Using a NanoVNA and the TDR Feature to Measure the Impedance and Electrical Length of an Unknown Cable

I purchased a house with audio cables running through the house from the television area to a sound cabinet across the room from the location of the TV. The cables were installed in the walls of the house long before I came on the scene, probably during construction of the house approximately 18 years ago. I wanted to determine the impedance of the cables and if there were any serious issues with the cables along the entire length of the cable which is in the walls of the house. Since I didn't want to tear into the sheet rock to physically view the cables, I used a non-invasive approach based on Time-Domain Reflectometry (TDR.) This document illustrates a means of determining the impedance, consistency, and electrical length of the unknown cables using a nanoVNA and Time-Domain Reflectometry. The only software beside that in the nanoVNA itself I used was nanoVNA MOD v3 by alex_m which was used to capture screen shots of the display on the nanoVNA. The firmware in the nanoVNA itself is version 0.4-4-e679893 with a build time of November 26, 2019 – 17:34:01. The steps in making this measurement are described below.

Step 1

I calibrated the nanoVNA over the range from 50 kHz to 900 MHz using the typical open-short-load method. This calibration was stored in memory 0. Every time the nanoVNA turns on it loads this calibration.

Step 2

Because I knew the length of the cables was probably less than 100 ft (30.4 m). I changed the nanoVNA stop frequency to 130 MHz which gives a maximum length that can be observed in the nanoVNA of about 31.5 m. Smaller values for the stop frequency increase the electrical length of cable in seconds that can be observed natively by the nanoVNA. A significant part of this limitation is the fact that the nanoVNA is limited to 101 points in both the frequency domain and in the time domain transform of the frequency-domain data.

Step 3

I made sure the far end of the cable by the sound cabinet was disconnected so that no harm would be done to equipment in the sound cabinet by signals from the nanoVNA. I connected port 0 of the nanoVNA to the unknown cable through appropriate adapters. Transitions were made from SMA to BNC, then a 6 ft length of RG58 cable (more on why this was done is discussed later), and then to a BNC to RCA adapter and finally to the RCA connector on the wall behind the TV.

Step 4

The nanoVNA TRANSFORM mode was turned ON and the mode was set to LOW PASS STEP. A rough measurement to the far end of the cable was made by observing when the step transform of the return-loss data went to a high impedance. The length of all cable was measured to be well less than 200 nanoseconds, around 160 ns. Measurements will not be very accurate with this setup because the stop frequency was changed from 900 MHz to 130 MHz in step 3 without recalibration.

Step 5

Next the nanoVNA was calibrated over the 50 kHz to 200 MHz frequency range using a BNC open, BNC short, and BNC load. This choice of frequencies gives me the most detail I can get with the native TDR capabilities of the nanoVNA while being able to view the entire length of the cable I am testing.

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Calibration must be done with TRANSFORM mode turned off. This recalibration will enable more accurate impedance measurements because the nanoVNA is calibrated at every RF frequency in use. At the end of the calibration steps I stored this calibration in memory 3. The mode was then switched to TRANSFORM mode and again I made sure LOW PASS STEP was set for the mode of the TDR analysis. I disabled all traces but the yellow trace and the green trace which are typically the Log magnitude of the Return Loss and the Smith Chart representation of the impedance, respectively. At this point I re-saved the configuration in memory 3 again. When memory 3 is loaded, the nanoVNA state will be restored along with the calibration. This enables one to quickly return to an appropriate state of the nanoVNA and the appropriate calibration by recalling memory 3.

Step 6

The calibration of the nanoVNA was checked using a 50 ohm load connected to the BNC adapter. The resulting trace is shown in Figure 1. For this plot I modified the default in memory 3 to show the yellow trace as the resistance of the TDR measurement and set the scale per division to 50 ohms.

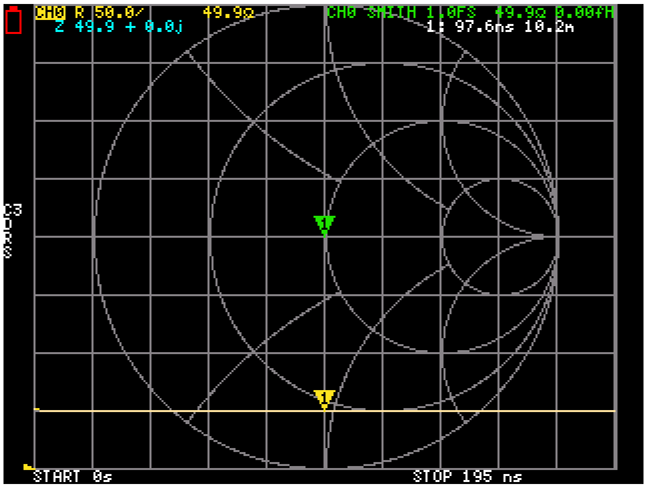

Figure 1. TDR for 50 ohm load.

Several things can be observed in this figure. First, the maximum cable length available is 195 ns which is sufficient for my estimated cable length of around 160 ns. Second we can see that the impedance of the 50 ohm load is constant from 0 to 195 ns. The Smith chart impedance at 97.6 ns, the number “1” marker, shows 49.9 ohms which is very near to ideal which is what one would expect after a good calibration.

