TDR EVALUATION OF THE TEKTRONIX 012-0482-00 CABLE FOR THE SG503 LEVELED SINE WAVE GENERATOR *(REVISED AND UPDATED)*

Dennis Tillman W7PF, MAY 25, 2019

Every few years on the TekScopes Forum, someone will ask one or more of the following questions:

1. "Is it really necessary to use only the 012-0482-00 cable called out in the manual on the output of the SG503 Leveled Sine wave Generator"?
2. "Why is the 012-0482-00 so hard to find and why is it so expensive"?
3. "How does the 012-0482-00 different from any other coaxial cable"?

I can't answer the first question because I don't know precisely why the 012-0482-00 is required by the SG503. To put it another way "Does the 012-0482-00 have some special characteristic(s) not shared by any other cable" that is necessary for the SG503 to meet its specifications? I don't know.

The answer to the second question is: Only one thing distinguishes this cable from any other 50Ω coax cable that I am aware of–it doesn't bend as easily –so almost nothing prevents it from being separated from the SG503. I if it isn't kept with the SG503 it might be mixed with all the other coax cables, abused, and/or discarded, because it was not flexible enough or long enough, etc.

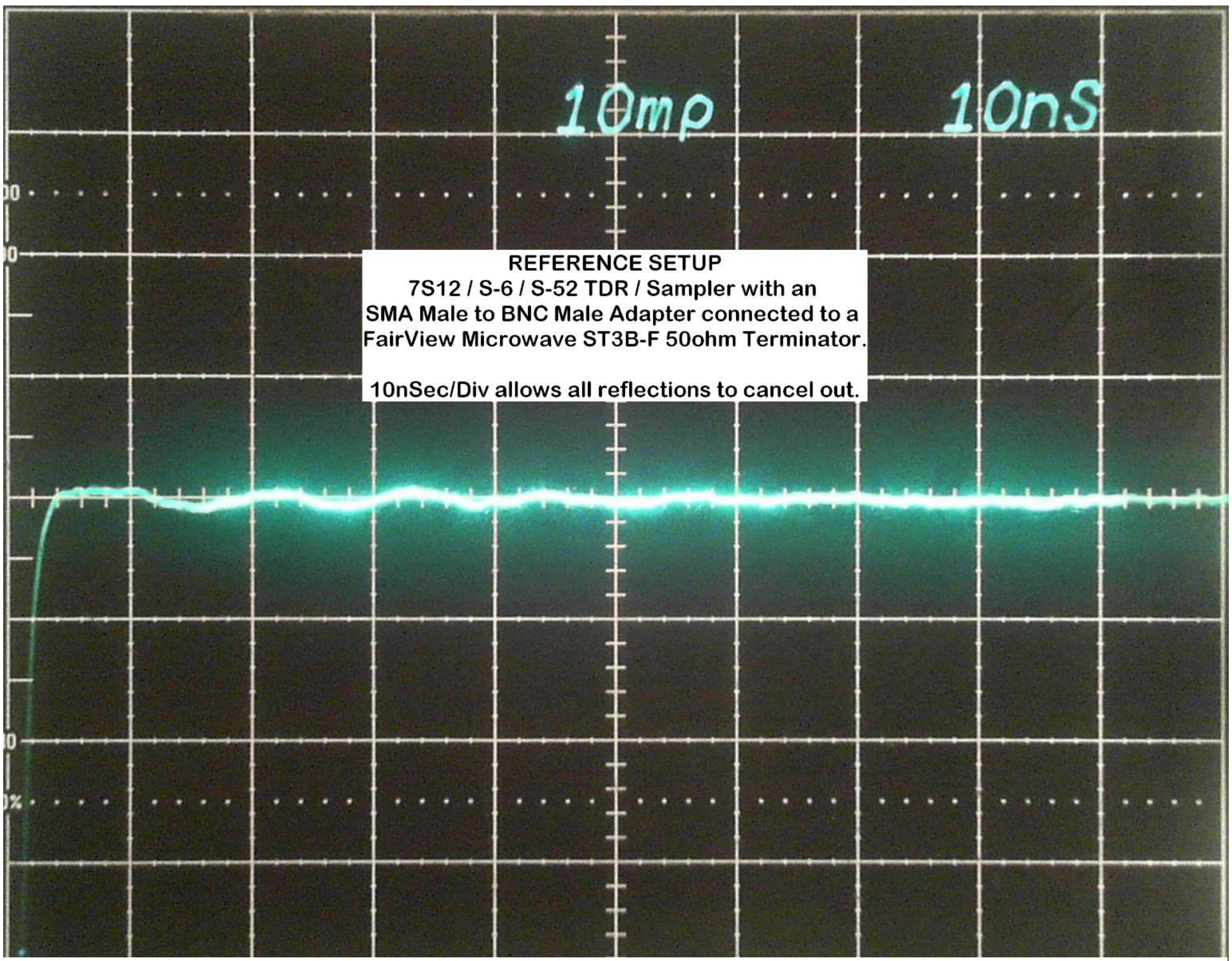

Figure 1 7S12 / S-6 / S-52 TDR Sampler with Tektronix 015-1018-00 SMA to BNC adapter and a Fairview Microwave Inc. ST3B-F 50Ω Terminator; no cable.

