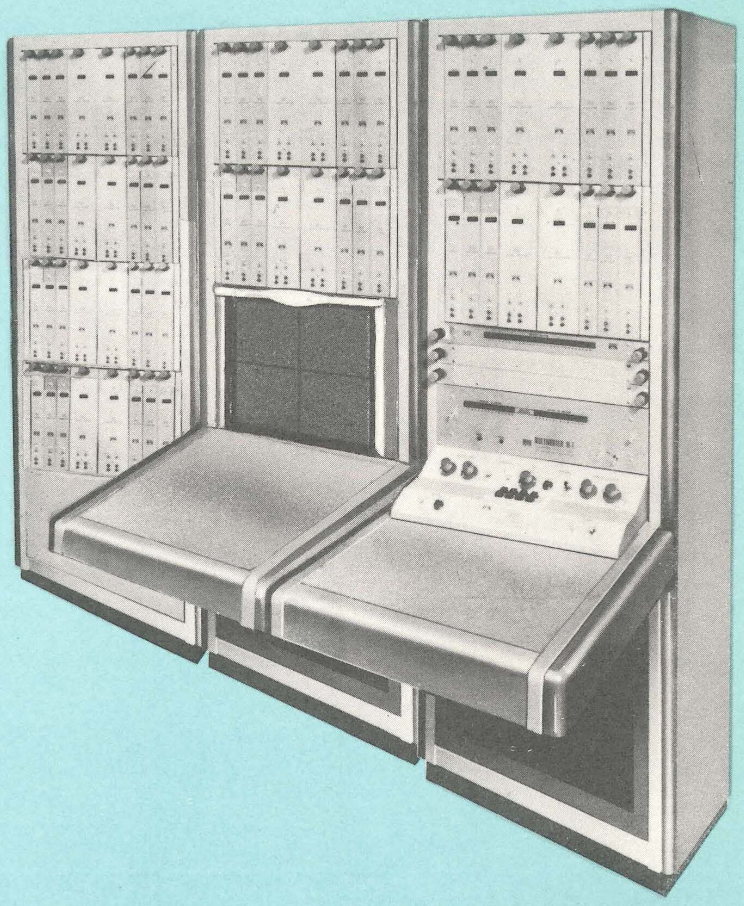
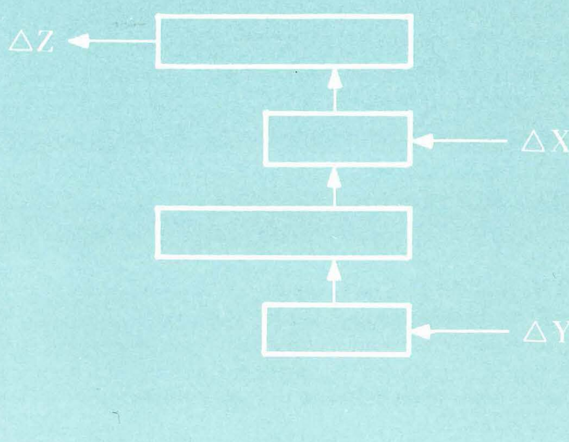
TRICE

- TRANSISTORIZED
- REALTIME
- INCREMENTAL
- COMPUTER
- EXPANDABLE





PACKARD BELL COMPUTER CORPORATION

1905 Armacost Avenue • Los Angeles 25, California • GRanite 8-4247

TRICE

THE FIRST DIGITAL COMPUTER TO OPERATE AT THE SPEED OF ANALOG COMPUTERS

WHAT TRICE IS

TRICE (Transistorized-Realtime-Incremental-Computer-Expandable) is an extremely high speed, completely solid state, incremental digital computer which combines the accuracy and repeatability of a digital computer with the speed, flexibility and ease of programming of an analog computer.

TRICE is composed of independent computing elements constructed on etched boards, each with its own memory in the form of an electrical delay line. Elements include Integrators, Digital Servos, Variable Multipliers, $\triangle Y$ Summers, and Constant Multipliers. These elements operate in parallel and are interconnected (programmed) by means of a plugboard.

