TDRO-1 Time Delay Reflectometry Oscillator

A few months ago, I had cause to look for another means of measuring the length of an unknown section of coaxial cable. This was prompted by the fact that I was getting questionable results from both my RigExpert AA-650 Zoom and my NanoVNA H4. At the time, I was not sure which one, if either, was correct, and I was concerned as to why I was getting such widely differing results as I was seeing.

Doing some research online, I came up with a design idea (see Figure 1) for a basic time delay reflectometry oscillator that is extremely simple, uses a minimal parts count, and can be tailored to the characteristic impedance of the designer's choice. In the design stages, the selection of certain components will control the oscillator output frequency. The printed circuit board layout for this circuit is shown in Figure 2.

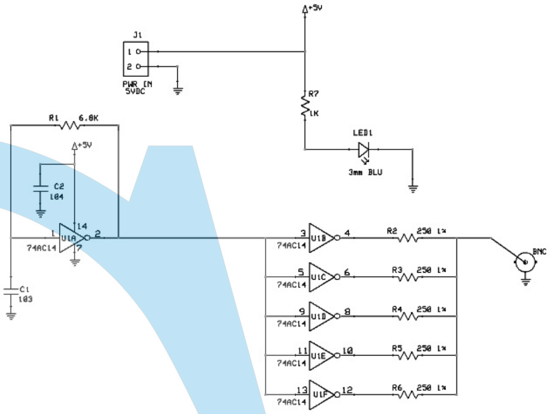

Figure 1 - TDR schematic diagram

The oscillator output frequency is controlled by the resistor and capacitor in the oscillator loop. I chose the pairing of a 0.01µF (10nF) capacitor and a 6.8kΩ resistor, which produced an output of 12.680kHz. The actual formula is $F_{OUT} = k / RC$ where k is a specific factor (discussed below), R is the oscillator loop resistance in ohms, and C is the oscillator loop capacitance in farads.

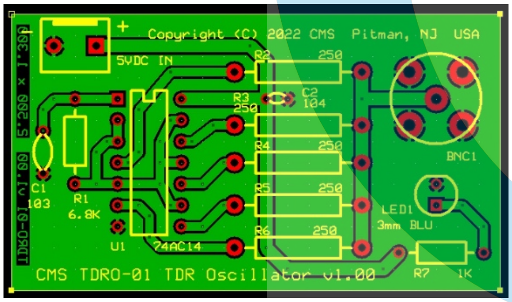

Figure 2 - PCB design

The specific factor referenced above is a fixed value typically between 0 and 2 which is based on the exact type of the device chosen as the active component in the oscillator, the supply voltage, and the rise/fall time of that active device. This specific factor is known as the *"constant value of the Schmitt Trigger".* I started out with a base constant of .85, which produces a predicted frequency of 12500 hertz (.85 / 0.000068). The value 0.000068 is derived by multiplying the nominal resistor value of 6800 ohms by the nominal capacitor value of 0.00000001 farads. Upon assembly and testing, the actual oscillation frequency turned out to be 12680 hertz or 12.680kHz as stated above. Assuming that I selected an accurate constant value, the difference between the prediction and the produced frequency would likely be due to component tolerances. If I were to accurately measure and use the true component values, I could in turn calculate the actual constant value for this particular IC and power supply configuration.

The heart of the oscillator is the 74AC14 hex Schmitt inverter IC. One of the inverter sections is used as a square wave generator with very fast rise and fall times – approximately 2nS – on the verticals of the square wave. The generated square wave is then simultaneously fed into the remaining five inverter sections, and through a parallel set of five 250Ω 0.1% 250mW precision resistors. The output signals from the parallel resistors are then combined into a single 50Ω impedance signal to the BNC output jack. The whole shooting match is built up on a 2.5” x 1.3” printed circuit board (Figure 3).

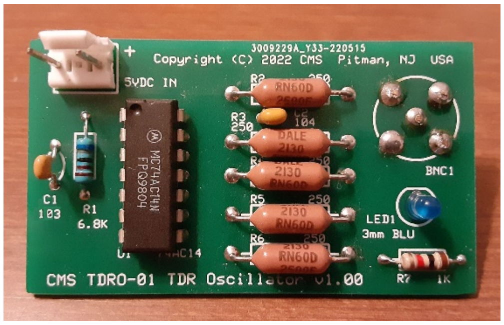

Figure 3 - Assembled TDRO

The theory behind using this oscillator to measure an unknown cable length is that the output pulse train from the oscillator is imposed upon the cable, where it travels to the opposite end of the cable. If that opposite cable end is open, the signal will be reflected back to the source. The travel time of the pulse train out and back on the cable can be measured and used to calculate the cable length.

A couple of factors must be known in order to covert the pulse travel time into cable length. We must know the speed of light, c, in terms of inches per nanosecond. This is a simple matter of arithmetic, as shown below.

$c = 186{,}000$ miles per second… x 5,280 gives us

$c = 982{,}080{,}000$ feet per second… x 12 gives us

$c = 11{,}784{,}960{,}000$ inches per second… move the decimal point nine places left to get

$c = 11.78496$ inches per nanosecond.

