects a pair of remote trunk appearances (six wires) to the link going to the desired base-remote stage switch. The second crosspoint is located in levels 0 or 1 and selects which of the pair is desired. The third and fourth crosspoints perform similar functions in the base-remote stage of the concentrator.

2.2.3 Distributed control

All the concentrator switch select and hold magnets are operated by controller circuits arranged on three plug-in circuit packs. The eight groups of packs used for control of base-remote stage switches are physically mounted on the concentrator frame and are always provided. However, the groups of circuit packs controlling each trunk stage logical switch (up to 32) are provided as part of the trunk buffer circuit. An RTA office can have up to 32 trunk buffers, 31 of which can each contain 16 trunks. Thus, as each group of 16 trunks is added to an RTA, a corresponding piece of the concentrator (the three controller circuit packs) is also added. The control of the trunk stage portion of the concentrator is thus distributed over all RTA trunk buffers arranged on up to five separate frames. Some cost saving is obtained by this arrangement, since only the portion of concentrator control actually required by trunks present in the office are purchased. However, of much more importance is the distribution of this control over many equipment units and the resulting overall reliability obtained; i.e., problems affecting a group of trunks affect only that part of the concentrator serving those particular trunks.

The SPC orders distributed to a particular concentrator controller by the signal distributor specify the switch number desired, the particular select and hold magnets to be used, and the function (connect or disconnect). A single trunk stage controller controls two logical switches, since each RTA trunk has two appearances on the concentrator. These two appearances (local office side and toll office side) are provided so that an outpulser connection to the toll office can be set up while an operator connection to the calling customer is established.

[Thus the 8:1 concentration ratio is approximately the ratio of incoming trunks (up to 496) to base-remote trunks (up to 64), while the ratio of trunk appearances is actually 16:1.] In general, the sequence of control orders to establish a concentrator connection is as follows: Trunk stage connect order, followed by a base-remote stage connect order, followed by operation of relays in the selected base-remote trunk. A verification test later performed by the base-remote trunk circuit results in establishment of a control path via the concentrator sleeve lead which locks the trunk stage hold magnet to the base-remote stage hold magnet. Connections are broken by a base-remote stage disconnect order which resets the base-remote stage hold magnet flip-flop and in turn releases both the base-remote and trunk stage hold magnets.

2.3 RTA trunks

The general approach to trunk design for electronic offices has been to keep the trunk simple and temporarily connect it to more sophisticated equipment for such things as digit reception, ANI reception, coin control signal generation, and outpulsing. That this requires many trunk and link orders for each call is of little concern when the trunks and their associated scanners and signal distributors are close to the processor and reached over high-speed buses. However, when the trunks are several hundred miles from the controlling processor, and when excessive numbers of orders can exceed the capacity of relatively slow-speed data paths, the simple trunk concept is not so appropriate. Thus the RTA trunks tend to be more complex than their base-location counterparts and include several features on a per-trunk basis which might otherwise be provided by a separate pool of circuits.

Another feature of each RTA trunk is that it is packaged on a single 5 by 7 in. circuit pack. The single Printed Wiring Board (PWB) construction is made possible by using miniature wire-spring relays, miniature mercury relays, miniature networks, and a specially designed integrated circuit. A typical trunk is shown in Fig. 7. The custom integrated circuit handles several signaling tasks, including coin control signals and ringback signals sent from TSPS to the local office.

The coin control and ringback considerations, including the ability to disable or enable a station set *TOUCH-TONE®* dialing pad at certain points in a call, require that five separate signals be sent from the RTA trunk to the local office. A custom-made IC provided in each trunk provides these "multiple-wink" signals. The ring-forward signal to the toll office is also provided within each RTA trunk. The custom integrated circuit uses a 3-bit binary input set as a command to generate 1 to 5 pulses, each of which turns on (operates) a pair of mercury relays for a timed interval. This pair of mercury relays has contacts arranged in the tip-and-ring leads to provide a reversal to the
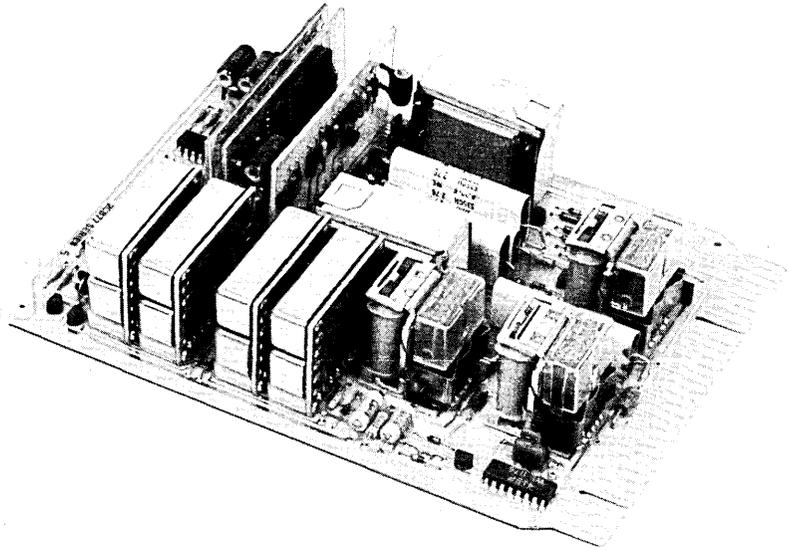
Fig. 7—Typical RTA trunk.

local office. Thus, 1 to 5 timed reversals (winks) can be sent from an RTA trunk. Since this uses only six of the eight possible input states (OFF and one to five winks), the other two are used to operate other relays including a set of "ring-forward" mercury relays which apply +130 V to the toll office side of the trunk. The 3-bit binary input comes from the trunk buffer which generates the 3-bit output from a single SPC order.

With the exception of the use of miniature components and the custom integrated circuit mentioned above, many other talking path and relay states in RTA trunks are similar to previous electronic office trunk designs. The 4-wire trunks utilize the TSPS 3-way 4-wire bridging repeaters mounted on separate repeater bays together with the PWB on the RTA trunk frame. A group of 16 trunks, together with a trunk buffer and appropriate portions of the concentrator controller (Section 2.2) and of the scanner (Section 2.1.2) comprise a *trunk unit*. This trunk unit has each component part arranged to control only the 16 trunks of that unit and is thus completely separate from any other trunk unit. A malfunction in any portion of the trunk unit will thus affect, at most, 16 trunks.

The trunk buffer is similar to all the buffers to which the signal distributor distributes SPC orders and consists essentially of a flip-flop matrix and the necessary control circuitry to set and reset each flip-flop. Output drivers connected to each flip-flop then operate relays in the trunks or send signals to the multiple-wink integrated circuit in

each trunk of this particular trunk unit. The trunk buffer is provided with a "super-initialization" input so that, under severe maintenance conditions, an entire buffer or all buffers in the office can be cleared by a single pair of SPC orders. This initialization path is arranged so that all trunks are cleared *except* those trunks in the cut-through (talking) state. Such trunks are *assumed* to be cleared by the initialization routines but are protected by a circuit design that inhibits the action of the clear signal when in the cut-through state. The corresponding program actions are discussed in Section 3.3. This approach allows rapid system initialization when necessary, while at the same time protecting all customer-to-customer talking paths.

2.4 100C position

As mentioned at the start of this chapter, the Position Subsystem (PSS) No. 2 is only briefly mentioned. By adding 100C consoles to the PCL described in Section 2.1, together with some voice path switching and supervisory circuits, a PSS No. 2 is obtained. The 100C position is treated by the PCL signal distributor as one of several "buffer" circuits to which it distributes orders. The single exception to this is the *sequence* of orders required to light up a numerical display (1 to 12 digits) on the 100C console (see Section 2.1.3). A console consists of two positions, and throughout the TSPS literature "100C console" and "100C positions" are used interchangeably.

The upper portion of the position consists of two large keyshelf printed wiring boards and the LED numeric display PWB. Each keyshelf board contains 30 to 50 key/lamps and some integrated circuits and discrete components associated with those lamps and keys. The single "make" contact of each key connects to a cluster of three diodes, which are in turn connected to three leads of a 9-lead bus. Thus each key generates a 3-out-of-9 code on this 9-lead bus whenever it is depressed. The 9-bit bus is examined by the scanner at regular intervals as discussed in Section 2.1.2. The numerical display PWB contains twelve 7-segment LED numerics and the memory and driving electronics associated with them.

The lower portion of the 100C position contains a dc-to-dc converter and several circuit packs of flip-flops, lamp order buffers, and control circuits. The control circuit decodes the serial bitstream from the signal distributor and determines whether it is part of a numerical display sequence or a single lamp order. The numerical display orders are delivered with little change to the LED display PWB. The lamp orders are formed into a vertical select, horizontal select, and group select output set to address a flip-flop matrix. The result is the setting or resetting of a single flip-flop and generation of a check-back signal to inform the signal distributor that the correct conditions for accessing

a flip-flop were present (a sort of all-seems-well signal). In many cases, the flip-flop connects directly to a console lamp and simply lights or extinguishes that lamp. However, in some cases a console lamp may be placed in a flashing state and in such cases the flip-flop output connects to a lamp order buffer (LOB). These LOBs generally have two flip-flop inputs and a single lamp driver output. One input is used for a steady lamp "on" condition, while the other is used to connect the lamp to a 60 or 120 IPM interrupter circuit. On a typical call, the TSPS processor might initially send several orders to a position causing three or four lamps to light up and then light and extinguish two or three more in the course of the operator's involvement on the call. For coin calls, part of the numerical display will also be lighted, showing the charge and initial period interval for each call.

In summary, the console contains all the lamps, lamp drivers, memory cells (flip-flops), and overall controls to turn on and hold on the various combinations of lamps required for each call. It contains the circuitry to encode up to 84 keys in a 3-out-of-9 format for the scanner. It also contains duplicated input (signal distributor) and output (scanner) capability and the ability to permit input orders to generate output codes directly, with no operator present, for diagnostic purposes.

2.5 Voice circuits

Although the PCL data lines are voice-grade circuits, they are used to transmit only data between the base and remote locations. Other voice-grade circuits provide connections between the RTA trunks and the base office (base-remote trunks), provide for operator talk paths (for PSS No. 2), and also connect the remotely located maintenance teletypewriter to the base location. Standard 4-wire voice-grade circuits are needed for base-remote trunks, and any type toll-grade carrier system with groups of either 12 or 24 circuits may be used.

For reliability, maximum diversification in the carrier groups, including a spare group, is required. This means that the carrier groups should be evenly distributed over two or more carrier route facilities and, within a route, the carrier groups should be distributed as much as possible over independent terminal equipments and power supplies.

Carrier transfer circuitry is provided at the base and remote locations to switch the spare group into service in place of any other group that fails. Switching is controlled by a program at the base location which requires carrier group alarm signals as an input. Since there is only one spare group, loss of more than one carrier group results in partial facility loss and possible delays in handling calls from that RTA.

III. RTA OPERATIONAL SOFTWARE IMPLEMENTATION

When it was first proposed, the RTA operational software was visualized as being relatively straightforward. At the very beginning of an RTA call, a pair of base-remote trunks would be seized and used to "extend" the remote trunk to the base network. The appearances of the base-remote trunk would be arranged to be the software equivalent of those of a base universal trunk. Thus, throughout the succeeding stages of the call, the existing TSPS operational software[6] could be used without significant modification until, when the operator was released, the base-remote trunks would be disconnected and idled.

Early in the planning, however, it was realized that this was not feasible. Not only was it uneconomical to leave both base-remote trunks up throughout the early stages of a call, but economics also dictated that trunk supervisory states be sensed and controlled via the PCL rather than by sensing and controlling the state of base-remote trunks. Moreover, the technology and complexity of the RTA trunks (see Section 2.3) caused the sequence of orders required to control them to be wholly different from that of base trunks so that the software which constructs trunk orders for base trunks could not be used. Also, the structure of the TSPS operational software did not allow the type of changes required for RTA call processing to be made simply or in a small number of low-level modules.

The result was that the RTA operational software design was forced to evolve away from the initial concept of a few relatively large new modules with most of the existing operational software left intact. Instead, many small changes had to be made to most operational programs in the system. These changes were inserted at points where a position or service circuit is connected or released and at points where trunk control orders are formulated. Typically, the changes involved the addition of a software switch based on a test of the location (base or RTA) of the trunk under consideration. This test is facilitated by bits at several points in the trunk parameter register which have a value of 1 if the trunk is an RTA trunk and 0 otherwise. If the trunk is at the base, the switch directs execution of the previously existing program code. If not, a new RTA program leg is used to handle the call.

Thus, most RTA operational software is relatively straightforward and will not be discussed further. However, several program areas are new to RTA and have no analog in the previous TSPS software. These include the control of the RTA concentrator, the base-remote trunk queuing structures, the "virtual" scanner used to maintain the state of remote trunk supervisory scan points, and a new type of audit. Each of these is discussed in the following sections.

3.1 Concentrator control

During a normal TSPS call, various connections must be made to positions and service circuits. If the call is on an RTA trunk, such a connection requires the selection of:

(*i*) An idle base-remote trunk and an idle path from the RTA trunk through the concentrator to that base-remote trunk and

(*ii*) An idle position or service circuit and an idle path through the TSPS base network from the base-remote trunk to that position or service circuit.

Ideally, the path selection routine should hunt both (*i*) and (*ii*) simultaneously in one unified procedure. Such a procedure would be very complex because it would have to consider the RTA concentrator, the set of base-remote trunks, and the base network as one large, complex, six-stage network (two stages at the RTA and four at the base). However, since the probability of success on (*ii*) is virtually independent of the choice made on (*i*), little effectiveness is lost by hunting the path sequentially: first selecting (*i*) and then (*ii*). This allows one potentially complex single procedure to be replaced by two simpler sequential ones. The first of these is handled by the Concentrator Control program—a new program for RTA—while the second is the previous Network Control program with slight modifications.

Also used with slight modification is the path memory annex register,[6] which is linked to the call register during a network connection. It is used to store the identity of the connected circuits, and the paths used, their states, and, in the case of RTA, the concentrator paths and base-remote trunks used and their states.

The Concentrator Control program is a subroutine capable of hunting, connecting, and breaking paths from RTA trunks through the concentrator to the base via base-remote trunks. It has an interface with the other call processing programs which is similar to that of the Network Control program. Like the latter, it has a set of linkage maps, shown in Fig. 8, which are used in the calculations.

Conceptually, hunting and selecting a path for a call through the RTA concentrator, like any connecting network, may be done in two steps:

(*i*) Find all idle paths from the concentrator inlet of a specified RTA trunk appearance to the base network. If no idle paths exist, the call is said to be "blocked." By "idle path" is meant a combination of an idle base-remote trunk and an idle link connecting the trunk stage switch containing the inlet to the base-remote stage switch containing the base-remote trunk.

CONCENTRATOR
MAP HEADCELL

RTA
NUMBER

0

7

LINK MAP

7   0

0

TRUNK STAGE
SWITCH NUMBER

31

EACH WORD CONTAINS 1'S IN
THOSE BIT POSITIONS CORRESPONDING
TO IDLE LINKS ON THAT TRUNK STAGE
SWITCH

RELATIVE
BUSYNESS MAP

n

7   0

0

7

EACH WORD CONTAINS 1'S IN
THOSE BIT POSITIONS CORRESPONDING
TO BASE–REMOTE STAGE SWITCHES
CONTAINING $8-n$ OR MORE
BASE–REMOTE TRUNKS IDLE

BASE–REMOTE
STAGE SWITCH
NUMBER

BASE–REMOTE
TRUNK MAP

7   0

0

7

EACH WORD CONTAINS 1'S IN
THOSE BIT POSITIONS CORRESPONDING
TO IDLE BASE–REMOTE TRUNKS

Fig. 8—Concentrator maps.

(*ii*) Select one of these idle paths to be used for the call. The procedure used to do this is called the "routing procedure."

The choice of a routing procedure is important because it affects the blocking probability of the network—the probability that the call is blocked at step (*i*) above— and hence the amount of traffic that the network can carry. One requirement of a routing procedure is that it equalize the long-term mechanical wear of the network crosspoints. Thus, a good routing procedure will minimize network blockage while equalizing crosspoint wear.

An unusual feature of connecting networks such as the RTA concentrator is that none of the routing procedures commonly used for other networks, such as random selection (which is presently used in the TSPS base network) or packing (which is used in the No. 5 and other Crossbar Systems), is a particularly good choice. However, it may be shown[7] that a near-optimal routing procedure is to select the path which goes through the base-remote stage switch which contains the largest number of idle base-remote trunks (with ties broken at random). The base-remote trunk to be used should also be selected at random. Studies show that use of this procedure increases the traffic capacity of the group of base-remote trunks by up to 3/4 Erlang at the

engineered load (about 40 Erlangs for a typical, large RTA) compared to the random routing procedure. This means that one less base-remote trunk is typically required—a substantial saving.

The actual implementation of the path hunting procedure integrates the two steps above into one algorithm. First, a test is made to see if all base-remote trunks are busy. If they are, the call is placed on one of the base-remote trunk queues as described in the next section. If one or more base-remote trunks are idle, the routine reads the proper link busy/idle word from the link map (Fig. 8) and forms the logical product of it with word n of the relative busyness map for n as small as possible such that the result is nonzero. A binary search is used to quickly find the proper value of n. If no such n can be found, the call is blocked. If the call is not blocked, then one of the l's in the result is selected at random, the corresponding word of the base-remote trunk map is read, and one of the l's in it is selected at random. The two l's which are selected determine the path to be used by the call. To connect the path, the program loads the appropriate concentrator control orders in an output buffer, updates the concentrator maps, writes the path information into the path memory annex, and then terminates.

3.2 Base-remote trunk queuing

With RTA, a new group of hardware resources, namely base-remote trunks, is added to the TSPS system. One of these resources is routinely applied to a call at the same time as other resources such as operator positions and service circuits. In addition, on some calls, a connection must be made to two base-remote trunks at the same time (on dial-0, dial pulse, non-ANI calls, for example). And most calls have two base-remote trunks up simultaneously at some point in the call (for position and outpulser). Although the normal engineering of these relatively expensive resources is adequate, the supply may be cut in half by an outage of one of the two diverse routes which the base-remote trunks traverse. Since the base-remote trunks are normally engineered near or over 50 percent occupancy, such an outage can instantly throw the RTA into heavy overload. Although rare, this condition is the most likely RTA failure state because of the excellent reliability of the rest of the equipment.

These facts imply that the group of base-remote trunks must be carefully administered. Also, it was desirable to cleanly integrate the queuing for base-remote trunks into the existing TSPS queuing structures which, although they are basically quite powerful and flexible, have the built in assumption that only one resource may be queued for at a time.

The solution chosen is to have two first-come, first-served base-remote trunk queues served in priority order for each RTA.

If all in-service base-remote trunks are busy, calls wait in one of these queues. When a base-remote trunk becomes idle and available for use, it is connected to the first call on the high priority queue. If there are no calls waiting on the high priority queue, the base-remote trunk is connected to the first call on the low priority queue.

Generally, if no base-remote trunks are available the first time in a call when one is needed, the call waits on the low priority queue. Thereafter on that call, the high priority queue is used whenever base-remote trunk congestion is encountered.

This structure has several advantages. First, it gives priority to calls already in the system on which considerable system resources and real time have already been invested. Also it fits well into the existing "one resource per queue" TSPS queuing structure. For example, if a call needs two base-remote trunks at the same time and none are available, the call waits on the low priority queue until it gets one. Then it waits on the high priority queue and it will get the very next base-remote trunk that becomes available (the fact that it received one base-remote trunk while on the low priority queue means the high priority queue was empty). Thus, the call gets two base-remote trunks in slightly more than one waiting time.

Under conditions of RTA overload (caused by, say, a traffic overload or a route outage affecting up to half the base-remote trunks), simulation studies show that the low priority queue can become quite long while the high priority queue remains very short, usually with either zero or one call in it. In this case, every RTA call waits in the low priority queue exactly once, and thereafter uses the very short high priority queue. The result is that every call receives a roughly equal grade of service no matter how many base-remote trunks it needs during its course. (It is impossible for the high priority queue to become very long in the steady state, for if it were to become long, then the low priority queue would never be served and no new RTA calls would ever get into the system—a contradiction.)

The same simulation studies show that, with this queuing structure, the probability of deadlock is *extremely* low. An example of deadlock is as follows. Consider an idle RTA with N in-service base-remote trunks. Suppose that exactly N dial-0 calls arrive nearly simultaneously. Each would be connected to an operator using a base-remote trunk, thus making all such trunks busy. Each operator would then key in the called number and attempt to initiate outpulsing. Since outpulsing requires a second base-remote trunk, all N calls would be loaded onto the high priority queue. Since no base-remote trunks are available, all N calls will be deadlocked until one of the operators or customers abandon. Because the probability of this occurring was determined to be very low, no defensive measures have been added to the programs.

The programs seek and obtain a base-remote trunk for a call, queuing if necessary, before attempting to obtain a position or service circuit. Since positions are a more expensive resource, the base-remote trunk normally remains connected to the call throughout any position queuing to avoid adding the time required to queue for and connect the base-remote trunk to the operator work time. Thus the position queuing time is added to the base-remote trunk holding time. Because this has the potential to translate an operator overload into a base-remote trunk overload, a complex overload procedure is utilized which disconnects the base-remote trunk from the call if the position queue is very long and uses the high priority queue if necessary to reobtain one quickly.

3.3 The virtual scanner

The TSPS programs often determine the supervisory state of a trunk by directly scanning it. This cannot be done with RTA because the RTA scanner is autonomous. To solve this problem, a software image of the state of each trunk scan point is maintained in temporary memory. This is called the virtual scanner, since the required directed scans can be done by "scanning" (a memory read) this area of memory.

It is implemented by adding a virtual scanner (vs) bit to the two bits already assigned to each scan point[6] (one of these gives the last reported supervisory state while the other indicates that reporting supervisory changes has been temporarily suspended on this trunk).

The vs bit represents the software's best estimate of the current state of the scan point and is always updated whenever a trunk supervisory state change report is received from the RTA.

The only complication occurs when an RTA initialization is required. Such an initialization leaves talking state RTA trunks intact, but idles all others. Often when this happens, the information in the virtual scanner is probably unreliable so that the state of the trunk is no longer considered known.

When this occurs, charging is canceled on all RTA talking calls at the time and the RTA trunks are put into a special software "limbo" state. This state means that the software does not know whether the trunk is idle or talking. When an on-hook report is received on a limbo state trunk, the software assumes the trunk was in the talking state and initiates disconnect actions. Conversely, if an off-hook report is received, the trunk is assumed to have been idle and initial seizure actions commence.

3.4 Audits

The existence of the virtual scanner required a new type of audit program called the "virtual scanner update program" which is quite different from other system audits.

Normally, system audits are run on a routinely scheduled basis. Their purpose is to check the integrity of the software data structures. The virtual scanner update, however, is designed to check the consistency of the virtual scanner with the hardware state of the trunks. It does this by sending out a sequence of special orders which cause the trunk to send back several reports which together indicate its current state. Since doing this on all RTA trunks could overload the PCL, it is done very slowly over several minutes. When it is complete, an output message is printed, stating the number of errors found.

The audit is normally run during off-peak night-time hours and is used to verify the integrity of the virtual scanner and resolve any limbo state trunks which may exist at that time. It is also run after certain rare types of fault recognition activity which cause the scanner word buffer to be initialized with the possibility that one or more RTA trunk supervisory reports may be lost.

IV. RTA MAINTENANCE PLAN

Reliability requirements for an RTA subsystem have been set to meet the overall objectives of a TSPS No. 1 system: less than 2 hours downtime per 40 years service and less than one mishandled call per 10,000 calls. The maintenance plan for RTA is further influenced by the fact that an office is frequently unattended and may be located hundreds of miles from the base TSPS.

Sections 4.1 and 4.2 discuss PCL error detection as implemented in the hardware and software, respectively. Remote diagnostics are covered in Section 4.3. Section 4.4 deals with initialization of RTA circuits, while Section 4.5 describes trunk test capabilities for RTA.

4.1 PCL error detection (hardware)

The PCL data lines may be subjected to errors from a variety of causes. To aid in detecting multibit errors which result in single word errors, each word transmitted is encoded with a 5-bit cyclic error detecting code and a parity bit. In addition to single word errors, multiword errors on a data line may occur as a result of hits and fades. Each word error within a multiword error is treated separately by the group gate and remote data circuits. As a result, single and multiword errors are handled similarly.

As mentioned previously, the group gate and the remote data circuit send data to each other over a data line. An error detected by the receiving circuit must be reported back to the sending circuit so that the word can be transmitted again. This is accomplished by a verification system whereby a "scan-complete" is used to acknowledge a report received by the group gate, and a "check-back" acknowledges

a properly executed order received by the remote data circuit. If an acknowledgment is not received, the word is retried until it succeeds or the retry limit is reached.

A system requirement of RTA is that the voice circuits and data lines may use any transmission facility. This means that the PCL data lines must be able to operate over voice-grade circuits that have a relatively slow data transmission rate. Because of this and the distance (several hundred miles) between base and remote locations, about 45 ms are required to verify that an order or report has been sent without error. Since a PCL data rate of one order every 25 ms is required to deal with momentary call processing peaks and to allow use of as many existing TSPS No. 1 programs as possible, an overlap operation is employed. This means that, before verification of the first word is received, the second word is sent. If an error is detected, the receiving circuit discards both it and the succeeding word. The sending circuit retransmits both words if it doesn't receive verification of the first word. Therefore, the group gate and remote data circuit are designed to retain information about the last two words sent in case repeat transmissions in either direction are necessary. The overall maintenance strategy is strongly influenced by this aspect of the PCL.

The PCL hardware can detect errors other than transmission failures that would be seen by parity or cyclic code check failures. These faults are classed as "send" or "receive" direction faults. The former type will be discussed first.

The normal mode of PCL operation requires that each PCL half independently handle a processor order until it has been received at the remote location by the remote data circuit for each half. The two remote data circuits then compare the orders and if they match, one PCL half (a so-called "active" half) actually distributes the order to a trunk, concentrator, etc. If one half has a "good" order and the other half has received nothing or has a transmission failure, then the half receiving the good order becomes the active half and distributes the order. This mechanism, known as Full ORed Mode, is intended to reduce order retries due to data line transmission errors.

Each time the processor sends an order via the PCL to the remote location, the buffer which is to handle the order generates a checkback report as verification. This checkback is returned to the processor as an indication of correct operation; its absence indicates unsuccessful operation. The use of checkbacks allows for detection of faults beyond the signal distributor but only partly through the RTA buffers; the actual operation of relays and crosspoints are not verified by checkbacks. Those failures which occur beyond the checkback origination point are detected by error analysis programs.

Due to the overlap operation of the PCL described above, the remote data circuit is designed to also fail the order arriving after an order

which results in a checkback failure. This ensures that the second order is not executed before the first, necessary because the second order may depend upon the success of the first order and might lead to a mishandled call if the first order is unsuccessful.

The receive direction faults are those pertaining to the reception of signals originated by RTA circuits. The detection of these faults depends primarily on mismatches between PCL halves. Normally, the two PCL scanners each detect a change of state of an RTA circuit point and generate a report. These two reports are passed back to the group gates where they are compared. Subsequent to receiving the reports, the group gates transmit "scan-complete" words to the remote data circuits so that another pair of reports can be sent to the base.

In addition to matching, however, a cyclic code check is made, an all-seems-well indication from each scanner is checked, a parity check is made, and a sequence code check is made in each report received. The cyclic codes are inserted into the report by the remote data circuit; the all-seems-well, parity, and sequence indications are generated in the scanner. Cyclic codes and parity have been described earlier. A sequence code occupies two bits in each report and is used to eliminate redundant reports received at the group gate. This typically occurs when a "good" report is received but the scan-complete signal fails, causing an unnecessary retransmission of the report by the remote data circuit. If the sequence code check fails, the report is discarded by the group gate. The all-seems-well signal is generated by self-checking circuits within each scanner, as described in Section 2.1.2.

With both PCL halves in service (duplex), one group gate is designated as active. If a mismatch occurs and the active half has a "good" report (one which has correct cyclic code, parity, sequence, and all-seems-well), while the other half has received nothing or has a transmission failure, the good report will be passed on to the processor. However, if the active half has received nothing or has a transmission failure while the other half has a good report, a null scan-complete is generated, causing the report to be retransmitted. This mechanism, known as Half ORed Mode, takes into account the fact that the active group gate controls the matching. (If the program determines that only the active half has a transmission failure or has received nothing, it simply changes the designation of the active half to the one receiving the good report, leaving the PCL in duplex mode.)

In accordance with the circumstances described above, a group gate mismatch results in automatic retransmission of reports. However, if the group gates continuously mismtach several times, the PCL fault recognition program will take action to resolve the mismatch. The tolerance for a few mismatches allows the PCL to automatically recover from a momentary transmission impairment affecting one of the data lines.

Many faults can occur in the scanners which can only be detected by matching. The key characteristic of these faults is the presence of two apparently valid but different words that repeatedly mismatch. The cause of this is either the generation of an extra word or the lack of a generated word in one of the scanners. Under these circumstances, the list of reports in the two memories of the scanners become skewed and a mismatch occurs. The mismatching words represent two scanner inputs, one of which is faulty. This situation is handled by the "receive chain" fault recognition programs, which are discussed in the next section.

4.2 PCL fault recognition (software)

As described in the previous section, the PCL circuits have been designed to detect and correct for most errors which are the result of transmission impairments of short duration. For longer hits, fades, and PCL circuit failures, various other hardware indications, such as check-back failures and group gate alarm ferrods, allow PCL fault recognition programs to maintain working send and receive chains. The send chain refers to those circuits involved in the distribution of a PCL order: the group gate, remote data circuit, signal distributor, and the PCL buffers. The receive chain refers to those circuits involved in the reception of a PCL report: the group gate, remote data circuit, and position and trunk scanner.

If an order has been retried on a duplex PCL without the reception of two successive check-backs for 0.5 second, the send chain fault recognition program will be entered. When this occurs, call processing is suspended and a special test order is sent to an independent buffer. If that order is executed successfully, the original buffer accessed is deemed faulty. If the test order fails, the program splits the PCL so that each PCL half is completely independent with no matching taking place. The resulting simplex operation allows the original failing order to be tried first on one and then on the other PCL half. If the order fails over both halves, the program tries a second test order (to a different buffer) over each half. Based on the results of these tests, the program decides which half is faulty and places that PCL half out of service. Normal call processing is resumed on the good half, and diagnostics are run on the out-of-service half.

For receive chain faults, the fault recognition programs are entered whenever an error rate monitor (administered by software) corresponding to a group gate alarm ferrod exceeds its threshold. The absence of either all-seems-well, good parity, or proper sequence on a PCL half automatically indicates the faulty half. Mismatches between two valid reports involve more detailed processing.

Due to the overlap operation of the PCL, two reports on each half are sent to the base during retransmission. In the case of skewed

reports, chances are that two of the reports received match; that is, one of the reports received on one half may match one of the reports on the other half. The receive chain program checks for this case to eliminate the need for testing all four reports. Only those reports seen by only one half are further tested.

When the receive chain fault recognition program is entered, call processing is suspended. The PCL is again split into two simplex paths and a bypass in the scanners is activated to allow test results to be sent back to the base without disturbing the scanner word buffers. Each scanner is then checked, via test points, for the ability to generate the reports to be tested. These test results are analyzed by the program to determine which PCL half is in trouble. The faulty half is placed out of service, and diagnostics are run on it. Call processing resumes on the in-service half. The flow of reports proceeds from where it was interrupted, with the PCL in the simplex mode. While in the simplex mode, subsequent faults of this type go undetected.

In general, fault recognition program actions are transparent to call processing programs. In the case of a PCL mismatch, the original reports are retained in processor memory so that, once it is determined which PCL half is faulty, the reports already received on the good half can be passed to call processing programs. As already mentioned, the PCL scanners contain word buffers that can retain up to 31 reports which may have occurred while fault recognition tests were being applied. This is sufficient memory to handle a back-up of reports caused by fault recognition activity in all but the very worst cases.

In addition to the send chain and receive chain fault recognition programs, the data line fault recognition program responds to transmission errors reported to the SPC. Error rate monitors, driven by the group gate alarm ferrods, are maintained for each connected data line. When the allowable error rate is exceeded, the line that appears to be faulty is replaced by the spare line. After a delay of a few minutes, the apparently faulty line is reconnected. If its error rate is acceptable, no further action is necessary. If it fails again, however, the spare line is used until the faulty line is repaired or has been determined by subsequent automatic tests to have recovered. The spare data line is also used periodically so that its operational status can be monitored.

The state of the data lines must also be considered by the fault recognition programs when reconfiguration is being performed. If all circuits on a PCL half are working but both data lines that can connect to it are out of service, then that PCL half is not usable.

Although the normal mode of the PCL is the duplex mode, it is possible that a fault could occur while the PCL is simplex. The PCL could be simplex because diagnostics are being run on the out-of-service half or because a circuit on that half is inoperable. If the fault recognition program determines that the active half has a circuit in

trouble while the PCL is in simplex, the out-of-service half will be placed in service and the active half removed from service.

In cases where the out-of-service PCL half is already marked in trouble or has been manually made unavailable to fault recognition and a fault has also been detected on the in-service half, no known working path of PCL units exists between the base and remote locations. Rather than to place the entire PCL out-of-service, a special fault recognition program is invoked which attempts to find a working path, regardless of the software status of the units. This program systematically tests both the send chain and the receive chain of the PCL by using test orders and different combinations of data lines and base peripheral circuits that interface the processor to the group gates. In the event that these tests fail, the PCL will then be placed out of service. However, the program will automatically retest the PCL every few minutes and restore it to service as soon as one working (simplex) path is found. Because the duplex state offers maximum error detection, an out-of-service PCL half is also automatically tested for the absence of units in trouble (or a manual request to leave the half out of service) when the PCL is simplex. If no reason for the simplex configuration is found, the PCL will be restored to the duplex mode.

4.3 Remote diagnostics

The long data paths to RTA and PSS No. 2 installations and the desire to use voiceband facilities resulted in the use of 2400 b/s data rates between the SPC location and the remote locations. If lengthy strings of diagnostic tests were run from the SPC over an in-service PCL half to locate a trouble in the other (bad) PCL half, then call processing would be virtually halted for the duration of the diagnostic. To prevent such adverse call processing effects and still allow thorough diagnostics, the entire set of diagnostic test sequences are placed at the remote end and controlled by a diagnostic control circuit (DCC) which, in turn, is controlled by the SPC. The concept of placing the diagnostics *at* the remote location provides two other very desirable operations as well as minimizing adverse call processing effects. It allows the tests to run very fast since no transmission time is involved, and it allows the DCC to have direct access to various internal points of the circuits being diagnosed which would otherwise be impossible to obtain. With the exception of the scanner with its need for 25 ms to recognize a change of state (see Section 2.1.2), diagnostic orders can run at least an order of magnitude faster than regular PCL orders. This significantly reduces the time between a request for a diagnostic and TTY output of results.

The DCC is essentially a very low-level minicomputer with sequences of tests and expected results of those tests stored in Read-Only-Memory (ROM). Each ROM word is 24 bits long and contains a 3-bit operation code (op code), 20 data bits, and a parity bit. The data bits

usually apply a set of test conditions to a PCL circuit and cause that circuit to take some action. A subsequent ROM word contains an expected result which is matched against the actual result. If the result agrees, then another test word is selected from ROM and the process continues. The access that the DCC has to the various PCL circuits is shown in Fig. 9. Note that *indirectly* the DCC has access to *all* remote circuits; e.g., although it has no direct connection to a 100C console it can send orders to the RDC which can cause the signal distributor to send an order to a console. Similarly, while it has no input from a console it can check the scanner output to see if the scanner received a console output.

When comparisons of actual and expected results fail, a reply (noting the failure) is sent back to the SPC over the in-service PCL half. However, if massive failures are encountered, this reply capability is limited, so as to limit its effect on call processing. Also, massive failures will cause the SPC to terminate the diagnostic early since they quickly pinpoint a source of trouble. Whether or not comparison failures occur, every 64th ROM word causes a "progress report" type reply to the SPC to inform it that the diagnostic is continuing. The "failure report" sent back to the SPC on all mismatches provides a number between 0 and 63. The first 64 words of ROM store these 64 possible failure reports. The action taken by the DCC when a comparison failure (expected result versus actual result) occurs is to just set all but the least
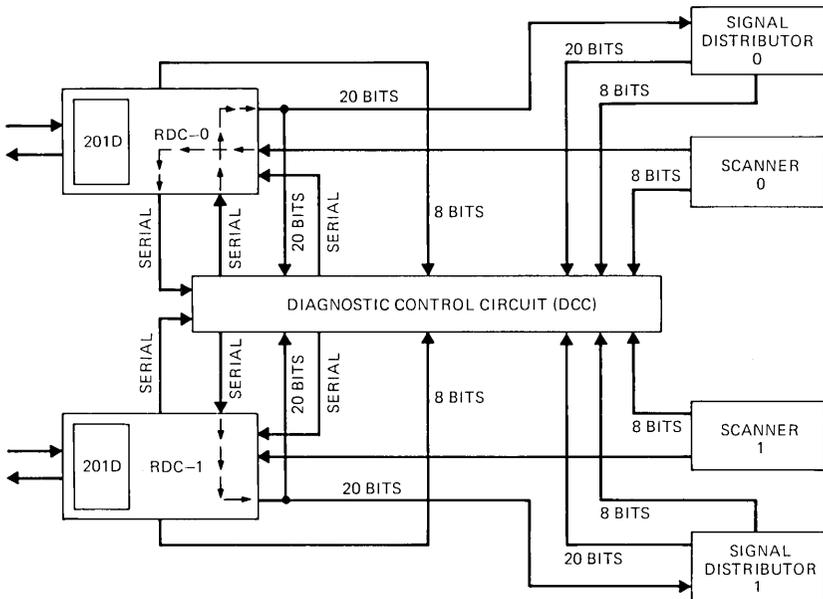

Fig. 9—DCC access to PCL circuits.

significant 6 bits of the address counter to zero. The next ROM word selected will then be one of the first 64 words and as this reply is sent back to the SPC and upper address counter bits are unclamped. With all address counter bits operational, the next word selected is the next word in the diagnostic test sequence. Thus no real program transfer and return function is needed in the DCC since this hardware approach to changing the address counter output does the transfer job and automatically includes the correct return condition.

The SPC controls the DCC by three steps. First, an order is sent over the inservice PCL half to place the out-of-service half RDC in the diagnostic mode, i.e., connect it to the DCC. Second, an order is sent to the DCC (again, over the in-service PCL half) to preload the desired starting address into the DCC address counter. Finally, a "start" command is sent to the DCC to select the first ROM word (at the starting address). This first word of any diagnostic sequence is always an "SPC reply" type word that returns the starting address to the SPC. The SPC checks this against the desired starting address and stops the DCC if the return is incorrect.

Since the SPC knows the starting address and is informed when every 64th subsequent address is reached, it can quickly compute the exact location of a comparison failure (its location in *that* diagnostic sequence) whenever it receives a failure report with its 0-63 tag number. Thus at the end of a diagnostic sequence, the SPC has a pattern of failures and uses these to generate a "trouble number." This number is then compared to a trouble dictionary to locate the failure.

The overall access which the DCC has to each remote RTA circuit can be understood by looking at the 8 possible operation codes together with the expansion of one such operation code. The 8 operation codes (op-codes) are listed below. This listing also gives the reader a glimpse at the DCC programming possibilities and indicates the ease with which each RTA circuit designer could write the appropriate diagnostic.

000 8-bit comparison or 25-ms delay
001 20-bit comparison from RDC
010 RDC test vector (DCC output)
011 20-bit scanner comparison preceded by 25 ms delay
100 Signal distributor test vector (DCC output)
101 20-bit comparison from signal distributor
110 RDC test vector (DCC output)
111 SPC reply word (DCC output)

The 000 op code is expanded within the 20-bit data field since only eight of the data bits are actually needed for an 8-bit comparison. The

order has the form:

23	22		15	11		6		2	0
P	Z_7 Z_6 Z_5 Z_4 Z_3 Z_2 Z_1Z_0 1 1 1	C/D	X_3 X_2 X_1 1	M C B A	0 0 0				

where
  Bits 0 to 2 are the op code (000).
  CBA = 3 bits used to select the particular 8-lead input desired.

C	B	A	Compare Input
0	0	0	Input from signal distributor
0	0	1	All ones input
0	1	0	Input from RDC
0	1	1	Input from scanner
1	0	0	Spare input set Y
1	0	1	Spare input set X
1	1	0	Input from DCC
1	1	1	All zero input

$\quad$ M = "Mask" bit used to insert 1-bit mask. If M = 1, no mask is used and all 8 bits specified by CBA are compared against $Z_7 - Z_0$. If M = 0, a 1-bit mask is enabled as specified by the $X_3X_2X_1$ bits.

$X_3X_2X_1$ = Mask selection bits used to specify which of the 8 input leads are to be compared.

$\quad$ C/D = Compare/delay bit used to differentiate between use of this order for 8-bit comparisons or for 25-ms delay intervals.

$Z_7 - Z_0$ = 8 comparison bits.

The other seven op codes perform only the function listed and all 20 data bits are either applied by the DCC as a test vector or used by the DCC for a comparison.

The op code listing together with the 8-bit comparison possibilities shown above indicate the large number of internal points of all remote PCL circuits to which the DCC has access. The DCC concept allowed diagnostic points to be placed where they would do the most good. This makes every test/comparison pair of orders a powerful pair and leads to short diagnostic phases. These short phases together with the fast execution times allow most diagnostics to complete in a few seconds. As the diagnostic completes one phase (and before it starts a subsequent phase), a few SPC orders can be sent out to reconfigure the PCL half under test. For example, the RDC can be configured to loop back on itself. The DCC can then send orders to the scanner input side of the RDC—similar to reports normally returned by the RDC to the SPC—and, since the RDC is looped, these orders will come right back

through the receiving half of the RDC. They can then be examined by the DCC or allowed to continue to the Signal Distributor and cause some action there. Again, at the Signal Distributor, the test vector can be examined by the DCC or allowed to propagate even further and cause some other action further downstream. Judicious use of such DCC comparison tests allow very thorough diagnosis of remote circuits.

The DCC also has inputs from itself as well as all 1 and all 0 type inputs. It can use these inputs to run tests on itself and inform the SPC of possible DCC troubles. Massive failures in other circuits usually trigger (via an SPC program decision) this self-test of the DCC to ensure that the massive failures are real and not just the result of an inability of the DCC to make comparisons.

The DCC currently uses about eleven thousand 24-bit ROM words to test out all remote PCL circuits. The memory layout provides three circuit pack locations, each of which can contain $8K$ (K=1024) words so the memory can grow to 24K words if needed. The upper 16K addresses are also available in eight other circuit pack locations, each of which can accommodate a 2K-word PROM circuit pack. With this arrangement, the memory can be placed on ROMs on 1-1/2 circuit packs. Then, as various remote PCL circuit changes and additions take place which would tend to degrade the original diagnostic effectiveness, new versions of selected diagnostic phases can be placed in PROMs on, say, one new memory board plugged into a PROM circuit pack location. A 1-word change in the SPC program can then be used to specify a new starting address for the affected phase (or phases). The old version of the diagnostic is still there, but never gets used while the new (higher numbered) starting address selects *that one phase* from the PROM board. As PROMs are added over a period of years, and several sections of the original (ROM) program become unused, the ROM can then be redone to reflect several years of change.

4.4 RTA initialization

The RTA maintenance buffers contain a variety of distributor points used in conjunction with the operation of several remote circuits. When PCL reconfigurations occur, either by manual request or as a result of fault recognition action, some points in each buffer must be cleared. Some points are used to initialize the remote data circuit, signal distributor, and position and trunk scanner. Each buffer also contains points not connected with a particular PCL half which should not be cleared when reconfiguration takes place. To achieve the desired results, each maintenance buffer has been functionally divided such that selective initializations of these buffers can be performed. The selective initialization feature of the maintenance buffers also provides the capability of regenerating the PCL status display at the remote location upon manual request. In addition to the selective initialization

leads, each maintenance buffer is equipped with a lead which clears all points in the buffer. These leads are pulsed only when the entire PCL is being initialized, such as when a system initialization occurs, or when the PCL has developed faults on both halves.

Under certain circumstances (e.g., RTA or TSPS system initialization), it is desirable to place all the remote and base-remote trunks in an idle state. Since the number of remote trunks (496 max) and base-remote trunks (64 max) in an RTA may be large, individual trunk initialization would be very time-consuming. The trunk super-initialization feature of RTA allows all the remote trunks to be initialized with two orders and all the base-remote trunks to be initialized with one order. This allows for speedy initialization of the RTA trunks when necessary. It should be noted that those trunks already in the talking state will not be affected by the super-initialization orders.

4.5 Test frame capabilities

The test frame at the remote location displays status information and provides control and test facilities including a maintenance tele-typewriter. As shown in Fig. 10, the out-of-service status lamps for the PCL equipment are physically arranged to depict the equipment ar-
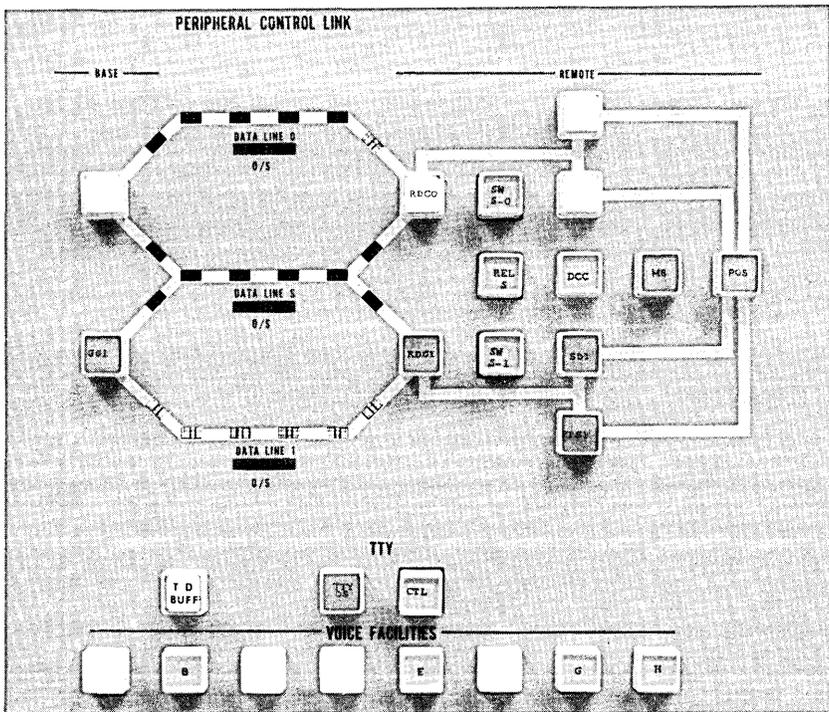

Fig. 10—PCL and voice status displays.

rangement in block diagram form. The three data lines are represented by three rows of light-emitting diodes which, when lit, indicate active working routes. The SW 0, SW REL, and SW 1 keys in the status display enable the remote ends of the data lines to be switched. This capability is provided to allow manual intervention in the rare case that both active data lines fail before the maintenance program at the base location has the opportunity to order the remote equipment to switch.

