Complete Feedline Validation

Wesley Cardone, N8QM, March 1, 2025

A WORD TO THE WISE:

Why did you get started with amateur radio? If part of that reason was that you wanted to do things cool, then recognize that equations are not evil. They are a means to an end and, for amateur radio purposes, are simple once properly explained. You will think of ways to accomplish things having that understanding and your peers will begin to come to you with their questions.

Having explained that, please do not be dismayed at the appearance of equations in this document. They are simple though at first they may look disheartening. Do not necessarily expect to comprehend their purpose initially and merely recognize that you have encountered them. In time they will mean something to you and you will feel a sense of accomplishment.

PROBLEM:

An amateur suspects that the coax feedline stretching from his HF transmitter to his BVP4 HF antenna may be compromised. He is considering spending several hundred dollars to replace it.

OBJECT:

This testing will validate Jim's existing coax feedline. We may find that it is

1. acceptable,
2. unredeemable, or
3. has an unredeemable section to replace.

ACCEPTABLE OPERATION:

Acceptable operation is defined as a consistent 50 Ohms characteristic impedance from the feedline input at the transmitter to a 50 Ohm dummy load at the antenna. We can loosely assign a success tolerance as +/- 20% of the magnitude, real, and reactive impedance. But more importantly, success requires that any one junction traveling to the antenna does not have a characteristic impedance discontinuity exhibited by a reflection. That leaves a loosely described success criteria as:

$$40 \text{ Ohms} < \text{Acceptable } Z_0 < 60 \text{ Ohms}$$

FIRST THINGS FIRST

First, we look for corrosion and marginal connectors. Simply disconnecting and reconnecting connectors can make a difference.

THE TESTING PLAN:

Using Time Domain Reflections, we will identify characteristic impedance mismatches. An optimal transmission line would have two ends: one at the transmitter and one at the antenna. Let us say

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that a transmission feedline was 100 feet. If somewhere in that path there was a damaged point (maybe somebody was digging a hole with a spade and nicked the coax, damaging it), time domain reflectivity testing would clearly show how far that damaged point was from the transmitter. That part of the transmission could be unearthed and adjudicated as to its remedy.

WHAT IS TIME DOMAIN REFLECTIVITY

A successful transmission line will have a characteristic impedance, from start to finish, that matches both the characteristic impedance of the transmitter and the antenna. Under such conditions, there will be a SWR of 1:1 and, therefore, no reflections.

But let us suppose that there was a PL-259 connector at about mid-way in the transmission line. Let us then suppose that, maybe because of corrosion, the connector was exhibiting an effective 75 Ohms characteristic impedance. The signal would leave the transmitter and travel unimpeded until it got to that nasty, mismatched point at the transmission line's mid-position point.

ENTER A REFLECTION COEFFICIENT AND ITS RELATIVE, THE SWR:

It sounds intense but is really simple. There is a "reflection coefficient" (Γ), a load impedance (Z_L), and a transmission line characteristic impedance (Z_0). Let us assume that the mid-way impedance (Z_L) were 75 Ohms. The reflection coefficient is

$$\text{Reflection Coefficient: } \Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad \textit{Equation 1}$$

But we are more familiar with a voltage standing wave ratio, VSWR.

$$Voltage\ Standing\ Wave\ Radio: VSWR = \frac{1 + \Gamma}{1 - \Gamma} \qquad \textit{Equation 2}$$

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When we substitute the Γ of Equation 1 into Equation 2 and simplify using high school algebra, we arrive at the simplified and easy-to-digest equation for the voltage standing wave ratio:

$$VSWR = \frac{Z_L}{Z_0} \qquad \textit{Equation 3}$$

Therefore, the standing wave ratio is equal to the load impedance divided by the characteristic impedance. For our case at hand, we will identify the mid-way connector as the load, Z_L. Therefore, the SWR is expected to be 75 Ohms/50 Ohms or 1.5:1. This is a ratio and therefore has no units. This means that some of the energy is going to be reflected back to the transmitter and some of the energy will pass through the connector and continue on its way to the antenna. But how much is reflected and how much passes through?

HOW MUCH IS A REFLECTION?

Because of the law of conservation of energy, all of that energy which left the transmitter is what is split at the mid-way connector (other than parasitic dissipation losses of the copper). Avoiding equations, consider Figure 1 to quantify SWR into percentage reflections. With an SWR of 1.5:1 there will be a 20% reflection. That means that 20% of the signal is reflected back to the transmitter and 80% goes on to the antenna.

