TIME DOMAIN REFLECTOMETRY
application notes

TEKTRONIX®
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technical excellence

Number 1

PULSE ECHO TESTING OF ELECTRICAL TRANSMISSION LINES USING THE TEKTRONIX® TIME DOMAIN REFLECTOMETRY SLIDE RULE

INTRODUCTION

Most people who make quantitative reflectometry tests or measurements should find the TEKTRONIX TDR Slide Rule helpful. Those new to the subject will find the slide rule graphically summarizes a wealth of information on reflectometry. The illustrations, notes and instructions here should serve to clarify that information.

Section

1. VSWR versus Percent Reflected Voltage.
2. Return Loss, dB, versus Percent Reflected Voltage.
3. Percent Reflected Voltage or ρ versus Characteristic Line Impedance, Z_0, for either 50- or 75-Ω source.
4. Percent Reflected Voltage or ρ versus Load Resistance, R_L, for either 50- or 75-Ω source.
5. Z_0 or R_L versus Reflection Amplitude as seen on your Reflectometer.
6. Centimeters versus Inches, or Meters versus Feet.
7. Dielectric Constant versus Velocity Factor.
8. Time versus Short Distances, in Centimeters or Inches, any dielectric.
9. Time versus Long Distances, in Meters or Feet, any dielectric.
10. Distance versus Time seen on your Oscilloscope for cables with AIR, FOAM, TFE, or POLYethylene dielectrics.

TERMS AND SYMBOLS

R_S	is Source Resistance, of a signal generator
Z_S	is Source Impedance, of a signal generator
Z_0	is Characteristic Impedance, of a transmission line
Z_L	is Load Impedance, for a transmission line
R_L	is Load Resistance, for a transmission line
ρ	is Reflection Coefficient (rho), the ratio of incident to reflected voltage
mρ	is Reflection Coefficient divided by 1000 (milli-rho)
%	is Ratio of incident to reflected voltage times 100
VSWR	is Voltage Standing Wave Ratio (Peak-to-Valley ratio)
c	is Velocity of light in air
V_P	is Propagation Velocity of a signal in a transmission line
V_F	is Velocity Factor (fraction of velocity of light)
κ	is Dielectric Constant
D	is the outer diameter of the dielectric in a coaxial cable
d	is the diameter of the center conductor in a coaxial cable
L	is inductance in nanohenries per foot
C	is capacitance in picofarads per foot

RELATIONSHIPS

Z_0 = $(138/\sqrt{\kappa}) \times (\log_{10} D/d)$ for a coaxial cable

% = $\rho \times 100$

VSWR = $(1 + \rho) \div (1 - \rho)$ for the case where VSWR is the same for all frequencies

c = 30 cm per nanosecond = .984 feet per nanosecond

V_F = $1/\sqrt{\kappa}$

V_P = $30/\sqrt{\kappa}$ centimeters per nanosecond = $.984/\sqrt{\kappa}$ feet per nanosecond