Several trunk test facilities are provided on the test frame as indicated in Fig. 11. A Dial Access Test Line (DATL) permits local office personnel to check transmission and noise levels on incoming trunks between the local office and the RTA without requiring assistance at the RTA. The Master Test Line (MTL) permits RTA personnel to establish voice communication with any trunk that terminates on the concentrator. The access line permits any trunk to be connected to any one of the test frame facilities which include a voltmeter, transmission level and noise measurement apparatus, a variable frequency milliwatt supply, and a quiet termination.

The test frame voltmeter and transmission measuring devices have a digital readout capability. The measurements can be remotely read
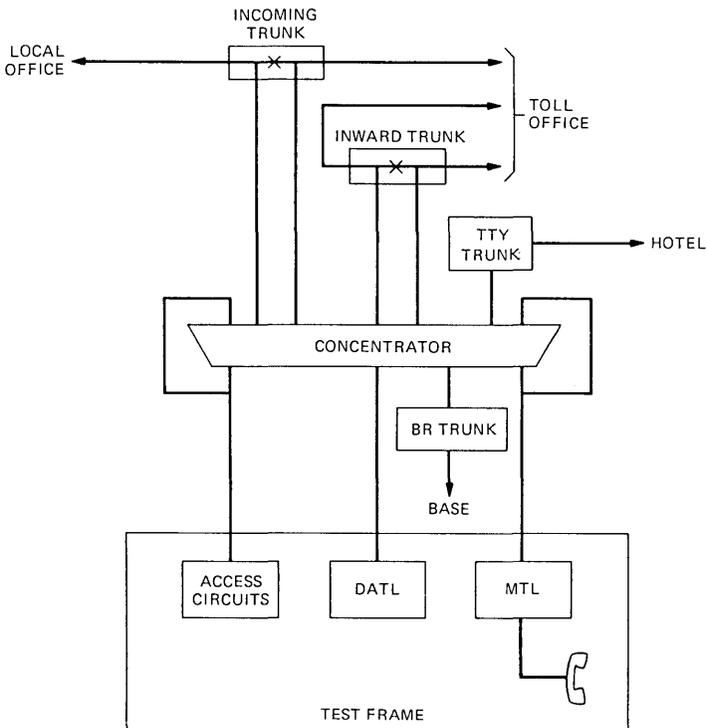

Fig. 11—Trunk test facilities.

by the base program and printed on the base location maintenance teletypewriter. This permits detection, verification, and sectionalization of many trunk problems without anyone present at the RTA.

V. ACKNOWLEDGMENTS

REFERENCES

1. E. Tammaru, "Correlated Error-Rate Results in Data Links with Duplicated Channels," National Telecommunications Conference Record (December 1975), p. 42.26.
2. E. O. Elliot, "Estimates of Error Rates for Codes on Burst-Noise Channels," B.S.T.J., *42*, No. 7 (September 1963), pp. 1977–97.
3. J. A. Hackett, et al, "TSPS/RTA Reliability and Maintainability in the Hardware Design," ICC 75, *3*, pp. 46-5—46-10.
4. A. F. Bulfer and B. D. Wagner, "Calculating Delay and Buffer Overflow Rate of Feedback Data Channels," 7th Hawaii International Conference on System Science, 1974.
5. F. H. Smith and J. M. Catteral, "Uses for the New Crossbar Switch," Bell Laboratories Record, *49*, No. 7 (August 1971).
6. A. W. Kettley, et al, "TSPS No. 1—Operational Programs," B.S.T.J., *49*, No. 10 (December 1970), pp. 2625–2685.
7. A. F. Bulfer, "Blocking and Routing in Two-Stage Concentrators," National Telecommunications Conference Record, December 1975, pp. 19-26 to 19-31.

Traffic Service Position System No. 1:

Automated Coin Toll Service: Overall Description and Operational Characteristics

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(Manuscript received December 11, 1978)

Automated Coin Toll Service (ACTS) has recently been developed for use on Traffic Service Position System No. 1. ACTS automates the handling of most calls paid for at coin stations, gives time and charge quotations, and provides customer notifications. To accomplish this, a new microprocessor-controlled subsystem is added to TSPS. This subsystem generates announcements and monitors coin deposits. Since ACTS reduces the operator involvement on coin toll calls, it achieves significant savings for the operating companies. ACTS was developed together with several other associated features. This entire package was first put into service in November 1977, in Phoenix, Arizona. This paper gives a functional description of the new subsystem and details the customer interface with ACTS and the other features.

I. INTRODUCTION

To reduce the operating expenses associated with handling coin toll calls at a Traffic Service Position System (TSPS) No. 1,[1] Automated Coin Toll Service (ACTS) has been developed. ACTS permits automated processing of (*i*) the initial contact on most station calls paid for at coin stations (station-paid coin calls), (*ii*) notification at the end of the initial period on all coin-paid calls, (*iii*) overtime charge-due seizure on most coin calls, (*iv*) the customer-requested notification on a call that is not coin-paid, and (*v*) the quotation on time and charge calls. This is accomplished by giving machine-constructed announcements

to the customer and by providing machine recognition of coin deposit signals. Thus, ACTS reduces the operator work time on coin toll, noncoin notification, and time and charge calls, and thereby achieves significant savings for the Bell System.

The technology and concepts of Automated Coin Toll Service evolved over several years. First, the technical feasibility of ACTS was demonstrated in 1973 by building an exploratory model. System engineering studies were conducted in conjunction with American Telephone and Telegraph Company (AT&T) and the operating telephone companies that showed the reduction of operating expenses would offset introductory costs. Three parallel and interrelated development activities emerged. First, a new subsystem was added to TSPS. This subsystem, the Station Signaling and Announcement Subsystem (SSAS), uses a microprocessor called the Programmable Controller (PROCON) and semiconductor memory. The memory is loaded with speech segments that have been digitally encoded. The SSAS retrieves and concatenates these speech segments into sentences. By converting the bit stream to analog signals, SSAS can "speak" to customers. In addition, SSAS monitors coin deposits by the customer to determine when a coin deposit request is satisfied. Second, software and firmware were developed for the TSPS controller which is the Stored Program Control (SPC) unit[1] and the PROCON, respectively. This software allows the TSPS to interface with the subsystem and the subsystem to perform the desired tasks. Third, because of the complexities of the new machine-customer interface, a human factors study was conducted in Chicago, Illinois. In this study, a sampling of coin customers was exposed to the proposed ACTS service, which was simulated from existing positions. This human factors simulation established wording and timing parameters used in the ACTS design.

Part of the technical challenge was to introduce ACTS into live TSPS sites without interrupting the normal call-handling process. Not only was this challenge met, but additional features were introduced at the same time. These features include:

(i) Expanded direct distance dialing to Mexico.

(ii) Improved queuing strategy for calls transferred to TSPS for calling number identification for billing purposes (Centralized Automatic Message Accounting, or CAMA, traffic).

(iii) Special automated procedures to better control overload conditions.

(iv) The ability to more efficiently redistribute (rehome) TSPS trunks to different toll or local offices.

(v) Increased coin station test capabilities.

(vi) Other miscellaneous features.

These features and ACTS were packaged as a version of TSPS called Generic 8. Following initial service in Phoenix, Arizona on November

26, 1977, this generic was made generally available to the Bell System in mid-1978.

This paper gives an overview of ACTS and some of the other features associated with TSPS Generic 8. It highlights the hardware and software associated with each feature. Additional details of the three development activities that culminated in ACTS are specified in later papers in this special issue.[3-5]

II. COIN TOLL SERVICE PRIOR TO ACTS

TSPS provides a vast improvement in efficiency over cordboards in handling coin toll calls. Not only is the operator's interaction with a customer more efficient and accurate but, in addition, TSPS allows coin customers to dial their own calls, thereby providing faster service.

In a typical TSPS, between 10 and 15 percent of the calls handled by operators are toll calls made from coin stations and paid for with coins deposited at the station by the customer. On these calls in a non-ACTS TSPS, an operator is required (i) to quote to the customer the initial period length and charges, and to monitor the amount deposited, (ii) to notify the customer at the end of the initial period, and (iii) to quote and collect charges due for overtime at the end of the call or after 10 overtime intervals. To assist the operator in processing coin-paid calls, TSPS generally calculates the rates, automatically displays the charges at the operator position, and times the call.

To better understand how the various functions described above are handled by an operator at a TSPS prior to the introduction of ACTS, the following details how TSPS processes a coin-paid call. Figure 1 shows the layout of the keys and lamps on the operator position.

2.1 Initial period contact

To place a station-to-station call at a coin phone served by a TSPS, a customer makes an initial deposit and listens for a dial tone. (In a dial-tone-first area, the initial deposit is not required.) As soon as the dial tone is obtained, the customer dials the digit one* plus the complete 7- or 10-digit called number. The local office determines that this call is a toll call and routes it over a trunk to its associated TSPS. TSPS receives the called and calling number from the local office and determines the charges on the call. The TSPS establishes the necessary connections through its network to bring the call to an operator position. While the operator is responding to the call, the called number is outpulsed to the toll office.

The call arrives at the position with appropriate keys and lamps lit to indicate that this is a coin call. The station initial period charges

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* Some areas do not require the digit one to be dialed, depending on local number plan arrangements.

4 COMPARTMENT TICKET BOX

NEW   CANCEL

SCRATCH   COMPLETED

2 1 2   2 4 3   1 2 3 4

(CHARGE•) (HOURS•) (MINUTES•)   (SECONDS•)

INWARD   —NON-COIN—   —— COIN ——   —— HOTEL ——

YFY | OVER SEAS | SCRN | NON COIN | COIN   STA | 0+ | DIAL "0"   STA | 0+ | DIAL "0" | POST PAY | TONE   STA | 0+ | DIAL "0" | GST

OUTGOING TRUNKS   —RING—   RELEASE

| # | # | #   BACK | FWD | CALL BACK | TBC | NFY | CHG DUE | KEY CLG   BACK | FWD   SR | MAKE BUSY | MTCE | POS TRFR

CW

—— AMA ——

MULTI-LEAF BULLETIN TRAY

STATION   PAID | COL | SPL CLG | SPL CLD | AUTO COL | DDD

PERSON   PAID | COL | SPL CLG | SPL CLD | NO AMA

—COIN—   AMA TIMING

COL | RET   CNL TMG | ST TMG

CA CALL | REC MSG

POS RLS

TIME | CHG MIN | CLG NO | CLD NO | SPL NO

CLG   CLG   CLG
CLD   CLD   CLD
HOLD   HOLD   HOLD
ACS   ACS   ACS

—— DISPLAY ——

KP TRBL | KP RATE | KP HO   Q 1 | ABC 2 | DEF 3

KP NFY | KP SPL   GHI 4 | JKL 5 | MNO 6   ST

KP BAQ | KP FWD   PRS 7 | TUV 8 | WXY 9

Z 0

POS. NO. PLATE

LEGEND

☐ ILLUMINATED KEY

☐ NON-ILLUMINATED KEY

◆ LAMP

SINGLE COMPARTMENT TICKET BOXES

TRUNKS TO RATE AND ROUTE, INTERCEPT, INFORMATION CARD SWITCHBOARD, ETC. AS REQUIRED
• THESE DESIGNATIONS ARE NOT VISIBLE UNLESS SIGNIFICANT

and minutes are displayed to the operator, as depicted in Fig. 2. The operator then requests the initial deposit from the customer and depresses the station-paid class-of-charge key to indicate to the system that a station-paid call is being handled. The customer then deposits the coins, and the operator monitors coin signals to determine if the proper deposit has been made. Meanwhile, the call is forwarded through the Direct Distance Dialing (DDD) network.

When the customer deposits the correct amount, the operator acknowledges receipt of the deposit. Then, upon hearing the audible ring of the calling station, the operator prepares the system for automatic timing of the call after called party answer. This is done by depressing

NON-ACTS

1	1	5			3				
(CHARGE)			(MINUTES)						

ACTS — UNDER DEPOSIT ⟋ AMOUNT DUE

1	1	5			3			1	5
(CHARGE)			(MINUTES)						

ACTS — CORRECT DEPOSIT ⟋ AMOUNT DUE

1	1	5			3			0	0
(CHARGE)			(MINUTES)						

ACTS — OVER DEPOSIT ⟋ CREDIT

| 0	0	0						1	0
"(CHARGE)"			"(MINUTES)"					"FLASHING"	
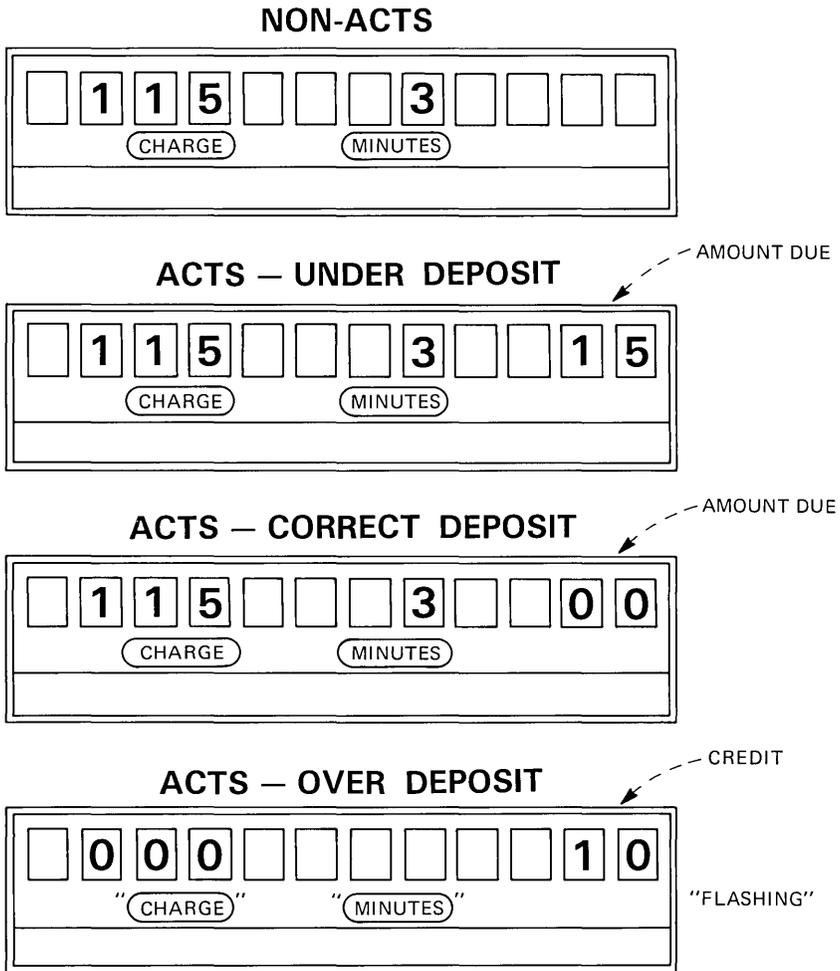
Fig. 2—TSPS No. 1 console numeric display.

the start timing key. The operator then releases the position, concluding the initial contact phase of the calls.

When the customer does not deposit enough money, the operator requests the additional amount. If the call has not yet progressed through the DDD network, the operator stops the forward action of the call by depressing the release forward key. When a full deposit is received, the operator reinitiates the network connection by depressing the start key, then he or she depresses the start timing key, and releases the position.

If a customer lacks proper change, he or she may deposit too much money. The operator acknowledges this overdeposit and instructs the customer to tell the operator that credit is due when overtime is collected.

With the operator released to handle another call, TSPS times the call for the initial period. Before the end of the initial period, TSPS sends a signal to the local office to cause the initial deposit to be collected.

2.2 Notification at the end of initial period

Generally, the call is again connected to an operator at the end of the initial period. This operator is not likely to be the same person who handled the initial contact. The call arrives at the position with the appropriate keys and lamps lit to indicate that this is a notify seizure. The operator notifies the customer that the initial period has ended and requests that the customer signal (by flashing the switchhook) when the call is completed. The operator releases the position and TSPS starts overtime timing.

2.3 Quotation and collection of charges due for overtime

If a call goes into overtime and reaches an elapsed time of 10 overtime intervals (usually 10 minutes), an operator is reconnected to the customer's line to request an intermediate deposit. This deposit is intended to limit coin overtime losses that result when a customer walks away at the completion of the call without paying the charges due. The operator counts the deposits and, when the request is satisfied, releases the position. Additional intermediate deposits are requested at appropriate intervals until the call terminates. Calls in overtime are not interrupted more frequently because of the operator work time penalty.

When the call is concluded, as indicated to TSPS by the calling customer signaling (flashing the switchhook) or either customer hanging up, the call is brought to a position for overtime collection. If the calling customer's phone is on hook, the operator rings the station by operating the ringback key. When the calling party is on the line, the operator requests the charges due and counts the coin deposits. When

the deposit request is satisfied, the operator thanks the customer, depresses a key which signals that coins are to be collected, and releases the position. If the calling customer does not answer the ringback or the operator is unable to obtain full payment for the call, a "walkaway" is recorded on a mark-sense ticket and the operator releases the position.

III. THE ACTS HARDWARE

A new hardware subsystem is added to the TSPS for ACTS, called the Station Signaling and Announcement Subsystem (SSAS). It is composed of a control unit containing a programmable controller called PROCON, an announcement store, and service circuits called Coin Detection and Announcement circuits (CDAs) (see Fig. 3). The control unit and announcement store are duplicated for reliability. One controller is active and the other is standby. The units are not run synchronously, but the temporary memory of each unit is updated on an ongoing basis.

The SSAS control unit contains the PROCON with a read-only program memory and a random access memory for temporary data storage. The SSAS control unit provides an interface with the Stored Program Control (SPC) unit,[1] its mate controller, the announcement memory,
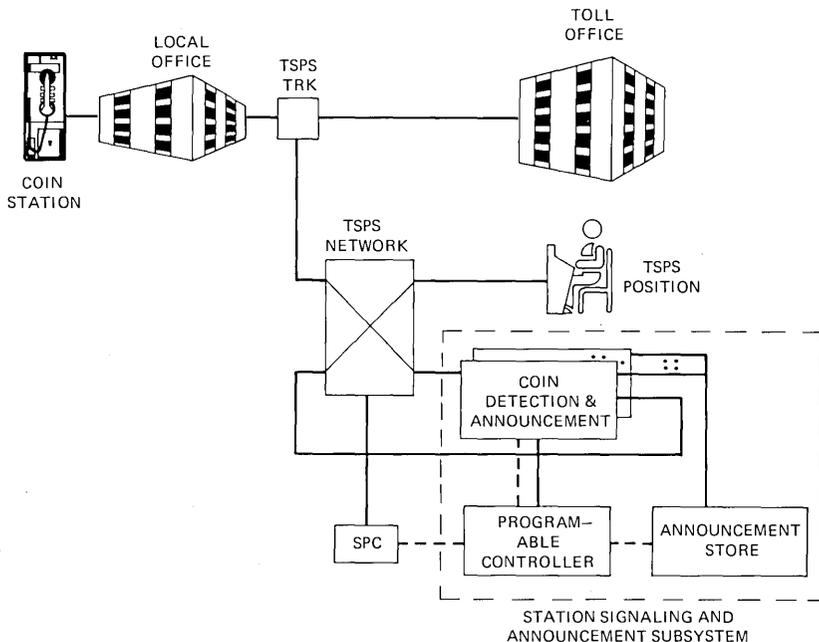

Fig. 3—ACTS block diagram.

and the CDA service circuits. The SPC communicates every 25 ms with the SSAS via software buffers as it does with other peripheral units.

The PROCON handles the internal control, data manipulation, and data transfer required for processing the call through the successive steps from customer contact through deposit acknowledgment. Within each control unit, the PROCON provides a self-checking mechanism for immediate detection of faults.

Prerecorded words and phases are digitally encoded and stored in the announcement store. The announcement store can be expanded in increments of eighty 512-ms speech segments. It is organized to be tolerant to single-bit faults and is diagnosed via the SPC. PROCON forms announcements by directing speech segments from the announcement store to the CDA in the appropriate sequence.

The CDA circuits have appearances on the TSPS switching network and perform the functions of making announcements to customers and of detecting coin deposits. The CDA circuits also are used to monitor for coin deposits when an operator is handling the call. CDAS are traffic-engineered with a typical TSPS requiring from 30 to 40 of these service circuits for ACTS. These service circuits convert the digital bit stream to an analog announcement.

IV. COIN SERVICE WITH ACTS

ACTS uses SSAS to automate the handling of (i) initial period coin collections, (ii) notifications of the end of the initial period, (iii) charge due coin collections, (iv) time and charge quotations, and (v) notifications on nonpaid calls. This section details the procedures used to automate these call seizures.

4.1 Initial period coin collection

With ACTS, a coin customer initiates a station-to-station call as in the past by dialing one* plus the called number. Since no local office trunk modifications are needed, the local office goes through normal routing of the call to TSPS. After TSPS receives the called and the calling numbers, it determines the rate and computes the initial period charges. However, instead of connecting an operator, TSPS makes network connections that bring the call to a CDA circuit and passes the initial period and charge information to the SSAS. The call is not outpulsed forward until the SSAS completes the initial contact with the customer. In the following sections, the procedures and announcements for the initial collection are described.

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* Some areas do not require the one to be dialed.

4.1.1 Initial deposit request

The SSAS constructs the following announcement:

$$\text{``} \begin{Bmatrix} \text{X dollar(s)} \\ \text{X dollar(s) and Y cents} \\ \text{Y cents} \end{Bmatrix} \text{please.'' (2-second pause)}$$

$$\text{``Please deposit} \begin{Bmatrix} \text{X dollar(s)} \\ \text{X dollar(s) and Y cents} \\ \text{Y cents} \end{Bmatrix} \text{for the first Z minute(s).''}$$

4.1.2 Initial coin prompt

In studies of customers making coin-paid toll calls, it was observed that many customers ask the operator to repeat the amount before they begin depositing. This even occurred on calls in which the amount was stated twice in the initial request. In view of this, if no deposit is detected within an allotted time after the initial announcement, the SSAS prompts the customer with, for example:

"Please deposit 1 dollar and 50 cents."

Although a 5.5-second initial coin timing interval is used for the beginning of the call, all timing intervals are designed so that they can be changed in case significant differences in customer behavior are encountered as a result of growing customer familiarity with the service or as a result of demographic differences.

4.1.3 Intercoin prompt

Some customers begin depositing, but stop before the request is satisfied. For example, the customer may lose count of the coins deposited. To accommodate these customers, an intercoin prompt is given. If the time between coin deposits exceeds an allotted time and the deposit is not satisfied, the SSAS prompts the customer by announcing the additional deposit needed in a manner similar to the initial coin prompt.

4.1.4 Acknowledgment of a correct deposit

Data show that over 80 percent of the customers satisfy the deposit request within the allotted time intervals. When the customer deposits the correct amount, the SSAS takes three actions. First, it informs the TSPS to outpulse the call. Second, while the call is being outpulsed, the SSAS acknowledges the deposit to the customer by

"Thank you."

Third, when the announcement is completed, the SSAS reports the

amount detected to TSPS. Following this report, the TSPS disconnects the CDA circuit and proceeds to time the call.

4.1.5 Acknowledgment of an overdeposit

Some customers lack the proper change and deposit too much money. With ACTS, an overdeposit is acknowledged and credit toward overtime charges is automatically obtained. This eliminates the need for a customer to indicate a credit is due. When the overdeposit is recognized, the SSAS informs TSPS to outpulse the call and to record the amount of the overdeposit. The SSAS acknowledges the overdeposit with the following phase:

> "Thank you. You have W cents
> credit toward overtime."

If the customer does not use the overdeposit credit and wants a refund, the customer must reach an operator and request a refund.

The SSAS does not time for overdeposits greater than breakage, but as long as the CDA circuit is attached, subsequent deposits are credited towards overtime. Breakage occurs when the denomination of the last coin brings the amount deposited over the amount due (i.e., $0.05, $0.10, $0.15, or $0.20). As soon as the amount deposited equals or exceeds the amount due, the SSAS informs TSPS to outpulse. To time for additional overdeposits (i.e., prepayment of overtime), the SSAS would have to delay all calls. If the customer overdeposits inadvertently and wishes to redeposit the correct amount, the customer must hang up to have the coins returned. This can be done any time before the called party answers.

4.1.6 Deposits during announcements

The CDA circuits monitor coin deposits during deposit requests. If a coin is detected during a request, the request is truncated immediately. If this coin does not bring the amount deposited up to the amount due, intercoin timing begins. If the amount due is met, the appropriate acknowledgment is transmitted. This allows customers who know the charges for a call to deposit the required amount without listening to the entire deposit request.

4.1.7 Operator assistance

Coin customers may not properly respond to fully-automated service and may need operator assistance. For example, customers who lack the correct change may request that the charges be billed to a credit card, to a third party, or to the called party. To deal with such occurrences, an operator is needed. Thus, if the customer fails to deposit within the allotted time following a prompt, the call times out and receives operator assistance. In addition, if a customer flashes the

switchhook during the coin deposit announcements, the call is also brought to an operator.

When the operator is attached, a new pattern of keys and lamps as well as a new numeric display (see Fig. 2) are lit on the operator console. This informs the operator of an ACTS call and provides the operator with the additional information concerning the amount still to be deposited. The CDA circuit remains connected between the customer and the operator. The circuit continues to monitor coin deposits but makes no announcements. The operator assists the customer in making a full deposit.

When the CDA circuit detects the full deposit, the SSAS reports "deposit satisfied" to the TSPS. The TSPS updates the operator's numeric display and outpulses the call. If the coin deposit tones are not being accepted by the CDA circuit and the operator suspects an equipment malfunction, the operator can override the SSAS and allow the call to progress.

4.2 Notification at the end of the initial period

The SSAS can provide the notification of the end of the initial period on all coin-paid calls whether the initial contact was handled by the SSAS or by an operator. When the initial period timing ends, the call is connected to a CDA circuit instead of an operator. TSPS informs the SSAS of the length of the initial period and the CDA circuit being used. The SSAS then announces to the customer:

"Z minute(s) has ended. Please
signal when through"

where Z ranges between 1 and 6.

When the announcement is complete, the SSAS informs the TSPS that the CDA circuit is idle. The TSPS disconnects the CDA circuit and starts overtime timing.

4.3 Charge due seizures

The ACTS procedures for fully automating overtime charge due seizures on coin-paid calls are presented in this section. The same sequence of deposit requests, coin deposit timing, prompting, and acknowledging described for the initial period deposit request are used for the overtime deposit request. However, the announcement wording is appropriately changed to indicate that money is due for the preceding connection time.

4.3.1 Charge due deposit request

In the same way as before ACTS, if a call lasts a certain number of overtime intervals, an intermediate deposit is requested from the customer. With Generic 8, the number of overtime intervals can be

varied in accordance with the amount of overtime charges (previously it was fixed at 10). Additional intermediate deposits are requested until the call terminates. The SSAS automates the collection at both intermediate and end-of-call overtime charge due seizures on ACTS-handled calls. The collection sequences for end-of-call deposits and intermediate deposits are essentially the same.* Furthermore, these collection sequences are very similar to those used for the initial contact on station (1+) calls.

Without interrupting the conversation path, TSPS connects an idle CDA circuit to the call. TSPS informs the SSAS of the amount due, the number of minutes talked, the CDA circuit being used, and the fact that it is a charge-due seizure. The SSAS generates an announcement similar to that used for initial coin deposit requests.

If the customer overdeposited during the previous collection sequence, the credit is automatically given. The overdeposit is subtracted from the calculated charges due. If no money is due, no actions are taken. If money is due, the TSPS connects an idle CDA circuit to the call. TSPS informs the SSAS of the amount due, the amount of credit, the number of chargeable minutes, the CDA circuit being used, and that it is a charge-due seizure with credit.

To assure the customer that credit is being given, an announcement is used, such as

> "2 dollars and 10 cents please." (2-second pause) "You have 20 cents credit. Please deposit 2 dollars and 10 cents more for the past 10 minutes."

After the charge-due deposit request is made, the deposit timing and, if needed, the prompting announcements described for the initial contact are used. If the deposit request is satisfied, the "Thank You" acknowledgment is given. When the SSAS informs TSPS that the acknowledgment is completed, the CDA circuit is disconnected from the call.

As with initial contact, operator assistance is given if no coin is deposited within a time interval, presently set at 5.5 seconds, or if the customer flashes during the deposit sequence. An operator is also connected if the customer goes on-hook during the announcement sequence.

4.3.2 Walkaways

If the calling customer goes on-hook at the end of a coin-paid call and charges are due, TSPS automatically generates a ringback signal to

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* With intermediate deposits, the called party is off-hook. A special coin detection arrangement is used to monitor the calling and called stations.

cause the calling phone to ring. If the calling party answers, an ACTS overtime charge due announcement is made. The start of the announcement is delayed 2 seconds from the time the customer goes off-hook. This allows time for the customer to get the handset to the ear.

However, if the calling party does not answer, TSPS assumes a walkaway. Since the customer did not respond to an automatic ringback, the customer probably will not respond to an operator ringback. Hence, an operator is not connected. Instead, a traffic counter is pegged and a walkaway record is made on the Automatic Message Accounting (AMA) tape. These walkaway records can be processed later to determine patterns so that action can be taken to reduce fraudulent use of coin phones.

4.4 Time and charge quotations

When a customer requests a time and charge (T&C) quotation on a call, the operator instructs the customer to flash and remain off-hook at the end of the call. If the customer follows the operator's instructions and the called party goes on-hook for two or more seconds, the forward connection is released and the call is connected to an idle CDA circuit. TSPS informs the SSAS of the charges, the length of conversation, the CDA being used, and that it is a time and charge quotation. The SSAS generates an announcement, such as

"The charges are 3 dollars and 94 cents plus tax for 12 minutes."

If the calling customer remains off-hook, the quote is repeated 3 seconds later. The SSAS informs TSPS when the second quote is completed, and the call is terminated. If the calling customer goes on-hook during this sequence, TSPS informs the SSAS to suspend the announcement sequence, and the CDA circuit is idled.

The fully automated quotation is given only to calling customers who remain off-hook at the end of the call. If the calling customer goes on-hook at the end of the call, TSPS connects an operator to contact the calling customer and give the T&C quotation. An operator is required because a system ringback may not be answered by the calling customer. For example, a ringback could be answered by a PBX attendant who knows nothing about the call.

When the SSAS gives the T&C quotation, the AMA record specifies that an SSAS quotation was given and the charges the customer was quoted.

4.5 Customer requested notification

On a call that is not coin-paid, a customer can ask to be notified at the end of 1 to 10 minutes. During the initial contact, the operator enters the customer's request into TSPS memory. If such an entry is

made, TSPS connects the idle CDA circuit to the call at the appropriate time. TSPS informs the SSAS of the CDA circuit being used, the number of elapsed minutes, and that it is a notification seizure. The SSAS generates the prescribed tone and announces, for example,

"5 minutes has ended."

When the SSAS informs the TSPS that the announcement is finished, TSPS disconnects the CDA circuit and continues to time the call.

V. ADDITIONAL TSPS FEATURES ON GENERIC 8

In parallel with the ACTS development, other service and maintenance features were developed. Those features are released with ACTS in a software package known as a generic. Since the generic containing ACTS is the eighth for TSPS No. 1, it is called Generic 8. This section briefly describes some of the additional features in Generic 8.

5.1 Expanded dialing to Mexico

This feature expands customer dialing capability on calls to Mexico. The Generic 8 dialing plan for Mexico is eight digits, except that the Northwest border area has a 903 area code followed by seven digits. Presently, calls to the 903 and 905 (Mexico City) area codes are customer dialable. (In the case of Mexico City, the digit "5" is both the third digit of the area code and the first of the eight digits in the dialing plan for Mexico.) Other calls to Mexico are only dialable by an operator, and many areas can only be reached by an inward operator.

The expanded Generic 8 capability allows customers to dial directly, using the international format, calls that currently are only dialable by an operator. Specifically, a customer dials 011 or 01 plus a country code of 52 plus the 8-digit Mexican number. TSPS software recognized the 52 country code and bypasses the 2-stage outpulsing normally done on international calls. TSPS then outpulses 180 plus the 8-digit number for routine handling (6-digit translation) in the domestic toll network. A toll office with trunks to Mexico eventually is reached and outpulses the 8-digit number. In Generic 8, TSPS also continues to handle calls dialed using the 903 and 905 formats.

Besides expanding direct dialing, this feature also simplifies inward calls to Mexico. The TSPS operator keys 52x-121, where x = 5 for Mexico City, 8 for Monterrey, 1 for Chihuahua, or 6 for Hermosillo. TSPS uses the "x" digit to index into a translation table. This table contains the codes to be outpulsed to reach the appropriate Terminating Toll Center.

This feature improves service by allowing the customer to dial calls directly. It also is expected to yield significant economic savings by automating a class of traffic that is experiencing substantial annual growth.

5.2 Transfer CAMA queuing improvement

In some cases, TSPS operators provide Operator Number Identification (ONI) to a CAMA office which will record the billing information. For instance, many TSPSs handle transfer CAMA traffic at night, when CAMA boards are closed and traffic is normally light. If traffic fluctuations produce a relatively heavy load, incoming calls can experience delays before reaching an operator position. Generic 8 has an improved strategy, called delay ratio control queuing, for handling traffic in TSPS offices which perform a transfer CAMA function.

This new queuing strategy tends to maintain a preselected balance between the delays experienced by transfer CAMA and other TSPS customers. A separate queue is established for transfer CAMA calls waiting for a position. Other TSPS customers queue as they do now. The serving rate for transfer CAMA versus other TSPS customers is dynamically modulated by the ratio of the respective queue lengths. This approach has been verified by analytical simulation and field studies to provide better service to CAMA customers while maintaining good service to other TSPS customers.

5.3 Dynamic queuing strategy

The dynamic queuing feature provides measurements and controls of the delays experienced by calls which require an operator position. The delay measurements are used to determine when to light a "calls waiting" lamp indicating to the operators that a moderate number of customers are awaiting assistance. Operators can then expedite call handling. If the delays increase further, the dynamic queuing measurements trigger the application of delay announcements.* These announcements turn away some of the new calls that would otherwise enter the queues.

Previously, the number of TSPS positions staffed was used to index into tables giving critical queue lengths for activating delay announcements and the call waiting lamp. These tables were originally constructed on the assumption of a fixed (60-second) Average Work Time (AWT) per call. Tables based on fixed AWT are insensitive to variations in service rate.

The dynamic queuing feature measures the actual delay encountered by incoming calls. Call abandonments are also directly taken into account, since they affect the measured delay. This accurate delay estimate improves service to TSPS customers. The dynamic queuing feature interacts constructively with the transfer CAMA queuing feature, since separate data can be obtained on the delays seen in the transfer CAMA queue. An integrated approach to lighting the call

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* Position disconnect is supplied on transfer CAMA trunks so that reorder can be given at the toll office. The delay announcement is given to other TSPS traffic.

waiting lamp and turning on the delay announcement (or supplying position disconnect) is based on accurate assessments of all the queuing delays in the system.

5.4 Redistributing (rehome) TSPS trunks

The ability to redistribute (rehome) TSPS trunks to a different toll or local offices allows an operating company to react to changing traffic trends. This ability allows TSPS capacity to be efficiently used in adapting to the evolving traffic patterns. Rehoming can be used to relieve congestion at a toll office or when an existing office is being replaced by a more modern electronic office. As an example, perhaps a No. 4A Crossbar office is being replaced by a No. 4 ESS.

Office data parameters for the trunks can be changed en masse. The software limitation of a single office parameter per trunk group is deleted for rehome. The software accommodates a difference (for instance, wink versus delay dial signaling) between the offices.

5.5 Improved coin station tests capabilities

TSPS Generic 8 provides a new coin station test capability. With this capability, a craftsperson can make end-to-end, coin signaling tests between coin stations and TSPS. This new procedure directs the crafts-person at the coin station through a series of tests. The SSAS is utilized to provide appropriate feedback to the craftsperson concerning the denomination of the detected coins. Marginal/stress testing is an integral part of the test. With the test information, the craftsperson is able to determine whether the station is functioning correctly and, if not, what functional area of the station is defective. In addition, certain types of coin-deposit signaling errors detected by the SSAS are recorded with other call billing details. This failure information can be summarized by a telephone company using the new Coin Operational and Information Network (COIN) package.* This information can be used to direct the craftsperson to potentially defective coin stations. Together, the per-call failure information and the quick, simple, and flexible coin station procedures provide the telephone companies with improved detection and resolution of coin system problems.

VI. ACTS DEPLOYMENT AND ECONOMICS

Today, over 75 percent of the coin stations and 80 percent of the average business-day, coin-paid calls in the Bell System are handled on TSPS, and this coverage is increasing each year. The incorporation of ACTS into TSPS eliminates or reduces operator handling of most of

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* COIN is an off-line computer package which performs collection, scheduling, and revenue analysis functions for public telephones.

these coin-paid calls, thereby achieving significant operating expense savings for the Bell System.

To achieve these savings, the previously described hardware and software are added to TSPS. In preparation for the introduction of ACTS in the Bell System, new coin stations and coin chassis produced by Western Electric since 1975 have been (and will continue to be) equipped for ACTS coin detection.

On November 26, 1977, the first new TSPS equipped with the ACTS feature was introduced into service in Phoenix, Arizona. In March, 1978, an existing TSPS was first retrofitted with the Generic 8 features in Oakbrook, Illinois.

ACTS was made available on a standard basis to the Bell System operating companies in the middle of 1978.

VII. ACKNOWLEDGMENTS

REFERENCES

1. "TSPS No. 1," B.S.T.J., *49*, No. 10 (December 1970), pp. 2417–2731.
2. Ibid.
3. G. T. Clark, K. E. Streisand, and D. H. Larson, "TSPS No. 1: Station Signaling and Announcement Subsystem: Hardware for Automated Coin Toll Service," B.S.T.J., this issue, pp. 1225–1249.
4. R. Ahmari, J. C. Hsu, R. L. Potter, and S. C. Reed, "TSPS No. 1: Automated Coin Toll Service," B.S.T.J., this issue, pp. 1251–1290.
5. E. A. Youngs, W. J. Bushnell, and A. Baron-Wing, "TSPS No. 1: Automated Coin Toll Service: Human Factors Studies," B.S.T.J., this issue, pp. 1291–1305.

Traffic Service Position System No. 1:

Station Signaling and Announcement Subsystem: Hardware for Automated Coin Toll Service

By G. T. CLARK, K. STREISAND, and D. H. LARSON

A new subsystem, Station Signaling and Announcement Subsystem (SSAS), was added to TSPS to provide automated coin toll service. Presented here are descriptions of how this new subsystem generates announcements from digitally stored speech samples, how it responds to coin deposit signals from coin stations, how the announcement circuits and coin tone detection circuits are automatically tested, and how the subsystem is physically packaged.

I. INTRODUCTION

The new functions needed in TSPS for Automated Coin Toll Service are provided by the newly designed Station Signaling and Announcement Subsystem (SSAS). SSAS delivers voice announcements to customers at coin stations and responds to the coin deposit signals generated at the coin stations.

SSAS can be described from two perspectives, that of a coin toll customer and that of the TSPS processor. From the coin toll customer's viewpoint, it should sound and react the same as or better than the human operators the customer is accustomed to. From the standpoint of the TSPS processor, it operates as an "intelligent peripheral," using the existing instruction and data buses. In response to TSPS instructions, it constructs announcements to request and acknowledge coin deposits. It keeps track of each customer's coin deposits and then reports the amount of the completed deposit to the processor, which then sets up the call. If the customer does not deposit enough coins, SSAS delivers requests for the balance, or finally sends a time-out

report to the processor so an operator can be brought in to assist the customer. To provide reliable service, the SSAS control circuits are duplicated, with one control circuit active and the other standby. They contain self-checking features so faults can be detected promptly and reported to the TSPS processor, enabling a smooth switchover from the active to the standby SSAS controller.

The interface of SSAS with customers is through a number (up to 239 per system) of Coin Detection and Announcement circuits (CDAS). Each CDA provides service to one customer at a time. Each CDA contains a coin tone receiver that recognizes the nickel, dime, and quarter deposit signals from dual-frequency, single-slot, coin stations. Each CDA also contains a digital-to-analog decoder that converts bits at 31,250 b/s into natural-sounding voice announcements. To provide for connecting an operator if the customer has difficulty and to reduce the possibility that operator or automated announcement speech will interfere with correct coin recognition, each CDA also includes a 4-wire, voice-frequency network with an extra port for the operator. Each network contains 4-wire terminating sets and amplifiers to isolate the coin-tone receiver and digital-to-analog decoder from one another. In addition to the customer-serving CDAS, each SSAS contains one unique CDA circuit that functions as a built-in test set.

Figure 1 shows the essential parts of a connection from a customer to an SSAS CDA.

Before the advent of SSAS, a coin call needing TSPS operator service would be connected through a TSPS trunk and the TSPS network to an operator position or to a service circuit for ringing or busy tone. With SSAS, a call identified as eligible for automated coin detection handling is immediately connected to a CDA. If it later develops that an operator is needed, one can be connected to speak to the customer or to listen to the automated announcements and coin signals.

Figure 2 shows the principal parts of SSAS along with the input and output data bus connections to the TSPS processor.

The coin-tone receivers in the CDAS deliver detected coin data to digital registers, also in the CDAS. These registers are scanned periodically, and the data are ultimately relayed back to the TSPS processor. The digital-to-analog decoders that deliver the announcements were adapted from an earlier Bell Laboratories design, Subscriber Loop Carrier 40 (SLC^{TM}-40). They are preceded by serial buffers that are loaded sequentially, with bursts of 40 bits transmitted at a 1-mHz rate. The bits are decoded at a steady rate of 31,250 b/s.

As mentioned earlier, as many as 239 CDAS can be associated with one SSAS. Since the holding time needed to request and collect coin deposits for a typical call is relatively short, 239 is expected to be enough CDAS to handle the coin toll traffic in large metropolitan TSPS offices. The CDAS are operated by a controller frame and an associated
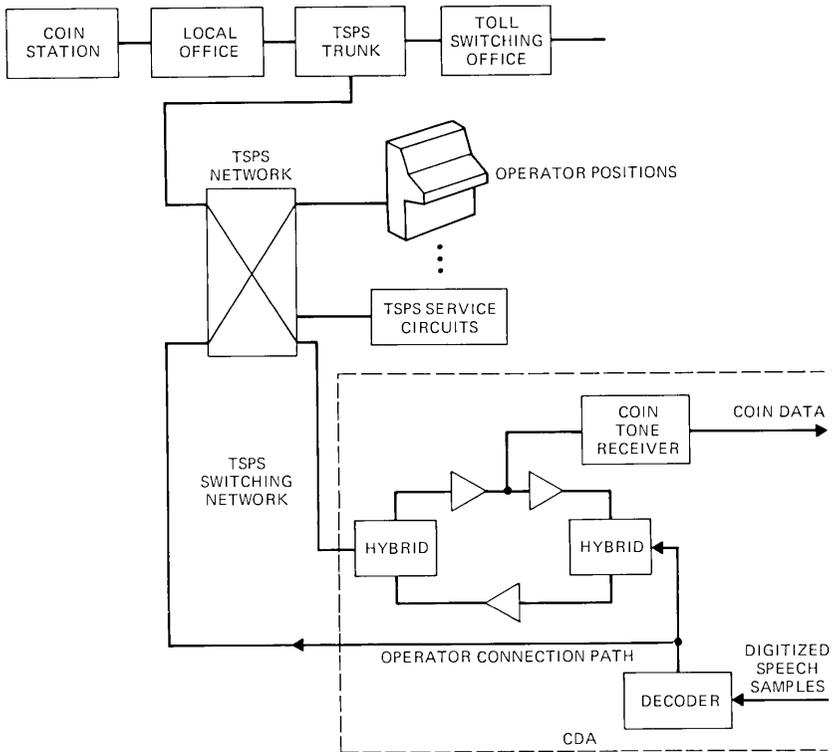
Fig. 1—Connection of SSAS CDA into TSPS.

semiconductor announcement store. For backup in case of failure, there is an identical controller frame/announcement store pair. The announcement store, except for minor modifications to make it accessible either from the SSAS controller or the TSPS processor, is the same design as the TSPS processor main store frames. It may contain up to six memory modules, each containing 32K 47-bit words. Forty bits of each word are data; seven are used for error detection and correction.

