A PCB for the W0SJ TDR
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Introduction

In the May 2021 edition of *QST Magazine*, Stan Johnson (W0SJ) published an article describing a device one can hook to an oscilloscope to turn it into a time domain reflectometer (TDR). Stan built his basically out of parts from the junque box for which he deserves kudos!

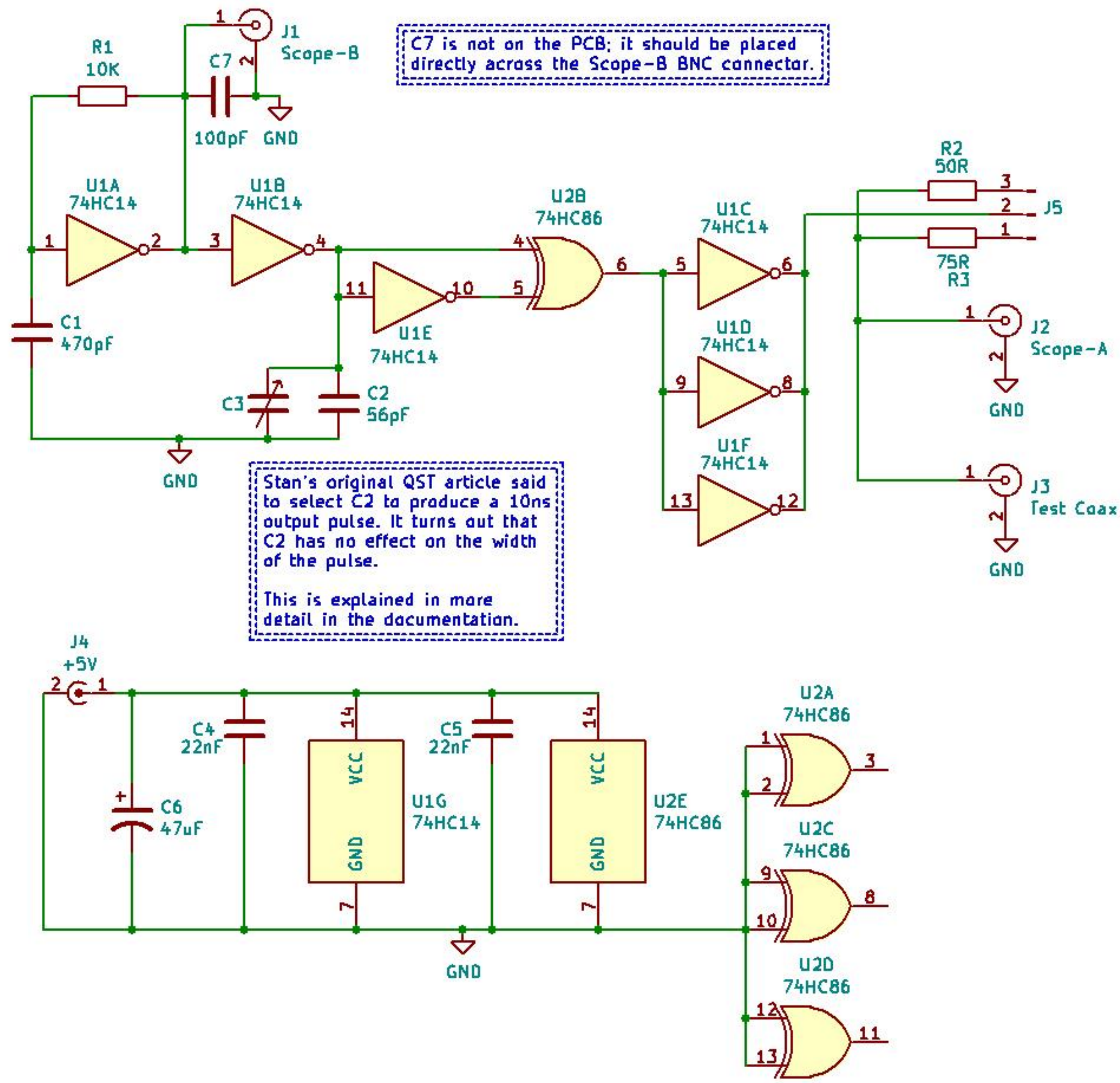
I hate hand wiring stuff so I decided to design a printed circuit board for it. My board makes a few changes in Stan's design which made the PCB layout a bit neater and added a couple of features, but otherwise it is basically the same as his design.