C = $7.36\kappa \div (\log_{10} D/d)$

L = $140 \log_{10} D/d)$

1 inch = 2.54 cm

1 foot = 30.48 cm

1 meter = 3.28 feet

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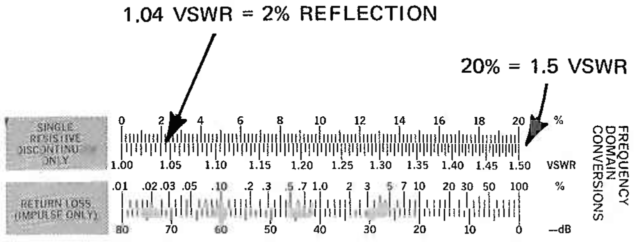
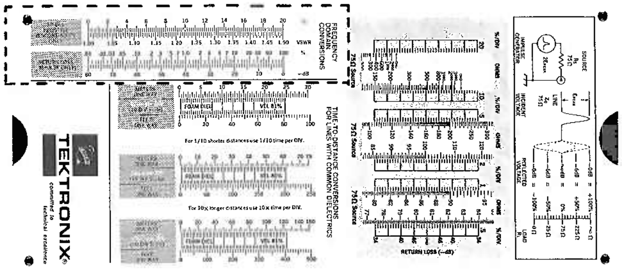
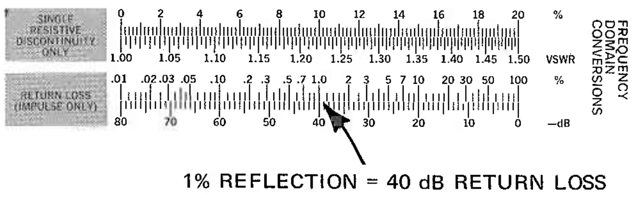
1. VSWR versus Percent Reflected Voltage.

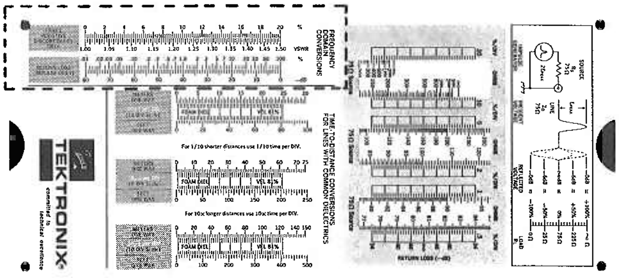




To find the Voltage Standing Wave Ratio, VSWR, knowing the percent reflected voltage (or vice versa) use the Frequency Domain Conversions section on the back of the slide rule. On the upper scale in that section locate the known value of VSWR or %. Adjacent to that point is the corresponding value for % or VSWR. VSWR is the peak-to-valley ratio of standing sinewaves. Note that this relationship between % and VSWR holds only when caused by only one impedance discontinuity that has negligible capacitive or inductive components—for example, a 75-ohm termination at the end of a 50-ohm cable. Another way to express the same caution is to say the VSWR must be essentially the same for all sinewave frequencies for the relationship to be valid.

2. Return Loss, dB, versus Percent Reflected Voltage.

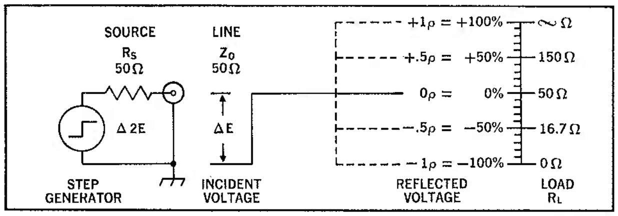


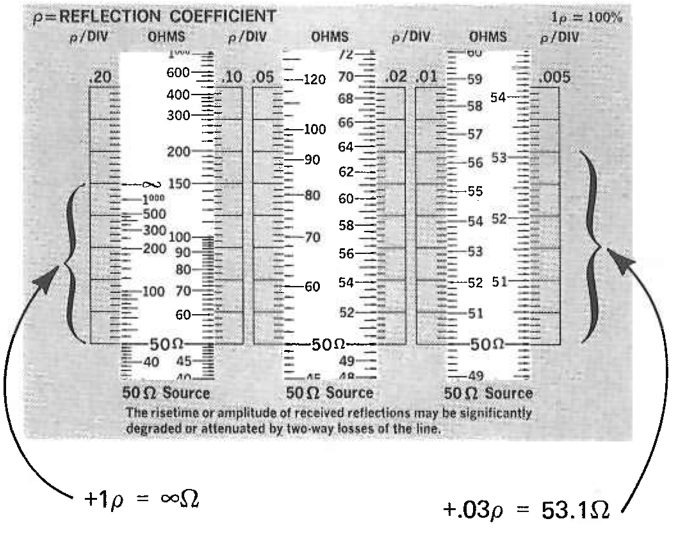


To find return loss in decibels knowing the percent reflected voltage (or vice versa) use the bottom scale in the Frequency Domain Conversions section of the slide rule. Locate the known value of percent reflected voltage or the known dB return loss and next to that will be the value of the corresponding expression on the adjacent scale. Note that only the impulse mode of Time Domain Reflectometry may always be suitably expressed in terms of return loss. Also keep in mind that a narrow impulse will be attenuated by losses in the cable and reflections will be attenuated likewise.

