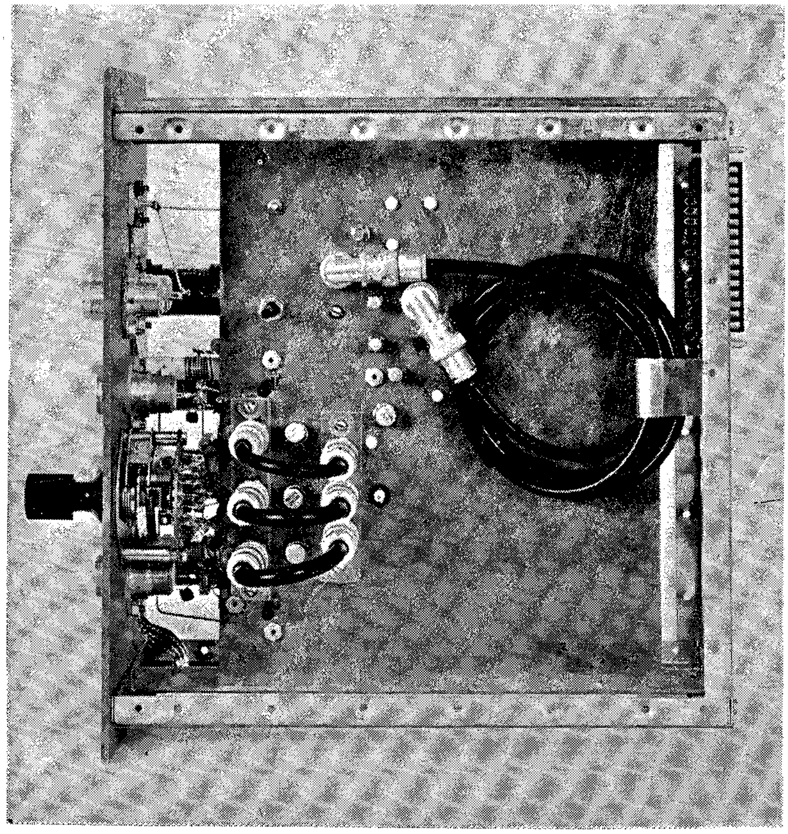
Laboratori Nazionali di Frascati

LNF-61/68 (1961)

C. Infante, F. Pandarese: TUNNEL DIODES. STABILIZE COINCIDENCE CIRCUIT.

Estratto da: Electronics, 34, 133 (1961)

Characteristics of tunnel diodes enable circuit to determine pulse coincidence within nanosecond limits. Circuit design combined with other properties of the diodes result in good temperature stability and limited sensitivity to transistor parameters



Component layout is shown in bottom view of chassis for nanosecond coincidence circuit

TUNNEL DIODES

Stabilize Coincidence Circuit

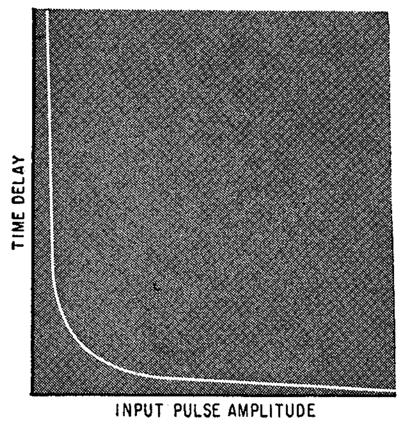


FIG. 1—Variations in delay of a regenerative circuit are a function of input amplitude

By C. INFANTE*
F. PANDARESE
Labortori Nazionali Di Frascati
Rome, Italy

PERFORMANCE requirements for a coincidence circuit to be used in high-energy physics experiments were obtained using tunnel diodes. The high ratio of loop gain-bandwidth to loop delay obtainable with these inherently regenerative devices permitted design of a circuit in which timing jitter is limited to a few nanoseconds.

Coincidence circuits in some high-energy physics experiments function like the AND gate, but specifications are usually different. A coincidence circuit must handle high peak input rates, accept coincident pulses that vary widely in amplitude and shape, and reject pulses that do not coincide in time within a few nanoseconds.