This document not only describes the circuit board but offers some insight into some of the things you can do with the device.

It should be noted that there are two types of TDRs. This one is a pulse type TDR and cannot do some of the things that are possible with a step type TDR. This video explains the differences.

The Schematic

Here’s the (simplified) schematic for my PCB; on the PCB there are actually provisions for two of each of the ICs; one for a DIP package and one for an SOIC-14 SMD package; the pin numbers are identical for both packages. On the PCB, the pads for the ICs are labeled as “U1/U3: and “U2/U4” to be consistent with the full schematic that was actually used to generate the PCB layout:



The *Scope-B* output is the oscillator which is used to sync the scope; trigger the scope on the trailing edge of the oscillator pulse. Note, Stan used the *Scope-A* output in his design. Switching them facilitated the PCB layout.

There are a couple of additions to Stan's original design. I added a 75Ω resistor and a jumper (R3 & J5) so that the device can be used to test either 50Ω or 75Ω coax. One could probably use a switch instead of a jumper. A better solution might be to add a proper cable TV type connector in parallel with the existing output (I used an SO-239 for that).

A second change was to add a provision for an optional trimmer capacitor (C3) which could be used in conjunction with C2 to adjust the output pulse width; I didn't use it in my build. It turns out this wasn't needed (see the section about choosing the proper value for C2 and C3).

One final addition was a 47uF filter cap on the 5V rail. Before I put it in an enclosure with proper connectors I was getting a lot of jitter on the oscillator output (*Scope-B*).

Other than that the only changes to Stan's original design was to shuffle some of the gate assignments around to facilitate the PCB layout.

Component Selection

The values of R1 and C2 as shown on the schematic are those originally specified in Stan's article. The values of both may need to be adjusted.

R1

Stan's original design specified a value of 10K for R1 and his oscillator ran at about 200 KHz in his hand wired version. When both I and Glenn (VK3PE) built the TDR both our oscillators were running at about 290 KHz; as a matter of fact I built up three of the boards and all three ran at 290 KHz. I found that changing the value of R1 to 15K produced an oscillator frequency of almost exactly 200 KHz.

C2 & C3

Stan's notes indicate that C2 in his design should be selected to produce an outgoing pulse width of 10 nanoseconds (measured at the bottom of the pulse). His original schematic specified 56pF.

I added the provision for using a trimmer type capacitor (C3) to allow the pulse width to be adjusted.

With a 56pF capacitor fitted for C2 (and no C3), I got a pulse width of about 14ns. Changing C2 to 39pF made no change in either the shape or width of the outgoing pulse.

