L-75

Diode Coincidence and Mixing Circuits in Digital Computers*

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Summary—**Basic circuits utilizing germanium diodes in electrically pulsed systems are described. The circuits are of the following types:**

1. Coincidence circuits—output signal occurs only when all the inputs receive signals simultaneously.

2. Mixing circuits—output signal occurs when any one of the inputs receives a signal.

The analyses of transient response of the output signal and the input impedance are given.

I. Introduction

Coincidence and mixing circuits, also known as gates and buffer circuits, respectively, occur frequently in many electronic devices and play an important role in electronic digital computers. A coincidence circuit produces an output when, and only when, all inputs are energized simultaneously. A mixing circuit combines several inputs without interaction into one output which is responsive to any one of the inputs. These circuits may be formed by using multiple control-grid vacuum tubes, tubes in parallel, or diodes.

The circuits, which are to be described, using germanium diodes are not amplitude sensitive, that is, the circuit operations depend only upon the presence or absence of signals provided the amplitudes are kept within a predetermined range. This property is desirable in most electronic digital computers and other similar applications.

In the following analysis and discussion it is assumed that the diodes are ideal except under the conditions where their back resistances cannot be neglected.

II. Coincidence Circuit

A basic coincidence circuit of n inputs for positive pulses is shown in Fig. 1. All the voltages shown are referred to ground. All the input pulses are assumed to be rectangular with the same duration and equal amplitude and will occur at the same instant when there is a coincidence. The supply voltages are adjusted so that:

$$E_1 > E_o > E_2, \tag{1}$$

and

$$I_1 > I. \tag{2}$$

When there is no signal at any of the inputs, the clamping diode X_c and all the coupling diodes $X_1, X_2, \cdots, X_n$ are conducting; hence, e_o equals E_o. When there is a pulse appearing at one of the inputs, taking input 1 as an example, X_1 is cut off. Since I_1 is greater than I the

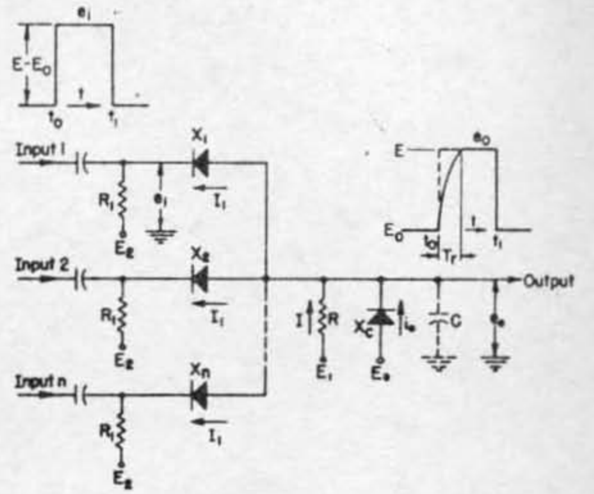

Fig. 1—Basic coincidence circuit for positive pulses.

clamping diode remains conducting, except when a coincidence of all the inputs occurs. With coincidence all the diodes are cut off and e_o rises exponentially with time constant RC, where C is the output capacitance including the capacitance of the diode X_c.

The rise time of the output pulse can be found to be:

$$T_r = RC \ln \frac{E_1 - E_o}{E_1 - E}. \tag{3}$$

If the voltage drop across R is large compared to the amplitude of the pulse, the rise time is approximately:

$$T_r = \frac{(E - E_o)C}{I}. \tag{4}$$

After the output voltage e_o has reached E, it follows the input voltage e_i exactly; because if e_o is greater than e_i, the coupling diodes will begin to conduct. If the input pulses do not have the same duration and do not occur at the same instant, the output pulse only occurs in the overlapping part of all the input pulses and has an amplitude equal to the smallest of the inputs.

The purpose of using the clamping diode is threefold. First, it acts as a clamper or dc restorer to permit the use of capacitive coupling. Second, it keeps e_o constant, except when there is a coincidence, regardless of the number of inputs at which signals are present. If the clamping diode were not present, the maximum change in e_o in the absence of a coincidence would be:

$$\Delta e_o = \frac{R_1E_1 + RE_2}{R_1 + R} - \frac{R_1E_1 + nRE_2}{R_1 + nR} \tag{5}$$

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1 of 4

L-75

and this variation may have sufficient amplitude to give a false response when n is large. Third, the clamping diode eliminates leakage signals caused by the back resistance of the coupling diodes. The maximum leakage signal, which occurs when signals are applied to n-1 inputs, is:

$$\Delta e_o' = \frac{(n-1)RR_1\Delta e_i}{(R+R_1)R_b+(n-1)RR_1} \tag{6}$$

for no clamping diode. R_b is the back resistance of a diode and Δe_i is the amplitude of the input pulses. With the clamping diode, the leakage signal will not occur until i_o becomes zero or:

$$\frac{(n-1)(E-E_o)}{R_b} = I_1 - I. \tag{7}$$

Under this condition the clamping diode is cut off. If the difference $I_1 - I$ is large enough so that the clamping diode remains conducting for the highest pulse amplitude, no leakage will occur.