The controller frame contains a programmable controller (PROCON) and wired logic which, in response to instructions from the TSPS processor, retrieves samples of digitized speech from the announcement store and distributes them in a multiplexed scheme, with a fixed sequence, 40 bits at a time, to the CDAs. The announcement distribution sequence has 256 time slots, of which 16 are used for test instructions and 240 are used to deliver bits to the 239 CDAs and the one test channel. The distribution sequence is repeated every 1.28 ms, so that each CDA, using bits out of its serial buffer at a rate of 31,250 b/s, for announcement generation, is supplied with precisely enough data to produce uninterrupted announcements consisting of 512-ms segments joined together.
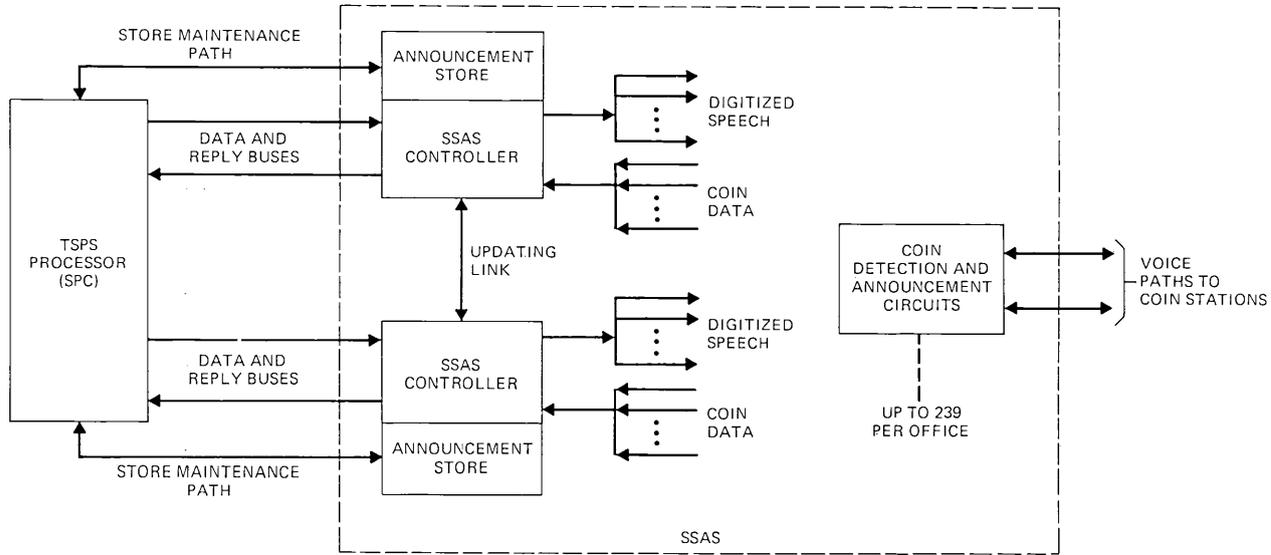
Fig. 2—ssas block diagram.

If an office were equipped with the full complement of 239 CDAs, it could deliver announcements to 239 customers simultaneously. When there are not 239 CDAs installed, or when not all installed CDAs are in use, a bit pattern representing silence is placed in each inactive time slot.

At the same time that the PROCON in the SSAS controller is distributing 40-bit digitized speech segments to the CDAs, it is sequentially scanning, over separate data paths, registers connected to the outputs of the coin tone receivers in the CDAs to gather data on coin deposits. The coin deposit data, including the time when the deposits occurred, is stored by the PROCON in "scratch pad" memory. The deposit and time data are used to determine future actions, i.e., additional announcements or reports to the TSPS processor when the deposits are sufficient.

Both the active and standby controllers have access (one at a time) to all CDAs. The two controllers do not operate synchronously with matching for error detection. Each, however, contains a close tolerance crystal-controlled clock, so any time difference between them would be only a few microseconds, a difference not noticeable to customers in the event of a switchover. The maintenance and initial loading of the announcement stores takes place over the store maintenance paths shown in Fig. 2. These paths, in fact, are extensions of the existing TSPS processor store buses.

The updating link shown between the two SSAS controllers is a parallel, 17-bit (16 plus parity), 1-mHz link interconnecting the PROCONs in the two controller frames. This link provides two very powerful features. First, if one announcement store is powered down for maintenance, reloading over the store bus would require human action to set up a tape drive and many minutes of loading time. With the updating link, however, the PROCON in the active controller can, interleaved with normal handling of announcements and coin data, transmit in a few seconds the entire contents of the active announcement store to the just-restored inactive announcement store.

Second, while the active controller is dealing with the ever-changing coin collection data stored in its "scratch pad" memory, the same data are being continuously relayed through the updating link to the memory of the standby controller. This makes it possible to perform a planned or unplanned switchover to the standby controller, usually without interrupting announcements or losing track of the coins that as many as 239 customers may be in the process of depositing.

II. DETAILED HARDWARE IMPLEMENTATION

The development of SSAS includes several areas that are felt to be of some general interest and will be discussed further here. These are:

1. Storage, retrieval, and decoding of announcements.

2. Coin deposit signaling and detection.
3. Automated testing of coin detection and announcement circuits.
4. Physical design.

2.1 Announcement storage and processing

The continuing orders-of-magnitude decrease in the cost of digital memories made it clear that the storage of announcements for SSAS should be digital rather than analog. A major decision for SSAS was whether to use writable store (RAM) or read-only memory (ROM) to store the announcement vocabulary. For some recently developed or proposed "talking" systems, ROM is clearly the better choice. For personal calculators for the blind, for example, the vocabulary is well defined to include just the digits zero through nine and the names of the arithmetic operations. Reloading a volatile memory in a portable calculator would be clearly impractical. Also, ROMs can be packaged more densely. For SSAS, however, although the vocabulary for coin traffic might appear to be constant, it is subject to change when call-handling practices change. There may have to be vocabulary differences among operating companies because of differences in their practices concerning overtime collection. More important, when new features are added to SSAS, a significant amount of new vocabulary will have to be added. If the SSAS vocabulary were stored in read-only-memory, the logistics and cost of managing spares, repairs, and additions appear to be objectionable. With a writable memory of the type already in use in TSPS, no special handling of memory units will be needed. New vocabulary can be distributed to operating companies as needed on reels of magnetic tape, using administration procedures already established for distribution of TSPS software updates. Although data in a writable store are subject to loss in the event of a power failure, the back-up power arrangements in Bell System central offices make a shutdown of both announcement memories unlikely; if it does occur, their contents can be restored from a tape stored in the office.

The SSAS announcement vocabulary presently includes 80 512-ms speech segments and the equivalent of 15 more speech segments containing test tones and timing data for automatic self-testing. Each 512-ms segment requires 16,000 bits, stored in the 40-bit data portion of the words at 400 consecutive addresses in the announcement store.

The semiconductor program/data store recently developed for use in TSPS was selected for use with some modification as the SSAS announcement store. Figure 3 is a photograph of this store. This store frame can be equipped with up to six modules, each holding 32,000 47-bit digital words. The 95 presently used vocabulary segments require 38,000 digital words, so the frame presently used in SSAS is equipped
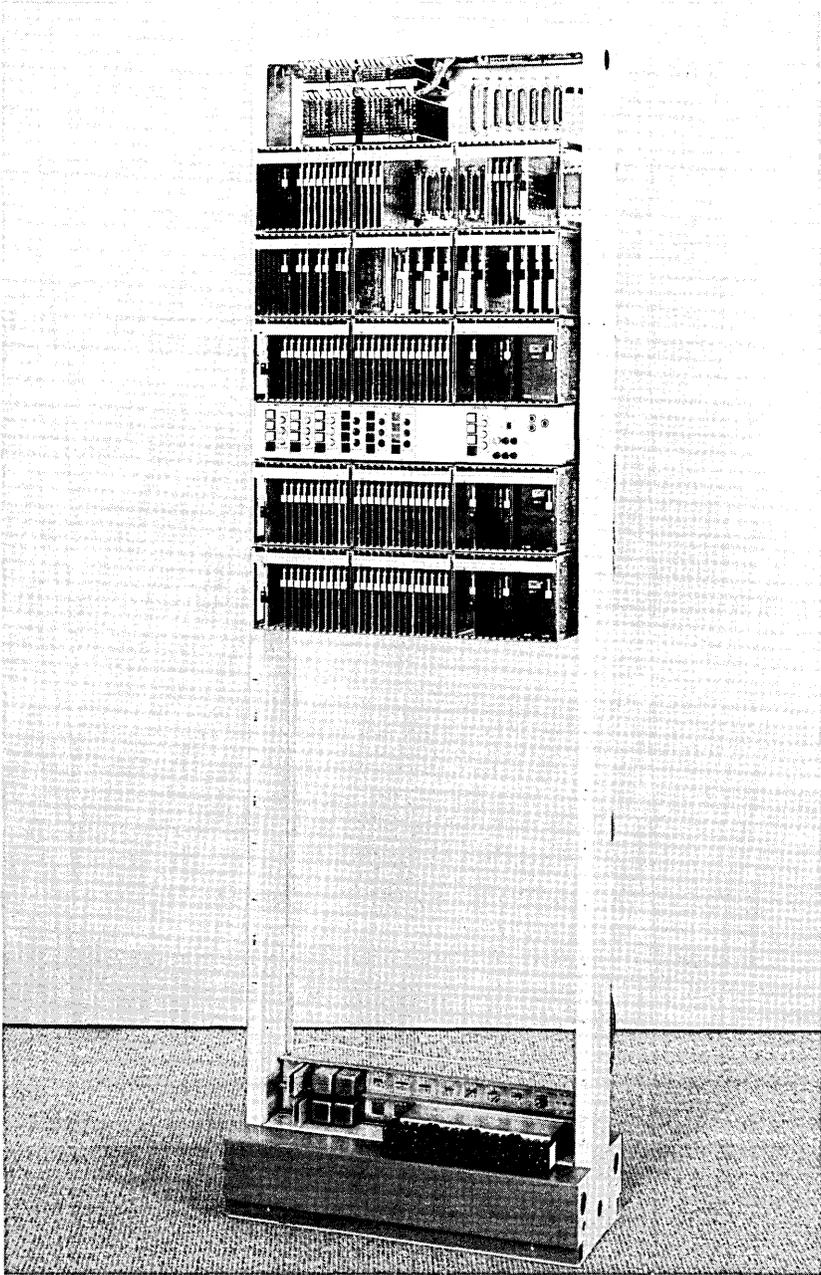
Fig. 3—Announcement store frame.

with only two memory modules. A store frame fully equipped with six modules would accommodate 480 512-ms segments. Since 95 are now in use for ACTS, as many as 385 more could be made available for new features. As mentioned earlier, the announcement store frame differs from a TSPS main store frame only by the addition of a selector to provide access either from the SSAS controller or the TSPS store bus.

The vocabulary of 80 words needed for the SSAS announcements was recorded by a professional announcer. The words were then digitally encoded using adaptive delta modulation with a bit rate of 31,250 per second. Next they were edited into 80 512-ms segments, each containing 16,000 bits. The editing was a subjective listening process, with attention paid to level, pitch, and the silent periods adjacent to each piece of speech, to assure the most natural possible sound when the pieces are rejoined in various combinations to form sentences. Many words are complete in a single 512-ms segment; the numbers over 20 and some common parts of announcements (e.g., "Please deposit") require two segments to complete. The words that are used both in the middle and at the end of sentences are included twice with two different inflections. The 15 equivalent segments containing test tones were recorded using laboratory signal generators.

The adaptive delta modulation (ADM) encoder used for the announcement recording and the decoders used in the CDAs were developed earlier at Bell Laboratories for use in the Subscriber Loop Carrier System (SLC-40) and are described in detail in Ref. 1. Briefly, ADM is a process for encoding a signal into a train of ones and zeros which are then decoded by the simple process of using each one to increment the charge on a capacitor in the positive direction and using each zero to decrement the charge by the same amount. Since the bit rate is several times higher than the highest voice frequency, the "stairsteps" in the wave can be easily filtered out. The delta modulation encoding and decoding process is made "adaptive" by using the last few bits in the pulse train to control the magnitude of the current generator that is used to increment the charge on the decoding capacitor. The rates of increase and decrease of the adaptive current generator are controlled by R-C networks tailored to the average parameters of speech syllables.

Adaptive delta modulation produces thoroughly adequate announcement quality using 31,250 bits per second, about half the bit rate that would be needed by 7- or 8-bit pulse code modulation (PCM) using an 8-kHz sampling rate.

The announcement decoder for each of the SSAS CDAs is on a single 6-by-8-inch circuit pack. Each pack includes the decoder circuit from the SLC-40 design (adapted for slightly different power supply voltages), a "silence" generator, and a serial input buffer. The silence generator is a flip-flop controlled by a clock to produce alternating

ones and zeros. It is intended to be brought into operation in midword to silence an announcement quickly when a customer starts to deposit coins. This feature allows a substantial speedup in service for customers who already know the charges for calls they are making. The serial input buffer is a self-shifting, first-in/first-out (FIFO) shift register device, available commercially from several manufacturers. It is loaded at a 1.0-mHz rate each time the 40-bit data bursts arrive. It is unloaded continuously into the decoder circuit by the 31,250-Hz clock distributed to all the CDAs.

The sequential distribution of 40-bit announcement segments to all the CDAs is controlled by the PROCON and by wired logic that automatically steps through the 400 store addresses for each speech segment and distributes the data to the 239 CDAs and one test circuit. The retrieval of the words from the 400 consecutive announcement store addresses is controlled from a pair of 256-word recirculating shift registers. These shift registers are used in an alternating fashion. One is loaded by the PROCON with the 256 initial addresses of the announcement segments needed for the next upcoming 512-ms period. One particular address is used to represent silence for inactive or unequipped CDAs. The second shift register, which was previously loaded with the initial addresses for all the announcements (or 512-ms silence segments) in progress, is recirculated 400 times, and each time a one is added to all the addresses. Thus the set of 256 starting addresses is altered at each recirculation to step through the 399 addresses that follow each initial address. These addresses are used to retrieve the announcement data words, which are then distributed in sequence to the CDAs for decoding. After the 400 recirculations, the roles of the two recirculating shift registers are reversed. The recirculation and incrementing begins with the new set of starting addresses, and the just-exhausted shift register is loaded with the still newer set of starting addresses for the next 512 ms of announcements. Each 512-ms interval, when a new set of announcement addresses is loaded, is referred to as a "base period."

2.2 Coin deposit signaling and detection

Coin deposits were reported to an operator for many years through a largely mechanical system. In the widely used 3-slot coin station, the coins rolled and bounced against gongs to produce "bing" for a nickel, "bing-bing" for a dime, and "bong" for a quarter. To provide added flexibility for changes in the initial deposit on local calls and to provide substantially more protection against counterfeit coins and slugs, a new single-slot coin station was introduced in 1966. In this coin station, the coins, after passing through a mechanism that tests them for dimensions, mass, and conductivity, trigger an electromechanical device called a totalizer. After each coin passes, the totalizer resets itself,

and in so doing, momentarily switches on a pulsed-electronic oscillator that produces one "beep" for a nickel, two for a dime, and five for a quarter. In principle, single-frequency "beeps" from such a coin station could be recognized by a tuned electronic detector and counter. However, Bell System experience with multifrequency and *TOUCH-TONE*® signaling indicated that adequate protection against errors caused by speech or noise could be provided only by using dual-frequency "beeps" to represent coin deposits. Accordingly, a low-cost dual-frequency oscillator assembly was designed and introduced into the manufacture and refurbishment of coin stations starting in 1975. This was done deliberately well in advance of the service cutover of SSAS (late 1977) so that a minimum of coin station modification visits would be needed when Automated Coin Toll Service is introduced to an area.

2.2.1 Coin tone receiver operating environment

Coin tone signaling may take place in the presence of ambient speech and noise. Speech interference, for example, may be due to a synthesized announcement in progress, customer speech, an operator talking, or background noise at the coin station at the same time that coins are being deposited. The SSAS coin tone receiver is required to respond correctly to these coin tone signals in the presence of such speech or noise interference. The human ear (and mind) usually has no problem identifying tone signals in the presence of speech and can easily differentiate tone signals from speech. Electronic detection of tone signals, if it involved only receivers tuned to the specific frequencies, would be vulnerable to errors from speech signals since vowel sounds in speech frequently contain frequency components in the recognition band of the coin tone receiver.

The speed of operation of the electromechanical totalizers in the coin stations is affected by temperature, by the dc current available from the loop to the central office, and by wear of the totalizer parts. Consequently, the coin tone receiver must accept a coin deposit signal whose timing varies over a considerable range.

2.2.2 Coin tone receiver overall design philosophy

The basic design requirements can be summarized as follows. The coin tone receiver should:

(*i*) Recognize coin tones from widely ranging coin stations.
(*ii*) Identify a coin station whose performance is outside of requirements.
(*iii*) Operate in the presence of speech.
(*iv*) Reject coin simulations.

The first two requirements are met by accurate timing of the received signal to identify both valid coin deposit sequences and those

from coin stations with defective timing mechanisms. The third and fourth requirements, operating in the presence of speech while rejecting coin simulations, are major considerations and have a significant impact on the receiver's design. As was mentioned earlier, speech may frequently contain sufficiently sustained tone components that simulate coin deposits. By using dual-frequency coin signaling for ACTS, where both tones have to be present simultaneously for a signal to be valid, the coin simulation rate is reduced by a considerable degree. A simple detector that looks only for the presence of the two required frequencies, however, still does not provide adequate simulation immunity. Further receiver protection against coin simulations by speech is obtained by looking at other energy (called guard energy) besides the signal frequencies. If the guard energy is sufficient, the "signal" is assumed to be speech, and tone detection is blocked even though signaling energy may also be present. However, speech from the operator, announcement, or the calling station may be present while coins are being deposited. Thus receivers designed to give good coin simulation protection may be blocked or "talked down" when speech or noise is superimposed on tone signals. This can be seen in Fig. 4, where ambient speech interferes with and partially blocks tone detection and at the same time causes false detection (coin simulation) during the silent interval between bursts. Since the cure for one problem makes the other worse, a compromise but exacting choice must be made in establishing receiver operating parameters.

To reduce the effect of "talkdown" and coin simulation due to the operator and/or announcement, a four-wire terminating set is used to isolate the receiver from speech signals directed toward the originating station. However, because of nonideal return losses associated with trunks, loops, and various terminations, some portion of this speech energy is reflected back to the coin tone receiver. The returned signal
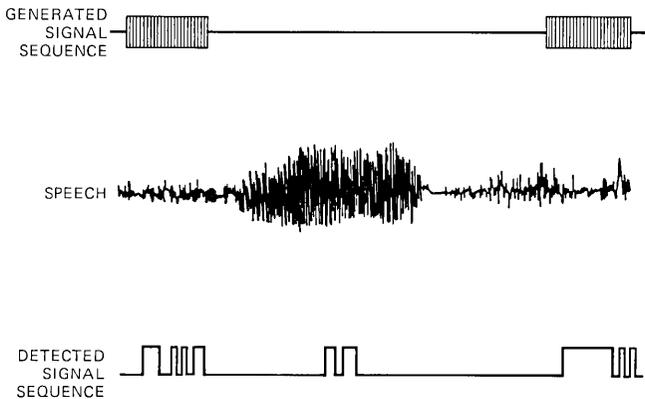

Fig. 4—Coin signal in the presence of speech.

is usually at a considerably lower level so that the probability of interference with signal reception is substantially reduced.

The interfering effect of the announcement is reduced even further by truncating it at the earliest indication of a received coin tone signal. The receiver sends to the ADM circuit pack in the CDA a command to truncate the announcement even before the minimum duration legitimate coin burst is timed. Hence, if a false detection were due to signaling frequency components within the announcement itself, the signal would disappear before a coin simulation could be produced. If the detection were legitimate, truncation would prevent any further talkdown by the announcement.

2.2.3 Coin tone receiver subdivision

Notwithstanding the coin simulation and talkdown protection provided by the four-wire terminating sets and announcement truncation, the receiver itself must have additional safeguards to distinguish between speech and coin tones, yet recognize tones in the presence of speech. This is accomplished in a two-phase processing approach: tone recognition and tone validation. The front-end analog tone recognition portion of the receiver "detects" the signal while providing the initial balance between coin simulation protection and "talkdown" protection; the digital tone validation timing portion then applies different validity standards to various portions of the "detected" signal to determine the coin denomination.

The analog portion (Fig. 5) is similar in principle to existing receiver designs for TOUCH-TONE signaling. (TOUCH-TONE signaling and receiver design considerations are described in Ref. 2.) It consists of filters, limiters, and detectors which produce a logic 1 output to the timing circuitry when both signal frequencies are simultaneously detected. As was mentioned earlier, tone detection is blocked when sufficient "guard" energy is present. The input bandpass filter (BPF) controls the total frequency range of signals entering the receiver. If this filter is broad, a considerable spectrum of the speech energy entering the receiver will be applied to the limiters. If the speech contains components at the signaling frequencies, it is likely that these components will be dominated by the other speech components, which will "capture" the limiters. Thus the signaling components passing through the bandpass filters, which follow, will not be of sufficient amplitude to operate the detectors. This method of preventing coin simulation is known as "limiter-guard action" and is the technique employed in TOUCH-TONE signaling to reduce the incidence of digit simulations. Therefore, a broad input BPF provides good coin simulation protection. If, however, legitimate coin signals are being transmitted while speech is present, they may also be blocked by speech.

f₁ LOWER FREQUENCY OF THE DUAL TONE
f₂ UPPER FREQUENCY OF THE DUAL TONE
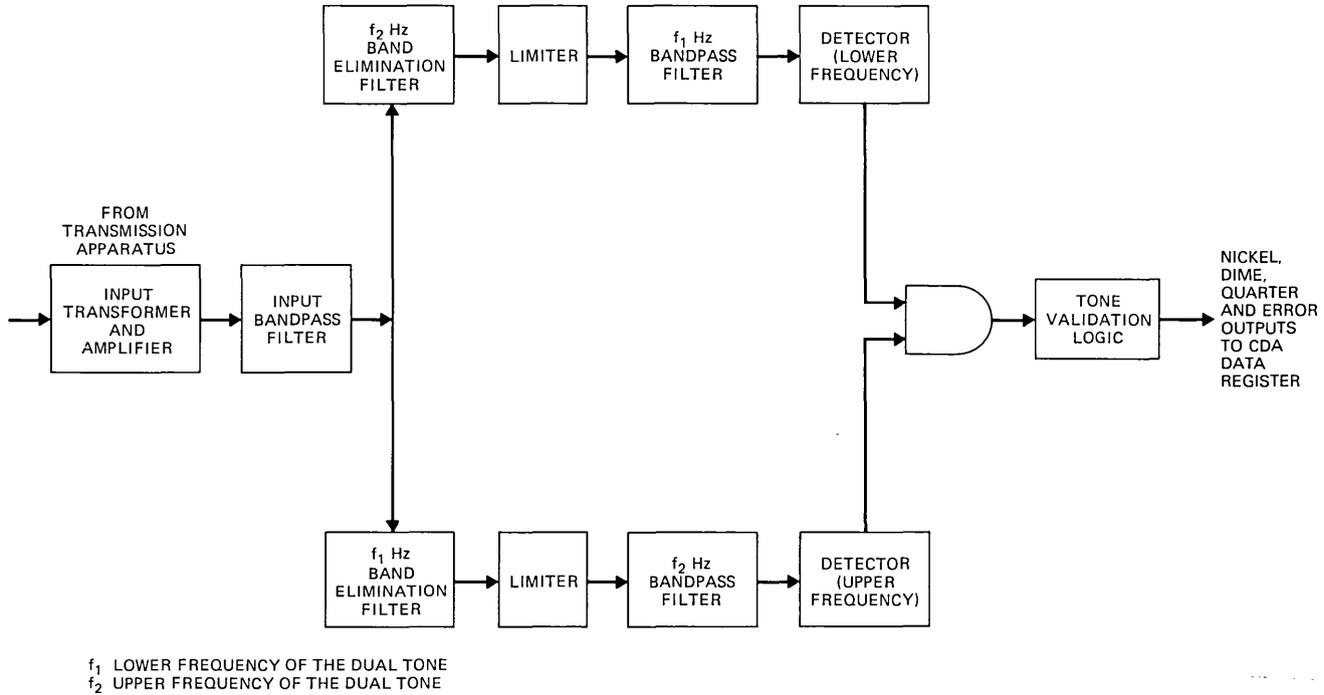
Fig. 5—Coin tone receiver.

Hence, "talkdown" protection will be poor. If the input BPF is narrowed (the input BPF must be at least wide enough to pass the two signaling frequencies), less speech energy can get through and, while "talkdown" is improved, less protection is provided against coin simulation. Based on laboratory and field tests, a filter was selected to optimize the tradeoff between the detector's coin simulation and "talkdown" protection.

The logic signal indicating dual-tone detection is applied to the receiver's tone validation timing circuitry which performs the following functions:

(i) Processes the detected signal (refer to Fig. 4 for a sample detected signal) to form "discrete" burst and silent interval logic signals in accordance with the timing algorithm by filling in some gaps while ignoring some burst portions.

(ii) Totalizes the number of "discrete" bursts received.

(iii) Categorizes each "discrete" burst or silent interval after it is formed and makes a preliminary determination of the coin denomination at that time.

(iv) Checks for consistency with previous burst and silent intervals to narrow the denomination possibility for that coin and also check for coin station timing malfunctions.

(v) Outputs the coin denomination or timing error signal when certain conditions are satisfied regarding the number of bursts received, the apparent coin category, and the amount of silence since the end of the last burst.

2.2.4 Receiver outputs

As the receiver performs signal timing in accordance with the timing flow diagram in Fig. 6a, certain output conditions may be satisfied and an output representing one of the coin denominations or a timing error (representing an out-of-tolerance coin station) will be delivered to a CDA data register. Before any coin or timing error outputs can be sent, however, the receiver must first deliver a Signal Processing (SP) signal. The SP signal is sent when the timing of the first burst of a suspected coin deposit reaches a certain minimum value. It remains active until a coin identification or timing error output signal is transmitted or the suspected coin deposit is deemed to be a coin simulation. At that time processing for the coin is assumed to be completed. The SP signal is used in the announcement decoder to truncate the announcement (see Section 2.2.2) by switching in the silence generator. The receiver also sends a DST (data strobe) signal along with the outputs, which gates the coin denomination or timing error indication into a data register in the CDA.
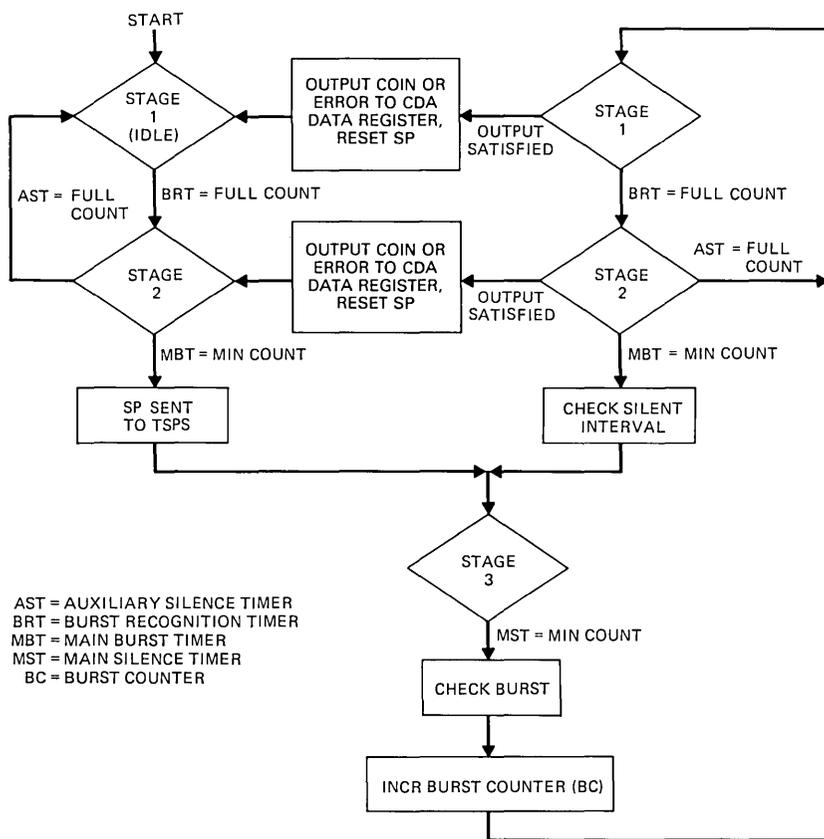
(a)
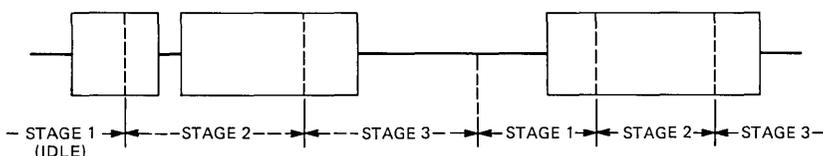
(b)

Fig. 6—Timing algorithm. (a) Algorithm flow. (b) Sample detected signal sequence.

2.2.5 Circuit implementation

The tone detection portion of the receiver (see Fig. 5) is based on existing receiver designs for *TOUCH-TONE* signaling. The input bandpass filter, which is critical to the detector's response to speech and also to its performance when tones are being received in the presence of speech, was discussed in detail in Section 2.2.3.

Following the bandpass filter are two band-elimination filters (BEFs) in parallel. The width of these filters is tailored to the tolerances of the coin station oscillators. The first filter rejects the higher of the two signaling frequencies, and the second filter rejects the lower. Thus the output of the high BEF will contain the lower of the two signaling frequencies, and the output of the low BEF will contain the upper signaling tone. The limiters that follow convert the signals to square waves. Hence, at this point, there are two square waves, one out of each limiter.

These signals now pass through bandpass filters centered at the two signaling frequencies. The square wave out of the low frequency limiter passes through a filter centered at the low frequency and a sine wave output is produced. The same occurs for the upper frequency square wave. Following the filters are threshold detectors that detect the sine waves if they are above a certain threshold level. The limiter employs a feedback arrangement to control the limiter operating threshold. The two detector outputs are combined to produce a logic output that is timed by the receiver's tone validation circuitry to determine the denomination of the coin.

Wherever possible, components originally designed for *TOUCH-TONE* signaling are used for design implementation. These include the limiter-threshold generator circuit module, STAR (standard tantalum active resonator) filter circuit modules similar to those for *TOUCH-TONE* signaling, and the detector modules. These circuit modules are hybrid integrated circuits. The analog tone detector circuitry occupies two 4- by 8-inch printed wire boards. The filters are on one board, and the remaining detector circuitry is on the other.

Tone validation timing is done digitally, with the circuitry consisting primarily of small scale integration (SSI) and medium scale integration (MSI) TTL devices. A 1-kHz clock signal synchronizes all tone validation timing operations within the receiver. This clock sets the rate at which the tone detect signal from the analog circuitry is sampled. Based upon whether the dual tone detector is high or low at the sample instant, the various gates, counters, flip flops, etc., are operated in accordance with the tone timing validation algorithm. This tone validation circuitry takes up four circuit packs, making a total of six packs for the entire receiver. Subsequent to deployment of the random logic timing circuitry, a cost reduction was made by having a microprocessor perform the timing algorithm. The entire tone timing validation circuit was placed on one circuit pack, lowering the overall circuit pack count to three.

2.3 Automated testing of announcement and coin detection circuits

The use of digital speech storage and PROCON control in SSAS made it possible, with a very small amount of added hardware, to provide

automated testing of the speech decoding and coin tone receiver circuits.

The adaptive delta modulation decoding circuits in the CDAs are tested by using four single frequency tones digitally stored in the announcement store. Three of the tones are within the frequency band of the voice announcements, and the fourth is just above that band. The three in-band tones verify the flatness of response of the decoder and the transmission network associated with it. The out-of-band tone verifies correct roll-off response of an active low-pass filter included in each CDA to filter out the 31,250-Hz "stairsteps" that result from the decoding process.

Under control of a diagnostic program, each CDA is periodically taken out of service, and the digitized test tones are distributed to it from the standby SSAS controller frame. The TSPS processor simultaneously sets up a network connection from the output of the CDA circuit under test to the CDA test circuit. The CDA test circuit connections for decoder testing are shown in Fig. 7. The CDA test circuit contains a bandpass filter that passes all the test frequencies, followed by a level detector that delivers "go/no-go" responses to indicate when the detected levels are in or out of tolerance. Also included in the CDA test circuit are four active "notch" filters followed by a detector and a smoothing filter. The notch filters remove the fundamental of each test frequency, and the detector responds to the residue, which includes harmonics and noise resulting from the adaptive delta modulation encoding/decoding process. The detector delivers a logic level "no-go" output if the residue is higher than normal. The smoothing filter is needed because, after the fundamental has been removed, the residual combination of harmonics and decoding products is partly random,
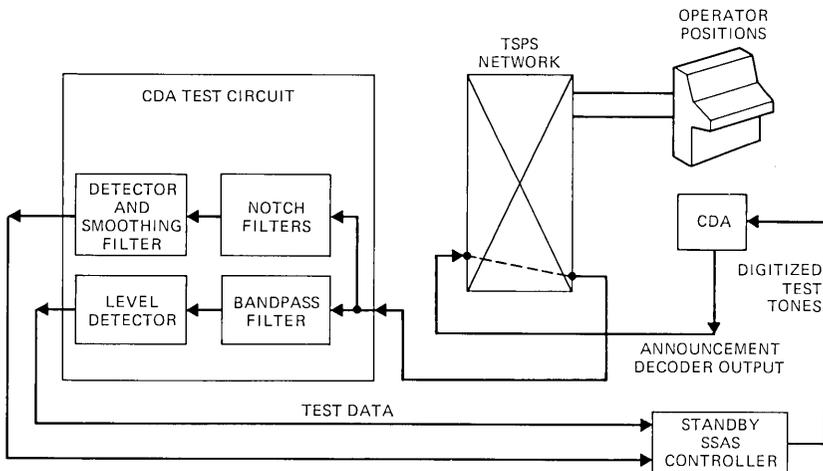

Fig. 7—Testing CDA decoders.

and without smoothing it would cause occasional "false alarm" responses at the detector output.

Testing CDA decoder circuits in the way described above verifies the integrity of the logic circuits and wiring that retrieve and distribute digitized speech segments, and it checks for continuity and proper alignment of the voice frequency transmission apparatus that connects the CDAs to the TSPS trunks.

The coin tone receivers are also tested by using tones stored in the announcement memory. The diagnostic program for the coin tone receivers directs the digitized coin test tones to a CDA decoder circuit pack that is dedicated for this purpose. The output of this decoder is routed through a solid-state switch controlled to produce tone bursts that simulate the coin station output signals that represent nickels, dimes, and quarters. The tone bursts are passed through switchable attenuators and through TSPS network connections to each coin tone receiver in turn. CDA test circuit connections for coin tone receivers are shown in Fig. 8.

A very comprehensive test sequence is applied to the coin tone receivers using the scheme described above. The coin test tones are recorded and stored with nominal frequencies and frequencies just inside and just outside the operating tolerances on both sides of the nominal frequencies. The solid-state switch is operated to produce the nominal tone bursts that check the receiver's detection of the various nominal and edge band frequencies and a variety of non-nominal durations and sequences that exercise the receiver's timing logic. The switchable attenuators control the levels of the tone bursts in the test sequence to provide verification that the coin tone receivers operate over the range of levels that result from coin station and transmission
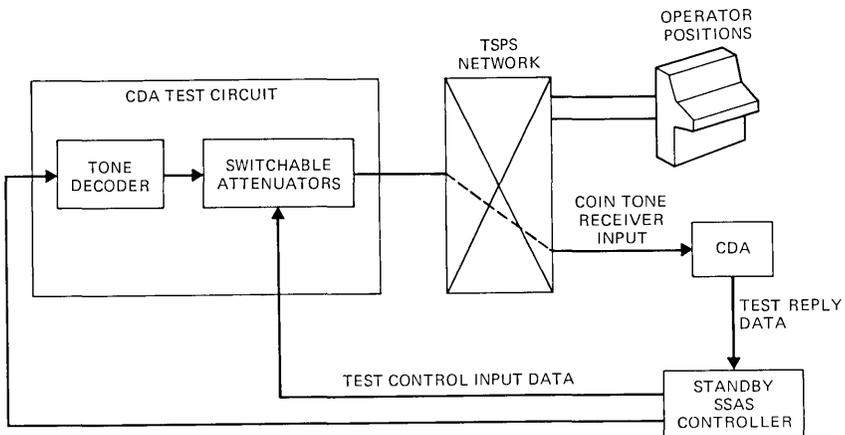

Fig. 8—Testing CDA coin tone receiver.

loss variations. The test sequence for each coin tone receiver is completed automatically in a few seconds.

The CDA test circuit includes four circuit packs identical to a set of four used in each CDA, and five additional packs unique to the test circuit. The CDA test circuit also has a self-test mode. In this test mode, the output of the tone generation and control circuits of the CDA test circuit are temporarily fed back to the input of the filter/detector circuits and a "wrap-around" test sequence is executed.

2.4 Physical design considerations

A complete SSAS installation includes two controller frames, two announcement store frames, from 2 to 15 pairs of frames containing coin tone receivers, announcement decoding circuits, voice frequency terminating sets and amplifiers. The coin tone receivers and announcement decoding circuits are mounted in service circuit frames (up to a maximum of 16 sets per frame) and the voice frequency circuits are similarly mounted in transmission frames.

2.4.1 Controller frame

The controller frame (Fig. 9) is a single-bay frame, 2-ft 2-in. wide and 7-ft high, using a 12-in. deep framework, as do most other TSPS frames. This frame is compatible with all other TSPS frames and requires no special hardware, mounting, or installation arrangements.

The communication bus and interconnection unit at the top of the controller frame contains multi-pin terminal strips for terminating cables from connecting frames. The connections to the announcement store are also made through this unit. Transformers are furnished for connection to the TSPS buses. Bus connectorization for growth is provided, and is compatible with existing office arrangements.

The logic unit in the upper part of the controller frame includes six levels of circuit packs and a control panel unit. Five-volt power and ground return for the circuit packs are provided by a double-sided, printed-wiring back plane for each of the six levels. Each level is split into two halves for power distribution. Five levels can accommodate up to 37 circuit packs on ½-in. centers. The sixth level can accommodate 28 circuit packs on ½-in. centers. A very large percentage of the backplane wiring is automated. The type of circuit pack used is a double-sided printed wiring board, 6 in. by 7 in. in size, with 80 pins. An example of this circuit pack is shown in Fig. 10.

The control panel unit contains the various keys, lamps, and jacks for maintenance and frame control functions.

The memory and control unit provides mounting arangements for the PROCON and its associated memory packs. Connectorized cables are provided within this unit and between parts of the logic unit.
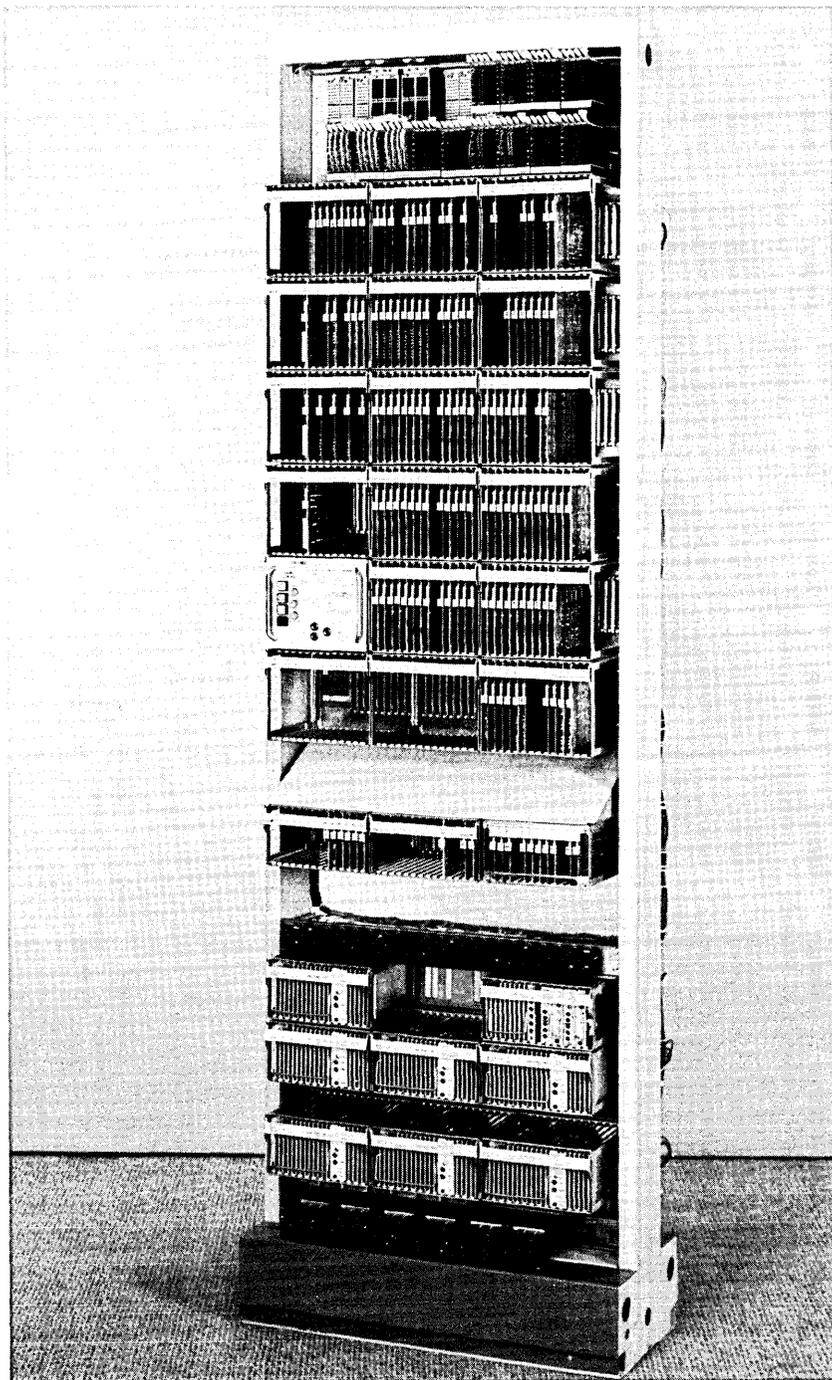
Fig. 9—Controller frame.
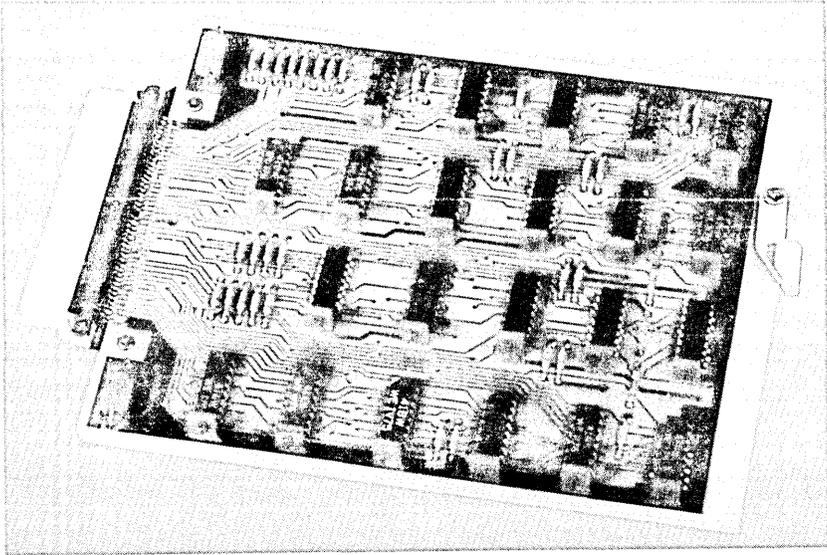
Fig. 10—Controller frame circuit pack.

The power converter unit contains +5 V and −12 V dc-to-dc converters and fuses. These power units are pluggable for easy replacement. A +5 V load fuse and a pilot fuse are provided for each half of the circuit pack levels and for the memory and control units.

The fuse panel unit contains −48 V and +24 V fuses, alarm relays, and power control relays. The −48 V is used to supply the dc/dc converters. The +24 V is used in the circuit packs that contain bus drivers.

2.4.2 Service circuit frame

The service circuit frame (see Fig. 11) is a single-bay frame, 2 ft, 2 in. wide and 7-ft high, using a 12-in. deep framework. Each frame may contain as many as 16 CDAs. A maximum capacity SSAS installation would include 15 service circuit frames to hold 239 CDAs plus one CDA test circuit.

The service circuit frame uses multi-pin terminal strips and bus coupling transformers for terminating cables from other connecting frames. In addition, the unit is arranged to hold three levels of circuited packs. These packs are associated with the 16 CDAs and the circuits that provide switchable access to either controller frame. The +5 V power is supplied individually to each service circuit and to each of the group controllers. Printed-wiring back planes provide +5 V ground return for each pack. A large part of the unit wiring is automated. This unit is always wired for 16 circuits and is equipped by plugging in circuit packs as determined by traffic requirements.
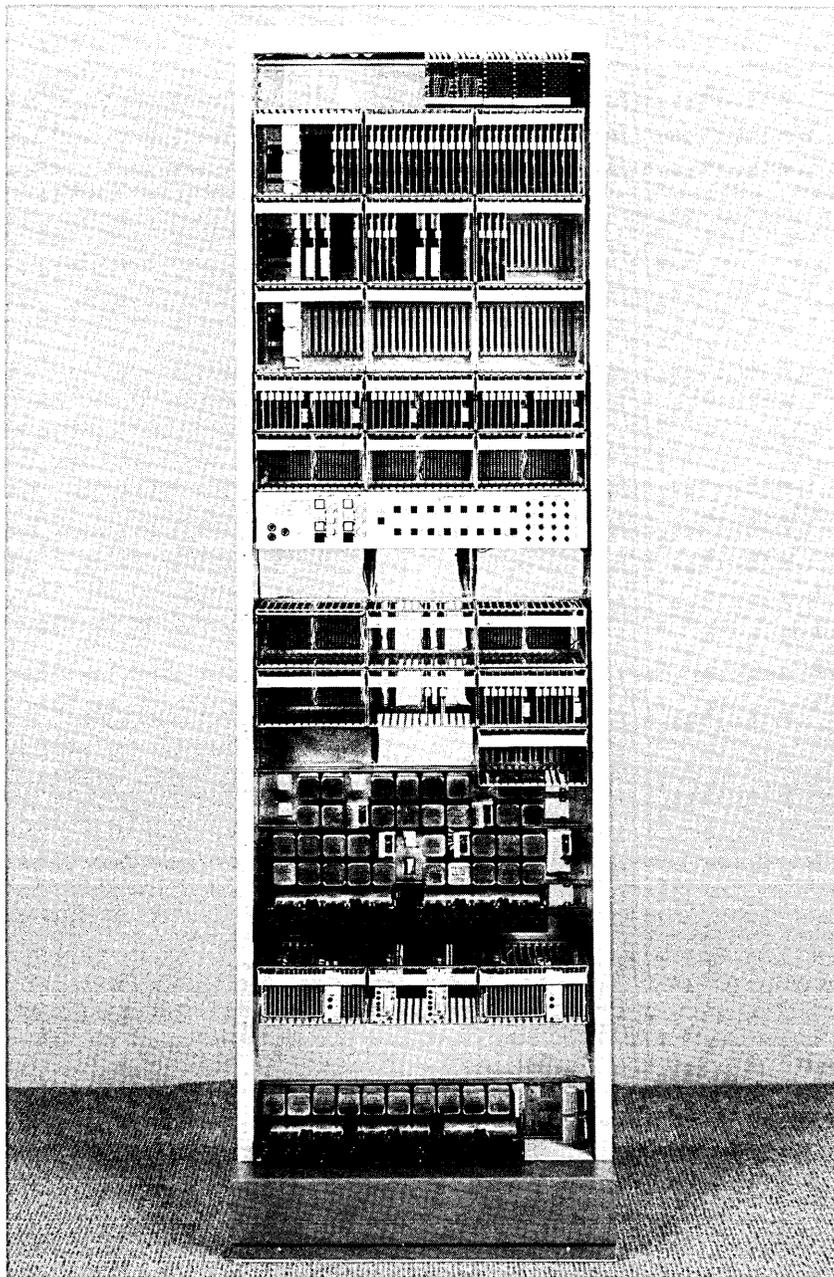
Fig. 11—Service circuit frame.