As with measurements of VSWR there is only a simple mathematical relationship between reflection measurements using sinewaves and reflection measurements using pulses when one resistive discontinuity is the whole cause for the sizeable reflections.

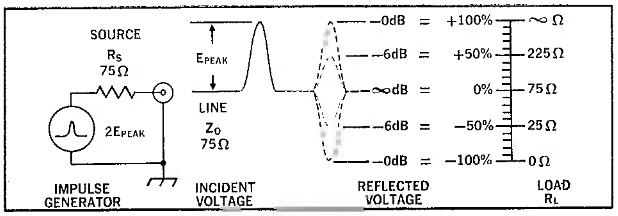
3. Percent Reflected Voltage or ρ versus characteristic Line Impedance, Z_O, for either 50- or 75-Ω Source.

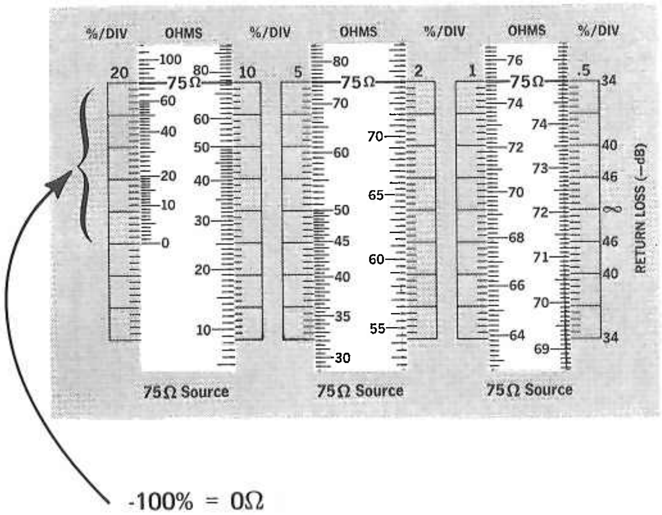




To find the characteristic impedance of a line or section of a line knowing the reflection coefficient, ρ, or the percent reflected voltage, you should first know the impedance of the pulse generator. It should be as close as possible to the nominal impedance of the line and be connected to the line through a length of cable having the same impedance as the source. Select the side of the slide rule that corresponds to the source resistance (R_s) of the generator used then select the longest scale this way:

Size of Reflection	*Use*	*Scale*
100% to 80% (1ρ to $.8\rho$) -	20%/DIV	($.2\rho$/DIV)
80% to 40% ($.8\rho$ to $.4\rho$) -	10%/DIV	($.1\rho$/DIV)
40% to 16% ($.4\rho$ to $.16\rho$) -	5%/DIV	($.05\rho$/DIV)
16% to 8% ($.16\rho$ to $.08\rho$) -	2%/DIV	($.02\rho$/DIV)
8% to 4% ($.08\rho$ to $.04\rho$) -	1%/DIV	($.01\rho$/DIV)
4% or less ($<.04\rho$) -	.5%/DIV	($.005\rho$/DIV)





-100% = 0Ω

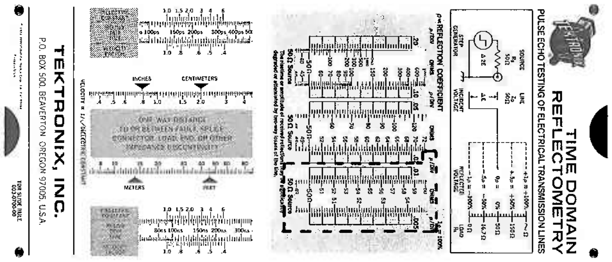
If the reflection is downward from the 50-ohm (or 75-ohm) reference level, set the reference level to the top of the chosen scale. If the reflection is toward a higher impedance than the reference level, set the reference level to the bottom of the chosen scale. Then count off the right number of divisions and subdivisions to locate the level corresponding to the peak of the reflection and read the corresponding impedance level (ohms) on the adjacent sliding scale.

