PRECISION PULSE-TIMING INSTRUMENTATION FOR ULTRASONIC NONDESTRUCTIVE TESTING

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1. Discriminator specifications
2. B-scan time-to-pulse-height converter specifications
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A new, pulse-timing discriminator and B-scan time-to-pulse-height converter have been developed for the inspection of production parts. The discriminator is easy to operate and features automatic echo gating and automatic pulse polarity discrimination. This instrument combines the noise-blanking advantages of threshold discrimination with the echo-timing precision of zero-crossing discrimination to improve measurement accuracy by a factor of two over the best previous techniques. When used with the discriminator, the B-scan unit allows detection of flaws at depths less than one-fourth those obtainable with commercially available instruments.

INTRODUCTION

There is a need for a high-speed, precision-timing instrument for ultrasonic inspection of precision parts. Commercially available instruments are too slow to obtain the desired measurement accuracy and require substantial operator skill. The many interconnections on commercial units also limit accuracy, because high-speed pulse-timing measurements are very sensitive to cable length (i.e., a 20-cm difference in cable length will cause a timing error of 1 ns). Thus, fast, self-contained instrumentation that is easy to use is needed for the inspection of production parts.

PULSE DISCRIMINATION

ULTRASONIC NONDESTRUCTIVE TESTING

Ultrasonic sound can be used to detect flaws or measure thickness by reflections of sound waves from defects and surfaces. In a conventional pulse-echo gauge, an ultrasonic transducer is excited by a high-voltage pulse. This pulse causes the resonant crystal transducer to vibrate, thereby generating the ultrasonic pulse. This pulse travels through water to the specimen as illustrated in Fig. 1. Every time the pulse encounters a change in material, such as a surface or a flaw, part of the pulse is reflected. The first reflected pulses from the front and rear surfaces are called the first and second echoes, respectively. These echoes are intercepted by the transducer, which converts them into low-voltage signals. The transducer is connected to a receiver amplifier to increase the amplitude of the echo signals. The time delay between first and second echoes for the pulse-echo technique is

\[ T_{pe} = \frac{2D}{v} \]  

(1)
where $D$ and $v$ represent thickness or flaw depth and material sound velocity, respectively. Other transducer configurations are discussed in Ref. 1.

Fig. 1. Pulse-echo thickness gauge.

PULSE DISCRIMINATION

Precise measurement of time delays between ultrasonic pulses is complicated by different amplitudes of echoes. Figure 2 (curve A) shows the echo waveform of a pulse-echo gauge for a 3-mm-thick steel plate. Note that the first echo is so much larger in amplitude
than the other echoes that it overloads the receiver amplifier. Timing of these pulses to 0.5 ns is made more difficult by the long rise times (approximately 50 ns) of the 5-MHZ pulses.

A zero-crossing discriminator has low sensitivity to pulse height and shape. A noise-blanking, zero-crossing discriminator was reported in which a threshold discriminator enabled 0a zero-crossing. Hence, the zero-crossing detector operates only for signals above threshold; thus, noise will not cause false triggering.

Fig. 2. Waveforms for a 3-mm steel sample (vertical scale is uncalibrated).
An improved noise-blanking, zero-crossing discriminator with automatic echo gating has been developed. In the circuit shown in Fig. 3, the output of comparator U1A goes low when the ultrasonic waveform (Fig. 4, curve A) falls below the negative threshold set by a potentiometer. This output is shaped and stretched by retriggerable monostable multivibrator U3A (Fig. 4, curve B). The output of this comparator (Q_{III}) shown in Fig. 4 (curve C) goes from low to high when the ultrasonic signal crosses zero in a positive direction. The output of NAND gate U12 (Q_{12}), represented by curve D of Fig. 4, goes low when Q_{III} goes high, provided the stretched signal (Q_{IIA}) is high. Q_{12} pulse widths are stretched by a retriggerable monostable multivibrator so that, if an ultrasonic input pulse has several cycles of ringing, the discriminator output can be one long pulse instead of several pulses.

Fig. 3. Block diagram of noise-blanking discriminator.

The highest frequency at which the basic discriminator (Fig. 3) can properly operate in a noise-blanking, zero-crossing mode is limited by propagation delays in devices U1A, U1B, and U3A. For instance, if an ultrasonic input (Fig. 4, curve A) just barely crosses the threshold, then U1A will begin to switch states at the waveform peak. If there were no propagation delay, Q_{IIA} would go high at this point, thereby enabling Q_{III} to trigger U12 on the next zero crossing (Fig. 4, curves B, C, and D). But if propagation delay through U1A and U3A is $T_A$ and propagation delay through U1B is $T_B$, then Q_{IIA} and Q_{III} are delayed by
Fig. 4. Discriminator waveforms showing effects of propagation delays.
T₃ and T₁, respectively, as depicted in curves E and F of Fig. 4. If the difference in time delays between Q₃A and Q₁B (T₃ - T₁) is greater than a quarter period of the ultrasonic signal, Q₃A can arrive at U12 after Q₁B. When this happens, Q occurs with the threshold signal Q₃A instead of zero-crossing signal Q₁B as shown in curve G of Fig. 4 (NAND gate propagation delay is neglected). For the zero-crossing discriminator to function properly,

\[ T_{TZ} > T₃ - T₁ \]  

(2)

where T₄₇ is the time between points where the ultrasonic waveform crosses the threshold and the following zero crossing. Thus, T₄₇ is greater than \( \frac{1}{4v} \) and less than \( \frac{1}{2v} \), where v is the oscillation frequency of the ultrasonic signal. The worst case condition may be used to estimate the maximum frequency of operation as

\[ v_{max} = \frac{1}{4(T₃ - T₁)} \]  

(3)

A typical value for T₃ - T₁ of 20 ns gives a v_{max} of 12.5 MHz.

