BNL 711 (T-248)

NANOSECOND COUNTER CIRCUIT MANUAL

R. Sugarman, F.C. Merritt, and W.A. Higinbotham

February 1962

BROOKHAVEN NATIONAL LABORATORY

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FOREWORD

This manual is intended for use by experimenters in high energy physics who will use the fast logic circuits at Brookhaven and for the people who will maintain the circuits. The circuits are compatible with the speeds of currently available photomultiplier tubes and with the variations in counting rate encountered at the Cosmotron and AGS accelerators. A large part of this system was described in the *Proceedings of the International Conference on Nuclear Electronics* held in Belgrade, Yugoslavia, in May 1961. Earlier reports were published in the *IRE Transactions on Nuclear Science*, NS-7, No. 1, 23 (March 1960) and in the *Proceedings of the Conference on Instrumentation for High Energy Physics* held at Berkeley in October 1960. Earlier revisions of the circuits and some miscellaneous topics were described in *Millimicronotes*, a set of internal BNL reports.

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CONTENTS

FIGURES

FIGURES

NANOSECOND COUNTER CIRCUIT MANUAL

INTRODUCTION

The nanocards form a 100-Mc counting system for use with experiments at accelerators. Current switching logic using both transistors and germanium tunnel diodes is used for all high speed logic. All critical circuits have a rise time and time jitter of 2 nsec or less. The chief logical elements are pulse-height limiters, discriminators, a multichannel coincidence circuit, a four-fold fanout, and a scale of 8. The fanout enables a limiter or discriminator output to drive any combination of four elements. Each element is a separate plug-in module. Elements are interconnected with 50-ohm cable at about a 5-ma level with at least one termination. All module inputs and outputs are compatible so that, for example, a discriminator can either drive or be driven from a coincidence circuit.

To insure reliable high speed operation and good time and temperature stability the transistors are operated at unity charge gain either in a current switching mode or in a linear mode in distributed amplifiers. Each tunnel diode provides a switching charge gain of from 2 to 5. Most modules will operate up to a continuous counting rate of 10^8 pulses per second. Wide variations in random counting rate may be tolerated.

To prevent spurious pulsing on overloads, a pulse-height limiter and delay line clip are used at the anode of each photomultiplier input. Modules have either a built-in delay line clip or provision for an external clip at the output. The clips produce a dc-free pulse for automatic baseline restoration of subsequent modules. They also can be used to produce a pulse shorter than the 4-nsec minimum pulse width of the discriminators.

The discriminators and scaler have provision for remote turnoff from auxiliary timing circuits. Exit from the high speed counting circuits to conventional scalers and logic circuits is via a 10-Mc regenerative pulse amplifier which delivers +9-volt pulses into 100 ohms. This will be referred to as the 10-Mc scaler-driver.

CONSTRUCTION AND SHIELDING

All nanocard chassis are mechanically identical and are of prepunched, die-stamped, gold plated brass. Except for power buses, printed circuitry is not used because of the special techniques that would be required for low inductance grounds, the chief wiring problem. Design tolerances permit a ±7% change in any one component or supply potential.

Power supplies must be adjusted to within ±1% and lock nuts put on all shafts if the system is to be set at its mid-tolerance point. Do not check power supplies with any meter that has not recently been calibrated against a primary reference standard. Many test meters are off by 10%!

Individual shields are available for the cards, or the whole receiver may be easily shielded. The following are some shielding hints:

1. Spark chambers can radiate frequencies beyond a kMc. Use complete air-tight shielding. Partial shielding is often worse than no shielding: it can act as a reradiator. Overlap partially contacting surfaces at least ¼ inch.

2. Use double-shielded coax cables. Do not use nonlocking General Radio 874 connectors without clip locks.

3. If any rf radiation travels along the outside of coax cable braid, it may be suppressed by slipping the cable through or around ferrite toroids.

All nanocard frames must be grounded. If not, touching the frame with any metal object the size of a penny or larger will give spurious counts. Capacity discharge to the frame travels through the internal grounds and switches the tunnel diodes.

The system will operate up to 50°C. Operation at higher temperatures may require temporary system recalibration and will in any event shorten the life of the transistors. In other words:

Do not operate above vacuum tube equipment without a fan!

NANOCARD INTERCONNECTIONS

Terminations

The discriminators, scale of 8, 10-Mc scaler-driver, and coincidence circuits are input terminated and may be driven by a nonterminated source of 5 ma or less. Under these conditions their reflection coefficient is 10% or less.

Larger currents may take the input circuitry out of its operating range and cause much larger reflection coefficients. Therefore, either photomultiplier anodes should be terminated or local limiters should be employed. The cascode transistor limiter of Figure 5 is suitable but complex. A simpler limiter is shown in Figure 1. The line clip is necessary for diode biasing and for pulse width stabilization of both coincidence circuits and discriminator inputs. If an input pulse is wider than the discriminator preset dead time, the discriminator may fire more than once. The clip also provides a dc-free pulse to the ac-coupled discriminators for high duty-cycle operation. (The limiter current should be reduced to 4 ma for use with the IH-53 0.5 to 2-ma discriminator by increasing R_1 to 3.6 K.)

The IH-75 fanout is unterminated and must be driven from a terminated 50-ohm source. The limiter must be terminated with 50 ohms, not a clip, when driving a fanout.

High Duty-Cycle Operation

Two types of interconnection are used for high duty-cycle counting: (1) dc-coupling, and (2) ac-coupling with delay line clipping to produce dc-free pulses.

The discriminators, scale of 8, and scaler-driver have ac-coupled inputs and should have delay line clipped inputs (clipped at the sending end). Coincidence circuits have dc-coupled inputs but may optionally be operated the same way.

Clipping

Clipping time is defined as the total down and back time and includes internal delays. Clips are used to shorten coincidence resolving time, prevent multiple discriminator pulsing, allow high duty-cycle operation, or introduce dead time.

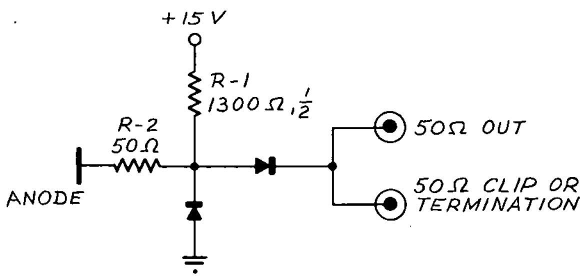


Figure 1. Diode limiter circuit. Diodes are Microwave Associates MA4121 or Sylvania D4109 or D41121.

1. To shorten electrical resolving times:

The minimum output pulse width of the discriminators is 4 nsec. With the discriminators used as input coincidence channels, the resolving time full width at half maximum (FWHM) would be limited to 8 nsec. A stub clip of 2 nsec (3.5-in. external cable) at the discriminators will reduce this FWHM to 2 nsec, not 4 nsec, because of finite rise time. These electrical resolving times are achievable from real scintillating sources with 99% efficiency only with fast phototubes (56AVP), a limited dynamic amplitude range (2/1), enough light in a short time (e.g., 1 Mev in Pilot B), and small detectors for isochronous light collection. The discriminators add negligible time jitter: when used as a time-to-pulse-height converter they give a statistical FWHM of ½ nsec with a channel selected 20% amplitude range and a few hundred kev equivalent. Under the same conditions when used with a coincidence circuit they give 2 nsec FWHM with 99% efficiency.

2. To prevent multiple pulsing:

The discriminator dead time is twice its output pulse width (without clip). If high duty cycle is not a problem, use a long width cable for long dead time and an output clip of any desired length. A choke may be used in place of the width cable without affecting output pulse shape, but the recovery time will be lengthened and be a function of input overdrive. For minimum dead time (8 nsec) use the shortest "width" cable and time-clip the input pulse to the discriminators to 4 nsec or less to prevent multiple pulsing on large pulses. The 2-ma discriminator reaches 95% sensitivity 1 nsec after an applied step function, but such a short clip will reduce amplitude from slow (6810-A) photomultipliers.

Table 1

Module Interconnections for High Duty-Cycle Counting

	Outputs						
Inputs to:	4-ma Limiter	10-ma Limiter	Fanout IH-75	Coincidence IH-56	0.5 to 2-ma Discriminator IH-53	2 to 5-ma Discriminator IH-51	Scale of 8 IH-54
Fanout		C			C and D	C	
Coincidence		A	A		A or C and D	A or C	
0.5 to 2-ma Discriminator	B		A				
2 to 5-ma Discriminator		A	A	A* and B			
Scale of 8		A	A		A	A	
10-Mc Driver		A	A		A or B	A or B	B

A = External delay line clip
A* = Built-in clip
B = Capacity coupled
C = dc-coupled
D = Terminated

3. For dc restoration:

The prediscriminator clip also provides baseline restoration. The discriminator-to-coincidence-circuit connection is dc-coupled so restoration is not needed at this point.

Other points requiring restoration are:

a. Scale of 8 input: for best (6-nsec) resolving time use a 2 to 4-nsec clip on the driving discriminator.

b. 10-Mc scaler-driver input: use a (10-nsec) clip only if the pulses are longer than 10 nsec and if the average input duty cycle exceeds 10%.

4. Increasing dead time:

Dead time may be increased at the discriminators as explained. This same dead time may be had at the scale of 8 input by not using a clip at the driving discriminator. The scaler will trigger only once on such a pulse of any length. Dead time for the 10-Mc scaler-driver can be increased by increasing its output pulse width.

Allowed Connections

A cross index of allowable connections for high duty cycle is shown in Table 1.

TRANSISTOR LIMITERS

The amplitude of photomultiplier pulses may vary over a wide range. As mentioned previously, photomultiplier pulse amplitudes should be limited before they are fed to the logic circuits. The photomultiplier may feed either the limiter circuit described here or the diode limiter of Figure 1 followed by one of the two discriminator circuits described in subsequent sections.

A normally *on* grounded base transistor may be used as a limiter by emitter turnoff from a photomultiplier anode. Anode currents greatly in excess of the transistor turnoff current cause emitter-base breakdown, with three harmful effects: (1) Transistor destruction if allowed emitter-base power dissipation is exceeded. (2) If a capacitor is used to couple from the anode to the emitter, the low impedance path caused by breakdown can greatly increase the transient capacitor current. This current must be discharged through the transistor between pulses, which will cause variation in the limiter quiescent current and therefore variation in output pulse heights. (3) The breakdown voltage pulse can be coupled to the output via the base-to-collector capacity, which will give an overshoot to the output at high overdrive.

Breakdown may be prevented by inserting in series with the emitter a diode that cuts off with overdrive or by placing a diode from emitter to ground that conducts when overdriven, or by both methods. The shunt diode alone, however, causes excess charging of the series capacitor when ac-coupling is used from the photomultiplier, unless it can be placed on the photomultiplier side of the coupling capacitor. It may then be difficult to prevent the diode bias from changing with counting rate.

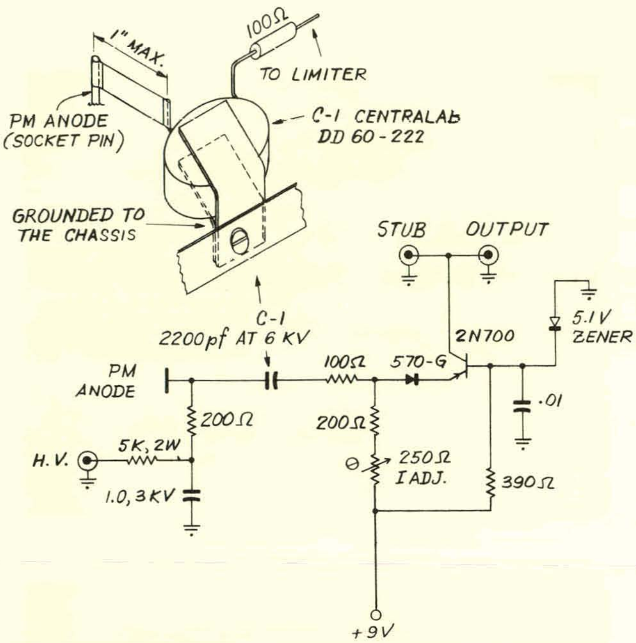


Figure 2. 10-ma, 2N700, ac-coupled, transistor limiter. The particular coupling capacitor shown has excellent high frequency response but requires the use of damping bars to prevent output ringing.

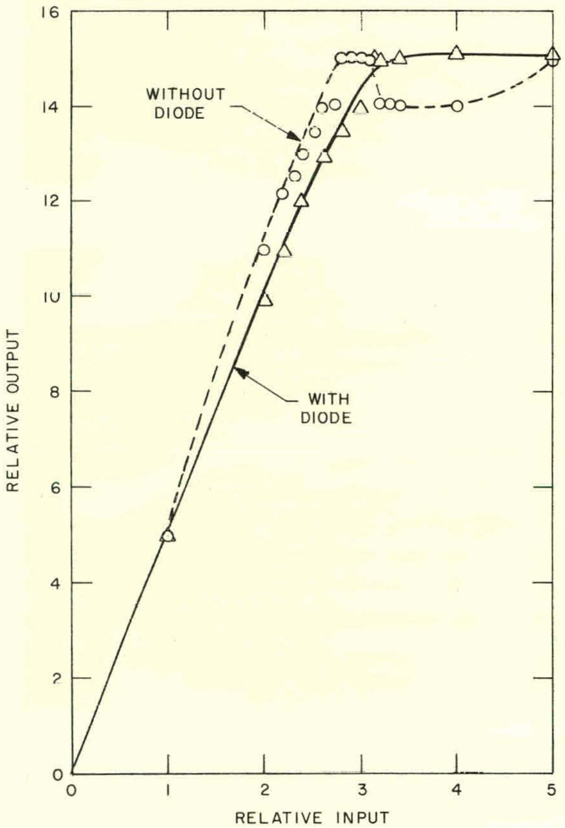


Figure 3. A plot of voltage in vs output current as observed on the sampling oscilloscope for step function inputs of 0.2-nsec rise time. The curves are similar for a step function input of 3-nsec rise time. The limiter used is shown in Figure 5.

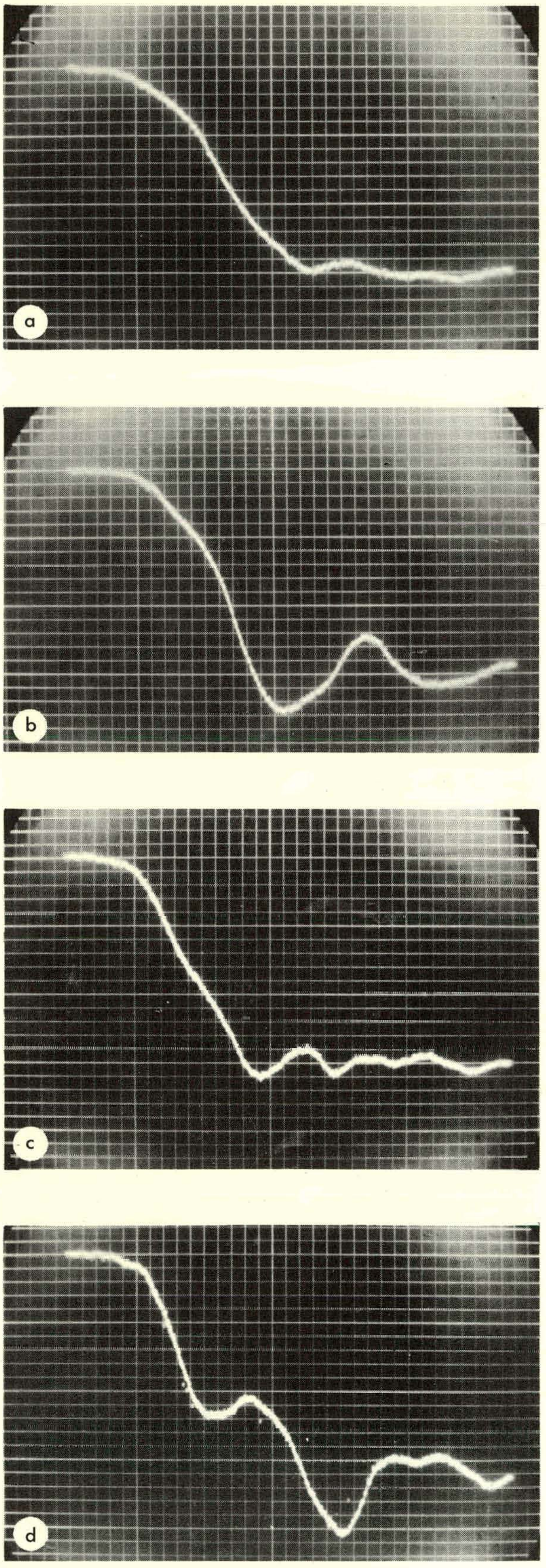


Figure 4. Output rise times for the limiter of Figure 2 for 0.2-nsec input rise times. Time scale is 0.1 nsec/small division. (a) Just limiting. (b) Twice limiting. (c) 4.5× limiting. (d) 9× limiting.

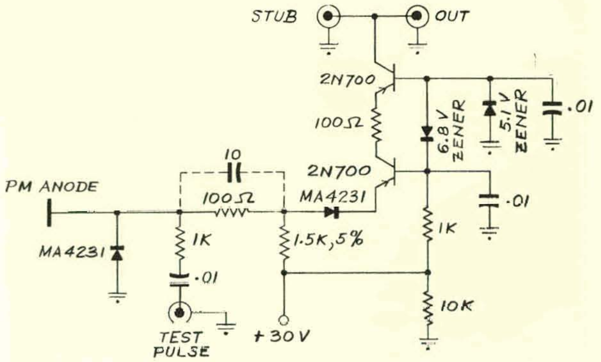
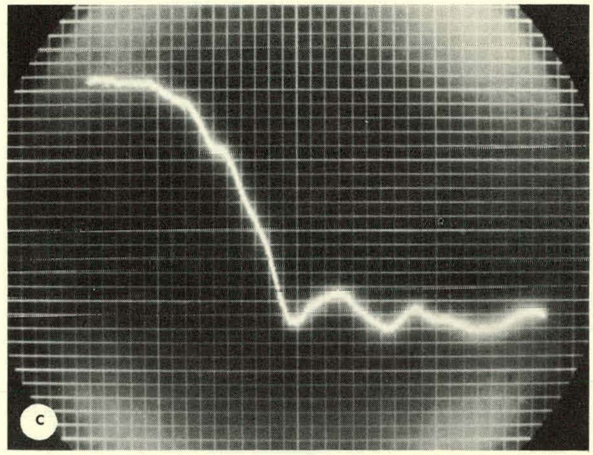


Figure 5. Cascode 2N700 transistor limiter. If desired, ac-coupling with an undamped capacitor may be used. The 10-pf shunt capacitor speeds up output rise times only for pulses of less than the turnoff current of 10 ma.