I set out to answer the third question by examining the characteristics revealed by a Tek 7S12 TDR / SAMPLER plugin. If there was something special about the electrical characteristics of the cable, the TDR should show what they are.

I began by assuming this cable was precision made. I found the very best SMA to BNC adapters and 50Ω loads I owned so that they would contribute as little as possible to the results. Towards that end, I documented the performance of the SMA to BNC adapters and 50Ω loads I used prior to connecting them to the 012-0482-00 cable. For these tests I chose components that had the lowest TDR reflections. The result is Figure 1 which shows the reflections are less than 2mρ. So ρ = 0.00 ±1mρ. This corresponds to a 50.0Ω ±0.1Ω impedance and VSWR of 1.004.

Also visible in Figure 1 is the level of the trace prior to when the reflections die out at about 65nSec. Z_0 after 65nSec is 50Ω exactly (ρ = 0). The ripples from the adapter and the 50Ω terminator are at the same level indicating the impedance of the signal prior to 65nSec varies less that ±0.1Ω from 50Ω.

***I just found out exactly what was used to make the cable and its important characteristics**.*

The Tektronix Common Design Parts Catalog #6 *Wire, Insulation, and Power Supplies*, says this about the entire 012-0482-00 cable: I bolded the most important parts of each catalog entry:

> *Cable Interconnecting, RF, 50Ω,* ***Precision BNC Male Both Ends, Length 36"***

The same catalog lists the coax used in this cable as 175-1455-00 which is described as:

> ***50Ω ±1Ω****, 0.210"OD PVC Outer Jacket, 0.170"OD Double Shielded Silver Plated Copper, 0.120"OD Polyethylene Dielectric, 0.036" solid Silver Plated Copper center conductor.*

The Tektronix Common Design Parts Catalog #4: *Electro-Mechanical*, indicates the Male BNC connector is 131-0125-00. The connector is described as follows:

> *RF Connector,* ***Male BNC, 50Ω Impedance****, 500Volt,* ***RG****55, 58,* ***223U cable size****,* ***Crimp Style***

Tektronix used their own proprietary precision 50Ω Male BNC connectors on the ends of this cable.

So the critical requirements of a replacement for the 012-0482-00 cable are:

> ***50Ω ±1Ω RG223U Coax, Length 36", Precision BNC Male, Crimp Style, Both Ends***

Some things to know when thinking about making a replacement for the 012-0482-00:

1. Tektronix used their own proprietary precision 50Ω BNC connectors which may be impossible to buy since almost all commercially made BNC connectors are 52Ω.
2. The ratio of outer diameter of the inner conductor to the inner diameter of the outer conductor primarily determines a cable's impedance. Attention to detail during manufacturing determines the tolerance. The cable must have an impedance that is 50Ω ±1Ω. This will affect the ripple in the frequency domain, i.e. its flatness.
3. Cable tolerance is almost impossible to find in manufacturer's specifications. It is rare for a manufacturer to list it. Alternatively this web site lists tolerances for 50Ω, 75Ω, and 93Ω coaxial cable specified by official cable standards:

   > https://www.wiremasters.net/products/grid?productname=m17%2F84-rg223-wiremasters-is-a-stocking-distributor&categories=all-coax-cables

   From this web site RG223U has a ±2Ω tolerance so Tek had their own ±1Ω tolerance RG223U made. NOTE: RG58/U and RG58 A/U are not acceptable since their tolerance is ±3Ω.

4. The dielectric constant of the insulator between the inner and outer conductors determines the cable's velocity factor. Polyethylene has a dielectric constant ε = 2.25.

$$Velocity\ Factor = \frac{1}{\sqrt{\varepsilon}} = \frac{1}{\sqrt{2.25}} = 0.667$$

5. Skin effect loss is heavily dependent on the diameter of the inner conductor and the conductivity of the material used for the inner conductor, which is almost always copper. Since the impedance depends on the ratio of the inner to outer conductors, the same diameter cable will have about the same skin effect loss. Skin effect losses will result in a slight upward slope of the TDR because they add up with length. If the transition from the end of the cable to the 50Ω termination is flat, the cable is 50Ω, as the cable and the termination have the same skin effect resistance in series.

