Optical Timing Receiver for the NASA Laser Ranging System

Part I: Constant-Fraction Discriminator

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Abstract

Position-resolution capabilities of the NASA laser ranging system are essentially determined by time-resolution capabilities of its optical timing receiver. The optical timing receiver consists of a fast photoelectric device, primarily a standard of microchannel-plate-type photomultiplier or an avalanche photodiode detector, a timing discriminator, a high-precision time-interval digitizer, and a signal-processing system. The time-resolution capabilities of the receiver are determined by the photoelectron time spread of the photoelectric device, the time walk and resolution characteristics of the timing discriminator, and the time-interval digitizer. It is thus necessary to evaluate available fast photoelectronic devices with respect to their time-resolution capabilities, and to design a very low time walk timing discriminator and a high-precision time digitizer which will be used in the laser ranging system receiver.

Part I of this report describes the development of a modified constant-fraction discriminator which reduces amplitude-dependent timing errors to ±40 psec over a dynamic range of input pulse amplitudes from 50 mV to 5 V. Within the same range of input pulse amplitudes, a time resolution of 30 psec FWHM was obtained with an input signal whose rise time was 0.4 nsec and width 1.0 nsec. The unit produces 800 mV negative output pulses with pulse widths of 10 nsec, and 3 V positive pulses with pulse widths of 15 nsec. The time delay through the discriminator was approximately 32 nsec. The input signal is amplified, clipped and properly shaped by an attenuation-subtraction technique to produce a pulse with a zero-crossing point. All essential functions responsible for the discriminator timing accuracy are performed by means of tunnel diodes with backward diodes as nonlinear load. The discriminator is designed for convenient linking to a conventional time-interval unit or a high-precision time-interval digitizer. Adjustment procedure for obtaining a minimum amount of the time walk is also given.

Introduction

The time-resolution capabilities of the optical timing receiver of the NASA laser ranging system are determined by the photoelectron time spread of the photoelectric device, the time walk and resolution characteristics of the timing discriminator, and resolution capabilities of the time-interval digitizer. The stability of the system over relatively long time periods is also important.

Since the study of fast photomultiplier resolution capabilities and the design of the high-precision time-interval digitizer with resolution of 10 psec will be performed at a later date in the Electronics Research and Development Group of the Lawrence Berkeley Laboratory, only high-resolution constant-fraction discriminator with picosecond time-resolution capabilities will be described in this report.

Although a number of circuits have been devised for deriving timing signals from scintillation detectors, with reduced amplitude-dependent error [1-2], our analysis and measurements have shown that the constant fraction-of-pulse-height timing, based on fast tunnel-diode circuits, is the best method for subnanosecond timing [3-4]. A modified pedestal-type constant-fraction discriminator was developed with subnanosecond time walk and resolution characteristics, in which the input signal is properly shaped by an attenuation-subtraction technique to produce a pulse with a zero-crossing point, and a pedestal added, allowing adjustment of the discriminator to the zero-crossing point. The fast baseline crossover point of a bipolar pulse is relatively independent of the pulse amplitude, and it can be conveniently used to obtain the amplitude-independent timing information. Despite the amplitude-independent crossover point of a bipolar pulse, a leading-edge detector being triggered at this point introduces a time walk, in the nanosecond region, when there is a large dynamic range of input pulse amplitude. To overcome this shortcoming, a pedestal is added to shift the bias up to the detector threshold at the right time. By doing this the detector triggers as soon as the zero-crossing point of the bipolar pulse is reached, producing an almost amplitude-independent timing pulse. To increase the input amplitude dynamic range of the discriminator, the bipolar pulse is additionally amplified and peak-limited before being applied to zero crossing and threshold detectors. All essential functions responsible for time walk in the discriminator, such as threshold discrimination and fast-pulse zero-crossing detection, are performed exclusively by means of tunnel diodes with backward diodes as nonlinear loads. Other less essential functions -- such as limiting, amplification, comparison, and gating -- are performed by hot carrier diodes, fast transistors, and emitter-coupled logic, MECL III Series.