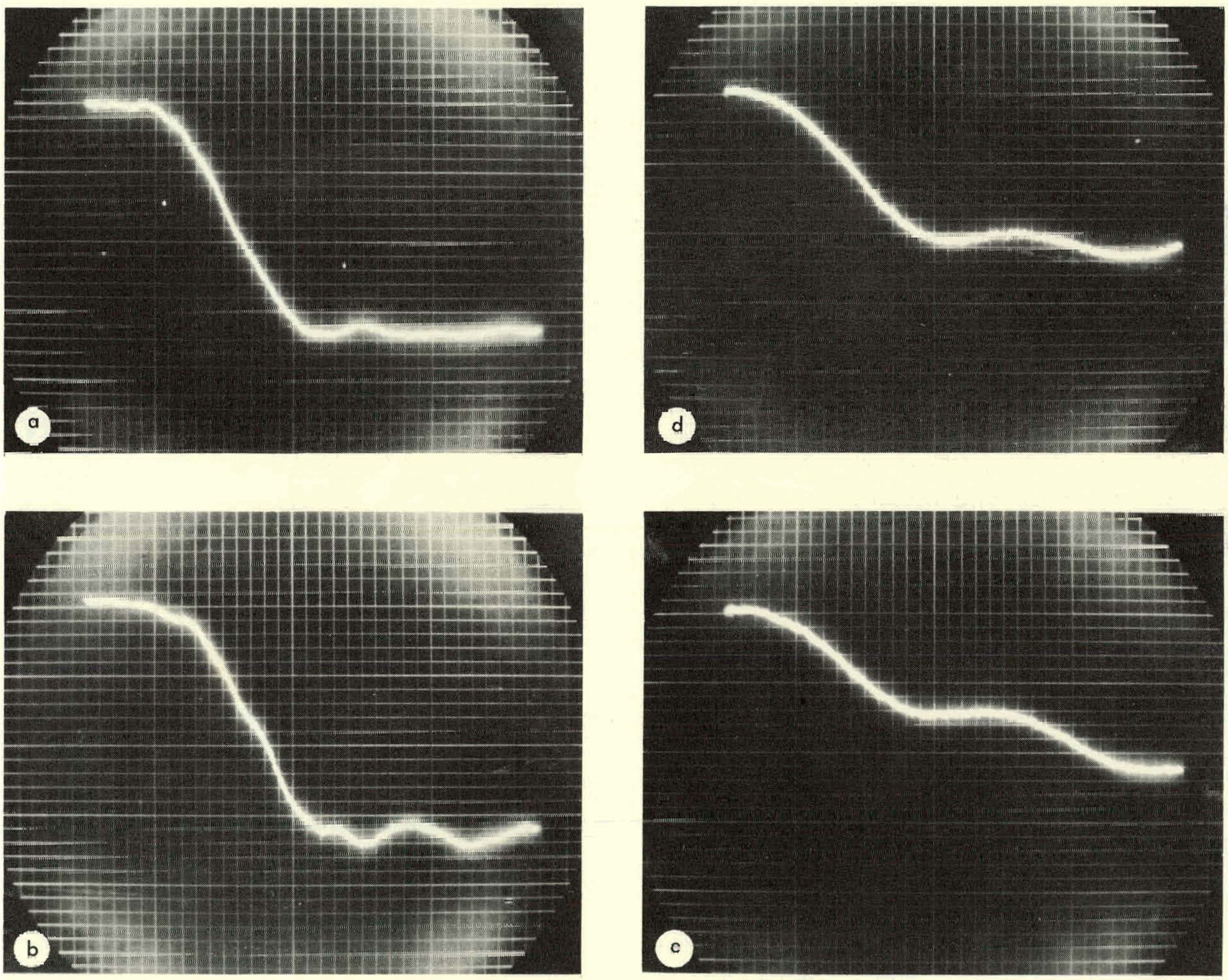


Figure 6. Output response of the limiter of Figure 5 for 0.2-nsec input pulses. (a) Just limiting. (b) 5× limiting. (c) 10× limiting. (d) ½ limiting with 10-pf shunt. (e) ½ limiting without 10-pf shunt. Responses (a) through (e) are identical with or without an undamped Centralab DD60-222 coupling capacitor of zero lead length; (a), (b), and (c) are identical with or without the 10-pf shunt capacitor.

For these reasons, the series turnoff diode has been employed as the main transistor protective device, as shown in the limiter circuit of Figure 2. A 570G diode was found to be superior to any of the microwave or other fast recovery series. It has at least 20 K back resistance up to 8 volts reverse. It has a sufficiently long hole storage to have almost no effect on turnoff, threshold, rise time, or nonlinearity for pulse rise times from 0.5 to 3 nsec. (See Figure 3.) It has sufficiently small capacity and hole storage to prevent more than 5-ma peak breakdown base current with drive currents from 10 ma (just cutoff) to at least 60 ma. Without the diode all of a 60-ma turnoff current passes through the base. Actually the diode and the emitter-base junction form a constant current source of 5 ma when both are reverse biased for any overdrive current up to 60 ma. Thus, for a sixfold overload of 60 ma the coupling capacitor charging current is 10 ma, required to turn off the transistor, plus 5 ma, emitter-base breakdown current, plus the current into the emitter current supply resistor, which may be made as small as desired depending on maximum available power supply voltage. The duty-cycle shift in standing transistor current for a 10-Mc repetition rate at sixfold overdrive with 10-nsec pulse width and constant current emitter supply would then be 15% vs 60% without the diode.

If additional protection is required, an additional shunt diode may be employed. For example, a shunt 570G will enable a 25-fold overdrive (250 ma) before the base breakdown current increases to 10 ma. With a minimum back bias of 1 volt it will not affect the turnoff characteristics. If this diode is to be employed with ac-coupling, it must be put on the anode side of the capacitor. Back bias can be obtained with a string of forward biased silicon diodes (0.6-v drop) using current from the HV supply. Another advantage of the shunt diode is reduction of transient voltage at the series diode, which may, in poorly shielded systems, couple through to the output. For example, the shunt diode reduces the anode pulse voltage by a factor of 7 at 50-ma overdrive.

The turnoff pulse shapes are shown in Figure 4. The residual overshoot is due primarily to resonance in the coupling capacitor and input leads. The overshoot is very much worse without the damping bars across the coupling capacitor. However, the overshoot is at very high frequencies and is hardly visible with only slightly reduced band-

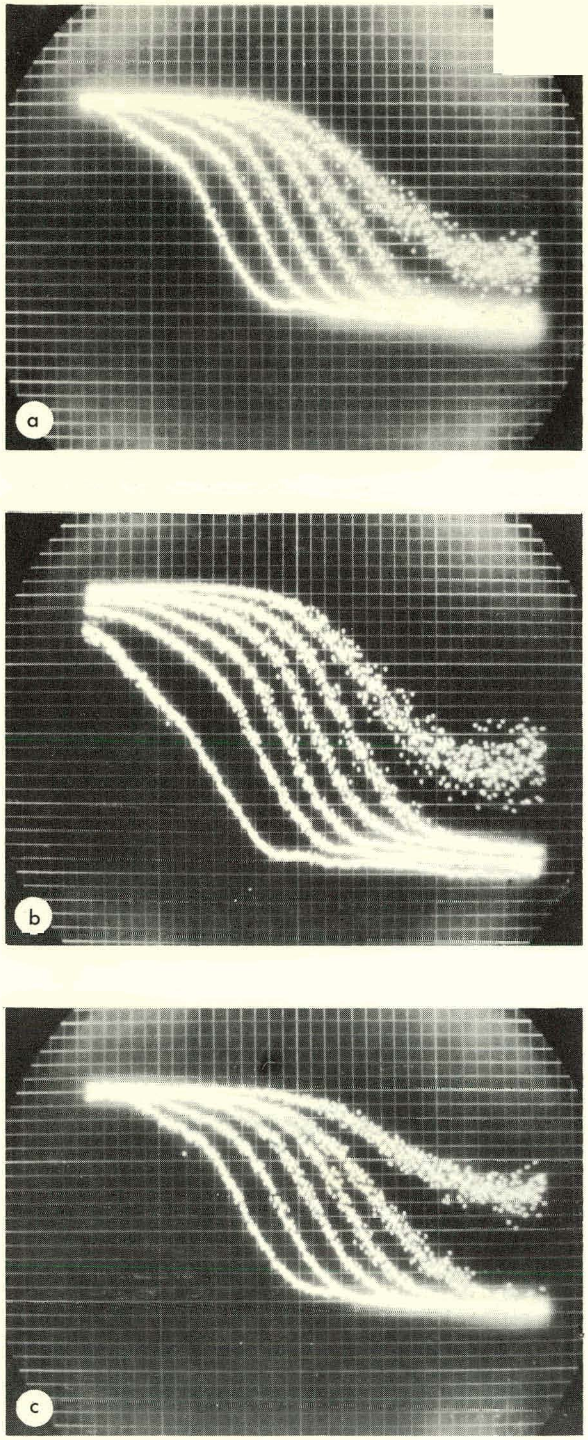


Figure 7. Limiter response for a 56AVP with light pulser set for about 1.5-nsec decay time (1100 volts). The statistics are set so that the smallest input pulse height corresponds to 660 kev in Pilot Plastic "B." Time scale is 0.2 nsec/small division. (a) Just limiting, 2× limiting, 4× limiting, 8× limiting, 16× limiting; no shunt or series capacitor. (b) Same with shunt capacitor. (c) Same with no shunt capacitor and Centralab undamped DD60-222 series capacitor. Since (a), (b), and (c) are essentially identical, the shunt capacitor is not recommended for use with 56AVP or slower tubes.

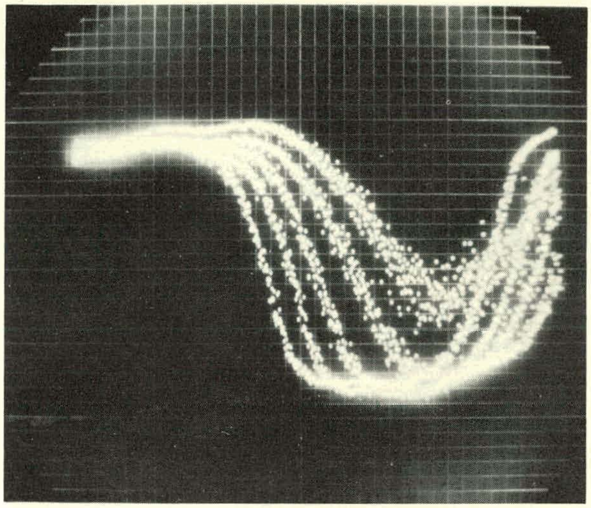


Figure 8. Same as Figure 7(a), but for 7264 phototube and at 0.5 nsec/small division.

pass, ½-nsec rise time. For this reason the single transistor limiter seems adequate for routine resolving times.

For ultimate resolution the limiter shown in Figure 5 is probably preferable. The cascode configuration damps out any ringing produced by even an undamped capacitor and residual overshoot due to emitter-base breakdown of the first transistor. Figure 6 shows the pulser output response for the cascode limiter with and without an undamped coupling capacitor, and with and without a shunt peaking capacitor that speeds up the response for pulses of less than limiting amplitude.

Figure 7 shows the limiter response to a light pulser and 56AVP photomultiplier. The time shift is 0.5 nsec per factor of 2 in input amplitude.

Figure 8 shows the time shift for a 7264; it is about 1 nsec for a twofold change in pulse height.

The single and cascode transistor limiters using 2N700's have an output rise time of 0.7 nsec. Rise times of 0.5 nsec can be obtained with the single transistor limiter by replacing the 2N700 with two selected 2N502's in parallel to prevent excess dissipation. Since the slower rise time is more than adequate with 56AVP's, however, and since selection requires a very high bandpass sampling oscilloscope (800 Mc), this is not recommended.

The limiters are normally built-in or on the photomultiplier base chassis. The layout is not shown here because it will depend on the tube mount.

IH-51 DISCRIMINATOR (2 to 5 ma)

This discriminator is a general purpose pulse shaper for use preceding coincidence circuits, time-to-pulse-height converters, scalers, and fanouts. It is also used following the IH-56 coincidence circuit when a completely standardized output is desired (see below). It has one terminated input and two outputs in parallel, each delivering at least 5 ma. If pulse widths 4 nsec or greater are desired, both outputs may be used to drive other nanocards.* If a clipping line is used to obtain shorter pulses, only one output is available. Proper input and output connections have been discussed in the Introduction.

Sensitivity

Full-scale sensitivity is adjusted by a front panel control and calibrated by plugging in a standard nanocard millivoltmeter. The cards are adjusted so that full scale on the meter corresponds to 2-ma sensitivity and a meter reading of 70 corresponds to a sensitivity of about 5 ma. After 1 nsec of an applied step function 95% or better sensitivity is reached. The discriminator linearity is shown in Figure 9. Within the accuracy of the recording meter, no deviations from linearity are measurable. With a more accurate meter, maximum integral nonlinearity from 0.75 to 7 ma input does not exceed 2%.

Threshold Uncertainty

The threshold of firing uncertainty is one part in several hundred and appears to be limited only to pulser and circuit noise. A partially formed output pulse has never been observed under any operating condition. Rise time variations of about 200 picoseconds from threshold to 100 times threshold are typical (see Figure 10).

Time Shift With Pulse Height

In the absence of noise the discriminator should have an infinite time delay at threshold. The presence of internal noise limits this to about 1.2 nsec from threshold to 30 times threshold for a step function or impulse. This time jitter is negligible for any photomultiplier detector system now available. When the discriminator is used to drive a time-to-pulse-height converter, for example, the

*An output dc level control shifter is available on the front panel for level setting into fanouts and coincidence circuits.

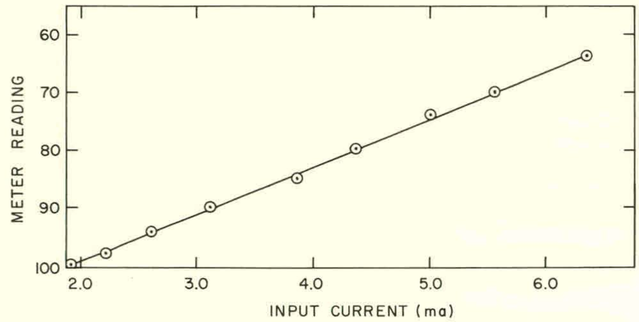


Figure 9. Input current vs nanocard meter reading for threshold.

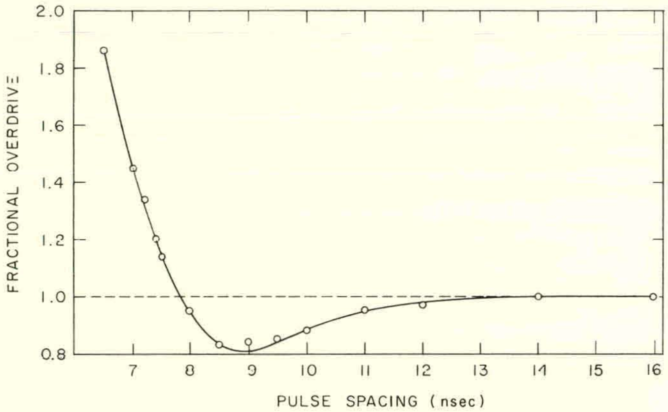


Figure 11. Sensitivity to second of a pair of pulses, 1.8 nsec wide, as a function of delay. Vertical scale is amplitude relative to single-pulse threshold.

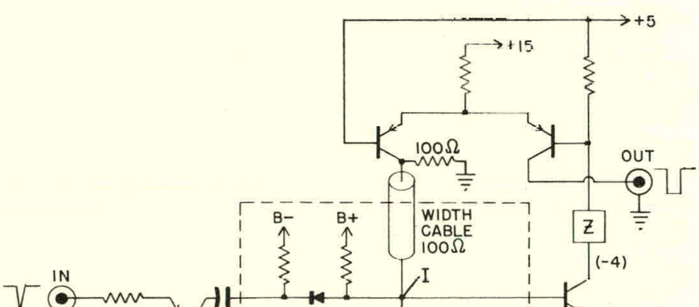
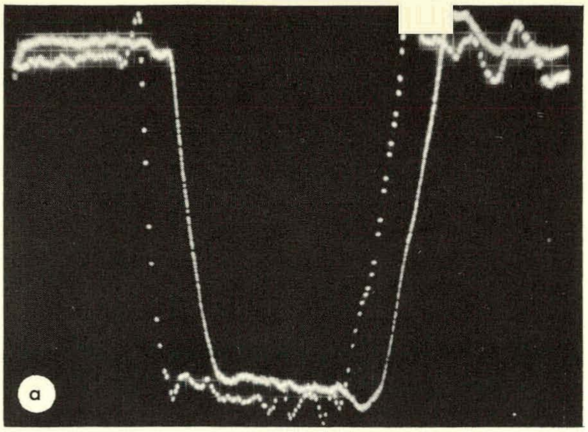


Figure 13. Simplified circuit for the 2 to 5-ma discriminator. The box at the bottom shows the circuit changes for the IH-53 discriminator described in the next section.



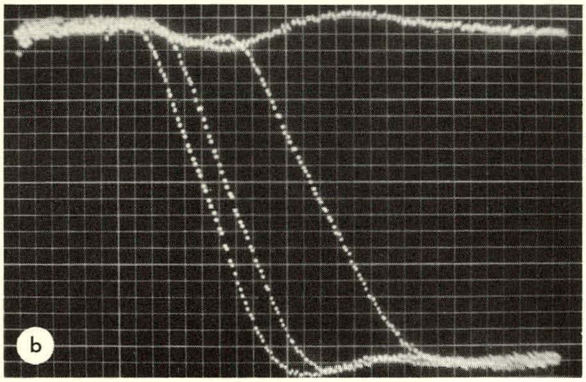


Figure 10. Waveforms of the 2 to 5-ma discriminator. Input pulse had a FWHM of 0.6 nsec. The output pulse width was set to 9 nsec. The solid trace of (a) shows the 12-ma output pulse for a threshold setting 3% above triggering for a 3-ma input pulse. The dotted trace shows the output for a 300-ma input at the same threshold setting. The only significant change is a 2-nsec time shift. The waveforms of (b) are the leading edges of the output pulse shown with a time scale of 0.2 nsec/small division. The disturbed baseline is the output just below firing for a 3-ma input. Reading from right to left, the other traces are the output for an input 3% above the baseline waveform; an input 3.2 times as large; and one 10 times as large. The respective time shifts are 1 nsec and 0.13 nsec.

