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**Evaluation of Fast Voltage Discriminators
in the Picosecond Time Range**

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EVALUATION OF FAST VOLTAGE DISCRIMINATORS IN THE PICOSECOND TIME RANGE

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ABSTRACT

An automated system for the evaluation of fast risetime voltage discriminators is described. A high-performance time digitizer is used to determine the elapsed time between the generation of a test pulse and the response of the discriminator under test. The measurement is repeated for a series of discriminator threshold levels generated by a digital-to-analog converter and the results compared to a photograph of the leading edge of the pulse obtained with a sampling oscilloscope. To obtain high accuracy, an average of several thousand individual digitizations is used in each measurement to reduce the uncertainty to a maximum of ± 3 ps. The measurement system is used with a test fixture to evaluate the performance of a number of tunnel diodes and in preliminary measurements of a prototype discriminator of new design.

INTRODUCTION

In the design of a properly functioning voltage discriminator, three key components must be considered. These are the input pulse driver amplifier, the nonlinear threshold detection device and the threshold sensing amplifier and output circuitry. For the adequate discrimination of nanosecond and sub-nanosecond risetime pulses, tunnel diodes have proved themselves to be reliable threshold detection devices. The tunnel diode is essentially a current sensing device. When the input current to the diode exceeds a certain threshold, it exhibits a negative resistance and an abrupt transition to a higher voltage state. This voltage transition can then be detected by the output amplifier and converted to a suitable output pulse. To set the operating threshold of the discriminator, a current source is used to bias the tunnel diode at an appropriate level.

The input amplifier must match the impedance of the input pulse transmission line and convert the voltage pulse into a current prior to injecting it into the tunnel diode circuit. It must, of course, have sufficient bandwidth and slewing capability to avoid distortion of the input pulse. In addition, in many applications, it must also provide sufficient isolation to prevent the tunnel diode from kicking back a distorting signal into the input line when it fires. This capability is particularly important if a number of similar discriminators are to be used in parallel to detect a given pulse with different threshold levels. Finally the input amplifier must be adequately protected against burnout or deterioration when subjected to large amplitude pulses.

The firing time of the tunnel diode is affected by a number of considerations including its current dependant resistance and capacitance resulting in a variable transition time constant prior to firing. It also exhibits a finite transition time through its negative resistance region. Both of these effects can be influenced by the pulse amplitude and slope at the time of firing if not properly controlled by the circuitry. These and similar effects in the output amplifier circuit can lead to distortion of the measured transition time.

Because of the many potential contributors to the distortion of the discriminated pulse, it is essential to provide a means for accurately measuring the performance of the discriminator under development. Such a test system must permit a rapid measurement of the discriminator response over a wide range of threshold levels with the measured results being immediately

available to the circuit developer in graphical or digital form. In order to permit evaluation under short risetime pulse conditions, the testing system must have a time resolution and accuracy of a few picoseconds. The system described below goes a long way towards meeting these requirements.

MEASUREMENT SYSTEM

A block diagram of the discriminator test system used is shown in Fig. 1. The major components include a precision time digitizer, an LBL built instrument¹ with a 24 bit resolution in which the LSB corresponds to 78.125 ps, a Kinetic Systems model 3112 12-bit digital-to-analog converter and two pulse generators. These components are mounted in a CAMAC crate and controlled by an IBM PC/XT computer via a DSP Technology model 6001 crate controller. A Picosecond Pulse Laboratories model 4000 pulse generator is used to produce fast (120 ps) risetime pulses. To generate slower pulses with variable risetimes, a Hewlett Packard model 8082A generator is employed. A Tektronix sampling oscilloscope serves to provide direct observation of the pulse waveforms.

Fig. 1. Block diagram of test system.

The time digitizer measures precisely the time interval between two pulses called the start pulse and the stop pulse. To avoid the possibility of jitter between the start and stop pulses, both are derived from the same generator output port. In the case of the picosecond pulse generator, a 6dB power splitter is used to divide the pulse output into two channels. One of these is attenuated by 20 dB and passed through an inverting pulse transformer to generate a NIM pulse waveform serving as the digitizer start pulse. The other is attenuated to a desired value by two precision 10 dB attenuators and is used as an input pulse to the discriminator under test. To avoid distorting the pulse, wideband (12 GHz) components and high quality coaxial lines are used. In the case of the Hewlett Packard generator, the requirements are less stringent. The normal output of this

generator is attenuated to produce a test signal and the complementary (inverted) output is level shifted by a capacitor to create a NIM level start pulse.