Since the coincidence circuit is usually fed by a scintillation counter, input pulse amplitudes vary statistically and limiting circuits are incorporated before the AND circuit to establish the range of pulse amplitudes accepted. Trigger circuits or discriminators are also used preceding the AND circuit to

*Now with Tektronix, Beaverton, Oregon

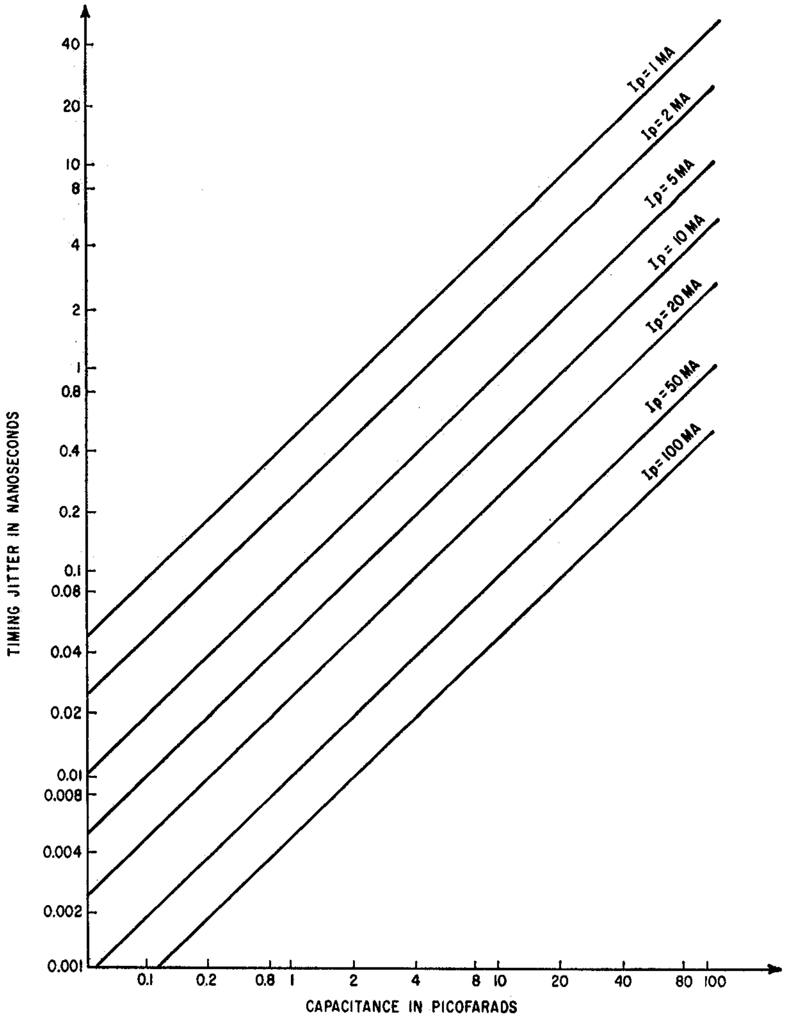


FIG. 2—Timing jitter for a current pulse 10 percent above threshold is a function of peak current and capacitance of a germanium tunnel diode