Step 7

The 6 ft length of RG58 cable with BNC connectors was then attached to CH0 of the VNA while using the previously saved configuration of the VNA. The end away from the VNA was not terminated. The resulting TDR plot is shown in Figure 2. The purpose of connecting the unknown cable to the VNA with a cable of known impedance is to assist us in interpretation of measurements of the unknown cable. You will see practical uses of the measurements of the RG58 cable in the next step.

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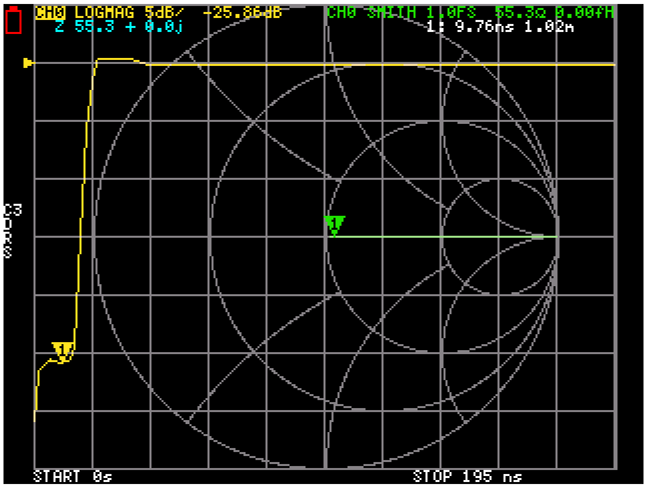

Figure 2. TDR of 6 ft RG58 cable.

When the marker is set to 9.76 ns, we see that the impedance is estimated to be about 55.3 ohms with a return loss of -25.86 dB. Later in time the impedance rises sharply to a much higher value which is shown as a near 0 dB return loss when the step response reaches the time associated with the end of the cable. Again, this is what would be expected for an unterminated length of RG58 cable and gives us an estimate of the impedance and electrical length of the RG58 cable. Note that the return loss is flat along the RG58 cable length.

Step 8

The far end of the 6 ft RG58 cable was then attached to the RCA connector on the wall plate behind the TV to take a look at the impedance and length of the unknown cable hidden in the walls of the house. The resulting data is shown in Figure 3.

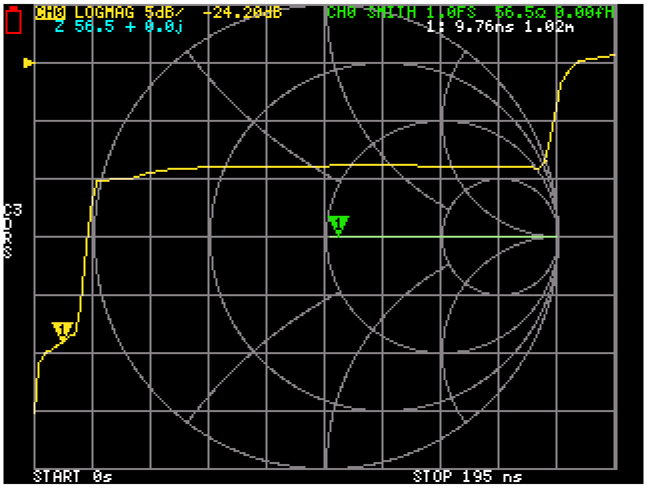

Figure 3. TDR plot with 6 ft cable and unknown cable attached to the nanoVNA.

The marker in this plot is set to 9.76 ns again which shows the impedance near the middle of the RG58 cable. The impedance this time measures about 56.5 ohms which is very similar to the previous measurement of the cable. The fact that the impedance is nearly the same gives us pretty good confidence in the measured impedance of the unknown cable as shown in Figure 3 above and Figure 4 below.

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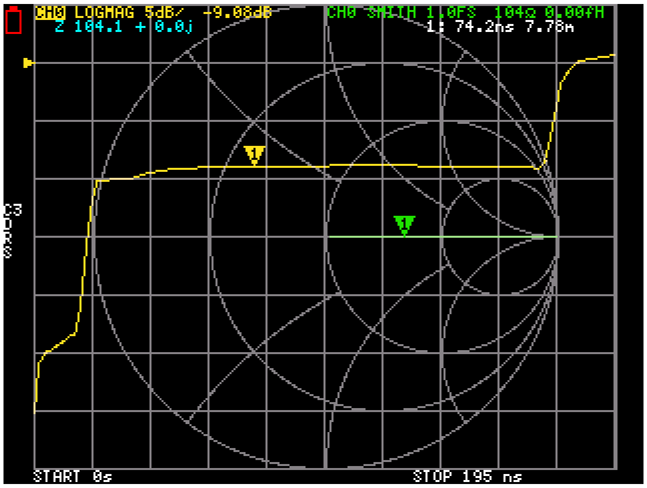

Figure 4. TDR plot of 6 ft RG58 cable and unknown cable with marker set to 74.2 ns.

