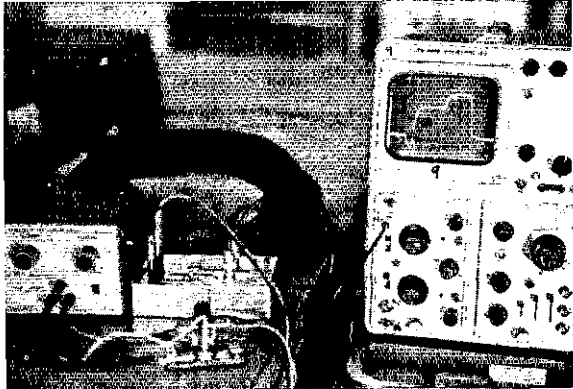The setup for making time-domain reflectometer measurements. The TDR circuit is contained in a Minibox, center. Its power supply is visible at the left. The cable being tested, coiled up in the background, is terminated with a potentiometer mounted for testing, foreground.

An Inexpensive

Time-Domain Reflectometer

BY WARREN JOCHEM,* WB2IPF

CHECKING YOUR transmission line with a VOM and SWR meter is easy, but locating the problem may not be. There is a simple technique called time-domain reflectometry (TDR) that works like a closed-circuit radar system to physically locate a fault. More than that, it can find multiple faults along a single line, measure SWR, and even tell you the characteristic impedance of your cable.

Industry has used TDR for some time, but commercial TDR systems are very expensive. For amateur applications a simple TDR can be assembled for only a few dollars, provided a wide-band oscilloscope (10 MHz or better) is available.

Fig. 1 shows a block diagram for a basic TDR. It consists of a fast rise-time pulse generator, a wide-band oscilloscope, and a T connector. The scope should be connected to the T through a short length of RG-62/U, 93-ohm coax. A 10:1 probe can also be used but a short piece of cable will make the system more sensitive.

In operation a voltage step (the leading edge of the pulse) from the generator is sent down the transmission line under test. At the same time the

* 53 Montague Ave., Trenton, NJ 08628.

scope starts sweeping to the right to display the top of a single pulse, Fig. 1B. If the voltage step encounters any discontinuities (shorts, opens, or mismatches) along the line, a reflected step will be set up at that point and will travel back up the line. If the line is not too long, the reflected step (or steps) will return soon enough to add algebraically to the forward voltage pulse, Fig. 1C. This produces a series of bumps on the top of the displayed pulse. The position of these bumps on the scope face is directly related to the position of the faults along the line. A nice advantage of this over the old VOM is that all faults on the line will be shown, not just the first one. See Fig. 2.

If a fault is too far down the line, the reflected step may not return to the scope in time to add to the positive pulse, and this information will be lost. Therefore, the wider the pulse, the longer a cable you can test. Using a 1-MHz square-wave source (500 nanosecond duration of the positive portion of the wave), cables up to about 150 feet in length may be tested.

The pulse generator used here is a simple crystal-controlled astable multivibrator. It was constructed from a 7400 series TTL quad NAND/NOR
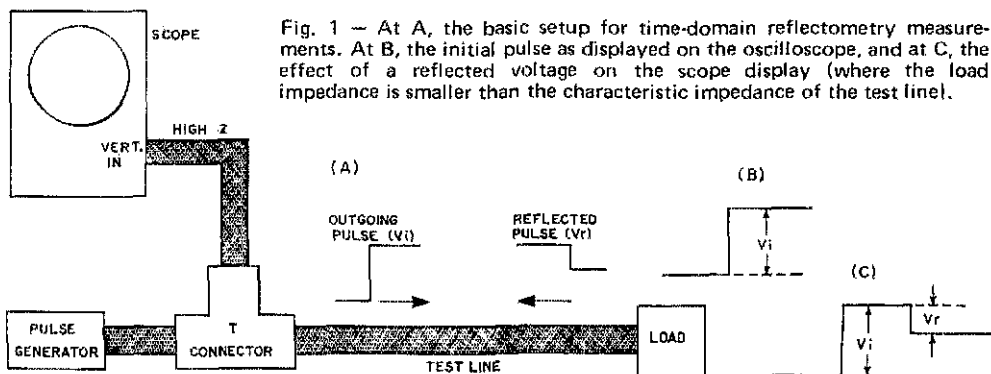