Description of the Constant Fraction Discriminator Circuit

A schematic diagram of the constant-fraction discriminator is shown in Fig. 1. Pertinent waveforms at the specified points in the diagram and the sequence of operation of the discriminator are given in Fig. 1a. Referring to both figures simultaneously, the negative unipolar input anode signal, having an amplitude anywhere from 50 mV to 5 V, enters the discriminator at point A, where it is split into two parts. The first part of the input signal is delayed for time t_2, by means of the delay line DL1, point B. The second part of the input signal is immediately attenuated, by a factor of 5, by means of an attenuator consisting of resistors R2 and R3, point C. The value of the resistor R1 is experimentally selected to obtain a discriminator input impedance as close as possible to 50 Ω; this reduces the amplitude of the reflected signal from the input of the discriminator. The attenuated signal is inverted by means of a wideband transformer which has a bandwidth greater than 400 MHz. The delayed signal and the inverted signal are added together, creating the bipolar wave shape seen at point D. An amplitude-limiting network, consisting of the hot carrier diodes CR1 and CR2, limits the amplitudes of the bipolar signal to a maximum of 400 mV, to prevent damage and to minimize the time walk due to the overloading of the discriminator stages which follow. After limitation, the bipolar signal is amplified by a factor of 3 and inverted by the microwave transistor Q1. (This is indicated by the wave shape at point E.) At this point, the zero-crossover point of the bipolar signal is stable within ±15 psec through an input signal amplitude dynamic range from 50 mV to 5 V. The bipolar output of this first system after amplification is again amplitude-limited by means of diodes CR3 and CR4. The signal amplitude dynamic range is thus effectively reduced to the 50-400 mV range by the limiter-amplifier-limiter operation. The signals of the 50-400 mV dynamic range are applied to the threshold tunnel-diode zero-crossing discriminator.

The positive portion of the bipolar pulse serves as a trigger pulse for the tunnel diode CR7 threshold detector. The peak current of this diode (CR7) is 4.7 mA. The fast-crossover slope provides better triggering for the leading-edge threshold discriminator, resulting in a pedestal with less time shift caused by wide dynamic range of the input signal pulse amplitude. When the leading-edge threshold detector was operated in this fashion the pedestal time shift was found to be approximately 500 psec better than the same detector triggering at the leading edge of the input signal pulse, over a dynamic range of 30:1. The variable resistor R19 provides a threshold adjustment for diode CR7. Inductor L8 and the backward diode CR8 serve as the nonlinear load for tunnel diode CR7. Operating a tunnel diode in this mode improves the sensitivity of the circuit and reduces its standby power dissipation. The output of this stage in turn triggers the tunnel diode CR9, which is the pedestal generator. Diode CR9 has a peak current of 10 mA. A shorting stub is the load for this stage, which generates a 25-nsec-long pedestal (point G). While this is taking place the bipolar pulse is being delayed for time $t_5 - t_4$ approximately 5 nsec, by the delay cable (point F), before appearing across tunnel diode CR14, which serves as the zero-crossing detector. Diode CR14 has a peak current of 10 mA. Variable resistors R33 and R28 provide the bias adjustment for the tunnel diode CR14 and the pedestal generator diode CR9, respectively. The bias pedestal is applied to the zero-crossing detector diode CR14 through inductor L10 and resistor R31. L10 is used to suppress the overshoot at the leading edge of the pedestal. The pedestal is used to raise the bias of CR14 nearly to its threshold level, thus reducing the trigger delay due to different slew rates of the zero-crossing pulses. The zero-crossing detector is in the form of a one-shot multivibrator, using an inductor L9 and a backward diode CR13 as a nonlinear load.

The driver stage that follows uses the tunnel diode CR17 and transformer T2 and the backward diode CR18 as its nonlinear load. Diode CR17 has a peak current of 10 mA. Variable resistor R35 provides a bias adjustment for CR17.

The driver stage output signal, at the point I, is further delayed 10 nsec (time t_6-t_5). This is done to allow enough time for the gating signal generated by the comparator M2, operating as a leading-edge threshold discriminator, and the gate generator, tunnel diode CR11, to be properly applied to the reference input of comparator M1 through the entire signal amplitude range, before the driving pulse arrives at M1. Since the comparator M2 operates in the leading-edge trigger mode, the walk range of the gate signal, at point M, is approximately 5 nsec through a dynamic range of 50 mV to 5 V, or 1 to 100.