The circuit pictured in Fig. 5 substantially increases v_{max}. In this circuit, an extra delay U₃B is used to delay Q₁B by T. Thus, the propagation delay of the zero-crossing signal up to the input of U12 is T₁ + T. If T is adjusted so that

\[ T₃ = T₁ + T \]  

(4)

as shown by curves E, H, and I in Fig. 4, then operation frequency is not limited by propagation delays. U₃B may be realized by a cable (approximately 5 ns/m delay), a delay line, or another monostable multivibrator. The latter choice is particularly attractive if a dual integrated comparator such as the NE521 is used for U1A and U1B, and a dual integrated monostable multivibrator such as the AM26S02 is used for U3A and U3B. Because dual devices have well-matched characteristics, Eq. (4) is approximately satisfied. Furthermore, NAND gate U12 can be represented by two monostable multivibrator inputs.

The maximum frequency is also limited by the minimum trigger pulse width of the monostable multivibrator. At best, the comparator output pulse width is half the period of v_{max}. Assuming a minimum trigger pulse width of 8 ns, v_{max} is 62.5 MHz. As the RF signal amplitude is reduced toward threshold level, the output pulse width of the threshold comparator will decrease; therefore, v_{max} will decrease.

![Fig. 5. Delay compensation for discriminator.](image-url)
Still another limiting factor in the maximum frequency of the zero-crossing discrimination is the comparator risetime. The minimum signal amplitude required to cause the comparator to switch states increases at high frequencies. This minimum signal requirement behaves in a similar fashion to threshold discrimination with the threshold set to the minimum amplitude. The risetime indicates the bandwidth of the comparator. The bandwidth is approximately

\[
\text{BW} \approx \frac{0.35}{T_r}
\]  

(5)

Using a risetime of 2.5 ns with a 5-mV input step for the NE521 comparator, the bandwidth is 140 MHz. The minimum required input amplitude is

\[
A_{\text{min}} \approx \frac{5v}{\text{BW}} \approx \frac{5T_v}{0.35}
\]  

(6)

in units of mV peak.

Thus, the minimum required amplitude for a 14-MHz signal is 0.5 mV.

**AUTOMATIC PULSE POLARITY**

A means of selecting discrimination polarity was developed because ultrasonic echoes may be of either or both polarities. For instance, curve A in Fig. 2 has a positive front-surface echo but has negative rear-surface echoes. A polarity selection circuit is shown in Fig. 6. Positive outputs of positive and negative pulse discriminators are connected to NAND gates U5B and U5A, respectively. Zero-crossing outputs are utilized for thickness measurements, but threshold outputs are used for flaw detection to allow shorter output pulse widths without multiple pulses. U5B and U5A function as inverters if switches S7 and S8 are in the "ON" position. However, if S7 or S8 is in the "OFF" position, then the outputs of U5B or U5A will remain high. Therefore, if only S8 is on, then U5C acts as an inverter for the output of U5A; however, if both switches are on, then the output pulse of U5C will occur with the first input pulse, as illustrated in Fig. 7.

**AUTOMATIC ECHO GATING**

An automatic echo gating circuit was developed to provide separate outputs for any three consecutive echoes (Fig. 6). Any two gated echoes may be used to start and stop a timer to measure time between echoes. Three flip-flops (U7A, U7B, and U8A) and a monostable multivibrator (U11) are incorporated in the gating circuitry. In operation, a pulse which is synchronized with the transducer excitation pulse is applied to Trigger In to generate a blanking delay pulse, as depicted in Fig. 2, curve B. The time delay between trigger pulse and the blanking delay pulse is controlled by a potentiometer. (In the actual circuit, an additional monostable multivibrator is used to increase the adjustment range of the pulse.) The main purpose of the delay pulse is to reset the "flip flops" to zero. On the first discriminator output pulse after the delay pulse, the output of flip-flop 1 (Echo 1) goes high (Fig. 2, curve C). Then, on the second discriminator output pulse after the delay pulse, the output of flip-flop 2 (Echo 2) goes high (Fig. 2, curve D). Finally, Echo 3 goes high on
Fig. 6 Automatic Waveform Timing Circuit.
the third discriminator output pulse after the delay pulse. (In the actual circuit, a fourth flip-flop with an Echo 4 output is included.) Note that curves C and D show Echo 1 and Echo 2 after being processed by monostable multivibrators to shorten pulse widths. Only the positive pulse discriminator was used in Fig. 2.

The minimum spacing between the echo gating pulses is determined by the flip-flops and monostable multivibrators. The minimum one-shot pulse width is 40 ns, while the minimum negative pulse width for the flip-flop clock is 16 ns. Therefore, the latest clock will have a 40-ns positive pulse width of 40 ns and a negative pulse width of 16 ns. Hence, the minimum echo spacing is 56 ns.
SHEAR-WAVE TESTING

When conducting ultrasonic shear-wave experiments, the angle of incidence (θ₁) is adjusted so that the refracted angle (θ₂) is 45° ± 5°, as pictured in Fig. 8. The transducer is placed far enough away from the specimen so that it does not intercept the normal-wave front-surface and rear-surface echoes. The shear wave reflects off the rear surface and is scattered or reflected by flaws. A portion of the scattered or reflected shear wave is refracted at the specimen’s front surface and received by the transducer.

Because the transducer does not receive the front surface echo, a dummy front surface pulse (Fig. 9, curve C) is provided. This pulse is generated by the monostable multivibrator U6B (Fig. 10) which is triggered on the trailing edge of the 5-μs-delayed pulse. A triple-input NAND gate, U5C in the pulse polarity selection circuit, combines the dummy front surface pulse with the discriminator outputs selected by switches S7 and S8.

Fig. 8. Shear-wave transducer configuration.
Fig. 9. Shear waveforms for 3-mm steel sample (vertical scale is uncalibrated).
RADIO FREQUENCY INPUT

POSITIVE-PULSE DISCRIMINATOR

NEGATIVE-PULSE DISCRIMINATOR

DELAYED BLANKING DELAY PULSE, IN

U6B MONOSTABLE

DUMMY FRONT SURFACE PULSE

LONGITUDINAL

Fig. 10. Dummy front-surface-pulse circuit.
FABRICATION AND RESULTS

A delay-compensated, noise-blanking pulse discriminator was constructed on a printed circuit board. Separated ground planes were used for analog and digital circuitry to minimize coupling of switching noise into the ground of the comparator circuit. The unit was constructed in a Tektronix TM500 series plug-in module, as shown in Figs. 11-13.