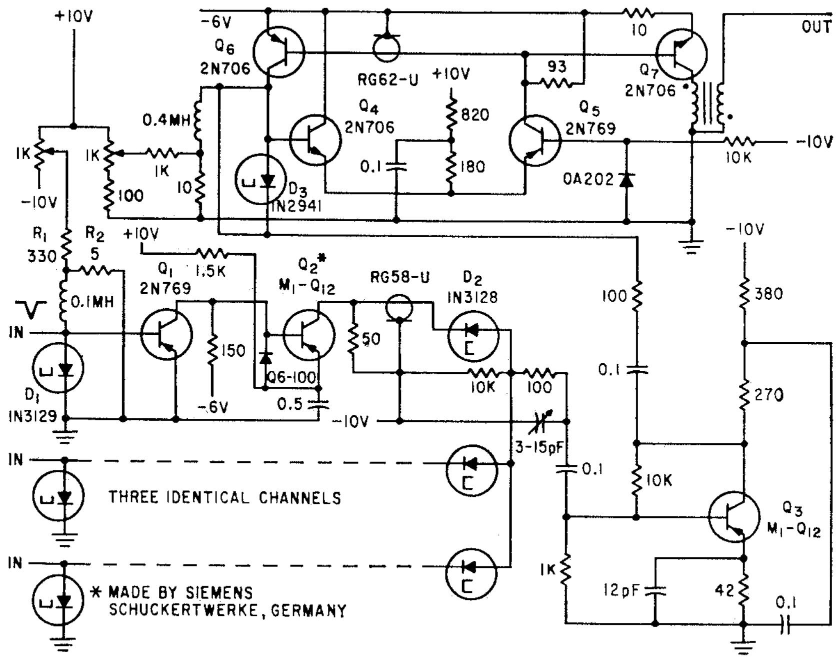


FIG. 3—Coincidence circuit using tunnel diodes has limited timing jitter, good temperature stability and is insensitive to transistor parameters

establish the shape of pulses that will be accepted, although these circuits have rarely been used in the past because timing jitter is encountered in regenerative circuits operating with pulses near the threshold level.[1]

Circuit delay is plotted as a function of input pulse amplitude in the curve in Fig. 1, which shows that some deterioration in timing results. In a regenerative circuit, it can be demonstrated that timing jitter is dependent on loop gain-bandwidth and on loop delay.[1] The tunnel diode, which is inherently a regenerative device, behaves similarly, but loop gain-bandwidth is so large and loop delay so small that timing jitter can be limited to a few nanoseconds.

The plot in Fig. 2 is based on an analytical approximation of the voltage-current characteristics of the tunnel diode.[2] From measurements of peak current and capacitance of a germanium tunnel diode, timing jitter can be found from the plot. The resulting number is the variation in delay between an input current pulse 10 percent above the threshold and an infinitely large input pulse. For example, a tunnel diode with 20 ma peak current and 10 pf capacitance has timing jitter of 0.2 nsec. In contrast, timing jitter of vacuum-tube circuits is one or two orders of magnitude greater.

The coincidence circuit is shown schematically in Fig. 3. In operation input tunnel diode D_1 is biased by resistors R_1 and R_2 so that it operates close to maximum sensitivity. Since the scintillation counter is connected to the coincidence circut through 125-ohm coaxial cable, the circuit acts as a voltage generator with 125 ohms impedance. To properly terminate the cable, it must be matched at the multiplier phototube end

When magnitude of an input current pulse exceeds the difference between peak diode current and bias current, the diode switches on transistor Q_1. Emitter current in Q_2, which is normally 10 ma, is switched off, producing a pulse of standard amplitude at the collector. The pulse is clipped by the 50-ohm shorting stub so that electrical length of the shorting stub deter-

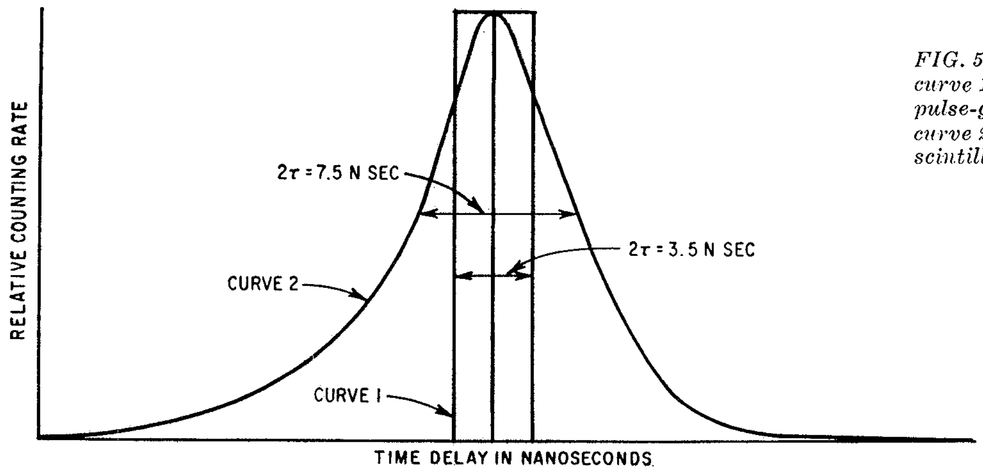


FIG. 5—Resolution-time curve 1 was taken using pulse-generator and curve 2 using scintillation counters

mines resolving time of the coincidence circuit. Shape of the output pulse for different cable lengths is shown in Fig. 4. By using voltage to bias the tunnel diode, linearity and independence from diode characteristics is greater than that obtainable using current-biasing techniques.