In the case where the total capacitances of the coupling diodes is comparable to the output capacitance, the output voltage changes abruptly to the value:

$$\frac{nC_xE}{C+nC_x}, \tag{8}$$

where C_x is the capacity of a coupling diode and the rise time is:

$$T_r' = (nC_x + C)R \ln \frac{E_1 - \dfrac{nC_x}{nC_x + C}E}{E_1 - E} \cdot \tag{9}$$

If the voltage drop across R is large compared to the amplitude of the pulse, the rise time is approximately:

$$T_r' = \frac{CE}{I} \cdot \tag{10}$$

Several types of input circuits are shown in Fig. 2 where the notations are identical with those used in Fig. 1. Input 1 is a capacitive coupled input. Inputs 2 and 3 are used for direct coupling which is sometimes necessary for gate signals of long durations. Input 2 should not be driven to a potential lower than E_o for then excessive current may exist in X_c and X_2 in series, if the output impedance of the driving source is low. This limitation is avoided by the use of input 3, since diode X_5 is cut off when the input voltage is less than E_o.

Input 4 is an inhibiting input. A coincidence of inputs, 1, 2, and 3 will give an output, except when a coinciding negative pulse is applied at input 4. Normally, diodes X_6 and X_4 are cut off and the presence of a negative pulse at the input makes the diode X_4 conduct and inhibits the output. Diode X_6 is merely used for clamping, while the series resistor R_3 is used to limit the current through X_c and X_4 during the negative pulse when the output impedance of the source is low.

It should be noted that if there is no signal existing at the inhibiting input for a considerable length of time the potential of point A is approximately midway between E and E_o, assuming the back resistance of diodes

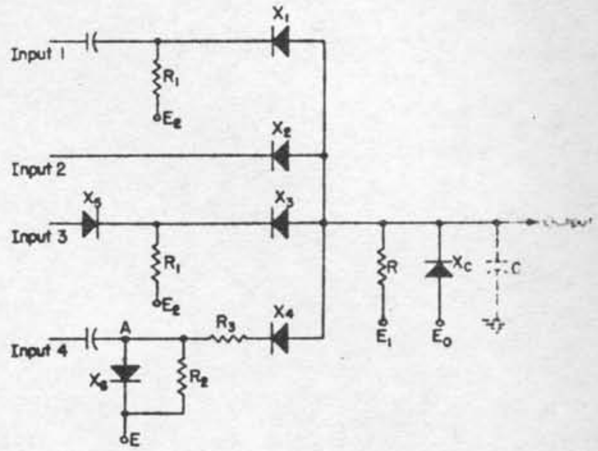

Fig. 2—Coincidence circuit for positive pulses · different types of inputs.

X_4 and X_6 are equal and large compared to R_3. The output voltage, when it reaches the potential of point A, is affected by the output impedance of the inhibiting source. The shunt resistor R_2, having a resistance small compared to the back resistance of the crystal diode, maintains the potential of point A very [illegible] the absence of inhibiting pulses.

Any combination of the inputs described above will form a coincidence circuit. The number of inputs is limited by the current capacity of the clamping diode X_c, since the current in the clamping diode, when no signal exists at any of the inputs, is:

$$i_o = (n-p)I_1 - I, \tag{11}$$

where n is the total number of inputs and p is the number of inhibiting inputs.

A coincidence circuit for negative pulses is identical with the one for positive pulses, except that all the diode connections are reversed and the relation of the various voltages is:

$$E_2 > E_o > E_1. \tag{12}$$

Positive pulses are required for the inhibiting inputs.

III. Mixing Circuits

A mixing circuit for positive pulses is shown in Fig. 3. The voltage E_3 is negative with respect to E_o and all diodes are conducting in the absence of input pulses. The diodes X_2, X_4, etc., are used for clamping. When a signal is applied to any one of the inputs, taking input 1 for example, X_2 is cut off and X_1 conducts more heavily. Other coupling diodes X_3, etc. are cut off when e_o rises above E_o and the output voltage e_o will follow the input voltage e_i exactly until time t_1. All the coupling diodes are cut off and e_o falls exponentially with time constant

L-75

RC. If the voltage drop across R_4 is large compared to the amplitude of the pulse, I and C determine the fall time T_f. The number of inputs is limited by the required transient response of the driving source which sees a capacitance of $C+(n-1)C_s$, where C_s is the shunt capacitance of a diode.

