Transmission-Line Fault Location Case Study

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Teacher's Note

This is a very small, compact Case Study. It is less open-ended than most Cases, as well. Quoting from the Instructor's Manual: "Though the theory behind the solution is quite technical, the explanation is presented in a manner suitable for Associate-level students. The complete solution (except for final calculations) is presented in the Case in an attempt to model successful technical problem solving for the student."

The Student Manual includes the narrative and a section of questions. It is quite short. The Instructor's Manual primarily contains answers to student questions and some course application suggestions. It has no additional narrative material.

This Case was designed for use in technical courses for Associate-level or B.S.-level Electrical Engineering Technology students. The length and depth of the Case was designed for use during one two-hour lab period. This particular Case Study is intentionally self-contained rather than open-ended, as an example and model of technical problem-solving for the students reading the Case. The student participation is primarily accomplished in answering the accompanying questions (which include math problem-solving and technical writing), and replicating the experience in lab. As indicated in the Instructor's Manual, the Case could be modified to provide breakout points for class discussion, if an instructor so desires. This author believes that Cases of this style are needed in technical education to supplement traditional lecture and lab experiences.

Student Handout to Transmission-line Fault Location: A Case Study

Bill looked up from his workbench in the electronics shop to see Joe, the college's head electrician, walk in, followed by Dan, the Director of the Computer Center.

"Oh-oh. There must be trouble somewhere for you two to visit like this," Bill said, greeting them.

"Yep," replied Dan. "We know you always enjoy a challenge, and we have a good one for you. We've got to have a remote computer terminal working by tomorrow over in the Student Center, and we just found out that it doesn't work. The setup worked fine last semester, but when we plugged everything up to the underground data cable there was no response this time. We know the terminal equipment is good because it works fine using a different data cable to another building. Joe thinks that the underground cable has been cut or broken somehow".

"How have you determined that, Joe?" Bill asked.

"By using an ohmmeter and a terminating resistor on the far end", Joe replied. "Instead of seeing the resistor's 50-ohm value plus a few ohms for wire resistance, we have a very high resistance, several hundred thousand ohms. I figure that the cable has been cut and the little continuity that we do see is due to moisture in the ground supplying a poor path across the ends of the wire. But I can't figure any way to determine where the break is without digging up the whole 800-plus feet of cable, and we don't have time to do that. Besides, that would make a real mess, and my boss would have a fit! If we could just know about where to dig, we could splice the break in time. Is there any way you could figure where the problem is?"

Bill thought for a minute. He knew that if the line had a dead short, he could make a rough guess using an ohmmeter and the measured resistance from each end; but with an open, the results wouldn't be precise enough for a determination. But there was a way to answer the challenge: send a pulse of current down the cable, and measure the time required to see the "reflection" of the pulse come back to the source after it encountered the broken end of the cable. The concept is called *Time-Domain-Reflectometry*: just as a ball bounces off a wall or a beam of light off a mirror, a pulse of current will "bounce back" from an open or shorted transmission line (there's no reflection from a properly terminated line). If the Velocity of signal travel in the cable is known, and the travel Time can be measured, then calculating the Distance can be done using the familiar **D** = **V** x **T** formula. Fancy instruments are available to do this directly, but the college didn't own a "Time-Domain-Reflectometer", so something would have to be improvised.

"OK", Bill replied; "I can do it. Help me carry the pulse generator and oscilloscope over to the Computer Center."

Once there, Bill connected the pulse generator to the cable's connector and hooked the 'scope across the same point using a "Tee" and short leads. He set the generator to send a very fast-rising 5-volt pulse down the cable. Sure enough, the oscilloscope showed the initial pulse followed by a strong reflection of nearly the same amplitude in 1.2 microseconds. Pointing to the reflection, Bill announced, "there's the problem, just 1.2 microseconds away!"

"How far is that in feet?" asked Joe.

Bill grinned. "I thought you would want to know that! Well, we know that signals in wires travel somewhat slower than the speed of light; in fact, every cable has a "velocity factor" that gives its speed rating as a percentage of **c**, the speed of light, which is 186,300 mi/sec. This is standard coaxial network cable with a velocity factor of 66%."

Bill whipped out his pocket calculator.

"We have to convert the miles/second

to feet/second by multiplying by 5280 feet per mile. Also, the distance to the fault is found by using half the measured time on the 'scope, since the pulse has to travel that distance twice, both down and back."

After punching in the numbers, Bill announced, "that means your fault is about 390 feet from here."

Joe pulled out his map of buried cables on campus and studied it closely, figuring out where 390 feet away would be. Suddenly, he snapped his fingers.

"I know! That's right where the grounds crew replaced a section of broken sidewalk last month! They must have dug too deep and cut the cable!"