Preliminary tests of the discriminator showed excellent timing accuracy. Timing walk of the discriminator is shown in Fig. 14 for a 7-MHz transducer and a 10.9-mm-thick aluminum part. The transducer and part were submerged in water and adjusted so that the second echo was about 4 dB larger in amplitude than the third echo. Discriminator threshold was set at 49.5 mV, and the ultrasonic signal level was varied by an adjustable attenuator. For an ideal discriminator and a perfect attenuator (one that does not change waveform shape), the measured time between echoes would be independent of attenuation (i.e., the graph would be a horizontal straight line). The dashed curve shows that the measured time between second and third echoes for threshold discrimination varied +740 and +5860 ps as attenuation was adjusted from 2 to 11 dB and from 0 to 22 dB, respectively. The solid curve shows that measured echo time for noise-blanking, zero-crossing discrimination varied only +300 and +1860 ps as attenuation was adjusted from 2 to 8 dB and from 0 to 22 dB, respectively. Timing jitter for threshold and zero-crossing discrimination was typically 117 and 58 ps, respectively, over the full 22-dB range. Thus, zero-crossing discrimination is two to three times more accurate than threshold discrimination for this experiment.

The best results obtained in the zero-crossing mode were a timing walk and jitter of 200 and 30 ps, respectively, for a 30-dB attenuation range with a 5-MHz transducer. Timing measurements vary less than 100 ps with time. Comparing the new discriminator with the best previous method (the pulse superposition) shows an accuracy improvement of more than a factor of 2 and a substantial saving of time.

Results obtained depend on the RF waveform, particularly with threshold discrimination. Of particular importance is baseline flatness. Also, the first cycle of a given echo ideally should be larger than the next cycle of the same polarity to prevent the threshold detector from shifting cycles as the signal is attenuated. Proper grounding of the discriminator circuit is also very important. For example, the glitches (deviations from an ideal horizontal straight line) in the solid curve of Fig. 14 for attenuation above 8 dB are caused by switching noise coupled into the comparator circuit. The noise has since been reduced by using triaxial input cable where the inner shield is grounded only at the chassis BNC socket, while the outer shield is connected at both the BNC socket and the printed circuit board analog ground plane. A heavy copper braid connects the analog ground plane to BNC socket chassis ground. This improved shielding reduces glitches, as shown in Fig. 14 for the zero-crossing discriminator, by about 50%.
Fig. 11. B-scan and pulse discriminator modules.
Fig. 14. Discriminator-timing walk versus attenuation for 10.9-mm-thick aluminum with a 7-MHz ultrasonic waveform having an echo amplitude ratio of 4 dB.
INSTRUMENTATION

The discriminator has been combined with a new time-to-pulse-height converter to improve B-scan measurement accuracy (Fig. 15). In operation, a pulse, which is synchronized with the transducer excitation pulse, is applied to Trigger In to generate a pulse via monostable multivibrator U16A. This pulse closes a normally open CMOS switch, thereby discharging capacitor C to 0 V. Monostable multivibrator U16B generates a front surface Z-axis pulse (Fig. 16, curve E) on the trailing edge of the blanking delay pulse, while \(-V_c\) (Fig. 16, curve D) is still zero. Flip-flop outputs, ECHO 1 and ECHO 2, are applied to U12 and U11B to form a negative pulse at B1 (GATE) so that the voltage across C is a ramp. The GATE waveform is depicted as curve C in Fig. 16. At the end of pulse B1, C holds constant at

\[
V_c = \frac{\alpha(V_{cc} - 3V_{thr})T_{pe}}{3R_{20}C},
\]

where \(T_{pe}\) is the width of the GATE pulse, as given by Eq. (1), and \(\alpha\) is the common-base current gain of transistor Q3 (\(\alpha\) is slightly less than 1). Therefore,

\[
V_c = \frac{2\alpha(V_{cc} - 3V_{thr})D}{3R_{20}Cu}.
\]

Thus, \(V_c\) is proportional to flaw depth or part thickness \(D\) and inversely proportional to part sound velocity \(u\). The trailing edge of pulse B1 is delayed by monostable U16B to generate the rear-surface Z-axis pulse after B-Scan Out has settled to the value given in Eq. (8).

\[\text{V-Y GA 89-12751}\]

Fig. 15. Simplified circuit of B-scan time-to-pulse-height converter.
Fig. 16. B-scan waveforms (vertical scale is uncalibrated).
The scale factor is adjusted in two ways—amplification and capacitance. In the former method, two opamps (U12 and U14) invert and amplify \( V_x \), as depicted in Fig. 17. To minimize leakage currents at capacitor C, U12 acts as an impedance buffer. Opamp U14 also acts as a low pass filter; therefore, the B-scan waveform shown in Fig. 17 is delayed and rounded. Amplifier gain adjustment allows calibration of \( u \). In the latter technique, capacitor \( C \) is switched in a 10, 5, 2, 1 sequence to allow scale factor multiplication in a 1, 2, 5, 10 sequence.

The instrument features automatic blanking of the rear-surface Z-axis pulse when overload occurs. Overload can occur when an excessive scale factor is used or the rear-surface echo disappears. When \( V_c \) exceeds 7.5 V, the output of comparator U20 goes low. Similarly, when the amplified and inverted B-scan signal falls below an adjustable threshold, the output of comparator U19 goes low, and A is prohibited from triggering U16B; thus, no rear-surface Z-axis pulse is generated. A diode clamp (D2) prevents transistor Q3 from saturating to ensure quick recovery from overload.

**FABRICATION AND RESULTS**

The B-scan instrument was constructed on a printed circuit board and mounted in a Tektronix TM500 series plug-in module, as shown in Figs. 10, 17, 18, and 19. When compared with commercially available B-scan instruments, the new B-scan shows a large reduction in noise. Moreover, it is easier to operate, and it can automatically track irregular surfaces. Furthermore, it can accommodate a wide range of thicknesses and velocities. Linearity error is better than 30 \( \mu \)m in aluminum.