The control panel unit contains the various keys, jacks, lamps, and switches associated with maintenance and frame control functions. Each CDA is controlled individually.

The power converter unit contains +5, +6, and −6 V dc-to-dc converters and fuses for the +5 V distribution. These power units are pluggable for easy removal. A +5 V load fuse and a +5 V indicator fuse is provided for each service circuit.

The fuse panel unit contains −48 and +24 V fuses, alarm relays, and power control relays. The −48 volt is used to supply the dc/dc power units. The +24 V is used for bus drivers.

Even-numbered frames and odd-numbered frames are fused from separate power distribution frames.

Space for up to 16 coin-tone receivers is provided on all frames except the first frame of the subsystem, where the CDA test circuit unit replaces one of the coin-tone receivers. The coin-tone receivers are connected to their associated CDA circuits by plug-ended cables to facilitate growth and rearrangement due to changes in traffic patterns.

2.4.3 CDA transmission frame

Associated with each service circuit frame is a single-bay frame (see Fig. 12) containing voice frequency transmission equipment.

Growth and rearrangements are accomplished with pluggable apparatus.

2.4.4 Announcement store frame

Associated with each controller frame is an announcement store frame (see Fig. 3) that provides storage for the digitally encoded announcement segments.

The bus unit at the top of the store frame contains terminal strips for interconnecting cables from connecting circuits in the office. Transformers are furnished as part of this unit to connect to the TSPS processor store bus. Store buses are connectorized to facilitate growth.

As mentioned earlier, two memory modules are required for Automated Coin Toll Service. Additional memory modules up to a total of six may be added to provide storage for additional vocabulary words if required by future features.

III. ACKNOWLEDGMENTS
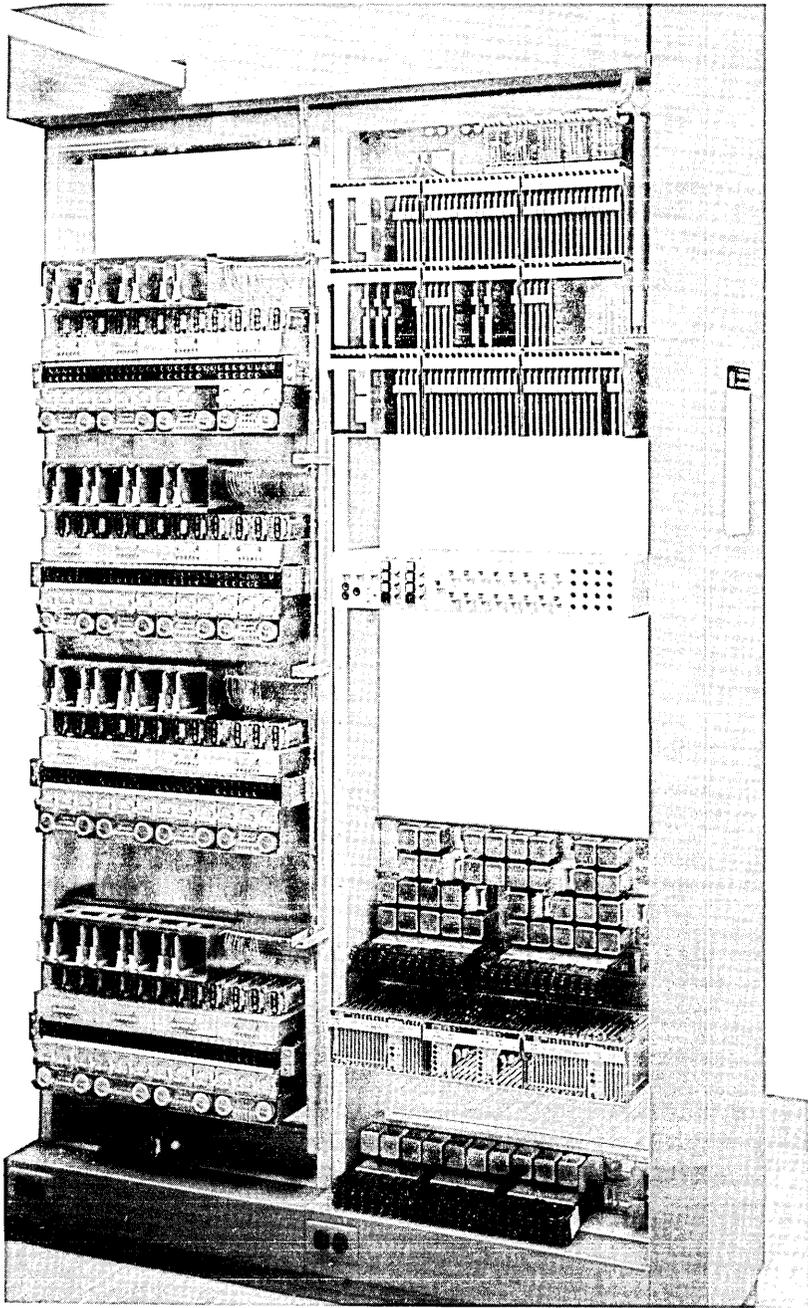
Fig. 12—Transmission frame.

M. Schmidt; for guidance and assistance in physical design, R. D. Garside, H. A. Hilsinger, and W. J. Proetta; for skillful electrical design and testing of SSAS circuits, J. O. Croswell, R. L. Grenzow, J. O. Hardy, D. C. Peterson, T. L. Roush, and B. G. Ruel.

REFERENCES

1. R. J. Caniff, "Signal Processing in *SLC*-40, A 40 Channel Rural Carrier Subscriber Carrier," International Conference on Communications, San Francisco, California, June 1975.
2. R. N. Battista, C. G. Morrison, and D. H. Nash, "Signaling System and Receiver for *TOUCH-TONE*® Calling," IEEE, Trans. Commun. Elec., March 1963, pgs. 9–17.

Traffic Service Position System No. 1:

Automated Coin Toll Service: Software

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(Manuscript received December 28, 1978)

The Traffic Service Position System (TSPS) No. 1 operational soft-ware for Automated Coin Toll Service provides the logic which controls the handling of coin-originated calls served by the system. The partitioning of responsibilities between the Station Signaling and the Announcement Subsystem (SSAS) are illustrated. The main-tenance philosophy, fault detection, diagnostics, and fault recovery aspects of the SSAS are described. The maintenance strategy is cen-tered on a multilevel fault detection scheme in which faults are analyzed and classified according to their degree of seriousness in affecting the SSAS operation.

I. OPERATIONAL SOFTWARE

Automated Coin Toll Service (ACTS) is a feature of the Traffic Service Position System.[1] A Station Signaling and Announcement Subsystem (SSAS) has been added to TSPS to detect and process coin deposits and to construct announcements for coin sent-paid toll cus-tomers.

The SSAS contains a programmable controller (a microprocessor), which has a Read Only Memory (ROM) for program and a Random Access Memory (RAM) for transient data. It also has a set of Coin Detection and Announcement circuits (CDAs). These circuits detect coin deposit signals from coin stations and decode digital speech phrases to produce analog announcements. The SSAS also has an Announcement Source and Distributor (ASD) which contains an an-nouncement memory with digitally encoded speech phrases (see Fig. 1). Commands to the SSAS are sent by the TSPS processor over the
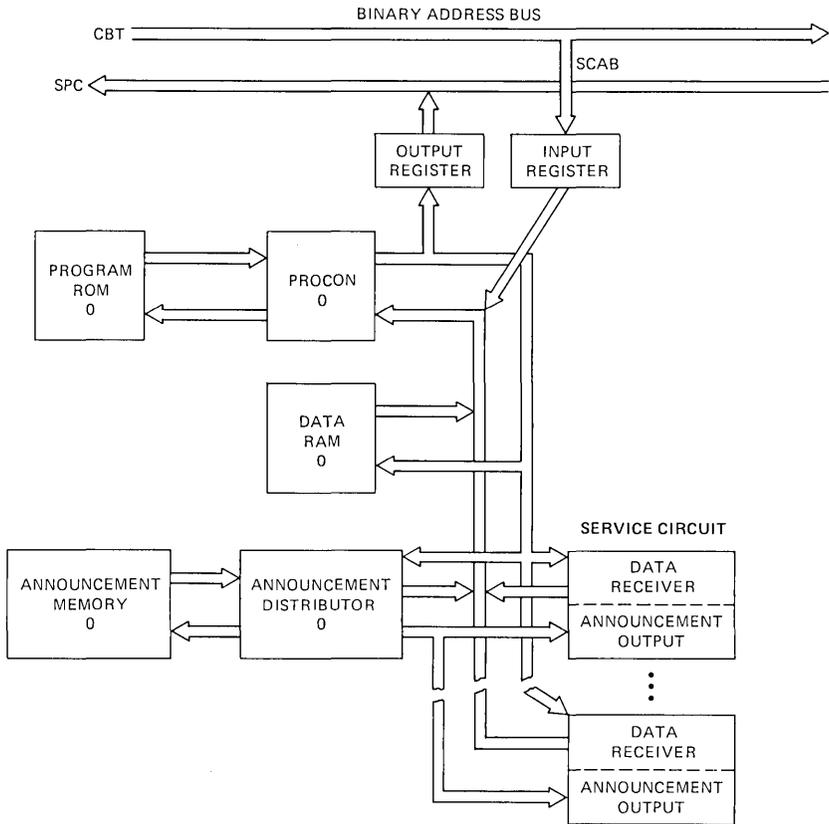
Fig. 1—SSAS configuration.

Peripheral Unit Address Bus (PUAB). Replies to the TSPS processor are sent over the Scan Answer Bus (SCAB).

1.2 Functional description of ACTS call processing

1.2.1 Initial call setup

When the TSPS call connections program* receives a report of an incoming trunk seizure† from the supervisory scan program, it establishes the required network connections for called digit and calling digit reception. (The latter is for Automatic Number Identification [ANI] offices.)

The ANI digit analysis program assumes control until reception of the calling party's number is completed.

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* This program runs on the TSPS main processor.
† The description that follows deals only with calls that originate on trunks on the base network. Calls that originate on the network of an RTA are also handled by the operational software but not described below.

When the calling party identification has been received, control is returned again to the call connection program. At this time, a general analysis is performed on the information obtained, and the call is marked as 0+, 1+, etc. The 1+ coin-originated calls are candidates for automated treatment. (Coin customers expecting to make deposits to pay for a station-to-station call will dial the call with a "1" prefix or no prefix.)

1.2.1.1 Initial ACTS processing. The next step in processing the call is to determine whether the call can be automated. This is done by a program in the main TSPS processor.

Conditions for Automation. 1+ calls that satisfy the following criteria are candidates for automation during the initial contact on the call.

(*i*) ACTS-Converted Trunk Group. The call must be on an ACTS-converted trunk group. Certain modifications are needed in the coin station to generate dual-frequency coin deposit tones which the Coin Detection and Announcement circuits can recognize. All coin stations served by a trunk group must be modified before any calls on that trunk group can be automated.

(*ii*) Machine Ratable. The call must be machine-ratable; i.e., TSPS must receive or have in office data sufficient rating information to calculate the charges due on a call.

(*iii*) Not a Postpay Coin Originating Station. The call must not be from a postpay station. Coins deposited at postpay coin stations cannot be returned. An operator must verify that the correct party or station has been reached before the customer makes any deposit.

(*iv*) Not a Large Charge Call. The call must have an initial charge less than a certain threshold. Coin station hoppers handle only limited numbers of coins (24 nickels, for example). Operating practices instruct operators to make partial collections for every two to three dollars deposited if the call has large charges. Large charge calls require multiple collections. Hence, an operator is required to verify called party answer before any coins are collected.

(*v*) Automatic Number Identification. The call must have successful Automatic Number Identification. If an ANI failure occurs or the call is Operator Number Identified (ONI), the call cannot be rated. An operator must key the calling number.

Coin deposit monitoring on calls that fail condition (*i*) is not automated but is handled by operators using current procedures. However, notification at the end of the initial period can be automated on all

coin calls, even if dual-frequency oscillators are not installed in the coin stations.

Calls that fail conditions (*ii*), (*iii*), or (*iv*), as well as person-paid, coin-originated calls (which are dialed as 0+ calls), seize a position for the required operator assistance. If the trunk group is ACTS-converted, a Coin Detection and Announcement circuit is attached to assist the operator in counting deposits. Subsequent deposit monitoring for overtime can be fully automated unless the large charge threshold is exceeded.

Calls that fail only condition (*v*) seize a position for the purpose of acquiring the calling number. After the number is keyed in by the operator, further handling of the call is automated.

If the above conditions for automation are met, the call connections program seizes an idle Peripheral Order Buffer (POB) and transfers control to the network control program which loads the POB with orders to establish a connection between the calling customer and a Coin Detection and Announcement circuit. If a CDA is not available, the call connections program seizes an idle POB and transfers control to the network control program which loads the POB with orders to establish a connection to both a position and an outpulsing circuit. The call is subsequently handled as a non-ACTS coin call.

SSAS Processing of Initial Deposit Requests. Processing in the SSAS begins when the Programmable Controller (PROCON) receives an initial deposit request command from the TSPS processor. The command is read by PROCON from the SSAS input registers. The command message includes the number of the CDA handling the call, the initial duration of the call, and the amount to be requested from the customer (see Fig. 2). For purposes of illustration, assume the charge is $1.15 and the initial period is three minutes.

The command field of the message is used as an index into a transfer table. The PROCON transfers to the address retrieved from the table. That program records the call data in the SSAS data RAM, sets the initial state indication for the call, and sends an output command to initialize the CDA circuit.

The PROCON next initiates scanning of the CDA circuit for coin deposits. The PROCON will continue scanning the CDA circuit at least once every 250 ms for the duration of the initial deposit phase of the call. The PROCON also instructs the SSAS announcement control cir-

|	19	17	13	12	8	7	0	
WORD 1		INITIAL PERIOD		COMMAND		CDA CIRCUIT NO.		IRA
WORD 2				12 9 CREDIT	8	CHARGES	0	IRB
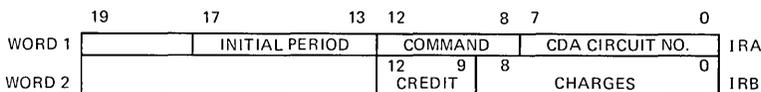
Fig. 2—Typical SSAS input message from TSPS processor. Message is in format as sent from TSPS processor (two 20-bit words).

cuitry to send the first segment of the appropriate announcement phrase to the CDA circuit. It sends subsequent commands for successive portions of the announcement every 512 ms. The announcement used for the call being described is:

"One dollar and fifteen cents,* please." (2-second pause) "Please deposit one dollar and fifteen cents* for the first three minutes."

If the customer deposits during the announcement, the CDA circuit instantly inhibits the announcement. When the PROCON scans the CDA circuit and recognizes the deposit, it ceases sending further announcements, adds the value of the coin deposit to the previous amount deposited, and compares the total with the amount due. Assuming a sufficient deposit has not been made, the PROCON begins timing. If the customer fails to deposit within *five or six seconds*, a prompting announcement is provided indicating the amount still to be deposited. For example, if the customer deposits three quarters in the above example and then stops, the prompt is:

"Please deposit forty cents more."

If the initial deposit announcement completes without a deposit, timing will begin at that point. If the customer has made no deposits and a time-out occurs, the announcement wording for the prompt is:

"Please deposit one dollar and fifteen cents."

Each deposit made causes the PROCON to reset its software intercoin timing register for the call.

The PROCON will report the final results of the initial deposit request to the TSPS processor by loading a message into the SSAS output FIFO buffer (see formats in Fig. 3). There are basically three situations possible.

(*i*) If the customer has failed to deposit within five to six seconds after a prompt, the PROCON sends a reply (Fig. 3, format B) to the TSPS processor indicating this fact so an operator can be connected to provide assistance.

(*ii*) If the customer deposits the exact amount requested, the PROCON sends reply format A which contains the amount deposited.

(*iii*) If the customer overdeposits by using too large a denomination coin, the PROCON sends reply format A. (The TSPS processor

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* The announcement format varies slightly, depending on whether the charge involves a dollar amount, a cents amount, or both.

	15	14	8	7	0

FORMAT A: | 1 | AMOUNT DEPOSITED | CDA CIRCUIT NO. |

FORMAT B: | 0 | REPLY CODE | CDA CIRCUIT NO. |
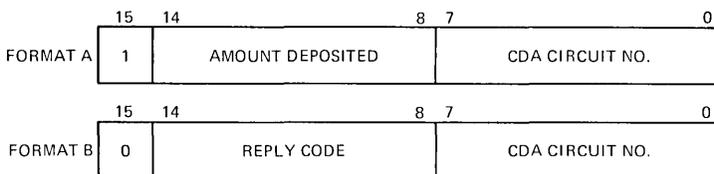
Fig. 3—Formats of SSAS output FIFO buffer.

recognizes the overdeposit and records a credit towards over-
time.)

The PROCON acknowledges the latter two cases above by initiating
announcements. If the exact amount is deposited, the announcement
is:

"Thank you."

If an overdeposit has been made (for example, $1.25 on the $1.15
call described above), the announcement is:

"Thank you, you have ten cents credit towards overtime."

The PROCON continues to scan the CDA for further deposits until the
acknowledging announcement is completed and sends a final deposit
report to the TSPS processor at the end of the announcement. (This
ensures credit for a belated deposit.) Finally, the PROCON places the
CDA and the associated call memory in the SSAS data RAM in the idle
state. The PROCON performs no further action on the CDA until a new
command is received from the TSPS processor.

At any time during the processing described above, the TSPS proces-
sor can send a special command which causes the PROCON to idle the
CDA circuit and associated call processing memory. (One example of
this happening is if the customer hangs up.)

Successful Initial Seizure. Upon receipt of the reply from SSAS
indicating an exact deposit or overdeposit, the call is processed to
completion. The call connections program seizes an idle POB and
transfers control to the network control program which loads the POB
with orders to connect an outpulsing circuit. If an outpulsing circuit is
not available, the call connections program queues until the circuit is
available. The call connections program loads the orders to perform
the appropriate relay operations required to complete the connection
and activates the POB. Upon successful POB completion, control is
returned to the call connections program where the POB is idled. The
outpulser loading routine is called next. It loads the digits to be

outpulsed in an outpulsing register and activates sender-attached scanning for the receipt of a sender-attached signal from the toll office. Outpulsing of the called number to that toll office proceeds as described in Ref. 2, page 2658 ff.

Receipt of called party answer and call timing also follow the description in Ref. 2.

Operator Assistance on Automated Initial Seizure. If the customer fails to deposit in response to prompting by the SSAS or flashes the switchhook* to acquire operator assistance, the customer will be connected to an operator. This section discusses the display presented to the operator, the operator actions, and potential race conditions.

If the call must queue for a position, it is given "recall priority" to minimize customer delay. The Coin Detection and Announcement circuit is connected to the calling customer during the queuing interval. If the call is being sent to a position because of a time-out and the customer subsequently satisfies or exceeds the charges while queuing for a position, the SSAS informs the TSPS processor, the call is removed from the position queue, and outpulsing is initiated without operator assistance. When the call reaches the position, the following keys and lamps on the operator console (see Fig. 4) are lit steadily.

The loop access key (ACS)
The appropriate supervision lamps (CLD), (CLG)
The station coin lamp (STA)
The AMA station-paid key (PAID)
The release forward key (FWD)

The lighting of the AMA station-paid key and the release forward key indicates to the operator that an ACTS time-out or a customer switchhook flash has occurred during an ACTS initial contact.

In addition to the above, an ACTS underdeposit display is given to the operator (see Fig. 5). The "charge-minute" designation strip is lit steadily and the numeric field contains, from left to right, up to three digits for charges due, one digit for the initial period and up to three digits for the amount due.

While the call is attached to a position, the operator assists the customer in making a full deposit. The operator must announce the amount due (the right-hand quantity) in the numeric field. The CDA circuit monitors and counts the coin deposits. The numeric display is not automatically updated with each coin deposit. However, the operator can update the display by using the charge and minutes (CHG-

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* For a time-out, the SSAS indicates the request for an operator by a message. For a flash, the TSPS processor initiates the request.

Fig. 4—100B traffic service position key shelf.

ACTS — UNDER DEPOSIT
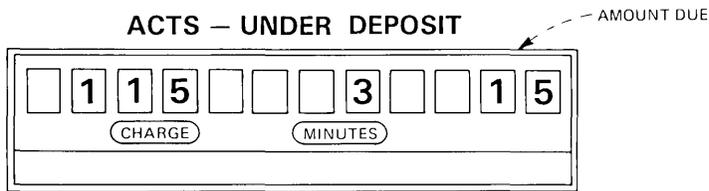
Fig. 5—TSPS No. 1 console numeric display.

MIN) key. (The SSAS will be interrogated for the current amount deposited and the appropriate display presented.)

When the SSAS recognizes that the deposit request is satisfied, the TSPS processor is informed. The forward number is outpulsed and the correct display is presented to the operator (see Fig. 6).

The operator receives several indications that the deposit is satisfied: outpulsing occurs, the amount due display changes to zero, the release forward key darkens, and the start key lights during outpulsing.

After acknowledging the deposit, the operator depresses the start timing* and position release keys.

At position release, the TSPS processor requests the amount detected by the CDA circuit. Upon receipt of the report, the CDA circuit is disconnected from the call. This final report accounts for all money deposited (while the CDA was connected to the call) so no late deposits are missed.

If an overdeposit occurs, the numeric display is changed to an overdeposit display (see Fig. 7). This display has a flashing "charge-minutes" designation strip and a numeric display of zero in the charge field, blanks in the minutes field, and two digits having the overdeposit. The operator informs the customer that credit will be given towards subsequent overtime charges on the call, depress start timing, and position release. On subsequent deposit requests, the overdeposit is automatically subtracted from the charges due.

1.2.1.2 Coin notification. At the end of the initial period, coin sent-paid customers are notified. With ACTS, this no longer requires an operator. The description below applies to coin sent-paid calls from both ACTS and non-ACTS converted stations.

TSPS Processing of Coin Notification. When a call reaches the talking state, it is under the control of the disconnect program. The call is placed on a timing list when the called answer has been established. A time-out occurs 7 seconds prior to the end of the initial period. Subsequent to this time-out, a coin collect sequence† occurs

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* Timing on the call is initiated by the TSPS processor only if the called customer answers.

† The coin collect sequence does not occur on postpay coin stations.

ACTS — CORRECT DEPOSIT

— AMOUNT DUE

| | 1 | 1 | 5 | | | | 3 | | | 0 | 0 |

CHARGE   MINUTES

Fig. 6—TSPS No. 1 console numeric display.

ACTS — OVER DEPOSIT

—CREDIT

| | 0 | 0 | 0 | | | | | | | 1 | 0 |

"CHARGE"   "MINUTES"   "FLASHING"
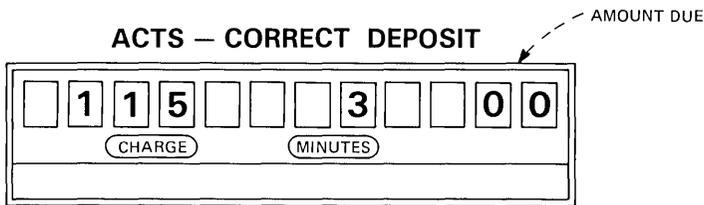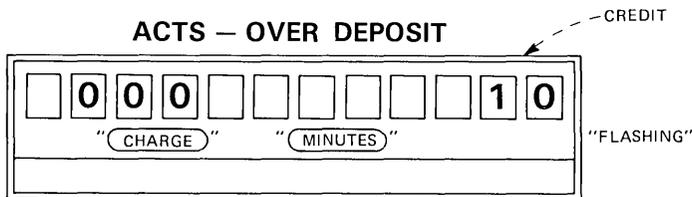
Fig. 7—TSPS No. 1 console numeric display.

and the call is returned to the timing list for the remainder of the initial period.

At the end of the initial period, the disconnect program seizes an idle Peripheral Order Buffer (POB) and transfers control to the network control program which loads the POB with orders to establish a connection between the calling customer and a Coin Detection and Announcement circuit.

SSAS Processing of Coin Notification. When the PROCON receives an input message requesting an end-of-initial-period notification on a coin call, the data accompanying this command are the CDA number and the time of the initial period. In response to this command, the PROCON directs the SSAS announcement control circuitry to give the following announcement:

"Three minutes has ended, please signal when through."

(A three-minute initial period is used for this illustration.) No coin scanning is performed, as no deposits are expected. After the announcement, the CDA hardware and software are idled and an announcement complete reply code (Fig. 3, format B) is sent to the TSPS processor.

1.2.1.3 Charges due seizures. The ACTS procedures for fully automating overtime charges due seizures on coin-paid calls are presented in this section.

Conditions for Automation. The SSAS can fully automate overtime charges due seizures on coin-paid calls on an ACTS-converted trunk group even if the initial contact requires an operator. Since the call is

already rated, no rating or calling number identification (ANI) restrictions apply to overtime seizures. Furthermore, charges due seizures for postpay calls are handled in the same manner as calls from other coin stations. However, there is one additional restriction on charge due seizures. All previous deposit request seizures (either initial contact or charges due) must have been successfully monitored by a CDA circuit. Successful monitoring implies that CDA circuit blocking did not occur and that the CDA circuit did not malfunction. This condition ensures that overdeposit credits are not lost. (If a seizure is not monitored successfully and an overdeposit occurs, the credit is not recorded.) If successful monitoring does not occur, the call is processed by an operator using current practices. In summary, the conditions for automating overtime charge due seizures are:

   (i) The calling station is on an ACTS-converted trunk group.
  (ii) The charges do not exceed the large charge threshold* (see Section 1.2.1.1).
 (iii) All previous seizures were successfully monitored.
  (iv) CDA must be available.

If a call continues for a certain number of overtime intervals (usually 10) and all the conditions for automation are satisfied, the SSAS automates the changes in seizure. Additional intermediate deposits are requested at successive specified overtime intervals until the call terminates. Then the SSAS automates the final charges due seizure at the end of the call. The collection sequences for end-of-call deposits and intermediate deposits are essentially the same. Furthermore, these collection sequences are very similar to those used for the initial contact on station (1+) calls (Section 1.2.1).

With only a momentary interruption to the conversation path, TSPS connects an idle CDA circuit to the call. TSPS informs the SSAS of the amount due, the number of minutes which have elapsed, the CDA circuit being used, and that it is a charge due seizure.

SSAS Processing of Overtime Deposits. SSAS deals with the two overtime situations (end of call and intermediate overtime deposits) in a similar fashion. After receiving the command from the TSPS processor, the PROCON processes the call in a fashion similar to the initial deposit case and the reports returned to TSPS are also similar. However, the TSPS sends the amount of credit from previous deposits (if any) and the time sent is the elapsed overtime talked (in minutes), not the initial period. The announcement wording is also different. Assume that the call has progressed for five 25-cent overtime periods of two

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* The office data provided for the initial-period large-charge threshold is also used to specify the overtime large-charge threshold.

minutes duration each and that the customer had no credit. The announcement would be as follows:

(Alerting tone) "Please deposit one dollar and twenty-five cents." (0.5-second pause) "One dollar and twenty-five cents for the past ten minutes."

If the customer had a ten-cent credit, for example, the announcement is altered.

(Alerting tone) "One dollar and fifteen cents please." (2-second pause) "You have ten cents credit. Please deposit one dollar and fifteen cents more for the past ten minutes."

In the intermediate overtime deposit case, both customers are on the call and intend to continue talking. They both can hear the announcement and talk during the deposit interval. In the end-of-call overtime case, only the calling customer is on the call.

As with the initial deposit situation, if a customer stops depositing coins, a prompting announcement is given. Failure to respond to this announcement results in a report to TSPS requesting an operator.

Operator Assistance. If the call times out or the customer flashes the coin station switchhook during the charges due phase of a call, an operator is connected to the call. The following keys and lamps on the operator's console are lit steadily:

  (*i*) The loop access key (ACS).
 (*ii*) The appropriate supervision lamps (CLG, CLD).
(*iii*) The appropriate coin lamp (STA, 0+, or Dial 0).
 (*iv*) The appropriate AMA key (station paid or person paid).
  (*v*) The charges due (CHG-DUE) lamp.

These are the same keys and lamps lit by TSPS on charges due seizures prior to ACTS. In addition to these keys and lamps, the ACTS underdeposit display, previously described for initial contact, is lit on the operator's console. The appearance of the ACTS underdeposit display indicates two things to the operator. First, a CDA circuit is attached to the call to monitor the deposits. Second, if the customer overdeposited on a previous seizure, the charges displayed have been corrected by the amount of credit. (Note that, on non-ACTS charge due seizures, the operator must subtract any credit claimed by the customer from the charges displayed.)

The operator assists the customer until a full deposit is received. When the SSAS recognizes that the deposit request is satisfied, the

correct deposit display is given. The operator thanks the customer and depresses position release. Upon releasing the position, TSPS requests the amount detected by the CDA circuit. After TSPS receives this information from the SSAS, the CDA circuit is disconnected.

If the customer overdeposits during an overtime collection with an operator attached, the overdeposit display is lit on the operator's console. If this is a charges due seizure for intermediate collections, the operator should inform the customer that credit will be given on subsequent overtime charges. If the overdeposit occurs at the end of the call, the operator should handle the disposition of the overdeposit in accordance with current operator practices.

If the calling customer hangs up during the ACTS charge due announcement sequence, or the calling customer leaves the phone off-hook, the operator should try to reach the calling customer, if necessary, by ringing back against off-hook. The operator may need to wait for the customer to return. If the operator is unable to obtain full payment for the call, the operator keys a walkaway trouble number. A traffic counter is pegged, and a special bit and the amount of shortage is recorded on the AMA tape.

Even after the decision is made to go to an operator, the CDA circuit still monitors coin deposits. If the deposit is satisfied before the Peripheral Order Buffer (POB) which connects the position is activated, the position seizure is aborted. The SSAS acknowledges the deposit, and the call is released.

If the position is seized and then the deposit is satisfied, the SSAS does not acknowledge the deposit. When the operator's numeric display is lit, it shows (or may quickly change to show) that the deposit is satisfied. The operator should acknowledge the deposit and release the call.

1.2.2 Non-coin features

The announcement without coin detection mode of operation is used to provide announcements for time and charges quotations and notification on calls other than coin sent paid. A different command is used in each case to select a different announcement.

1.2.3 SSAS as a coin detector

The PROCON is also programmed to provide a mode of operation in which it gives no announcements but does monitor for coin deposits. This is used on operator-handled ACTS calls. In this mode, the PROCON informs the TSPS processor when the required deposit or an overdeposit has been made. If the operator collects or returns coins while a call is in this state, TSPS informs the SSAS so the PROCON can appropriately update the amount deposited and the amount due in its data RAM. If

the operator requests that the amount deposited be displayed, the SSAS will transmit that amount to the TSPS processor in response to the appropriate command.

1.2.4 Coin station maintenance and administrative features

One unique aspect of ACTS operation is that inband signals (the coin deposit tones) are transmitted directly from the station through to the TSPS over the voice path. Two special features were developed that are related to coin tone signaling. First, a coin station test capability was developed which allows a craftsperson at the station to test that coin deposits for that station can be detected at the TSPS. Second, a precutover mode of operation was devised to help detect stations that have not been converted to be compatible with ACTS. These features are described below.

Coin station test call. After the craftsperson has performed the usual coin station tests, the TSPS is accessed by dialing a special test code. When TSPS receives this number, it connects the call to an idle CDA and sends a message to the SSAS with a command code indicating that this is a station test call. The remainder of the call is handled by the SSAS except that TSPS supervises the call. If the craftsperson goes on-hook, the TSPS aborts the call by sending a command to SSAS. Also, TSPS will return coins on request from the SSAS.

When the PROCON receives the station test call command, it initializes the CDA, begins coin scanning, and initiates the following announcement:

"Coin Test." (1-second pause) "Please deposit nickel."

If the craftsperson deposits a nickel, the announcement,

"Nickel"

is given, acknowledging the deposit. A dime and quarter deposit are also requested and acknowledged. Then, the craftsperson may make additional deposits which will be acknowledged if received correctly. If no coin is deposited for about six seconds, the deposit request is repeated. If the wrong coin is deposited, a coin return is requested by the PROCON and the test is repeated. If repeated requests for deposits are not satisfied or a total of two minutes elapses on the call, the PROCON issues instructions for the announcement.

"Test has ended."

and reports the time-out to the TSPS, which gives a coin return and disconnects the call.

1.3 PROCON program design

The PROCON has relatively high processing capacity. It has a relatively powerful instruction set which is largely at the assembly language level rather than the microprogramming level, and it manipulates a 16-bit word. It uses a paged program memory and can execute instructions within a page in arbitrary, fixed order. (The next inter-page address (displacement) is specified in each 24-bit instruction.) Because of this characteristic, care must be exercised in relocating code to avoid improperly crossing a page boundary. (Such errors are detected during compilation.)

The PROCON's 16K program memory limit requires that the programs be very compact. While an attempt was made to use modern, structured, design and documentation techniques, the limited memory size caused compromises in some areas. (The SSAS application requires a far larger program than most PROCON applications.)

Multiprogramming was achieved by storing all call- (process) related information in the data RAM. Each program retrieves all data from that memory when it begins processing a new call. Each program is a pure process stored in ROM (i.e., the program contains no variable data and cannot alter itself).

The PROCON has very extensive self-checking features. In addition to a variety of parity checks (including next address parity), the arithmetic and logic circuits are duplicated and checked by matching.

1.3.1 PROCON program administration and design standards

Several designers developed separate programs which were integrated into one large program. Loading was accomplished by using a linkage editor and a common file of symbols and macros. All symbols (except labels) and all macros were defined in the common file. No numerical references were permitted, and input/output control designation symbols were keyed to the circuit drawing names for the same leads. Thorough prologue comments were required for each routine. Standard labels and standard symbolic designations and usage for all PROCON internal registers were agreed upon by all programmers.

1.3.2 PROCON active monitor

The basic program loop for the PROCON in the active SSAS (i.e., the SSAS which is processing calls) is called the active monitor. The PROCON executes this program while looking for tasks to perform. In this loop, the PROCON first makes some maintenance checks and then reads a clock to determine if a new 512-ms period has begun. The 512-ms interval is called a base period. Its length is keyed to the length of an announcement speech segment. If a new base period has begun, a

special flag is marked in the system status register.* The PROCON then scans for a message from the TSPS processor. If such a message has arrived, it records the data in the appropriate RAM area.

The PROCON then begins a loop in which each CDA is processed. Each CDA has a dedicated eight-word call register associated with it. (Figure 8 is a typical CDA register layout.) First, the PROCON reads the address of the program which should process the call. This address, which also defines the state of the call, is called a Progress Mark (PM). If the PM is zero, the CDA is idle or unequipped, so no action is taken. A typical PM program is the program which scans a CDA for coins. The PM is stored as a page number and a displacement within the page. The active monitor transfers to the PM routine. If the PM routine determines that the call requires timing, it checks the new base period flag. If that flag is set, the required timing counter is updated.

When the PM program returns to the active monitor, the monitor checks the new base period flag. If that flag is set, all timing counters for the CDA are updated as required and a new announcement segment is selected. (The announcement processing is described in Section 1.3.4.) After the announcement program is completed, the monitor processes the next CDA. When all CDAs have been processed, the monitor clears the new base period bit, checks for various maintenance tasks, and then begins the main loop again.

1.3.3 Announcement store layout

Each announcement speech segment consists of 16,000 bits of digital data stored in 400 consecutive announcement store locations. Each location contains 40 bits of data. Decoded at a 31,250 bits/second rate, this corresponds to 512 ms of speech. For programming ease and circuit design convenience, all segments must begin at an address which is a multiple of 16. Most words used fit in one segment (for example, the numbers "one" to "ten"). However, several words or phrases require two segments (for example, the word "eleven" or the phrase "please deposit"). A few phrases require three segments (for example, the phrase "please signal when through").

Because the announcement circuitry bit-synchronizes segments, two or more segments can be blended together with no loss in quality. Therefore, words can be split between 512-ms segments to achieve the best cadence of speech.

Successive segments constituting 1-second and 1.5-second phrases need not occupy consecutive announcement store addresses. However, these segments generally must be used together. In contrast, suffix segments used for compound numbers may be combined with a variety

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* One of the PROCON general registers was reserved for critical status indicators.

15		8	5		0	
PROGRESS MARK PAGE			PM DISPLACEMENT			WORD 0
ANNOUNCEMENT PAGE			ANN. DISPLACEMENT			WORD 1
13 COIN TIMING		8	6 AMOUNT DEPOSITED		0	WORD 2
15 12 CREDIT		8	AMOUNT DUE			WORD 3
15 OVERALL TIMING		8	4 TIME		0	WORD 4
				1 T	0 C	WORD 5
CDA PARTIAL REPLIES						WORD 6
						WORD 7

NOTES:

1. PM = PROGRESS MARK
2. AMOUNT DEPOSITED, AMOUNT DUE AND CREDIT IN NUMBER OF EQUIVALENT NICKELS
3. C—TYPE OF CDA
4. T—TRUNK TYPE (2 WIRE = 0,4 WIRE = 1)

Fig. 8—CDA data RAM call register.

of other segments. For example, the suffix "-teen" can be combined with the syllables "thir-," "four-," etc. to form the numbers "thirteen," "fourteen," etc. with minimal use of memory. Similarly, the units place suffixes "-one," "-two," etc. can be combined with the numbers "twenty," "thirty," etc. to form the full required set of numbers (e.g., twenty-one, twenty-two, thirty-one, thirty-two).

Several words are duplicated in the announcement store so that both neutral and falling inflections are available. The falling inflections are used only at the ends of sentences, while the neutral inflections are used elsewhere.

In total, about 80 speech segments 512 ms in length are required for ACTS call handling. About 15 more are required for maintenance purposes.

1.3.4 Announcement table structures

Two major announcement tables are stored in the PROCON ROM. The first is simply a table of addresses. Reading this table using the speech segment number as an index provides the address of the first announcement store location containing the data for that speech segment.

The second table is more complex, as it controls the sequencing of announcement segments to form sentences. The logic for this process is embedded largely in this table rather than the program code. This makes debugging easier and also simplifies the process of adding new announcements. The table consists of program addresses for generalized routines dealing with each step of the announcement. The address

of the current table entry is stored in the second word of the CDA register (see Figure 8). Each announcement routine must decide what speech segment is to be reproduced next and also update the table address in the CDA register. The major situations the various routines must deal with are demonstrated by the following example.

The structure of a portion of a typical announcement is represented schematically in Fig. 9. This is the end of the time-and-charges announcement used for noncoin calls. A typical example of this announcement follows.

"The charges are one dollar and twenty cents plus tax for seven minutes."

The three major types of announcement routines are each involved in this announcement. One type of routine simply sequences speech segments in fixed order (for example, the words "plus tax for"). The second type of routine chooses a word or sequence of words ("one minute" versus "M minutes") based on the value of a parameter (whether M is one or greater than one). The third type of routine translates a parameter (M) into a speech segment (for example, the number "seven") or a series of segments (for example, "twenty-one"). This last program is a subroutine since the action to assemble the number is the same whether it represents a dollar amount, a cents amount, or a time period.

II. MAINTENANCE

2.1 Overview

2.1.1 TSPS maintenance requirements

In TSPS, as in other Bell System electronic switching systems, the maintenance strategy is based on duplicating vital hardware units[3] and providing hardware checking circuits for other units, using signals to indicate the successful execution of orders and using programs to test the state of the hardware, to detect faults, and to diagnose trouble.

TSPS provides fault recognition and diagnostic programs for all major circuit elements. The purpose of the fault recognition programs is to quickly detect faulty equipment units and, if necessary, remove them from service. Hardware checking circuits are used for trouble detection
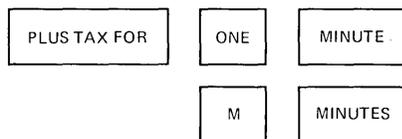
Fig. 9—Typical portion of an announcement phrase.

during operation. When a trouble detection circuit identifies a serious problem in the system, it notifies an interrupt circuit. The interrupt circuit immediately stops operational program processing and transfers control to a fault recognition program associated with the particular trouble indication. The functions of the fault recognition programs are to distinguish nonrepeating troubles (errors) from repeating troubles (faults), and, in the case of faults, to quickly establish an operational system configuration. This is generally done by switching out the faulty unit. When the fault recognition process is completed, operational program processing is resumed at the point of interruption.

Fault recognition is the highest priority function in a real-time system like TSPS. It is of the utmost importance to high system reliability that minimum time be taken away from the operational processing functions because of faulty circuits.

Once the faulty circuit has been taken out of service by the fault recognition program and the system brought back to an operational configuration, diagnostic programs are called in to test the out-of-service unit to isolate the trouble to a small number of circuit packs. A diagnostic program is normally broken into logic testing entities called subphases or phases so that a series of rigorous tests can be performed on the out-of-service circuit unit. Depending on the outcome (pass-fail) of each test, a trouble-locating number is printed on the maintenance teletypewriter. This trouble-locating number is used by the maintenance personnel to reference a trouble-locating manual to isolate the particular fault involved.

2.1.2 SSAS maintenance requirements and anticipated reliability

SSAS reliability and maintainability objectives are based on the fact that a significant part of TSPS traffic is served by the SSAS. The objectives are

(*i*) An average of about one SSAS outage in 10 years.
(*ii*) An average repair time of about 2 hours.

The maintenance plan for SSAS impacts on the reliability objective in three major areas. First, it is necessary to provide fault detection mechanisms (primarily hardware checks) so all failures can be detected rapidly. Second, provisions must be made to minimize the interruption of call processing once a failure is detected, with few or no calls lost. Third, sufficient circuitry must be provided to obtain diagnostic resolution to hold repair time to the 2-hour average as specified above.

The SSAS maintenance strategy relies on a multilevel fault detection scheme in which faults are classified according to their impact on the SSAS operation. A fault that does not affect normal operation of the

SSAS is considered "tolerable." An SSAS side with this type of fault may continue to perform its normal function adequately as long as it is required to do so. As an example, all single bit failures in the SSAS semiconductor announcement memory are tolerated, since they would have very little effect upon the quality of the speech. By using a maintenance strategy that permits an SSAS side to be used with certain "tolerable" faults, the SSAS reliability is further enhanced.

To verify that the SSAS design meets the reliability objectives, a reliability estimate was made by classifying and counting the boards on the SSAS side. The failure rate for each board type was calculated. The failure rate determines the Mean Time Between Failure (MTBF) of an unduplicated SSAS side. The Estimated Downtime (EDT) for the duplicated system was then calculated with the assumption that the mean time to repair for one side down and both sides down are identical. This is a valid assumption because the diagnosis of all critical circuits in SSAS can be done on each side independently. Plugging necessary parameters into the appropriate reliability model showed that the above reliability objectives are well satisfied.

2.2 Announcement Store Maintenance

2.2.1 SPC bus and store switch

The Stored Program Control No. 1A (SPC 1A) is the TSPS main processor.[4] The SPC memory is used for both programs and data. It is partitioned into a maximum of 24 duplicated stores. Each store is permanently assigned to one of the two SPC store buses. An SPC store can be equipped with a piggyback twistor (PBT) or semiconductor memory. Two sequential or complimentary name codes are assigned for an SPC store when equipped with semiconductor memory and one name code when equipped with PBT. The name code serves to identify the stores for addressing purposes. A semiconductor store consists of a semiconductor memory module and its associated semiconductor memory controller, shared by all modules in the same memory frame. The SPC store is the maintainable unit of SPC memory; i.e., it can be removed from or restored to service, diagnosed, and updated with the contents of its duplicate.

The SSAS announcement memory is used to store digitized announcements. An Announcement Store Frame (ASF) is permanently assigned to each side of each SSAS. The SSAS ASF consists of an announcement memory controller and up to six announcement memory modules. To simplify development effort and to take advantage of the memory loading facilities and diagnostic software of the SPC, the SPC semiconductor store frame with a second access port is used as the announcement store frame. This is accomplished by placing a switch on the announcement memory which allows the memory to be connected to

either the SSAS side or the SPC store bus. Furthermore, to reserve the maximum number of memory name codes for the SPC store, all SPC memory access operations use odd parity name codes while all announcement memory access operations use even parity name codes.

Under the normal mode of operation, the switch is set to the SSAS side so that access to the announcement memory can be performed. In the SPC direct access mode, the switch is set to the SPC side so that loading from the Program Tape Unit (PTU) and diagnosing by the SPC can be accomplished. More discussion on loading and diagnostic operations is presented in a later section.

2.2.2 The choice of announcement memory

To handle all TSPS station-paid coin call announcements as well as time and charge quotations for noncoin calls, it was calculated in 1974 that announcement capacity equivalent to about 80 half-second words would be needed. An ultimate memory capacity of 200 to 400 half-second words was forecast at that time if vocabulary for future features as well as space for other TSPS announcements were considered.

A number of storage media were examined for the announcement memory. After some consideration, it was decided that with minor modifications the semiconductor memory used for the SPC 1A store would also be suitable for the SSAS announcement store. This choice of the announcement memory would provide flexibility in areas such as future vocabulary growth and vocabulary reload in the field from a magnetic tape. It was also estimated that most hardware and maintenance software designed for the SPC 1A store could also be applied to the announcement store with only a modest amount of effort.

2.2.3 Diagnostic implementation

The SPC store diagnostic programs were modified to be used for the SSAS announcement store diagnostic. Major objectives for the announcement store diagnostic implementation were specified as follows:

(*i*) Circuits common to both designs to be tested by existing SPC semiconductor memory diagnostic programs.
(*ii*) New announcement store circuits to be tested by the SSAS controller diagnostic.
(*iii*) Same Trouble Locating Manual (TLM) to be used for SPC and SSAS announcement stores.
(*iv*) Similar TTY input/output messages.