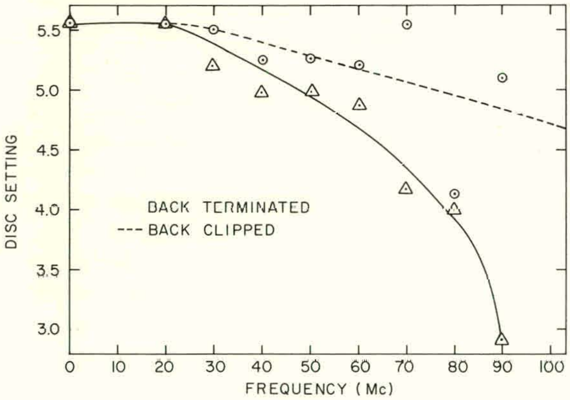


Figure 12. Frequency vs discriminator setting for a 5.6-ma input pulse 4 nsec wide as shown in the "back terminated" curve and 2.5 nsec wide in the "back clipped" curve. Input pulses were derived by connecting two IH-51 discriminators in series to a CW oscillator with a line clip at the output of the first, the second driving the discriminator under test.

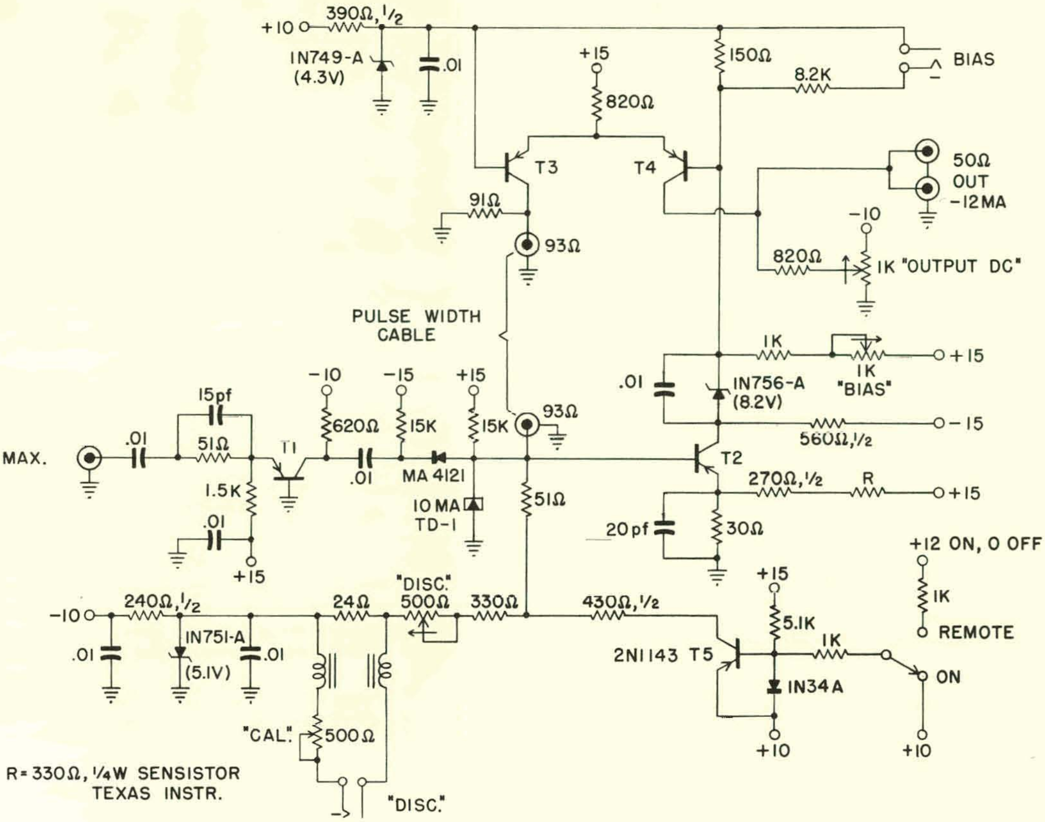


Figure 14. Complete schematic of the IH-51 discriminator. The resistor R connected to the emitter of T2 is used for temperature compensation. Transistors are 2N700 selected to withstand 10 ma at 5 v. Monitor Isolation Chokes are four turns on Amprex 3B Damping Bead.

resolving times are probably within ±100 picoseconds of the results obtainable with use of limiters alone. (For a discussion of the limiting factors in resolving time see BNL 5715 by A. Schwarzschild.) Time delay at threshold is about 4 nsec when the discriminator is used with a photomultiplier. Figure 39 shows an example of such a discriminator system with a resolving time FWHM of 320 picoseconds for Co^{60} gammas. Similar curves obtained with the IH-56 coincidence circuit are shown with that circuit, below.

Resolving Time

The resolving time is shown in Figure 11 and is about 10 nsec. The increase in sensitivity after firing is due to an overshoot in the reset pulse applied to the tunnel diode and is controlled by the value of the peaking capacitor C-1 (Figure 13).

Counting Rate

The discriminator sensitivity vs counting rate is shown in Figure 12. Up to 20 Mc there is no measurable change. From 20 to 50 Mc there is a 10% drop. Above 50 Mc the sensitivity drops rapidly without a delay line clipped input to reset the coupling capacitors. With such a clip the sensitivity remains constant within about 10%. The clipped curve, however, oscillates rather badly as a function of frequency. Standing waves on the input line due to a 10% input reflection coefficient are chiefly responsible for this effect. The unclipped curve is doubly terminated and hence smoother.

Circuitry

The basic discriminator circuit is shown in the upper section of Figure 13. A current bias *I* at the tunnel diode is set from 2 to 5 ma below the tunnel diode peak current. This difference is equal to the current required from the input buffer transistor to trigger the tunnel diode from its low to its high voltage state. The three other transistors are used both to turn off the tunnel diode and to deliver a fixed output current. The transistor immediately to the right of the tunnel diode is a class A amplifier which switches the current in the long-tail-pair formed by the other two transistors. The output transistor of the pair is normally on and is turned off by the diode transition. The other member of the pair is turned on and sends a signal through the delay cable to turn off the tunnel diode. The output duration is determined by the cable length plus about 3 nsec for transistor switching. The turnoff pulse continues to propagate in the line for a period equal to the output pulse length, so that the dead time is equal to twice the output pulse width. Reflections from the tunnel diode back into the delay cable are absorbed in the termination at the collector end. This circuit permits a precise dead time and a duty cycle some 2 to 5 times greater than can be obtained with conventional tunnel diode univibrators. The diode to the left of the tunnel diode prevents premature turnoff by an excessive positive excursion from a delay line clipped input pulse. For bias currents below 5 ma, false turnoff is still possible. For bias currents within 2 ma of the diode peak current, the fractional threshold stability begins to be affected by changes in the base current and collector leakage current of the output transistors. A complete schematic is shown in Figure 14, and photographs in Figure 15.

A typical temperature coefficient for a 3-ma threshold is 0.6%/°C from 20° to 40°C.

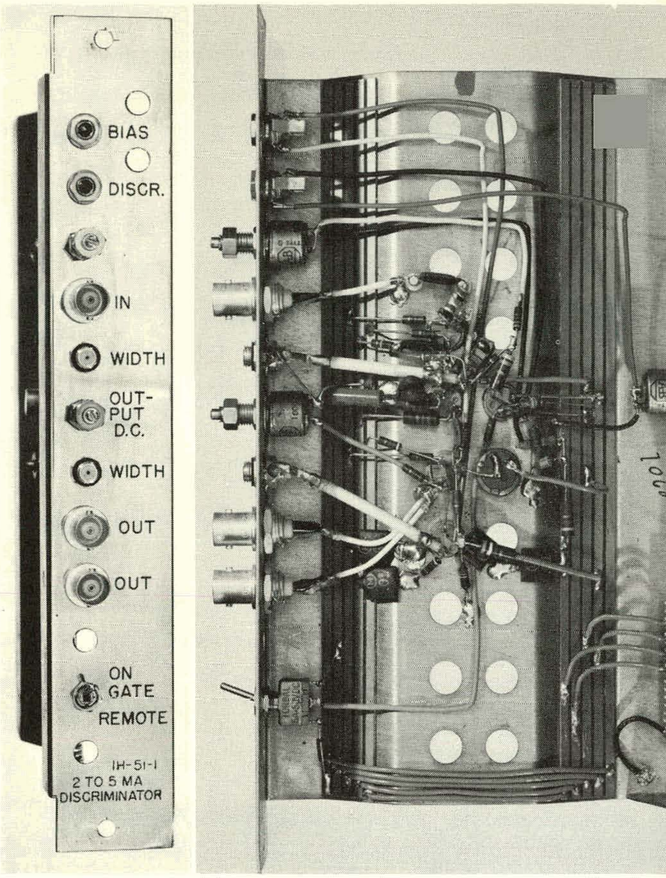


Figure 15. IH-51 (2 to 5-ma) discriminator.

IH-53 DISCRIMINATOR (0.5 to 2 ma)

This discriminator (Figure 16) was designed for the low level outputs of Cerenkov detectors and for the output of the EH1-935 coincidence circuit (now out of production). Time delay at threshold is about 8 nsec. It has about the same time shift from 10% above threshold to 320% above threshold (1 nsec) as the IH-51 discriminator has from threshold level to 320% of threshold. A shorting stub may be attached to the connector labeled "clip" for automatic baseline restoration at counting rates to 100 Mc.

Performance

Amplitude calibration is shown in Figure 17, pulse pair resolution in Figure 18, and sensitivity as a function of frequency in Figure 19. A typical temperature coefficient at 0.5-ma threshold is 0.6%/°C from 20° to 40°C and 0.8%/°C from 40° to 50°C. This is entirely due to the tunnel diodes in the

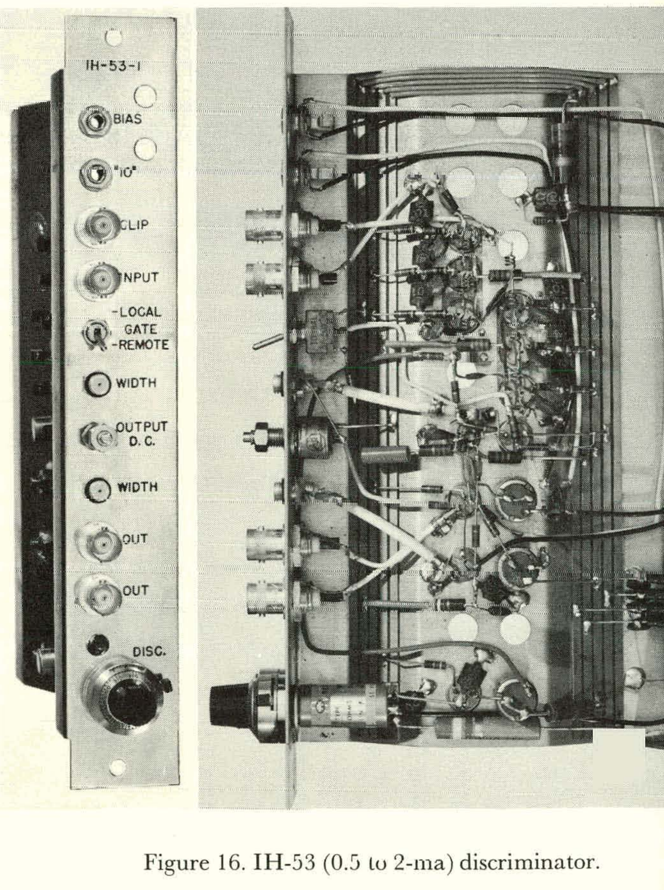


Figure 16. IH-53 (0.5 to 2-ma) discriminator.

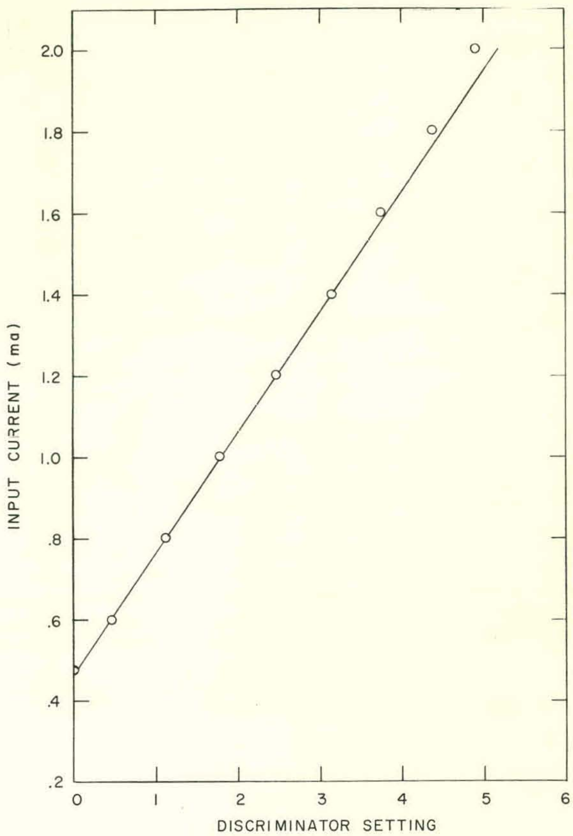


Figure 17. IH-53 discriminator, amplitude calibration.

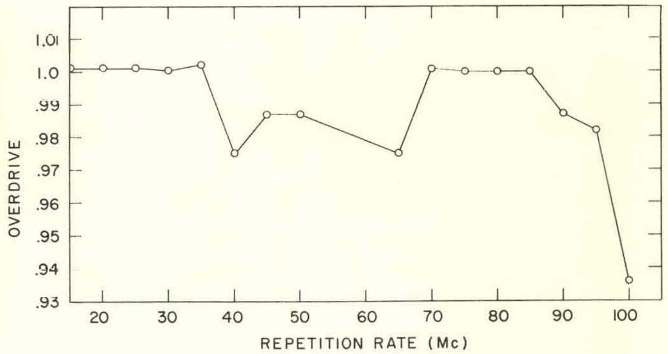


Figure 19. Required overdrive relative to a single pulse as a function of frequency. The pulse source was a sine wave generator connected to two IH-51 discriminators in series, both with minimum width cables. The output of the first was clipped to 2 nsec. The second was terminated and went through an attenuator to the IH-53 unit with a 1-nsec down and back external line in the "clip" jack. Input current was nominally 0.5 ma. The overdrive is defined as the required input current relative to the current for a single pulse. It was actually obtained by varying the discriminator dial and using the calibration curve of Figure 3.

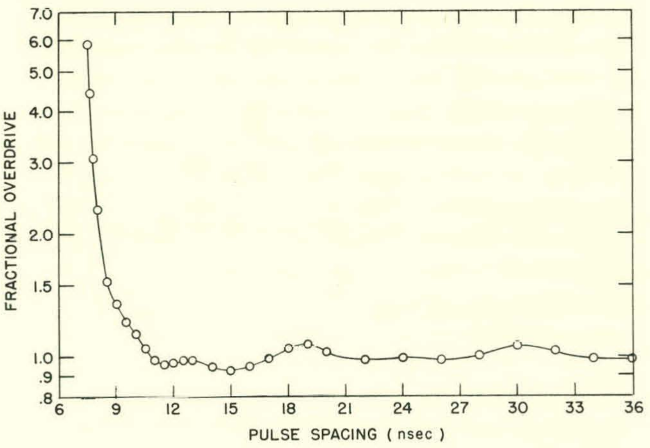


Figure 18. Sensitivity to the second of a pair of pulses, each 4 nsec wide, as a function of delay. Vertical scale is the amplitude of the second pulse relative to the first. Discriminator level is set at 0.65 ma. "Clip" stub is 1 nsec down and back.

circuit, the internal amplifier having a coefficient of only 0.1%/°C.

Circuitry

The basic circuit is shown in Figure 13. The threshold level is determined by the bias current of the first (5-ma) tunnel diode. When a negative pulse switches it to a high voltage state, the current through the resistors connecting the two diodes forces a similar transition for the 10-ma diode. The turnoff pulse from the width cable returns both of them to the low voltage state. This configuration permits a wide range of discriminator settings: at a high sensitivity threshold the 5-ma diode is isolated by the 10-ma diode from base and leakage current variations of the output transistors;* at insensitive settings (low or reverse bias) premature turnoff is not possible, since if the 5-ma diode turns off too soon it still cannot switch enough current to turn off the 10-ma diode, the latter having about a 9-ma hysteresis. The complete schematic is shown in Figure 20. The first six transistors form two stages of a pseudodistributed amplifier. An interstage clipping line is used to provide baseline restoration and to prevent spurious output pulses when the discriminator is set for a short dead time. Gain is about four and rise time 1.5 nsec. The distributed technique was not

*The (Zener regulated) bias of the 10-ma diode has little effect on the 5-ma bias; a 1% change in the 10-ma bias causes <1% shift of sensitivity at 0.5-ma threshold; 1.2% at 2 ma.

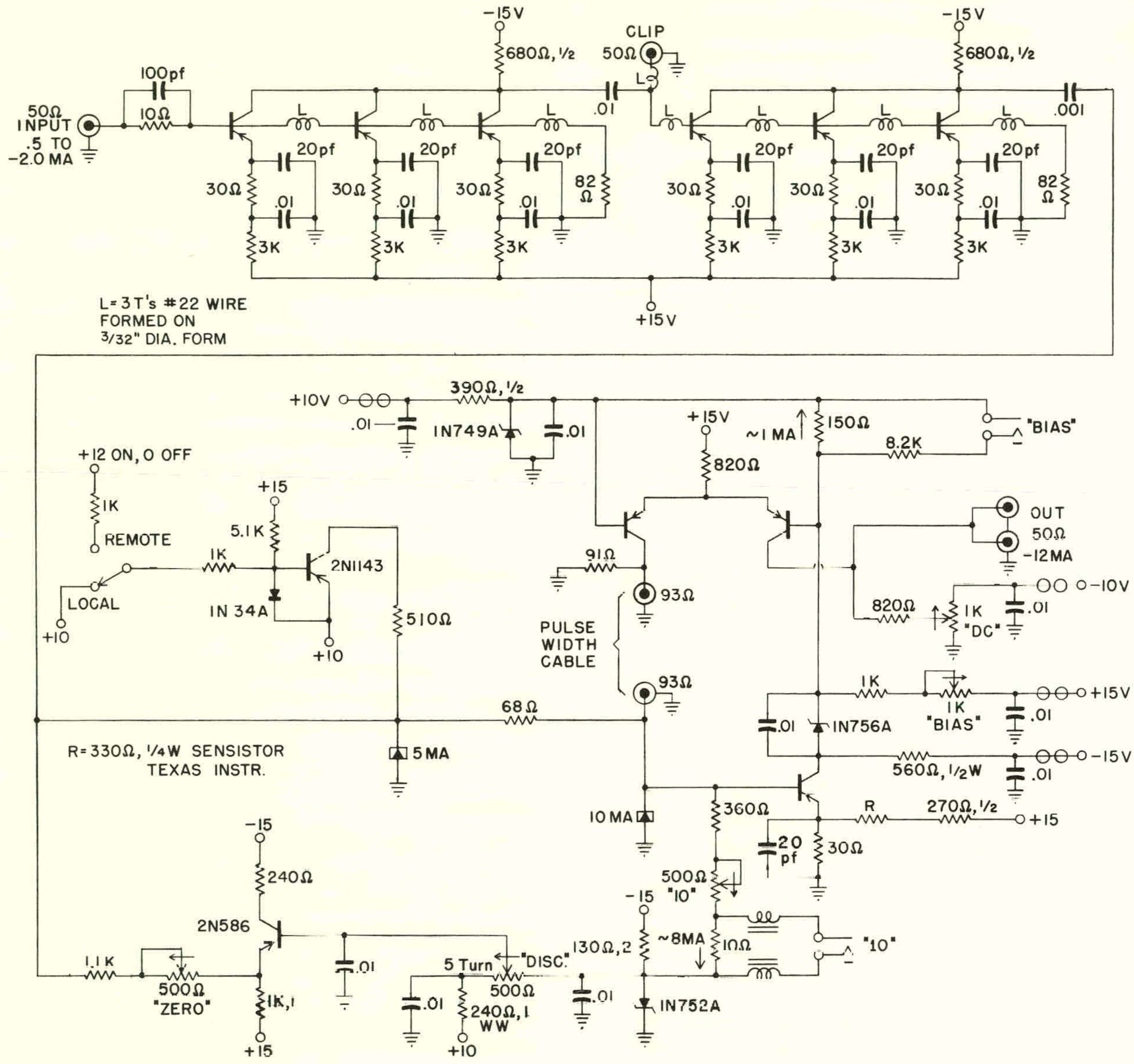


Figure 20. Complete schematic of IH-53 (0.5 to 2-ma) discriminator. Transistors are 2N700. Output transistors selected as described in text. Two 3B Damping Beads on all supply leads.

necessary to obtain the desired gain-bandpass product. It is used instead to obtain a wide dynamic range and good temperature stability. The output circuitry is the same as for the IH-51, described in the preceding section.