In order to avoid the degradation of the time walk characteristics of the discriminator as a whole, the comparator M2 is used as a lower-level discriminator which inhibits output pulses when the input signal is below a certain level. In this way the threshold level of the tunnel diode CR7 is adjusted to obtain the best possible time walk characteristic throughout the entire input pulse amplitude dynamic range, and it stays fixed at that level. The variable resistor R14 is used to set the threshold level of the comparator M2 through a voltage range from 50 mV to 500 mV. The output of comparator M2 (point K) is differentiated by the capacitor C17 and the resistor R72. The bias provided by the voltage divider formed by R75 and R76 prohibits comparator M1 from operating except when it receives a recognized input signal. The maximum driver output signal at point J is approximately -400 mV. A recognized signal at the input produces a positive pulse at point L, which triggers CR29 that serves as a buffer stage for CR11. The positive pulse generated by CR29 in turn triggers CR11, generating a gating pulse with a duration of 50 nsec, causing the comparator M1 to yield an output pulse at the MECL logic levels, "0" being -1.9 V, "1" being -0.8 V. Transistors Q_5 and Q_6 are used to convert the signal from the MECL logic levels back to the Nuclear Instrument Module (NIM) standard level, -0.8 V across 50 Ω. Transistors Q_2, Q_3, and Q_4 are used to provide an alternative positive output pulse. If necessary, the width of the positive output pulse can be lengthened by using a pulse standardizer or a retriggerable one-shot multivibrator. Transistors Q7-Q12 are used to provide three more NIM outputs, making a total of four NIM outputs and one +3 V output. The transit time (the time between an input signal pulse and the output pulse) of the discriminator is approximately 32 nsec, and the transit time difference between the four NIM outputs is within ±150 psec. For high-precision measurements the same output should be used accordingly throughout the whole experiment.

Time Walk and Resolution Characteristics of the Constant-Fraction Discriminator

The time walk and resolution characteristics of the constant-fraction discriminator, as a function of the input pulse amplitude, were measured with the input pulse rise time and width as parameters. Measurements were made using the system illustrated in Fig. 2. Essentially, the source of the discriminator input pulses was a fast-rise-time pulse generator, which was combined with a step recovery diode pulse shaper when pulses with different rise times were necessary. The triggering signal from the pulse generator was applied to the external trigger terminal of a two-channel sampling oscilloscope. The output pulses from the pulse generator (pulse shaper) were applied to the constant-fraction discriminator through an 18-GHz attenuator, which has a negligible time walk for different attenuation settings.

Also, a part of the same generator output pulse was applied as a reference timing signal to one channel of the sampling oscilloscope by means of a pick-off probe and a delay line. The output signal from the constant-fraction discriminator was applied to the other channel of the oscilloscope. The time walk characteristics of the discriminator were then found by comparing the 50% point of the amplitude of the leading edge of the reference pulse and the 50% point of the amplitude of the leading edge of the discriminator output pulse. Using the 20 dB attenuator setting as a reference point, the time walk characteristics of the discriminator were measured. The characteristics are shown in Figs. 3 and 4. The time walk of the discriminator, at a repetition frequency of 100 kHz, in the best possible case had a value from -40 to +40 psec for an input pulse amplitude variation from 50 mV to 5 V, and an input pulse rise time and width of t_r = 0.4 nsec, and t_w = 1 nsec, respectively. The time walk was from -50 to +50 psec for the same input pulse amplitude variations as in the previous case, where the input pulse rise time and width was t_r = 0.8 nsec and t_w = 1 nsec, respectively. Other time walk characteristics are given in Figs. 3 and 4.

The discriminator time resolution was also measured, as a function of the input pulse amplitude, with the input pulse rise times as parameters, by means of the measuring system shown in Fig. 2. There was practically no change in the time resolution with different pulse widths. The measured time resolution of the system without the constant-fraction discriminator was 15 psec FWHM. Results of the measurements are given in Fig. 5. It can be seen that the total system time resolution, including the constant-fraction discriminator, is 22 psec FWHM for an input pulse amplitude variation from 300 mV to 5 V and for a pulse rise time and width of 0.4 and 0.8 nsec, respectively. The time resolution is 30 and 40 psec for input rise times of 0.4 and 0.8 nsec, respectively, with input pulse amplitude of 50 mV.

Operation

The discriminator should be turned on for approximately three hours before it is being tested, adjusted, or used. This time is required to stabilize the critical components in the system. Operating ambient temperature should preferably be 18-35° C. If possible the discriminator should be left on all the time. The voltage of the ±6 V and +12 V supplies required by the discriminator should be within 1% or better.