SWR vs Reflected Voltage or Power

VSWR	*Voltage Reflected (%)*	*Power Reflected (%)*
1.0:1	0	0
1.1:1	5	0.2
1.2:1	9	0.8
1.3:1	13	1.7
1.4:1	17	2.8
1.5:1	20	4
1.6:1	23	5.3
1.7:1	26	6.7
1.8:1	29	8.2
1.9:1	31	9.6
2.0:1	33	11
2.5:1	43	18.4
3.0:1	50	25
4.0:1	56	36
5.0:1	67	44.4
10.0:1	82	67

Figure 1 Illustrated a quantified SWR

TIME DOMAIN REFLECTOMETRY

At this time we are able to comprehend the concept of a time domain reflectometry. In electricity there are "domains." Primarily there is a frequency domain and there is a time domain. We can express a signal in terms of a time domain or in terms of a frequency domain.

For example, suppose we have a 1 MHz signal. Just in that expression there is at least an allusion to a frequency domain.

But we can also express the same signal in terms of a time domain. If it is a sine signal, it will have a period of 1 µsec. Otherwise, it will have a pulse width, duty cycle, and period. and have a duty cycle or pulse width. Those are expressions within the time domain.

Therefore, in time domain reflectometry, we have a pulse width (its magnitude is somewhat irrelevant) and a duty cycle. The signal travels at nearly the speed of light, but what is important is that it travels as measured in seconds or fractions of seconds. It takes a known amount of time for a pulse to reach our mid-way connector. When that pulse reaches the connector, 20% of it is reflected back to the transmitter. There are, therefore, two elements to the "time" that we are looking at. The first is the time it takes for the signal to reach the connector, and the second is the time it takes to travel back from the connector to the transmitter.

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WHAT IS A VELOCITY FACTOR

Electricity travels at the speed of light…in free space. In anything else, it travels at LESS THAN the speed of light. A "velocity factor" is a tool to simplify how we express how much slower than the speed of light that travel is.

It is given that the speed of light is about 3e6 meters per second in free space. If a velocity factor is 66% in a given coax cable, what is the speed of the electric signal? It would be

3e6 * 0.66 = 198 meters per second

But it is all much simpler than that. Cable manufacturers specify what the velocity factor is for any cable that they sell or manufacturer.

Suppose we have a 25-foot coax cable (7.62 meters). Our signal source connects to the input and the other end (out in the wilderness) is open—nothing connected to it. The cable's velocity factor is specified by the manufacturer as 66%. We want to send a pulse down that cable and look for its return. We have a rough idea of when to expect that return pulse

$$t_{return} = 7.62\ meters \frac{second}{3e8\ meters} 0.66 * 2 = 33\ nsec$$

Recall the pulse is making two trips (the first to the load and the second back to the source), and thus, we multiply by 2.

Because we are expecting the returned bounced signal at 33 nSec, we need to make sure that the period of the signal is considerably more than 7 uSec. Let us consider using 10 uSec.

Then we must make sure that the pulse width is considerably less than the period. This will be the duty cycle.

WHAT ARE WE ABLE TO ACTUALLY OBSERVE?

All this gobbledygook is fine to talk about in travel times, but all that really counts is what we are able to measure with the instrumentation that we have. How are we able to measure the time it takes a signal to travel to the downstream connector? It is impractical to make that measurement since we would need to have instrumentation at the downstream connector as well as at the transmitter source. It is much easier (in fact, it is as simple as pie) to measure the time that it takes the reflection to return to the source. We already have our instrumentation there. But there are some important considerations in order to make this measurement possible.

CHOOSING A VIABLE DUTY CYCLE

The prime consideration is to select a pulse-width duty cycle that will not send out another pulse before the reflection has returned to the source.

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WHY IS Z_0 Z_0?

The characteristic impedance, Z_0, is a function of the transmission line reactance per unit length.

$$Z_0 = \sqrt{\frac{L}{C}} \qquad \textit{Equation 4}$$

Consider the specifications for RG-58 coax cable giving the characteristic parameters listed in Table 1. The table lists a characteristic capacitance per unit length. The associated inductance per unit length shown in the table was derived from its C via Equation 4.

It is important to recognize that although we classify these reactances as parasitic, they do in fact exist as if they were component values. It is not as easy to measure their values as it is to measure the resistance of a carbon resistor with an Ohm meter. It is much easier to deal with these in terms of the associated characteristic impedance.

Parameter	Value	Units
Z_0	50	Ohms
vf	65.9	%
C	30.8	pF/ft
	101.05	pF/m
L[1]	77.0	nH/ft
	0.2526	uH/m
R	39.0	Ω/km
	11.89	Ω/1,000 ft

Table 1

VELOCITY FACTOR

The transmission line used in LTSPICE serves as a model for many varied applications and consequently it is modeled for general usage. The model does not have a velocity factor to directly specify. However, our solution is even better than if the LTSPICE model accepted a characteristic impedance directly. The solution is to consider a transmission line as a component that you will pull off the shelf or order from DX Engineering. This is done via the LTSPICE .model card.