Fig. 1 — At A, the basic setup for time-domain reflectometry measurements. At B, the initial pulse as displayed on the oscilloscope, and at C, the effect of a reflected voltage on the scope display (where the load impedance is smaller than the characteristic impedance of the test line).
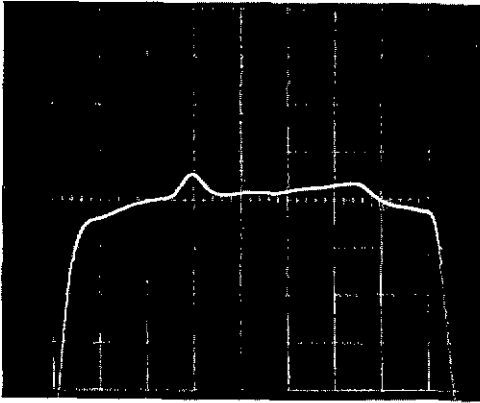
gate. The circuit (shown in Fig. 3) is straightforward and inexpensive.[1] We have built several on perforated board and others on pc board with no layout problems. R1 should equal the characteristic impedance of the line being tested (i.e., for RG-59/U, R1 = 75 ohms). This prevents multiple reflections on the line, which can distort the scope display.

Multiple reflections result when both the generator and the load end of a line are mismatched. A voltage step partially reflected by the load would be partially rereflected at the generator and will continue traveling back and forth on the line until dissipated by losses. By matching the generator end of the line the second reflection of the voltage step does not occur. Rereflection can also be a problem with more than one fault on a line, so it is best when testing a line to fix the fault closest to the generator and then work on down the line.

The resolution of this system is limited chiefly by the rise time of the pulse. Even so, pronounced faults as close together as one foot can be resolved. Using the generator shown and a 10-MHz scope, the scope is the limiting factor. If a better scope is available, using 74H00 gates or shaping the pulse

1 For this and subsequent references, see listing at the end of this article.

with a high-frequency flip-flop (7490) will significantly improve the resolution.

Testing a Line

In operation the test line is connected as shown in Fig. 1. Here is an important limitation of this simple TDR. The test line *must* be terminated in a pure resistance. For example, it must be disconnected from an antenna, or a tuner, or a loading coil. The display is simply too complex when *reactances are present*. Once the system is set up and the test line resistively terminated, the scope sweep should be set to display the top of a single pulse across the entire screen (see Fig. 4). In this test a length of RG-59/U was terminated in 150 ohms. To find the length of this line, l, we use the equation

$$l = \frac{V_p T}{2} \qquad \text{(Eq. 1)}$$

where V_p is the velocity of propagation on the line and T is the time it took the pulse to go down to the load and back. V_p equals the velocity factor (VF) of the cable in use times the speed of light. VF varies from cable to cable depending primarily upon the dielectric constant of the cable. The VF for common cables can be found in most electronics handbooks.[2] For RG-59/U, VF = 0.66.

$$V_p = (0.66)(9.84 \times 10^8 \text{ ft/s})$$

$$V_p = 6.5 \times 10^8 \text{ ft/s}$$

T is read directly from the scope face. Reading from the midpoint of both leading edges (Fig. 4), T = 4.6 divisions on the X axis, with the scope set to .05 μs/div.