IH-56 COINCIDENCE CIRCUIT

The coincidence circuit (Figure 21) has four YES inputs and one NO input, all dc-coupled. It will count singles, doubles, triples, and quadruples, all with or without anticoincidence. Required inputs are at least 5 ma negative with 1 nsec extra overlap for the NO input. The output pulse is nominally 5 ma negative, 5 nsec wide, and double-clipped for automatic baseline restoration when driving such ac-coupled nanocards as discriminators or scalers. In normal use the circuit requires no readjustment or switching for operation at any coincidence level, resolving time, noise rejection level, or counting rate. The coincidence level is automatically equal to the number of connected inputs; the resolving time down to 3 nsec FWHM is set by input clipping lines. At normal settings pulses

$>\sim 2.5$ ma are effective. The *output* counting rate can go from zero to 90 megapulses/sec CW with no more than ½ nsec change in FWHM.

Although the coincidence circuit will handle large pulse overloads with good rejection ratios, some form of input pulse limiting and shaping is recommended for control of resolving time. Transistor or diode limiters and clipping lines will often suffice even in the presence of high background counting rates because of the circuit's freedom from baseline shift and its built-in noise rejection feature. Input discriminators are of course preferred to limiters when it is necessary to have accurate tracking of several coincidence circuits in parallel, accurate coincidence input monitoring, greater sensitivity, wider input pulses, and/or pulse-height selection.*

*For example, a 100-Mc single-channel analyzer with the same time resolution as a limiter may be had by branching an input to two discriminators, with the outputs connected to a YES and a NO input of a coincidence circuit.

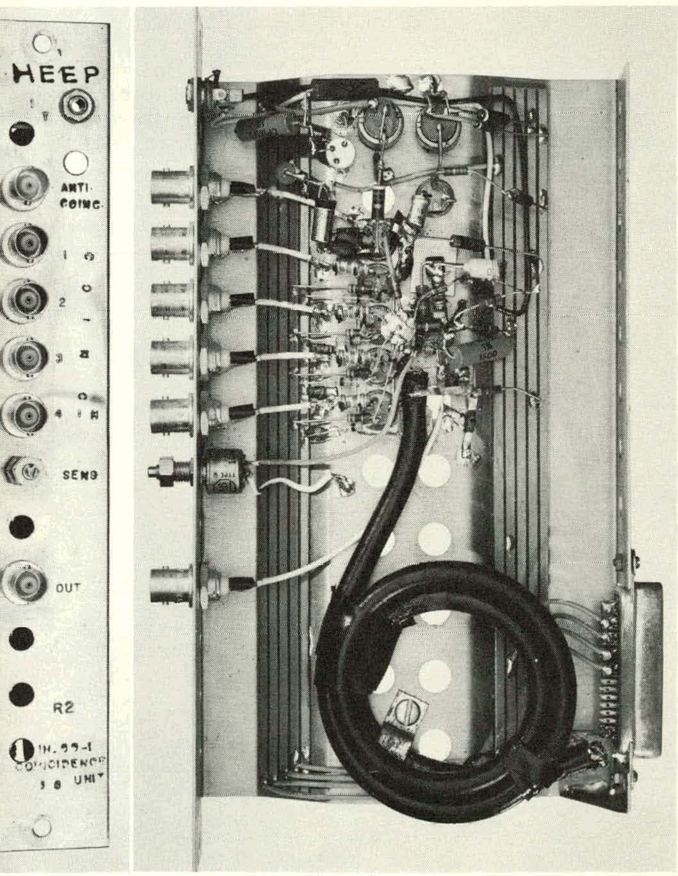


Figure 21. IH-56 coincidence circuit.

Please note that discriminators firing on the leading edge of a pulse *cannot* give a better resolving time at a given coincidence efficiency than limiters. This is determined only by the time and amplitude jitter of the phototube outputs. The IH-51 discriminator is, however, sufficiently fast to show no measurable increase in resolving time.

Output Connections

The output pulse is delay line clipped with zero net charge and is over in 10 nsec. Connection to a slow amplifier (0.1 μsec) will therefore give no output unless the internal delay line is opened. If the coincidence overlap time is <5 nsec, the output pulse will not reach full height or width. Under these conditions the output can still be fed directly to a 100-Mc scaler, coincidence circuit, 10-Mc scaler-driver, fanout, etc., but the resolving time will depend on the gain of these units, which is not well defined or stable. It is then advisable to go first to an IH-51 discriminator. The gain of the latter should be decreased until there is no output, then increased by a factor of 2. If discriminators are used at the coincidence input and the overlap time exceeds 5 nsec, the output discriminator is not needed.

Controls

The circuit has three adjustable controls. On the panel is a sensitivity control which does not serve as a discriminator but only changes the output pulse height by 50%. For resolving times of 2 to 5 nsec it may have to be turned to maximum to give 5 ma output. There is an internal control I_T which determines the current threshold above which *each* YES input can contribute to a pulse overlap required for coincidence. For resolving times >5 nsec it is primarily a noise rejection device. For resolving times approaching 2 nsec it has a large effect on resolving time, since at this width the pulse is triangular rather than square. With 2.5-nsec input pulses a resolving time of 2 to 6 nsec can be selected with it. The control is usually set at about 3-ma equivalent input threshold (30% of full scale on the nanocard meter with two shorted YES inputs). With this setting an input pulse below 2 ma will inhibit the output, whatever the amplitude, of the other YES inputs. Also, with two time-coincident 2.5-nsec input pulses, a time shift of typically 1.4 nsec between them will reduce the output by a factor of 2. If an IH-51 output discriminator is used as described in the preceding paragraph, this will give a resolving time of 2.8 nsec for fast photomultiplier pulses (56AVP). (For reasonable coincidence efficiency at this resolving time, input time jitters must be low.) The third control, I_{anti}, is used to bias the NO input just into conduction. This should increase I_T by roughly 1% when the NO input is connected to its driving source.

Performance

Except for passage through zero systems, coincidence resolving time curves chiefly measure the time jitter in the detection system, not the electronics. Nevertheless custom dictates that every coincidence system shall be so evaluated. To be even partially relevant such a test must be easily reproducible and the coincidence efficiency must be stated, since any coincidence system can be adjusted to give vanishingly small resolving times at low efficiency. For the present test Co^{60} gamma-gamma coincidence was chosen with 56AVP photomultipliers and Pilot B scintillators *fully* covering the cathodes. An IH-51 discriminator was used at the coincidence output, set to 2-ma sensitivity. To measure efficiency, four inputs of the coincidence circuit were used. Two of these were for determining counting rate at 100% efficiency. Signals from the two dynodes (transformer inverted) went to IH-51 discriminators set at 20-nsec output pulse width and thence to the coincidence circuit. With these inputs alone the coincidence was assumed to have lost no events by excess time jitter. The "100%" discriminators were set to pass pulses above 500 Mev. The two anode signals were fed to discriminators set so that this energy was twice their threshold, and the discriminator outputs were stub-clipped with 2.5-nsec cables. The ratio of counting rate with the fast discriminators to that without them as a function of their relative time delay is shown in curve *A* of Figure 22. The plateau efficiency was >99% and the FWHM 2.5 nsec. For curve *B* the fast discriminators were replaced with IH-10 cascode limiters set so that they were twice limiting at 500 Mev. Two 2.0-nsec stubs were used. The plateau had >99% efficiency and the FWHM was 2.5 nsec. Note that the slope of curves *A* and *B* is identical to say 50 picoseconds, which shows that under identical conditions the resolving time with the IH-51 discriminator is the same as that obtained with limiters. In curve *C* four discriminators were again used, all set to 500 kev. The fast discriminators were clipped with 3.2-nsec stubs. The FWHM was 4 nsec with a plateau efficiency of 97%. This represents about the worst possible case of threshold rejection the discriminators will ever have to contend with at an accelerator. It would be impossible to take a meaningful curve with limiters under these conditions, since the number of events lost because of improper limiting would be too sensitive a function of photomultiplier and coincidence circuit gain.

Counting Rate

The maximum counting rate of a coincidence circuit has in itself no meaning. What is important is the variation in resolving time with counting rate in a complete system. To determine this variation a sine wave generator was connected to an IH-51 discriminator with a 4-nsec output pulse. This was clipped to 2.5 nsec and fed to a second similar discriminator with the same pulse width. The output went to a fanout, two of whose outputs were clipped to 2.5 nsec and sent through a variable delay line box to a coincidence circuit. Its output was connected to a third IH-51 set at 2 ma. As with all such tests, units were picked at random from the production line. At each frequency the delay line box was used to measure the time interval (FWHM) between the coincident input pulses for which there was a final discriminator output. The results may be summarized as follows:

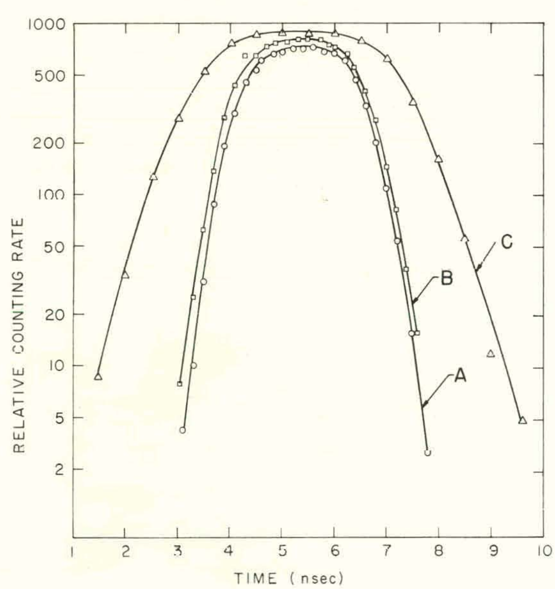


Figure 22. Coincidence circuit resolving time curves. The curves were deliberately displaced on the vertical axis to show the shape. *A* and *B* have 99% efficiency and *C*, 97%.

Frequency (Mc)	FWHM (nsec)
0– 30	3.0–3.2
30– 70	2.8–3.4
70–100	2.2–2.9

When the sine wave generator was replaced with a step function input at low repetition rate, the fanout gave a pulse train at 11-nsec spacing due to repetitive firing of the first discriminator. The FWHM's for the first, second, and third pulses in the train were 3.2, 3.0, and 3.2 nsec respectively.

Circuitry

The design goal for the coincidence circuit was to combine the advantages of a Garwin circuit[1] (current switching to avoid charging of capacity), dc-coupling (to avoid baseline shift), and a Schmitt discriminator (output pulse height and amplitude independent of coincidence input rise time). In addition, the circuit was to operate with no critical parameters, which rules out for example a simple tunnel diode univibrator biased somewhere between zero and peak current, depending on the required number of inputs.

The complete schematic is shown in Figure 23. The four YES inputs go to grounded base buffer transistors operated class A for minimum reflection coefficient (see Figure 24). The input pulses are standardized by turnoff of series diodes in the collectors. Shunt diodes clamp the collector voltage after turnoff to permit subsequent rapid turn-

[1]R.L. Garwin, *Rev. Sci. Instr.* 21, 569 (1950).

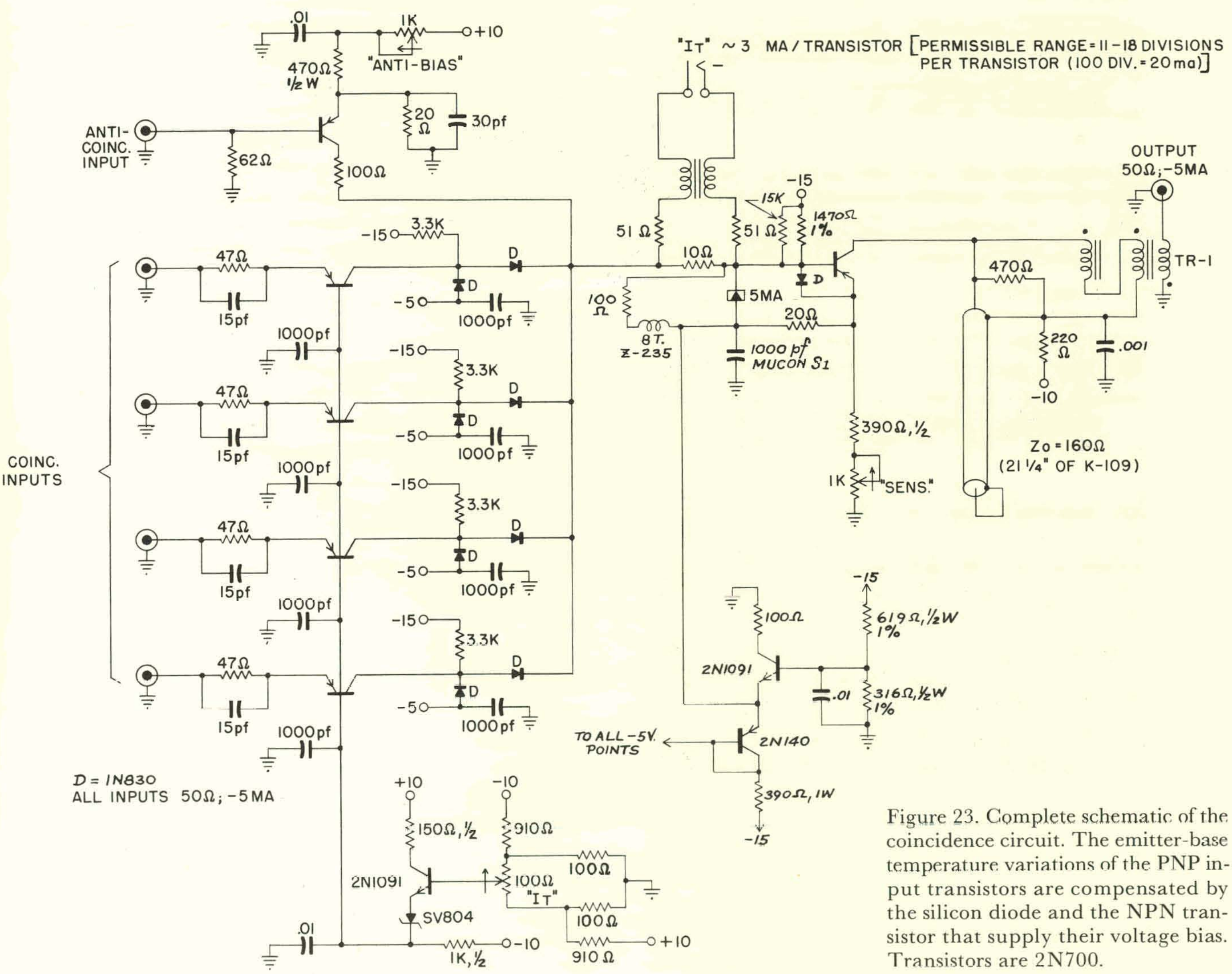


Figure 23. Complete schematic of the coincidence circuit. The emitter-base temperature variations of the PNP input transistors are compensated by the silicon diode and the NPN transistor that supply their voltage bias. Transistors are 2N700.