**CONCLUSIONS AND RECOMMENDATIONS**

Precision instrumentation has been developed for use in ultrasonic thickness gaging and flaw detection. The instrumentation includes a pulse discriminator, a B-scan instrument, an improved gated peak detector, and graphic displays. The discriminator features both threshold and zero-crossing detection with automatic echo gating and pulse polarity selection. The instrumentation can detect flaws close to the front surface (250 \( \mu \)m in aluminum). Ease of use results in less operator influence on accuracy and a substantial savings in time. Also, the instrumentation can be used in normal-wave or shear-wave experiments. The instrumentation can be used with display instruments discussed in Ref. 3 to obtain a pictorial display of flaws in parts. Specifications are listed in Tables 1 and 2.

The primary remaining limitations to high-frequency performance in the discriminator are the dual monostables U3 and U4 (Fig. 20, eng. drawing 12D-56519). When the monostable multivibrator input pulse width becomes less than 20 ns, the output pulse width may decrease. This condition can occur with ultrasonic signals above 12.5 MHz or at lower frequencies when the signal barely crosses the threshold. When the discriminator was originally designed, the fastest available monostable multivibrator IC, AM26S02, was used in this circuit. In the event that a faster monostable multivibrator with a compatible pin configuration becomes available, it is recommended that a trial substitution be made for U3 and U4.
Fig. 17. Complete circuit of B-scan time-to-pulse height converter.
Fig. 19. Right view of B-scan module.
### Table 1. Discriminator Specifications

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<tbody>
<tr>
<td>Zero-crossing timing errors*</td>
<td></td>
</tr>
<tr>
<td>Walk, 30-dB range</td>
<td>200 ps</td>
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<tr>
<td>Drift</td>
<td>100 ps</td>
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<tr>
<td>Jitter</td>
<td>30 ps</td>
</tr>
<tr>
<td>Threshold timing errors*</td>
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</tr>
<tr>
<td>Walk, 22-dB range</td>
<td>5860 ps</td>
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<tr>
<td>Jitter</td>
<td>120 ps</td>
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<td>RF input</td>
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<tr>
<td>Voltage range</td>
<td>+5V</td>
</tr>
<tr>
<td>X1 optimum frequency range</td>
<td>2 to 12.5 MHz</td>
</tr>
<tr>
<td>X1 maximum frequency</td>
<td>60 MHz</td>
</tr>
<tr>
<td>X10 frequency range</td>
<td>0.5 to 8 MHz</td>
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<tr>
<td>Trigger input</td>
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<td>Impedance</td>
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<td>Voltage level</td>
<td>TTL</td>
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<tr>
<td>Minimum pulse width</td>
<td>40 ns</td>
</tr>
<tr>
<td>Repetition rate range</td>
<td>0 to 200 kHz</td>
</tr>
<tr>
<td>Delay range</td>
<td>4.5 to 213 μsec</td>
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<tr>
<td>Power supply input</td>
<td></td>
</tr>
<tr>
<td>Positive voltage range</td>
<td>8 to 15 V</td>
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<tr>
<td>Negative power supply range</td>
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<tr>
<td>with Zener diode</td>
<td>-27 to -51 V</td>
</tr>
<tr>
<td>without Zener diode</td>
<td>-9 to -33 V</td>
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<tr>
<td>Discriminator outputs</td>
<td></td>
</tr>
<tr>
<td>X1 pulse widths</td>
<td>40 to 500 ns</td>
</tr>
<tr>
<td>X10 pulse widths</td>
<td>0.12 to 2 μsec</td>
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<tr>
<td>Voltage</td>
<td>TTL</td>
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<tr>
<td>Impedance</td>
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<tr>
<td>Echo outputs</td>
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<td>Pulse-width adjustment range</td>
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<td>Minimum spacing</td>
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<td>Voltage</td>
<td>TTL</td>
</tr>
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<td>Impedance</td>
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*Second and third echo of 7-MHz transducer with 10.9-mm-thick aluminum part, second echo 4 dB larger than third echo.
### Table 2. B-scan time-to-pulse-height converter specifications

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Specifications</th>
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<tr>
<td><strong>Power supply input</strong></td>
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<tr>
<td>High positive voltage range</td>
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</tr>
<tr>
<td>with Zener diode</td>
<td>27 to 44 V</td>
</tr>
<tr>
<td>without Zener diode</td>
<td>18 to 35 V</td>
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<tr>
<td>Low positive voltage range</td>
<td>8 to 15 V</td>
</tr>
<tr>
<td><strong>Negative power supply range</strong></td>
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</tr>
<tr>
<td>with Zener diode</td>
<td>-27 to -44 V</td>
</tr>
<tr>
<td>without Zener diode</td>
<td>-18 to -35 V</td>
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<td><strong>Time-to-voltage conversion</strong></td>
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<tr>
<td>Time range</td>
<td></td>
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<tr>
<td>X1 range</td>
<td>0.056 to 15 μsec</td>
</tr>
<tr>
<td>X2 range</td>
<td>0.056 to 7.5 μsec</td>
</tr>
<tr>
<td>X5 range</td>
<td>0.056 to 3 μsec</td>
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<tr>
<td>X10 range</td>
<td>0.056 to 1.5 μsec</td>
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<tr>
<td><strong>Conversion factor</strong></td>
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<td>X1 range</td>
<td>-0.1 to 2.1 V/μs</td>
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<tr>
<td>X2 range</td>
<td>-0.2 to 5.2 V/μs</td>
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<tr>
<td>X5 range</td>
<td>-0.5 to -10.5 V/μs</td>
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<tr>
<td>X10 range</td>
<td>-1 to -21 V/μs</td>
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<td><strong>Conversion nonlinearity</strong></td>
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<td><strong>B-scan output</strong></td>
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<td>Output impedance</td>
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<tr>
<td>Minimum load impedance</td>
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<tr>
<td><strong>Z-axis output</strong></td>
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<td>Voltage adjustment range</td>
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</tr>
<tr>
<td>Pulse-width adjustment range</td>
<td>0.5 to 4 μsec</td>
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<tr>
<td>Output impedance</td>
<td>&lt; 300 Ω</td>
</tr>
</tbody>
</table>
REFERENCES


APPENDIX A

INSTALLATION

PULSE DISCRIMINATOR

1. Plug the unit into a Tektronix TM500 series power supply.

WARNING

Pins 16A, 24A, 26A, and 28A are used by the unit and must not be connected to any other plug-in unit in the same power supply except the companion B-scan time-to-pulse-height converter. Only one discriminator unit should be used in each power supply unless care is taken to avoid connecting these pins.