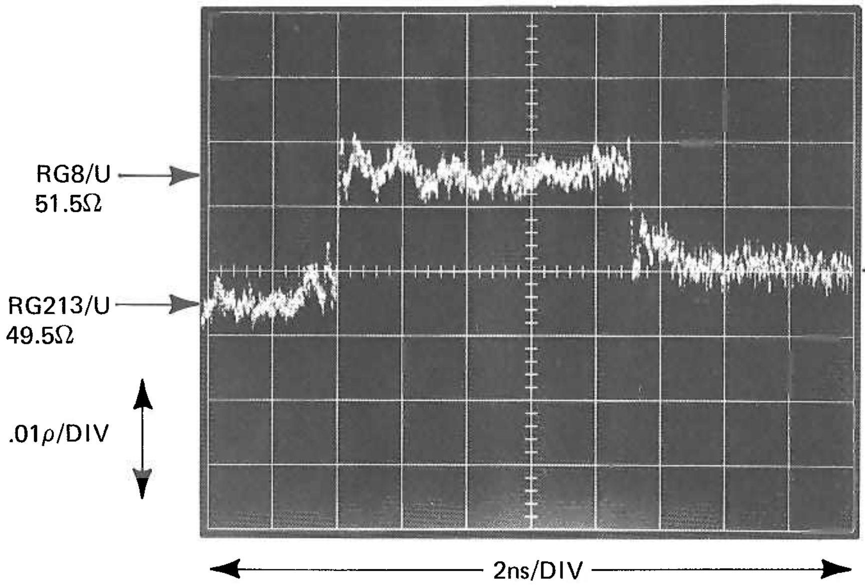
To find the size reflection to expect knowing the line impedance and the source resistance, first select the side of the slide rule having the right source resistance. For cables having a higher impedance than the selected source resistance, put the sliding reference level even with the bottom stationary scale markings. For cables having a lower impedance than the selected source resistance, move the reference level even with the top of the scale markings. For best accuracy select the scale farthest to your right in which the impedance level (ohms) of interest is within view. Read from the adjacent stationary scale the Reflection Coefficient or Percent Reflected Voltage that corresponds to the ohms selected.

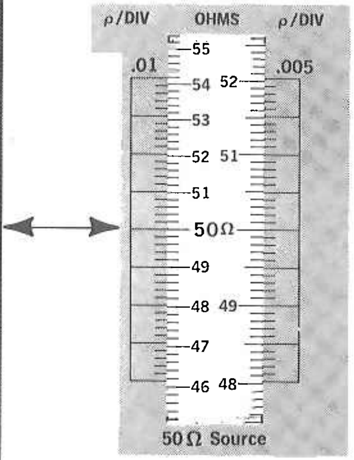
4. Percent Reflected Voltage or ρ versus Load Resistance, R_L, for either 50- or 75-Ω Source.

To find the terminating load resistance (R_L) of a line knowing the percent reflected voltage or reflection coefficient use preceeding instruction number 3. Also use instruction 3 to find the size reflection to expect knowing the load resistance. An error may be introduced if the impedance of the connecting cable doesn't match the source resistance of the pulse generator.