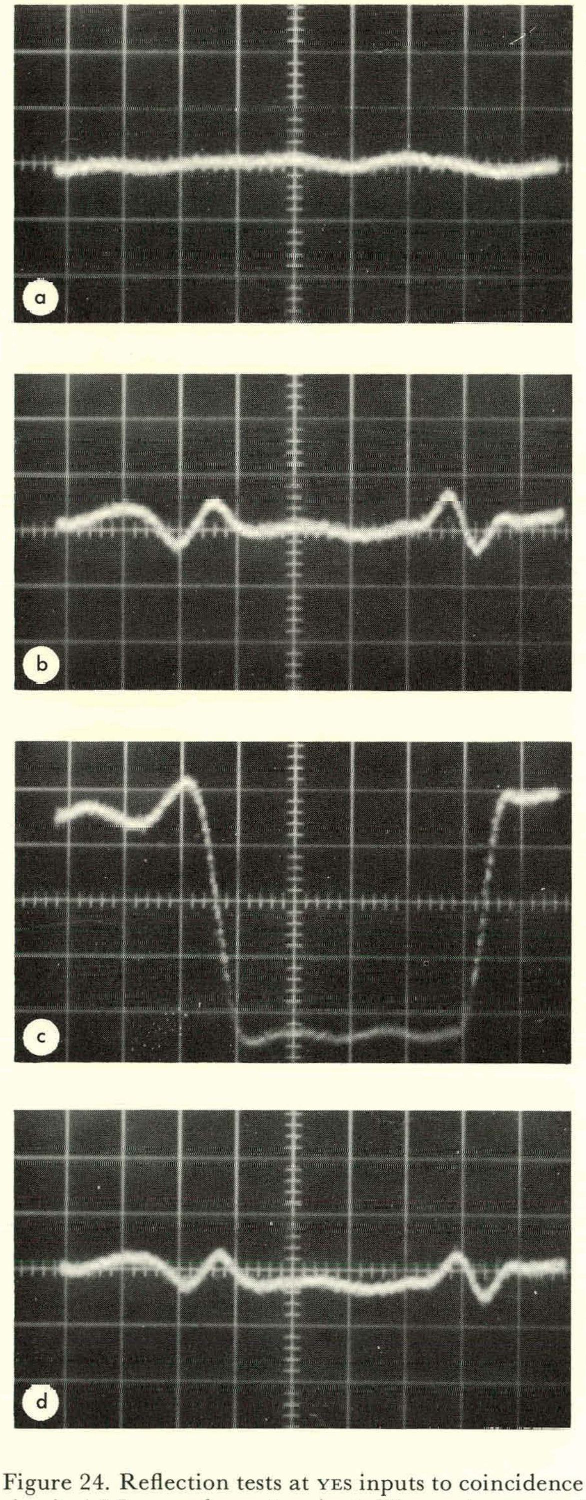


Figure 24. Reflection tests at YES inputs to coincidence circuit. (a) 5-ma pulse on terminated line, not connected to input. (b) 5-ma input to coincidence with $I_T = 4$ ma/transistor. There is a 5% ohmic and 11% reactive mismatch. (c) Same signal on open cable showing 100% reflection. (d) Same as (b) except $I_T = 2$ ma/transistor. Mismatch is 12% ohmic and 11% reactive.

on. All of the normally *on* diode currents (3 to 4 ma/diode) flow through the 5-ma tunnel diode to ground, biasing it in the back (low voltage) direction. When all the collector series diodes turn off, the tunnel diode voltage has to make only about a 120-mv excursion. The 6-ma bias current through the 1.5-K resistor will then switch the diode to a high voltage state. Before switching, the diode acts only as a low impedance Garwin diode. The high voltage transition is however regenerative and also amplitude-limited by the good voltage regulation of the diode in its high voltage state. The output transistor is biased below cutoff and serves to reduce feedthrough. Worst case feedthrough is 1/10 of the output coincidence amplitude and usually considerably less. When any input is not connected, the corresponding transistor current is automatically cut off so that it is effectively out of the circuit. The number of inputs used determines the coincidence configuration.

There are two reasons for requiring the circuit to count singles:

1. It can then monitor singles at about the same threshold level as required for coincidence.
2. If it is desired to monitor the number of coincident events before adding anticoincidence, a second coincidence circuit can be fed from the output of the first, with its NO input used for negation.

If the 5-ma tunnel diode were in a high impedance circuit, it would require about 4 ma to reset it. Except for a very narrow range of I_T threshold settings a single input would not supply enough reset current. The hysteresis is therefore reduced to <2 ma by the 100-ohm shunt resistor across the tunnel diode. Normally this would reduce the regenerative gain substantially, so a small inductance is placed in series with the resistor. It is effective for a few nanoseconds, long enough for the tunnel diode to switch, but resets it completely within 10 nsec so as not to decrease the output counting rate.

IH-75 FANOUT

The fanout (Figure 25) requires a minimum of 5 ma negative input and has four outputs of negative 10 ma $\pm 10\%$ with a rise time of 0.9 to 1.3 nsec. It has a dc-input which must be adjusted as described in the calibration record, Appendix B. The adjustment is quite stable with time and temperature, the output changing by only 3% from

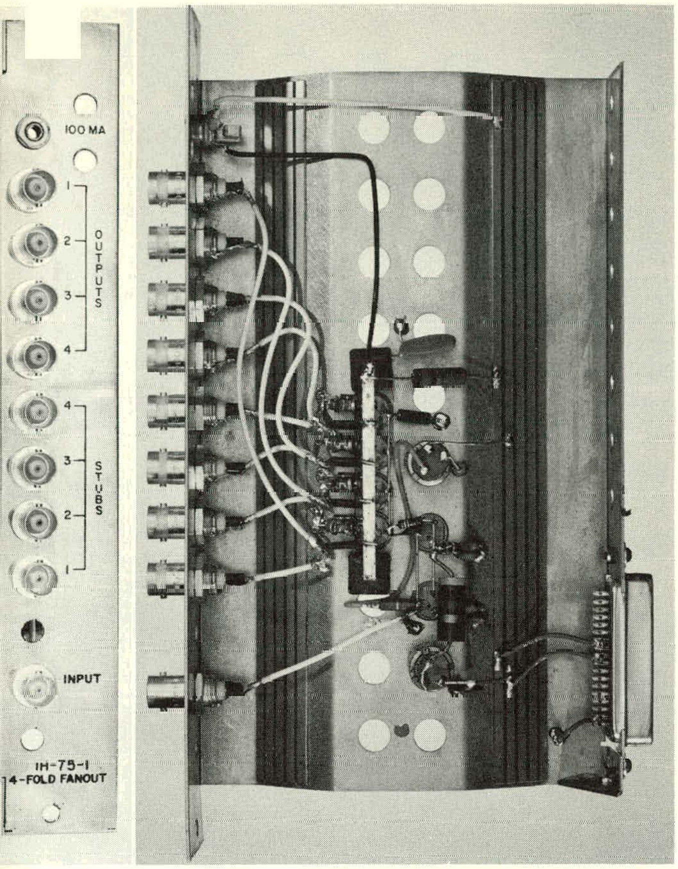


Figure 25. IH-75 fanout.

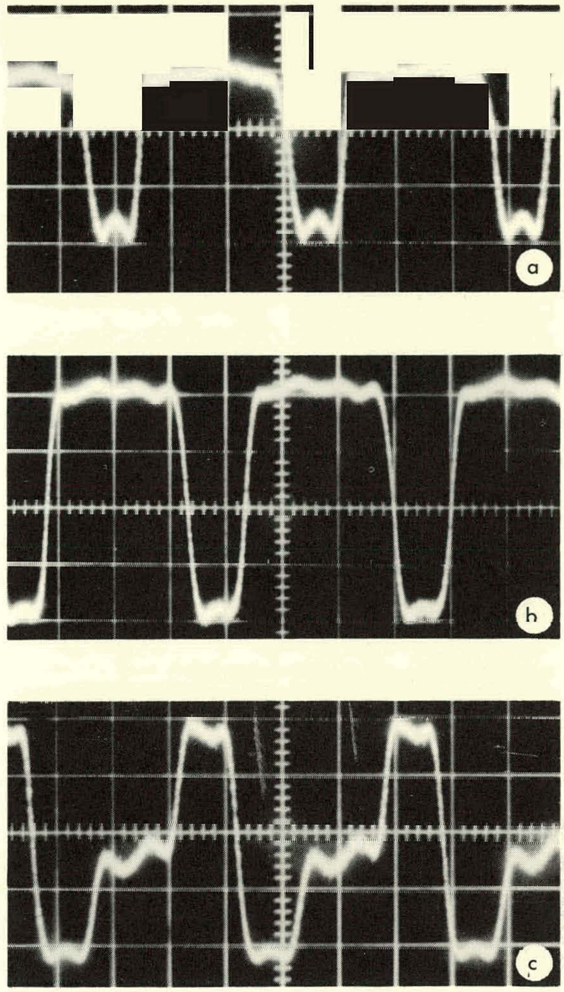


Figure 27. (a) Discriminator output at 50 megapulses/sec. (b) Unclipped 10-ma output of fanout fed by discriminator. (c) Clipped 5-ma fanout output. All time scales are 5 nsec/div. and read from right to left.

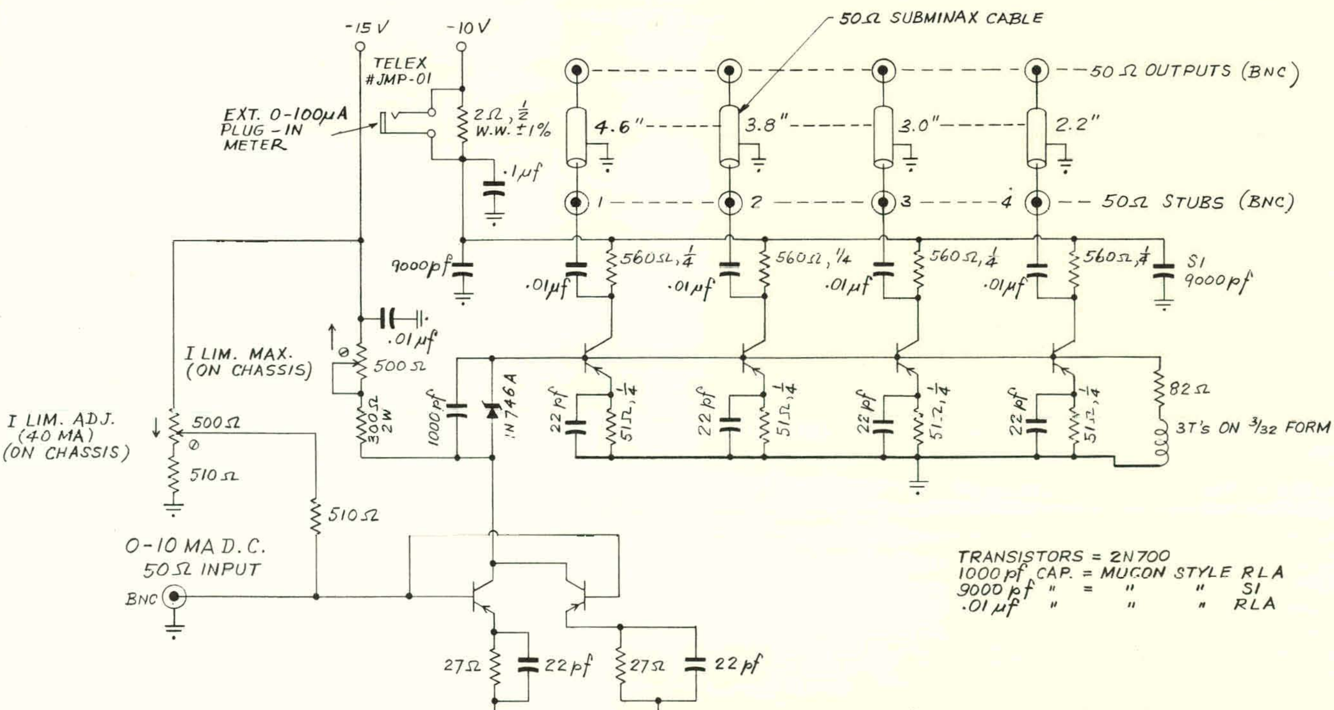


Figure 26. IH-75 fanout circuit.

20° to 50°C. The fanout may also be used as a limiter, but for accurate bookkeeping of counting rates, coincidence efficiencies, etc., in a complex system, it is always wiser to use a discriminator between it and a photomultiplier. For proper operation at high duty cycles the fanout should be stub-clipped at its output, which is ac-coupled, never at its input. This will also obviously result in more stable output pulse widths. The fanout has an unterminated input and must be driven from a terminated sending end, as is available from the nanocard limiters and discriminators, by plugging in a 50-ohm termination. NOTE: For a clean output, terminate all unused connections.

Circuitry

The circuit is shown in Figure 26. Two transistors in parallel drive four transistors with their bases in parallel. Two input transistors are used because it is possible to operate them with a higher emitter degeneration resistor than would be the case for one alone. This gives better stability against drift of bias current with temperature and also gives a better gain bandpass than one alone, since there is relatively less internal emitter resistance (which cannot be by-passed with a speed-up capacitor).

Counting Rate

The fanout may be and has been operated at duty cycles of 50% and CW counting rates up to 200 Mc. There will of course be a baseline shift at the output because of the ac-coupling, but this is removed by using a clipping line at the output. Figure 27 shows some fanout waveforms.

IH-54 SCALER (100 Mc)

The IH-54 scaler (Figure 28) is a binary scale of 8 with lamp indicators and local or remote reset. It has a nominal sensitivity of 2.5 ma for 2.5-nsec-wide pulses and can be driven from any fast nanocard or limiter. If a stable threshold is desired, use an IH-51 or IH-53 discriminator with a minimum "width" cable. If counting rates to 100 Mc are anticipated, delay line clip the output to a pulse 2 or 3 nsec wide. The clip resets the input ac-coupling of the scaler. Under these conditions its sensitivity at 100 Mc is within a few percent of that for a single pulse (the scaler will in fact count properly to 200 Mc). The output is a negative-going pulse of roughly 5-ma peak current and 15-nsec exponential decay. It will readily drive a 10-Mc scaler-driver circuit.

Circuitry

The scale of 8 uses diode steering into a tunnel diode flip-flop. Figure 29 shows a simplified circuit and current-voltage diagram. The steering diodes are normally off and receive equal and opposite turnon current pulses. Resistor R establishes two dc operating points. Inductance L provides the memory. The curve labeled "tunnel diode composite" is that due to the tunnel diodes alonc biased with a voltage source. The "load line" curve is determined by R. A state transition is shown by the solid curve, with the assumption, for simplicity, that the length of the input pulse (from point 1 to point 3) is much shorter than the memory L/R time constant (4 to 5). At half-transition

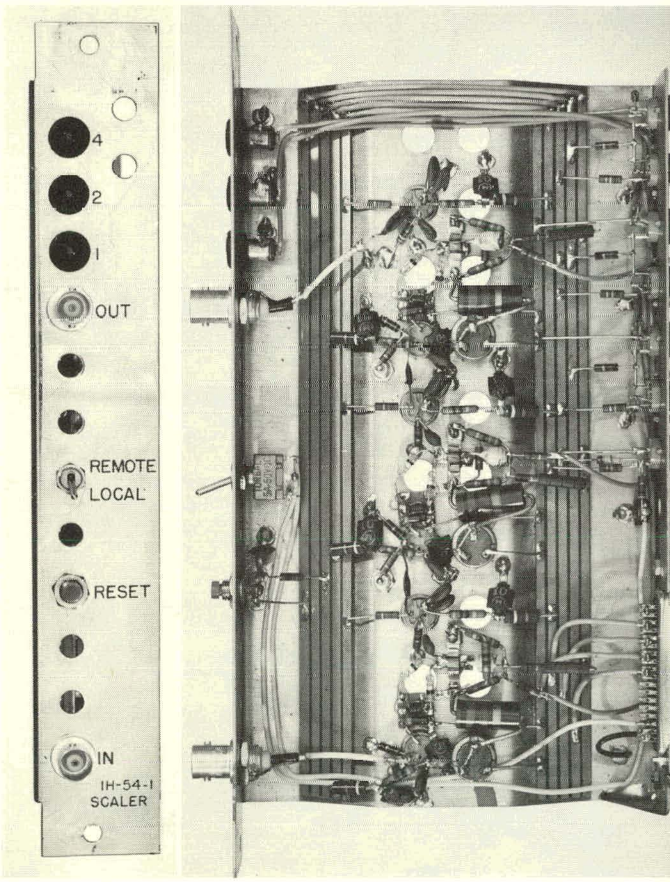


Figure 28. IH-54 scaler.

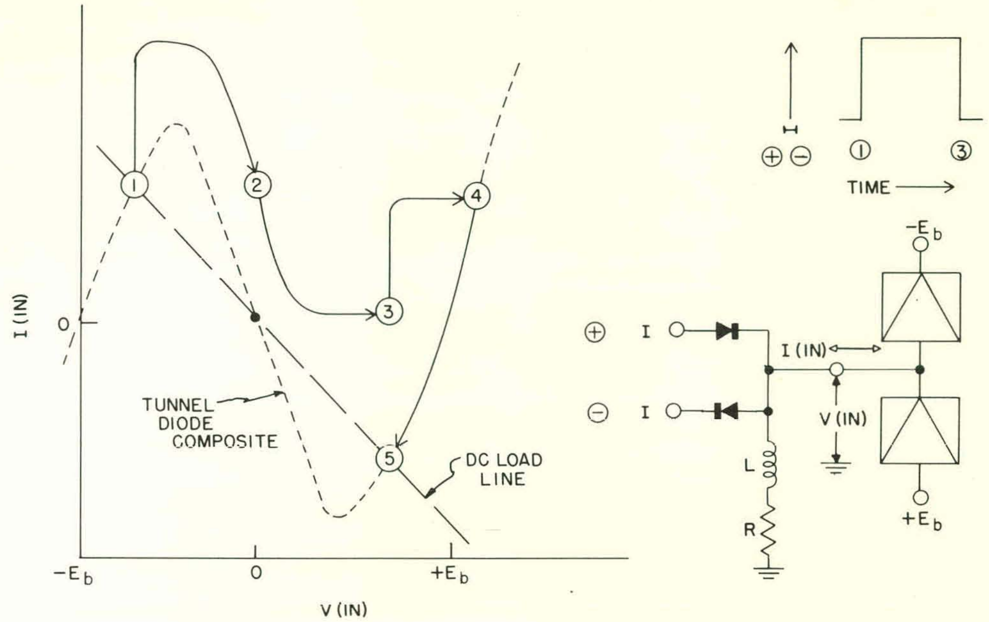


Figure 29. Current-voltage relations, waveforms, and a simplified circuit of 100-Mc scaler.