Several diagnostic characteristics are common for the SPC and announcement store diagnostic programs: the basic diagnostic unit is a controller and one memory module, seven diagnostic phases are in

the program, the diagnostic terminates on early detection of errors, there is a special bus configuration for increased fault detection, and finally, there are automatic exercise tests for all 32K words. For these common areas, existing SPC store diagnostic programs were applied to the announcement store with only very modest modifications.

On the other hand, some diagnostic characteristics pertaining only to the SSAS announcement store must be added to the existing store diagnostic programs. First, the announcement store has to be switched onto the standby SPC store bus before it can be diagnosed. Second, since during normal operations, the PROCON and ASD circuits in the SSAS controller control the operation of the announcement store, they must be stopped during SPC diagnostic tests. Third, the SSAS controller and memory modules use even parity names while the SPC store uses odd parity names; consequently, diagnostic programs must be capable of distinguishing these two cases and proceeding accordingly.

2.2.4 Loading store from program tape unit

To save development effort, the SPC program used to load from the Program Tape Unit (PTU),[4] compare with PTU tape, and dump the memory contents of the SPC stores to a PTU tape is used to perform the same functions for the SSAS announcement stores. However, since there are some significant differences regarding tape format, loading procedures, and priority levels between the SPC stores and the announcement stores, some changes were made in the PTU program to extend its capabilities.

The requirements for the handling of the tape unit are as follows:

(i) The announcement information should be separate from office data and generic programs. A separate tape containing only announcement data should be used for announcement stores.
(ii) For the load operation, the craftsperson must force one SPC bus active, simplex, before using the program to access the announcement stores on the other bus.
(iii) The announcement tape header should be modified to distinguish it from an SPC tape.
(iv) SPC reliability should be given the highest priority. The announcement store should not be accessed if the SPC is not able to run full duplex with all stores operational.
(v) Changes must be made to minimize SPC downtime resulting from undetected SSAS store faults.

With these requirements in mind, the craftsperson is instructed not to use the program to access the announcement stores if the SPC cannot run full duplex with all stores operational. With the SPC fully operational, one bus may safely be forced active for the load operation,

thus placing the system in the simplex mode. This choice of which bus to force active must be made such that the standby SPC bus will correspond to the SSAS side requiring PTU actions. This procedure ensures that the announcement stores will never be placed on the active SPC bus. Following this line of conservatism, the announcement stores are normally switched off the standby SPC bus and are connected just prior to a read or write instruction. After this instruction is completed, the stores are removed from the bus.

The SSAS side to be accessed must first be placed in the out-of-service or unavailable state for the compare or dump option. If the operation is to load an SSAS announcement store with data from tape, the SSAS side must be in the unavailable state. This state will not allow SSAS side switching if a fault should be detected on the active side.

2.3 SSAS fault recovery

2.3.1 PROCON detected and reported faults

SSAS fault recovery strategy is based on a fault detection scheme which uses both the SPC and the programmable controller (PROCON) to detect various faults associated with the SSAS hardware. Faults detected by PROCON are reported to SPC. The decision to choose one method or the other was based on the following considerations.

(*i*) SSAS faults, particularly those with serious impacts on call processing, should be detected as quickly as possible.

(*ii*) SPC routine processing time required for detecting SSAS faults should be kept as small as possible.

(*iii*) PROCON should not be responsible for detecting those faults which could affect its integrity or its ability to communicate with the SPC.

Those faults which are detected by PROCON are analyzed before being reported to SPC. PROCON has the capability to analyze available data and reinterrogate appropriate maintenance registers. If failures are indicated, the result of analysis and reinterrogation are sent to the SPC. The reports sent by PROCON are analyzed by the SPC and, if necessary, appropriate commands are sent to PROCON to prevent it from flooding the SPC with unnecessary information.

2.3.1.1 Continuous exercises. Continuous exercise of hardware by PROCON is a means of verifying the correct operation of the hardware and detecting various failures. Exercises are used both on active and standby SSAS sides, but these are particularly important on the standby side since no call processing is taking place. (Call processing exercises the SSAS rather completely.)

The announcement subsystem[5] (i.e., the announcement store and

announcement distributor combined) is among those units which is continuously exercised by PROCON on both the active and standby sides to ensure the integrity of the speech heard by the customers. Any malfunction in these units would result in the appropriate flags being set in a maintenance register called the Error Summary Register (ESR). This register is periodically scanned by PROCON, which analyzes the content and sends the appropriate information to SPC.

2.3.1.2 Announcement subsystem failure reports.

PROCON can recognize failures associated with the announcement subsystem by scanning the Error Summary Register (ESR) periodically. The presence of any announcement subsystem failure will result in one or more flags being set in the ESR. If the content of ESR is different from its last look, PROCON sends a message to SPC indicating what trouble has occurred, provided PROCON has received no commands from SPC to stop sending information.

During normal operation, a Hamming and parity check on the address and data received from the announcement stores is performed by hardware[5] before the data are sent on to the service circuits. Once an error is detected, an error flag will be set in the ESR. The 67 bits of address, data, Hamming and parity for the error will be trapped in special maintenance address and data registers.

The content of the ESR is scanned periodically by PROCON. Upon identifying an announcement store error flag in the ESR, PROCON saves the contents of trap registers. Then it performs a read using the saved announcement store failure address. Subsequently, it loads the FIFO output register with the available information. This information includes (see Fig. 10) the content of ESR, the content of failure trap address and data registers (both original and retry values), and an extended reply code used to distinguish the cases where no error is detected upon retry from those where error is also detected upon retry.

Upon receiving a PROCON report, SPC analyzes the reported errors and decides whether a hard fault or a transient error is present. Detected errors and faults are categorized according to their types and seriousness. Types of errors and faults detected by SPC are repeating double bit data fault, repeating single bit data fault, transient double bit data error, transient single bit data error, and repeating single bit address fault. The address and data associated with the errors and single bit data faults are also saved, and are printed hourly or upon manual request on the maintenance teletypewriter for manual troubleshooting. The failing address is also passed to the store diagnostic program to allow extensive tests of the suspected area of the memory.

A feature that will aid in detecting announcement store errors is the announcement store recital program, which sequentially accesses every announcement phrase by loading its address into the maintenance

15		8	7		4	3				0
REPLY CODE						EXTENDED REPLY CODE				
						NO. OF WORDS TO FOLLOW				
CONTENT OF ESR										
ADDRESS (BITS 13–0)										
ADDRESS (BITS 19–14)										
DATA (BITS 15–0)										
DATA (BITS 31–16)										
DATA (BITS 47–32)										
ADDRESS–RETRY (BITS 13–0)										
ADDRESS–RETRY (BITS 19–14)										
DATA–RETRY (BITS 15–0)										
DATA–RETRY (BITS 31–16)										
DATA–RETRY (BITS 47–32)										

Fig. 10—Format of announcement subsystem failure report.

time slot of a Recirculating Shift Register (RSR). This type of routine exercise will guarantee that the memory used by every speech segment is accessed periodically. If any store error associated with a particular speech segment exists, a flag will be set in ESR notifying PROCON of the error and the address and data associated with the errors will be trapped. This program is implemented on both active and standby SSAS sides.

2.3.1.3 Mate frame buffer failure reports. Communication between the two SSAS sides (see Fig. 11) takes place asynchronously through a first-in, first-out serial memory called the Mate Frame Buffer (MFB). Each transmission through the MFB usually consists of data and an ID field which identifies the data.

During normal operation, all the data associated with the calls in progress are sent from the active side to the standby side through the MFB. This operation enables the standby side to have an up-to-date copy in its Random Access Memory[5] (RAM) of the data associated with each call for use if it is required to change role from standby to active. To test the validity of the data before it is stored, a 1-out-of-16 encoded ID word is associated with the data coming through MFB, to indicate what it contains. The standby PROCON checks for a valid ID format and for proper sequences of IDs. If the standby PROCON detects an error, it informs the SPC by loading appropriate data in its FIFO output register.
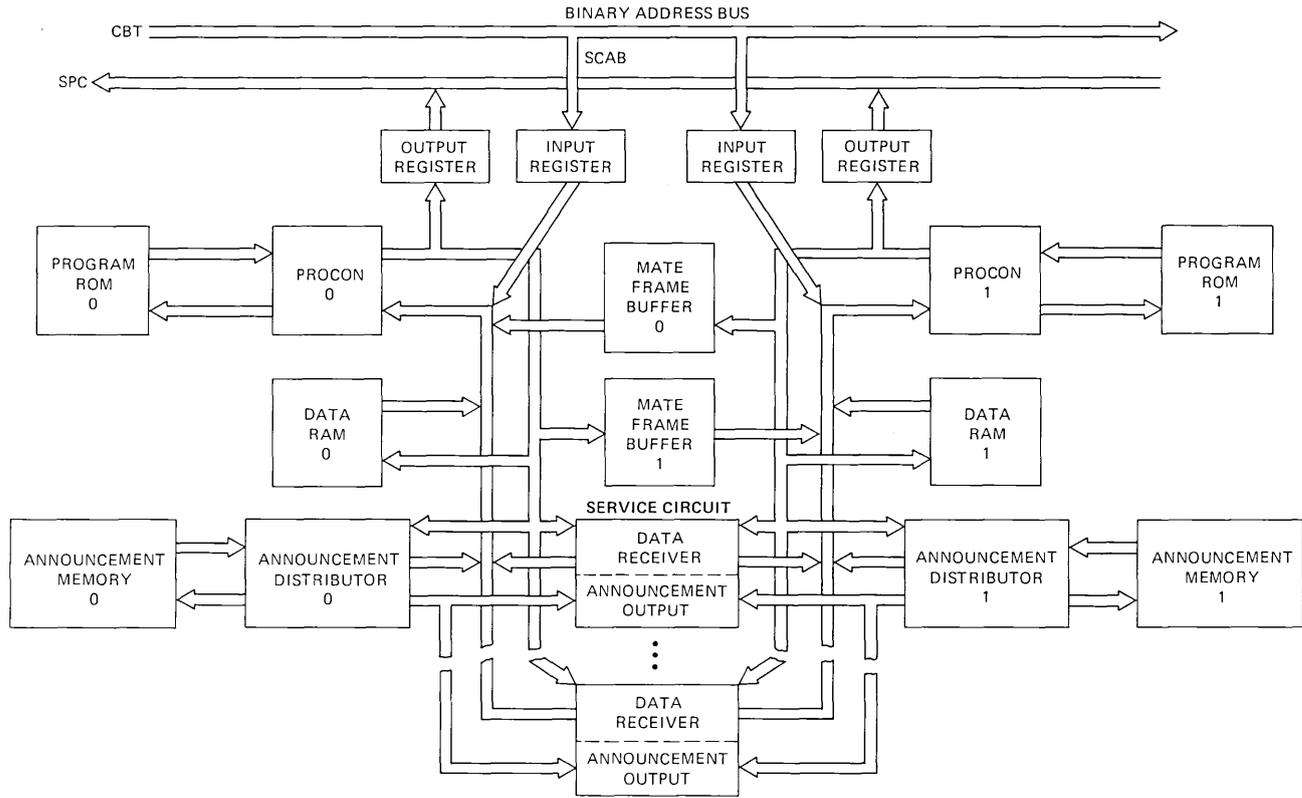
Fig. 11—Duplicated SSAS configuration.

During the unloading of the MFB by the standby side, an overflow condition in the MFB results in an MFB full flag being set in the ESR associated with the active side. This overflow condition could be caused by either an MFB failure or a failure in the standby side which prevents it from unloading the MFB. The MFB full flag in the ESR is monitored by the active PROCON. Upon detecting the MFB full condition, the active PROCON notifies SPC by loading the necessary information in the FIFO output register.

2.3.1.4 CDA error reports.

A CDA failure is recognized by PROCON during normal interrogation. All calls except those that are in the announcement mode only require interrogating the CDA reply register for coin deposits. Prior to sending the first interrogation command to a CDA, PROCON reads the reply register to ensure that there are no premature replies from the CDA. In the case of premature reply, all records of the call are erased and a message is sent to SPC indicating a bad CDA. During the course of interrogation, the parity of the data received from the CDA is checked by PROCON. In the case of a parity failure, PROCON again erases the records of the call and informs the SPC of the failure.

During the course of interrogation, PROCON continuously monitors the format and the validity of the data in the CDA reply register. A reply with invalid format is considered a CDA failure. In this case, the records of the call are also erased, and SPC is notified of the CDA failure. Another means of CDA error detection is the CDA maintenance register. If a maintenance bit is set in the reply register, the maintenance register is read to check the type of error. In this case again, PROCON notifies SPC and erases the records of the call. Upon receiving a CDA error report from PROCON, SPC routes the call to an operator position and also takes the bad CDA out of service, so it is not used for any future call. A diagnostic automatically will be requested for the bad CDA to aid the craftsperson in locating the faulty units. If too many CDA failure reports are received within a certain period of time, all associated with the same group controller, SPC then assumes that the group controller associated with the active side is faulty.

PROCON can only detect failures in the digital circuitry of a CDA. Failures in the analog circuitry of a CDA are detected by an error analysis program which resides in SPC. The success rate of attempted calls for a given CDA is analyzed, and if it is below a certain average threshold, the CDA is considered faulty and is taken out of service and automatically diagnosed.

2.3.2 SPC detected and reported faults

2.3.2.1 Maintenance interrupts.

Maintenance interrupts are used as a means of identifying faults in SPC-SSAS interface registers. These

types of faults have a serious impact on the operation of SSAS. They can result in isolation of the SSAS, thus crippling the capability of SPC to determine the basic integrity of the SSAS. This basic integrity is a necessary condition for the SPC to have confidence in the capabilities associated with PROCON in detecting SSAS faults.

As with other TSPS peripherals, any malfunction in SPC-SSAS communication is detected by using standard peripheral unit fault recognition techniques that can cause an F-level interrupt (such as central pulse distributor enable verify, and all-seems-well signal failures).[4] Upon occurrence of an F-level interrupt, appropriate fault recognition programs are entered to analyze the faults present in SPC-SSAS interface areas. These programs have the capability of distinguishing serious faults from nonserious faults and reporting them to appropriate reconfiguration programs.

During a scan operation of SSAS by SPC, a malfunction in one or both Scan Answer Buses (SCAB) results in an SPC processor mismatch which in turn causes a C-level interrupt to occur.[4] Upon occurrence of a C-level interrupt, appropriate fault recognition programs are entered which first determine whether SSAS caused the interrupt, and then by performing some tests isolate the faulty SCAB. The nature of failure and its degree of seriousness are also passed to SSAS reconfiguration programs.

2.3.2.2 *Periodic scans.* SPC detects faults in PROCON itself or in the PROCON peripheral control system by interrogating maintenance registers on the scan answer bus. This interrogation is done periodically (every 25 ms). The information provided by this interrogation (scan) is used by the SPC to determine the sanity of the PROCON for processing calls and to verify the capability of PROCON to detect SSAS faults. Among faults detected by periodic scanning are PROCON all-seems-well failures, Random Access Memory (RAM) all-seems-well failures, PROCON clock-stopped and output register-full indications. Both active and standby SSAS sides are monitored by the periodic scanning. The scan result is analyzed and is used to distinguish serious faults from nonserious faults, and to determine whether or not an immediate action is needed by the SPC.

2.3.2.3 *Dead side tests.* Despite the fact that extensive error checking circuitry has been built into the SSAS hardware, the possibility still exists that some faults may elude the checks and not be reported to the SPC. Potential faults in this category are nonclassical faults, multiple faults, certain PROCON and RAM failures, etc. A possible consequence of such faults is a dead SSAS side which appears to be free of faults during a period of no normal SPC-SSAS communications. To detect such a failure mode, the SPC performs an exercise periodically. The exercise involves sending a command to an SSAS side and receiving a specific reply. If an SSAS side fails to reply as expected, then the side

is considered to be faulty, and appropriate information is reported to the reconfiguration program.

Since SSAS functional integrity is constantly checked by call processing functions, the dead side test for an active SSAS side will be skipped if traffic is present on the side. More specifically, an SSAS side will not be tested if valid replies are coming through its output register at a regular interval.

2.3.3 Reconfiguration

2.3.3.1 Classification of faults. The response of the SSAS reconfiguration program to various SSAS faults is based on a fault classification scheme which categorizes the faults according to their impact on the normal operation of SSAS. Faults fall into one of four categories which can be summarized as follows:

(*i*) Serious faults. This type of fault corresponds to those which seriously affect the call processing capability of SSAS. For example, a fault which stops normal operation of PROCON is considered to be serious. A serious fault on an active SSAS side will cause an immediate switch to the other side.

(*ii*) Nonserious faults. A nonserious fault is defined as a type which does not seriously affect the call-processing capability of an SSAS side. An active side with this type of fault can continue to perform its normal function adequately as long as it is required to do so. This in turn implies that the switching action to the mate side can be delayed indefinitely, if necessary. For example, a single bit failure on the announcement data can be considered nonserious since its impact on the quality of the announcement is insignificant. As another example, a group controller failure on the active side can also be considered nonserious, since the side can continue to process calls using the remainder of the group controllers and their associated CDAS.

(*iii*) MFB faults. This type of fault is usually an indication of a failure in the MFB itself or the standby SSAS side, with no impact on the active SSAS side. No switching of sides is performed in this case. Instead, the standby side and MFB are both diagnosed for isolation of faulty units.

(*iv*) CDA faults. This type of failure usually represents a problem in an individual CDA. Since there are many CDAS in SSAS, an individual CDA failure does not have a serious impact on the call-processing capability of SSAS. A faulty CDA is marked out of service and will not be used until it is diagnosed and repaired.

2.3.3.2 Smooth side switch. The process of interchanging the active side and standby side is referred to as a side switch. If this is

done so that the flow of announcements is not interrupted, the switch is called a smooth switch.

A smooth switch between two SSAS sides is performed under two circumstances. One case is when the active side has a nonserious fault such as single bit failure in announcement data. In this case, the system can afford to wait as long as needed to switch smoothly. The other situation is when a routine switch to the standby side is desired to test the hardware controlling the reconfiguration and to provide a chance to run a routine set of diagnostics on the previously active side. This process (the smooth switch exercise) is performed three times a day.

A smooth switch is typically characterized by the following actions. First, the SPC sends a command to the active side, telling it to go standby gracefully. Second, the active side brings the standby side in loose synch with the active. Third, the standby side is told to go active gracefully. Since by now the active and the standby are loosely in synch, both sides time themselves until the right moment when the old active goes standby followed almost immediately by the old standby going active. The new active verifies its success by sending a reply to the SPC. Upon receipt of this reply, the SPC changes the SSAS status words to record the new configuration. This type of side switch does not provide any discontinuity in the announcement heard by the customer and also has no effect on the call processing operation.

2.3.3.3 Other types of side switch. The handshaking between the two sides required to perform a smooth switch may not be possible if the active side develops a serious fault such as a PROCON all-seems-well failure. Assuming that the nonactive side is in the standby ready state, the SPC simply takes the faulty side out of service and makes the standby side active. This type of switch is referred to as an *immediate switch*. Since the standby's data RAM is up to date with the active side, only a minor disruption to call processing results. The announcement heard by a customer is interrupted. Approximately a half-second elapses, and then the entire announcement is repeated. In addition, it may result in mishandling a single call. However, this minor disruption of the call processing is considered a small penalty, as hardware faults occur rarely.

Another type of side switch, called a *rough switch*, happens when the active side is doing call processing and the nonactive side is running a routine diagnostic on itself. If the active side develops a serious fault, it is immediately taken out of service. In the meantime, the routine diagnostic on the nonactive side is aborted, and the side is made active. Since the data RAM on the standby side is not up-to-date while a diagnostic is being run, it will be initialized before becoming active. Therefore, all processing on existing calls is aborted and the SSAS starts

afresh. Considering the reliability objectives of the SSAS, the probability of occurrence of a rough switch is estimated to be very small.

2.3.3.4 Tolerance of software errors. Software errors are usually analogous to a serious component failure, causing both SSAS sides to go down and remain down until the problem has been rectified. However, certain classes of software errors could be considered tolerable. An erroneous software instruction which is executed infrequently, if it is considered to be nontolerable, could cause a permanent outage of the SSAS upon its first execution. On the other hand, if at this time the SSAS is reinitialized and restarted, it will continue to perform its normal function until some later time, when it will encounter its second failure, due to the execution of the erroneous software instruction. Following this strategy would substantially decrease the SSAS downtime in cases where infrequently executed software errors are present.

The above considerations provided the basis for developing a strategy which tolerates certain classes of errors in the PROCON software. Upon occurrence of an SSAS outage, the SPC performs an analysis for both sides using past history of SSAS outages. First the side with the fewer past failures is selected. Then after the analysis a decision is made on the nature of the problem for that side, as to whether a hardware fault or a software error exists. In the latter case, the side is reinitialized and used for call processing after a successful initialization, while a diagnostic is requested for its mate side. In the former case, both SSAS sides are diagnosed to pinpoint the hardware malfunctions.

2.3.3.5 Duplex failure. If SSAS becomes totally unavailable, the call processing function performed by the SSAS is aborted and all new calls will be routed to the operators. The new calls are blocked from attempting to cease CDAS for service. Also, several clean-up actions are performed by the SPC to allow for rapid restoration of ACTS. For example the peripheral orders waiting to be sent to the SSAS are searched and disposed of. The SSAS is blocked from providing ACTS until all the clean-up tasks are completed.

2.4 SSAS diagnostics

2.4.1 Controller diagnostic

2.4.1.1 Interface SPC—PROCON. The SSAS diagnostic programs run on one SSAS side at a time, always a nonactive side. The diagnostic request is made either by manual request or by fault recognition programs, either as a result of a fault being detected or as a routine diagnostic. The routine diagnostic is run once a day to do a complete check of the SSAS hardware.

As a direct consequence of the SSAS architecture, the SSAS diagnostic control is divided into two parts; the first part resides in SPC, and the second resides in PROCON's Read Only Memory (ROM) and is under

the control of a standby monitor program which controls the various activities of a nonactive SSAS side, including diagnostics. Other activities associated with the standby monitor include fault recognition, unloading of the Mate Frame Buffer (MFB) and other SPC-requested nondiagnostic functions. SPC retains the overall control over the SSAS diagnostic. SPC initiates SSAS diagnostics by first marking the SSAS side out of service and then sending a diagnostic request to the PROCON. The request indicates that a group of tests referred to as a "phase" is to be run by PROCON. In some cases, this request is also accompanied by a test pattern to be used by PROCON. The standby monitor decodes the request, performs error checking, and invokes the PROCON diagnostic control program. This program further decodes the diagnostic request to select the proper diagnostic phase. Once a diagnostic phase is initiated, the standby monitor exercises control over the execution of the diagnostic. A diagnostic phase performs tests on the SSAS functional block being diagnosed, using predetermined test patterns and sends the test results to SPC through the FIFO output register. The test results are used by the SPC to isolate the particular fault involved.

2.4.1.2 Levels of raw data compression. The diagnostic test results sent by PROCON through the FIFO output register are compared against the expected result by the SPC. The result of that comparison is saved as a binary string of ones and zeros referred to as "raw data" results. The zeros represent the tests passed and ones indicate the tests failed. Although PROCON does considerable data comparison, in many diagnostic phases the test results sent by PROCON are quite voluminous and exceed the capacity of the trouble number generation programs. In such cases, SPC uses a compression algorithm for converting the test results into a compressed raw data bit string. The algorithm uses a simple procedure: If any test result word sent by PROCON does not match the expected value, the SPC diagnostic program will map this mismatch into one raw data bit. The compressed raw data bit string is further reduced by the SPC to a 4-part, 16-digit number referred to as a "fault signature," which uniquely identifies the string. The fault signature is used by the maintenance personnel to reference a trouble-locations manual to isolate the particular fault involved.

In some cases, the fault signature generated by SSAS diagnostic programs fails to provide enough information to clear the trouble associated with the SSAS. In such cases, the maintenance personnel can manually request either compressed raw data or expanded raw data. The raw data printout is used by maintenance personnel as an aid in manual troubleshooting.

2.4.1.3 Power of PROCON test. The SSAS architecture has partitioned the hardware in functional modules (such as PROCON, peripheral

control, announcement memory, service circuit group controllers, etc.).[5] Each of these functional modules are further partitioned to attain the desired level of maintainability and diagnostic resolution.

PROCON access to each functional module results in a simple diagnostic structure consisting of segments that diagnose only one functional module. In general, diagnostic resolution is directly related to the size of the module's diagnostic. Resolution can be improved by reducing the size of the module. A further improvement can be realized by choosing a diagnostic structure that begins with the diagnosis of the most basic functional module and proceeds to test each module by adding diagnostic segments that use the diagnosed modules. These considerations have been taken into account in planning the SSAS diagnostic structure, which provides an average diagnostic resolution of three or fewer circuit packs, with the capability of detecting greater than 90 percent of potential SSAS faults. These diagnostic objectives are required to limit the average repair time to about 2 hours as specified by the SSAS maintainability objectives. PROCON access capability combined with the modular architecture allows the SSAS diagnostic objectives to be achieved.

Another feature that helps to achieve the SSAS diagnostic resolution objective is the bit-sliced architecture used in designing SSAS input and output bus interfaces. The bit-sliced architecture is used to aid the SSAS diagnostics in pinpointing faulty packs and to reduce the number of board codes. This means that the common bits for all registers on a bus are grouped together on one or a few circuit packs (i.e., bit i for all registers on the bus are grouped together). Because of this architecture, it is only necessary for the SSAS diagnostic to know which bit is bad to isolate the faulty circuit boards.

2.4.2 CDA diagnostic

2.4.2.1 SPC-PROCON interaction. The CDA diagnostic is initiated by the SPC either as a result of CDA failures detected by fault recognition programs, error analysis programs, or a manual diagnostic request via the maintenance teletypewriter channel. Also, an automatic progression test of the CDAs is performed to ensure that each CDA is diagnosed once a day.

A service circuit known as the CDA test circuit is used to diagnose CDAs. It has network appearances so it can be connected to the various CDA ports for analog circuit tests.[5] When a CDA diagnostic is requested, the SPC attempts to establish a test configuration if the requested CDA is available for testing. It first verifies that the CDA test circuit is available and the nonactive SSAS side is in the standby ready state. If not, the diagnostic is blocked; otherwise, the CDA test circuit is made maintenance busy, and orders are sent to the active SSAS side to switch

both the CDA test circuit and the CDA under test over to the standby SSAS side. Next, the Signal Distributor (SD) controlled relays in both the CDA and CDA test circuits are released without regard to their previous states, and the two circuits are connected via the TSPS network.

Once the test configuration is established, various phases of the CDA diagnostic are initiated by the SPC. For each phase, the SPC first operates the required SD-controlled relays, and then sends an order to the standby SSAS side to run tests of the specified phase.

The PROCON standby monitor program processes the diagnostic order and transfers PROCON control to the CDA diagnostic program. This program performs the tests of the specified phase and sends the results to the SPC via the FIFO output register. Once the PROCON reply is received, the SPC compares the test results with the expected results. The result of this comparison is the diagnostic raw data. Each bit set to a one in the raw data represents a test failure. The raw data is then converted into a trouble number which is used by the maintenance personnel to isolate the trouble.

When all the phases of the CDA diagnostic have been completed, the SPC releases the relays of the CDA and CDA test circuits, breaks the network connection between them, and sends orders to the standby SSAS side to switch them back to the active side. The CDA test circuit is returned to the maintenance idle state, and the CDA under test is either returned to service or placed out of service, depending upon whether the diagnostic tests have been passed or failed.

2.4.2.2 *CDA test circuit use.*

The CDA test circuit is a special type of SSAS-controlled service circuit. There is one CDA test circuit per SSAS, and it is always equipped as circuit 15 of the service circuit frame 1.

The primary functions of the CDA test circuit can be summarized as follows:

(*i*) It produces simulated coin deposit signals for testing a CDA coin tone receiver.

(*ii*) It detects test tones produced by a CDA announcement decoder.

The CDA test circuit architecture is quite similar to that of the other SSAS service circuits. It consists basically of digital circuitry to interface with SSAS, a tone generator and a tone detector (see Fig. 12). Its digital interface circuitry with SSAS consists of command decoding logic, reply registers, and control logic which provides additional decoding of CDA test circuit commands, and also controls the miniature relays which provide switching of pads and filters.

The tone generator consists of an announcement decoder, an inter-
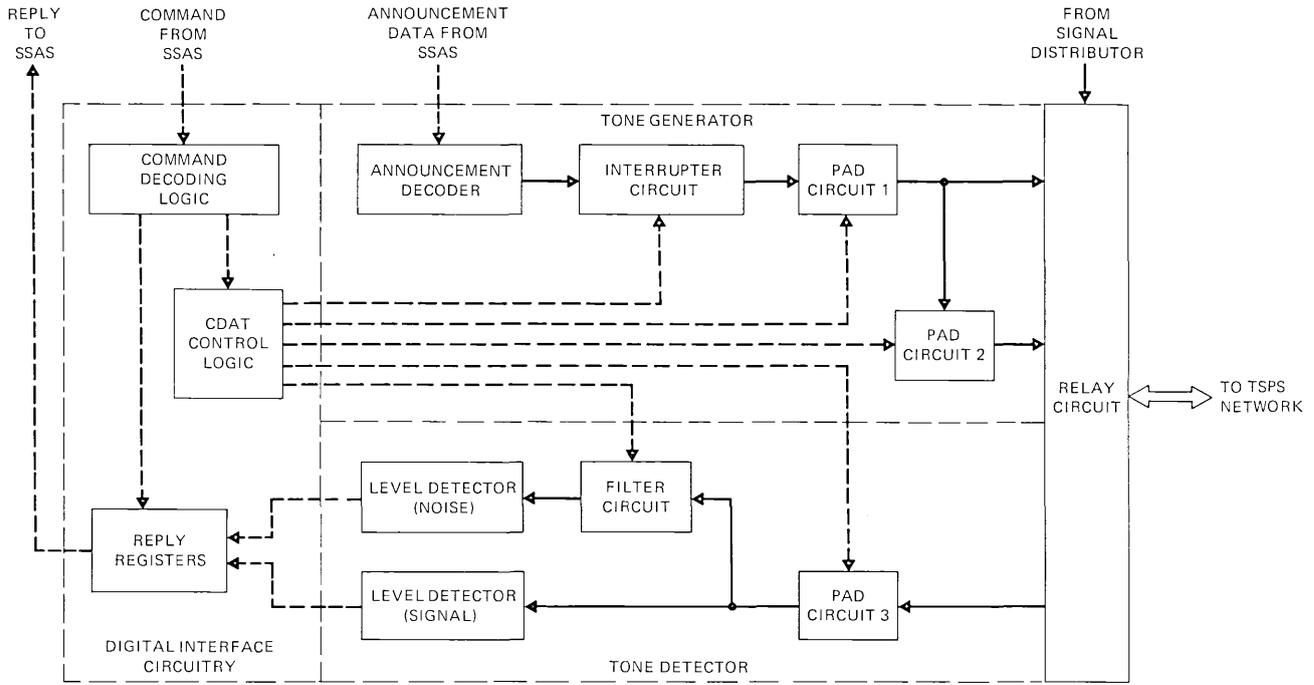
Fig. 12—Block diagram of CDA test circuit.

rupter switch, and a set of switchable attenuation pads. The interrupter switch is used to clamp the analog output of the announcement decoder to ground, thereby silencing the tone generator. The switchable pads provide the level variation needed for a CDA coin tone receiver testing.

The tone detector consists of a switchable pad circuit, level detectors, and a switchable filter circuit. The switchable pad circuit provides level adjustment for signals generated by a CDA announcement decoder. The output of the announcement decoder of a CDA circuit is tested by the level detectors for both signal loss and distortion. During the process of checking for signal distortion, the switchable filter circuit is used to remove the expected fundamental frequency component of the announcement decoder test tone without attenuating any harmonic frequency components.

2.4.3 Use of test tones from announcement store

Many tests performed during the course of CDA diagnostic are aimed at detecting possible malfunctions in either the announcement decoder or the coin tone receiver associated with the CDA under test. Proper operation of the announcement decoder is verified by monitoring its response to a set of digitized test tones. This response is checked for possible abnormalities in both frequency response and output level using a tone detector associated with the CDA test circuit. The coin receiver is tested by using the tone announcement decoder of the CDA test circuit to produce coin deposit signals from data stored in the SSAS announcement memory, and checking the response of the coin tone receiver to deposit signals having various level, frequency, and timing characteristics.

The test tones required for checking the proper operation of the announcement decoder and the coin tone receiver are stored as announcement data. A total of 18 test tones are required for CDA diagnostic tests. The storage requirement for many of these tones is significantly reduced by packing several of them into a single announcement phrase. Combining up to four 125-ms test tones into a single segment reduces the number of the required segments to six. One hundred twenty-five milliseconds allows ample time for the announcement decoder output to stabilize and for the CDA test circuit tone detector to achieve a stable measurement. However, this approach adds additional timing functions for the standby PROCON to perform. PROCON must determine the appropriate time to strobe the tone detector and, for some tests, it must blank out the unwanted tones by operating an interrupter switch within the CDA test circuit which turns off the analog output of the tone announcement decoder.

2.5 CDA alignment and manual tests

2.5.1 Trunk test panel connections

The TSPS Control, Display, and Test (CDT) panel provides a means of manually initiating tests on trunks, operator positions, and service circuits appearing on the TSPS switching network.[6] In conjunction with the ACTS feature, provisions have been made for testing both the CDA and the CDA test circuits from the CDT panel.

Most CDA circuit tests originating from the CDT panel require that test connections be established between the CDA circuit and the CDT circuit. Operation of the Master Test Line–Test key on the CDT panel causes the SPC to connect an MF receiver to the Position Master Test Line (PMTL) of the CDT circuit via the TSPS network. Once this connection is established, the SPC lights the Master Test Line (MTL) lamp on the CDT panel, indicating that codes can be entered via the CDT multifrequency (MF) key set. At this point, a test connection can be requested with any CDA circuit appearing on the TSPS network by entering its trunk group and member number and the camp-on bit via the CDT MF key set. A special display on the CDT panel indicates to the maintenance personnel whether the request was successful, aborted due to system failure, or invalid.

The SPC indicates the status of the requested CDA on a special display lamp. This lamp indicates whether the CDA is idle, traffic busy, maintenance busy, or out of service. If the CDA is busy and camp-on is requested, the SPC reserves it for maintenance by placing it out of service as soon as it becomes idle and notifies the maintenance personnel of its availability via a teletypewriter output message. If the CDA is idle or out of service, the SPC disconnects the MF receiver from the PMTL, extinguishes the MTL lamp, and establishes the test connection between the CDA and CDT circuits.

Several other test features involving CDT panel key actions have also been provided for CDA circuits. By operating appropriate keys, the maintenance personnel can place the CDA connected to the CDT out of service, or return it to service. Also, a display of the ferrod states of the CDA under test can be requested by operating a special key. This key action causes the scan row containing the CDA ferrods to be displayed on the program display of the control and display panel.

2.5.2 Trunk test panel measurements

The CDA circuits contain analog transmission components which provide a part of the talking path between the customer or customers and the CDA announcement decoder. These CDA circuit voice paths must be tested with respect to noise and signal loss whenever transmission problems associated with the circuit are suspected. The trunk

test panel, shown in Fig. 13, provides a convenient means of performing noise and loss tests on CDA circuits that appear on the TSPS network.

Testing of the transmission path of a CDA circuit involves separate tests for performing noise and loss measurements. First, a test connec-
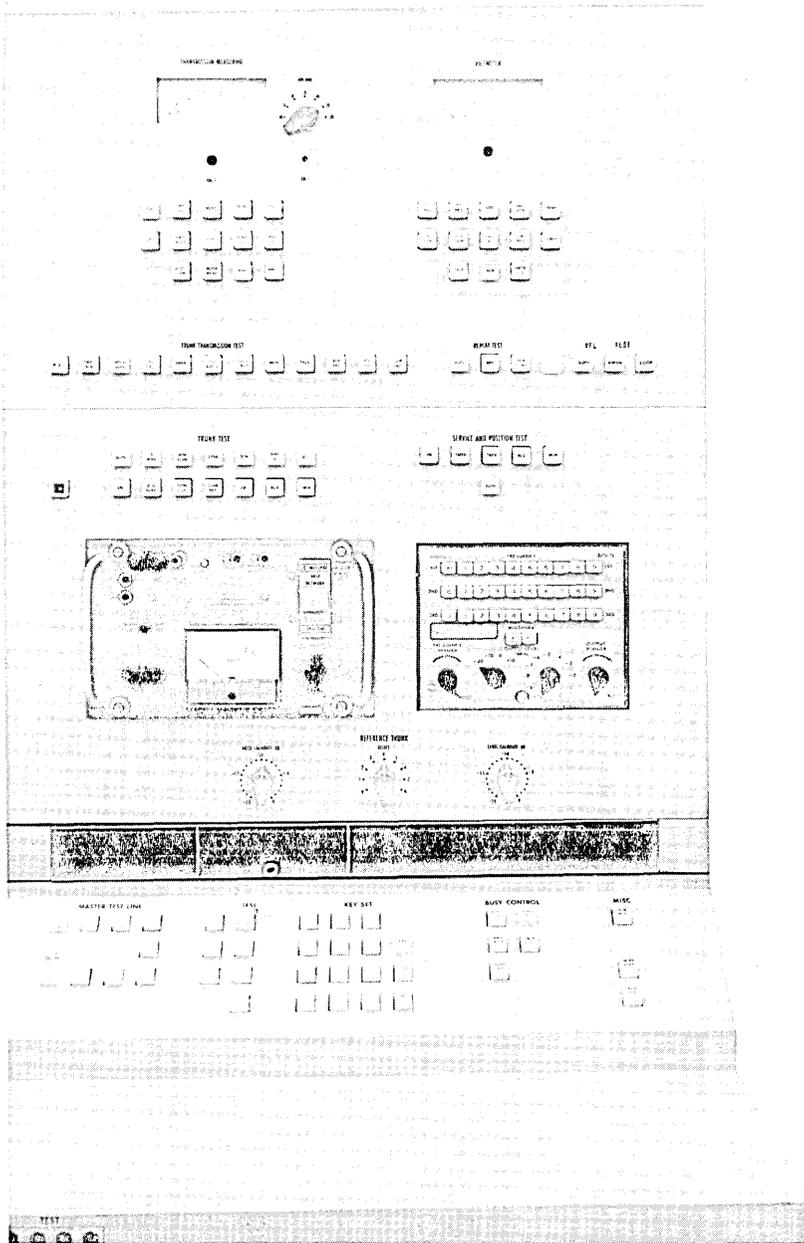

Fig. 13—Trunk test panel.

tion is established and the Master Test Line–Test key is operated to signal the SPC to connect an MF receiver to the PMTL. Next, by entering an appropriate test code and appropriate test control key actions, each of these tests can be initiated. These tests can be repeated or performed in any sequence as long as only one test control key is operated at a time. These tests can also be sequenced under the SPC control by using an appropriate test code. As soon as the code is entered, the SPC establishes the connection for the first test. Upon completion of the first test, the connection for the second test is established. This process is continued until the completion of the last test. At this point, the CDA circuit is disconnected from the CDT panel and is returned to its previous state.

Manual transmission tests of all CDA circuits in the office can be initiated by entering a special test code. The SPC connects each CDA circuit in sequence to the CDT panel. If the circuit is traffic or maintenance busy, it is skipped and a teletypewriter message is printed. After the completion of the tests, the SPC disconnects the CDA circuit from the CDT and connects the next one.

Automatic sequencing of the transmission tests of all CDA circuits can be initiated by entering another special code. The SPC connects each available CDA circuit to the CDT panel, and sequences through each of the tests. Once all of the tests for a CDA circuit are complete, another CDA circuit is connected. Busy circuits which are skipped are identified by teletypewriter messages.

2.5.3 Vocabulary recital

Because the announcement decoding aspect of the SSAS has no existing counterpart in the TSPS, a totally new test feature is provided from the CDT panel. This feature is an announcement vocabulary recital exercise whereby the maintenance personnel can listen to each speech segment in the announcement vocabulary via the CDT telephone head set.

Listening to the announcement output of a CDA circuit provides a manual check not only of the CDA circuit announcement decoder, but also of the SSAS announcement subsystem circuits. When an announcement store is loaded from tape, this feature can be used to verify the contents of the store before it is made active. The announcement recital test can be performed from both active and standby SSAS sides. Two options are provided for the recital test. They can be summarized as follows:

(*i*) The decoding of every announcement segment and phrase in sequence.

(*ii*) The repetitive decoding of a specified announcement segment or phrase.

The announcement recital test on an active SSAS side begins with a CDA circuit connected to the CDT panel. By operating appropriate keys and entering a special test code, the SPC starts the PROCON-controlled announcement exercise on the active side. This exercise accesses the announcement data for a phrase and sends it to the CDA circuit under test. It sequences through every word or phrase in the announcement vocabulary and then stops. Each word or phrase is separated by ½ second of silence.

Entering another test code causes a specified announcement phrase to be repeated at a constant rate. This is controlled by another PROCON exercise which accesses the announcement data for the specified phrase and sends it to the CDA circuit under the test. One-half second of silence is inserted between repetitions. The phrase is repeated until the circuit is released from the CDT panel.

Similar procedures are used for the announcement recital test from a standby SSAS side. Again by entering special codes, appropriate announcement exercises are started. If the SSAS diagnostic is in progress on the standby side, the exercise is not run and a teletypewriter output message is printed.

III. ACKNOWLEDGMENTS

REFERENCES

1. M. Berger, J. C. Dalby, E. M. Prell, and V. L. Ransom, "TSPS No. 1: ACTS Overall Description and Operational Characteristics," B.S.T.J., this issue, pp. 1207–1223.
2. A. W. Kettley, E. J. Pasternak, and M. F. Sikorsky, "TSPS No. 1: Operational Programs," B.S.T.J., 49, No. 10 (December 1970), pp. 2625–2683.
3. R. J. Jaeger, Jr., and A. E. Joel, Jr., "TSPS No. 1: System Organization and Objectives," B.S.T.J., 49, No. 10 (December 1970), pp. 2417–2443.
4. G. R. Durney, H. W. Kettler, E. M. Prell, G. Riddell, and W. B. Rohn, "TSPS No. 1: Stored Program Control No. 1A," B.S.T.J., 49, No. 10 (December 1970), pp. 2445–2507.
5. G. T. Clark, K. E. Streisand, and D. H. Larson, "TSPS No. 1: Station Signaling and Announcement Subsystem; Hardware for Automated Coin Toll Service," B.S.T.J., this issue, pp. 1225–1249.
6. W. K. Comella, C. M. Day, Jr., and J. A. Hackett, "TSPS No. 1: Peripheral Circuits," B.S.T.J., 49, No. 10 (December 1970), pp. 2561–2623.

Traffic Service Position System No. 1:

Automated Coin Toll Service:
Human Factors Studies

By E. A. YOUNGS, W. J. BUSHNELL, and A. BARONE-WING

Automated Coin Toll Service replaces operator handling on most toll calls paid for with coins and provides operator handling when customers fail to deposit. Human factors work on ACTS consisted of first documenting the range and frequency of existing operator interactions, then simulating various possible versions of machine-provided service, and last analyzing simulation results to provide service recommendations, performance estimates, and a list of important, but unanswered, questions. The simulation also led to the early development of operator practice and training materials, evaluation tools, and operational requirements, as well as timely discovery of potential problems.

I. INTRODUCTION

Companion papers describe the hardware and software used to provide Automated Coin Toll Service (ACTS).[1-3] This paper describes human considerations which contributed to the design and evaluation of the automated service.

Prior to the development of the hardware and software described in the previous papers, many questions were raised:

(*i*) Would the automated service be an acceptable substitute for Traffic Service Position System (TSPS) operators performing routine functions, e.g., deposit request, coin counting, deposit prompt, deposit acknowledgment, and others?

(*ii*) How would customer depositing (and other behaviors) depend on service design?

(*iii*) How would customer satisfaction with the service depend on the design?

(*iv*) How would operators be affected by the automated service?

These few broad questions implied many specific questions: How should performance be measured? What aspects of customer behavior are most important? and How should these be measured?

The human factors work proceeded in three stages: detailed observations of existing (operator-assisted) coin toll service to comprehend the range and relative frequencies of events; a highly instrumented service trial to obtain performance measurements and customer opinions; and a data analysis and recommendations phase to formulate a final service offering, estimate performance, and isolate potential difficulties for further study. The remainder of this paper is organized around these stages.

Section II briefly describes early observing studies upon which the original service proposal, as well as the provisional announcement and timing schemes, were based. Additional confirming observing studies are also mentioned. Section III describes the usefulness of service simulations—first with operators only, later with computer-driven equipment to provide service and measure customer-service performance. Section IV describes the technical implementation of the computerized simulation, Section V describes simulation results and recommendations, Section VI estimates performance and acceptance, Section VII enumerates unanswered questions, and Section VIII briefly mentions some cost-worth factors to be considered in evaluating the simulation.

II. EARLY HUMAN FACTORS WORK—OBSERVING HOW COIN CALLS ARE PRESENTLY HANDLED BY OPERATORS

At TSPS, toll coin calls are divided into several parts (called position seizures) for efficient operator handling. Each seizure accomplishes a single function: (*i*) initial period deposit request and verification of complete deposit, (*ii*) notification at the end of the initial period that overtime charges would apply unless the call ended immediately, (*iii*) call interruption, deposit request, and verification after each additional 10 minutes of overtime conversation, and (*iv*) ringback (if necessary), deposit request, and verification at the end of conversation. The human factors effort concentrated on replacing operators performing these functions.

The initial service proposal by J. C. Dalby was based on the characteristics of (operator-assisted) station-to-station coin toll calls monitored at Neptune, New Jersey and Chicago, Illinois.[4] Of particular interest were:

(*i*) The wording of the operators' deposit requests.

(ii) The time from the deposit request until customers deposited their first coins.

(iii) The number of times operators repeated deposit requests before customers started depositing.

(iv) The times between coins (intercoin intervals).

(v) How frequently customers began depositing, then stopped and asked operators how much was still due.

C. E. Bronell and M. S. Schoeffler[5] conducted a more extensive service measurement study in Seattle, Washington, Miami, Florida, and Rochelle Park, New Jersey. The objective of this study was to reinforce earlier observations and accumulate enough direct observations of operator-handled calls to provide a thorough, general description of the process and of the most common situations likely to be difficult for an automated system. Location differences were also analyzed.