5. Z_O or R_L versus Reflection Amplitude as seen on your Reflectometer.







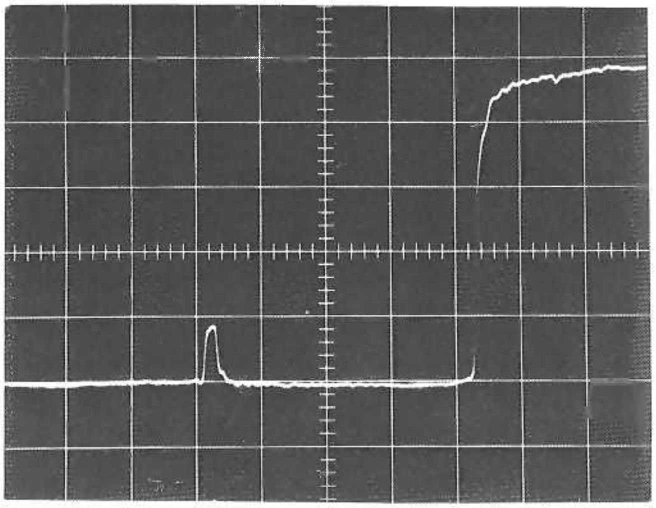
Precision Load Resistor used for 50Ω Reference Level

Line Impedance (Z_O) or Load Resistance (R_L) may be derived directly from the amplitude of a reflection displayed on a Time Domain Reflectometer Cathode-Ray Tube or Chart. The displayed reflection should first be positioned vertically to a known 50-ohm (or 75-ohm) reference level. For a reference level, use either a section of line of known impedance ahead of the line or load under test, or use a termination of known resistance at the end of the line. The slide rule may then be used by selecting the side with the same source resistance and the same scale as the reflectometer and positioning the 50-ohm (or 75-ohm) reference level on the sliding scale to a line on the stationary scale corresponding to the one selected for the reference level in the display. The impedance (ohms) causing the reflection may then be read from the sliding scale by noting the position on the fixed scale corresponding to the position of the reflection in the TDR display.

You should note that the peak level of any reflection that does not have a discernible plateau may be an erroneous indication of the impedance discontinuity that caused it. There may be several reasons for the error. First, the discontinuity may occupy such a short segment of the line, compared to the propagation velocity of the line and the risetime of the test pulse wavefront that part of the wavefront starts to emerge from the segment while the remainder is still entering. This causes a spike shaped reflection, the amplitude of which may vary depending on the risetime of the test pulse, how badly the risetime may have been degraded by the cable before it arrives, and how much attenuation the cable may impose on the reflection before it arrives back at the source. Secondly, if the risetime of the TDR system is too long, a reflection with a plateau will appear as a spike.

Vertical = .2ρ/DIV **Horizontal = 5ns/DIV**

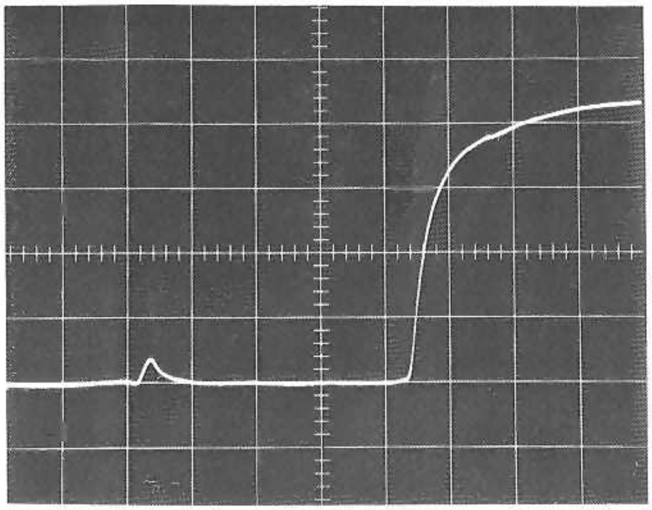
4-inch Piece of 73Ω Cable Near Open End of 20 feet of 50Ω RG213/U