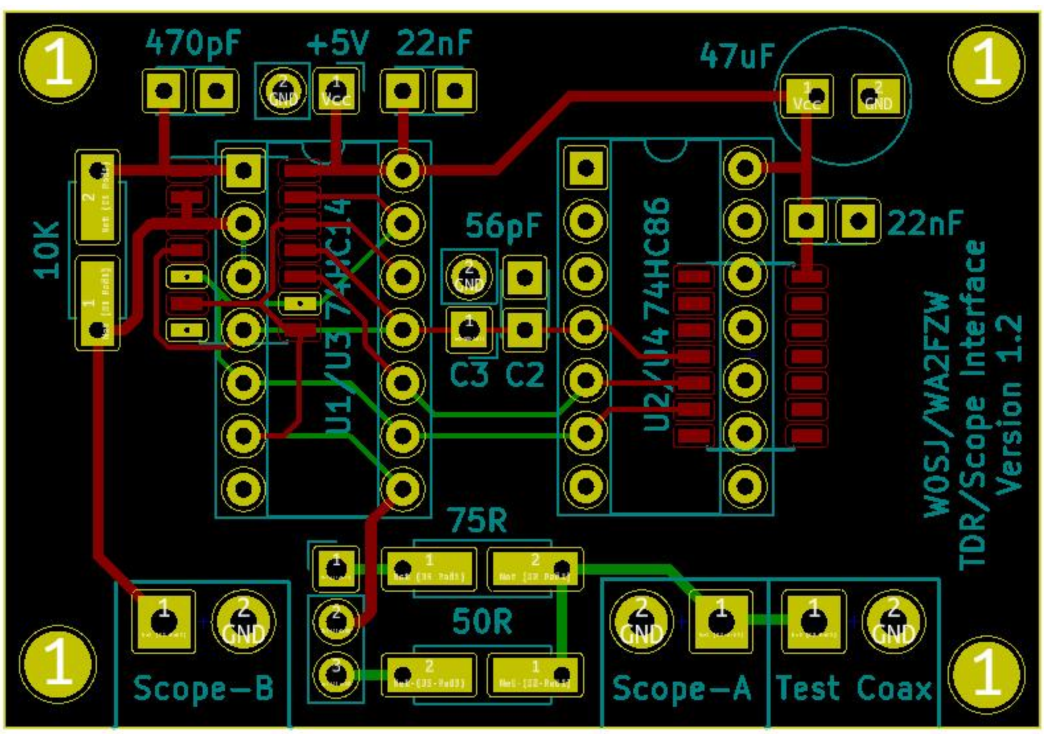
On the second unit I built, I tried completely leaving C2 out and then tried a number of values between 22pF and 140pF. There was absolutely no change in the duration or shape of the pulse with any value I tried.

Glenn used a pair of 39pF capacitors in parallel (total = 78pF) and got a pulse width of 12ns.

Based on these results, Glenn and I believe the value of C2 (in conjunction with C3) has little or no effect on the pulse width, but rather the pulse width is completely controlled by the gate delay of U1E specified as t_{PHL} and t_{PLH} on page 5 of the [74HC14 datasheet](). The specification is less than 15ns with Vcc at 4.5V. The 14ns I'm seeing is therefore within the specification.

The PCB

Here's what the Version 1.2 board looks like:

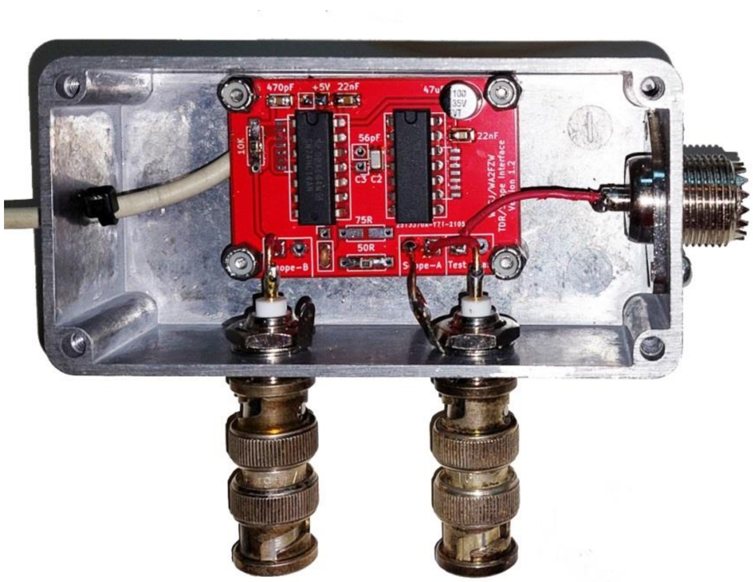


It measures 1.95” x 1.3”. The red traces are on the top side and the green ones (X-Ray view) are on the bottom side of the board.