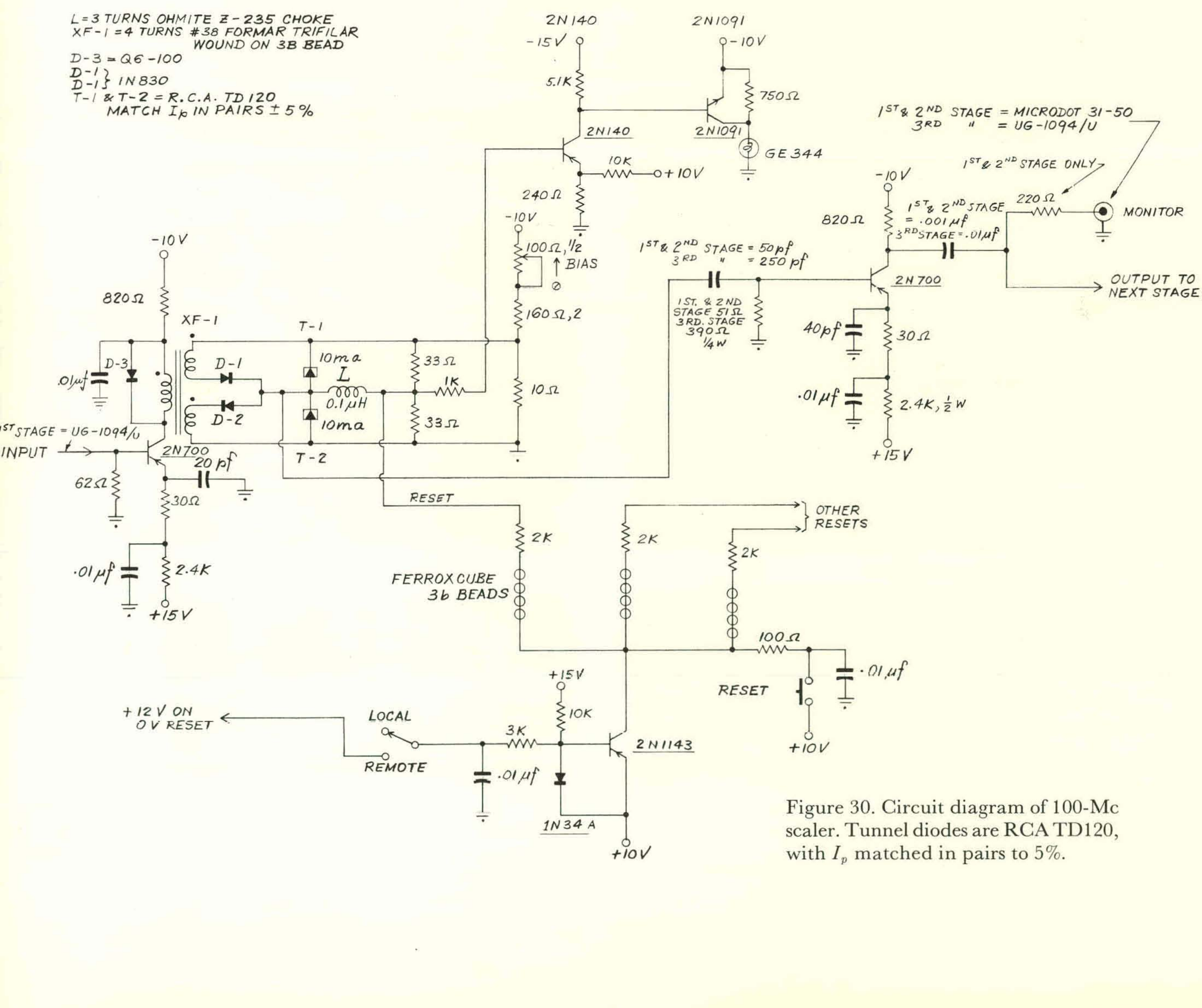


Figure 30. Circuit diagram of 100-Mc scaler. Tunnel diodes are RCA TD120, with I_p matched in pairs to 5%.

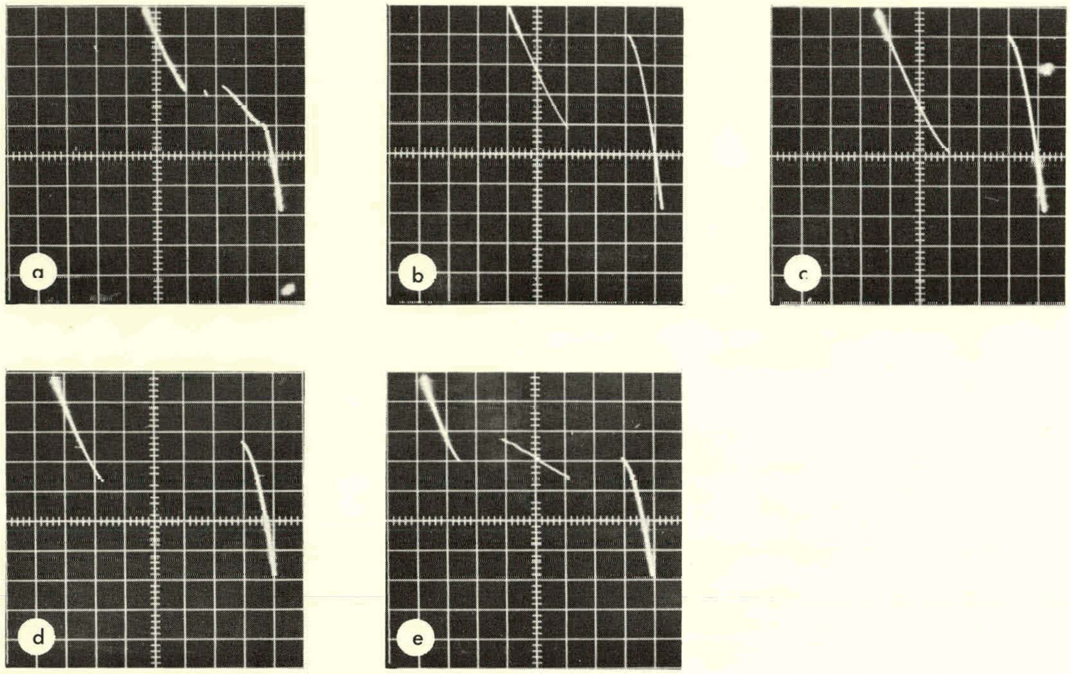


Figure 31. Scaler waveforms: V(IN) vs I(IN) as defined by Figure 29 for various values of E_b. Taken with a Tektronix 575 curve tracer connected to the junction point of the tunnel diodes in an actual circuit. The values of $2E_b$ are (a) 200 mv, (b) 250 mv, (c) 270 mv, (d) 400 mv, and (e) 430 mv. Modes (b), (c), and (d) are correct operating modes with only two stable states; (a) and (e) are incorrect with three stable states. Scale is 2 ma/div. vertically, 50 mv/div. horizontally.

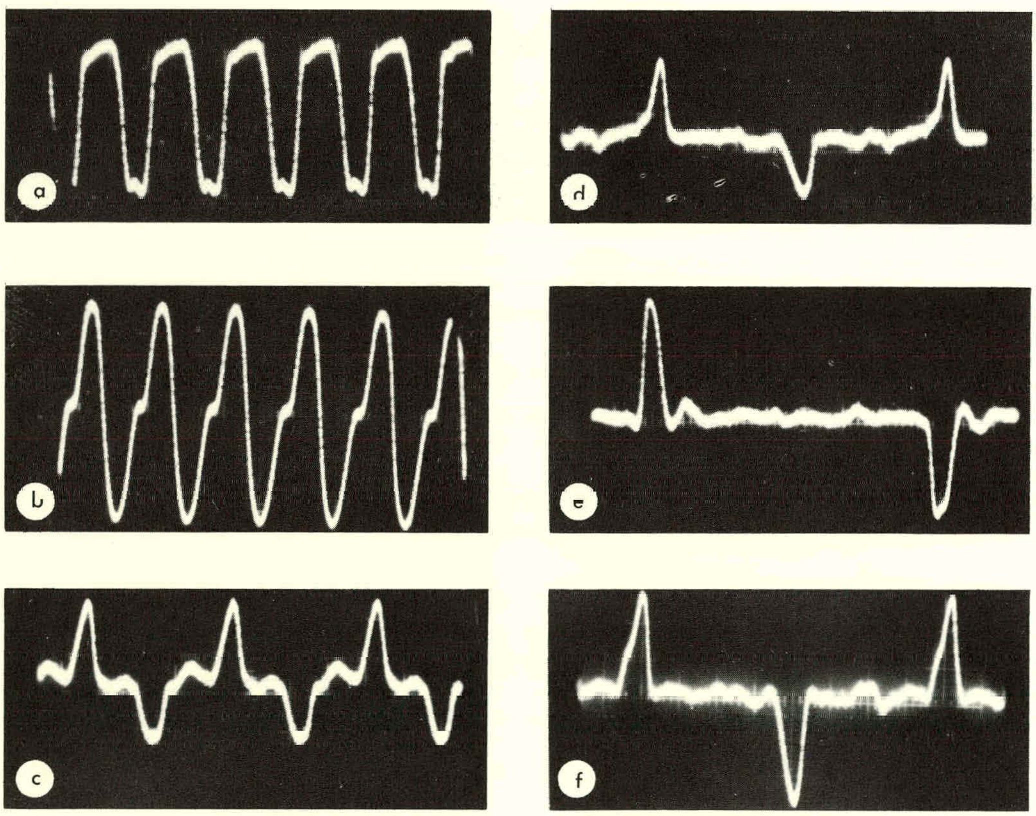


Figure 32. System waveforms: (a) IH-51 discriminator output at 100 Mc. (b) Clipped fanout driven by discriminator. (c), (d), and (e) Output waveforms of the first, second, and third stages respectively of the scale of 8 driven by the fanout. (f) Third stage output but with special discriminator input to the first scaler stage at 180 Mc. Note: The duration of the output scaler pulse has been shortened for these photographs so as to work properly above 100 Mc.

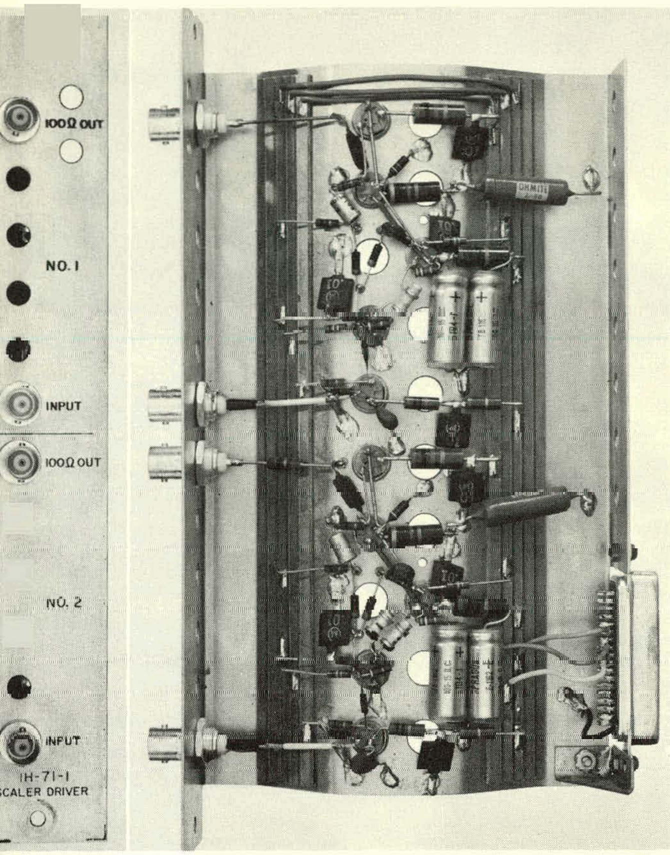


Figure 33. IH-71 (10-Mc) scaler-driver.

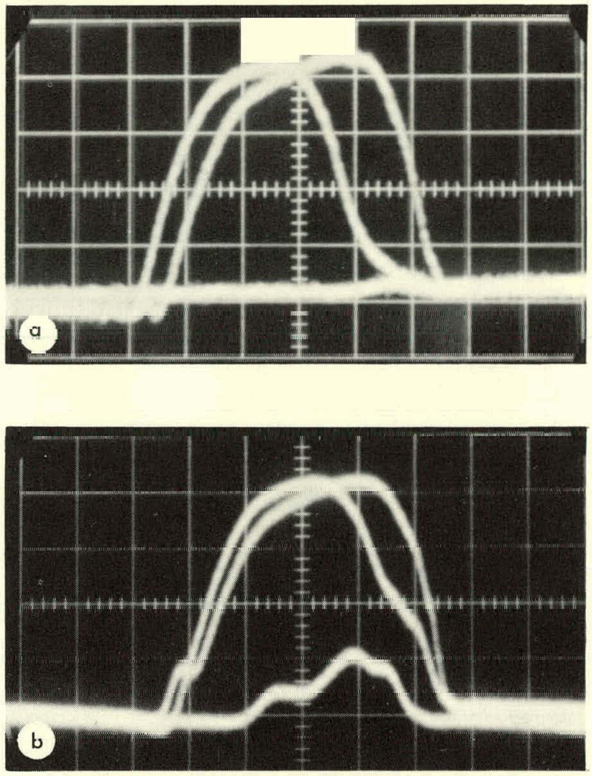


Figure 34. Output waveforms: (a) Single input pulse from 100-Mc scaler attenuated 0, 6, and 7 db. (b) Same but at 12 Mc CW with 0, 5, and 6 db. Time scale is 10 nsec/div. for both photographs.

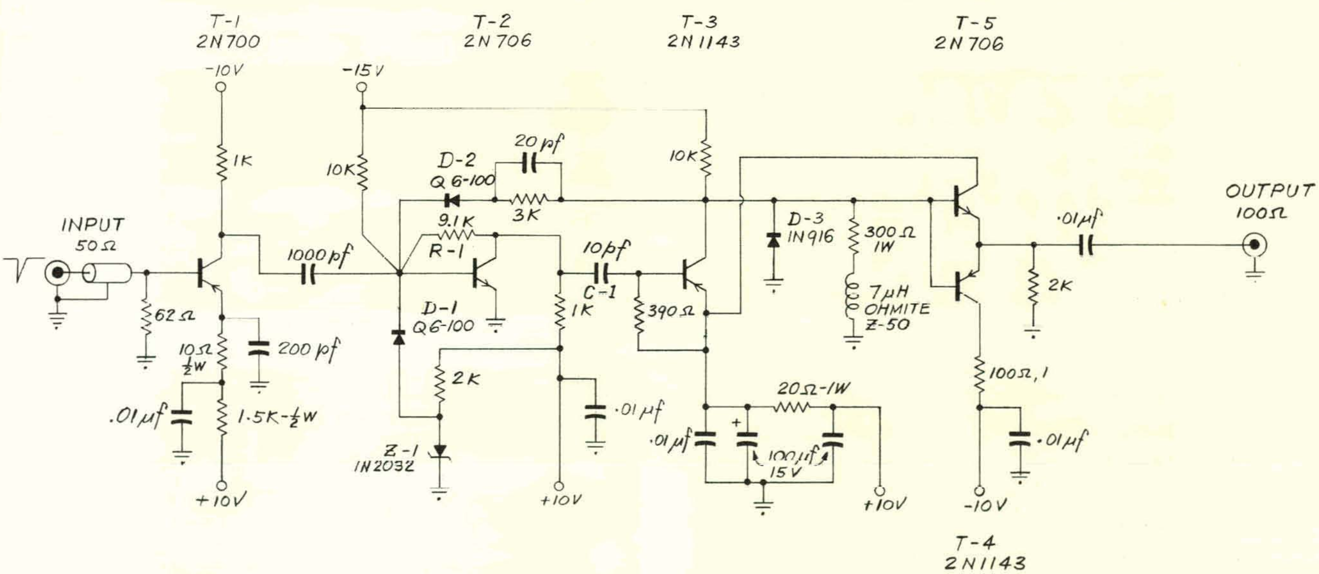


Figure 35. Circuit of IH-71 scaler-driver.

time 2 the input voltage is zero and the two steering diodes are equally biased. Beyond this point the input current must reverse until turnoff at time 4. The complete circuit including drivers, indicator lamps, and reset is shown in Figure 30. The interstage circuitry is ac-coupled but is not duty-cycle sensitive because short coupling time constants are employed, interstage signals alternate in polarity, and the transformers have a 5-nsec recovery in this circuit. An input pulse of opposite polarity would be differentiated by the first transformer and produce spurious counts. Diode D-3 prevents this from happening.

Figure 31 shows the actual current-voltage relationships in the scaler circuit, and Figure 32 shows signal shapes at several points in a system composed of the scaler and previously described fast logic elements.

IH-71 SCALER-DRIVER (10 Mc)

This univibrator (Figure 33) has a sensitivity of about 2.7 ma when driven with pulses 10 nsec wide. For pulse widths of 3 nsec it has about a 5-ma sensitivity. For input pulse widths <10 nsec, therefore, use the full 10-ma output of the nanocard discriminator, limiter, or fanout. The maximum input reflection coefficient is $\pm 10\%$.

The output pulse is 9.5 volts positive into 100 ohms. Its width is 40 nsec. The unit is rated for operation up to 50% continuous duty cycle. Some waveforms are shown in Figure 34. The output waveforms are the same for all counting rates to 12 Mc.

Circuitry

This circuit was developed from a basic complementary pair first used for this purpose at the University of Rochester by S. Weaver. It is shown in Figure 35. Diodes D-1 and Z-1 are normally on, with T-2 conducting slightly as regulated by resistor R-1. An input turns off D-1, saturating T-2 and T-3 for a time determined by C-1. Diode D-2 isolates the turnon pulse from the output circuitry, and D-3 provides a baseline clamp at the end of the pulse. T-4 is necessary at high duty cycles to provide a return path for the current delivered to the output capacitor. Otherwise this capacitor would turn T-5 off, reducing the output amplitude.

IH-142 FOUR-FOLD FAN-IN NANOCARD

This nanocard (Figure 36) has four separate inputs and two outputs in parallel. It serves as a logical OR circuit, i.e., the simultaneous presence of one or more inputs gives an output pulse.

Required input levels are 50 ohms, -5 ma. The two 50-ohm outputs are each -5 ma, independent of the number of coincident inputs. The unit is thus compatible with all previous nanocards. Output rise time is 2 nsec and decay time 5 nsec. Since there are no regenerative circuits, output and input pulse widths are approximately equal. (The slow decay time may be removed by inserting a delay line clip at one of the outputs.) The input reflection coefficient is $\pm 12\%$ for pulses $\leqslant 10$ ma. A limiter, diode or transistor type, should be used to prevent overdriving the input transistors. If peak duty cycles in excess of 10% are anticipated, use a delay line clip at the output of the limiter, since this will automatically restore the ac-coupling

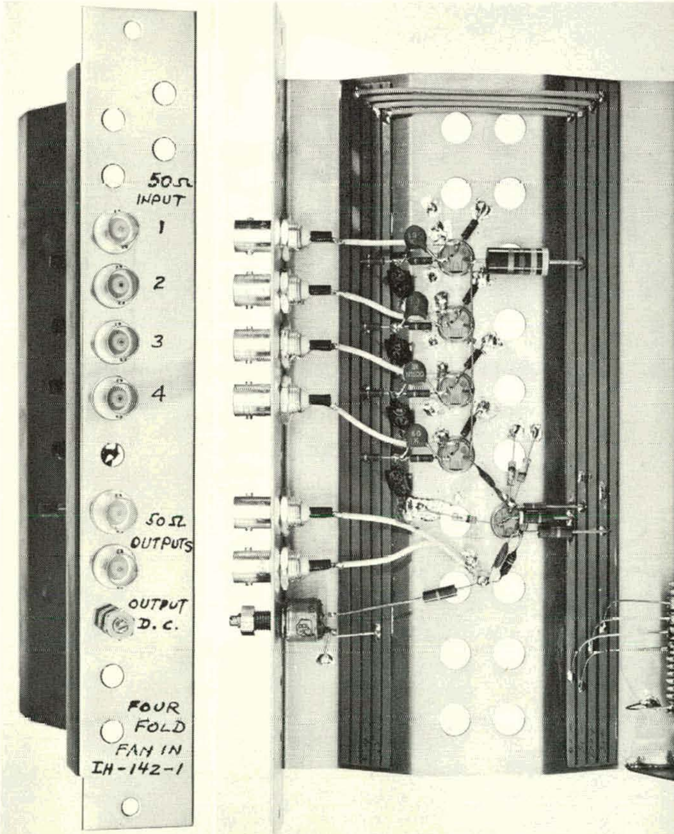


Figure 36. Four-fold fan-in IH-142.