From these observational studies, it became apparent that there are two general types of coin customers: experienced and (those presumed to be) inexperienced. Experienced customers are familiar with coin service. They had correct change and often knew the exact charges before making the call. After a short initial deposit request (e.g., "50 cents please"), experienced customers immediately started depositing and continued until the requested amount was deposited. If the operator used a longer initial deposit request (e.g., "Please deposit 1 dollar and 75 cents for the first 3 minutes"), experienced customers often began depositing while the operator was still talking.

At the other extreme, inexperienced customers are not prepared for the initial deposit request and often ask for a repetition. They began depositing, but occasionally lost count and asked for the remaining amount due. Inexperienced customers often did not have the correct change and had to deposit too much. The operator informed these customers that extra deposits would be credited toward additional charges, if any. Some inexperienced customers dialed the call as if they wanted to pay with coins when they did not wish to do so and were unprepared. (They should have dialed 0 plus the called number.) On these calls, the operator adjusted the method of payment.

As a result of these observations, it was concluded that the sequence of announcements and coin deposit intervals should provide experienced customers with fast efficient service and inexperienced customers with repetitive requests for deposits, prompts for the remaining amount due, and automatic transfer of calls to operators when difficulties were detected. In addition, the automated service should be able to acknowledge extra deposits and provide credit toward additional conversation time.

It was estimated that provisional announcements and deposit inter-

vals would handle approximately 85 percent of initial deposit seizures without operator intervention. On this basis, automated service was an economically sound development. However, it was also recognized that further refinements in the announcements and timing intervals which increased the proportions of mechanized seizures, even by only a few percent, would yield substantial additional savings.

III. FIRST AUTOMATED SERVICE—SIMULATION BY OPERATORS

In the spring of 1975, O. O. Gruenz, Jr., conducted an experiment at Harrison, New York, Fort Washington, Pennsylvania, and New York City, in which the automated service was manually simulated.[6] Several TSPS operators requested deposits and prompted customers using proposed announcements and approximate timing intervals. These operators were instructed to ignore any questions or comments made by customers.

During the experiment, two variants of the provisional deposit request ("Please deposit 35 cents for the first 3 minutes") were tried to reduce customer requests for repetitions of the amounts due:

(i) "Thirty-five cents please." (2-second pause) "Please deposit 35 cents for the first 3 minutes,"

(ii) "Please deposit 35 cents." (2-second pause) "Thirty-five cents for the first 3 minutes."

Both these announcements were successful in reducing customer needs for additional information. Furthermore, these results indicated that mechanized initial deposit seizures could be increased by several percent with the proper announcement wordings and timing intervals. However, because all record-keeping for this experiment was done manually, it was not feasible to explore many options. Thus, the experiment did not finally answer any design questions; rather, it demonstrated that proper design choices could substantially improve system performance.

3.1 Additional questions about customer/system performance and customer acceptance which justified additional simulation

In addition to announcement wording and deposit timing, early work raised other specific design questions:

(i) Would an alerting tone preceding announcements help customers deposit more quickly and/or more reliably?

(ii) How would customer/system performance and customer acceptance be affected by the use of a nasal monotone ("machine-like") voice as opposed to more natural-sounding announcements? (There was some speculation that informing customers that they were being machine-served would be beneficial, and it was thought that voice quality was a reliable, non-time-consuming way of doing so.)

(*iii*)   Should coin station instruction cards inform customers that service is being machine provided?

Furthermore, a properly designed simulation was expected to:

(*iv*)   Identify potential overall system weaknesses, overlooked by even careful examination of individual system elements and stimulate further work where required.

(*v*)   Give useful experience with microprocessor-controlled, announcement-generating equipment and software.

(*vi*)   Stimulate early development of operator procedures and training materials.

(*vii*)   Aid preparation of an appropriate public relations campaign for the introduction of automated service.

(*viii*)   Provide some engineering information useful in early site equipment provisioning.

(*ix*)   Complement performance measures with customer interviews which would reveal preferences and sensitivities to machine-provided service.

IV. COMPUTER SIMULATION OF ACTS

Various versions of the automated coin toll service were simulated using microprocessor-controlled, announcement-generating equipment. This equipment was originally built by an exploratory development group to demonstrate the feasibility of generating announcements using digitized segments of speech stored in semiconductor memory. However, this equipment lacked much of the hardware and software necessary to provide the fully automated service. First, the coin detection circuits had not been designed and, second, the circuitry and software to interface the microprocessor and the TSPS processors had not been developed. Thus, to simulate the automated service, it was necessary to have TSPS operators relay call and coin deposit information to the microprocessor. A minicomputer and a TTY were used as interface between the operator and the microprocessor. In addition, the minicomputer provided all the necessary timing intervals and a record of the call events on a 9-track tape (see Fig. 1).

The sequence of events on a simulated ACTS call were as follows:

(*i*)   The call seized a position and the initial period length and charges were displayed to an operator.

(*ii*)   The operator transmitted the information to the minicomputer via the TTY.

(*iii*)   The minicomputer sent instructions to generate an announcement (deposit request) which was patched into the customer-operator voice path.

(*iv*)   As the customer deposited coins, the operator depressed keys on the TTY which were interpreted by the minicomputer as nickels, dimes, or quarters.
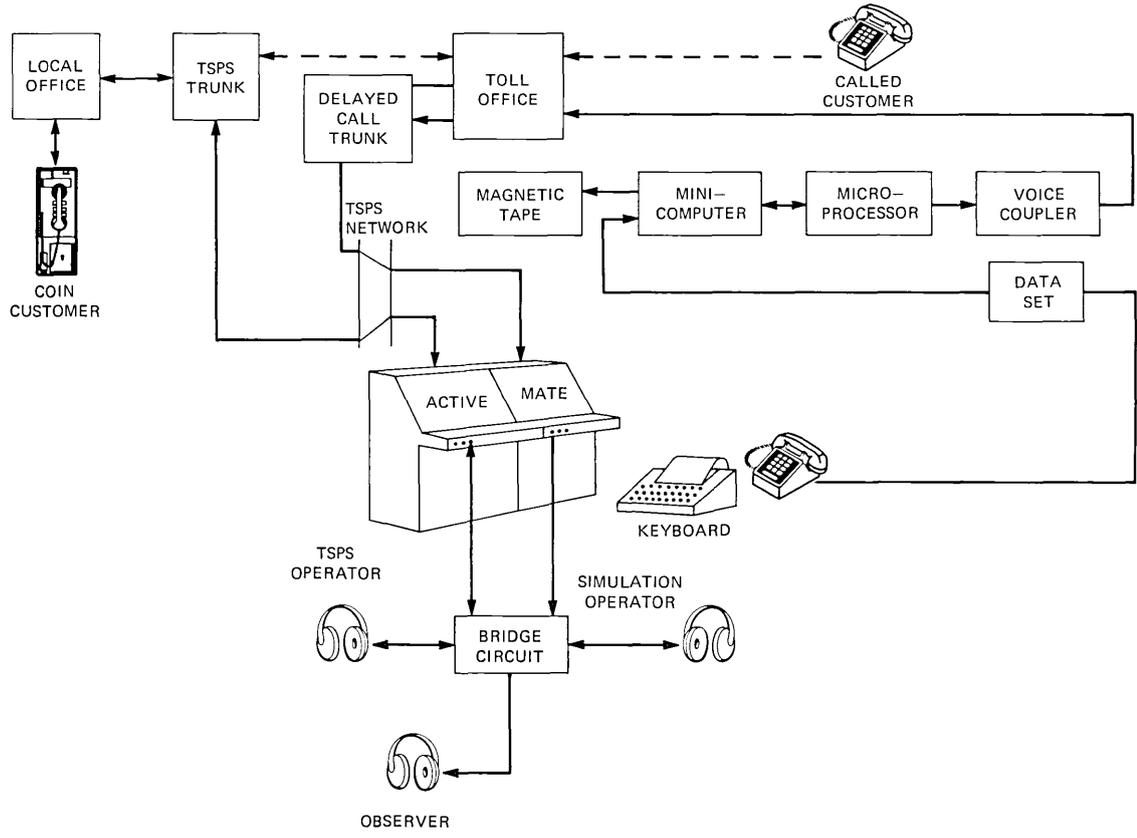
Fig. 1—Simulation block diagram.

The timing and initiation of the announcements were under mini-computer control, as were instructions to the operators. If the customer did not deposit coins, a second operator (sometimes with no previous knowledge of the call) assisted the customer, providing a customer-operator situation much like the eventual service.

Two operator positions (each with two operators) were equipped with TTYs. To ensure that these positions received only station paid coin calls, a special set of program overwrites was installed in the TSPS. In addition, other overwrites were inserted to ensure that calls at the special positions originated from one of a selected set of coin stations. Coin stations were selected to facilitate interviewing, traffic management, station instruction card study, and traffic sampling.

4.1 Administration of the simulation— hourly traffic distribution

Figure 2 illustrates the hourly distribution of simulation traffic and the corresponding distribution for coin-paid toll traffic at Illinois Bell's Great Lakes TSPS. This representative sampling for weekdays was attained by choosing an appropriate mix of 8-hour shifts over the three months of study. The simulation was operated for one shift per weekday, as well as a few weekends.

4.2 Station selection and activation

Stations participating in the trial were those most frequently used for coin-paid toll calls in the host TSPS serving area. A total of 732 stations were activated at various times. However, at busy times during the day, fewer than 100 generally received simulated service. The number of active stations was adjusted dynamically to keep (one or) two trial positions as busy as possible, without overflowing calls to the regular team more than 10 to 15 percent of the time, on the average.

4.3 Varying elements of the service design

To answer the service design questions at hand, a daily schedule of service variants was constructed to sometimes include an alerting tone/no tone, a "machine-like"/natural announcement voice, etc. Overall service was composed of variable elements in a way that allowed the effects of each element to be partialed out by appropriate analyses. Ongoing analyses quickly suggested that some service elements be eliminated from further consideration and that others be tried.

V. CUSTOMER/SYSTEM PERFORMANCE—ANALYSES, RESULTS, AND DESIGN RECOMMENDATIONS

Table I presents some key results derived from simulating over seventeen thousand automated initial deposit seizures. The table
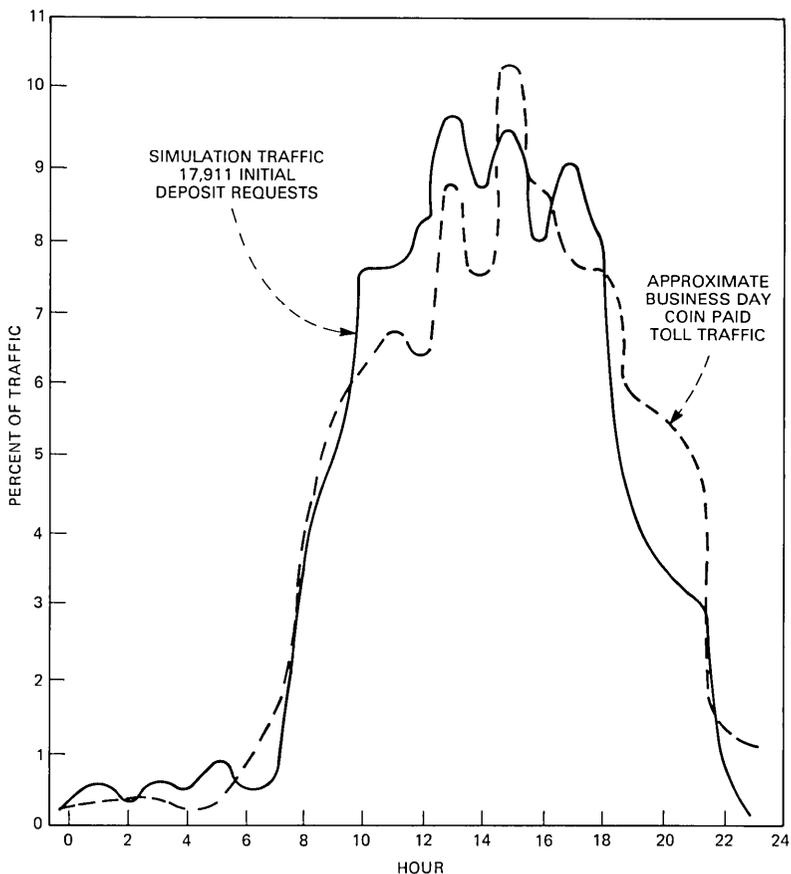
Fig. 2—Approximate business day and simulation study sampling distributions.

shows regression estimates of the effects of design decisions on important service performance measures. Mechanization rate is the percentage of calls handled without operator assistance. Walkaway rate is the percentage of calls going into overtime but not fully paid for by customers "walking away." Abandonment rate is the percentage of calls that customers abandoned prior to receiving busy or ringing signals.

The body of the table contains estimates, as percentages, of the incremental effects of several important service components. For example, the alerting tone is estimated to decrease mechanization rate by 0.2 percent, to increase walkaway rate by 1.4 percent, and to have no measurable effect on abandonments. Service component effect estimates are arbitrarily constrained to a zero sum on each performance measure.

Table I—Estimates of design decision effects on initial deposit request handling performance measures
(√ indicates decisions taken)

Service Components	Estimated Performance Measure Increments		
	Mechanization Rate (%)	Walkaway Rate (%)	Abandonment Rate (%)
Alerting Tone (T)			
Present (Tone)	−0.2	+1.4	Nil
√ Absent (No Tone)	+0.2	−1.4	Nil
Voice Quality (V)			
Machine (Mach)	−0.1	+1.8	+0.2
√ Natural (Nat)	+0.1	−1.8	−0.2
Announcement Wording			
"Please deposit $X.XX for. . ."	−2.2*	+4.7	+0.1
√ "$X.XX please. Please de-posit. . ."	+1.3*	−1.7	−0.8
"Please deposit $X.XX, $X.XX for. . ."	+0.9*	−3.0	+0.7
Deposit Interval Allowed			
4.5 secs	−3.7*	−1.6	−0.9
√ 6.0 secs†	+1.3*	+1.5	−0.3
8.0 secs	+2.4*	+0.1	+1.2
Speech Detector (S)			
Present (Det)	−1.0	+0.9	−0.1
√ Absent (No det)	+1.0	−0.9	+0.1
Interactions			
Tone/Voice			
√ Tone-mach or No tone-nat	+0.7	+0.5	+0.3
Tone-nat or No tone-mach	−0.7	−0.5	−0.3
Voice/Speech Detector			
√ Mach-det or Nat—no det	+0.3	−1.5	−0.2
Mach—no det or Nat—det	−0.3	+1.5	+0.2
Constants	86.4	19.8	11.5

* (Column) contrasts statistically different (p < 0.01).
† 5.5 secs selected, but 6.0 secs estimates used.

Most individual effects are estimated to be small—too small to be considered statistically different from zero with confidence. Those large enough to reach statistical significance at the 99-percent confidence level are indicated with asterisks. However, estimated effects are additive, in general.

The lower section of the table, labeled "Interactions," presents the estimable two-component interactions. These are, in effect, adjustments to the additive estimates above them. Because of the experimental design, not all such adjustments can be estimated.

To compare the performance of designs, sum estimates corresponding to each service design. For example, the service utilizing tone, natural voice, operators' announcement wording (shown first in the table), a 4.5-s deposit interval, and no speech detector would be expected to have a 10.3-percent lower mechanization rate than the service indicated by the checks (√). By adding the constants given in the bottom row of the table, the actual estimated rates are obtained.

Thus, the checked components result in estimates of 91.3, 14.5, and 10.4 percent for mechanization, walkaway, and abandonment rates, respectively, whereas the example alternative service results in estimates of 81.0, 19.6, and 10.1 percent, respectively—slightly better abandonment performance at the expense of mechanization and walkaway rates.

5.1 Alerting tone effects and recommendations

Prior to the simulation, it was reasoned that a short alerting tone would better prepare customers to understand the announcement requesting deposit and/or better prepare them to deposit promptly in cases when they knew the amount from previous experience. Thus, use of the tone should result in shorter times to first coin and better overall performance.

In addition to the effects presented in Table I, our data indicated that the ½-s alerting tone we used had no significant effect on time to first coin in most situations. However, on intermediate overtime request seizures, the tone boosted the seizure mechanization rate significantly: the tone, apparently, interrupts conversation more effectively than the announcement alone. Thus, the alerting tone is being used only on intermediate deposit seizures.

5.2 Voice quality

As mentioned earlier, a machine-like voice quality was tested in the simulation. It was thought customers might be able to respond more effectively to deposit requests if they realized they were being machine-served and they did not try to converse with the system.

The system performance effects of the machine-like voice were small, mixed, and generally not of practical importance; though walkaway rates are, apparently, increased. Overall, trends favored a natural voice slightly. However, interviewed customers strongly preferred the natural voice. Consequently, natural voice announcements are incorporated in the system.

5.3 Announcement wordings

Fairly early in the simulation study, the operator deposit request phrase (typically), "Please deposit 25 cents for the first 3 minutes," (listed first in Table I), was found to be less effective for the automated service than others. Repetition of the amount decreased average time to first coin and walkaway rate while increasing average proportion of seizures automated.

In retrospect, the improved performance associated with repeating the amount due is not surprising since Bronell and Schoeffler found that operators repeat deposit requests 3 to 15 percent of the time.

Because the automated service would not be able to respond directly to customer repeat requests, improvement is achieved by repeating amounts to everyone who does not deposit immediately.

The request wording chosen for ACTS is "25 cents please." (2-second pause) "Please deposit 25 cents for the first 3 minutes." Most customers begin depositing during the pause, truncating the announcement sequence.

5.4 Deposit and announcement intervals

The primary tradeoff for deposit timing is between allowing short intervals that favor customers who deposit quickly (but occasionally need the amount repeated) or need an operator,* and long intervals that avoid attaching an operator needlessly for customers who deposit slowly.

Announcements that repeat the deposit amount reduce the need for whole announcement repetition. Thus they increase the overall desirability of long interannouncement intervals, i.e., fewer customers must wait for prompting announcements. However, for customers needing an operator, lengthening interannouncement intervals degrades service quality. Therefore, in the final ACTS environments where relatively few customers reach ACTS when they need an operator, relatively longer intervals are desirable; in the environment where more who reach ACTS need an operator, shorter intervals are desirable. The appendix contains a discussion of a potential means of discriminating between customers who need operators and those who do not.

For initial deposit request seizures, 5.5-s interannouncement intervals were incorporated into the system. This choice represents an attempt to balance the mechanization rate benefit of 6.0 s and the walkaway reduction of 4.5 s (see Table I). For intermediate and end-of-conversation seizures, an 11-s interval is followed by operator attachment because repetition of the whole announcement was found to be ineffective in obtaining additional deposits.

5.5 Instruction cards

Bright orange instruction cards were placed on half the simulation coin stations, chosen randomly. Previous studies had indicated that coin station instruction cards are rarely noticed or used by customers. It was reasoned that, if such an attention-getting color was ineffective, no less noticeable card would work.

As anticipated, no practical, consistent changes in customer/system performance resulted from the use of bright orange cards. Customers

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* Incorrectly dialing a "1" instead of "0" prefix will result in reaching ACTS instead of an operator. This dialing error is quite common now in areas where "1" is used to specify a station toll call to be paid by coin deposit.

did use stations with orange cards about 6 percent more often on the average, indicating that they noticed the cards from a distance. However, when interviewed about service, immediately after using stations with these cards, customers very rarely remembered any card details, including the color or the statement, "Note: Charges may be requested by a recorded announcement during an equipment trial." Therefore, no special card design or card information was recommended.

VI. CUSTOMER/SYSTEM PERFORMANCE AND CUSTOMER ACCEPTANCE ESTIMATES FROM SIMULATION RESULTS

Simulation results are not only useful in reaching design decisions but also in estimating customer/system performance for the design chosen. However, these estimates are strictly applicable only to the simulation site. Because the Bronell and Schoeffler service measurement study indicated that sites bear many overall similarities as well as significant differences, many findings of the simulation are expected to be accurate more generally. (Field performance of the final ACTS in the simulation site will provide valuable information about the adequacy of the simulation.)

6.1 Times to first coin

Fifty percent of first coins were obtained within 6 seconds of the beginning of the first announcement. Ninety percent of first coins were obtained in 12 seconds, 95 percent in 14 seconds.

6.2 Proportions of seizures mechanized

Seizure mechanization rates are estimated at 91 percent for initial deposit seizures, 64 percent for intermediate deposit seizures, and 76 percent for end-of-conversation deposit seizures. Notification (at the end of the initial period) seizures, because they require no deposit, will be essentially 100 percent automated. Overall, these rates are expected to rise with customer experience, but the rate of increase cannot be predicted from simulation data, since it was conducted over a relatively short (3-month) period with intermittent service at a limited number of stations.

6.3 Abandoned call attempts

Abandoned call attempts, which can occur only on initial deposit seizures, are estimated to be about 10 percent of initial deposit seizures. This rate is expected to decline as customers become accustomed to service. Abandonment from the stations used in the trial, on calls handled normally by operators, was about 7 percent.

6.4 Walkaway rate

The walkaway rate for the design chosen is estimated initially to be about 14.5 percent of calls extending beyond the initial period. How-

ever, the validity of this estimate is difficult to assess. It is considerably higher than the 7 percent for operator-handled calls from the same stations over the trial period. Furthermore, even though no trends were detected during the trial, the walkaway rate is not expected to decrease with customer experience.

Walkaway rate is being carefully monitored in the first ACTS installations to determine the need to adopt alternative overtime collection strategies.

6.5 Customer acceptance of automated service

Interviewed simulation customers generally preferred operator service to automated service. More than a third expressed very strong preference for operator service (8 or 9 on a 9-point scale from 1 = "strongly prefer automated service" to 9 = "strongly prefer operator service"). About 15 percent preferred automated service.

The quality of announcements was the most often noticed clue to customers that they were being machine-served. Seventy-one percent of the interviewed customers receiving the natural voice announcements recognized machine handling; 79 percent recognized the machine-like voice. However, it should be noted that 28 percent of the interviewed customers who received operator service thought their calls had been automated.

Overall, interview data indicate that customers will prefer operators to ACTS initially. As they gain experience with ACTS, acceptance is expected to grow due to increasing familiarity.

VII. QUESTIONS UNRESOLVED BY THE SIMULATION TRIAL

Several important questions were not answered by the simulation study. They will be studied in early ACTS sites:
- (i) Will long-term customer acceptance require modification of the service?
- (ii) How will the operator task be affected by ACTS? (Customers reaching operators will often be those who have failed to satisfy ACTS.)
- (iii) Will walkaway rates remain at tolerable levels?
- (iv) Should ACTS employ different announcements, timings, etc., in different locations? In the same location over time?
- (v) Should a voice detector be incorporated into ACTS? (See the appendix for discussion of the voice detector.)

VIII. COST/WORTH ANALYSIS OF SIMULATION AND OTHER HUMAN FACTORS STUDIES

In addition to the savings provided by the initial proposal for ACTS, improvements in the ACTS seizure mechanization rate due to human

factors work will yield substantial additional savings. Operator procedures and associated training materials developed for the simulation study were valuable in preparing for the actual service. Customer/ system performance and customer acceptance evaluation tools prepared for the trial are now being used to evaluate early ACTS installations.

In addition, the simulation experiment forced the development, systems engineering, and AT&T operator services organizations to understand the new service in depth early in the development cycle. This understanding permitted early formulation of very detailed operational requirements. The experiment also provided an early indication of some unanticipated development problems. For example, it was discovered that the editing features for analog announcement source tapes were not adequate for producing high-quality announcements. A digital phrase-editing system was consequently proposed and developed in time for the first installation.

IX. ACKNOWLEDGMENTS

We wish to express our deepest appreciation for the efforts of those who supported the human factors studies. Particularly central were the efforts of B. W. Rogers, D. J. Miller, D. E. Confalone, W. K. Comella, and M. S. Schoeffler of Bell Laboratories, as well as the Illinois Bell staff of the Great Lakes TSPS.

APPENDIX

Considerations Leading to Proposal and Evaluation of a Voice Detector to Discriminate Between Customers Who Need an Operator and Those Who Do Not

Manual simulations revealed a problem inherent in the scheme of using machine-controlled announcements to obtain customer deposits: a *long* interannouncement interval is desirable to allow the slowest customers to make deposits without being "rushed," but a *short* interannouncement interval gives better service to customers who need immediate repetition of the announcement or operator assistance. What is needed is a way to discriminate between the two situations.

A potential solution was suggested during the manual simulations when we observed that customers desiring operator assistance often ask questions or make statements during the intervals following announcements, whereas customers preparing to deposit generally do not. For example, customers who say things like, "How much was that, operator?" "Make that a credit card call, operator," or "This is a collect call," need either an announcement repetition or an operator.

A "voice detector" was devised and built to end the ongoing deposit interval if speech occurs. Initially, this causes the announcement to be

repeated. If talking persists, an operator is more quickly attached. Intuitively, this makes possible the provision of long intervals for (silent) customers slow to deposit while responding more promptly to those (speaking) who need announcement repetition or operator assistance.

The simulation trial did not provide a sensitive test of the voice detector for several reasons:

(i) Potential benefit is limited *a priori* to those users who need announcement repetition or an operator. The need for announcement repetition was largely eliminated by selecting announcements that state the amount twice. Also, customers needing an operator due to dialing errors ("one plus" instead of "zero plus") were unusually rare in Chicago compared to other cities Bronell and Schoeffler characterized.

(ii) No sensitive measures of the service improvements afforded by the voice detector were readily available. (Customers are unaware of the voice detector, and we were able to obtain very limited observer data.)

Our limited data indicate that the voice detector operated as intended. It was triggered in about 56 percent of the cases for which a shortening of the interval was beneficial but acted only 6 percent of the time when it was not potentially beneficial. The majority of cases it missed were due to customers talking during an announcement (when it was disabled because it would have been triggered by the announcement—an easily rectifiable design flaw). However, the voice detector had only a minor impact on primary performance criteria.

Inclusion of the voice detector cannot be recommended on the basis of the data available from the simulation. However, the problem the voice detector was devised to solve still exists and could, at some future time, be shown to justify voice detector inclusion in ACTS or other mechanized services where customer speech is a reliable and useful indicator.

REFERENCES

1. M. Berger, J. C. Dalby, E. M. Prell, and V. L. Ransom, "TSPS No. 1: Automated Coin Toll Service Overall Description and Operational Characteristics," B.S.T.J., this issue, pp. 1207–1223.
2. G. T. Clark, K. Streisand, and D. H. Larson, "TSPS No. 1: Station Signaling and Announcement Subsystem: Hardware for Automated Coin Toll Service," B.S.T.J., this issue, pp. 1225–1249.
3. R. Ahmari, J. C. Hsu, R. L. Potter, and S. C. Reed, "TSPS No. 1: Automated Coin Toll Service," B.S.T.J., this issue, pp. 1251–1290.
4. J. C. Dalby, personal communication.
5. C. E. Bronell and M. S. Schoeffler, personal communication.
6. O. O. Gruenz, Jr., personal communication.

Traffic Service Position System No. 1:

Software Development Tools

By J. J. STANAWAY, Jr., J. J. VICTOR, and R. J. WELSCH

This paper is concerned with the development tools, strategies, and methodologies employed by Traffic Service Position System (TSPS) application programmers for the creation and testing of TSPS software. Two environments are described: (i) The support environment provided by an IBM 370/168 and related TSPS support software packages for the production of testable TSPS software. (ii) The support environment provided by the TSPS system laboratory, utility system, and specialized hardware for testing the TSPS software.

I. INTRODUCTION

This paper describes the tools of TSPS software generation and testing in the following environments:
  (*i*) The facilities provided via a general-purpose IBM processor for the production of testable TSPS software.
  (*ii*) The facilities provided by the TSPS system laboratory for testing new and changed TSPS software in an operational environment.
  Section II is concerned with the IBM support environment utilized by TSPS application programmers. The major tools and strategies are described. More important, the methodologies that make use of these tools are explained. Section III is concerned with the testing environment provided by the TSPS system laboratory. This environment combines an actual TSPS machine, a utility system and related software, and special hardware for debugging TSPS software.

II. SOURCE CODE DEVELOPMENT AND GENERATION OF SPC-LOADABLE OBJECT CODE

This section concerns itself with the general environment of TSPS source code creation, modification, and preparation for testing using the TSPS system laboratory and associated utility systems.

2.1 General software support environment of TSPS

The software required to operate a particular TSPS installation is comprised of approximately 300 programs (PIDENTs) totaling over 200 thousand 40-bit Stored Program Control (SPC) 1A machine instructions. The combination of these 300 PIDENTs into an issuable (via Western Electric) software package is referred to as a generic release. There are currently four active TSPS generic releases, each having implemented a major new TSPS feature.

The implementation of new minor enhancements are normally provided by a new release of an existing active generic. All capabilities provided by the software of a lower numbered generic are also provided by the higher numbered generic in addition to the new major feature. The starting point for software development of a new generic will be the current state of the source modules comprising the previous generic. Many of these modules remain unchanged in the new generic. Others are modified to produce a new version of the PIDENT that adds the new capabilities for the new generic. In addition, new PIDENTs are created for the new generic. It is therefore possible to have to maintain as many versions of a PIDENT as there are active generics.

2.1.1 Featuring and a single source environment

Four active generics with 300 PIDENTs per generic could imply that 1200 PIDENT source modules would have to be maintained. This is not the case. TSPS employs the use of "featuring" to maintain a single source module for a PIDENT regardless of the number of distinct versions of that PIDENT. Featuring basically means the following:

> Any addition to a PIDENT source module must be bracketed by feature control directives which, during the assembly of the source module, direct the assembler to either assemble or ignore the bracketed source code. Any existing source lines to be replaced/deleted are likewise bracketed.

This implies that a single source for a PIDENT can be maintained which is capable of generating multiple versions of the PIDENT's object module (i.e., the output of the assembler). By appropriate feature control directives to the assembler, different versions of a PIDENT can be assembled. In speaking of multiple versions of a PIDENT due to four active generics, what actually is meant is that multiple versions of a PIDENT's object module are producible from a single PIDENT source module.

The feature control directives employed by TSPS are:

INFOR feature expression

OUTFOR feature expression
ENDFOR feature expression.

The term "feature expression" in all three is a Boolean expression which is evaluated as "true" or "false" by the assembler. INFOR implies "assemble" the following source lines if the feature expression is true. OUTFOR implies "ignore" the following source lines if the feature expression is true. ENDFOR is the terminating bracket for source lines to be assembled/ignored. INFOR with a true feature expression is the same as OUTFOR with a false feature expression. "Feature expressions" may be combined with Boolean "and," "or," and "not" operations.

Each generic has associated with it sets of feature expressions that always evaluate as true. Every assembly of a PIDENT source module is initiated by the processing of a special control statement which specifies the generic for which the PIDENT is being assembled and therefore the feature expressions which are to be "true" for this particular assembly.

2.1.2 Software development support environment

Software to be executed on the TSPS SPC 1A is generated by means of the computing facilities of an IBM processor located at the Columbus, Ohio branch laboratory of Bell Laboratories. This facility operates the OS/370 operating system with the IBM Time Sharing Option (TSO). The latter point is significant because the TSPS development organization resides at the Indian Hill laboratory in Naperville, Illinois. All accesses to the TSPS software data base are through TSO via dial-up terminal access from Indian Hill. The high-speed data network (VIPERDAE) connecting Columbus and Indian Hill allows hard copy and tape output to be returned to Indian Hill.

TSO provides the needed interactive facilities to both TSPS application programmers and TSPS program administration personnel for data base administration, PIDENT creation and modification, and submission of OS/370 batch jobs for assemblies, loads, etc. It should be mentioned that this interactive environment was new for TSPS with the development of Generic 8. Before Generic 8, the software development environment was punched-card-oriented, with all functions to be performed being initiated via over-the-counter submission of card decks.

2.1.2.1 Creation and modification of PIDENT source modules.
The major TSO-provided tool utilized by TSPS application programmers for the creation or modification of PIDENT source is the QED text editor. QED is a powerful, flexible, and general-purpose text editing facility capable of either line number or context editing on a range of various OS/370 file organization types. It should be mentioned at this time that TSPS application programmers do not directly modify existing

PIDENT source modules. Since a single-source module is used to generate (via assembly) the object modules for more than one active generic, it is felt that direct modification of the PIDENT source for any particular generic is too dangerous. Instead, TSPS employs the use of two editors for PIDENT source modification. Via QED, the application programmer is actually creating the editor statements to be processed by the Advanced Processor Editor (APE). APE is a very simple, line-number-oriented editor. It provides only the basic "insert," "replace," and "modify" functions and is specifically designed to operate in conjunction with the TSPS assembler. In almost all cases, APE and the TSPS assembler are executed in sequence in the batch environment of the OS/370. APE applies the edits created via QED to the official PIDENT source and outputs a temporary edited copy of the PIDENT source, which is then assembled. The actual PIDENT source module is not altered during this sequence, although the mechanism does exist in APE to permanently apply the edits to the PIDENT source module, renumber all lines sequentially, and regenerate the PIDENT source module. From this point on, any reference to a PIDENT source module is actually a reference to a PIDENT source module in combination with the official module of APE edits for that PIDENT.

2.1.2.2 The TSPS assembler. The creation/modification of TSPS PIDENT source (source + APE edits) is only the first step in a sequence. This sequence of functions will eventually produce an output from the IBM support machine which is capable of being executed and tested on the TSPS system.

The second step in this sequence is the conversion of the PIDENT source module into an assembled object module suitable for input to the load step. This conversion process combines the execution of the APE editor to produce a temporary modified source module, followed by the assembly of this modified source module by the SPC-SWAP (*Sw*itching *A*ssembly *P*rogram) assembler. Primary outputs of the SPC-SWAP assembler are an object module and an assembly listing corresponding to a particular version of the PIDENT. SPC-SWAP is an excellent, high-powered assembler which possesses an assortment of pseudo-operations for controlling listing format, symbol definitions, etc. SPC-SWAP also includes powerful MACRO definition and usage facilities.

Another facility of the SPC-SWAP assembler which is heavily used by TSPS in its multigeneric environment is the capability to create a special file (referred to as a library) of symbol or macro definitions which can then be accessed by subsequent PIDENT assemblies for the purpose of symbol or macro resolution. It is the library and macro facilities of SPC-SWAP which allow the single-source, multiple-generic environment of TSPS to be viable. The feature control directives described in Section 2.1.1 are actually macros available through the

library facility to each TSPS PIDENT assembly. The control statement which initiates each PIDENT assembly is again a macro (the PACKAGE macro). Execution of the PACKAGE macro, which basically takes a generic name as a parameter, establishes the generic environment of the assembly (i.e., what feature expressions evaluate as "true"; what generic-dependent libraries of symbol, macro, and data definitions will be available during the assembly; what "name" should be given to the produced object module; etc.). Simply by "inserting" via APE a different specification for the PACKAGE macro and reassembling, a single-source module is capable of producing many different generic-dependent versions of its object module.

2.1.2.3 The TSPS loading process.
Object modules produced by the SPC-SWAP assembler are not suitable as input to the TSPS. The final step in the sequence of operations which produces SPC-compatible output is the execution of the SPC loader on the IBM support machine. Primary inputs to the SPC loader are the object modules for all PIDENTs comprising a particular generic software release and control directives specifying such things as (i) what areas of SPC memory are available for loading PIDENTs, (ii) what PIDENTs are to be loaded and, if necessary, at what addresses, and (iii) what types of maps and cross references are to be generated. In these respects, the SPC loader is very similar to most relocatable linking loaders. Primary output of the SPC loader is an 800-bits-per-inch, 9-track tape representing the relocated, fully linked generic load module which is capable of being read into SPC memory and executed. Corresponding to the tape output is a printed load map showing memory assignments, available space, etc., and optionally cross-reference listings showing entry point definition and PIDENTs referencing.

An additional capability of the SPC loader is somewhat unique to ESS-type loaders and is heavily used during TSPS software development. When creating a full generic software load of all 300 or so PIDENTs, the SPC loader can be directed to create a special file, called a HISTORY, into which detailed information concerning the generated load is written. The information includes the names of all PIDENTs loaded; the addresses at which they were loaded; how much space each consumed; what entry points each defined; where each entry point was referenced; where and how much free SPC memory remains; what SPC memory was originally available to be loaded; and a complete copy of the relocated, linked, and loaded SPC memory. On a subsequent execution of the SPC loader, the HISTORY file can be reinput to provide the capability for what is known as a partial load. On a partial load, the SPC loader need only be informed of changes to be made to the previous full load represented by the HISTORY. Previously loaded PIDENTs can be unloaded or replaced by new versions, new PIDENTs can be added, additional SPC memory can be made available for loading into, and a

new HISTORY reflecting all changes can be generated. Of particular importance is that, on a partial load, the tape that is generated reflects only the difference between the updated load image and the previous load image that had been saved on the input HISTORY file. This partial load facility of the SPC loader provides SPC application programmers with an incremental load capability that is the basis for one of TSPS's primary software development methodologies to be described.

2.1.2.4 The Interactive Program Administration System. IPAS (Interactive Program Administration System) is a tool developed for use by TSPS and other SPC 1A based systems. IPAS executes in the interactive TSO environment and primarily serves to shield the application programmers and program administration personnel from the complexities of the OS/370 operating system, specifically the nontrivial Job Control Language (JCL) required for batch execution of SPC-related support tools. IPAS is based on the concept of PIDENTs and versions of PIDENTs and utilizes the Bell Laboratories Data Management System (DMS), a hierarchical data base system. IPAS provides the TSPS user with access to QED for line edit file creation and a simple command language for initiating the execution of the SPC-SWAP assembler, the SPC loader, and other minor support tools. IPAS was developed for use with all TSPS generics but to date has been most extensively used on the Generic 8 development.

2.2 TSPS software generation methodologies

The discussion to this point has centered on the support tools and basic implementation strategies available for generating and preparing for execution the TSPS PIDENT source modules. The discussion now turns to the methodologies which make use of these tools and strategies. Two methodologies will be covered, one which applies to software generation in a relatively free administrative atmosphere, and another which applies to software generation in a very tightly controlled change environment. Both have been applicable to the recent Generic 8 development, and in fact both were formulated for the Generic 8 development. Both are equally applicable to the other generics. The two methodologies correspond to the two administrative modes under which TSPS application programmers work. The "development" mode implies the free atmosphere; the "frozen" mode, the tightly controlled atmosphere.

2.2.1 Development mode methodology

The "development" mode primarily applies to the generation of a major new feature, and therefore to a new generic. In this mode, the object is to provide the application programmers with as much freedom as possible in generating the new feature. For this reason, there is little restriction on how the programmers modify existing PIDENTs or create

new PIDENTs. The methodology formulated for this "development" environment is heavily based on the team programming concept and the partial load capabilities of the SPC loader.

The overall software development of the Automated Coin Toll Service (ACTS) feature was divided basically along functional lines. TSPS application programmers were organized in programming teams based on these functions. The implementation of a given function required the modification of some subset of the 300 or so TSPS PIDENTs and the creation of new PIDENTs. The functional subsets of PIDENTs were not necessarily mutually exclusive. Many times multiple functions required modification to the same PIDENT. The startup point for the software development of Generic 8 was the stable state of the TSPS software as it existed for Generic 7 in the second quarter of 1976. TSPS program administration personnel set up the proper PACKAGE macro for Generic 8 and established the Generic 8 dependent macro and symbol libraries which the PACKAGE macro would make available to the SPC-SWAP assembler when performing Generic 8 assemblies. All Generic 7 PIDENTs were then reassembled to produce relocatable Generic 8 versions of the PIDENT object modules. Recall that a PIDENT source is actually the combination of the official (i.e., Program Administration Group [PAG] controlled) PIDENT source module and the official file of APE line edits for that PIDENT. All relocatable Generic 8 object modules were then input to the SPC loader to produce a full Generic 8 load module. This load module was designated the "Base 0" Generic 8 load, capability-wise identical to the Generic 7 state from which it was generated, and loadable and executable in the TSPS system laboratory. The foundation upon which to build Generic 8 was established.

The programming teams were now capable of incrementally modifying this "Base 0" load and testing their function implementation. To illustrate the methodology, assume programming teams 1 and 2. The function of team 1 requires modification of PIDENTs A, B, and C, and the creation of a new PIDENT D. The function of team 2 requires modification of PIDENTs A, E, F, and G. Team 1 would proceed as follows:

(*i*) Exact copies of the official line edit files for PIDENTs A, B, and C would be created using QED. Each would be modified as needed for team 1 function implementation.

(*ii*) The source for new PIDENT D is created using QED.

(*iii*) An SPC-SWAP assembly is initiated via IPAS or other TSO facilities utilizing the copied and modified team 1 line edit files for PIDENTs A, B, and C and the created source file for PIDENT D. The object modules produced by SPC-SWAP are saved as team 1 object modules.

(*iv*) Using the SPC loader, initiated via IPAS, a partial load is gen-

erated based on the HISTORY file corresponding to the "Base 0" Generic 8 load. PIDENTs A, B, and C are replaced by team 1 versions, and PIDENT D is added. The partial load tape produced reflects only the differences between the team 1 load and the "Base 0" load.

(v) Team 1 is now capable of overlaying their partial load image on top of a known-to-be-stable "Base 0" load image in the TSPS system laboratory and testing their function unencumbered by new code from other teams.

(vi) The cycle can be reiterated as problems are discovered during testing, except that modifications are made to team 1 line edit files.

Team 2 has concurrently been developing their function following the same procedures as outlined for team 1. This approach allows very extensive testing of individual functions, comprising large amounts of new and modified software, to be accomplished prior to a large-scale integration of functions.

The PAG personnel again became involved with the Generic 8 development at periodic intervals (usually 6 to 8 weeks) to produce an updated base load. In preparation for performing the official reassemblies for all PIDENTs modified by the programming teams, a merging of official and team line edit files must take place.

Recalling that both teams 1 and 2 copied the official line edit file for PIDENT A, the PAG personnel would first merge the team line edit files for PIDENT A, and the result would then be merged with the official line edit file for PIDENT A to produce an updated official line edit file. PIDENTs modified by a single team required only a single merge. The final merge with the official line edit file guaranteed that no original official line edits had been inadvertently deleted or modified in such a way as to adversely affect generics. Having completed the merging process, PAG could then make any required modifications to Generic 8 macro or symbol libraries, and then reassemble all modified PIDENTs to produce updated official Generic 8 object modules. These object modules now would contain all the function code tested by the individual teams up to the time the new base was created. PAG then reexecutes the SPC loader to produce a "base $n + 1$" load module and corresponding HISTORY file. The base load image in the TSPS system laboratory is then updated to "base $n + 1$," and the new base can be system-tested to ensure stability.

Although a large amount of new and modified software is introduced with a new base load, the interval between the start of the merging process and the completion of the system testing of a new base averages about 2 weeks. During this interval, the programming teams are able to continue working against "base n," with the stipulation that any additional team line-edit changes must be incorporated with

the updated official line-edit files reflecting "base $n + 1$." Due to heavy testing of individual team functions, a minimum amount of system testing is required to stabilize the new base load, even though the functions had not previously been integrated.

Prior to Generic 8, the "development" mode methodology was based on manually overwriting a load image in the TSPS system laboratory to test new functions or including untested software in new load images. System testing of new load images was an enormous, time-consuming task. Function testing via manual overwrites was more of a hindrance to software development than a help.

2.2.2 Frozen mode methodology

The "frozen" mode of software generation applies primarily to active generics which have been issued through the Western Electric Company, and to the latter stages of the development of a new generic. The objective of the "frozen" mode is to maintain the maximum amount of stability in the generic software by providing a highly controlled and documented change environment through which application programmers must make software corrections.

For a generic in the "frozen" mode, software change is initiated in response to a written Trouble Report (TR) documenting a suspected problem or a needed improvement. The "frozen" mode imposes a number of restrictions on the application programmers and PAG as to the manner of software change:

    (*i*) No change to a PIDENT can cause the size of the PIDENT's object module to either increase or decrease.

   (*ii*) The primary method for testing is not the partial load, but incrementally applied changes to the frozen generic's load image in the TSPS system laboratory.

  (*iii*) Line edit changes corresponding to a laboratory change must produce a bit-for-bit match between the PAG-generated (via PIDENT reassembly) next release of the frozen generic and the overwritten old release in the TSPS system laboratory.

  (*iv*) All programmer-generated changes must be independently tested and approved by a generic test team.

   (*v*) The application programmer must generate a written Correction Report (CR) documenting any changes made in response to a TR.

  (*vi*) Not only must the change be independently tested, but the TR, CR, overwrite, and line edits must be approved by a generic software change review committee prior to the line edits being included in the next release of the frozen generic.

To alleviate some of the problems associated with (*i*), (*ii*), and (*iii*), above, a functionally identical set of "patching" directives exists,

available to both the SPC-SWAP assembler and the test laboratory utility system overwrite assembler. In the case of SPC-SWAP, these are TSPS system macros available to any PIDENT assembly. They are merely control directives to the utility system overwrite assembler. These "patching" directives allow the application programmers to add new software, replace existing software, or delete existing software within a PIDENT without altering the assembled size of the PIDENT.

Primary input to utility system overwrite assembler is a deck of punched cards, composed of symbolic SPC source to be assembled, and utility system control directives. A few major restrictions on the change to be assembled are:

 (i) There is no macro capability. Any macro to be assembled must be manually expanded prior to input.
 (ii) There is no LIBRARY facility as with the SPC-SWAP assembler. The utility system overwrite assembler must be explicitly informed of the value of any and all symbols referenced by the overwrite but not defined within the overwrite.
 (iii) No arithmetic beyond addition and subtraction is allowed.
 (iv) Many data defining pseudo-ops of the SPC-SWAP assembler are not recognized by the overwrite assembler.

Given these restrictions of the overwrite assembler and the previously stated restrictions of the "frozen" mode environment, the change implementation flow prior to Generic 8 (and therefore prior to general TSO usage by TSPS) went as follows:

 (i) The TR would be received by the application programmer who would be making the software change.
 (ii) The application programmer would generate an overwrite deck to fix the stated problem and test the fix by temporarily overwriting the generic load image in the system laboratory.
 (iii) Satisfied with the results, the application programmer would generate the corresponding CR and a deck of line edits for the PIDENT source which produced results identical to the overwrite.
 (iv) The TR, CR, overwrite deck, and line edit deck would then be submitted to the generic software change review committee for approval. If rejected, back to step (ii).
 (v) If approved, the TR, CR, overwrite deck, and line edit deck are submitted to the generic system test team for independent overwrite testing. If rejected, back to step (ii).
 (vi) If approved, the TR, CR, overwrite deck, and line edit deck are submitted to PAG. The line edit deck is included in the official line edit deck for the PIDENT(s) involved, the TR and CR are filed, and the overwrite deck is saved.