Selection of transistor Q_2 was based primarily on cost. Any transistor with a minimum gain-bandwidth product of 300 Mc and a dissipation rating of 100 mw can be used (2N1143 and 2N1385 have been used successfully).

Output of each discriminator is fed to the input of a tunnel diode coincidence circuit.[3] The ratio of coincident to noncoincident pulse amplitudes can be increased by integrating output from the circuit with a time constant equal to the diode switching time. Output of the AND circuit is inverted and amplified by transistor Q_3 with a large amount of negative feedback.

The amplified output is then fed to a final discriminator and shaper.[4] In the shaper circuit, tunnel diode D_3 is operated in the bistable mode. The diode is reset to the low-voltage state through transistors Q_4, Q_5 and Q_6 after a time determined by the RG 62-U coaxial cable. Transistor Q_7 is saturated by the signal, furnishing a 4-volt pulse at the output. Either a positive or negative pulse can be provided depending on how the transformer is connected.

Because of the small temperature coefficients of tunnel diodes and the large amount of negative feedback in the circuit, the coincidence circuit has proved to be temperature stable and to be insensitive to transistor parameters. Each input discriminator and the combination amplifier-output discriminator were stable within less than 1 percent over an 8-hour period under laboratory conditions. At their most sensitive settings, the input discriminators are triggered by a 2-ma current pulse at a 20-Mc maximum input rate. Because of the relatively small number of a-c couplings, no shift in d-c base potential was experienced.

Typical curves of resolving time using standard pulses from a pulse generator are shown in Fig. 5. The curves were plotted under actual operating conditions. The increased width of the second curve resulted from both timing jitter in the input circuits and from statistical variatons in multiplier phototube output. The second curve was plotted using carbon 60 with detection by two plastic scintillators.

The authors gratefully acknowledge the assistance of R. Rizzi, who designed and tested the apparatus, and M. Tanzini, who assembled most of the test circuits and the final coincidence circuit.

REFERENCES

(1) J. May, L'onde electrique, 38, p 622, 1958.
(2) C. Infante and F. Pandarese, The Tunnel Diode As A Threshold Device: Theory and Application, Proc 1961 Belgrade Conference on Nuclear Electronics (to be published).
(3) R. C. Sims, E. R. Beck, Jr., and V. C. Kamm, A Survey of Tunnel Diode Digital Techniques, *Proc IRE*, **49**, 136, 1961.
(4) R. M. Sugarman, Proc 1960 Conference on High-Energy Physics Instrumentation at Berkeley.