2. Ventilation should be provided to the power supply to prevent excessive temperatures.

3. The RF and TRIG inputs have internal 50Ω terminations (R15 and R38). These may be changed or removed, if desired. R15 and R38 should match the impedance of the connecting cable. The trigger pulse may be input either at the front panel or at the edge connector pin 24A.

4. Output cables should be either 91Ω, 75Ω, or 50Ω impedance (91Ω preferred). The cables should be terminated with a matching load, as shown in Fig. A.1.

B-SCAN TIME-TO-PULSE-HEIGHT CONVERTER

1. Jumper together pins 16A, 24A, 26A, and 28A on at least two edge card connectors in a Tektronix TM500 power supply as depicted in Fig. A.2. Wires should be kept short.

2. Optional. Pins 18A, 22A, and 24A on at least one edge card connector can be jumpered to BNC connectors on the rear of the power supply. In this manner, B-SCAN output (pin 18), Z output (pin 22), and TRIG IN (pin 24) will be accessible at the rear of the power supply. Thus, front panel cable clutter can be reduced.
Fig. A.1. Precision thickness gauge wiring diagram.
Fig. A.2. Wiring diagram for Tektronix TM500 backplane.
3. Plug the unit into a Tektronix TM500 series power supply.

**WARNING**

Pins 16A, 18A, 22A, 24A, 26A, and 28A are used by the unit and must not be connected to any other plug-in unit in the same power supply except the companion NOISE-BLANKING PULSE DISCRIMINATOR. Only one B-scan module should be used in each power supply unless care is taken to avoid interconnecting these pins.

4. Plug a NOISE-BLANKING PULSE DISCRIMINATOR into the power supply.

5. Connect as shown in Fig. A.1.
APPENDIX B

OPERATION PROCEDURE

PULSE DISCRIMINATOR

NOTE

The locations of side panel adjustments for the discriminator are shown in Fig. B.1.

1. Install unit as per installation instructions in Appendix A.

2. Select mode of discrimination via +THRES/+ZERO and -THRES/-ZERO switches on the side panel. Generally, zero-crossing discrimination is recommended for applications where echo timing accuracy is important (i.e., thickness gauging, time-of-flight, etc.). Threshold discrimination may give better results for ultrasonic flaw detection (B-scan) because the discriminator pulse widths are narrower. These switches determine the type of discriminating used with the automatic echo gating outputs (ECHO 1, ECHO 2, and ECHO 3), but they have no effect on the discriminator monitor outputs (+THRES, +ZERO, -THRES, and -ZERO).

WARNING

When the discriminator is used with the companion B-scan instrument, loading ECHO 2 may cause a malfunction of the B-scan. Therefore, it is recommended that external cables attached to ECHO 2 be removed (except for temporary monitoring during experimental set up) when using the B-scan module.

3. Select discriminator polarity to be used with the automatic echo-gating outputs via the +DISC and -DISC switches (front panel). If echo timing accuracy is important, the discriminator polarity should be the same as the first lobe of the two echoes of interest. If these two echoes are of opposite polarity, then both the +DISC and -DISC switches should be "on." In this mode, the discriminator automatically selects the proper discriminator polarity. Again, these switches have no effect on the discriminator monitor outputs (+THRES, +ZERO, -THRES, and -ZERO).

4. Select normal (LONG) mode with LONG/SHEAR switch (front panel), if ECHO 1 is to be timed from a RF input pulse (as in ultrasonic longitudinal waves) or SHEAR mode if ECHO 1 is to be timed from an internally generated pulse (as in ultrasonic shear waves). The first two prototypes not have a SHEAR mode.

5. Adjust +THRES dial and/or -THRES dial (front panel) to the lowest setting that gives reliable triggering of each echo of interest if +DISC is "on" and/or -DISC switch is "on." To obtain high-precision discrimination over the widest possible range of pulse heights without readjusting THRES dials, adjust receiver damping so that the first lobe
Fig. B.1. Discriminator component assembly.
of each echo is greater than the third lobe (see Fig. 4). Adjust receiver high-pass filter for the flattest baseline. RF signal level should be as high as practical (within +5 V) without clipping in the receiver amplifier. If more than one pulse occurs per echo at the discriminator monitor outputs (+THRES, +ZERO, -THRES, and -ZERO) or if two echoes give only one pulse, then see Appendix C, Pulse Discriminator.

6. Adjust BLANKING DELAY screwdriver potentiometer (P5 front panel) so that BLANKING DELAY pulse ends before the first echo of interest. In LONG mode, ECHO 1 output will occur on the first echo after the blanking delay pulse. In SHEAR mode, ECHO 1 will occur 5 µs after the delay pulse unless an echo occurs within the 5-µs interval. (The first two prototypes do not have a SHEAR mode.) Thus, the dummy front-surface pulse may be adjusted via the delay pulse and monitored at ECHO 1. The BLANKING DELAY potentiometer adjusts the delay of the beginning of the delay pulse referred to the TRIG pulse. The adjustment range is approximately 1.5 to 30 µs from 3 to 60 µs if BLANKING DELAY RANGE MULTIPLIER switch (side panel) is in X1 or X2 position, respectively. The delay pulse width may be adjusted from 3 to 153 µs via the BLANKING DELAY ADDITION dip switch (side panel). This switch array is weighted in a binary sequence:

switch 1 = 10,
switch 2 = 20,
switch 3 = 40,
switch 4 = 80;
switch 5 = 10,
switch 6 = 20,
switch 7 = 40,
switch 8 = 80.