"Let me know if that's what you find," Bill said, packing up the equipment.

Two hours later, Bill's telephone rang.

"I'll buy you a cup of coffee tomorrow morning," Dan said. "That was it, and the problem is repaired!"

QUESTIONS FOR THE STUDENT:

1. Explain how Dan used good troubleshooting principles to narrow the scope of his problem to the buried cable.

2. Illustrate and explain how Joe knew that the cable was open using an ohmmeter.

3. Why couldn't the location of the fault be accurately determined using an ohmmeter?

4. If the cable fault had been a dead short, how could an ohmmeter be used to determine an approximate location?

5. Draw a diagram illustrating Bill's equipment setup and the cable-fault situation.

6. Verify Bill's result of 390 feet with your own calculations.

7. Reduce the calculations required in case this problem were to be solved repeatedly; i.e., derive a simple formula that gives the distance to a fault in feet if the velocity factor of the cable and the total pulse travel time, in microseconds, are known.

8. Suppose that the velocity factor of the cable is unknown. How could the problem be solved if another piece of the same type cable, of known length, is available?

9. Suppose the velocity factor of the cable is unknown and no other cable is available for comparison, but both ends of the cable are accessible and its total length is known. How could the distance to the fault be found?

10. Suppose Joe had called back and said: "My boss said I can't dig up that new sidewalk unless I can prove to him that the problem is there. I saw what you did but don't understand it well enough to explain to him. Can you write a memo for him explaining why you think that the fault is there?" Write a memo to the Director of Buildings and Grounds explaining your determination, using technical facts to justify your position, but with enough explanation that a non-technician can understand them.

11. In the Lab, use a long spool of coax cable and the test equipment that is available to duplicate this type of experience. (Data for standard cables, including velocity factors, is typically available in industrial catalogs or on various web sites. One suitable web site is: http://hereford.ampr.org/coax/coax.html. Make sure that your cable has the same type dielectric (center insulation) as the reference you are using states, as it is primarily the dielectric properties that determine velocity factor). Write a Results & Conclusion statement for your lab experience and your learning experience with this Case Study.

Instructor's Guide to Transmission-line Fault Location: A Case Study

Case Overview: this Case describes an actual incident involving a severed underground cable that had to be repaired rapidly. Only general electronic test equipment was available, but the technologist was able to provide a solution to the problem, which the Case describes. Though the theory behind the solution is quite technical, the explanation is presented in a manner suitable for Associate-level students. The complete solution (except for final calculations) is presented in the Case in an attempt to model successful technical problem solving for the student. The Case ends with a number of questions and exercises for the student. The Case could be modified to provide "break-out" points for discussion, if desired.

Learning Objectives:

a. The learner will apply, through a prac tical problem, the basic principles of signal propagation through cables.
b. The learner will observe good trouble shooting principles in practice.
c. The learner will utilize algebra and physics in the solution of data com munications troubleshooting.
d. Application of basic test equipment will be reinforced for the learner.
e. An opportunity to practice Technical Writing will be provided.

Courses and Levels: This Case is intended for use in Electrical and Computer Engineering Technology courses at the Associate and Baccalaureate level. Ideally, the student should have studied the theory of Transmission Lines before reading this Case, but it is presented in a manner that it can be understood even without this background. A math background of algebra is needed.

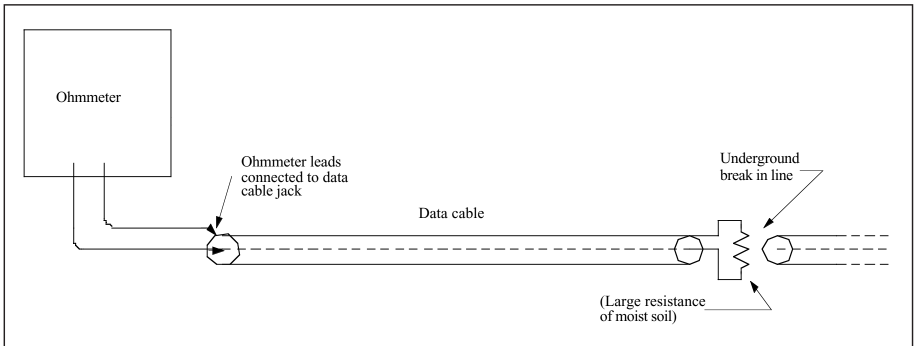

Figure 1

Solutions to Student Questions:

1. Explain how Dan used good trouble shooting principles to narrow the scope of his problem to the buried cable. By moving the equipment to another cable and finding that the equipment worked on the other cable, the problem is reduced to just the first cable. This assumes that intermittent problems aren't a factor, that the cable lengths and quality are comparable, etc. Also, since the cable under suspicion worked previously, it is probable that its original design was satisfactory and that some new fault has occurred.