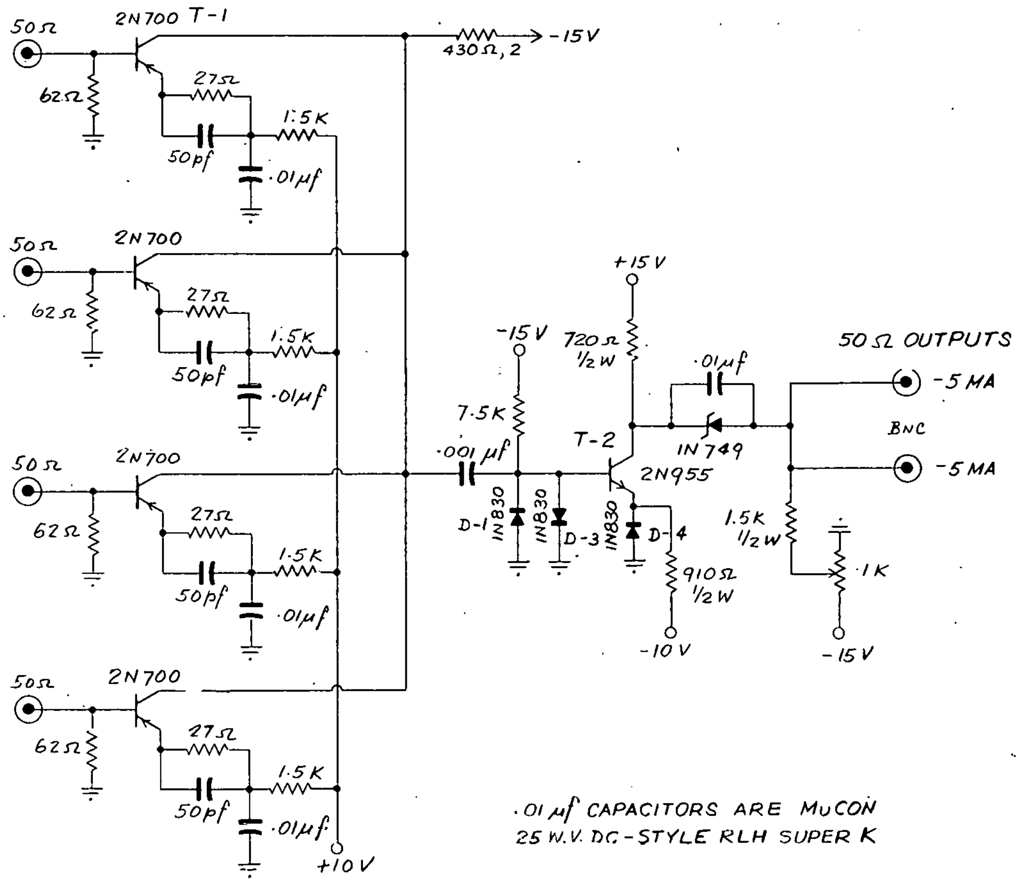


Figure 37. Four-fold fan-in circuit.

of the unit. The output may be used to drive a discriminator, fanout, coincidence circuit, scaler, etc. The "output dc control" may be used to adjust the output potential to zero when no 50-ohm termination or delay line clip is used at the output. A delay line clip must not be used when connecting the output to a fanout if the fanout outputs are themselves clipped, as this will triple-delay-line-clip the pulses and cause spurious secondary pulses.

The circuit is shown in Figure 37. The transistors are biased class A. Discrimination against noise pulses is obtained by the forward bias of D-1 and the cutoff of T-2. Diodes D-3 and D-4 limit the output pulse.

The discrimination is such that a single 10-nsec input of 1.2 ma will result in 10% of normal output. For pulses between 1 and 5 ma the circuit tends to act as an integrator producing outputs proportional to both time duration and amplitude.

IH-134 TIME-TO-PULSE-HEIGHT CONVERTER

The circuit is shown in Figure 38. It is essentially a twofold coincidence circuit and integrator designed to be driven from IH-51 or IH-53 discriminators. It has the resolution shown in Figure 39 as determined by A. Schwarzschild but may or may not be as good far down on the wings of the curve. A 12-hour stability is 50 picoseconds or less, singles rejection rate at least 20 to 1. The linearity is shown in Figure 40. The large number of diodes shown in Figure 38 helps to stabilize switching levels. The input transistors are operated class A for low reflection coefficients. When there is a coincidence, D-3 and D-4 turn off and D-1 and D-2 turn on. This turns off the Garwin diode D-5 and turns on D-6 to supply integrator current from R-1 to C-1. Internal switching times are from 1 to 2 nsec. A more stable or higher gain output amplifier may be desired in some cases.

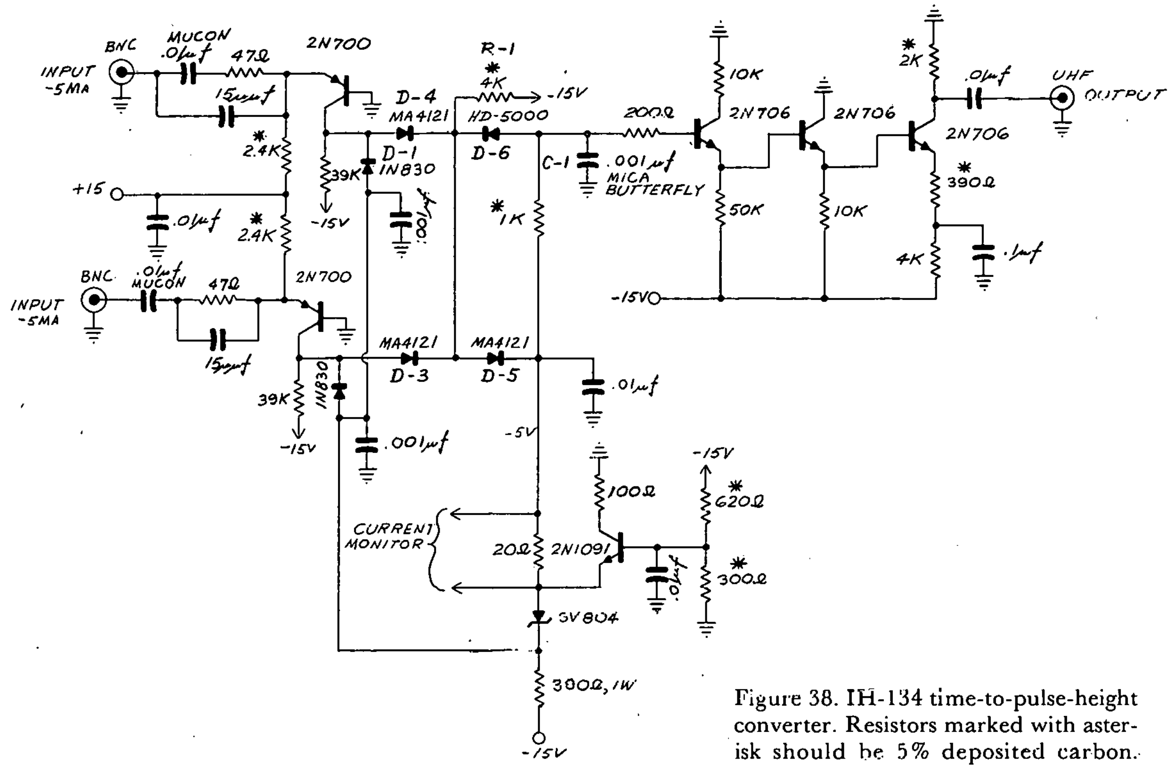


Figure 38. IH-134 time-to-pulse-height converter. Resistors marked with asterisk should be 5% deposited carbon.

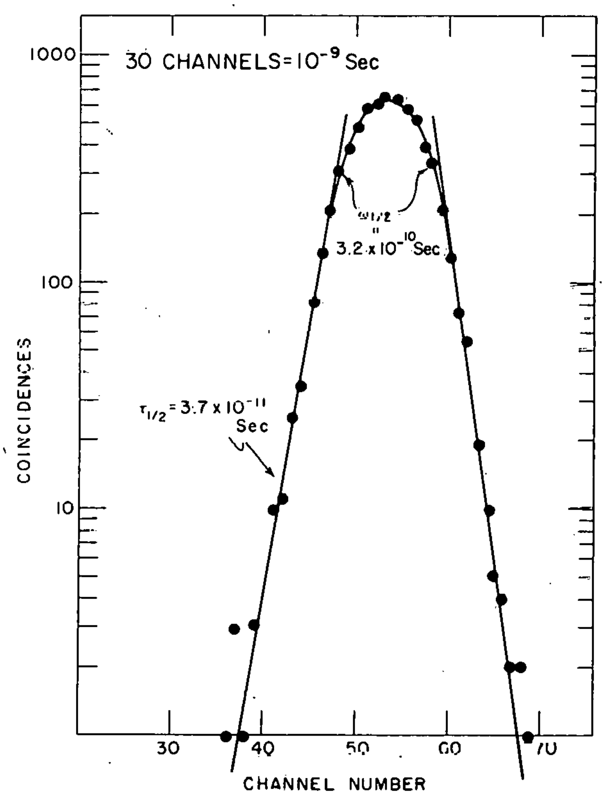


Figure 39. Discriminator and time-to-pulse-height converter, prompt spectrum with Co^{60}. (From A. Schwarzschild, BNL 5715.)

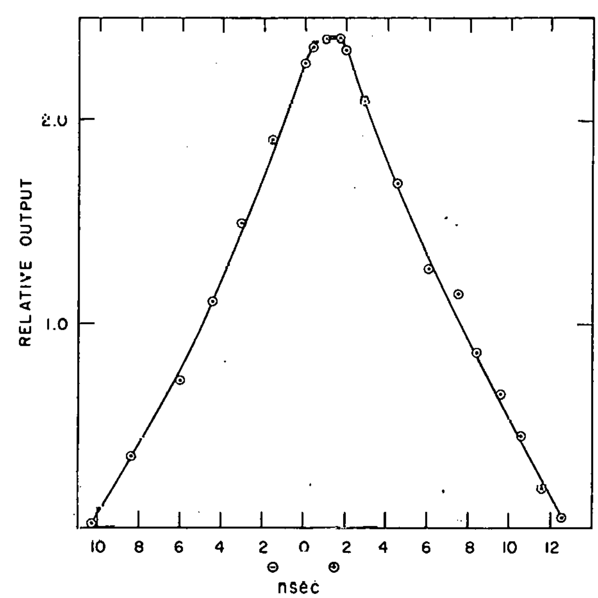


Figure 40. Relative output of IH-134 as a function of time separation between two 10-nsec input pulses.

IH-145 SINGLE-SHOT PULSER

This is useful to determine if nanocards are working. It will be found easier to use it if in doubt than to randomly recalibrate all equipment (Figure 41).

IH-136 GATE CIRCUIT

The discriminators and scaler have provision for remote count control. When connected to this gate circuit, the discriminators are blocked and the scaler is locked in the reset condition. The circuit (Figure 42) is a univibrator or single-shot multivibrator. If a pulse is applied to the ON input, the circuit flips on for a period of 0.01 to 0.1 sec, controlled by a potentiometer on the panel. Or it may be turned on and off within these limits by external clock pulses. The capacitor may be changed to give other time ranges. It is designed for operation from the standard predetermined timers used at the Cosmotron and AGS accelerators.

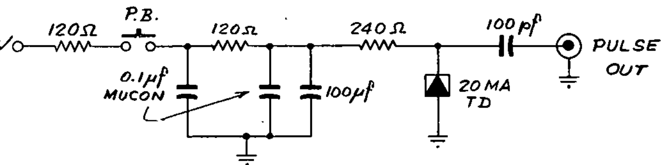


Figure 41. IH-145 single-shot pulser.

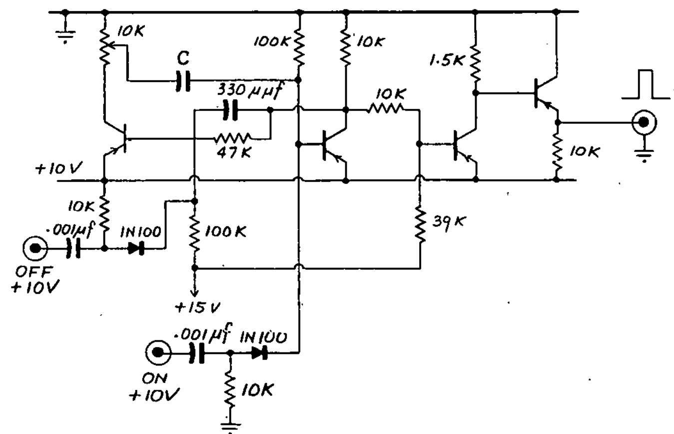


Figure 42. IH-136 gate. Transistors are 2N414, $C = 1$ μf for 1 to 8×10^{-3}-sec period.

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Appendix A. Miscellaneous Information and Figures

Appendix A includes the following:

- List of circuit drawings
- List of mechanical drawings
- Information on special components
- Schematic of IH-10 photomultiplier rf power supply and limiter circuit (Figure 43)
- Photograph of tunnel diode socket (Figure 44)
- Photograph of meter module (Figure 45)
- Photograph of nanocard frame (Figure 46)

LIST OF CIRCUIT DRAWINGS FOR NANOCARD LOGICAL MODULES

BNL Drawing No.	Circuit
IH-10-1	Transistorized high voltage photomultiplier supply and cascode limiter
IH-10-2	6 to 14-v Regulator for use with IH-10-1
IH-56-1	Coincidence unit
IH-75-1	Fanout
IH-53-1	0.5 to 2-ma Discriminator
IH-54-1	100-Mc Scaler
IH-51-1	2 to 5-ma Discriminator
IH-71-1	10-Mc Scaler-driver
IH-142-1	Fan-in
IH-134-1	Time-to-pulse-height converter
IH-145-1	Single-shot pulser
IH-136-1	Gate circuit

LIST OF MECHANICAL DRAWINGS FOR NANOCARD DRAWINGS

BNL Drawing No.	Item
IH-30-1-4	Nanocard mechanical drawing
IH-45	Power wiring and receiver wiring
IH-84	Nylon bushings and washers for Telex monitor jacks
IH-85	Nylon washers for thumb screws
IH-86	Nanocard frame with rods
IH-87	Nanocard extender with rods
IH-89	Potentiometer spacer for side mount
IH-90	Shields for IH-54-1 scaler
IH-91	Shields for other nanocards
IH-72*	Tunnel diode sockets, single and double
IH-92	Meter panel
IH-1001-11A	Cascode limiter EH1-935-8 outrider chassis

*See Figure 44.

INFORMATION ON SPECIAL COMPONENTS

Thumb screws: Amatom #5088; 6-32 – 7/16″.

Meters: International Instruments Model #1135 VRB – 100 μa (adjusted with an added series resistor to 20 mv full scale).

Toggle switches: Torsion Balance Co. Type SP-1.

50-ohm Subminiature coaxial cable: 50-ohm Microdot #50-3902; plugs, Microdot #32-23; receptacles, Microdot #31-50.

93-ohm Subminiature coaxial cable (Microdot): cable, 93-3902; plug, 32-17 or right-angle plug 32-14;* receptacle, 31-52; straight adapter, 33-36.

Special Parts Commercially Available

Power connectors: male, Amphenol #57-10360; female, Amphenol #57-20360.

Transistor sockets and rings: Elco socket #3304; Elco ring #757.

Coaxial cable hardware for module interconnections using BNC connectors with RG55/U cable: receptacle, bulkhead, UG-1094/U; adapter, straight, UG-914/U; shorting plug, CW-159/U; plug, Amphenol #31-301; 50-ohm termination, Dage 95712; 534-2.

Telex miniature phone plug and jack: plug, Telex #PM01; jack, Telex #JMP01.

Miniature potentiometers: Ohmite Type AS.

Capacitors: Mucon .001 μf, GMV, 25VDC, Style RLA, High K; Mucon .01 μf, GMV, 25 VDC, Style RLA, Super K; Mucon .008 μf, 200 VDC, Style S1, Super K.

Tunnel Diodes

Until October 1961 we used RCA diodes, produced to our specifications. All diodes were inspected and color coded at BNL, as follows:

RCA TD 1015 (blue)	$I_p = 5$ ma $\pm$ 5%, $C < 6$ pf
RCA TD 119 (green)	$I_p = 10$ ma $\pm$10%, $C < 8$ pf
RCA TD 120 (red)	$I_p = 10$ ma $\pm$10%, $C = 8$-15 pf

TD 120's used in the IH-54 scaler are matched to ½ ma in pairs for each stage.

The TD 1015's have recently been replaced by GE Type STD-517.

The TD 119's are no longer used since TD 120's give essentially the same performance in any of these circuits.

Power Supplies

Power Designs Inc., Mod. 1515A (2 to 15 volts, 0 to 1.5 amps).

*The right-angle plug is strongly recommended for all timing cable lengths $>$1 foot to avoid stress on the connectors.