The array is divided into two groups: switches 1 through 4 and switches 5 through 8. The former group is active in the LONG mode while the latter group is active in the SHEAR mode. Within each group, the delay pulse width is determined by the sum of the weights plus 3, all in units of µs. For example, if 1 and 3 are on, then the delay pulse width is

\[(10 + 40 + 3)\mu s = 53\mu s\]

In this way, a blanking range after the TRIG pulse of 4.5 to 213 µs is obtainable. The dip switches work just like rocker switches (i.e., to turn it on, push down the side of the rocker nearest the side marked "on"). The red band of that rocker will then be visible on the side farthest from the side marked "on."
In this way, a blanking range after the TRIG pulse of 4.5 to 213 \(\mu s\) is obtainable. The dip switches work just like rocker switches (i.e., to turn it on, push down the side of the rocker nearest the side marked "on"). The red band of that rocker will then be visible on the side farthest from the side marked "on."

**B-SCAN TIME-TO-PULSE-HEIGHT CONVERTER**

**NOTE**

The locations of side panel adjustments for the B-scan unit are shown in Fig. B.2.

1. Adjust NOISE-BLANKING PULSE DISCRIMINATOR for the desired echoes at ECHO 1 and ECHO 2.

2. Select VEL1 or VEL2 sound velocity calibration (front panel). Velocity calibration pots (P6 and P7 on front panel) allow a time-to-pulse-height conversion gain to be adjusted from 0.1 to 21 V/\(\mu s\).

3. Select the velocity or gain multiplication factor by the RANGE switch (front panel). The velocity or gain can be multiplied by 1, 2, 5, or 10 with errors better than ±6.5%.

**NOTE**

The maximum time that can be converted linearly is the quotient of 7.5 \(\mu s\) divided by the multiplication factor. This may be increased by increasing C34, C35, C36, and C37, if desired.

4. Select Z-axis pulses via FS/RS SWITCH (front panel). In FS position, a Z-axis pulse will occur only on the front-surface portion of the B-scan. The B-scan signal is replaced by a dc voltage set by FS ADJ (P9, front panel). This mode is particularly useful when the rear surface echo is frequently lost, such as in shear wave experiments. In the center position (marked as "+"), a Z-axis pulse occurs on both front-surface and rear-surface portions of the B-scan. In RS position, Z-axis pulse occurs only on the surface.

5. The B-scan unit features an adjustable rear-surface blanking level adjusted by RS BLANK V2 (side panel). The rear-surface Z-axis pulse will disappear when the B-scan output exceeds this level. This is useful in tests when the rear-surface echo is lost. It can prevent multiple rear surfaces from appearing on the display.

6. For single shot applications, place the HOLD/NORMAL switch (front panel) in the HOLD position. The B-scan output will then hold its rear-surface value until the next trigger pulse. Therefore, a voltmeter can be used to measure the rear-surface value. Note that the voltage should be read immediately after the rear-surface echo occurs, because the B-scan output will drift slowly.
APPENDIX C

CALIBRATION PROCEDURE FOR PULSE DISCRIMINATOR

NOTE

All adjustments are accessible through the labeled side panel unless specified otherwise. All outputs are front panel BNC connections unless specified otherwise. The locations of side panel adjustments were shown previously in Fig. B.1.

ECHO OUTPUT PULSE WIDTHS

If desired, ECHO 1, ECHO 2, and ECHO 3 output pulse widths may be adjusted via ECHO 1 PULSE WIDTH ADJ (P7), ECHO 2 PULSE WIDTH ADJ (P8), and ECHO 3 PULSE WIDTH ADJ (P6). Clockwise rotation increases pulse width. The dip switches work just like rocker switches (i.e., to turn them on, push down the side of the rocker nearest the side marked "on"). The red band of that rocker will then be visible on the side farthest from the side marked "on."

BLANKING DELAY

The following procedure is optional.

1. Put LONG/SHEAR switch (front panel) in LONG position.

2. BLANKING DELAY ADDITION switches 4 and 8 should be on, while all the remaining switches should be off.

3. Adjust BLANKING DELAY ADDITION ADJ (P9) so that the BLANKING DELAY output pulse width is 83 ± 4 μs (clockwise increases).

4. Put LONG/SHEAR switch (front panel) in SHEAR POSITION.

5. Confirm that BLANKING DELAY output pulse width is 83 ± 4 μs. If not, readjust BLANKING DELAY ADDITION ADJ (P9).

NOTE

If BLANKING DELAY output pulse width changes more than 10% when LONG/SHEAR switch is changed from LONG to SHEAR position, a malfunction is indicated.
DISCRIMINATION

The following adjustments may be required if the transducer frequency is changed. Unless specified otherwise, all adjustments are accessible from the side of the discriminator. It is recommended that an extender board or cord be used during calibration. The PULSE WIDTH MULTIPLIER switches set the ranges of adjustment for the +THRES and +ZERO outputs to 0.12 to 2 μs in the X10 position and 40 ns to 500 ns in the X1 position. Use X1 for high-frequency transducers (> 2 MHz) and X10 for the low-frequency transducers (500 kHz to 8 MHz).

+Threshold Discriminator

Adjustment is unnecessary if only negative discrimination is to be used.

1. Adjust +THRES, then turn dial (P12 front panel) so that +THRES output is low (-0 V) for each echo of interest. Turn the dial clockwise to increase the threshold level (-0.5 V \times \text{number of turns}) to reduce noise sensitivity.

2. The pulse width of +THRES output should be adjusted via +THRES PULSE WIDTH ADJ (P4) so that only one negative pulse is obtained per echo. If the echoes of interest are spaced at least 2 ms or 200 ns apart for low-frequency or high-frequency transducers, respectively, then the pulse widths may be adjusted to maximum (15 turns clockwise) regardless of transducer frequency. But for closer echo spacing, reduce the pulse width (turn counterclockwise). The minimum usable pulse width equals the period of a transducer RF pulse.