COMPUTER ELEMENTS

INTEGRATOR. The basic element of TRICE is a self- contained Integrator. Each Integrator is composed of three registers: a Y register, an R register and an I register to store initial conditions. Three adders are used to add $Y+\triangle Y$, $Y+R$, and to make the necessary trapezoidal correction. The output is stored in two flipflops that indicate the sign and the existence of the output, respectively. As an added feature, if an overflow occurs (indicating that the integrand has exceeded its pre-assigned full scale value), an indicating light turns on and computation is stopped.

An Integrator receives three incremental inputs: $\triangle X$, $\triangle Y_1$ and $\triangle Y_2$, and generates an incremental output that is an approximation to YdX where $Y=Y_1+Y_2$. If these incremental outputs are summed, the result is a number Z where $Z \approx \int YdX$ over the interval of $\triangle X$ values that have been employed. The independent variable may be any function and need not be time.

VARIABLE MULTIPLIER. The Variable Multiplier generates $\triangle(XY)$ from the inputs $\triangle X$ and $\triangle Y$. This unit generates $\triangle(XY)$ using the formula: $\triangle(XY)=(Y+\triangle Y)\triangle X+X\triangle Y$, which is exact.

ΔY SUMMER. The Integrator and Digital Servo can accept two $\triangle Y$ inputs. When a larger number is required, a $\triangle Y$ Summer must be employed. This device will accept six $\triangle Y$ inputs, and, within two pulse times (0.67 microseconds), generate the binary representation of the sum. The output of the $\triangle Y$ Summer is connected directly to the Integrator or Digital Servo.

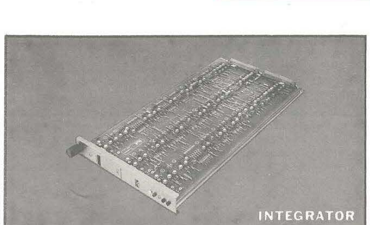
CONSTANT MULTIPLIER. The Constant Multiplier has a single input, $\triangle X$, and a single output, $K\triangle X$. No initial condition line is required.

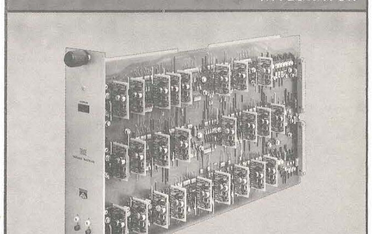
DIGITAL SERVO. The Digital Servo is a unit which generates an output whenever $-\frac{1}{2}<Y<+\frac{1}{2}$ and $Y\neq O$. The sign of the output is determined by the product of the signs of Y and $\triangle X$.

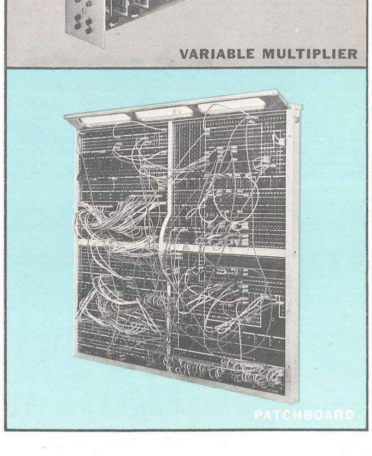
CONTROL UNIT. The Control Unit consists of a clock generator, a counter to provide timing pulses within each iteration, a number of control flipflops, and an overflow detector. The clock frequency, 3 megacycles, is controlled by a crystal and provides enough power to drive the lines to each board and the input stage of a clock amplifier on each board.

INPUT/OUTPUT. Both manual and automatic initial condition input devices are available. The latter employs a mechanical or photoelectric paper tape reader. Arbitrary function generators and analog to digital converters are employed for entering other types of data into the computation.

The results of computation can take the form of printed copy, or, via a digital to analog converter, results can be represented graphically.


INTEGRATOR


VARIABLE MULTIPLIER


PATCHBOARD

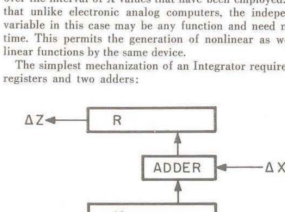
THEORY OF OPERATION

The basic element of an incremental computer, an Integrator, is a device that receives two incremental inputs, $\triangle X$ and $\triangle Y$, and generates an incremental output that is an approximation to YdX. If these increments are summed, the result is a number Z where

$$Z \approx \int YdX$$

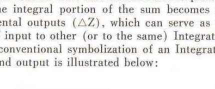
over the interval of X values that have been employed. Note that unlike electronic analog computers, the independent variable in this case may be any function and need not be time. This permits the generation of nonlinear as well as linear functions by the same device.