Adjustment

During the initial tune-up the bias adjustments are set at the optimum levels, hence drastic adjustment should not be required. However, if adjustment is needed, the system shown in Fig. 2 or an equivalent system should be used to test the discriminator. It is important to use an attenuator similar to the HP8496B and a sampling oscilloscope similar to the Tektronix 661. Excessive walk normally occurs at the low-input-pulse amplitude range, 50-150 mV. The 50 mV point in the walk curve can be compensated by the back panel threshold adjustment (not to exceed 1 turn), and the 150 mV point can be compensated by the back panel zero-crossing adjustment (not to exceed 1 turn). The 50 and 150 mV points correspond to the 40 and 30 dB settings of the attenuator when the input pulse amplitude is 5 V at 0 dB attenuator setting. The front panel 10-turn helipot provides a lower threshold adjustment from 50 to 500 mV. Threshold level drift is less than 0.2 mV/°C in the temperature range from 18° C to 35° C. Figures 6 and 7 show the 0.4 and 0.8 nsec risetime pulses used for the testing; the pulse width in both cases is 1 nsec.

Acknowledgments

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References

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3. C. C. Lo and B. Leskovar, A Measuring System for Studying the Time-Resolution Capabilities of Fast Photomultipliers, IEEE Trans. Nucl. Sci. NS-21, No. 1, 93-105 (1974).

4. B. Leskovar and C. C. Lo, Single Photoelectron Time Spread Measurement of Fast Photomultipliers, Nucl. Instrum. Methods 123, 145-160 (1975).

Figure Captions

Fig. 1. Schematic diagram of the constant fraction discriminator.

Fig. 1a. Waveforms at the particular points in the constant fraction discriminator of Fig. 1.

Fig. 2. Block diagram of the measuring system.

Fig. 3. Time walk characteristic of the constant-fraction discriminator as a function of input pulse amplitude with input pulse risetime of 0.4 nsec and pulse width as parameters.

Fig. 4. Time walk characteristic of the constant-fraction discriminator as a function of input pulse amplitude with input pulse risetime of 0.8 nsec and pulse width as parameters.

Fig. 5. Discriminator time-resolution characteristics as a function of the input pulse amplitude with output pulse risetime and width as parameters.

Fig. 6. Input signal test pulse with 0.4 nsec risetime.

Fig. 7. Input signal test pulse with 0.8 nsec risetime.

Fig. 8a. Front panel of the constant-fraction discriminator.

Fig. 8b. Rear panel of the constant-fraction discriminator.

Fig. 9. Right side view of the discriminator.

Fig. 10. Left side view of the discriminator.

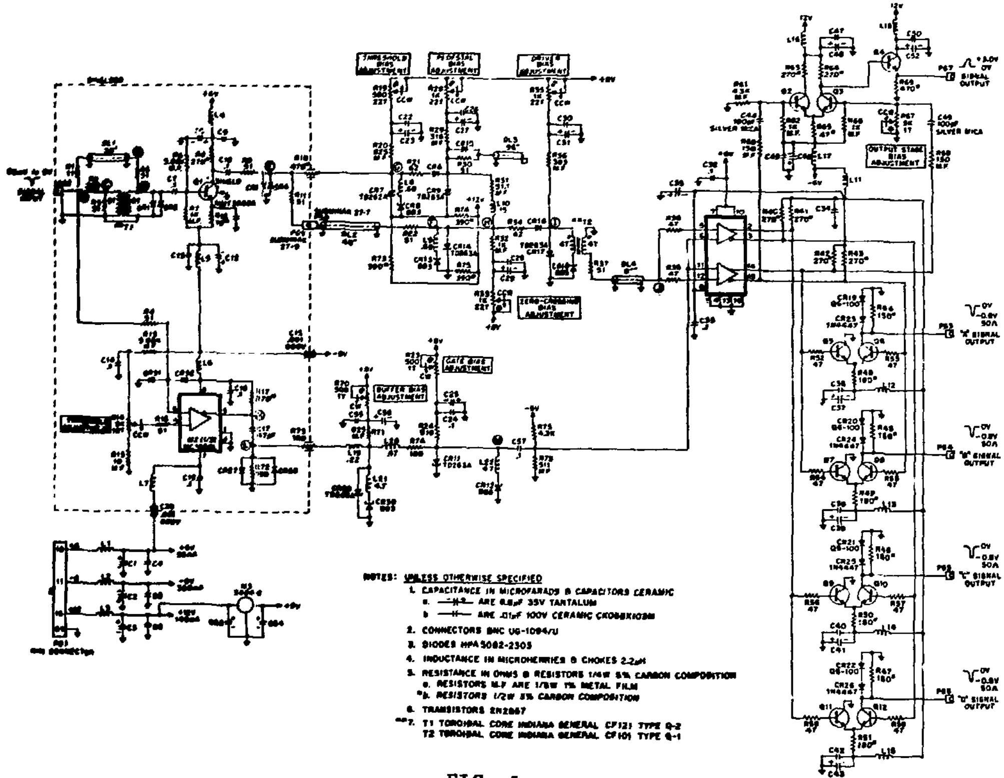
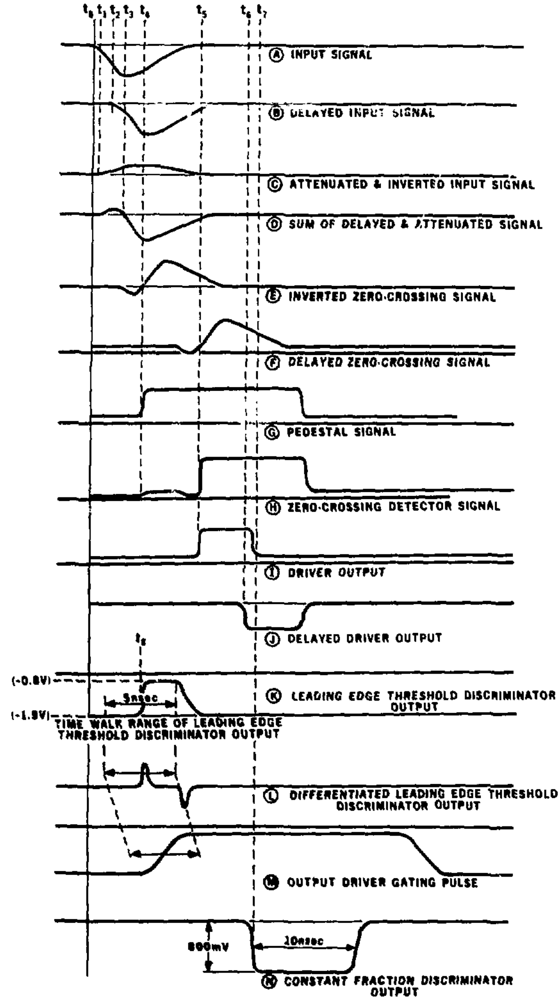