-Zero Discriminator

Adjustment is unnecessary if only positive discrimination is to be used.

1. Adjust -THRES then turn dial (P13 front panel) so that -THRES output is low (-0 V) for each echo of interest. Turn the dial clockwise to increase the threshold level (-0.5 V \times \text{number of turns}) to reduce noise sensitivity.

2. The pulse widths of -THRES output should be adjusted via THRES PULSE WIDTH ADJ (P1) so that only one negative pulse is obtained per echo. If the echoes of interest are spaced at least 2 μs or 200 ns apart for low-frequency or high-frequency transducers, respectively, then the pulse widths may be adjusted to maximum (15 turns clockwise) regardless of transducer frequency. But for closer echo spacing, reduce the pulse width (turn counterclockwise). The minimum usable pulse width equals the period of transducer RF pulse.

+ Zero Discriminator

The following adjustments are necessary only if a positive zero discriminator is used. The positive threshold discriminator should be calibrated first.
1. Adjust +THRES, then turn dial (P12 front panel) so that +THRES output is low (-0 V) for each echo of interest. Turn the dial clockwise to increase the threshold level (~0.5 V \times \text{number of turns}) to reduce noise sensitivity.

2. The pulse width of +ZERO output should be adjusted via +ZERO PULSE WIDTH ADJ (P3) so that only one negative pulse is obtained per echo. If the echoes of interest are spaced at least 2 \mu s or 200 ns apart for low-frequency or high-frequency transducers, respectively, then the pulse widths may be adjusted to maximum (15 turns clockwise) regardless of transducer frequency. But for closer echo spacing, reduce the pulse width (turn counterclockwise). The minimum usable pulse width equals the period of a transducer RF pulse.

**-Zero Discriminator**

Adjustment is necessary only if negative zero discriminator is used. The negative threshold discriminator should be calibrated first.

1. Adjust -THRES, then turn dial (P13 front panel) so that -THRES output is low (-0 V) for each echo of interest. Turn the dial clockwise to increase the threshold level (~0.5 V \times \text{number of turns}) to reduce noise sensitivity.

2. The pulse width of -ZERO output should be adjusted via -ZERO PULSE WIDTH ADJ (P2) so that only one negative pulse is obtained per echo. If the echoes of interest are spaced at least 2 ms or 200 ns apart for low-frequency or high-frequency transducers, respectively, then the pulse widths may be adjusted to maximum (15 turns clockwise) regardless of transducer frequency. But for closer echo spacing, reduce the pulse width (turn counterclockwise). The minimum usable pulse width equals the period of a transducer RF pulse.

**DISCRIMINATOR WALK**

**NOTE**

The calibration may be performed with the LONG/SHEAR switch in either position. In shear mode, ECHO 1 will normally occur 5 ms after trailing edge of blanking delay pulse.

**+Discriminator**

1. Connect an ultrasonic echo signal as shown previously in Fig. A.1. Adjust pulser/receiver for ultrasonic echoes with a clean, flat baseline.

2. ECHO AND B-SCAN MODE toggle (side panel), +THRES/+ZERO, should be in the +ZERO position.

3. Turn +DISC toggle switch on (front panel) and -DISC toggle switch off (front panel).
4. Adjust Blanking Delay potentiometer (front panel, P5) so that the first echo of interest causes a negative output pulse at ECHO 1.

5. Use ECHO 1 and ECHO 2 outputs to stop and start timer.

6. Adjust +THRES dial (front panel) to the lowest level that will cause the timer to consistently read the correct time between consecutive echoes.

7. Reduce ultrasonic RF level via an attenuator.

8. Adjust +ZERO potentiometer (P11, front panel) to minimize discriminator walk (i.e., the change in time between ECHO 1 and ECHO 2 with RF level). If the time interval between ECHO 1 and ECHO 2 increases as the RF level decreases, turn +ZERO potentiometer clockwise.

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Discriminator

1. Connect an ultrasonic echo signal as shown previously in Fig. A.1. Adjust pulser/receiver for ultrasonic echoes with a clean, flat baseline.

2. ECHO and B-SCAN MODE toggle switch (side panel), -THRES/-ZERO, should be in the -ZERO positions.

3. Turn +DISC toggle switch off (front panel) and -DISC toggle switch on (front panel).

4. Adjust BLANKING DELAY potentiometer (front panel, P5) so that the first echo of interest causes a negative output pulse at ECHO 1.

5. Use ECHO 1 and ECHO 2 outputs to stop and start timer.

6. Adjust -THRES dial (front panel) to the lowest level that will cause the timer to consistently read the correct time between consecutive echoes.

**NOTE**

The -ZERO output can be used to monitor this. It is assumed that -THRES PULSE WIDTH ADJ and -ZERO PULSE WIDTH ADJ have been appropriately adjusted to yield one pulse per echo.

7. Reduce ultrasonic RF level via an attenuator.

8. Adjust -ZERO potentiometer (P10, front panel) to minimize discriminator walk (i.e., the change in time between ECHO 1 and ECHO 2 with RF level). If the time interval between ECHO 1 and ECHO 2 increases as the RF level decreases, turn -ZERO potentiometer clockwise.
APPENDIX D

CALIBRATION OF B-SCAN TIME-TO-PULSE-HEIGHT CONVERTER

NOTE

The locations of side panel adjustments were shown previously in Fig. B.2.

1. Adjust OFFSET (P8, front panel) so that front surface segment of B-SCAN output is at 0 V (or other level if desired). FS/RS switch should be in the "+" position.

2. Adjust FS ADJ (P9, front panel) so that the front surface segment of B-SCAN output does not change level when FS/RS switch is switched from FS to the "+" position.

NOTE

That FS ADJ can be used to intentionally shift the front surface segment of the B-SCAN output with FS/RS switch in FS position to compensate for errors in the B-SCAN rear-surface segment. This is accomplished by using a calibrated step wedge specimen. The B-SCAN time-to-pulse-height converter is either connected to a cathode ray tube (CRT) or a voltmeter (see single shot mode discussion of NORMAL/HOLD switch in step 6 of operating instructions). The best straight line fit to calibration data is used to find what the best voltage for the front surface should be. This is adjusted with FS ADJ. Then the FS/RS switch is used in the FS and RS positions to write the front surface and rear surface separately on the CRT.