The discriminators currently being tested produce output pulses which vary slightly in width depending on the threshold level. To eliminate possible time shifts from this effect, the discriminator output is passed through a Chronetics model 151 leading edge discriminator before being used as a stop pulse. A fixed delay of 120 ns is used in the stop input line to ensure that the digitizer start circuitry is fully settled before the stop is applied. It should be pointed out that extreme care is required to ensure that the ± 3 ps measurement capability of the system is preserved by all components. Even the slight flexing of a coaxial line can easily produce changes of this magnitude.

Software to control the operation of the test system was written in the language C and is an adaptation of an earlier system previously developed² for the testing of time digitizers. The operator is provided with the capability of setting, via a parameter list, the voltage range to be swept by the system, the number of voltage steps, and the number of individual digitizations to be averaged for each step. Provision is also made for setting the digital-to-analog converter voltage to any desired value under keyboard control. After the data is acquired, the resulting voltage and averaged time sequence is plotted on the computer monitor and can be stored in a file for archiving and further analysis.

MEASUREMENT PROCEDURE

In order to measure the performance of a test discriminator, the unit under test is installed in the test circuit as described above. With the digital-to-analog voltage set equal to zero, the threshold control of the discriminator is set to a level to permit the discriminator just to fire. The program is then instructed to set the DAC to various voltages over a preselected range and to measure the corresponding firing times of the discriminator. Typically, a series of 2000 time interval measurements is averaged for each setting of the DAC. The results are then stored on the disk and plotted for further analysis.

The stability of the time interval measurements is demonstrated in Fig. 2 where the discriminator has been replaced by a second inverting transformer connected to the stop input of the time digitizer. For each of the data points shown in the figure, 2000 individual measurements were averaged. In the individual time measurements making up the average, a spread of about 4 channels is found. Thus the uncertainty of a single measurement is on the order of 300 ps but, with averaging, this is reduced to about ± 3 ps.

Fig. 2. Time interval measurement uncertainty for averages of 2000 samples each.

TUNNEL DIODE MEASUREMENTS

The bandwidth and driving characteristics of the discriminator input amplifier can significantly affect the response of the discriminator system to an input pulse. To better evaluate the performance of the tunnel diode alone, we have constructed the special test circuit shown in Fig. 3 in which the input amplifier is eliminated. In this arrangement, the coaxial line from the input pulse is carefully terminated with 50 ohms and the pulse current applied to the tunnel diode through a moderately large resistance of 1000 ohms. The diode output is then coupled to the output sensing amplifier through a small (4 turns 2 mm dia.) choke to provide additional isolation. The sensing amplifier (Q2, Q3 and Q4) is adjusted to trigger at a point in the voltage switching range of the tunnel diode. A fast leading edge discriminator is used to condition the pulse output of the sensing amplifier to present a NIM pulse of constant width to the stop input of the time digitizer.

Fig. 3. Schematic diagram of tunnel diode test circuit.

Five different tunnel diodes were tested with this circuit. In all measurements the model 4000 picosecond pulse generator was used, and each diode was measured with at least three different pulse amplitudes selected (at 2 dB intervals) with the 12 GHz precision attenuator. The diodes tested included a Custom Components Inc. model 151050G, 10 mA diode, a Germanium Power Devices Corp. 10 ma diode, and three General Electric Inc. diodes operating at 5, 10 and 22 ma. All of the diodes tested exhibited similar risetimes with the exception of the Germanium Power Devices unit which was dramatically slower, due, apparently to a larger device capacitance.