FIG. 1

XBL 758-1922



XBL 738-1971

FIG. 1A

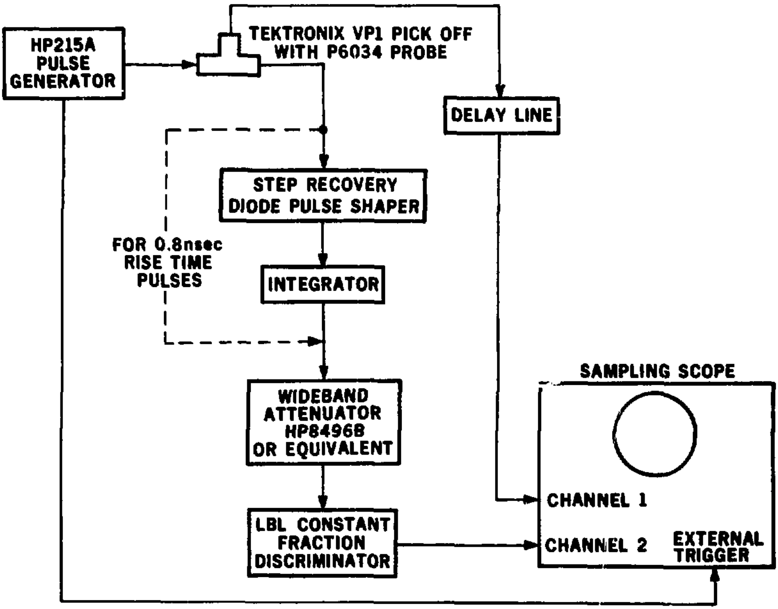
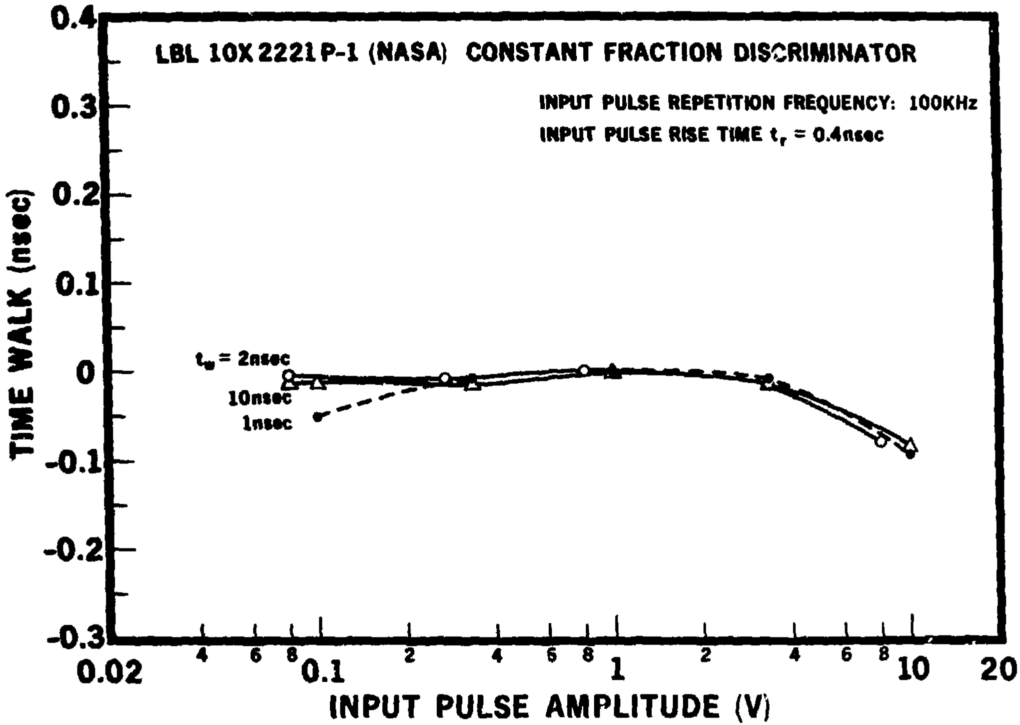
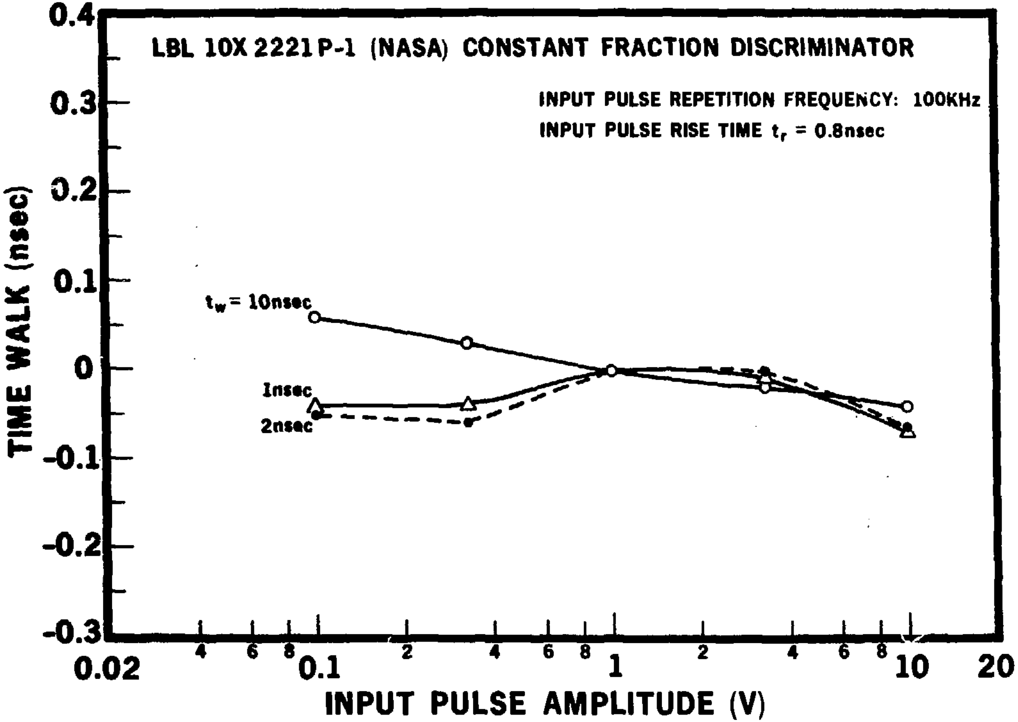

HP215A
PULSE
GENERATOR
TEKTRONIX VP1 PICK OFF
WITH P6034 PROBE
DELAY LINE
STEP RECOVERY
DIODE PULSE SHAPER
FOR 0.8nsec
RISE TIME
PULSES
INTEGRATOR
WIDEBAND
ATTENUATOR
HP8496B
OR EQUIVALENT
LBL CONSTANT
FRACTION
DISCRIMINATOR
SAMPLING SCOPE
CHANNEL 1
CHANNEL 2
EXTERNAL
TRIGGER