The simplest mechanization of an Integrator requires two registers and two adders:

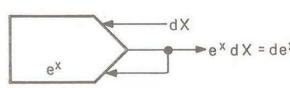


$\triangle Y$ is added to the first register to yield the successive values of Y. Upon the occurrence of a $\triangle X$ pulse, $Y\triangle X$ is added to R. The R value is thus $\lesssim Y\triangle X$, which is an approximation to $\int YdX$. Rather than accumulate this complete sum, however, the integral portion of the sum becomes a series of incremental outputs ($\triangle Z$), which can serve as the $\triangle X$ or the $\triangle Y$ input to other (or to the same) Integrators.

The conventional symbolization of an Integrator with its input and output is illustrated below:

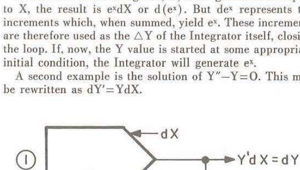


Two examples will indicate how integrators are interconnected. The first shows the generation of e^x.



If the value in the Y register, e^x, is integrated with respect to X, the result is $e^x dX$ or $d(e^x)$. But de^x represents the increments which, when summed, yield e^x. These increments are therefore used as the $\triangle Y$ of the Integrator itself, closing the loop. If, now, the Y value is started at some appropriate initial condition, the Integrator will generate e^x.

A second example is the solution of $Y''-Y=O$. This may be rewritten as $dY'=YdX$.



The first Integrator holds Y' and is integrated with respect to X, and so generates $Y'dX=dY$. The increments representing dY are summed in the second Integrator and again integrated with respect to X. The result, YdX, is, according to the given equation, equal to dY'. Therefore, employing the output of Integrator No. 2 as the dY input to Integrator No. 1, closes the loop and generates the required solution:

sinh X and cosh X.

MATHEMATICAL CONSIDERATIONS

All computer methods for the solution of differential and related equations involve the use of approximations. The resultant errors are minimized in TRICE through the use of a number of techniques. In order to minimize the error resulting from lags that are introduced by the parallel organization of the computer, each Integrator extrapolates. The truncation error generated by each integrator is $5/12h^3f'''(X^*)$ where X^* is some value within the interval of integration. With $h=10^{-3}$, this error is close to 10^{-9} assuming that the third derivative of the function is well behaved.

The second group of errors that must be considered are those that result from round-off. In many incremental computers, the $\triangle Z$ increments can take on only two values: $+1$ and -1. If no zero state exists for $\triangle Z$, the error can vary between $+1$ and -1. With a zero state, this error is at most $\pm\frac{1}{2}$ of an increment. If the truncation error is small, it can be shown that a three-valued (ternary) $\triangle Z$ effectively doubles the speed of computation. For these reasons a ternary $\triangle Z$ system has been adopted.

SIZE, POWER AND CONSTRUCTION

SIZE. The modular elements of TRICE are 12¾ inches high and 20 inches deep. The elements are 1¾ inches wide, except for the Variable Multiplier which is 3½ inches wide.

POWER. The Integrator and $\triangle$Y Summer require 8 watts each; the Constant Multiplier and Digital Servo require 6 watts each; the Variable Multiplier requires 10 watts.

CONSTRUCTION. The modular elements are slide supported at the top; each element can be pulled out for servicing and, by means of extension boards, elements can be operated extended from the cabinet.

SPECIFICATION SUMMARY

PULSE REPETITION RATE ....3 megacycles
WORD LENGTH ....30 binary digits (bits)
ITERATION RATE ....100,000 per second
(regardless of number of elements)

APPLICATIONS OF TRICE

- **Control System Stability Simulation**
- **Autopilot Response Simulation**
- **Pilot Plant Simulation**
- **Missile Trajectory Studies**
- **Satellite Orbit Parameter Studies**
- **Impact Prediction**
- **Coordinate Transformation for Target Acquisition**
- **Stable Platform Calculations**
- **Transformation of Coordinate Systems for Stabilizing various devices such as Radar, etc.**
- **Satellite Orbit Prediction**
- **Airborne Guidance and Control**

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