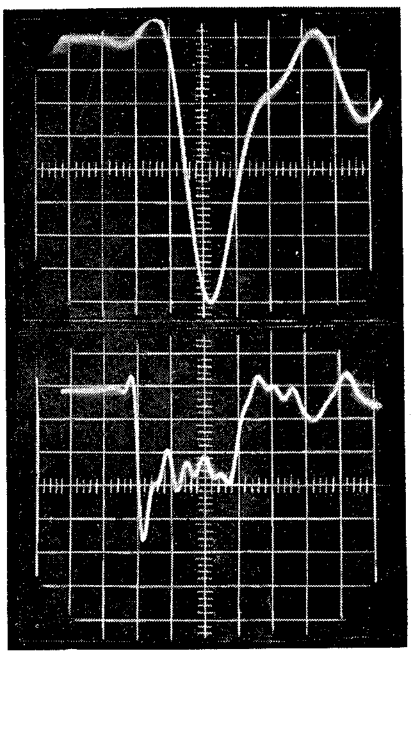
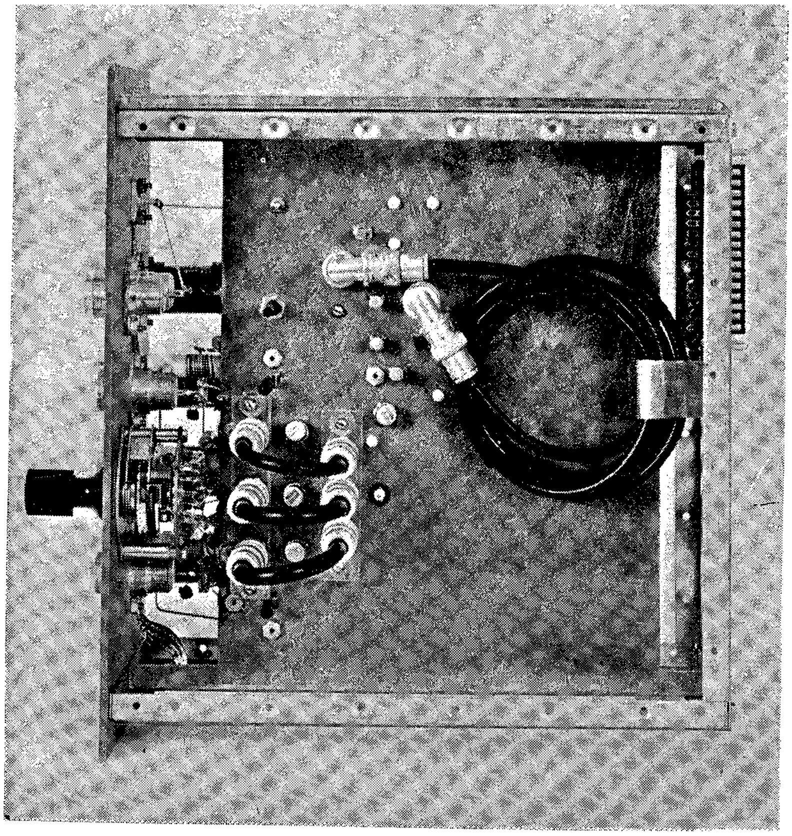


FIG. 4—Upper and lower discriminator pulses were photographed using 0.5 and 5 nsec shorting stubs, 0.06 and 0.1 volt per cm vertical sensitivities, and 1 and 4 nsec per cm horizontal sweep rates, respectively

Characteristics of tunnel diodes enable circuit to determine pulse coincidence within nanosecond limits. Circuit design combined with other properties of the diodes result in good temperature stability and limited sensitivity to transistor parameters



Component layout is shown in bottom view of chassis for nanosecond coincidence circuit

TUNNEL DIODES

Stabilize Coincidence Circuit

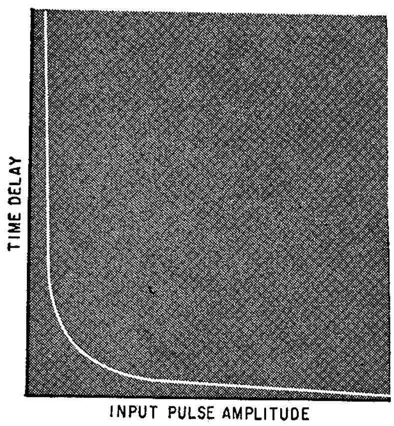


FIG. 1—Variations in delay of a regenerative circuit are a function of input amplitude

By C. INFANTE*
F. PANDARESE
Labortori Nazionali Di Frascati
Rome, Italy

PERFORMANCE requirements for a coincidence circuit to be used in high-energy physics experiments were obtained using tunnel diodes. The high ratio of loop gain-bandwidth to loop delay obtainable with these inherently regenerative devices permitted design of a circuit in which timing jitter is limited to a few nanoseconds.

Coincidence circuits in some high-energy physics experiments function like the AND gate, but specifications are usually different. A coincidence circuit must handle high peak input rates, accept coincident pulses that vary widely in amplitude and shape, and reject pulses that do not coincide in time within a few nanoseconds.