3. The amplitude and pulse width of Z output can be adjusted as desired via the side panel adjustments labeled Z AMPLITUDE (P3) and Z PULSE WIDTH (P2), respectively. Normally, Z AMPLITUDE is adjusted for maximum output level (TTL level).
APPENDIX E

TROUBLESHOOTING PROCEDURE

Equipment suggested for troubleshooting includes a multimeter and a fast (200 MHz or higher bandwidth) oscilloscope with delayed sweep. Also, an ultrasonic transducer with pulser/receiver is needed. The cable connections for the discriminator and B-scan units were shown previously in Figs. A.1 and A.2.

Drawings are provided to assist troubleshooting the discriminator and B-scan time-to-pulse height converter. The discriminator circuit diagram was pictured previously in Fig. 20. Also, troubleshooting flow charts for the pulse discriminator are shown in Figs. E.1 through E.4. Next, Figs. E.5 through E.7 show timing waveforms for three positive pulse discrimination modes. The dashed line in the RF waveform is the threshold voltage. To obtain timing diagrams for negative discrimination modes from these figures, invert the RF waveform and threshold level. The circuit diagram of the B-scan time-to-pulse-height converter was shown previously in Fig. 17. For the B-scan time-to-pulse-height converter, Figs. E.8 through E.10 depict normal timing waveforms. Next, Figs. E.11 through E.13 illustrate timing waveforms for the B-scan time-to-pulse-height converter when special ultrasonic conditions arise. Note that the actual B-scan waveform (picted previously in Fig. 16) is delayed and smoothed due to a low pass filter in the output amplifier stage. The timing diagrams show the relative timing and wave shapes and are not drawn to any particular voltage or time scale. Pulse width ranges were shown previously in Tables 1 and 2.

With new units, a common problem in the pulse discriminator is that the 7906 voltage regulator is not electrically insulated from the chassis regulator. If the tab of this regulator is shorted to the chassis and power has been applied, both the regulator and the fuse in the -33 V circuit of the TM500 power supply will have to be replaced. Another common problem is that plated-through holes do not always make good electrical contact between both sides of the circuit board.

On discriminators built before 1988, a high power-line voltage or high ambient temperature will sometimes cause malfunction. This is usually caused by overloading the 7906 voltage regulator. To fix this problem, the circuit should be modified as described in Appendix E. Because it improves the performance, this modification is recommended for all early discriminators.
Figure E.1. Positive discriminator troubleshooting chart.
-ZERO DISCRIMINATOR TROUBLESHOOTING CHART

Fig. 13.2. Negative discriminator troubleshooting chart.
-THRESHOLD DISCRIMINATOR TROUBLESHOOTING CHART

Fig. E.2. Continued
Fig. E.3. Blanking delay troubleshooting chart.
Fig. E.4. Echo troubleshooting chart.
Fig. E.5. Discriminator timing diagram with +DISC switch on, -DISC switch off, +ZERO/+THRES switch in +ZERO position, and LONG/SHEAR switch in LONG position.
Fig. E.6. Discriminator timing diagram with =DISC switch on, -DISC switch off, +ZERO/+THRES switch in +ZERO position, and LONG/SHEAR switch in LONG position.
Fig. 12.7. Discriminator timing diagram with +DISC switch on, -DISC switch off, +ZERO/+THRES switch in +THRES position, and LONG/SHEAR switch in SHEAR position.
Fig. E.8. Normal B-scan timing diagram with FS/RS switch in "+" (center) position.
Fig. E.9. Normal B-scan timing diagram with FS/RS switch in RS position.
Fig. E.10. Normal B-scan timing diagram with FS/RS switch in FS position.
Fig. 1:11. B-scan timing diagram with rear surface overload, FS/RS switch in "+" (center) position.
Fig. E.12. B-scan timing diagram with no rear surface echo and FS/RS switch in "+" (center) position.
Fig. 13: B-scan timing diagram with no rear surface echo, no excitation pulse, and RS/RS switch in "t" (center) position.
APPENDIX F

MODIFICATIONS

NEGATIVE VOLTAGE REGULATORS

The only negative power supply in Tektronix TM500 backplane is -33 V. This unregulated supply is close to the maximum limit for the 7906 regulator. If the ac power line is greater than 120 V, then this negative supply can cause overheating or malfunction of the negative regulator. To prevent this from occurring, discriminators built before 1988 should add two 1-watt 9.1-V Zener diodes, D23 and D24 shown previously in Fig. 20, between -33 V (pin 8 on the edge connector) and the input pin of the negative regulator. These diodes are easily installed on the printed circuit board. Likewise, 1-watt 9.1-V Zener diodes (D9 and D10 shown previously in Figs. 17 and B.2) can be installed between 33 V (pin 12 on the edge connector) and the input on the 7815 regulator and -33 V (pin 8 on the edge connector) and the input on the 7915 regulator in the B-scan module, respectively. These improvements have been incorporated into the circuit boards on all new discriminators built after 1988.

B-SCAN BLANKING THRESHOLD

The B-scan instrument can readily be modified to allow separate adjustments of rear-surface blanking level for each of the two velocity calibrations, VEL1 and VEL2. This is accomplished by replacing the VEL1 and VEL2 switch (S3) with a DPDT switch. The jumper connecting P5 to ground is removed. The ground is connected to the wiper of the second pole. The VEL1 and VEL2 positions of the second pole are connected to P5 and P4 jumper points.

B-SCAN OFFSET RANGE

The offset range can be modified by changing the value of R31, shown previously in Fig. 17. For trimming the front-surface level to 0 V, the best value is 51.1 kΩ. For shifting the entire B-scan level, a value of 4.64 kΩ works well. Values less than 2 kΩ are not recommended, as they may impair the performance of the circuit or cause damage to the circuit.