This procedure was followed for each TR requiring a software change. When a new release of the frozen generic was required, PAG would

reassemble all modified PIDENTs and regenerate the generic load, maintaining the starting address and size of each PIDENT. This new load was required to exactly match the overwritten load image in the TSPS system laboratory before it would be released to Western Electric for distribution. The methodology outlined above was successful but possessed inherent and painful shortcomings when it was time to generate and match the next release of the frozen generic. The shortcomings were primarily due to the overwrite assembler and the need to create a separate line edit deck producing identical results. The areas most susceptible to error were the manual symbol resolution and manual expansion of macros required by the overwrite assembler, but not required in the line edits.

For Generic 8, the basic theory of this overwrite methodology, with its checks and approvals, was not substantially altered. There was, however, the development of a new tool, an Overwrite Generation (OVGEN) program, which eliminated the need for separate manual generation of overwrite and line edit decks. OVGEN allowed application programmers to continue to create line edits as files via QED. OVGEN requires the application programmer to include in the line edit file special control directives, identified by the programmer I.D. and a trouble report number, which informed OVGEN of which line edits to extract for overwrite generation. OVGEN, actually a combination of three pre-processors, an SPC-SWAP assembly, and a post-processor, outputs a symbolic overwrite deck for input to the utility system overwrite assembler. The overwrite deck contains all information needed for external symbol resolution. Due to the fact that SPC-SWAP is used to assemble the line edits, the application programmer can utilize macros, libraries for symbol resolution, the SWAP data defining pseudo-ops, etc. In other words, for the application programmer, the environment is quite similar to the partial load environment, with final output being an overwrite deck instead of a partial load tape.

The advantages of the OVGEN procedures in the frozen mode are many.

   (*i*) The application programmer need only create the line edits in response to a TR.

   (*ii*) The macro facilities of SPC-SWAP are available for use.

  (*iii*) Symbols used which are external to the line edit are resolved via pre-processing and SWAP LIBRARY facilities.

  (*iv*) Line edits are individually assembled. This leads to far less assembly problems by PAG when the full reassembly of the PIDENT is performed for the next release of the frozen generic.

   (*v*) The final match between the new release of the frozen generic and the old release plus overwrites is considerably cleaner due to the overwrites having been generated directly from the line edits.

III. LABORATORY TESTING ENVIRONMENT

TSPS programmers use the TSPS system laboratory complex to test and debug new or changed PIDENTs. One or more programmers working on similar program areas will schedule time in the lab. Thus, this complex has been designed to provide a working environment conducive to high programmer productivity.

Two TSPS laboratories are available to programmers. Both consist of the Stored Program Control (SPC) No. 1A/TSPS complex, the nonresident utility system, and call-oriented simulators. The SPC/TSPS complex allows programmers to test in an environment much like a typical TSPS office. The utility system and simulators provide debugging aids not found in a typical office. This section describes the hardware and software facilities which make up the laboratory complex.

3.1 Hardware configuration

The TSPS laboratory configuration is shown in Fig. 1. This section discusses each component in the configuration except the simulators, which are discussed in Section 3.3.

3.1.1 Stored program control (SPC) 1A

The TSPS is controlled by the SPC 1A.[1] The SPC consists of a processor, memory system, central pulse distributor, signal distributor, master scanner, and a maintenance control center for the man-machine interface. Each of these parts is duplicated for reliability except the maintenance control center.

The SPC processor provides the control for the TSPS by executing the instructions in the memory. The processor cycle is 6.3 μs. The registers available in the processor include a 20-bit Program Address Register (PAR), 20-bit Address Image Register (AIR) which contains the address of the most recent store access, 47-bit Memory Access Register (MAR) for storing the information read from or written into the memory, and seven 20-bit index registers. The index registers are general purpose and may be used for any function.

The word length of the SPC memory is 47 bits (40 bits of information and 7 for error correction). There are 20 bits of addressing. Nineteen bits select the memory word. The remaining bit determines which half of the word is used.

The processor communicates to the peripherals and TSPS by three units: the Central Pulse Distributor (CPD) which allows the SPC to send pulses to points in the system where fast response to an instruction is needed, the signal distributor which allows the SPC to operate or release magnetic latching relays which are connected to output points, and the master scanner which provides status and supervisory inputs to the SPC from the various units in the SPC complex.
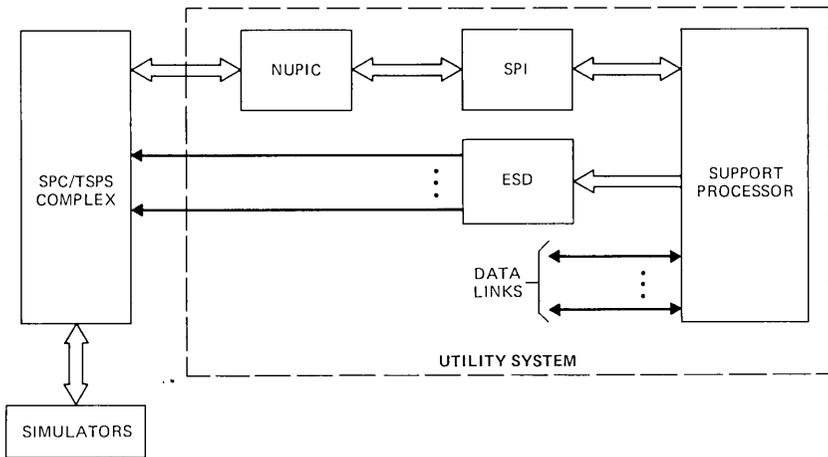
Fig. 1—TSPS system laboratory.

The Maintenance Control Center (MCC) consists of a control and display panel, a teletypewriter, and a program tape unit for loading the SPC 1A memory.

3.1.2 Nonresident utility system

The utility system provides a means for easily loading and reading the SPC memory, for debugging real-time programs in a noninterfering fashion, for controlling devices in the laboratory, and for transmitting or storing files. The advantage of this utility system over the earlier TSPS utilities is that the programs are nonresident to the SPC and that debugging of programs can be done without interfering with the execution of the system's real-time programs.

The utility system is a combination of hardware and software. This section discusses the hardware aspects of the system, and other sections discuss how the utility system is used for software change administration and program testing. The utility hardware consists of a support processor, a support processor interface, a noninteracting utility program interface console, an electronic signal distributor, and serial data links.

3.1.2.1 Support processor. The support processor used in the utility system is a commercial minicomputer. The minicomputer uses the XVMDOS operating system and its peripherals include a 9-track magnetic tape unit, fixed head disk, 3-disk-pack bulk memories, teletypewriter, high-speed printer, card reader, and paper tape reader and punch.

User files and TSPS generic programs are stored on the disk memory. These files can be updated and additional files added by means of the

magnetic tape unit, card reader, or paper tape reader. The user input is via the teletypewriter and card reader. The output is usually over the high-speed printer.

3.1.2.2 Noninterfering utility program interface console / support processor interface (NUPIC/SPI).

The interface between the SPC and the support processor is the Noninterfering Utility Program Interface Console (NUPIC) and the Support Processor Interface (SPI). The NUPIC and SPI are two separate circuits but are discussed together because they are so closely related.

The NUPIC interfaces directly with the SPC processors to allow the user to monitor and control the system programs. It provides access to the PAR, AIR, MAR, and the index registers in each SPC processor. It also provides processor clock control and interrupt interfaces. The circuitry in the NUPIC allows the user to load the SPC, read the SPC memory, set program matchers, and have the contents of the SPC registers read and stored. The NUPIC has a man-machine interface consisting of SPC register displays and manual controls. These manual controls are particularly useful if the support processor should fail. The section on program testing will discuss the debugging aids available with the NUPIC.

The NUPIC is controlled by the support processor via the SPI circuit, which provides a 2-way, high-speed data communications channel. Since the support processor and the SPC processors have different word lengths and different cycle times, buffering (core memory) is provided in the SPI. The SPI is used in conjunction with the NUPIC and the support processor for loading the SPC memory, reading the SPC memory, and collecting data during program debugging.

3.1.2.3 Electronic signal distributor (ESD).

In testing programs, it is often necessary to have TSPS configured differently due to multiple generics. This means that specified circuits can be connected to or removed from the TSPS buses, equipment can be removed from service, or equipment can be put into service. The ESD provides a means to do this automatically. Up to 2048 distributor points can be individually set or reset by the support processor. These points can be used to control relays, lamps, and logic inputs.

Each user can have a file on the support processor which specifies the generic program and how the ESD points should be set. Section 3.2.1.2 discusses the creation and execution of the user files.

Another use of the ESD is for physical fault insertion. This application is discussed in a later section on trouble location manual generation.

3.1.2.4 Serial data channels.

Several serial data channels are available on the support processor. The channels are full duplex, with data rates up to 10K baud. The channels are used for transmitting

files or receiving files for storage. Presently, one of these channels is used for transferring user call load files to and from the microprocessor controlled call simulator (Section 3.3.3.2) and another is used for loading the writable storage unit (used in program development) of the Programmable Controller in the Station Signaling and Announcement Subsystem for the Automated Coin Toll Service[2] (ACTS) feature.

3.2 Laboratory software change administration

The desire to add new features, as well as the need to correct software errors, make it necessary to be able to easily change programs in the TSPS laboratory. This is done differently, depending on the state of the software base being changed. If the code is being developed into a new major generic issue, programmers are free to perform large-scale code modifications and additions. This is termed the development mode. If the base is already an official generic issue, only minor changes and additions can be made in response to specific troubles. This is done to minimize the need for extensive retesting after applying the change. This mode is termed the frozen mode.

This section deals with the tools available for changing the TSPS program in the lab in both of the above modes.

3.2.1 Development mode

As mentioned in Section 2.2.1, the partial load is the primary means of changing code in the development mode. A partial load tape containing all new and changed object code is brought into the TSPS lab by the programmer for debugging. The programmer then uses two support processor programs to load the base load plus the partial load into the SPC. These programs are DZLOAD and ALCFG (Automatic Laboratory Configuration). Once the desired load is in the SPC, the NOVA (Noninteracting Overwrite Assembler) program is used to make minor code revisions until a new partial load tape can be generated.

3.2.1.1 The DZLOAD program. DZLOAD is the interchange and comparator program for SPC code and data residing on magnetic tape, disk, or SPC memory. It allows the user to easily load and verify SPC programs as well as create duplicate copies of SPC memory on disk or tape. The user may choose to store a partial load tape on disk in the support processor, which eliminates the need to carry the magnetic tape into the lab for subsequent debugging sessions.

DZLOAD deals with only one file at a time; however, the support processor can also load multiple files and control the TSPS lab's hardware configuration. The program that does this is called ALCFG.

3.2.1.2 The ALCFG program. The TSPS system laboratories are used to develop and test hardware and software for use at TSPS installations in the field. The laboratory is used to simulate configu-

rations existing in the field and new hardware configurations under development.

The ALCFG program allows the user to easily and quickly change the laboratory's program and hardware configuration. The result is increased lab availability, brought about by a decrease in the manual action required to establish a particular configuration. The user can predefine a configuration and store it on a support processor disk. Thus, calling in the configuration definition under ALCFG will cause the quick reestablishment of the desired lab environment—both software and hardware. The lab hardware is controlled by the Electronic Signal Distributor (ESD). The ESD is explained in Section 3.1.2.3. ALCFG allows the user to easily define a particular ESD state.

During a lab testing and debugging session, the user will probably uncover minor coding errors or oversights. These errors can be temporarily corrected in SPC memory using the NOVA program.

3.2.1.3 The NOVA program. NOVA is a utility program that allows the lab user to overwrite SPC memory. The input to NOVA is symbolic SPC source code residing on punched cards or disk, or typed directly on the user terminal. Since the program being changed resides at a fixed SPC memory location and occupies a fixed amount of storage space, code additions must be incorporated in a "patched" fashion. NOVA is therefore designed to manage a series of patch buffers. These buffers are the actual start and end addresses of spare program memory in the SPC. Definitions of these buffers are covered in Section 3.2.2.2.

NOVA allows the user to specify program changes in either relocatable or absolute fashion. NOVA reads the overwrite statements, assembles them into SPC object code, prints a listing, and stores a binary image of this code on a support processor disk. This binary file is then loaded into SPC memory. Another binary file is also kept by NOVA, namely, the contents of the addresses specified in the overwrite prior to loading the overwrite. This file is identified by a temporary overwrite number. The user can therefore instruct NOVA to flush a specific overwrite out of SPC memory by restoring all addresses to their contents prior to the change.

Many options are available to the NOVA user. Some commonly used ones are (*i*) assemble and produce a listing, (*ii*) assemble, produce a listing, and create a binary file, (*iii*) load the last binary file created, and (*iv*) print the old data along with the overwrite listing. Another option has to do with permanent overwrites. This is covered in the next section.

3.2.2 Frozen mode

The NOVA-assembled overwrite is the primary means of changing SPC code in the frozen mode (see Section 2.2.2). The main emphasis in

this mode is placed on incremental change documentation and testing, and administration of the updated generic base load. The NOVA program is used extensively during this process. A programmer submits, in addition to TR/CR (trouble report/correction report) forms and line edits, a symbolic overwrite to a system test team. This overwrite is designed to fix a particular trouble existing in the base generic. The test team tests the change as a temporary NOVA overwrite and, if accepted, prepares to permanently incorporate it in the base generic.

3.2.2.1 NOVA— Permanent overwrites. The mechanics involved in establishing a permanent NOVA overwrite are very similar to those for temporary overwrites. The main differences are

1. No old data file is kept (permanent overwrites cannot be flushed from SPC memory).
2. The pointers into the patch buffers are permanently changed to indicate that patch used in the overwrite is no longer spare program memory.

In addition, a permanent record of the start and end address of individual patches is kept on disk. This information is extremely useful to PAG when generating a patched load (see Section 2.2.2) corresponding to the updated lab base load. Each patch origin must be defined to allow the SWAP assembler to correctly assemble the patched code into the changed program. The NOVA permanent overwrite listing is used to document the change in the lab until the new PAG load and listings are produced.

3.2.2.2 NOVA— Generic administration. Up to this point in the lab software change section, only one base load is mentioned. However, as stated in Section 2.1, more than one TSPS generic issue is usually active at one time. Consequently, NOVA must be able to properly change and patch programs for each active generic. This generic is identified by the user each time the NOVA program gets called in. NOVA uses this identification to access a set of PIDENT and PATCH files unique to that generic. The administration of these PIDENT and PATCH files is handled by a portion of NOVA, called PIDAM. The system test group usually takes care of this administration. PIDAM allows the user to define and update the PIDENT and patch files for each generic. These files contain a list of all PIDENTs that make up the generic issue along with their start and end addresses, available patch buffers, a store patch map (i.e., a map linking SPC programs to a specific patch buffer), and a list of all permanently loaded patches (see Section 3.2.2.1).

3.3 Laboratory program testing

After the SPC has been loaded with a new generic program (development mode) or changes made to an existing generic program (frozen mode), the programmer is ready to begin testing. The following sec-

tions describe the hardware, software, and simulators available to the programmers for testing programs.

3.3.1 Hardware for program debugging

The NUPIC discussed in Section 3.1.2 gives the user extensive program debugging tools. These tools include matchers, visual displays, and processor controls (Fig. 2).

The matchers available with the NUPIC include:

Address Matchers—There are nine address matchers (one manual) which can be set to indicate when a specified program address is executed or when a specified data address is read or written.

Range Trap Matchers—Two range trap matchers are available. These matchers will indicate when any address within a range of program is reached or when any address within a range of data is accessed.

Bit Matchers—Two 20-bit matchers allow the programmer to match against an address, contents of a memory location, or the contents of an index register. The bit pattern to be matched against can have an associated mask. This mask will indicate which bits in the pattern are "don't cares."

Peripheral Matcher—The peripheral matcher is used to indicate when a particular peripheral order accesses a particular peripheral unit. The peripheral unit address can have an associated mask.

Each of these matchers can be set manually via keys on the NUPIC. All but the manual matcher can also be set automatically. When a matcher "fires," the contents of the SPC registers can be collected by the support processor, analyzed, and printed on the high-speed printer.

The matchers can be set up with different options which will be executed when the matcher fires. These options can be interfering and noninterfering. The noninterfering options include register snaps and transfer traces. The transfer trace gives a record of every transfer that occurs in the program once the matcher fires.

The interfering options cause an interrupt in the SPC program execution and transfer of control to the SPC resident utilities. The options include doing a write into unprotected memory, dumping portions of memory, writing to registers, jumping to a different address, and stopping the SPC.

The visual displays on the NUPIC include binary lamp displays for the major points in each SPC processor such as the index registers and buses. Octal displays are provided for the registers most often used. These include the PAR, AIR, MAR, selected matcher address, and relocatable address (least five significant digits). The PAR, AIR, and MAR displays are available for each processor.
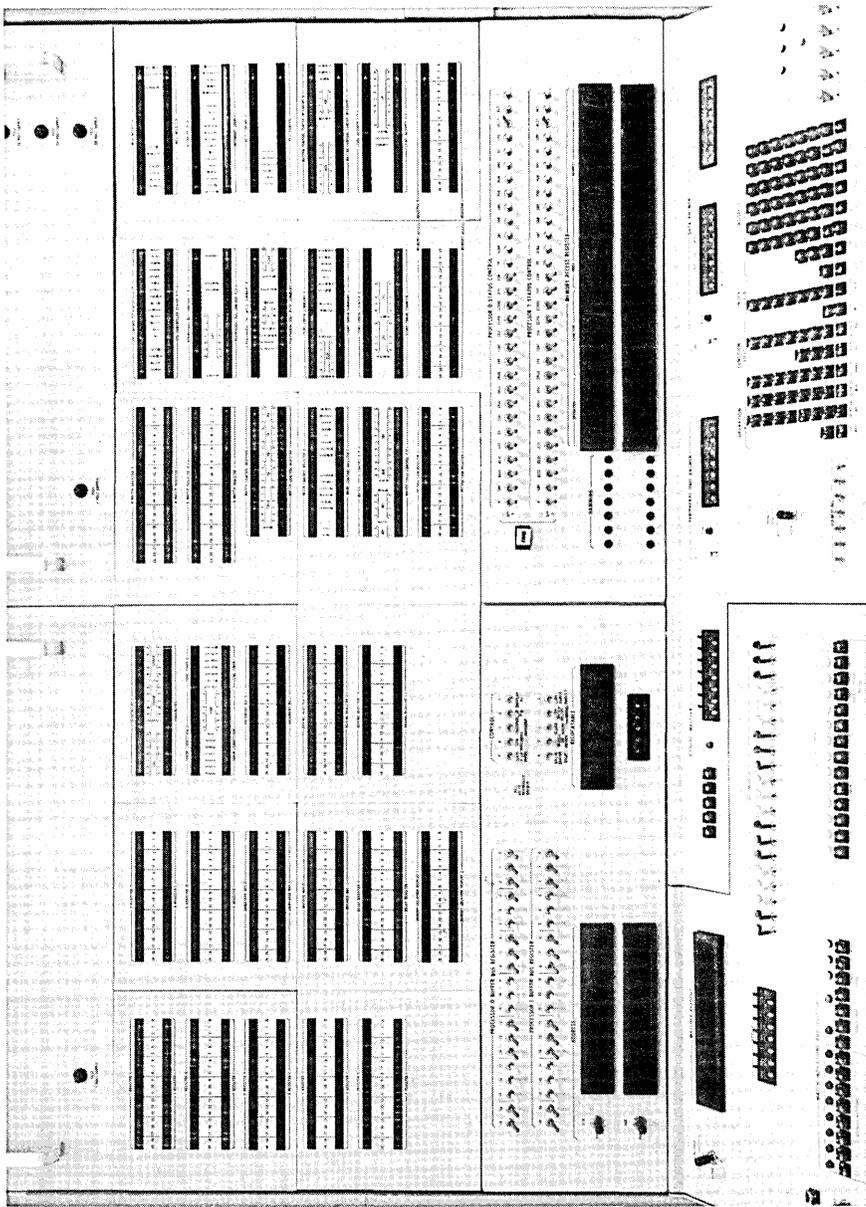
Fig. 2—Noninterfering Utility Program Interface Console.

Several manual control functions are provided to allow the user to selectively control either or both SPC processors.

    (*i*) The user can stop or start the processor clock and can step through instructions one cycle or one phase at a time.

    (*ii*) Instructions, data, and scanner answers can be inserted.

    (*iii*) Matchers can be set up.

    (*iv*) Utility interrupts can be generated and flags provided for the SPC resident utility programs.

    (*v*) Transient store errors can be simulated.

    (*vi*) The processors can be split into two independent systems.

3.3.2 Software for program debugging

Facilities exist in both the support processor and the SPC to aid in TSPS program debugging and testing. The most useful of these resides in the support processor and is called SPCDDT (Stored Program Control Dynamic Debugging Tool). This program activates matchers and traces via the NUPIC to give the user information about program flow in the SPC. Another useful support processor program is AMADMP (Automatic Message Accounting Dump). This program aids call processing programmers by providing formatted AMA information at the completion of a call. Finally, SPC-resident code assembled as a special set of Feature Assembly Debugging Aids (FADA) allows the programmer to selectively control the execution of TSPS programs.

3.3.2.1 The SPCDDT program. SPCDDT is used to set address matchers, range traps, bit matchers, and a peripheral matcher in the NUPIC circuit (see Section 3.1.2). The user has the ability to control certain actions before and after a matcher fires. Some of these options are:

    (*i*) Jump to a program address when a matcher fires.

    (*ii*) Dump the contents of specific SPC memory areas on the line printer when a matcher fires.

    (*iii*) Write information into an SPC memory location when a matcher fires.

    (*iv*) Start or end a transfer trace when a matcher fires.

    (*v*) Selectively print trace information on the line printer.

    (*vi*) Continually store trace information in the core memory of the SPI circuit (see Section 3.1.2.2). If the core fills, overwrite it with the more recent information (overlay mode). Freeze it and send the contents to the support processor for printing when another matcher fires.

Option (*vi*) is a particularly useful feature. It allows the programmer to monitor the entire flow of one (or more) program(s), and print out only the flow prior to an interesting event.

3.3.2.2 The AMADMP program. AMADMP provides formatted AMA

information on the support processor line printer at the completion of a TSPS call. This information is very useful to a programmer in debugging call processing or billing-oriented software.

Normally, the AMA Data Accumulation Program (AMAC) stores the billing information in buffers in TSPS memory. When a buffer is full, AMAC activates another program which records all buffered data on magnetic tape. This tape must then be processed on an off-line computer. The delays and logistics involved in this procedure make it undesirable for debugging purposes. Consequently, AMADMP was written during the development stage of the Remote Trunk Arrangement (RTA) feature of TSPS Generic 7.

AMADMP uses the NUPIC to activate two matchers in the AMAC program. One matcher fires at the start of AMAC's recording of the billing information and the other fires after all information has been buffered for a call. Using the information appearing in the SPC registers at the time the matchers fire, AMADMP requests a dump of the buffer locations used by AMAC. The data from these locations are then formatted in the support processor to make it more readable, and then printed on the line printer.

3.3.2.3 The FADA feature.
FADA is a collection of debugging software that can be assembled into a development base load. It consists of special code added to generic TSPS programs as well as a special PIDENT (ECDB). This code does not get released officially for use in live TSPS offices.

FADA was developed during the early stages of Generic 7 as an aid in the recovery of new program loads and a debugging tool. It accomplishes this by allowing the user to selectively inhibit execution of many program functions. This capability makes it possible to simulate many low probability events, cause race conditions, and exercise program failure legs.

3.3.3 Simulators

3.3.3.1 Single-call simulators.
Many times in testing programs, the programmer needs the ability to place a single call through the TSPS. Two types of test facilities are available for making single calls. The first of these facilities is the "single-line" simulator. This simulator consists of a local (calling) telephone connected to the local office side of the simulator and the toll (called) phone connected to the toll side of the simulator. The local and toll sides of the simulator are connected to a TSPS incoming trunk. This trunk is dedicated to a particular traffic type. For each traffic type (coin, hotel/motel, RTA), there is a single-line simulator.

Calls are placed by the programmer in the same way a customer would make a particular type of call. The simulator performs all

necessary signaling required by TSPS. The call is recognized by TSPS and handled appropriately by routing it to an operator's position or by connecting the called telephone.

The single-line simulator is used for calls which are to be handled normally. The simulator generates the correct KP, Start (ST) digit, and Automatic Number Identification (ANI) digit for the call. However, there are times when the programmer must have more control over the call. For instance, the programmer may wish to test a call using an improper ST digit or ANI digit. In these cases, the manual trunk test set (also known as the "Burelback Box") is used.

The manual trunk test set allows the programmer to place a single call and to have control over the entire call. The programmer selects the type of TSPS trunk circuit to be used and the call type. By operating switches, the programmer simulates seizure by the local office and responds to supervision from TSPS by keying in the KP digit, the call digits, a ST digit, an ANI digit, and the calling digits. When the toll side of the trunk is seized by TSPS, the programmer generates the toll supervision signals to TSPS. On ACTS calls, the coin tones can also be generated.

3.3.3.2 Multiple-call simulators.

There are program bugs which do not show up until there is a substantial traffic load on the system. In TSPS testing, a simulated load can be generated by the Electronic Load Box (ELB) and the Microprocessor Controlled Load Box (MICLOB). Both of these "load boxes" automatically generate calls on multiple TSPS trunk circuits. Each load box simulates the functions of both the local and toll offices.

The characteristics of the ELB are:
  (i) Generates up to 14 simultaneous calls. All calls must be the same type and the same length.
  (ii) Can generate 1800 calls per hour.
  (iii) Works with MF (multifrequency) trunks, 2-wire, or 4-wire, loop or E&M signaling.

To use the ELB, the user selects the number and the type of the calls desired. If more than one call type is required, another ELB must be used. To provide the user with more flexibility in setting up a call load and to provide the capability for coin signaling for ACTS, the MICLOB was developed. MICLOB (Fig. 3) has the following characteristics:
  (i) It generates up to 32 simultaneous calls of any call mix the user wishes.
  (ii) The call types include coin, noncoin, hotel/motel, and international.
  (iii) All call parameters are under user control.
  (iv) It works with either 2-wire or 4-wire trunks with MF or DP (dial pulsing) signaling and with loop or E&M supervision. Other
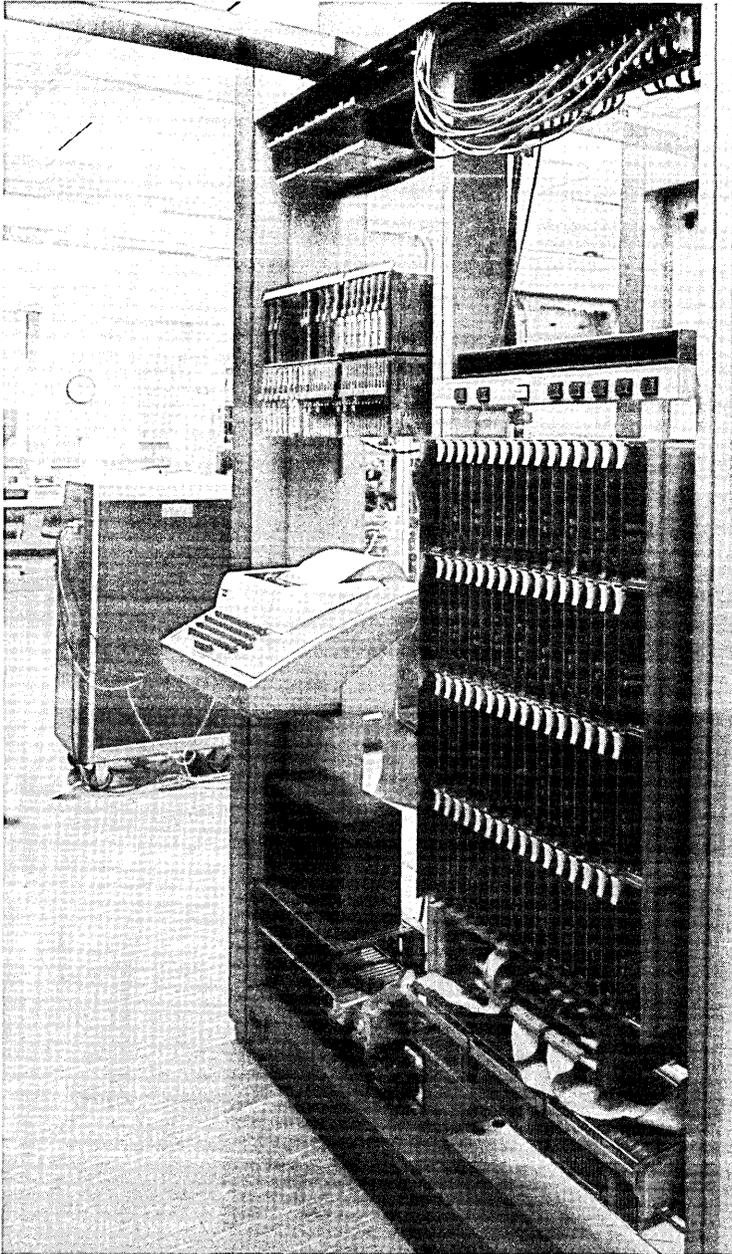
Fig. 3—Microprocessor Controlled Load Box.

trunk types can be easily handled by modifying the microcomputer program and providing the proper trunk interface.

(v) The call load can be as high as 10,000 calls per hour for short calls.

The user sets up his call load by entering the call parameters for each trunk via a teletypewriter or a terminal. Once the load is established, the calls can be started or stopped individually or as a group. The user can save his call load parameters on the support processor's disk via a serial data link (Section 3.1.2.4). This call load can be reloaded at a later time. This save/load capability allows users to set up a call load without entering the information via the teletypewriter each time.

Another feature of the MICLOB is the error messages printed on the TTY or terminal whenever calls do not proceed properly. These messages can alert the user to a problem with a trunk circuit or a MICLOB circuit.

In a testing environment where a heavy load is required, the ELB can be used to generate a background load of a particular call type. The MICLOB can be used to generate a load of special calls or of call types not possible with the ELB. In this manner, the TSPS programs can be exercised in the lab much like a live system.

3.3.3.3 Operator simulators. Operator simulators are used to simulate operator actions on calls arriving at positions. These simulators are used when a call load is generated containing calls which require operator assistance. The simulators recognize the call types arriving at the position and generate the required keying sequences. There are two types of operator simulators used in TSPS. The older simulator is hardwired. It can handle all call types except ACTS. Each of these simulators requires an actual position to operate.

The new Microprocessor Operator Position Simulator (MOPS) can handle all call types. Each call type can be handled differently, new call types can easily be added, and existing calls can easily be changed. This simulator can work with or without an actual position available. In this way, less positions are required in the laboratory. The advantage of having calls go to an actual position is that one can observe how the simulator is handling calls or one can manually handle a call if necessary. These functions can be duplicated via a terminal connected to the simulator.

The lamp and display orders sent to a simulator position by TSPS during a call can be converted to lamp names and digital displays and printed on the terminal. By monitoring a particular simulator position, the programmer can observe calls going to the position. The keys on the terminal are programmed to act as position keys so that the programmer can also manually handle a call if desired. The terminal can be remoted if necessary. This feature is useful when the TSPS

operator positions are not at the same location where program testing is being performed.

3.4 Trouble location manual (TLM) generation

The Trouble Location Manual (TLM) contains Trouble Location Numbers (TLN) for a circuit or subsystem. Associated with each TLN is the location of probable failing circuit packs in the circuit. These numbers which are an output from the diagnostic program are used to assist craft in fixing a faulty circuit.

The generation of a TLM for each circuit or subsystem requires that faults be physically inserted in these circuits. The diagnostic program for the circuit being faulted is run. The results from the diagnostic are used to generate the TLN. The collection of TLNs and faulted circuit locations make up the TLM.

Originally, in TSPS, most circuit pack faults could be inserted at the connector. However, with the introduction of RTA and the IGFET (Insulated Gate Field Effect Transistor) memory, circuit packs become much more complex. They contained many integrated circuits in Dual In-Line Packages (DIP). All necessary faults could not be inserted at the connector. To insert faults in the newer circuit packs and to speed up the TLM generation process, a minicomputer-controlled fault insertion technique was developed. This technique, which consists of fault insertion hardware and software, is discussed in the following sections.

3.4.1 Physical fault insertion

The type of faults inserted in the circuits are opens and shorts to desired voltage levels on the circuit pack connectors and the pins of the DIPs on the packs.

The circuit pack which is being faulted is a special version of the standard circuit pack in that the integrated circuits are socket-mounted. The circuit pack is mounted in a special extender board which is plugged into the circuit pack connector. The DIPs on the circuit pack have "daughterboards" inserted between them and their sockets. Both the extender board and "daughterboards" have relays which can be controlled to open or short the circuit pack connector pins and the DIP pins.

These relays are controlled by the support processor by setting selected points in the ESD. The fault insertion hardware decodes this information to operate the selected relays and thus insert the desired fault.

3.4.2 Diagnostic control and raw data accumulation

The support processor contains software to control automatic physical fault insertion and the SPC diagnostic programs. It also contains routines to gather the test results, or raw data, from these diagnostics.

These results are combined into a data base used to produce system TLMs. The support processor software designed to control these processes is called MCFIT (Minicomputer Controlled Fault Insertion Technique). The MCFIT program, together with special code in the SPC to interface with system diagnostics, make up the automatic physical fault insertion control software.

3.4.2.1 The MCFIT program. MCFIT was designed to allow rapid fault insertion and TLM generation. The majority of faults to be inserted are stored in a data base on the support processor's disk. This data base consists of all standard faults that are defined for each type of DIP used in the circuit being faulted. Thus, the user must only input the layout of the circuit pack to be faulted and any modifications to the standard fault list. MCFIT automatically controls the faulting of the entire pack, requiring manual intervention only to move the fault insertion hardware to the next pack.

Once the user has specified the pack layout, MCFIT retrieves the correct list of faults from disk and applies any necessary modifications. This list, together with the subsystem identification and circuit pack location, comprise the MCFIT "work file." MCFIT then executes a fault insertion program which sequentially inserts all faults appearing in the work file. This program controls the fault insertion hardware, activates a special SPC program which requests diagnostics on the specified subsystem unit, and records the failure data on the support processor's magnetic tape unit. It also prints summary data on the line printer. These data point out unexpected diagnostic ATPs (All Tests Passed) and inconsistent failure data for the user to examine.

3.4.2.2 SPC interface software. As mentioned above, the MCFIT program activates a special SPC program to request diagnostics. This SPC program is not part of the official generic, but is loaded into memory at the start of each fault insertion session in the lab. The diagnostic is requested through the NUPIC/SPI interface. An interrupt is generated in the SPC which transfers control to this diagnostic interface program. This program sets the appropriate bits in the diagnostic request words and status words corresponding to the subsystem unit being faulted. The diagnostic sequence proceeds normally in the SPC with one exception. Normally, each diagnostic transfers control to the SPC Diagnostic Output Control Program (DOCP) to print the pass/fail data on the maintenance teletypewriter. This special program, however, intercepts the data passed to DOCP and sends them to the support processor via the NUPIC/SPI.

IV. CONCLUSION

Effective software development depends very heavily on adequate development tools and test facilities. The tools and facilities described

in this paper came about through an evolutionary process. They started out in a much more basic form and were improved and expanded many times before they reached their present state. Thus, effective support software and hardware requires ongoing development. This point must be kept in mind so that programmer productivity can continue to improve.

V. ACKNOWLEDGMENTS

The support tools discussed in this paper are the combined effort of many people. Contributions to these tools were made by B. E. Holmes, J. R. Petty, and E. G. Pflaum in the area of program administration, by G. M. Jensen in the utility software, by M. R. Harder, P. L. Shepherd, and G. L. Taylor in the design of the various simulators, and by R. H. Allen and F. H. Ross in maintaining the utility and system laboratory hardware.

REFERENCES
1. G. R. Durney, H. W. Kettler, E. M. Prell, G. Riddell, and W. B. Rohn, "Stored Program Control No. 1A," B.S.T.J., 49, No. 10 (December 1970).
2. M. Berger, J. C. Dalby, E. M. Prell and V. L. Ransom, "TSPS No. 1: Automated Coin Toll Service: Overall Description and Operational Characteristics," B.S.T.J., this issue, pp. 1207–1223.

Traffic Service Position System No. 1:

System Verification and Evaluation Procedures

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(Manuscript received December 11, 1978)

This paper describes the verification and evaluation procedures followed in the development of new features for the Traffic Service Position System (TSPS). Beginning with the definition of new feature requirements, these procedures are adhered to throughout the TSPS development cycle. Hardware and software designs are reviewed to verify that all requirements are met and to ensure that Bell System standards for reliability are maintained. Finally, both system laboratory and site testing are performed to verify the proper implementation of each new feature and to evaluate the overall performance of the TSPS.

I. INTRODUCTION

A significant part of the effort required for any switching system development involves determining whether the system performs properly. The ultimate judge of system performance is the user. In making this judgment, the user considers both system reliability and maintainability. Since Bell System standards for service are very high, measures of acceptable performance are rigorous. Thorough plans are made to ensure that switching systems provide this required high level of performance. These plans begin with the initial concept of a switching system or new feature and continue throughout the development process. Every design decision is based on providing the best possible service at the lowest possible cost. Each decision is evaluated for its impact on the customer who uses the switching system and on the operating company that must administer and maintain it.

This paper discusses the methods used to verify and evaluate system performance of the Traffic Service Position System (TSPS). It also

describes the facilities specifically designed to support the verification and evaluation process.

II. STAGES OF THE TSPS VERIFICATION AND EVALUATION PROCESS

The verification and evaluation process for new TSPS features involves all aspects of system development. This process begins with the determination of feature objectives and continues with the verification that the design requirements for each new feature are consistent with these objectives. Finally, the system is tested to ensure that the implementation reflects the design requirements. This process is divided into several stages. The stages of verification and evaluation discussed in this article are (*i*) requirements reviews, (*ii*) design reviews, (*iii*) circuit analysis or program reviews, (*iv*) unit testing, (*v*) integration testing, and (*vi*) system testing. Figure 1 shows these six

IDEA FOR A NEW FEATURE

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1
REQUIREMENTS REVIEW
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DEVELOPMENT REQUIREMENTS MEMORANDA

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2
DESIGN REVIEW
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CIRCUIT DESCRIPTIONS AND DEVELOPMENT SPECIFICATIONS MEMORANDA

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3
CIRCUIT ANALYSIS AND PROGRAM REVIEW
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CIRCUITS AND PROGRAMS

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4
UNIT TESTING
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TESTED FUNCTIONAL UNITS

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5
INTEGRATION TESTING
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FROZEN FUNCTIONAL UNITS

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6
SYSTEM TESTING
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↓

NEW TSPS CAPABILITY
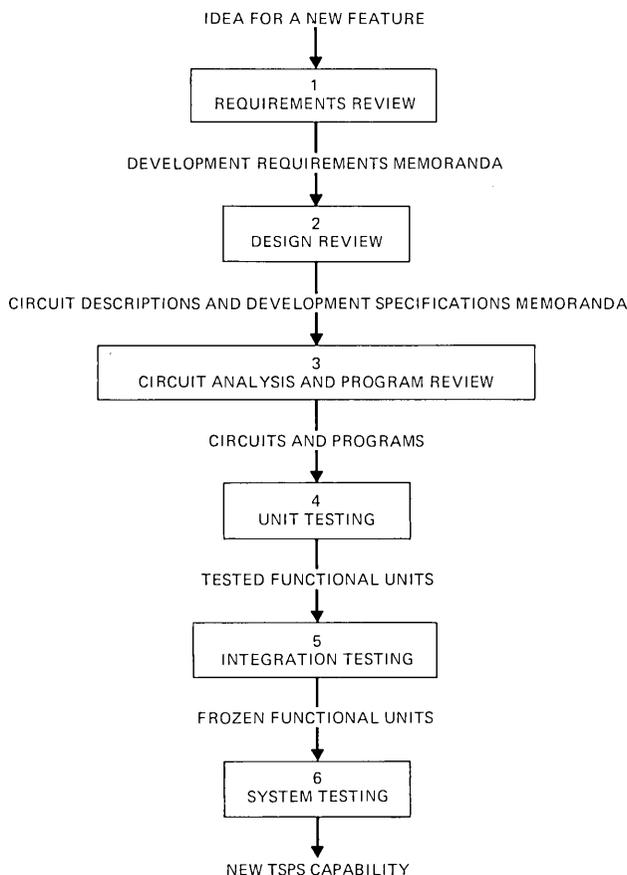
Fig. 1—Six stages in the TSPS verification and evaluation process.

stages and how the results of each stage are used in subsequent stages of the development.

The first stage of the verification and evaluation process begins when a new TSPS feature or system capability is proposed. Each new feature is analyzed to determine the service and maintenance requirements that must be satisfied. This analysis can be very extensive for some new features, such as the Automated Coin Toll Service (ACTS) feature. To perform this analysis for ACTS, an in-service TSPS was modified to simulate ACTS for a comprehensive human factors trial.[1] The results of this trial guided the formulation of the requirements for ACTS. These requirements are documented in development requirements memoranda and form the basis for detailed design and development.

The detailed design and development of a new feature is generally accomplished by partitioning the feature into functional units which are then assigned to development teams for implementation. Continued division of responsibility within a team for the development of a functional unit is dependent on the complexity of that unit. This partitioning applies to both hardware and software portions of the system.

The second stage of the TSPS verification and evaluation process begins when design reviews are held to determine if the conceptual aspects of each functional unit are consistent with the overall system requirements. Once the architectural design of the functional unit has been evaluated in this manner, the development team begins the detailed design of the functional unit. The design of each element in the functional unit is reviewed. Depending on the number and complexity of functional unit interfaces, members of other TSPS development teams may participate at this point in the process. After this review, development specifications memoranda and circuit descriptions are usually written documenting the detailed design.

The hardware development proceeds with the generation of circuit schematic diagrams and the specification of the circuit components used in constructing the circuit. The layout of the circuit components and their interconnections are specified, and prototype circuits are built. The prototype circuits are tested off-line from the system to ensure that they perform as required. Manufacturing tests are also generated for digital circuits using a logic simulation program.[2] After these tests and prototypes of the digital circuits are verified with a circuit pack tester, testing begins in the system laboratory. Once the circuit is verified to operate in accordance with the design intent, manufacturing and factory test information is transmitted to Western Electric. This activity is scheduled so that standard Western Electric-supplied hardware will be available when site testing begins.

The software development is done in parallel with the hardware development. After each program is written, a program review is conducted (*i*) to ensure that all development requirements are met; (*ii*) to verify that the interfaces between programs are correct; and (*iii*) to check that each program instruction is correct. Problems identified and corrected during this program review require much less effort than if they were left to be resolved during later stages of the verification and evaluation process.

The fourth stage in this process is the formulation of functional tests which utilize special test facilities (see Section III) and which ensure that each functional unit meets the design requirements. Upon the completion of unit testing, the fifth stage of the verification and evaluation process occurs when integration testing is performed. Integration tests ensure that each functional unit performs in a total system environment. Specifically, interactions between functional units and hardware-software interfaces are emphasized. Once the integration tests have been successfully run, the functional unit designs are considered frozen, in that changes to a functional unit can only be made on a more formal and controlled basis. The frozen functional units are now ready for system testing, the sixth and last stage in the verification and evaluation process.

During system testing, additional functional tests are written, and the total set of functional tests are performed by an independent group to ensure that any biases held by the design engineers are not reflected in the interpretation of test results. Beginning with this phase of TSPS testing, every change introduced into the system—hardware or software—must be initiated by a trouble report which specifies the seriousness of the problem so that corrections can be generated on a priority basis. Changes must be submitted in a formal manner and approved by a special committee called the change review committee.

Beginning with the system testing phase of the verification and evaluation process, each change is tested incrementally. That is, the correction to each problem, when possible, is considered an independent entity. Each correction can be rejected if not deemed appropriate by either the change review committee or the system testers. This procedure is used (*i*) to provide a high degree of visibility to all changes being introduced into the system, (*ii*) to provide a procedure whereby each change is individually and thoroughly tested, and (*iii*) to provide a procedure whereby design engineers can make changes without repeatedly going through the integration process.

To this end, each change submitted by the design engineer must be accompanied by a very specific test procedure which has been verified before the change is submitted. System testers then take great care to ensure that the test procedure is appropriate and that the change does not invalidate a previously verified functional capability. In some

cases, this can only be done by repeating a long series of previously completed functional tests. This verification and evaluation process is greatly enhanced by a comprehensive set of test facilities discussed in the following section. These test facilities are available to both designers and system testers.