Since the coincidence circuit is usually fed by a scintillation counter, input pulse amplitudes vary statistically and limiting circuits are incorporated before the AND circuit to establish the range of pulse amplitudes accepted. Trigger circuits or discriminators are also used preceding the AND circuit to

*Now with Tektronix, Beaverton, Oregon

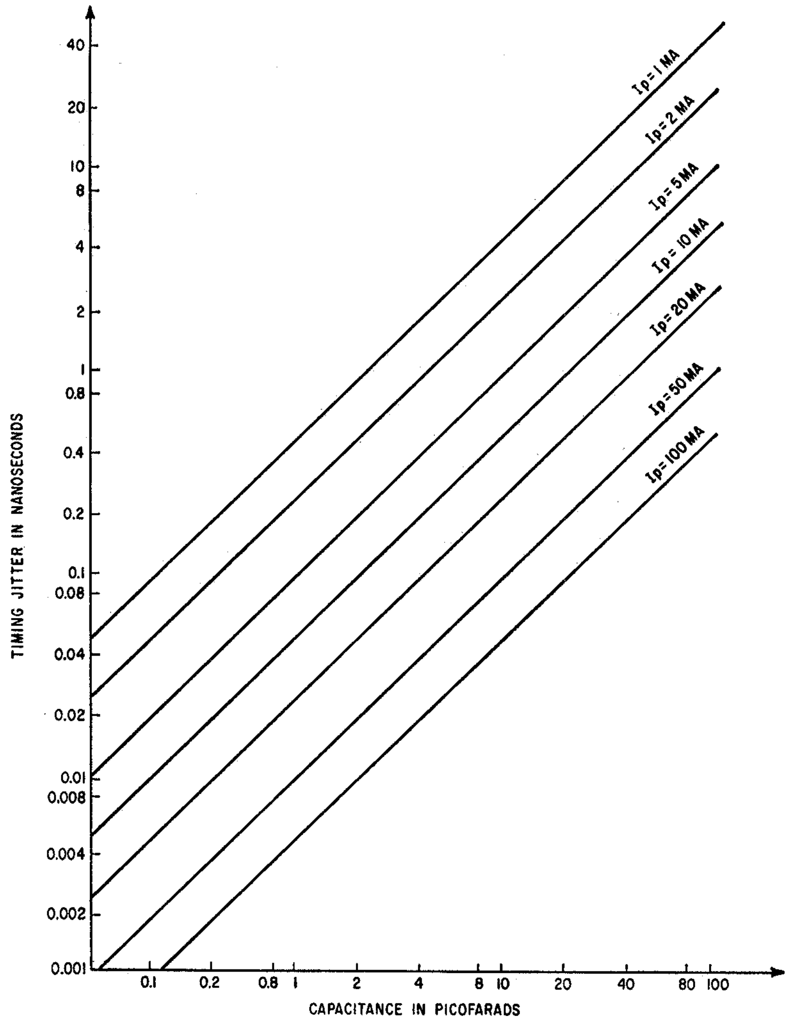


FIG. 2—Timing jitter for a current pulse 10 percent above threshold is a function of peak current and capacitance of a germanium tunnel diode