The results of a typical series of measurements is shown in Fig. 4 for the Custom Components model 151050G, 10 mA diode with the input pulse attenuated by 1, 3, 5, 7 and 9 dB. When the data is normalized by scaling all the amplitudes to 0 dB, good agreement in the amplitudes of the top of the pulses is obtained, but at low threshold levels the data exhibits a negative time shift of about 20 ps for each 2 dB increase in the pulse power. This shift is apparently due to pulse overdrive, i.e. amplitude dependent differences in the time required for the pulse to charge the device up to the threshold level and for the sensing amplifier to fire.

In Fig. 5 the response of four of the diodes tested is shown for an input pulse attenuation of 3 dB. The time origin of each of the curves has been arbitrarily adjusted to facilitate their presentation on a single graph. Of the four diodes, the Custom Components and General Electric 10 mA devices appear to have the fastest response.

Fig. 4. Firing time measurements of Custom Components model 151050G, 10 mA diode for (a) 1 dB, (b) 3 dB, (c) 5 dB, (d) 7 dB and (e) 9 dB input pulse attenuation.

Fig. 5. Comparison of measured firing times of four different tunnel diodes for 3 dB input pulse attenuation.

Fig. 6. Oscilloscope photographs of Picosecond Pulse Laboratories generator output for (a) 50 ps/div and (b) 200 ps/div.

Figure 6 illustrates the shape of the pulse produced by the model 4000 generator as recorded by the Tektronix oscilloscope. As shown, the 10 to 90% risetime of the pulse is about 120 ps, although the pulse exhibits significantly slower components near its maximum value. By way of comparison, the faster of the diodes tested show risetimes of about 140 ps when installed in the test circuit. Thus moderately good agreement between the actual pulse and the detected pulse envelope is obtained.

PROTOTYPE DISCRIMINATOR MEASUREMENTS

The circuit of the test discriminator is shown in Fig. 7. In this version, the sensing amplifier and bias circuitry are identical to that employed in the diode test fixture of Fig. 3. A single transistor stage operated in a grounded base configuration for maximum bandwidth is used as a pulse amplifier. The amplifier is a.c. coupled to the tunnel diode (Custom Components, 10 mA) to avoid the introduction of additional drifts in the threshold level.

Fig. 7. Schematic diagram of prototype discriminator.

The discriminator was tested using the model 4000 pulse generator in a series of measurements with amplitudes attenuated by 1, 3, 5, 7, and 9 dB. The results are shown in Fig. 8, curves (a) through (e). The data is normalized to 0 dB in (f). The observed risetime is about 200 ps, a measurement which includes effects due to the input and sensing amplifiers and the tunnel diode. As in the case of Fig. 4, good agreement is obtained at the top of the pulse where the circuitry has had sufficient time to respond completely to the pulse. However, near the bottom of the pulse, there is a noticeable shift in the firing time of the discriminator approximately 30 ps per 2 dB change in amplitudes. This is due to charging delays in the circuit resulting from pulse overdrive.

Fig. 8. Test measurements of discriminator performance for 120 ps input pulses. (a) through (e), input pulse attenuation of 1, 3, 5, 7 and 9 dB and (f), data normalized to input pulse attenuation of 0 dB.

Finally, Fig. 9 shows a series of measurements for pulses of 3 ns risetime having amplitudes attenuated by 1, 3, 5, 7, and 9 dB. An oscilloscope photograph of the actual input pulse is also shown in the figure. The linearity of this series of measurements is illustrated in curve (f) in which all of the pulse amplitudes are normalized to 0 dB and superimposed. As shown, excellent agreement among the various measurements is obtained.

Fig. 9. Test measurements of discriminator performance for 3 ns input pulses. (a) through (e), input pulse attenuation of 1, 3, 5, 7 and 9 dB and (f), data normalized to input pulse attenuation of 0 dB. Inset, photograph of input pulse.

SUMMARY

An automated system for evaluating the performance of high speed voltage discriminators has been developed. With this system, the threshold profile of the discriminator under test can be measured with an uncertainty of about 3 ps. We have demonstrated the applicability of the instrument to the testing of tunnel diodes for discriminator use and to the evaluation of a complete discriminator of preliminary design. At present the prototype discriminator exhibits a time walk of about 15 ps per dB change of input pulse amplitude and work is underway to evaluate and minimize this effect.

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