2. Illustrate and explain how Joe knew that the cable was open using an ohmmeter. With a 50-ohm terminator across the remote end, a good cable's resistance as measured with an ohmmeter should be 50 ohms plus the cable wire resistance, which can be accurately found in reference manuals or simply estimated to be a few ohms, less than another 50 ohms certainly. A shorted cable would read considerably less than 50 ohms. An open cable would ideally read infinite ohms, but moist soil can provide a path of a few hundred thousand ohms. (See Figure 1 below)

3. Why couldn't the location of the fault be accurately determined using an ohmmeter? Theoretically, if one knew accurately the soil resistance, that value plus the wire resistance would provide a method of estimating distance to the fault. However, the soil resistance isn't accurately known, and in fact will likely change as ohmmeter current causes migration of copper ions from the end of the wire through the soil! Even if that weren't a factor, a few hundred thousand ohms of soil resistance compared with a few ohms of wire resistance would produce a meaningless difference.

4. If the cable fault had been a dead short, how could an ohmmeter be used to determine an approximate location? Measure the resistance at the connector and, using wire data for the resistance per foot of the cable, calculate the distance to the short. In practical terms, this is often an imprecise technique, as "dead shorts" of zero ohms resistance are rare. Or, measure the resistance from each end; the distance from each end to the short is proportional to the resistance measured.

5. Draw a diagram illustrating Bill's equipment setup and the cable-fault situation. (See Figure 2 on next page)

6. Verify Bill's result of 390 feet with your own calculations.

$\mathbf{D} = \mathbf{V} \times \mathbf{T} = VF \times \mathbf{c} \times \mathbf{T}_{total}/2 =$
$.66 \times 186300 \text{ mi/sec} \times 1.2 \times 10^{-6} \text{ sec}/2 \times 5280 \text{ ft/mi} = 390 \text{ ft}$

7. Reduce the calculations required in case this problem were to be solved repeatedly; i.e., derive a simple formula that gives the distance to a fault in feet if the velocity factor of the cable and the total pulse travel time, in microseconds, are known.

$\mathbf{D} = VF \times \mathbf{c} \times \mathbf{T}_{total}/2 =$
$VF \times 186300 \text{ mi/sec} \times \mathbf{T}_{total}/2 \times 5280 \text{ ft/mi} \times 1 \text{ sec}/10^{6}\mu\text{sec}$

$\mathbf{D} \text{ (ft)} = 492 \times VF \times \mathbf{T}_{total} \ (\mu\text{sec})$

8. Suppose that the velocity factor of the cable is unknown. How could the problem be solved if another piece of the same type cable, of known length, is available? First, send the pulse down the cable of known length, leaving its end open, and observe the reflection time on the scope. Solve the equation above for VF and use that value in the solution of the problem.

9. Suppose the velocity factor of the cable is unknown and no other cable is available for comparison, but both ends of the cable are accessible and its total length is known. How could the distance to the fault be found? Measure the time from each end connector for the reflection. Each time will be proportionally the distance to the fault, or, from the first end, the distance to the fault is $\mathbf{D}_1 = (\mathbf{L} \times \mathbf{T}_1)/(\mathbf{T}_1 + \mathbf{T}_2)$.

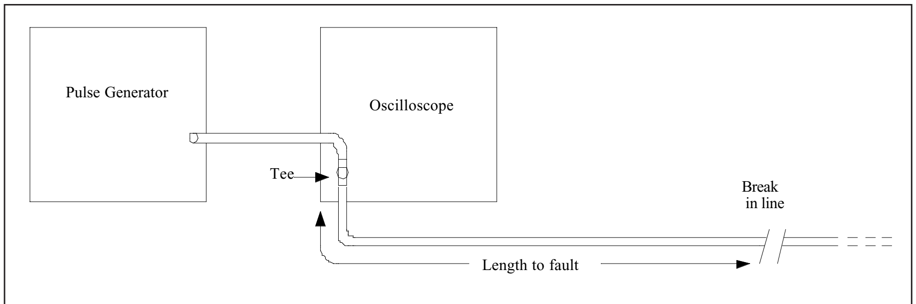

Figure 2

10. Suppose Joe had called back and said: "My boss said I can't dig up that new sidewalk unless I can prove to him that the problem is there. I saw what you did but don't understand it well enough to explain to him. Can you write a memo for him explaining why you think that the fault is there?" Write a memo to the Director of Buildings and Grounds explaining your determination, using technical facts to justify your position, but with enough explanation that a non-technician can understand them.