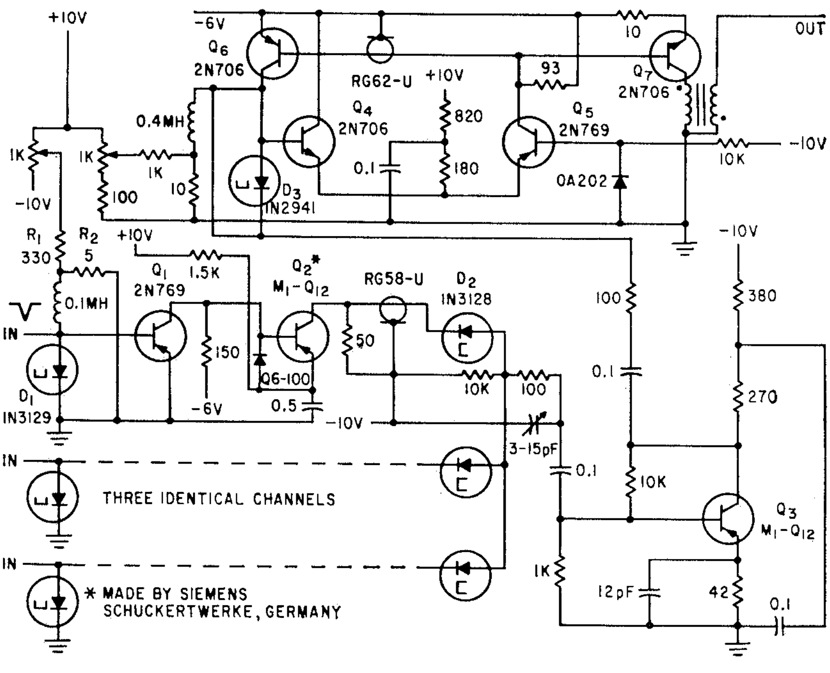


FIG. 3—Coincidence circuit using tunnel diodes has limited timing jitter, good temperature stability and is insensitive to transistor parameters

establish the shape of pulses that will be accepted, although these circuits have rarely been used in the past because timing jitter is encountered in regenerative circuits operating with pulses near the threshold level.[1]

Circuit delay is plotted as a function of input pulse amplitude in the curve in Fig. 1, which shows that some deterioration in timing results. In a regenerative circuit, it can be demonstrated that timing jitter is dependent on loop gain-bandwidth and on loop delay.[1] The tunnel diode, which is inherently a regenerative device, behaves similarly, but loop gain-bandwidth is so large and loop delay so small that timing jitter can be limited to a few nanoseconds.

The plot in Fig. 2 is based on an analytical approximation of the voltage-current characteristics of the tunnel diode.[2] From measurements of peak current and capacitance of a germanium tunnel diode, timing jitter can be found from the plot. The resulting number is the variation in delay between an input current pulse 10 percent above the threshold and an infinitely large input pulse. For example, a tunnel diode with 20 ma peak current and 10 pf capacitance has timing jitter of 0.2 nsec. In contrast, timing jitter of vacuum-tube circuits is one or two orders of magnitude greater.

The coincidence circuit is shown schematically in Fig. 3. In operation input tunnel diode D_1 is biased by resistors R_1 and R_2 so that it operates close to maximum sensitivity. Since the scintillation counter is connected to the coincidence circuit through 125-ohm coaxial cable, the circuit acts as a voltage generator with 125 ohms impedance. To properly terminate the cable, it must be matched at the multiplier phototube end

When magnitude of an input current pulse exceeds the difference between peak diode current and bias current, the diode switches on transistor Q_1. Emitter current in Q_2, which is normally 10 ma, is switched off, producing a pulse of standard amplitude at the collector. The pulse is clipped by the 50-ohm shorting stub so that electrical length of the shorting stub deter-

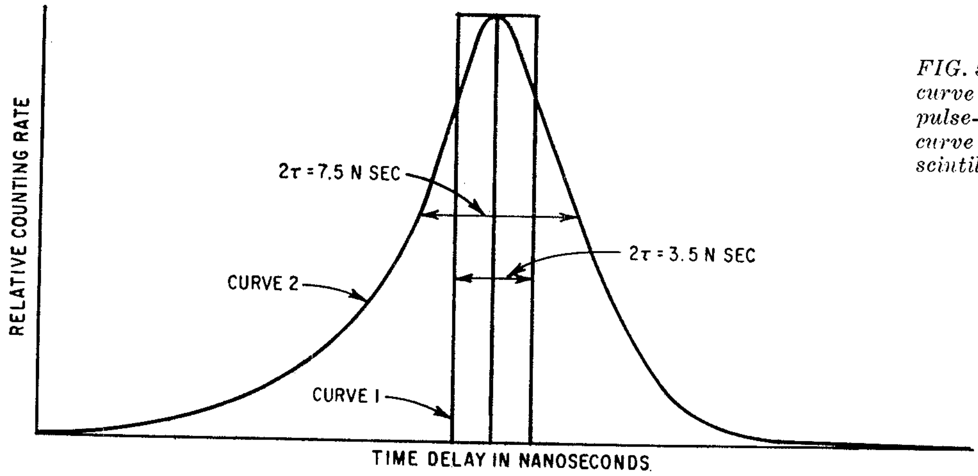


FIG. 5—Resolution-time curve 1 was taken using pulse-generator and curve 2 using scintillation counters

mines resolving time of the coincidence circuit. Shape of the output pulse for different cable lengths is shown in Fig. 4. By using voltage to bias the tunnel diode, linearity and independence from diode characteristics is greater than that obtainable using current-biasing techniques.