Notice that the PCB is designed such that it can be populated using through-hole parts or SMD parts or a combination of both which is what I did in the original build. I had already ordered the ICs in DIP packages before I did the board design, but I used SMD parts for the resistors and capacitors. I did build a complete SMD version later.

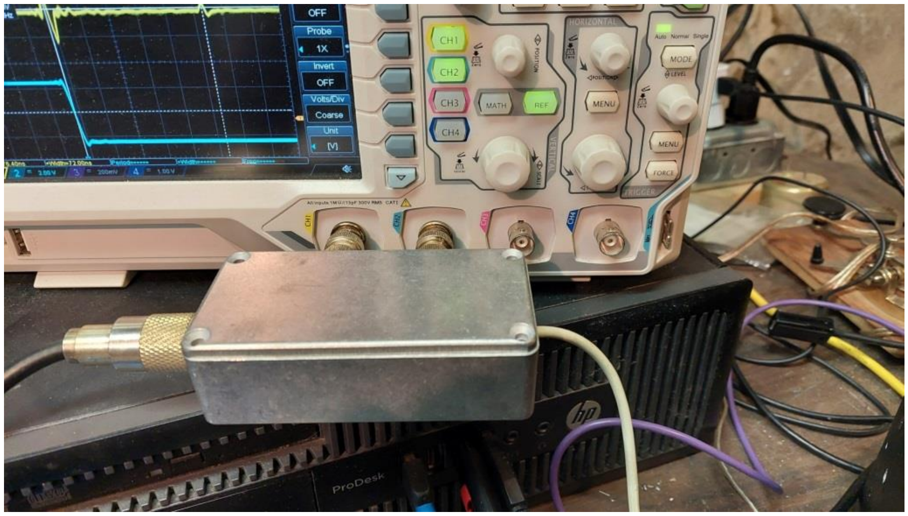
The Finished Project

Here’s my final assembly (with the SMD/THT hybrid PCB):



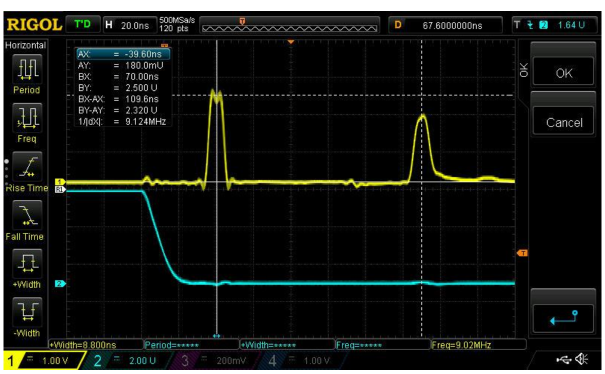
I didn’t bother fitting the 75 ohm resistor (R3) on this build.

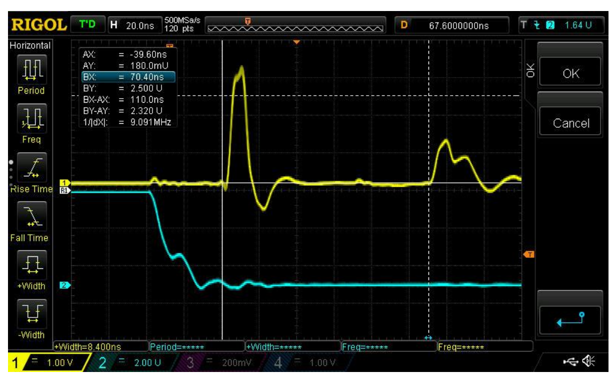
And here it is attached to the scope:



The enclosure is a [Hammond 1590G2]() which measures 3.9” x 2” x 1.1”.