6. The cutoff frequency of the coax is irrelevant because the SG503 is limited to 250MHz.

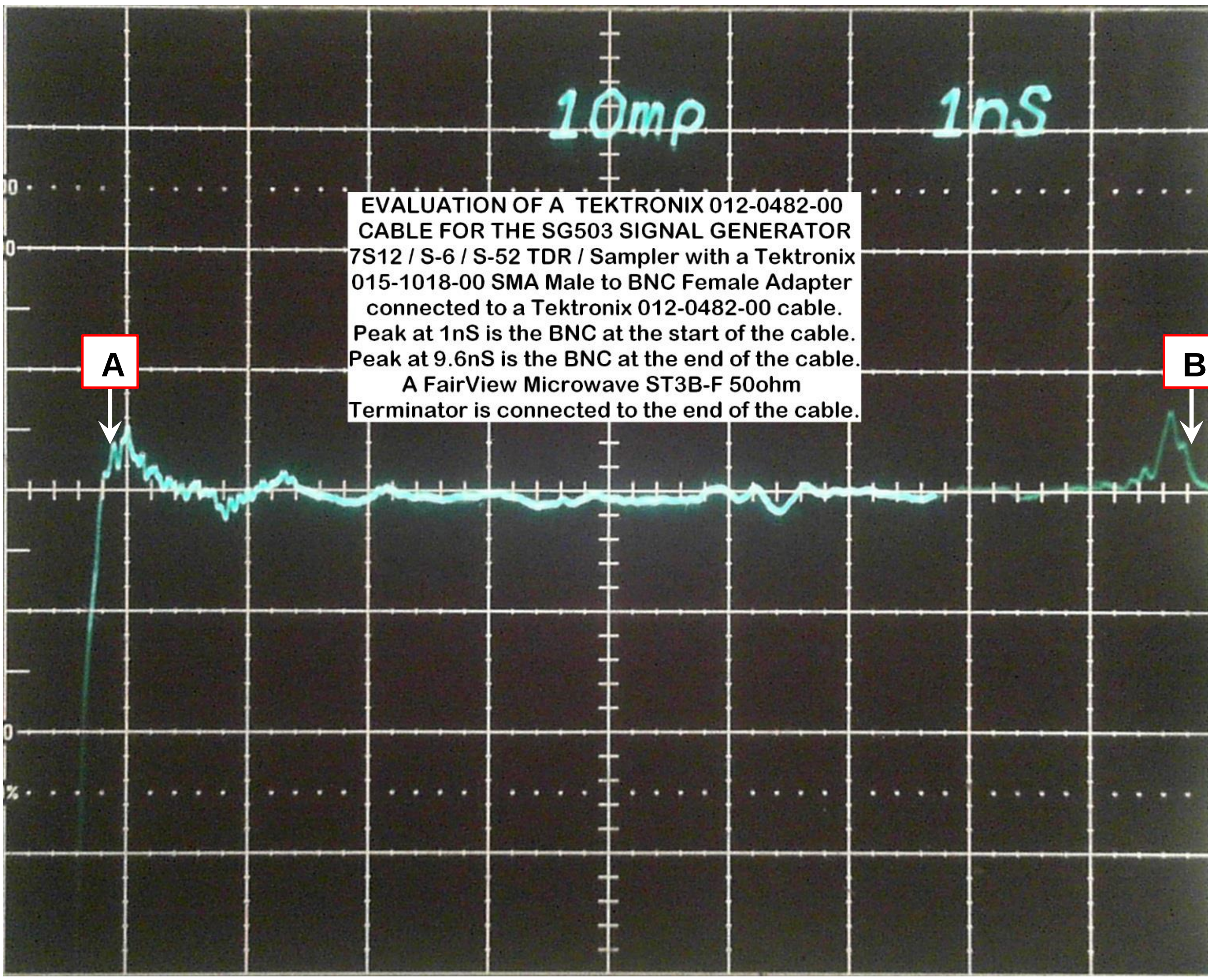

Figure 2 Same setup as Figure 1 but with the 012-0482-00 cable installed.

In Figure 2, we have inserted the 012-0482-00 cable into the circuit. ρ = 7mρ / -1mρ for a variation of 49.99Ω to 50.705Ω. The BNC connector at the far end of the cable is not mating perfectly with the SMA to BNC adapter creating a small mismatch of 7mρ. This physical mismatch between the male BNC connector and the female BNC terminator results in a slightly capacitive increase in the impedance.