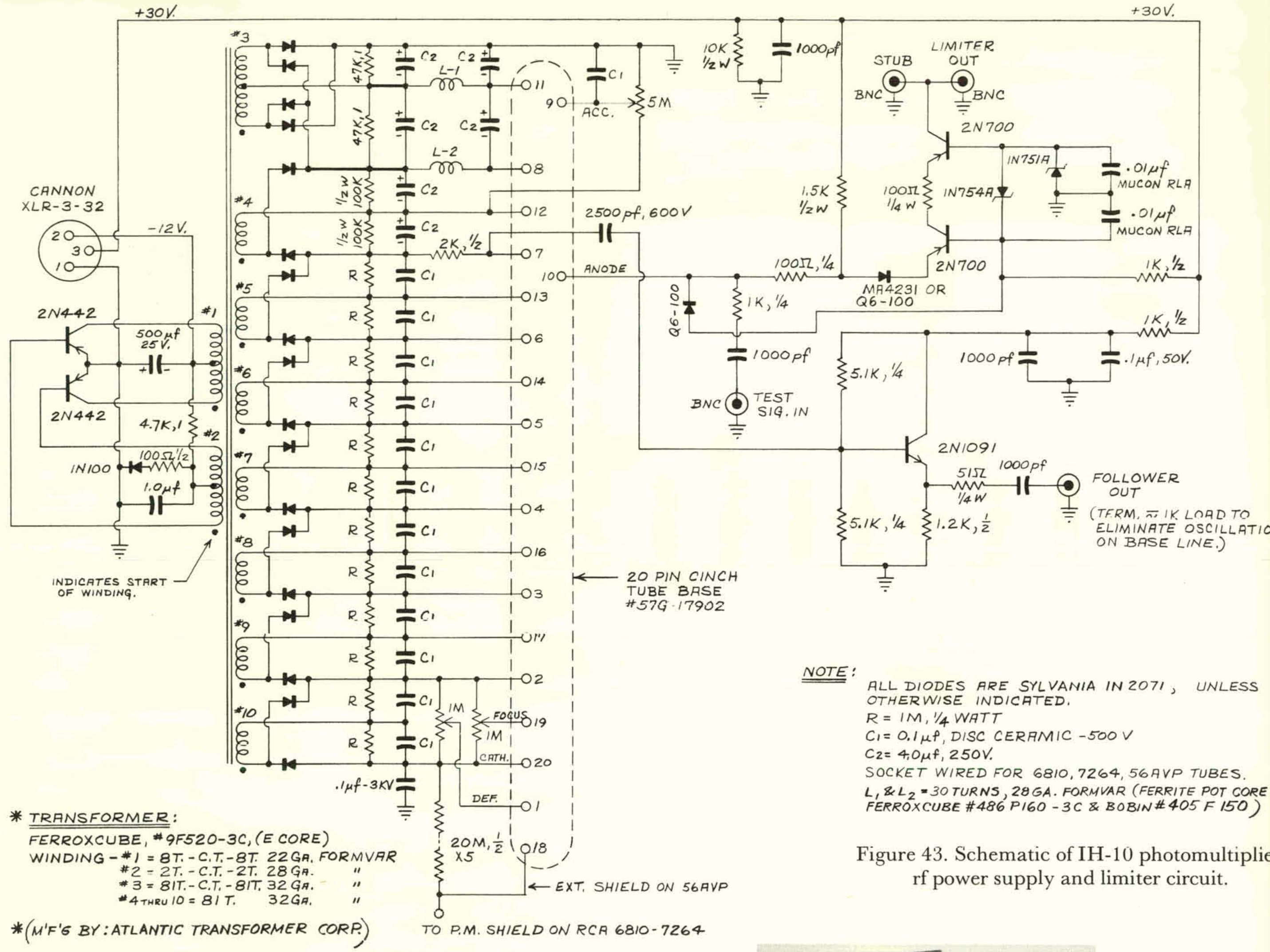

Figure 43. Schematic of IH-10 photomultiplier rf power supply and limiter circuit.

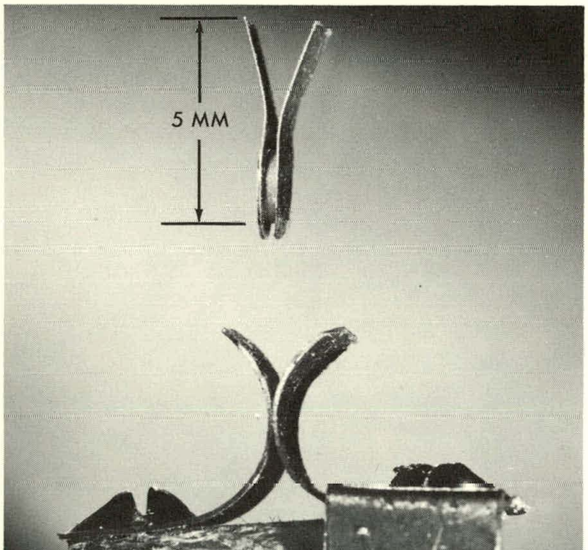

Figure 44. A tunnel diode (top) and tunnel diode holder (bottom). The nut on the right-hand screw is used to attach the holder to a metal ground plane.

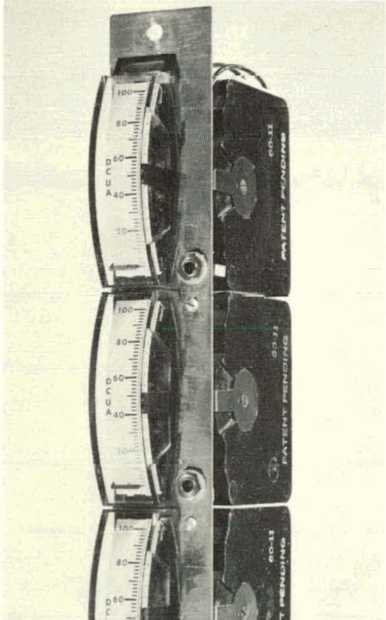

Figure 45. Meter module: nanocard with three monitor meters.

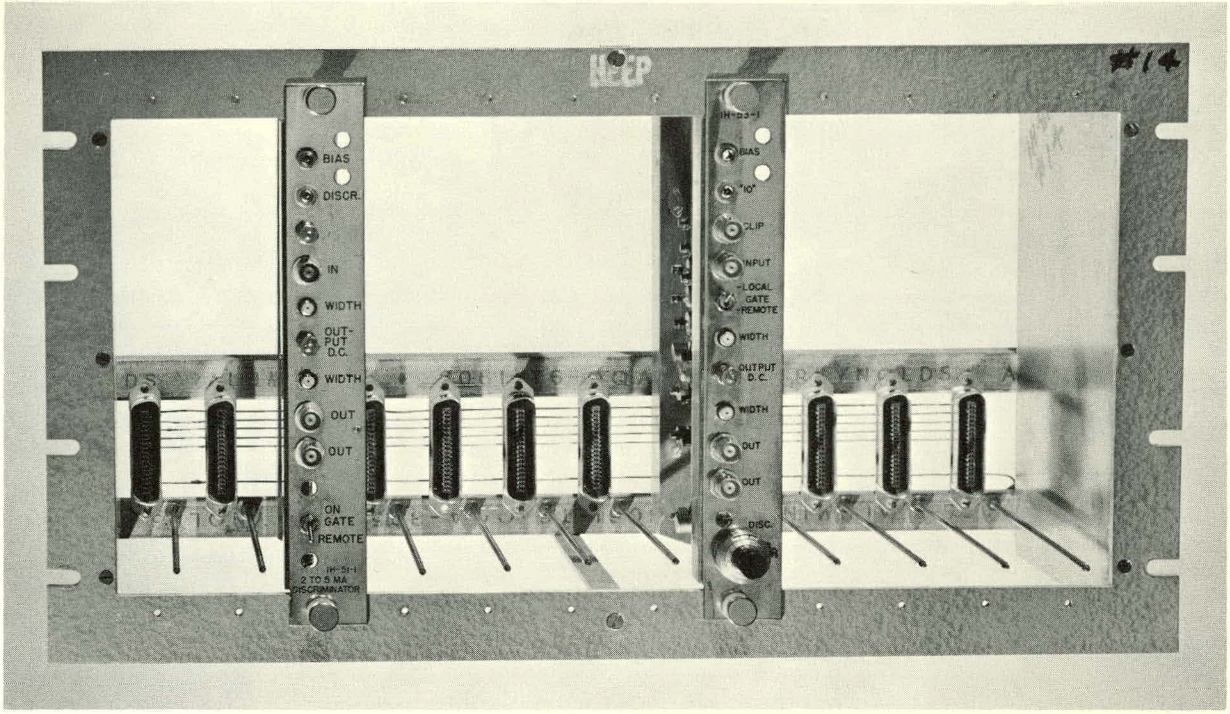

Figure 46. Nanocard frame; fits standard relay rack.

Appendix B. Checkout Sheets

This section contains copies of the checkout sheets for:

IH-51 Discriminator
IH-53 Discriminator
IH-56 Coincidence Circuit
IH-75 Fanout
IH-54 Scaler

The following equipment is required for calibrating the nanocards:

1. A 20-volt dc voltmeter of ½% accuracy. This meter should be frequently recalibrated.

2. A sampling scope having 1 nsec or less rise time and a 50-ohm input.

3. A 10-db attenuator with a 1000-Mc bandpass (General Radio or equivalent).

4. A 600-Mc attenuator 0 to 10 db in 1-db steps (Telonic or Hewlett-Packard).

5. A rectangular pulse generator for widths from 1 to 10 nsec, negative polarity, amplitude 10 mv to 1 volt adjustable in 1% steps over the whole range, and with a rise time <1 nsec. A Tektronix 110 pulser will do if the FP "amplitude" control is replaced with a 10-turn 20-K potentiometer and dial. A 10-cm air line will give a 1-nsec-wide output pulse with this pulse generator.

NOTE: When the nanocard meters are used for calibration, one of their divisions is defined as 1/100 full scale.

Serial # ....

Rev C ....

IH-51 Discriminator Alignment

The tests measure output rise time, sensitivity, and time shift with pulse height.

First calibrate all power supplies ±1%; use the shortest possible "width" cable on the discriminator, and set the bias to 20 divisions. Select three output transistors on Tektronix 575 transistor curve tracer which withstand 10 ma at 5 v. Paint them red.

1) Rise time tests

a) With a 50-mv, 1-nsec input set the discriminator just above threshold.

Rise time [Min. 1 nsec, Max. 1.5 nsec] ....

Decay time [Min. 0.9 nsec, Max. 1.5 nsec] ....

b) With a 6-nsec, 500-mv pulse and same discriminator setting.

Rise time [Min. 0.7 nsec, Max 1.2 nsec] ....

Decay time [Min. 0.8 nsec, Max. 1.3 nsec] ....

The next tests are made with no more than 5 ft of RG-8/U and 2 ft of RG-55/U between pulser and discriminator. Delay line is connected from discriminator output to scope input.

2) Sensitivity

a) Advance sensitivity until discriminator oscillates. Back off and record the required input voltage at 6 nsec, which will just fire. [Min. 15, Max. 40] ....

b) Set the 6-nsec input to 100 mv and set discriminator to fire. Set "zero" to 100-meter divisions.

c) Record required input to just trigger with 1-nsec input. [Min. 85 mv, Max. 100 mv] ....

d) With 6-nsec, 250-mv input record meter reading for threshold. [Min. 67 div., Max. 74 div.] ....

3) Time shift with pulse height

With at least 10 db in line set discriminator to just fire on 6 nsec,* 50 mv. Remove 10 db and record time shift. (If a plug-in attenuator is used, its time delay must be subtracted.) [Min. 0.5 nsec, Max. 1.0 nsec]** ....

4) Use a 6-nsec, 500-mv input and insert 25 pf in series with pulser line. Use a >10-ft-width cable. Record dial setting which makes output pulse width decrease to ~6 nsec. [Min. 53 div., Max. 58 div.] ....

Name ....

Date ....

Tunnel diode manufacturer ....

I_p (±2%) ....

C (max.) ....

*If one cannot produce a flat topped pulse to within 5% (poor generator or more cable required), use a 1- nsec impulse.

**For diodes <8 pf capacity; for diodes <15 pf, may go to 1.4 max.

Serial # ....

Rev ....

IH-53 Discriminator Alignment

1) Calibrate all power supplies ±1% and insert 2.5-nsec clipping line. Select three output transistors on 575 tracer to withstand 10 ma at 5 v. Paint them red.
2) Check potential across all 30-ohm resistors in distributed amplifier. [Should be 0.14 v ± 10%.]

....

3) Record potential at both common collector points.

1st section ....

2nd section ....

4) Insert shortest possible "width" cable for steps 5 through 10.
5) Set bias to roughly 30 (turn down "10-ma adj." if necessary to prevent output oscillation). With discriminator set at "zero," record "10" current which just causes oscillation as seen on scope or change in "bias" setting.* ....

Decrease this setting by 10±2%. ....

6) Adjust bias to "20."
7) Put in a 25±3-mv, 6-nsec negative pulse. Set "discriminator" to zero. Adjust "zero" potentiometer to just above threshold. Lower "10" 5%. Record sensitivity. ....
Return "10" to previous setting.
8) Record output rise, decay (10 to 90%), and FWHM.

Rise .... Decay .... FWHM ....

9) Lower —15-v supply to 14 v and record new input triggering level. (Change no other settings.)............................

Raise —15-v supply to 16 v and record new input triggering level. ....
Return to —15 v ±1%.

10) The next tests are made with no more than 5 ft of RG-8/U and 2 ft of RG-55/U between pulser and discriminator. Delay is connected from discriminator output to scope input. Use a 6-nsec input pulse width and ⩾10-ft-width cable with at least 10 db in line and set discriminator to firing threshold for a 30-mv pulse. Increase input pulse height 10%. Then remove attenuator and record time shift. (Compensate for attenuator time delay if necessary. If the short input cable setup is not convenient, use a 1-nsec-wide impulse.) ....

11) Set discriminator to maximum. Record input to trigger (in mv). ....
12) With discriminator at zero; 6-nsec input pulse width; >10-ft-width cable; and 2.5-nsec clipping stub on discriminator; record input amplitude which makes output pulse width <6 nsec. ....

Name ....

Date ....

10-ma T.D. Type .... Manufacturer ....

Capacity .... I_p (±1%) ....

5-ma T.D. Type .... Manufacturer ....

Capacity .... I_p (±1%) ....

*Remove input signal. This can suppress oscillations.

Serial # ....

Rev D ....

IH-56 Coincidence Circuit Alignment

1) Test tunnel diode for $I = 5$ ma $\pm 5\%$.
2) Set standing current per single transistor to 20 divisions. (Set standing I with all inputs open but antishorted to ½ division by adjusting antibias. All single-shorted inputs should agree to 3 divisions. Record current.

#1 .... #2 .... #3 .... #4 ....

3) Short all four inputs and after 3-min warm-up record drift for next 3 min.
Drift [Max. $=0.2$ div.] ....
4) Use a negative rectangular pulse of 50 nsec or more and ½ v high $\pm 30\%$. Use the following stubs with the outputs of a standard fanout: #1, 2.5 nsec; #2, 2.5 nsec; #3, ~5 nsec ± 1; #4, 10 nsec ± 2. Connect # 1 to 3 with cables of same length to fanout; #4 cable must be 2 nsec shorter. Connect the generator to fanout and adjust fanout current to 40 ± 1.
Calibrate all power supplies to $\pm 1\%$; failure to do so will invalidate all subsequent tests. Check sampling scope sensitivity to $\pm 5\%$. Check potential across 1.5-K precision resistor at T.D. [Should be 9.8 v $\pm 2\%$.] ....
Set sensitivity control for maximum for all following tests.
5) Connect outputs #1 and #2 to inputs #1 and #2. Lower -15-v supply until output is 160 mv with a standing current of 18 div. Record exact value of 15-v supply. ....

Record value for #3 and #4 coincidence circuit inputs. [Min. 12.3, Max. 14] ....
6) Return B— to -15 v. With a single input from #1, record range I for which output is >160 mv for all four inputs. [Min. range 11 div. (9-20), Typical range 15 div. (8-23)]

#1 .... #2 .... #3 .... #4 ....

7) Connect #1, 2, 3 to coincidence YES inputs with the other YES input shorted. Record standing current for which output feedthrough becomes >20 mv. [Min. 30 div., Max. 60 div.] ....
8) As in 7), but remove short from YES and connect #4 of fanout to ANTI. Set standing I to 65. Record output in mv (remove attenuators on scope). [No Min., Max 10] ....
9) Connect #1 and #2 to YES inputs through a constant impedance sliding delay box of range >5 nsec. Set standing I to 30 div. Record maximum output amplitude. [Min. 200 mv, Max. 380 mv] ....
Record delay required to go from a point of half amplitude through maximum to a point again at half maximum (nsec). ....
Do the same for the other two YES inputs. (Reset standing I if necessary.) [Min. 2.3, Max. 4.5, Typical 3] Amplitude ....

nsec ....

T.D. ....

Signed ....

Date ....

Serial # ....

Rev B ....

Test of IH-75 Fanout

Test uses input pulses at least 10 nsec wide. Use four fanout clipping stubs of 5-nsec width. Always terminate an unused fanout output either at the clip line or the output.

1) Set I_{max} to 55 with input shorted.

2) Set I_{lim} to 40 with input attenuators in place.

3) Record emitter to ground potentials of input transistors. [Min. 0.13 v, Max. 0.20 v] ....

....

4) Record collector potentials of output transistors. They should agree within a volt. [Min. 3.5 v, Max. 4.5 v]

1 .... 2 .... 3 .... 4 ....

5) Record all output amplitudes with input of 0.25 v compared to those with 1.0 v. Express as a percent figure. [Should be < 2% loss.]

1 .... 2 .... 3 .... 4 ....

6) Record output rise times 10 to 90% with 0.25 v in. [All Min. 0.8 nsec, Max. 1.2 nsec]

1 .... 2 .... 3 .... 4 ....

7) Record maximum percent of overshoot in negative direction after clip inversion. *Terminate unused outputs.* [No Min., Max. 8%]

1 .... 2 .... 3 .... 4 ....

Signed ....

Date ....

Serial # ....

Rev ....

IH-54 Scaler

Requires IH-51 and an IH-145 attenuator.

1) Select tunnel diodes having 15 pf or less capacitance. Match in pairs by I_p to ±5%. Insert matched pair in each stage. Record I_p for all six diodes (in ma).

Stage #1 ....

Stage #2 ....

Stage #3 ....

2) Adjust all power supplies ±1%. Leave a 1% voltmeter connected to an additional 15-v power supply and use this supply for providing −10 v to the scaler only. Connect an IH-51 discriminator to scaler using a 2.5-nsec clipping stub and shortest width cable on discriminator. (Use main −10-v supply for the discriminator.) Trigger discriminator from Tektronix 110 pulser. Connect first-stage monitor to sampling scope input and adjust first-stage current to midpoint of correct operation (two waveforms of the same shape, inverted with respect to each other).

Record lowest value of "−10" for correct operation ....

Highest value ....

If these voltages are not equally grouped about "−10," repeat adjustment and record final voltage values in above space. Return "−10" to −10 v ±1%.

Connect 2nd stage monitor and align 2nd stage as above (waveforms should be two baselines and two pulses, one the inversion of the other).

Lowest "−10" ....

Highest "−10" ....

Connect scope to output of third stage and repeat.

Lowest "−10" ....

Highest "−10" ....

(Correct output is four baselines and two pulses, one the inversion of the other.) Incorrect operation will result in only two baselines. Correct operation on sampling scope can be seen easily since the number of dots/output pulse will be half that for the previous stage.

HINT: If any stage oscillates, increase lead length of 10-ohm shunt resistor to ½ inch.

3) Check input sensitivity by inserting 1 to 10-db attenuator in 1-db steps between discriminator and scaler. Record maximum attenuation (in db) that just permits scaler to operate. ....

4) Connect IH-145 single-shot pulser to scaler and check for correct sequencing of scaler. To check for oscillation, turn off power supplies, then turn on. Scaler must count on *first* single shot. Failure to do so indicates a residual oscillation quenched by the first pulse. Repeat several times.

T.D. manufacturer ....

Type number ....

C (max) ....

Signature ....

Date ....