140 ps TDR System

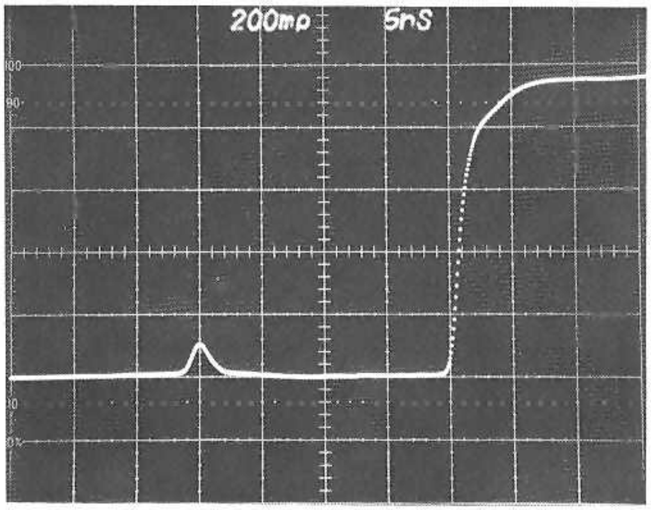
Risetime not degraded
Amplitude correct

4-inch Piece of 73Ω Cable Near Open End of 100 feet of 50Ω RG213/U



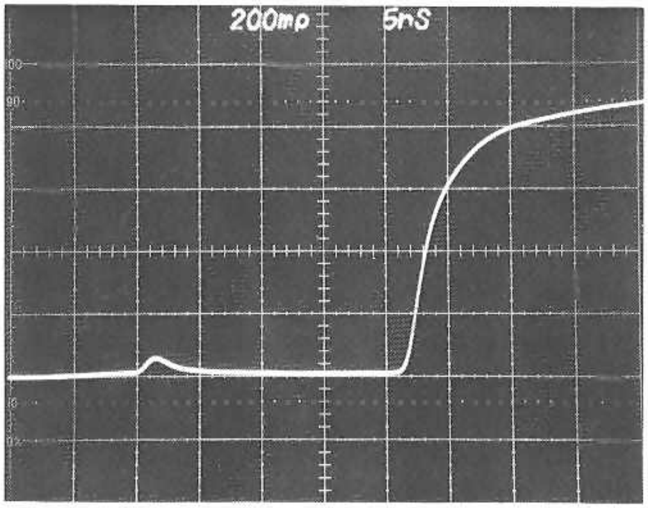
140 ps TDR System

Risetime degraded
Amplitude reduced



1.5 ns TDR System

Risetime not degraded
Amplitude reduced

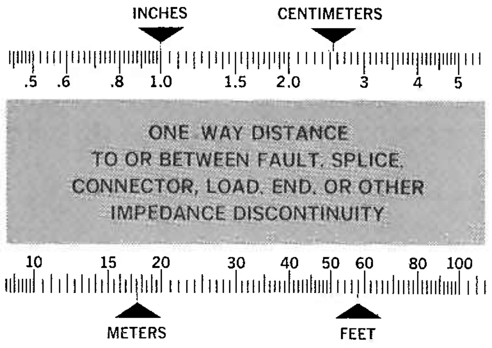


1.5 ns TDR System

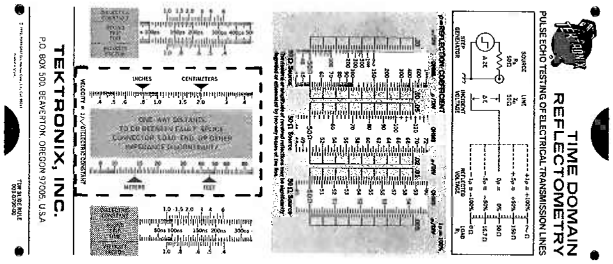
Risetime degraded
Amplitude further reduced

6. Centimeters versus Inches, or Meters versus Feet.

1 inch = 2.54 cm



17.5 m = 57.4 feet



A given number of inches may be converted to centimeters by placing the point on the sliding scale corresponding to that number next to the stationary arrow labeled Inches then reading the equivalent distance in centimeters next to the point of the arrow labeled Centimeters. Centimeters are converted to inches in just the opposite manner. Meters may be converted to feet and vice versa using the Meters and Feet scale in a similar way.