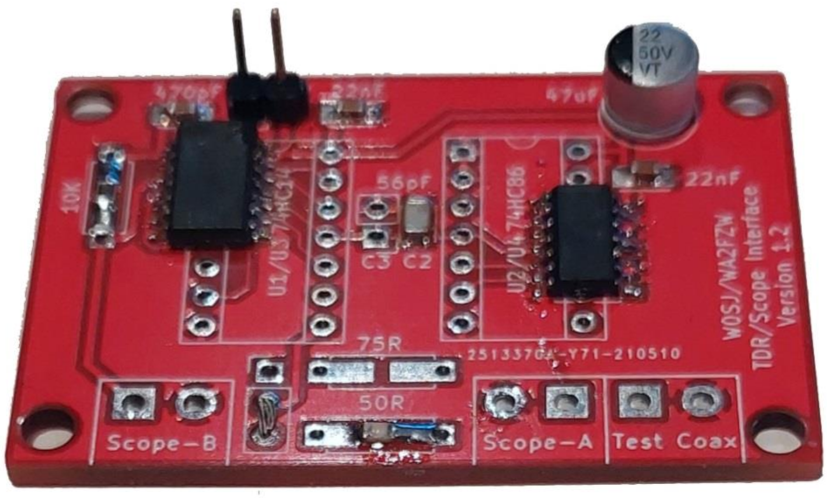
Notice that the device is attached to the scope with a pair of BNC double male connectors. Stan mentions this in his QST article, but didn’t explain clearly why this approach is necessary. If one was to use coax cables between the TDR and the scope, the capacitance inherent in the cables affects reflected pulse as shown in the following two pictures; the one on the left is with the unit connected directly to the scope as shown above and the one on the right is what you see with two 3 foot lengths of RG-316 connecting the unit to the scope:





Notice the ringing on the outgoing pulse and the distortion on the returned pulse in the right hand picture. Also notice there is some added delay between the falling edge of the oscillator pulse and the outgoing test pulse.

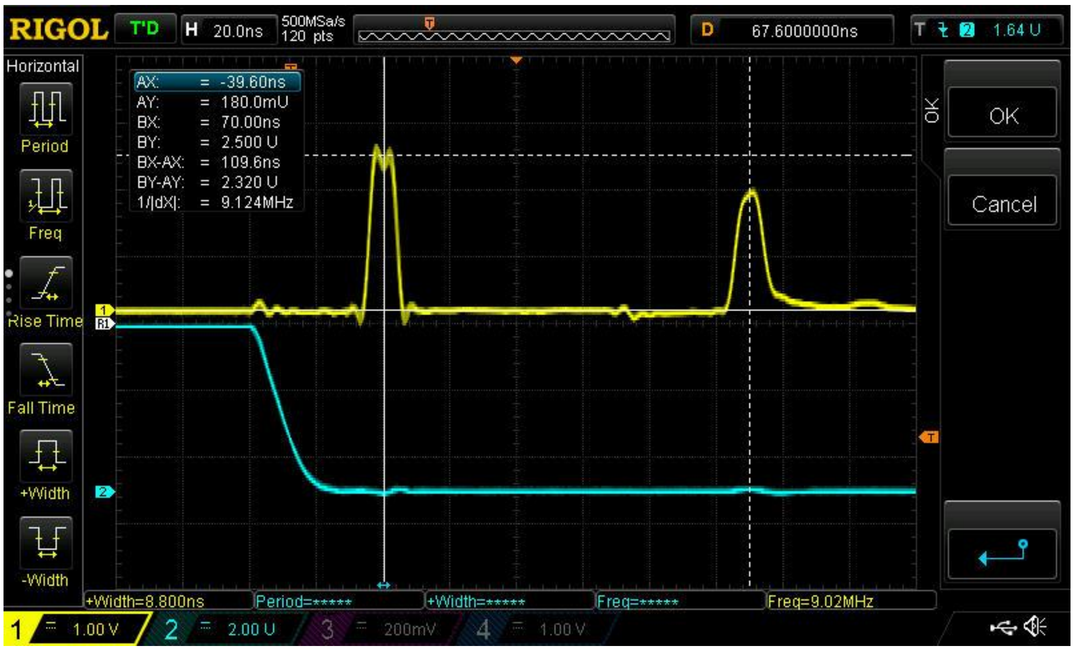
Here's the populated completely SMD PCB:



What It Looks Like in Operation

The following pictures show what I see on the scope with approximately 36 feet of RG-8X and various terminations:

1 – Unterminated Coax (Open):



Note that the difference in amplitude can give you some idea of how lossy the cable is. When I did this with a [36 foot piece of LMR-400], there was almost no noticeable difference in the amplitude of the outgoing pulse and the reflected one!

2 – Shorted:

Here the return pulse is inverted as opposed to the unterminated example where the return pulse is positive going.

3 - 50Ω Termination:

Notice there is a very small return pulse indicating that the termination is not a perfect match to the coax or it may be from the connector at the far end of the coax.

4 - 100Ω Termination:

Here, the return pulse is smaller in amplitude than either the open or shorted examples as only part of the signal is being reflected.

Interpreting the Measurements

Determining the Length

Here’s a marked up copy of the trace we saw with the coax unterminated:

The blue arrow shows a reflection of the small transient that got transmitted as the oscillator pulse started to fall.

The left hand red arrow indicates the outgoing pulse and the right hand red arrow is the reflected pulse. This was done on a Rigol DS1074Z Oscilloscope which has the ability to activate two cursors that can be moved to any place of interest on the screen. Here I have them set on the peaks. In order to really get accurate measurements it really is necessary to use this on a scope with the cursor functionality.

When you activate the cursors, the scope also displays some useful data in the upper left corner of the display. The data of interest here is highlighted in the red box. It might be a bit hard to read in the screenshot, but it says:

BX – AX = 109.6ns

indicating that the time between the two pulses is 109.6 nanoseconds which is the time the pulse took to reach the far end of the coax and return. In other words, the time it took the pulse to get from the TDR to the far end of the coax is half of that time or 54.8 nanoseconds.

Stan gives the formula for calculating the length of the coax in his article as well as the calculations for a couple of other things that you can use the device to measure.

Here's a simplified version of the formula used to determine the length of the coax:

L (in meters) = 0.3 * v * T / 2

Where:

v is the velocity factor for the coax (nominally 0.66)

T is the total time (BX – AX)

0.3 is the speed of light in meters per nanosecond

So plugging in some numbers:

L = 0.3 * 0.66 * 109.6 / 2

L = 10.8504 meters

To convert to feet:

L (in feet) = L (in meters) * 39.47 / 12

L = 35.69 feet

Which just so happens to be the exact length of the two connected pieces of coax I was using for the tests!

But it's Not Really RG-8X!

Two different datasheets (from different manufacturers) I looked at for RG-8X specify the velocity factor as being either 0.78 or 0.82, however based on the time differences observed, the velocity factor of what I have has to be 0.66. If you have a known length of coax, you can use the TDR to determine the velocity factor which is essentially what I did. That process is described in Stan's original article in QST.

This brings up an interesting point and a good reason to have a TDR!

Anytime you need to build something where a specific length of coax is required (for example a balun for an antenna) it's a good idea to use the TDR to determine the actual velocity factor of the coax to be used and then use that value to determine the physical length needed.

But note, you'll have to measure a significant length of the coax to be used before cutting it to the desired length. Why? If you watched the video describing the differences between pulse type TDRs and step type TDRs referenced in the *Introduction*, you learned that a pulse type TDR is blind for the duration of the outgoing pulse. As the outgoing pulse on this unit is about 14ns, the minimum length of coax (with a 0.66 velocity factor) that it is capable of measuring is a little over 4 1/2 feet (1.385 meters).

There's an App for That!