Figure 4 shows the marker at 74.2 ns. At this point in time, the impedance shown on the Smith Chart (the green plot) and the turquoise impedance measurement is approximately 104 ohms. The return loss of the unknown cable is approximately -9 dB. We do see a little change in the return loss and impedance along the unknown cable; however, the changes are fairly minor. Figure 5 shows an estimate of the maximum impedance which is around 107 ohms at 117 ns from the VNA reference location. A slightly better return loss is shown between about 20 ns (the second graticule vertical line) and 40 ns (the third graticule vertical line) because the impedance of the cable is about 95 ohms in this section of the cable.

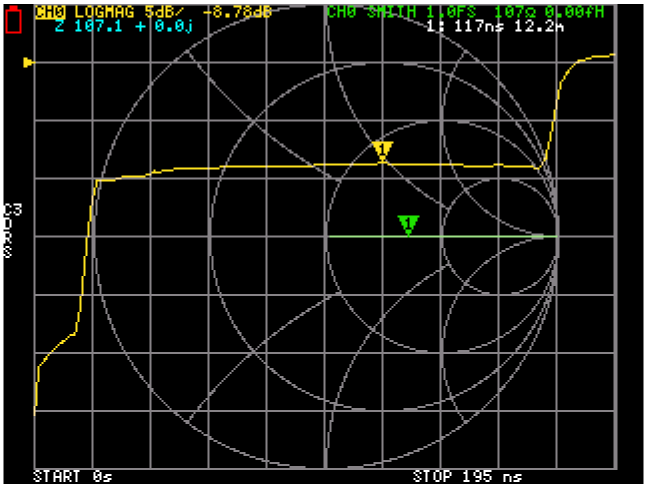

Figure 5. TDR of 6 ft RG58 cable and unknown cable with marker set to 117 ns.

We can get a fairly accurate measurement of the unknown cable's length by comparing the time at the beginning of the impedance transition at the start of the cable (Figure 6 showing 13.6 ns) to the time at the impedance transition at the end of the cable (Figure 7 showing 171 ns.) The difference is 157.4 ns. Because I don't know the velocity factor of the cable, the estimates of distance in meters is inaccurate in all of the TDR displays except for the RG58 itself.

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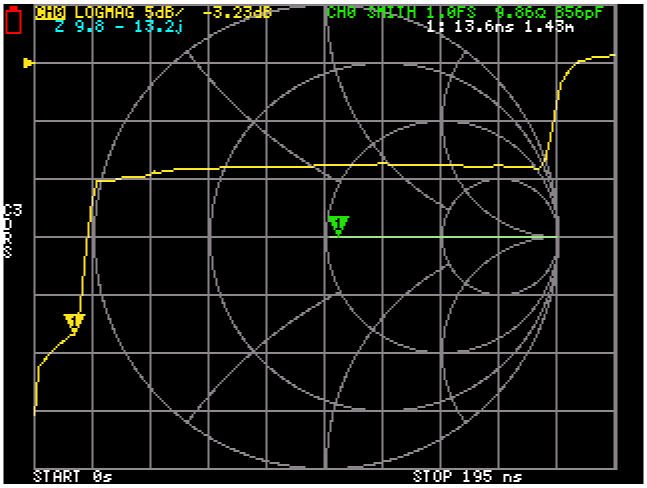

Figure 6. TDR showing time at start of unknown cable (13.6 ns.)

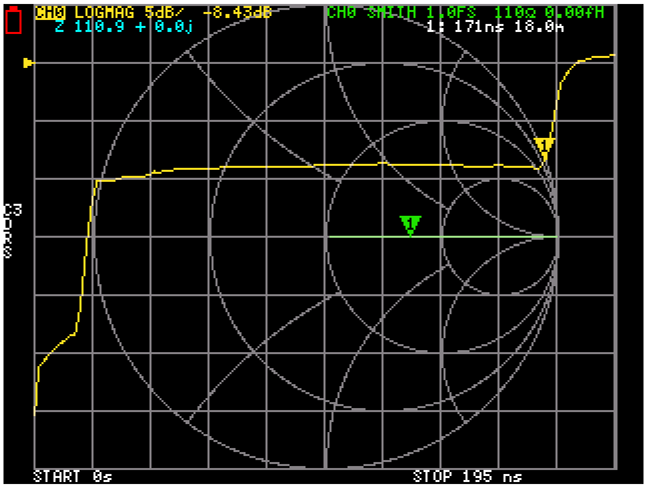

Figure 7. TDR showing time at end of unknown cable (171 ns.)

<u>Summary</u>

In summary, the impedance of the unknown cable is between 95 and 107 ohms along it's length of approximately 157 ns. Based on the fact that there are no wild perturbations in the impedance along the cable, we can be reasonably sure there are no funny splices in the cable. The physical length is still unknown because we don't know the appropriate velocity factor for this cable, but I don't really need the physical length for anything anyway.

I hope this written material helps folks understand the value of TDR measurements of unknown cables. I certainly think it is a far better approach than ripping into the walls of my house to check those cables.