7. Dielectric Constant versus Velocity Factor.

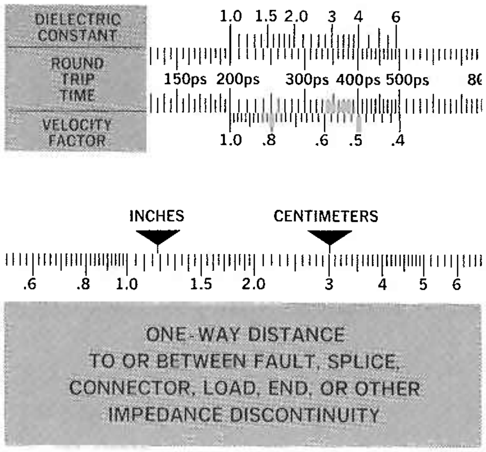
Dielectric Constant and Velocity Factor appear on two identical scales next to a sliding scale labeled Round Trip Time. To find one knowing the other read directly across the sliding scale. Any major division on the sliding scale may be placed next to the known value to help read directly across the sliding scale.

8. Time versus Short Distances, in Centimeters or Inches, any dielectric.

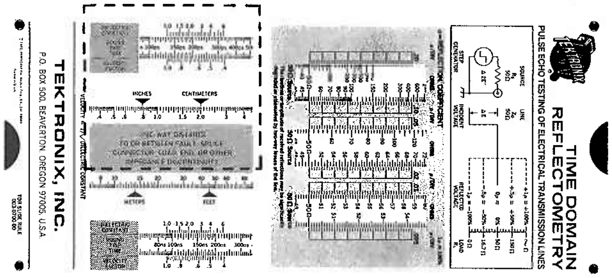
Dielectric is Air

Time = 200ps

Velocity Factor = 1



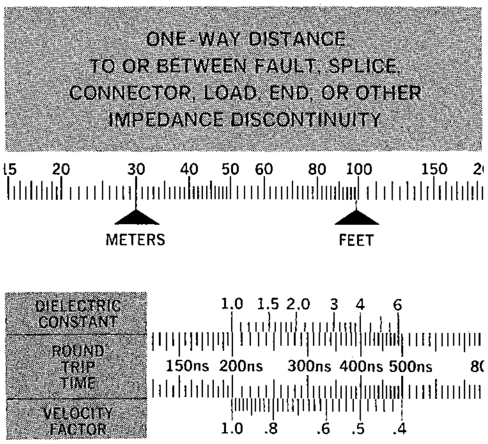
Distance is 3.0 cm or 1.18 inches



To find the distances to or between discontinuities in a transmission line knowing the time for a pulse edge to travel the distance and back (round trip time) it is necessary to know either the dielectric constant of the material between the conductors or the velocity factor of the line. For distances less than about three meters or ten feet use the Centimeters and Inches scale. The round trip time should be located on the sliding scale that is located above the Centimeters and Inches scale. Place the point on the sliding scale next to a point on one of the stationary scales that corresponds to the value of the dielectric constant or velocity factor. Then read the distance on the Inches and Centimeters scale.

If the distance to or between faults is known and you wish to find the time or velocity factor set the distance under the appropriate arrow first.