A .MODEL CARD TO DEFINE RG-58 COAX CABLE

Our objective is to develop a component that relates to the real world. There will be a generalized transmission line element in the schematic that is characterized to function as RG-58 coax cable. It will have an associated .model SPICE operative card.

A PRACTICAL EXAMPLE

In Figure 2 is shown an example amateur radio station transmission line configuration. The transmitter is in the house. The RG-58 coax feedline leaves the house and enters the ground. For some unknown reason, the station operator has a PL-259 connector about 25 feet from the house in the underground transmission line feed system. Another 75 feet of coax leads to the antenna.

[1] Solved for assuming Z_o=50 Ohms

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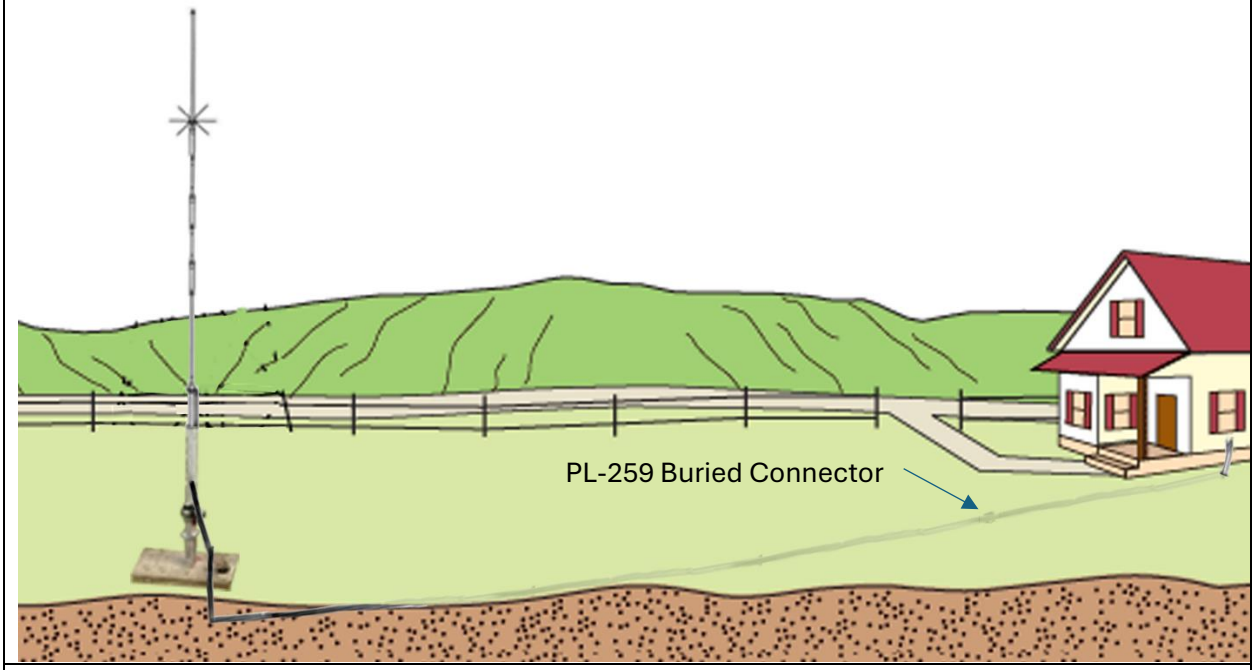

Figure 2 Radio station transmission configuration with underground feedline to antenna.

When the first pulse goes out it will arrive at the 25 foot distance PL-259 connector a predictable time later. That time will be the distance it takes the pulse to travel at the speed of light in free space less a velocity factor of 0.659.

$$t_{load} = 25\,ft\,\frac{381m}{1250ft}\,\frac{sec}{2.9979m}0.659 = 16.7\ nano\ seconds\ to\ load$$