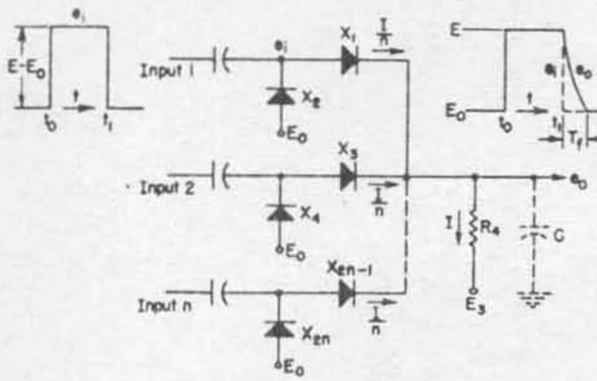

Fig. 3—Basic mixing circuit for positive pulses.

For direct-coupled input, the coupling capacitor and the clamping diode are omitted. When the inputs are a combination of direct- and capacitive-coupled inputs, it is desirable to shunt the clamping diodes with resistors having a low resistance compared to the back resistance of a diode for a similar reason as that described for the inhibiting input of a coincidence circuit.

IV. Input Impedance

The equivalent circuit of a driving source and one of the inputs of a coincidence circuit for positive pulses is shown in Fig. 4(a), where R_g is the internal resistance of the equivalent generator. It is assumed that the capacitance of the coupling capacitor C_c is large so that the change in voltage across it is negligible during the pulse. For the quiescent state current i_1 is zero, and the potential at point c is E_o. When a pulse is generated by the source, both e_g and i_1 are increasing. Since point c is clamped at E_o, I_1 remains constant and i_2 decreases until X_1 is cut off. The input resistance R_i across points a and

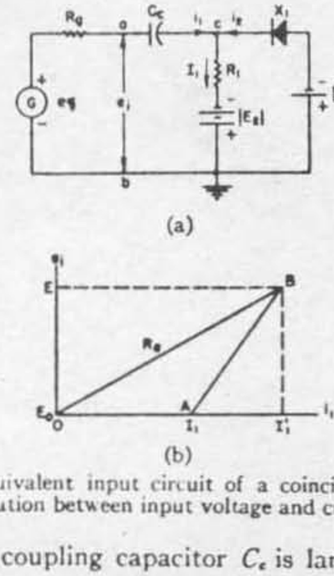

Fig. 4—(a) Equivalent input circuit of a coincidence circuit; (b) relation between input voltage and current.

b can be expressed by the function:

$$R_i = 0 \quad \text{for} \quad 0 < i_1 < I_1$$
$$R_i = R_1 \quad \text{for} \quad i_1 \geqq I_1, \tag{13}$$

which is represented by the slopes of the broken line OAB in Fig. 4(b).

Letting e_i swing from E_o to E, the input resistance can be represented by an equivalent resistance R_e which will satisfy the conditions at the end points O and B. The equivalent resistance R_e can be written as:

$$R_e = \frac{E - E_o}{I_1'} = \frac{E - E_o}{E - E_3} R_1, \tag{14}$$

where R_e is a function of the amplitude of the pulse. Since the circuits are not amplitude sensitive, only the minimum pulse amplitude is to be considered. The equivalent input impedance is then a parallel combination of R_e and C_s which is the capacitance of crystal diode X_1. The back resistance of the diode is usually very large compared to R_e and can be neglected. The input impedance of a mixing circuit can be found in a similar way, and will not be repeated here.

V. Applications

Coincidence circuits are commonly used for the following applications:

1. Reshaping of deteriorated pulses produced by the various components of electronic digital computers.
2. Selecting or inhibiting a certain one or groups of pulses from a pulse train.