9. Time versus Long Distances, in Meters or Feet, any dielectric.

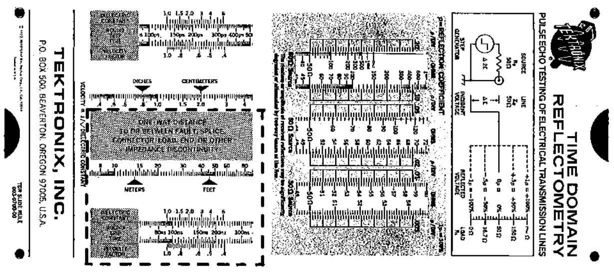


Distance is 30 meters or 99 feet

Dielectric is Solid Polyethylene

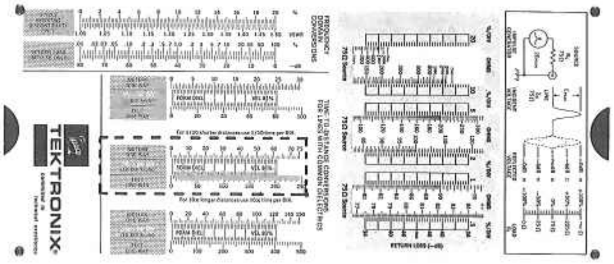
Time = 300ns

Velocity Factor = .66

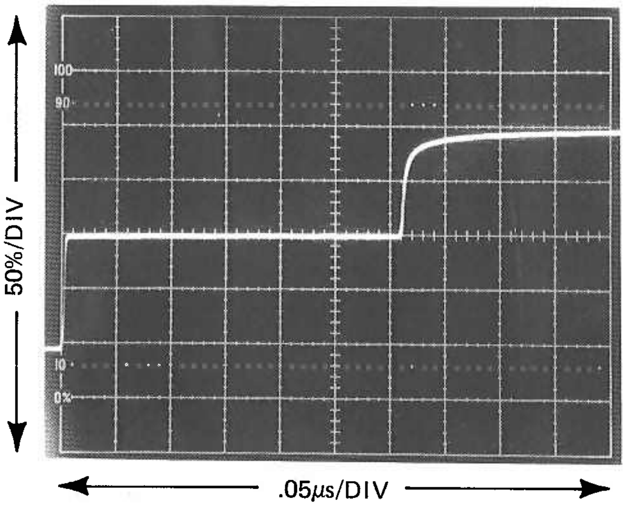


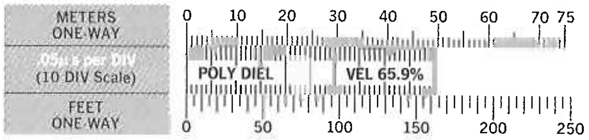
Distances to or between discontinuities further apart than about three meters or ten feet may be found on the Meters and Feet scale. Use the sliding Round Trip Time scale just below it and follow the same procedure as in 8 above.

10. Distance versus Time seen on your Oscilloscope for cables with AIR, FOAM, TFE or POLYethylene dielectrics.



453A Scope





6.2 divisions to open end of cable with solid polyethylene dielectric equals 100 feet at .05μs/DIV.

Distances to or between faults or discontinuities in a transmission line, that are displayed on an oscilloscope or TDR calibrated in units of time only, may be found for most cables without even measuring the time. Use one of the three scales labeled .02μs/DIV, .05μs/DIV or .10 μs/DIV. Select the scale corresponding to the time per division used on the oscilloscope. If the TIME/DIV on the scope is a factor of 10 greater or smaller than .02, .05, or .10 μs (.2, .5, 1 μs or 2, 5, 10 ns) the distance finally calculated should be 10X or .1X the amount indicated. After choosing the right stationary scale move the slider to choose the scale that corresponds with the kind of dielectric and propagation velocity factor the line has—either AIR (1), FOAM polyethylene (.81), TFE (.698) or solid POLYethylene (.659). Each of the four scales has ten divisions, the same as the oscilloscope, so if you set the scope display so the incident pulse edge is at the left edge of the CRT scale you should set the left edge of the slide rule scale next to zero (0) feet or meters. Then you may read the distance to the reflection by noting the point on the Feet or Meters scale that corresponds to the position of the reflection on the sliding scale. Remember to multiply by 10 if the scope was set to .2, .5 or 1 μs per division or to divide by 10 if the scope TIME/DIV was 2, 5 or 10 ns. Distances between two points in a transmission line that are each causing a reflection may be measured as above by positioning the first reflection to the left edge of the scale the same as for the incident pulse edge.