11. In the Lab, use a long spool of cable and the test equipment that is available to duplicate this type of experience. Write a Results & Conclusions statement for your lab experience and your learning experience with this Case Study. Suggestions: use at least 100 feet of cable to get enough delay to be measurable. Slower oscilloscopes and/or pulse generators require longer cable runs. Ordinary RG-58 with BNC connectors works fine (the Velocity Factor should be accurately known). The cable doesn't have to be removed from the spool, unless you want to confirm the length by direct measurement. A narrow pulse or wide pulse (referring to narrower or wider than the reflection time), or a square wave can be used; the pulse width and repetition time will need to be appropriate for the reflection time of the cable length. Pulse generators are easier to set up and interpret. Square wave generators are more commonly found in labs, though; but will take some experimenting to learn how to use. The References, particularly References 1 and 2, provide good explanation of TDR.

For illustration, the following figure (Figure 3) shows a typical oscilloscope pattern when a narrow pulse is used. This particular waveform was obtained in the lab, using about 200 feet of RG-58 cable. The scope was set on 200ns/div. The stronger initial pulse is seen on the left, followed by the reflection. A much smaller additional reflection is seen subsequently, indicating that some of the reflection from the end of the cable has "bounced back" again from the source (the pulse generator) and made another

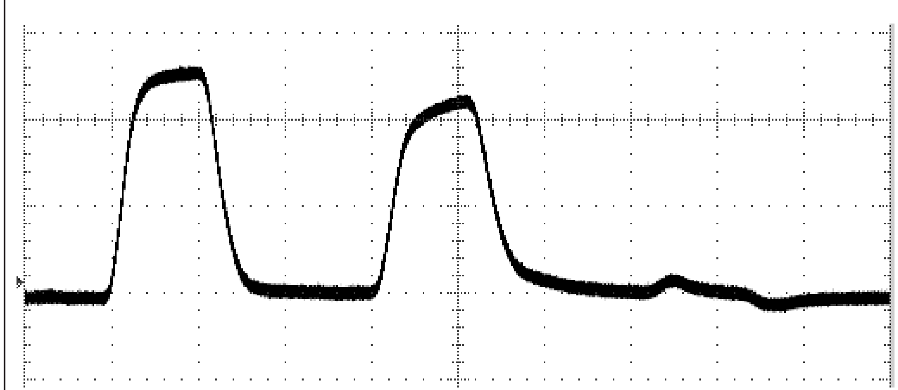

Figure 3

trip.

Using the same piece of cable and scope settings, the waveform below in Figure 4 shows how a squarewave pattern would appear. The initial rise of the waveform is loaded by the cable; after the pulse has made its return trip, the full squarewave height is seen. The reflection time is the delay from the first rise to the second; about 3 divisions, just like with the pulse waveform, but perhaps harder to interpret.

The effects of different termination resistances can be easily demonstrated with

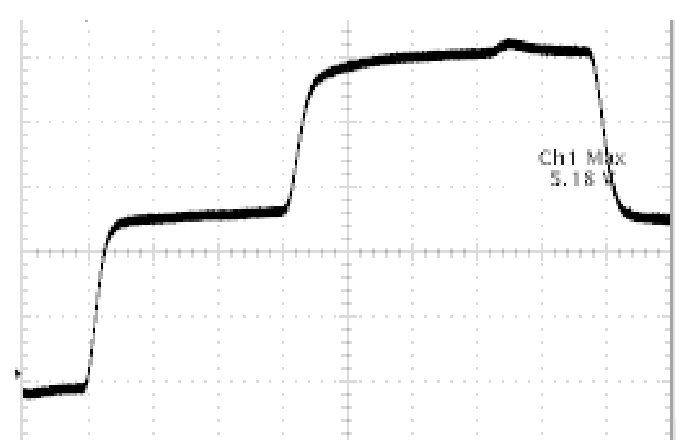

Figure 4

this setup, as well. The closer that the termination resistance matches the impedance of the coaxial cable, the smaller the magnitude of the reflection. Teaching Suggestion: the author has used this particular exercise in lab time for a Communications-Electronics course, following the classroom lecture on signal propagation through transmission lines, to reinforce the topics presented. To get students really involved, it's been handled as a competition: large spools of cable are distributed, and the students told that the first to electronically determine their cable's length to within 10% of its actual value gets a free soft drink. Very little guidance is given from this point forward. This makes for quite a spirited laboratory time! The spools of cable have been premeasured so that it is quick to determine the students' accuracy. The Case Study has been given to the students a few days earlier, with an assignment that it be read before lab. The cable's velocity factor is given to the students, but usually not until they ask about it. This could also be handled by having the students determine the value through research, assuming that the cable is a standard type whose velocity factor can be readily found.

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