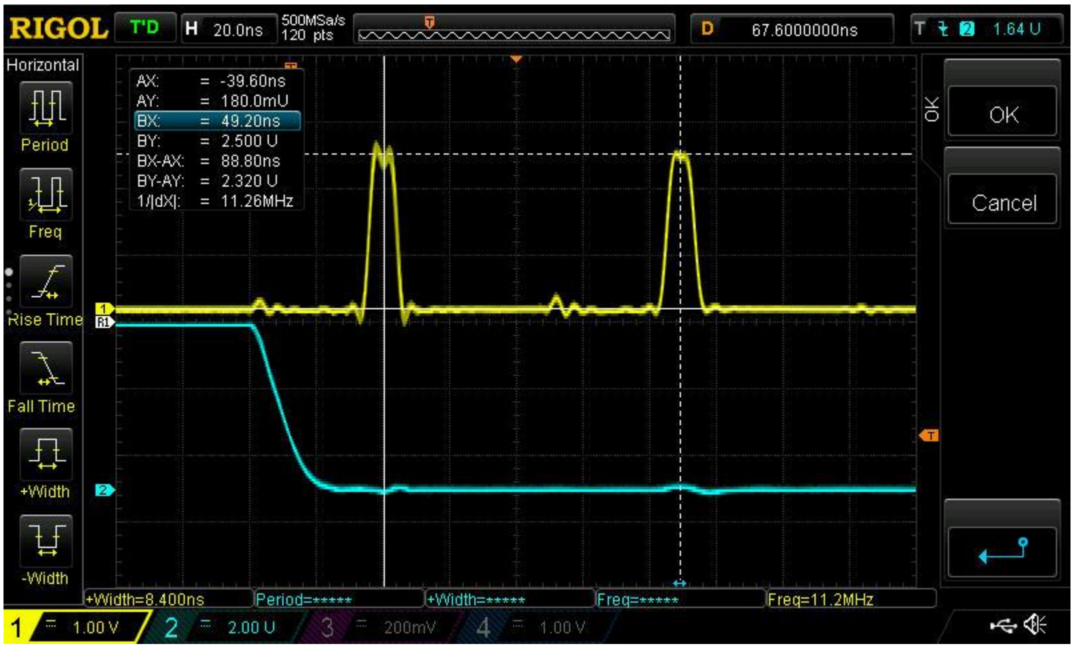
Actually, there are two apps for that!

Included in the distribution files you will see a file named "TDR_Length_Calc.apk". This is an Android app developed by Roderick Wall (VK3YC) that will do the length calculations and provide the answer in both meters and in feet, inches and 16ths of an inch.

Also in the distribution package is a file named "TDR_Vel_Calc.apk". This is a second Android app developed by Roderick which allows you to enter the length of a piece of coax (in meters or feet, inches and sixteenths of an inch) and the time difference from which it will calculate the velocity factor.

Low-Loss Coax

Here's another scope trace for an unterminated 36 foot length of LMR-400 coax:



Notice that the amplitude of the reflected signal is almost equal to the outgoing signal. This is a way of determining how lossy a piece of coax is. Compare this to the trace for the 36 foot length of RG-8X above. Big difference! This explains why LMR-400 is a favorite of us VHF/UHF guys.

A Couple of Issues

When I started building the TDR, before I had it in an enclosure with proper connectors, I was seeing a lot of jitter on the oscillator output. Once I had the unit properly finished, the jitter is no longer a problem when running it from a wall wart or the USB port on the scope.

But just in case, the Version 1.2 PCB includes a provision for a 47uF (or higher) filter cap on the 5V rail which should fix the problem. I actually used 100uF as I didn't have any 47uF ones.

If you look at the scope trace in the section on *Determining the Length*, you might notice that the outgoing pulse has a double peak. I think it's being caused by a reflection from one of the coax connectors, but haven't been able to conclusively prove that or correct it yet. It doesn't seem to be a problem in making measurements however.