FIG. 2



XBL 758-1968

FIG. 3



XBL 758-1969

FIG. 4

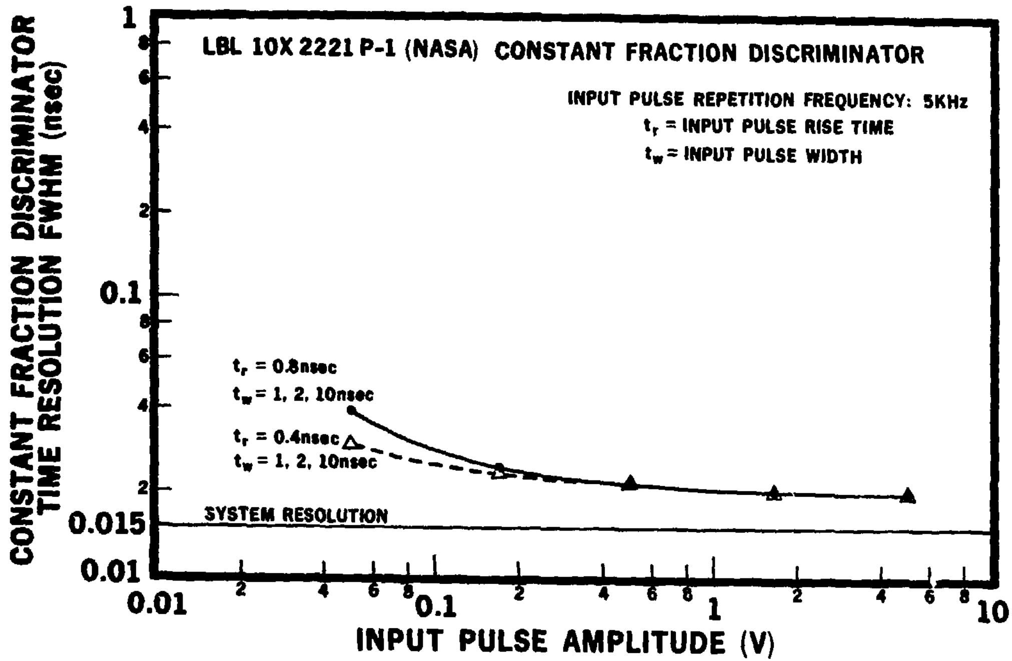

LBL 10X 2221 P-1 (NASA) CONSTANT FRACTION DISCRIMINATOR
INPUT PULSE REPETITION FREQUENCY: 5KHz
t_r = INPUT PULSE RISE TIME
t_w = INPUT PULSE WIDTH
t_r = 0.8nsec
t_w = 1, 2, 10nsec
t_r = 0.4nsec
t_w = 1, 2, 10nsec
SYSTEM RESOLUTION
CONSTANT FRACTION DISCRIMINATOR
TIME RESOLUTION FWHM (nsec)
INPUT PULSE AMPLITUDE (V)
1
0.1
0.015
0.01
10