III. SYSTEM LABORATORY TESTING

TSPS verification and evaluation is done at Indian Hill using two system test facilities. Each test facility contains a TSPS and its associated peripheral subsystems (i.e., a Position Subsystem No. 1,[3] Position Subsystem No. 2,[4] Remote Trunk Arrangement,[4] Station Signaling and Announcement Subsystem[5]—see Fig. 2). Minicomputers and var-
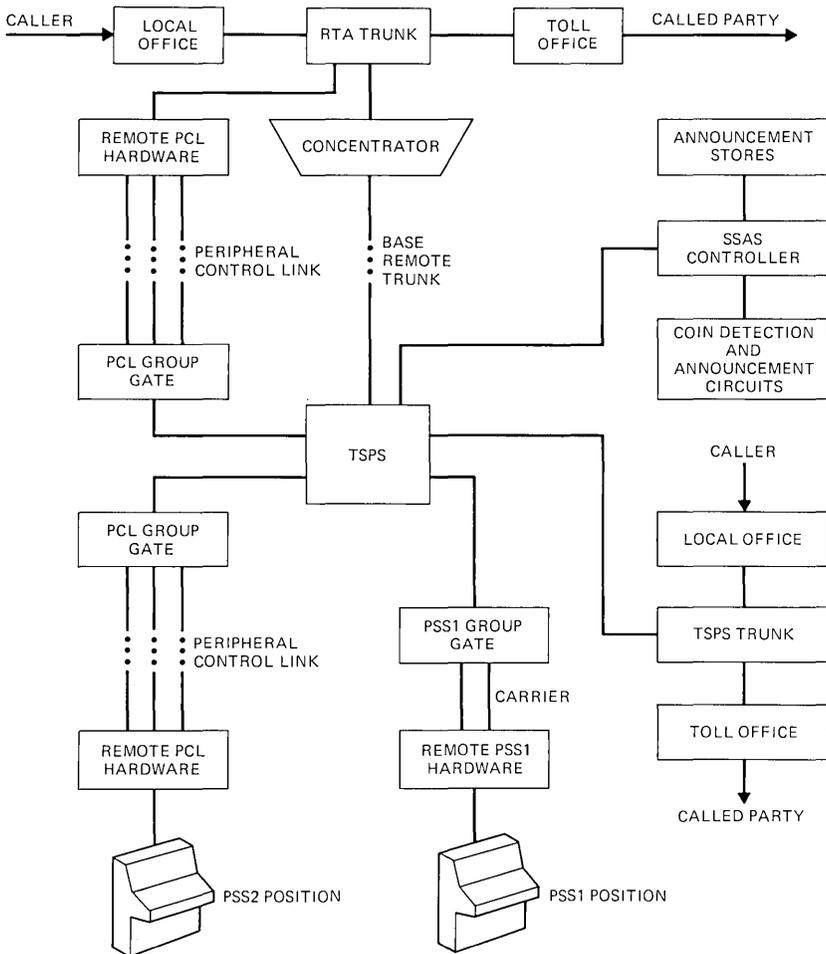
Fig. 2—Traffic Service Position System No. 1.

ious microprocessor-controlled circuits are utilized to produce the desired hardware and software environment.[6] In this environment, the system laboratory user can control and monitor the operation of the TSPS. Figure 3 shows one of the TSPS system laboratories at Indian Hill.

One aspect of controlling the TSPS operation is to establish the desired hardware and software configuration. The minicomputer provides three major capabilities for reconfiguring or modifying the system. First, the minicomputer provides the capability to load the TSPS with a new program, with the system's program stores being automatically reconfigured to match the memory requirements of the new program. Second, portions of the TSPS program can be modified with changes assembled by the minicomputer. This capability is used extensively in the incremental testing of modifications to frozen programs. Third, automatic fault insertion by the minicomputer is used to exercise system diagnostics in the preparation of trouble locating manuals. These manuals are used in conjunction with diagnostic outputs to identify hardware faults. The automatic process by which these faults are inserted helps to increase trouble locating manual resolution by allowing efficient generation of a large number of sample diagnostic results.

Once the desired hardware and software configuration has been established, the minicomputer can then be used to monitor the operation of the TSPS. Data associated with a specific event or combination of events can be recorded and later retrieved by the minicomputer. When correlated with the normal system responses such as teletypewriter messages, those data can be used to resolve problems or to confirm the proper operation of the TSPS.

An important part of testing TSPS features is ensuring that system interactions involving customers and operators are correct. Many inputs processed by a TSPS result from these interactions. To provide similar inputs in the system laboratory, stimuli comparable to those generated by customers and operators are produced using system utilities. A microprocessor-controlled facility is provided to simultaneously generate calls from many trunks. Both the traffic-handling characteristics of each trunk and call types can be changed under program control. Facilities are also provided to simulate the local and toll offices associated with a single TSPS trunk, thus allowing a laboratory user to completely control all stages of an individual call. Microprocessor-controlled operator simulators are provided to automatically handle calls at TSPS operator positions. In addition, calls can be handled manually at an operator position, thereby allowing the system laboratory user to test unexpected operator sequences.

System testing is divided into functional testing and system evalu-
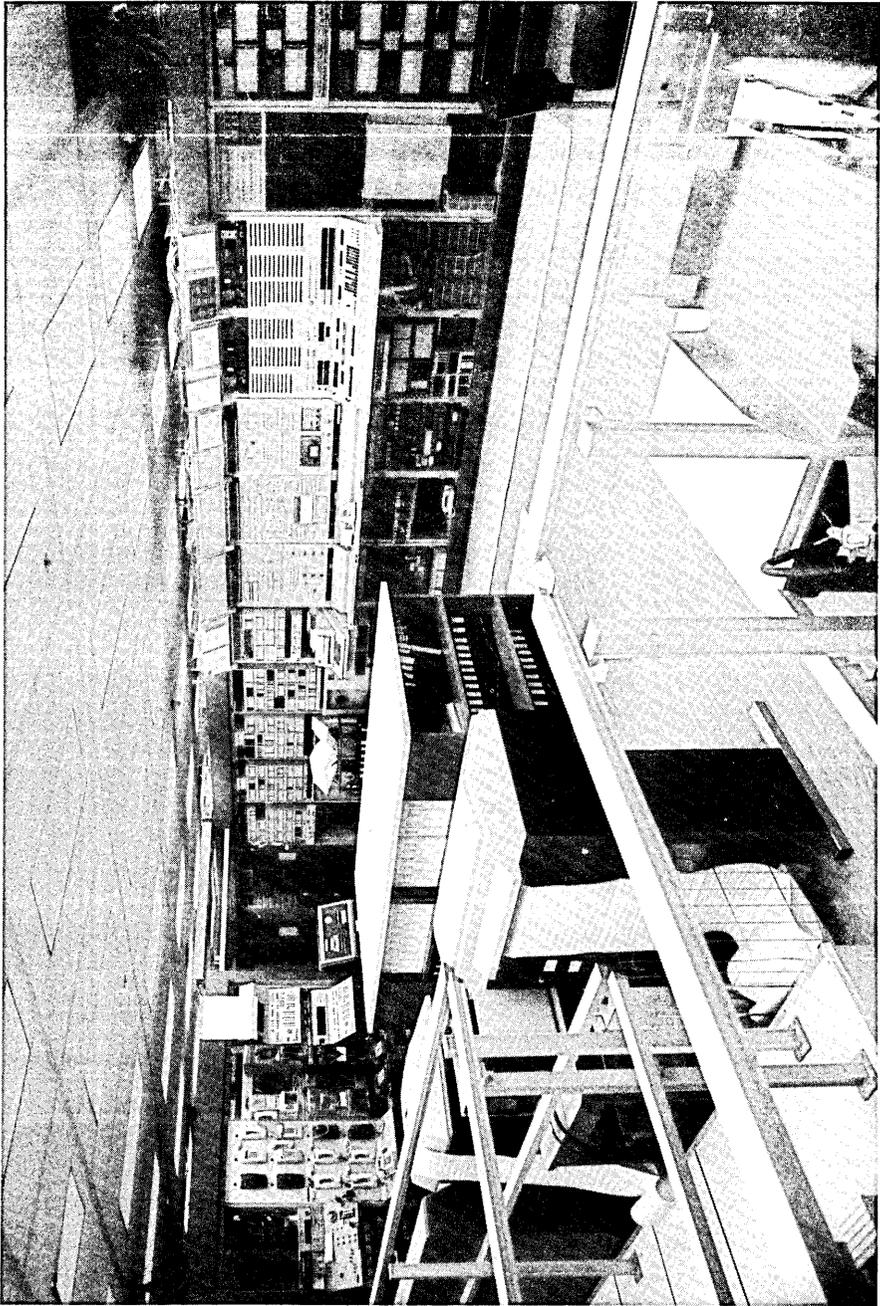
Fig. 3—The TSPS System Laboratory.

ation. Ideally, it would be desirable to write and perform functional tests in the system laboratory for each call processing and maintenance situation the TSPS will encounter. In practice, however, this is impossible. Consequently, during system testing, additional effort is required above and beyond the analysis of functional test results. This effort is referred to as system evaluation. In terms of cause and effect, functional testing involves setting up a prescribed set of initial conditions and then determining whether or not the proper response occurs. However, system evaluation involves observing every improper system response and then determining the cause of that response. This can be a difficult task, which at times is more of an art than a science. Reproducibility is a primary requirement for identifying the cause of a problem. Problems discovered during functional testing are generally reproducible, since a set of initial conditions have been specified for running each functional test. However, problems encountered during system evaluation frequently do not meet this reproducibility criterion. As a result, much more analysis of these types of problems is required.

During system evaluation, several indicators are used to determine that a problem exists. These indicators are:

(*i*) Unexpected teletypewriter output messages.
(*ii*) Loss of service of a hardware unit to the system for no apparently valid reason.
(*iii*) Unexplainable maintenance or call processing activity.

The audit messages[7] printed on the teletypewriter are a primary indication of system problems. Each audit message generally signifies the presence of some program error resulting in an inconsistency in unprotected memory. This memory is continuously updated by different programs to reflect the current state of the system. A detailed analysis of the audit messages will sometimes indicate what caused the error condition. The debugging capabilities of the minicomputer described above are particularly helpful in resolving this type of problem. With these capabilities, system activity which occurred before the audit program detected the error can be analyzed, and the cause of the problem can be identified.

The system laboratory provides a controlled environment where interfaces external to the TSPS have been simulated with system utilities. Although it is possible to test most aspects of the TSPS operation in this environment, increased confidence is built when new features are tested at a newly installed TSPS which interfaces with actual local and toll offices. For these and other reasons, the verification and evaluation process is continued at a test site.

IV. THE SITE TESTING INTERVAL

Each new generic is tested at a TSPS that has not been cut into service. This TSPS has been fully engineered by operating company personnel, and the hardware has been installed by Western Electric during a normal installation interval. Bell Laboratories testing of a generic at this pre-cutover TSPS evaluates the new features in a fully equipped TSPS. It also verifies the accuracy of the information provided to Western Electric and the operating companies on these new features. Testing is done with both local and toll offices to ensure that no interface problems exist. The length of the site test interval varies depending on the number of features being tested, amount and complexity of the new hardware, and size of the program change. Table I summarizes the test site, major new features, and size of the program change for each of the recent TSPS generics.

Testing at the site involves reverifying specific operational and maintenance capabilities for all new features, with the objective of determining whether or not the requirements for each feature are met. In particular, testing focuses on verifying interfaces with local and toll offices. Regression testing is also performed to ensure that previous TSPS capabilities are not adversely affected by the new features. Since site testing is performed after new feature development has been completed, problems identified at the test site are generally more subtle than those previously uncovered during system laboratory testing at Indian Hill. Furthermore, by the beginning of the site test interval, the hardware design has already been proven in the system laboratory. As a result, during this interval the majority of problems identified are in the software. Most are not due to any significant design problems and are easily corrected.

Both functional testing and regression testing at the site are done in a systematic manner; a specific set of tests are performed for each

Table I—Recent TSPS generics

Generic	Test Site	Major New Feature(s)	Size of Program Change (40-bit Words)
Generic 7, Issue 1	Syracuse, New York	Remote Trunk Arrangement, Position Subsystem No. 2	60,000
Generic 7, Issue 2	Saginaw, Michigan	Selective Call Screening, more than twenty stores on a bus	5,000
Generic 8, Issue 1	Phoenix, Arizona	Automated Coin Toll Service	40,000
Generic 8, Issue 2	Montgomery, Alabama	Automated Coin Toll Service with Remote Trunk Arrangement	7,000

feature, the results are observed, and these results are analyzed. The amount of detail with which functional test results are analyzed at the test site is minimal. Instead, any functional tests which fail are documented in trouble reports which are then sent back to the developers at Indian Hill. Extensive analysis at the test site is restricted to problems uncovered during system evaluation. In general, the exact conditions required to bring out these types of problems must be determined at the test site.

The combination of system laboratory testing and site testing during this interval complement each other in the verification and evaluation of a TSPS generic. In the system laboratory at Indian Hill, emphasis is placed on testing individual changes being made to correct specific problems. However, as indicated above, effort at the test site is oriented toward verifying and evaluating functional capabilities rather than testing changes or corrections.

The test facilities provided at the major test sites are comparable to those permanently installed in the system laboratories at Indian Hill. These facilities include the minicomputer, call generation capabilities, and operator simulators described in Section III. Additional capabilities are also provided to remotely control these test facilities so that testing can be done from one location.

The number of problems identified from the time the hardware and software were frozen until the completion of site testing is shown in Table II for each of the recent TSPS generics. These totals are broken down into: (i) problems identified at Indian Hill in the system laboratory and (ii) problems identified at the test site.

At the completion of the site testing interval, responsibility for monitoring system performance is given to TSPS field support personnel. In addition to continuing the evaluation of TSPS and new feature performance, field support personnel are responsible for updating the system with any necessary changes. To assist in these efforts, the TSPS's maintenance teletypewriter output can be transmitted to the TSPS Diagnostic Center at Indian Hill. Problems detected from this output or reported by the operating company are analyzed, and cor-

Table II—Trouble reports written through the completion of site testing

Generic	TRS Written at the Base Location	TRS Written at the Test Site	Total
Generic 7, Issue 1	600	615	1215
Generic 7, Issue 2	33	20	53
Generic 8, Issue 1	565	800	1365
Generic 8, Issue 2	108	58	166

rections are generated by designers working in conjunction with field support personnel.

V. SYSTEM CAPACITY

The addition of each new feature to TSPS has an impact on the real-time capacity of the TSPS. Overall system real-time capacity varies for each TSPS installation based upon the hardware configuration used and the particular call mix being processed. Each new feature is evaluated during the development cycle to determine its impact on system capacity. This evaluation is verified at the first in-service office or the first office close enough to capacity for a verification to be made. The real-time capacity estimation and verification process is extremely important due to its effect on the long-range planning of the operating companies. To assist the operating companies in their analysis of an individual office's real-time capacity, a program called TSPSCAP is available. This program runs on an off-line computer and is updated with each generic to reflect the addition of new features.

VI. SUMMARY

System verification and evaluation is a process that is interwoven with all aspects of the development of new TSPS features. From the inception of the idea for a new feature, development requirements are evaluated to ensure a proper understanding of the proposed capabilities and to verify that the proposed design will provide these capabilities. After formal reviews, these requirements are specified in development requirements memoranda, and the design is specified in development specifications memoranda and circuit descriptions. Next the design is implemented and each functional unit is verified in the system laboratory. Before the commencement of site testing, both hardware and software are placed in a frozen mode, after which all changes to the system are verified through a formal procedure. Site testing is done in a pre-cutover TSPS engineered by an operating company with hardware supplied and installed by Western Electric. During site testing, functional tests are run to verify the proper implementation of all new features and regression tests are run to ensure the proper operation of previous TSPS capabilities. In addition, system evaluation is done before the site is cut into service, thus resolving many of the more subtle problems. Finally, an analysis of the real-time effect of each new feature is made after cutover to confirm the theoretical analysis made prior to cutover.

This verification and evaluation approach is followed for each new TSPS feature. Adherence to this methodology allows new TSPS generics

to be properly verified and evaluated, thereby insuring Bell System customers of the best possible service.

VII. ACKNOWLEDGMENTS

Verification and evaluation of new TSPS features are accomplished through the efforts of many people in the Operator Systems Laboratory. Due to the laboratory-wide scope of this process, a list of all contributors to its success would be very long. However, the authors would like to acknowledge the special contributions of the following people: J. W. Hopkins, R. C. Jackson, R. Kroning, D. J. Rak, B. D. Reh, M. J. Traube, and D. A. Yackley.

REFERENCES

1. E. A. Youngs, W. J. Bushnell, and A. Barone-Wing, "TSPS No. 1: ACTS: Human Factors Studies," B. S. T. J., this issue, pp. 1291–1305.
2. H. Y. Chang, G. W. Smith, and R. B. Walford, "LAMP: System Description," B. S. T. J., 53, No. 8 (October 1974), pp. 1431–1449.
3. W. K. Comella, C. M. Day, Jr., and J. A. Hackett, "TSPS No. 1: Peripheral Circuits," B. S. T. J., 49, No. 10 (December 1970), pp. 2561–2623.
4. R. J. Jaeger, R. S. DiPietro, and S. M. Bauman, "TSPS No. 1: Remote Trunk Arrangement: Overall Description and Operational Characteristics," B. S. T. J., this issue, pp. 1119–1135.
5. M. Berger, J. C. Dalby, E. M. Prell, and V. L. Ransom, "TSPS No. 1: Automated Coin Toll Service: Overall Description and Operational Characteristics," B. S. T. J., this issue, pp. 1207–1223.
6. J. J. Stanaway, J. J. Victor, and R. J. Welsch, "TSPS No. 1: Software Development Tools," B. S. T. J., this issue, pp. 1307–1333.
7. A. W. Kettley, E. J. Pasternak, and M. F. Sikorsky, "TSPS No. 1: Operational Programs," B. S. T. J., 49, No. 10 (December 1970), pp. 2625–2683.

Traffic Service Position System No. 1:

Operator Training Facilities

By G. RIDDELL, C. R. SWANSON, and R. T. STEINBRENNER

The evolution of operator training facilities for TSPS No. 1 has involved the development of new program-controlled positions which have much greater flexibility and reliability than preceding training equipments. These PROCON-controlled positions and associated facilities are now the standard means for training TSPS operators. Coincident with the development of these facilities, a minicomputer system for generating master training tapes was designed to facilitate the generating of new training tapes and modifying existing ones to add new operating features.

Since the beginning of telephony, there has been a need to train switchboard operators in the procedures required to handle and complete telephone calls. These procedures started with "on the job" training and gradually improved over the years to specialized training facilities to give the trainees the ability to handle calls before they sat down at a switchboard handling traffic.

With the advent of the crossbar tandem Traffic Service Position in 1961, a new specialized training facility (100A trainer) was designed to train operators in the basics of handling traffic on this new type of switchboard (Fig. 1). This consisted of an operator position with two equipment cabinets. One of the two cabinets contained a paper tape reader, a magnetic tape player, power supplies, and racks for tapes. The second cabinet contained densely packaged electromechanical and solid-state circuitry which performed the necessary trainer functions under control of information on the magnetic and paper tapes.

Customer calls were simulated by verbal passages on the magnetic tapes which also provided synchronizing tones to start the paper tape reader. The paper tape reader and the magnetic tape player were

RELAY CABINET FOR
PORTABLE ARRANGEMENT

RELAYS MOUNTED IN
TERMINAL ROOM FOR
FIXED ARRANGEMENT

SECOND
SET

PROGRAM CABINET
(DOOR REMOVED)

TOTAL CALLS,
WRONG KEY AND
TIME-OUT FAILURE
REGISTERS

MAGNETIC TAPE
VOICE REPRODUCER

TELETYPE™
TAPE READER

TAPE STORAGE BINS

100 A/B TRAFFIC SERVICE POSITION
(STANDARD TWO-POSITION
SECTION)
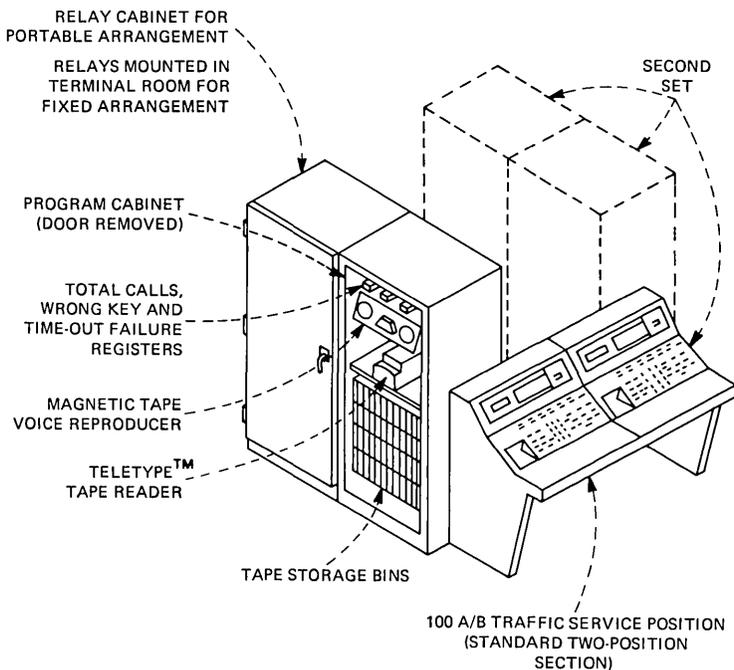
Fig. 1—Operator training equipment.

additionally controlled by the trainee sitting at the training position responding to simulated calls.

In effect, the training system was a simulator which could duplicate nearly all types of calls handled by a TSP. Different types of calls were simulated by different input tapes which were loaded by supervisory personnel.

With the development of TSPS No. 1, this 100A system was modified to provide added capabilities and was classified as the 100B trainer. Essentially, however, the basic operating principles and the physical appearance of the new trainer remained the same. This system has been used to train operators on TSPS call-handling procedures since its first application in 1969. However, as new features have been added to the TSPS, corresponding equipment modifications have been required in the relay circuitry. As there are over 2000 of these trainers in the field, this is a significant problem. In addition to this, the design of these changes becomes more difficult as control logic becomes more complex and as precise operating characteristics of the trainers is required.

To overcome these problems, a new programmable 100C trainer system was designed. Programmability enables new TSPS features to be introduced to the simulator quickly with few or no hardware

modifications. This system also provides a supervisory function not available on the 100B trainer. Furthermore, it uses standard 100C operator positions which can also handle regular traffic when not used as trainers.

This new trainer system shown in Fig. 2 consists of a maximum of eight training positions and one supervisory position. Each position can be switched to handle normal traffic. These positions can also be dedicated for training only and supplied on a stand-alone basis requiring no association with any chief operator group or TSPS No. 1 System. A photograph of a training position is shown in Fig. 3.

A standard 100C position is converted to a trainer by a wiring option added to the existing local cable wiring, and an applique column (Fig. 4) added to the rear of the position. This column contains a microprocessor called the programmable controller (PROCON) (Fig. 5), which provides the necessary control functions for the trainer. In addition to this, translator and temporary memory boards, voice and tone detectors, tone generators, I/O logic control circuitry, diagnostic indicators,
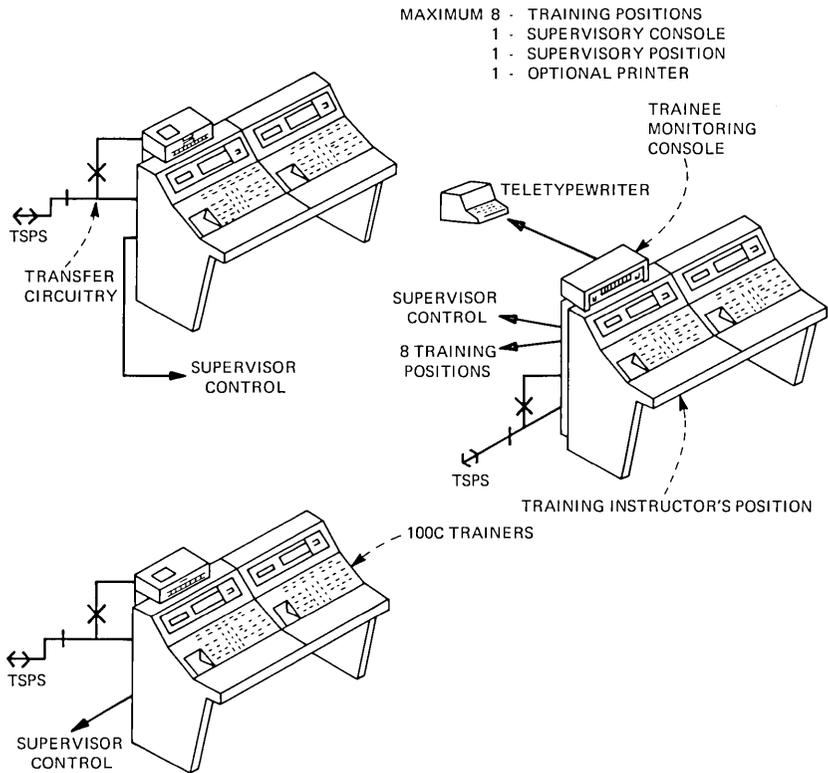
Fig. 2—100C training system.
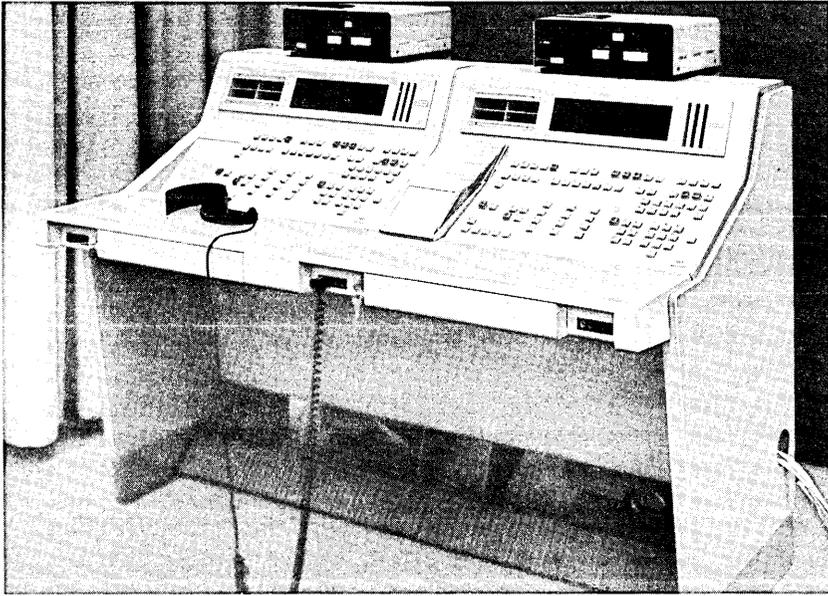
Fig. 3—100C training position.

switching circuitry, supervisory interface control, and isolation circuitry are all contained in the column (Fig. 6).

To provide the necessary combined data and voice inputs to the new trainer, a special cassette tape reproducer was required. This reproducer is largely based on conventional technology in the audio/visual and training fields. The prerecorded tape is in the standard Phillips cassette stereo configuration. However, several special features were required in this application:

 (i) A precise high speed reverse to enable the trainee to return to the beginning of a call pattern on the tape (called the "repeat" mode).
 (ii) Remote and local control functions customized for TSPS.
(iii) Power supplied to external interface circuitry.
(iv) Enclosure designed and stylized for a mounting location on the position accessible to the trainee.

The reproducer is manufactured for the Bell System by an outside supplier. The prerecorded cassette training tape contains the voice and data associated with a maximum of 30 minutes of simulated calls. The tape contains two tracks, one for voice and the other for control tones (Fig. 7). In a position being used for training, the PROCON processes the cassette control tones, operator-keyed actions, and verbal responses to simulate actual calls. The operation of the player is under
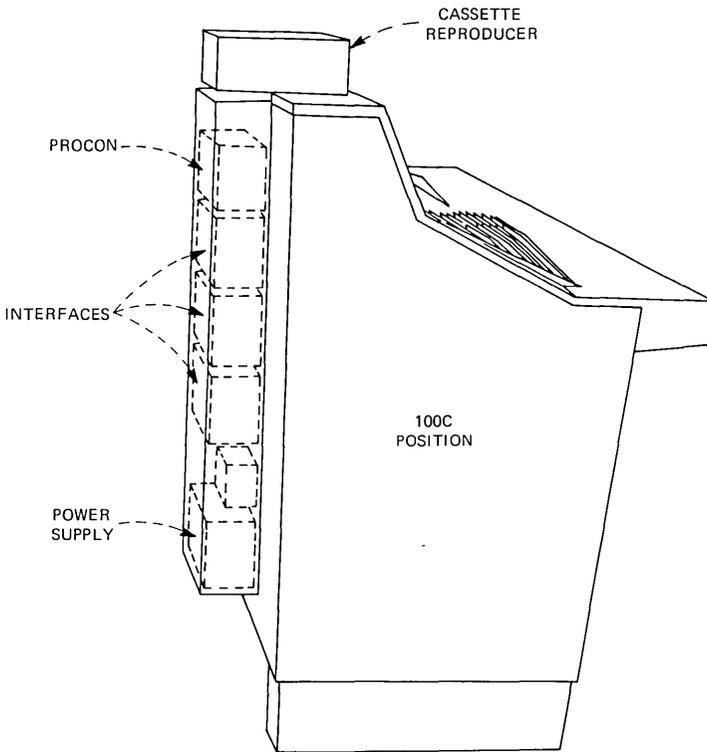
Fig. 4—Conversion of position to trainer.

control of the PROCON, although the trainee has some manual override capability. The trainee now has the ability to load the cassette and initiate and pace the training session, which was not possible in the previous system.

The control of the various components is shown in Fig. 8. The trainee inserts a prerecorded cassette in the reproducer and operates the play button. The cassette advances beyond a point where data, representing a TSPS lamp display, has been presented to the PROCON. A proper response by the trainee (either a key operation and/or verbal response) causes the PROCON to continue reading the tape.

The control data on the cassette are formatted in a 5-bit baudot code representation. Each bit is represented by a different frequency on the tape. A coded 5-bit character is represented by combinations of one to four frequencies simultaneously. These frequencies are present for 80 ms as the tape advances at 1⅞ inches per second (Fig. 7). A 20-ms interval is provided between consecutive characters as the tape advances. An instruction to the trainer generally is provided by two
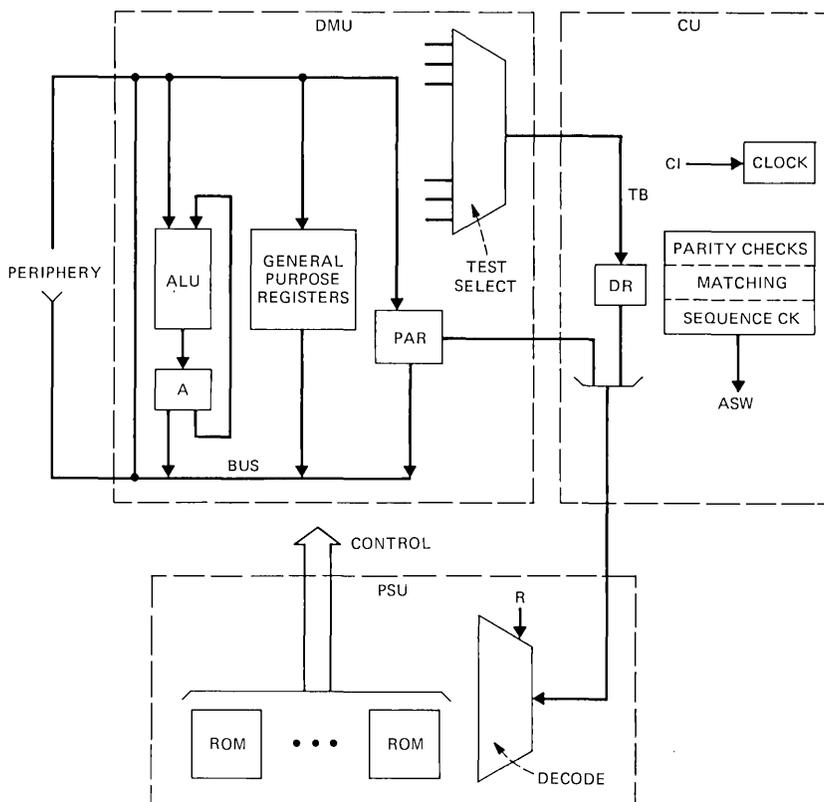
Fig. 5—Architectural overview of PROCON.

successive baudot characters although there are exceptions requiring only one. The data inputs are paired by PROCON and translated into a control function. For digital displays, telephone numbers are stored in the translator memory. There are standardized numbers for all trainees to use regardless of their location in the country. With this technique, a 10- to 12-digit display requires only a 2-character code. In addition, numbers keyed by the operator are stored in temporary memory. Both types of numbers can be displayed, when required, by operation of the corresponding display key at the operator's console. Other digital displays, for example, time and charges, are pre-coded and can be displayed on demand.

Operation of the time display key will produce a time-of-day display. When a position is powered up for the training function, the time is initialized to 8 o'clock. If desired, this can be changed by keying in the desired time on the keyset.

Operation of a key on the console generates one of the 84 possible ⅜
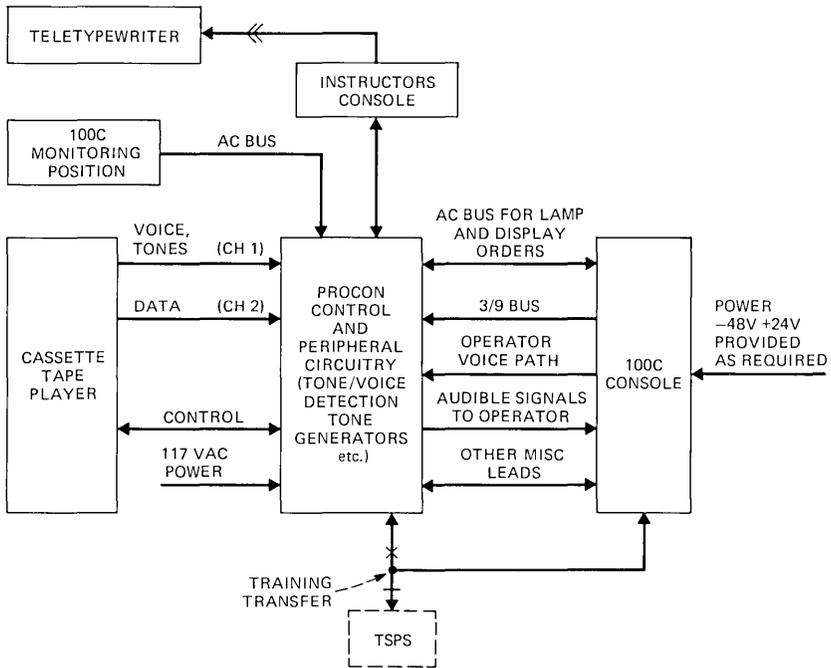
Fig. 6—100C operator training system.
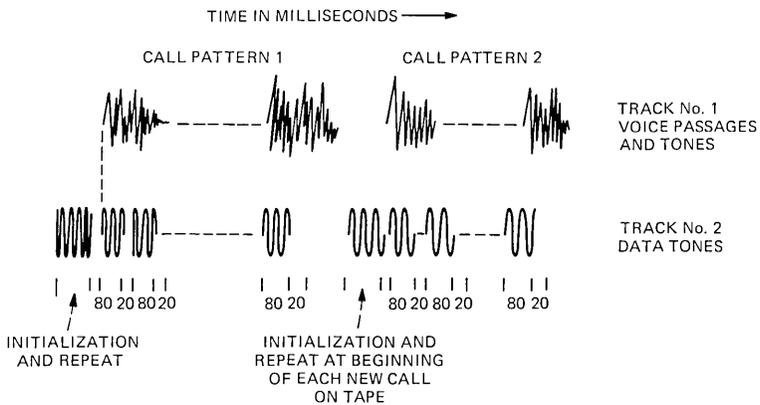
Fig. 7—Training tape information content.

key codes. These ⅗ codes are identified by PROCON through its associated position interface circuit, and appropriate action is taken to control the cassette player, and light, flash, or extinguish lamps on the trainer console.

INSERT
CASSETTE

```
DEPRESS
PLAY
BUTTON
```

```
LOAD
DATA
INIT. POS
```

```
TRAINEE
LISTEN
TO SCRIPT
```

```
TRAINEE
INTERACT
```

RIGHT KEY
DEPRESSED
?   NO

YES

```
ADVANCE
TAPE
```

END
OF TAPE
?   YES

NO

```
ALERT
SUPERVISOR
(ONLY IF
BEING
MONITORED)
```

NO   REPEAT
CALL?

```
DEPRESS
PROPER
KEY
```

YES

```
DEPRESS
REPEAT
KEY
```

```
CONTINUE
TRAINING
```

YES   CONTINUE
TRAINING?

```
RE-INITIATE
POSITION
```

NO

YES   REPEAT
TAPE

```
LEAVE
POSITION
```

NO

```
RETRY
CALL
PATTERN
```

```
REWIND
```

```
INSERT
NEW
CASSETTE
```

Fig. 8—100C trainer operations.

Verbal responses of the trainee are detected by a voice detector and forwarded to PROCON, which permits the call to progress to the next voice passage or group of data on the cassette tape.

In addition to lamps and display data, the cassette tape data also

control tone signals (ziptone, audible ring, busy) to the trainee. These tones can be present for indeterminate time periods. For these types of signals, tone generators are provided under PROCON control. In general, these tones are initiated or terminated by the trainee key actions.

The standard 100C operator position requires a 24-bit serial data word for each instruction to light a lamp or display pairs of numerical digits. In the 100C trainer, these 24-bit words are identical to those used on the standard 100C position but are generated by PROCON. As the trainee operates keys at the console, the ⅗ codes generated are translated and matched against expected results. If the correct response is made, the cassette is advanced to present new data. If a match is not made, the trainer does not respond, forcing the trainee to question his/her actions and give the correct responses. A flowchart of the operations of the 100C trainer is shown in Fig. 8.

The 100C operator training system also includes an instructor's console with an associated *DATASPEED* ® 40 printer to provide a record of trainee keying actions. The instructor's console provides a means to supervise trainees while they are learning to handle TSPS traffic. It permits the instructor to monitor the simulated calls and the trainee's responses. As keys are operated by the trainee, the corresponding lamps light on the instructor's console. Incorrect key actions by the trainee cause the corresponding lamp to flash at the instructor's console.

The instructor can select any one of eight positions to monitor. While this one position is being monitored, all other seven positions are also being checked to determine if the trainees are making excessive errors in their responses. Excessive errors generated at a training position cause a corresponding position number lamp to flash at the instructor's console.

A *DATASPEED* 40 printer produces a record of the numbers keyed by the trainees. This can be done on a position-by-position basis by operation of a print key on the console. These records provide information on keying accuracy, as no actual matching of keyed numbers is provided in the 100C trainer programs.

These trainers also require support facilities to provide training tapes. The production of these training tapes require the coordinated efforts of Bell Laboratories, AT&T, Western Electric and general trade suppliers. Initially, the efforts of BTL and the AT&T operator services organization are used to determine the correct operator actions and console displays required on calls. Once this has been determined, data codes required for new features are designed by BTL, and the information is provided to the operator training groups at AT&T. The necessary data patterns are then determined by the operator training

group and entered into the data base of the minicomputer-controlled support system used to produce master training tapes.

To put both the data patterns and voice passages on master tapes, the support system called Automatic Data Entry Console (ADEC) was designed (Fig. 9), and two custom-built systems were provided to the AT&T training organization. This system has the capability of editing tapes and synchronizing the recording of voice and data to accurately simulate actual calls. It is updated and modified as required to provide new features. In order to produce master tapes, a narrative script is provided by the AT&T operator training organization to a professional recording studio which in turn produces a voice master tape. The voice master tape is used by the ADEC to generate the combined master tape consisting of voice passages and data tones on separate tracks. The generating of these tapes can call for several revisions to achieve realistic simulations (Fig. 10).

The combined master tape provided by this system is then transmitted to Western Electric for quality control. Commercial suppliers provide cassette copies of the master tapes for use by the telephone companies. Tight specifications on the generation of the master tape and on the cassette duplication process are required to provide adequate operating margins in the use of audio cassette technology for the basic input to the control system.

The use of the ADEC system has been beneficial in providing capa-
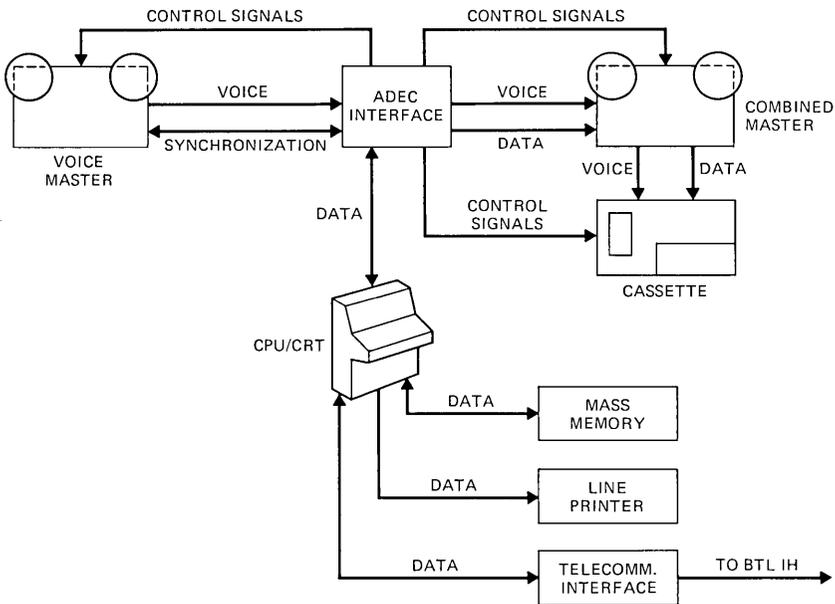
Fig. 9—ADEC system.
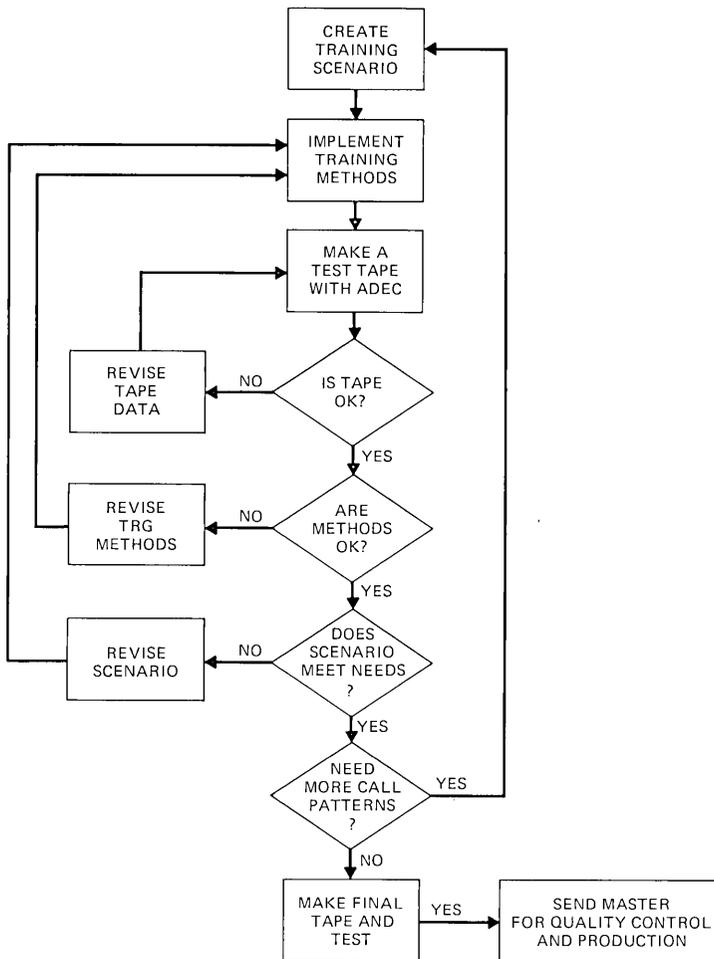
Fig. 10—Procedure for generating combined master tapes.

bilities for modifying and generating new training tapes not previously available with the older trainers. Requirements for training have been expanding continuously, and since the introduction of this system the production of training tapes has greatly improved.

ACKNOWLEDGMENTS

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D. Van Haften, B. S. and M. S. (Mathematics), 1970, Michigan State University; Ph. D. (Electrical Engineering), 1977, Stevens Institute of Technology; Bell Laboratories, 1970—. Mr. Van Haften initially worked on the Safeguard project. Since joining the Operator Systems Laboratory in 1974, he has been involved in TSPS system testing, field support, and call processing development. Currently he is a member of the Development Coordination and System Test Group. Member, Phi Beta Kappa, Phi Kappa Phi, Pi Mu Epsilon.

John J. Victor, B.S. (Mathematics), 1967, St. Peter's College; M.S. (Computer Science), 1971, Stevens Institute of Technology; Bell Laboratories, 1967–1978; Western Electric, 1978—. Mr. Victor's work at Bell Laboratories included TSPS input/output software design, maintenance software design, control software design, remote maintenance software requirements and design, system testing and integration, and field support. He currently is Department Chief at Western Electric, where his group is responsible for the planning and management of toll operator systems, including TSPS.

Laurance A. Weber, B. E. E., 1945, Cornell University; M. E. E., 1955, Polytechnic Institute of Brooklyn; Bell Laboratories, 1946—. Mr. Weber was initially involved in the design of signaling circuits. Later he participated in the design of circuits for crossbar tandem systems. Following this assignment, he was appointed supervisor in charge of designing data sets for the mechanization of TWX service. He was appointed head of the 101 ESS Design Department in 1960. He has had subsequent assignments in No. 2, No. 2B, and No. 3 ESS. He is presently head of the TSPS Evaluation and Test Department. Member, IEEE, Tau Beta Pi, Sigma Xi, Eta Kappa Nu.

R. J. Welsch, B.S. (Math), 1967, Marquette University; M.S. (Computer Science), 1972, Northwestern University; Bell Laboratories, 1967–1968; U.S. Army, 1968–1970; Bell Laboratories, 1970—. At Bell Laboratories, Mr. Welsch has had experience with No. 1 ESS/ADP, No. 4 ESS, and systems engineering for electromechanical switching systems. From 1974 to 1978, he was a member of the Program Administration and Support Program Group of the Operator Systems Laboratory. He is currently with the Software Development Systems (UNIX) Applications Group of the Microprocessor and Software Technology Laboratory.

Allen G. Weygand, M.E., 1957, Stevens Institute of Technology; M.S.(E.E.), 1959, New York University; Bell Laboratories, 1957–1962; Bellcomm, 1962–1972; Bell Laboratories 1972—. Before transferring to Bellcomm, Mr. Weygand conducted transmission performance studies of various exchange-area voice-frequency systems and short-haul analog carrier systems. While at Bellcomm, he performed communications and tracking systems planning, analysis, and engineering studies in support of the Apollo, Skylab, and space shuttle space flight programs of NASA. Since his return to Bell Laboratories, Mr. Weygand has been engaged in transmission planning and analysis for Bell System operator services and various customer attendant services. Member, Tau Beta Pi.

Edward A. Youngs, B. A. (psychology), 1964, Dartmouth College; M.A. (psychology), 1968, University of North Carolina; Ph.D. (psychology), 1969, University of North Carolina; Bell Laboratories, 1969—. Mr. Youngs initially worked on human factors aspects of electronic key telephones. Later, he contributed in-depth studies of the TSPS operator job. Recently, as supervisor of a human factors group concerned with customer and operator performance and acceptance of new TSPS services, he has participated in the design of Automated Coin Toll Service (ACTS) and other operator service mechanization efforts.

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