Fig. 5 illustrates all the functions mentioned above. The pulse train at input 1 is reshaped by the standard

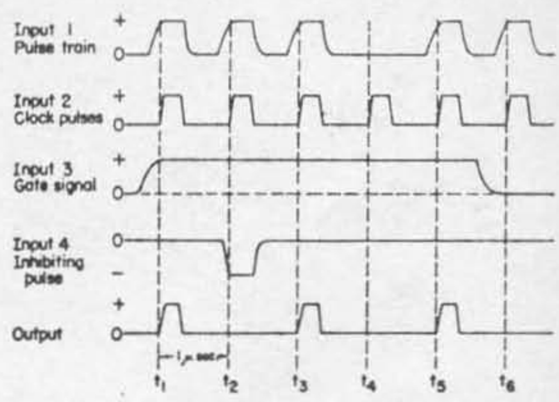

Fig. 5—Wave forms of a typical coincidence circuit for positive pulses.

timing or clock pulses at input 2 and a portion of the train is selected by the gate signal at input 3. The pulse at time t_2 is deleted by the negative inhibiting pulse at input 4. Complete inhibition can be assured if the inhibiting pulse envelopes the clock pulse, regardless of the shape of pulses of the pulse train. These operations are accomplished by the use of one diode coincidence circuit, whereas many dual control-grid tubes and their associated components would be required if vacuum-tube circuits are employed.

384

L-75

Mixing circuits are used primarily for combining and isolating the outputs of several sources which may have different output impedances. The transient response of many vacuum tubes connected in parallel is greatly improved if they are isolated by a mixing circuit.

Since the diode coincidence and mixing circuits have negligible attenuation, they can be connected in tandem, provided that the output of the driving circuit is capable of sustaining the current required by the input of the driven circuit. These circuits have been extensively used in the EDVAC, an electronic digital computer developed at the Moore School of Electrical Engineering, University of Pennsylvania. In the EDVAC the diode coincidence and mixing circuits are designed for pulses of 0.3-microsecond duration at repetition rates as high as one megacycle with rise and fall times of 0.1 microsecond. These diode circuits can be designed to operate at pulse repetition rates of several megacycles and having rise and fall times of the order of 0.05 microsecond or less.

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Discussion on

"Stabilization of Simultaneous Equation Solvers"*

G. A. KORN

Lofti A. Zadeh:[1] Dr. Korn's paper on "Stabilization of Simultaneous Equation Solvers" contains a few errors, possibly of a typographical origin, which distort the significance of his main result.

In the first place, equation (3) should read

$$\sum_{k=1}^{n}\left[a_{ik} - \delta_{ik}\frac{(n+1)}{A}\right]x_k + b_i = 0,$$

and consequently (8) should be written as

$$\frac{n+1}{A(p)} = \lambda_i.$$

In the second place, Dr. Korn's assertion that the real parts of the λ_i never exceed unity, provided a_{ik} is positive definite and $a_{ik} \leq 1$, is incorrect. Actually, the real parts of the λ_i may be greater than unity, but the magnitudes of the λ_i will certainly be less than $n+1$.

Finally, in the statement of Dr. Korn's stability criterion (immediately following equation (10)), a should read $|a|$ (magnitude of a). In the corrected form the criterion loses much of its simplicity, since in order to ascertain whether the computer will be stable or not, it is necessary to vary not only the magnitude of a but also its phase.

A perfectly general and yet simple criterion for stability of a simultaneous equation solver can easily be obtained through the use of Nyquist's criterion. Thus, we can state that:

A system of n equations

$$\sum_{k=1}^{n} a_{ik}x_k + b_i = 0$$

will have a stable solution if, and only if, the characteristic roots of a_{ik}, the λ_i, are such that the points $(n+1)/\lambda_i$ are not enclosed by the Nyquist plot of $A(p)$.

In conjunction with the above criterion it is useful to note that when a_{ik} is positive definite and $a_{ik} \leq 1$, the points $(n+1)/\lambda_i$ are located outside of the unit circle in the right half of the complex plane.

Granino A. Korn:[2] The writer is grateful to Dr. L. Zadeh of Columbia University for his criticism of the paper on "Stabilization of Simultaneous Equation Solvers."

With respect to Dr. Zadeh's first objection, it was considered fair enough to absorb the "mixing loss" $1/n+1$ of the summing network into the gain A of the amplifier, so that equations (2) and (3) may be considered as correct. Under these circumstances the real parts of the λ_i will, indeed, be less than $n+1$, not one, and greater than zero.

In the statement of the stability criterion following equation (10), a should read $|a|$ (typing error). The writer has, however, clearly stated below equation (10) that the phase as well as the magnitude of a must be varied. Dr. Zadeh's application of Nyquist's criterion is not self-evident but seems to be derived from the writer's equation (8).

* G. A. Korn, "Stabilization of simultaneous equation solvers," Proc. I.R.E., vol. 37, pp. 1000–1002; September, 1949.
[1] Columbia University, New York, N. Y.
[2] Curtiss-Wright Corporation, Columbus, Ohio.

484