FIG. 5

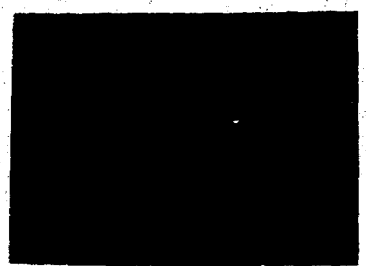


FIG. 6

XBB 758-6287

FIG. 7

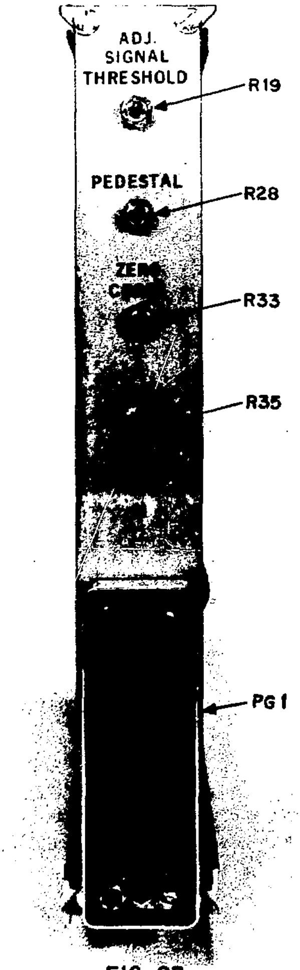


FIG. 8B

XBB 758-5969A

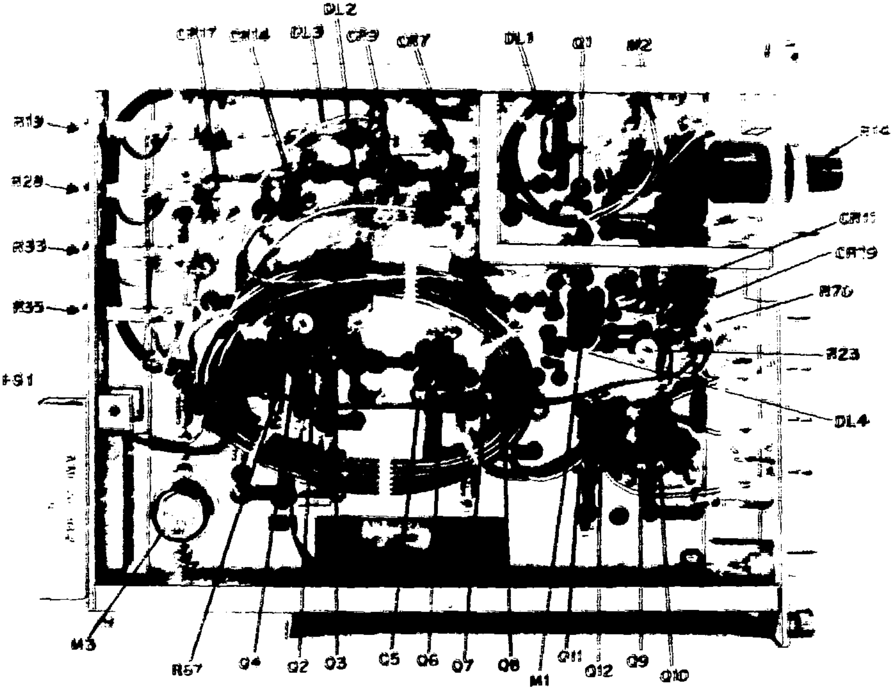


FIG. 9

XEB 758-5971A

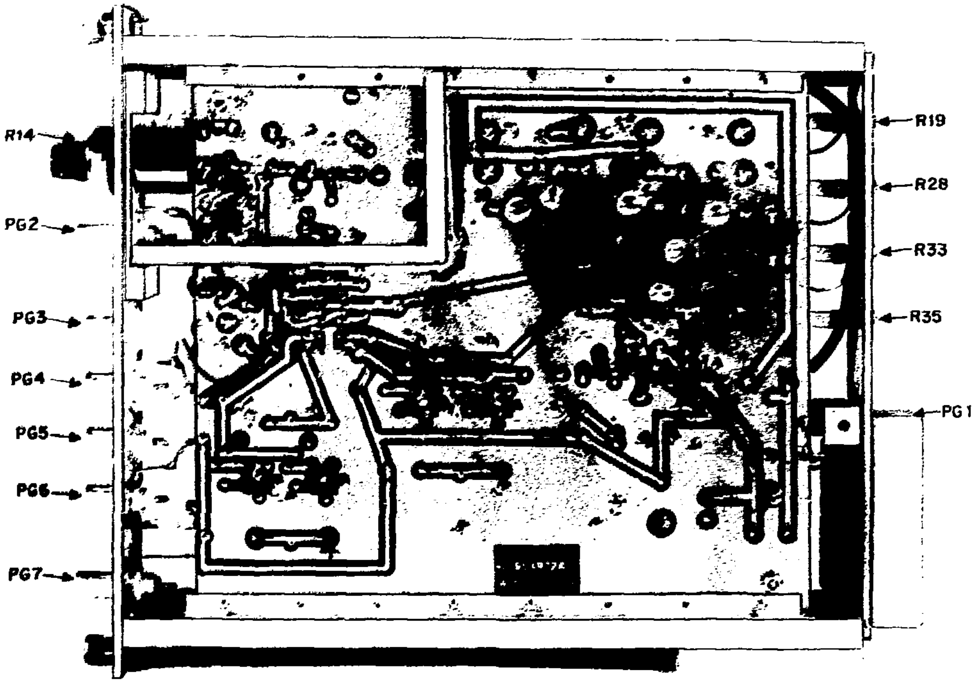


FIG. 10

XBB 758-5972A