Next, we have to apply the correct velocity factor (VF) for the cable being measured. Typical coaxial cable would be about 66%, which in turn makes the pulse speed 7.778 inches per nanosecond ($11.78496 \text{ X } 0.66 = 7.7780736$).

The final step of the calculation involves taking the measured pulse travel time, which we will discuss shortly, and factoring that into the equation, remembering that the pulse travel time is a two-way trip, meaning we need to halve the result to get our final answer in inches of length:

$$LENGTH_{CABLE} = TIME_{MEASURED} \text{ x } 7.778 \text{ x } 0.5 \text{ inches}$$

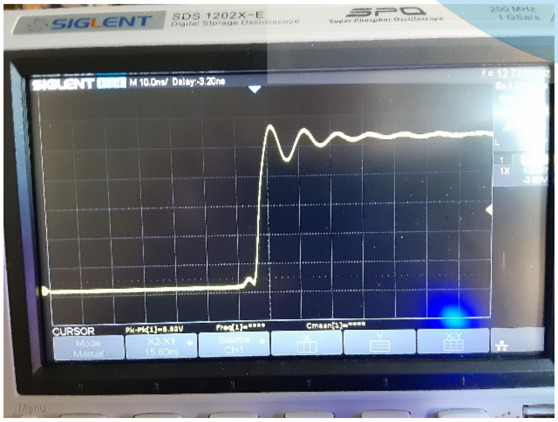

Figure 4 - First waveform

where $LENGTH_{CABLE}$ is the calculated length in inches, $TIME_{MEASURED}$ is the pulse travel time in nanoseconds, 7.778 is the pulse speed in inches per nanosecond, and 0.5 is the halving factor.

Obtaining the $TIME_{MEASURED}$ value is accomplished through the use of an oscilloscope. The TDR oscillator is connected to the oscilloscope input through a BNC tee, with the oscillator on the stem of the tee. One branch of the tee is connected to the oscilloscope with a BNC adapter, and the oscilloscope is adjusted to display a waveform of the oscillator output pulse. The unknown length of coaxial cable is then connected to the open branch of the tee and the new waveform that appears is analyzed.

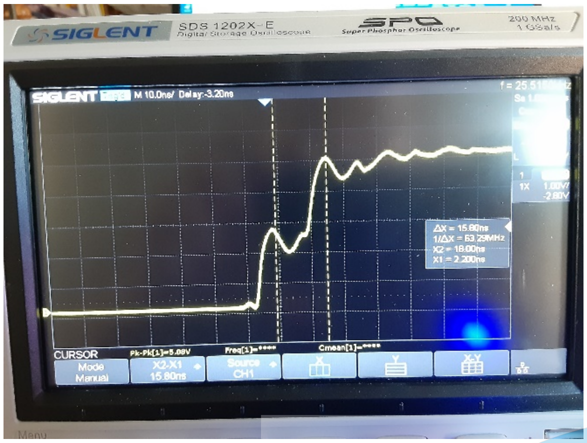

Figure 5 - Second waveform

The original waveform will show a steep rise to a ringing horizontal (Figure 4). The second waveform, with the cable connected, will show a step in the vertical (Figure 5). The time offset between the peak of the step and the peak of the overall waveform will be the value of interest. If the oscilloscope offers cursors, the time interval can be calculated by the oscilloscope with a great degree of accuracy. Without cursors, the user will need to analyze the pattern with regard to the graticule to determine the time interval.

In my initial test, the $TIME_{MEASURED}$ interval was 15.80nS. Now it is time to plug that value into the equation discussed above:

$$LENGTH_{CABLE} = TIME_{MEASURED}\ x\ 7.778\ x\ 0.5\ inches$$

$$LENGTH_{CABLE} = 15.80\ x\ 7.778\ x\ 0.5\ inches$$

$$LENGTH_{CABLE} = 122.8924\ x\ 0.5\ inches$$

$$LENGTH_{CABLE} = 61.4462\ inches$$

The actual test cable length, measured with a tape measure for validation of the method, turned out to be 59.5 inches. It can be assumed that the difference is due to the length of the adapter set used to make the connection to the oscilloscope. End result? This method works quite well. As a result, I felt safe in using this method to measure the original problem cable. As it turned out, the NanoVNA's reported length was much closer to the TDR Oscillator measurement than was the RigExpert's reading.

The result of all of this is that for just a few bucks' worth of parts, it is possible to build a very accurate time domain reflectometry oscillator that will work with any oscilloscope to give you good accuracy in the measurement of unknown cable lengths. It will work for coaxial cable, zip wire, open wire line (window line, ladder line, *etc*.), and even twisted pair wire. All that you need to make it work is the velocity factor of the wire at hand.

I have a limited number of these devices available in kit form for those who may want to build one but do not want to go through the work of laying out the circuit on a board, even though a small piece of project perf board will work well for this task. Drop me an email at ***chris@ad2cs.com*** for more information about purchasing a kit.