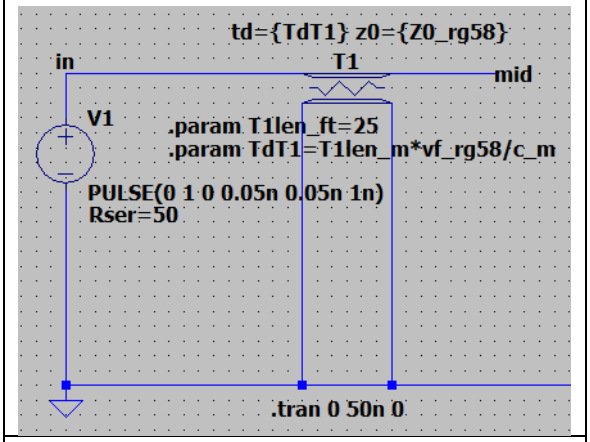

Figure 3 Test bench for measurement of signal travel time

But the problem is that we do not have a convenient method to validate that time with ordinary electronics bench test equipment. Refer to Figure 3 where it illustrates a test bench configuration to measure the travel time of a signal. In this test setup we have a 50 Ohm signal generator feeding an RG-58 coax cable of length 25 feet. As in an ordinary test bench, we are going to pretend that we don't have a convenient way to monitor the signal appearing at the load so what we do is look for the reflection returning to the source. But the difference now will be that we have an open end where the load would otherwise be forcing all of the signal to reflect back to the source. In so doing, we must account for both the time to travel to the antenna as well as the time to return to the source. Therefore, we expect that since it should take 16.7 nSec for the signal to reach the antenna, it will take another 16.7 nSec to return for a sum total of 33.4 nSec.

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An LTSPICE simulation was run to validate these calculations. Results are shown in Figure 4.

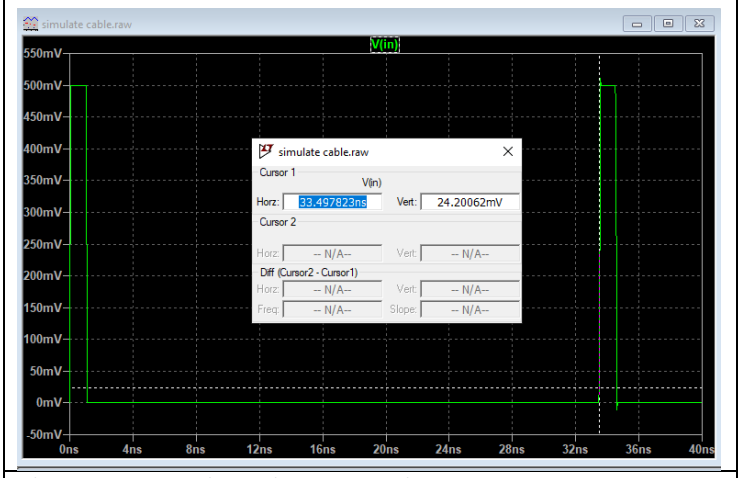

Figure 4 LTSPICE simulation of travel time of a pulse through RG-58 coax cable.

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APPENDIX

LTSPICE CABLE SIMULATION MODEL

We will use LTSPICE to simulate a transmission line cable within the time domain. The primary actor in the model will be the use of the T transmission line model. The T model is designed to serve many purposes in both frequency and time domains and as such must be handled properly to accommodate its use in the time domain.

There are two attributes of the T transmission line model of interest to us for the present application: td and Z0, time delay and characteristic impedance.

It would be nice if the model accepted traditional cable attributes such as velocity factor, length, and more. However, we are forced to define a cable length in terms of its time delay. While this may seem as a handicap, it need not be so.

We define the following universal constant variables:

1. .param len_m = len_ft * 381 / 1250 Length conversion from feet
2. .param c_m = 2.0079e8 The speed of light in free space
3. .param myTd = len_m * vf_rg58 / c_m The delay used the any one component

These variables are intrinsic to the model. As a general case, they never change.

We then define two variables that will characterize a given component such as an RG-58 coax cable. A model becomes a component when it has been characterized.

1. .param vf_rg58 = 0.659 The characteristic velocity factor
2. .param len_ft = 50 The length in feet of a component cable.

Figure 5 shows a graphical illustration of the characterized model in LTSPICE. Because the model exists as a component, we can treat it as a component defining its operation in terms of its component attributes. This lends itself nicely to schematic use emulating a schematic representation.

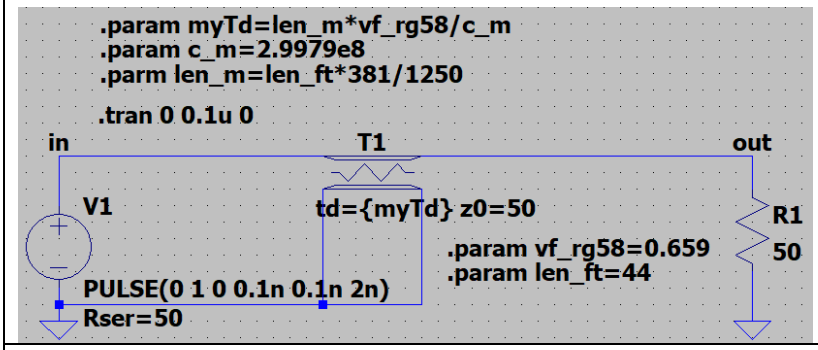

Figure 5 Represents the LTSPICE model for a characterized RG-58 coax cable.