Selection of transistor Q_2 was based primarily on cost. Any transistor with a minimum gain-bandwidth product of 300 Mc and a dissipation rating of 100 mw can be used (2N1143 and 2N1385 have been used successfully).

Output of each discriminator is fed to the input of a tunnel diode coincidence circuit.[3] The ratio of coincident to noncoincident pulse amplitudes can be increased by integrating output from the circuit with a time constant equal to the diode switching time. Output of the AND circuit is inverted and amplified by transistor Q_3 with a large amount of negative feedback.

The amplified output is then fed to a final discriminator and shaper.[4] In the shaper circuit, tunnel diode D_3 is operated in the bistable mode. The diode is reset to the low-voltage state through transistors Q_4, Q_5 and Q_6 after a time determined by the RG 62-U coaxial cable. Transistor Q_7 is saturated by the signal, furnishing a 4-volt pulse at the output. Either a positive or negative pulse can be provided depending on how the transformer is connected.

Because of the small temperature coefficients of tunnel diodes and the large amount of negative feedback in the circuit, the coincidence circuit has proved to be temperature stable and to be insensitive to transistor parameters. Each input discriminator and the combination amplifier-output discriminator were stable within less than 1 percent over an 8-hour period under laboratory conditions. At their most sensitive settings, the input discriminators are triggered by a 2-ma current pulse at a 20-Mc maximum input rate. Because of the relatively small number of a-c couplings, no shift in d-c base potential was experienced.

Typical curves of resolving time using standard pulses from a pulse generator are shown in Fig. 5. The curves were plotted under actual operating conditions. The increased width of the second curve resulted from both timing jitter in the input circuits and from statistical variatons in multiplier phototube output. The second curve was plotted using carbon 60 with detection by two plastic scintillators.

The authors gratefully acknowledge the assistance of R. Rizzi, who designed and tested the apparatus, and M. Tanzini, who assembled most of the test circuits and the final coincidence circuit.

REFERENCES

(1) J. May, L'onde electrique, 38, p 622, 1958.
(2) C. Infante and F. Pandarese, The Tunnel Diode As A Threshold Device: Theory and Application, Proc 1961 Belgrade Conference on Nuclear Electronics (to be published).
(3) R. C. Sims, E. R. Beck, Jr., and V. C. Kamm, A Survey of Tunnel Diode Digital Techniques, *Proc IRE*, **49**, 136, 1961.
(4) R. M. Sugarman, Proc 1960 Conference on High-Energy Physics Instrumentation at Berkeley.

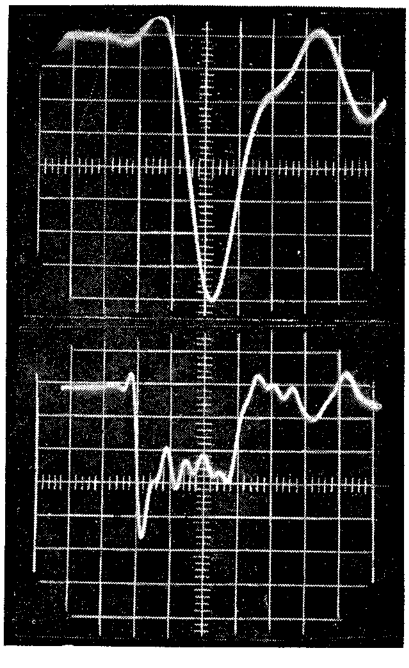


FIG. 4—Upper and lower discriminator pulses were photographed using 0.5 and 5 nsec shorting stubs, 0.06 and 0.1 volt per cm vertical sensitivities, and 1 and 4 nsec per cm horizontal sweep rates, respectively