$$T = (4.6 \text{ div.})(.05 \text{ μs/div.}) = 23 \times 10^{-8} \text{ s}$$

C1 — Electrolytic.
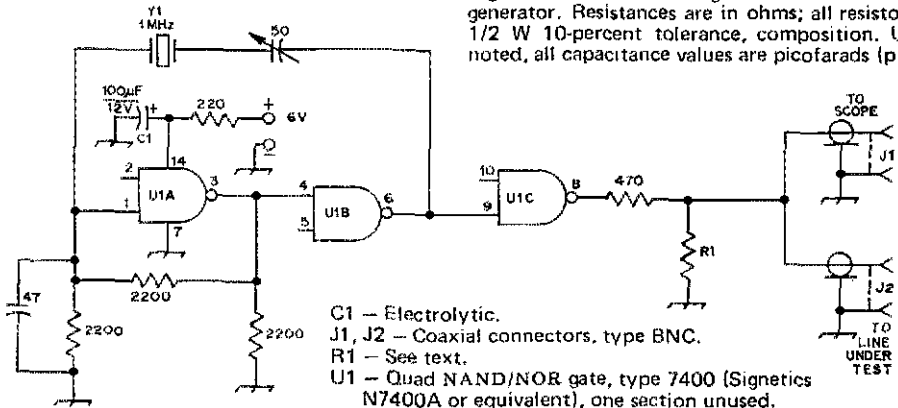J1, J2 — Coaxial connectors, type BNC.
R1 — See text.
U1 — Quad NAND/NOR gate, type 7400 (Signetics N7400A or equivalent), one section unused.
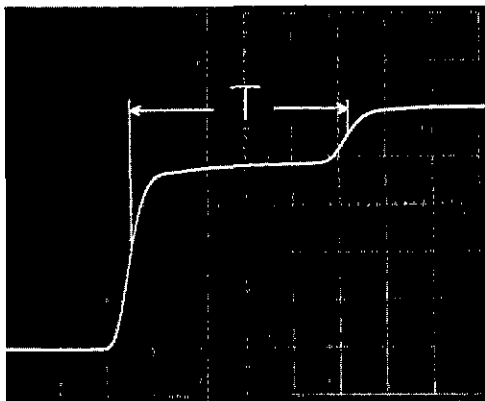
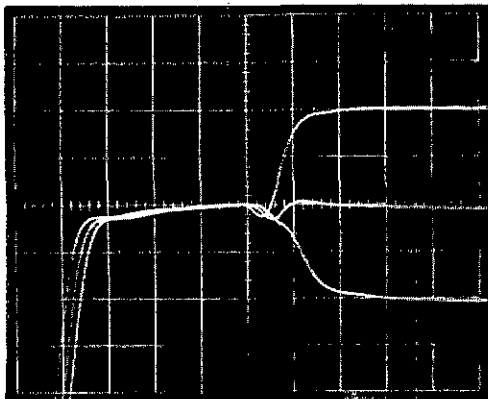Fig. 4 — TDR display with a 75-foot length of RG-59/U (75-ohm coax) terminated in a 150-ohm resistance.

Fig. 5 — Multiple-exposure photograph showing the TDR display with three different values of terminating resistance at the end of the test line. The trace which appears as almost a straight-line extension of the initial pulse amplitude results from a matched condition at the far end of the line.

Therefore:

$$l = \frac{(6.5 \times 10^8 \text{ ft/s})(23 \times 10^{-8} \text{ s})}{2}$$

$$l = 75 \text{ ft}$$

We divide by two since we want the cable length — not the distance the pulse has traveled, which is down and back. This 75 feet is in exact agreement with the measured length of the cable. It just happened that the fault was the end of the cable. If it had been in the middle a small bump in the pulse would appear, as shown in Fig. 2.

If you do not know the velocity of propagation simply rearrange equation 1.

$$V_p = \frac{2l}{T} \qquad \text{(Eq. 2)}$$

l = known cable length

T = time down and back, read directly

Now for those skeptics who do not believe in characteristic impedance, connect a 200-ohm potentiometer to the end of the line. Adjusting it through its range should provide a display like that of Fig. 5. When the display is completely flat the pot can be removed from the circuit and its resistance value measured on an ohmmeter. The pot resistance should be within one ohm of the characteristic impedance of the line.

If you ever wanted to actually visualize the VSWR on a line, set up a test to produce the displays shown in Fig. 6, and make calculations with this equation.

$$\text{SWR} = \frac{E_i + E_r}{E_i - E_r} \qquad \text{(Eq. 3)}$$

where E_i = incident voltage and E_r = reflected voltage.

Using Fig. 4 as an example,

E_i = 3.8

E_r = 1.2

$$\text{SWR} = \frac{3.8 + 1.2}{3.8 - 1.2} = \frac{5.0}{2.6} = \frac{1.9}{1}$$

Fig. 6 — TDR displays for SWR measurement, where Z_L is purely resistive.

Using another formula from which the SWR may be found if Z_L is known and is purely resistive,

$$\text{SWR} = \frac{Z_L}{Z_o} = \frac{150}{75} = \frac{2.0}{l}$$

As you can see, these two values are in very close agreement.

There are many other applications of this unusual measuring technique but I'll leave them open to amateur ingenuity. I would like to thank Dr. Allen Katz, K2UYH, Head of the Electronic Technology program at Trenton State College, for his help in this project and Paul Lamhut, WB2HHH, for the photography.

References

1) Pollock, "TTL Crystal Oscillator," Technical Correspondence, *QST*, October, 1971, p. 54. Also see Feedback, *QST*, December, 1971, p. 47, and Estes, "More on the TTL Oscillator," Technical Correspondence, *QST*, February, 1972, p. 55.

2) Antennas and Feed Systems chapter, *The Radio Amateur's VHF Manual*, or Transmission Lines chapter, either *The ARRL Antenna Book*, or *The Radio Amateur's Handbook*.

3) Allen, "A Practical Experimenter's Approach to Time-Domain Reflectometry," *Ham Radio*, May, 1971, p. 22.

4) Lenk, "Time Domain Reflectometry," *Electronics World*, September, 1966, p. 48.