We can estimate the Velocity Factor from the TDR results as follows: The round trip time from point A to point B and back to point A is 9.0nSec. The cable is precisely 36.0" long (0.914m) from end to end. The last thing we need to know is that light travels at 0.2998 m/nSec in a vacuum.

$$Velocity\ Factor = \frac{speed\ of\ light\ in\ the\ cable}{speed\ of\ light\ in\ a\ vacuum} = \frac{\frac{cable\ length}{1/2 \times time\ from\ A\ to\ B}}{0.2998m/nSec} = \frac{\frac{0.914m}{1/2 \times 9.0nSec}}{0.2998m/nSec} = 0.677$$

The 0.677 estimated velocity factor from the TDR is within 1½% of the actual velocity factor of 0.667

Figures 3 and 4 show the BNC connections at each end of the cable in more detail.

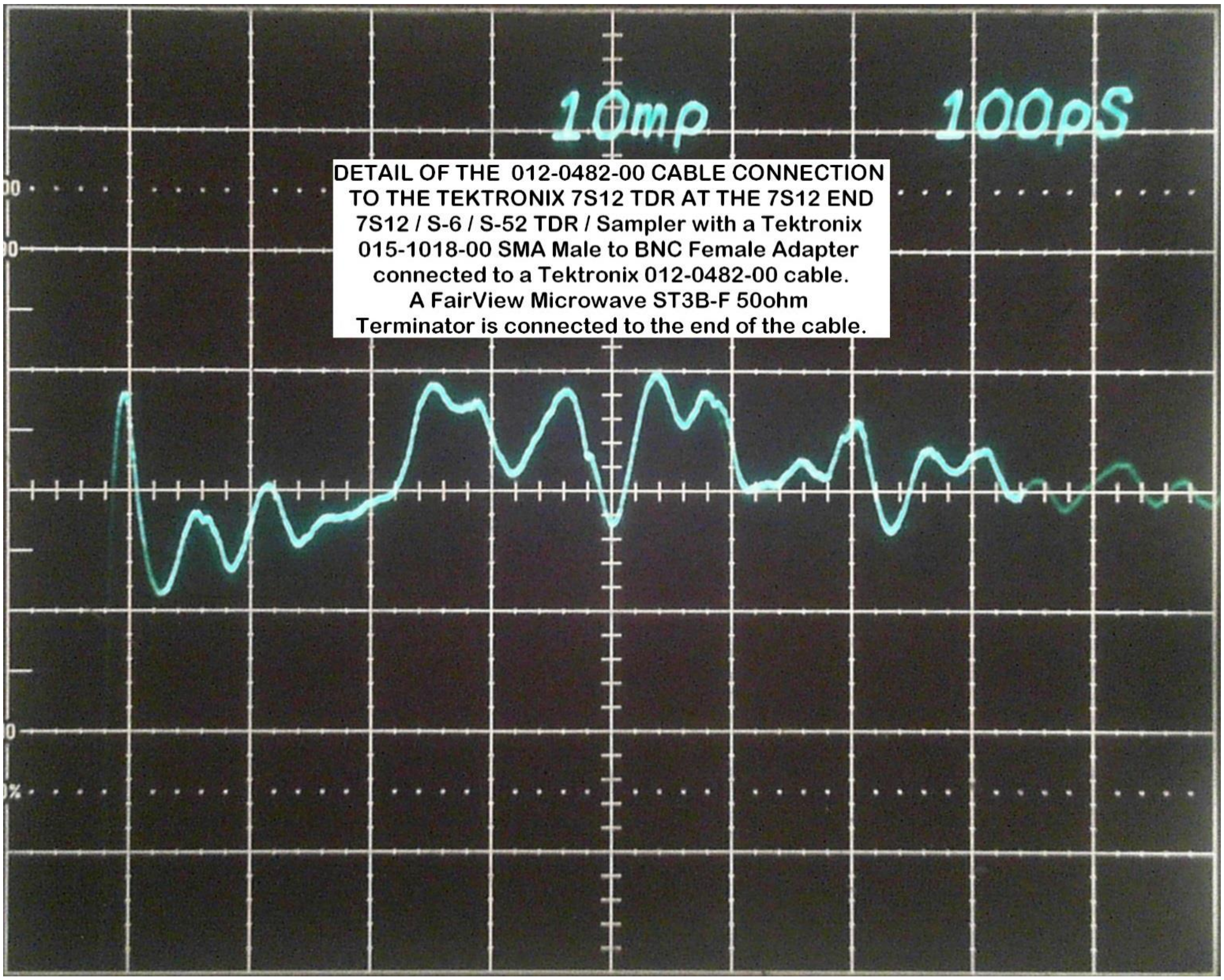

Figure 3 Detailed view of the BNC closest to the TDR. The pulse emerges from the TDR at the 100pSec graticule line. There are many small reflections at this end which are probably from within the S-6 Sampling Head and its loop through back to the S-52 Pulse Generator. The largest reflection (between 350pSec and 600pSec) is probably due to the BNC connector.

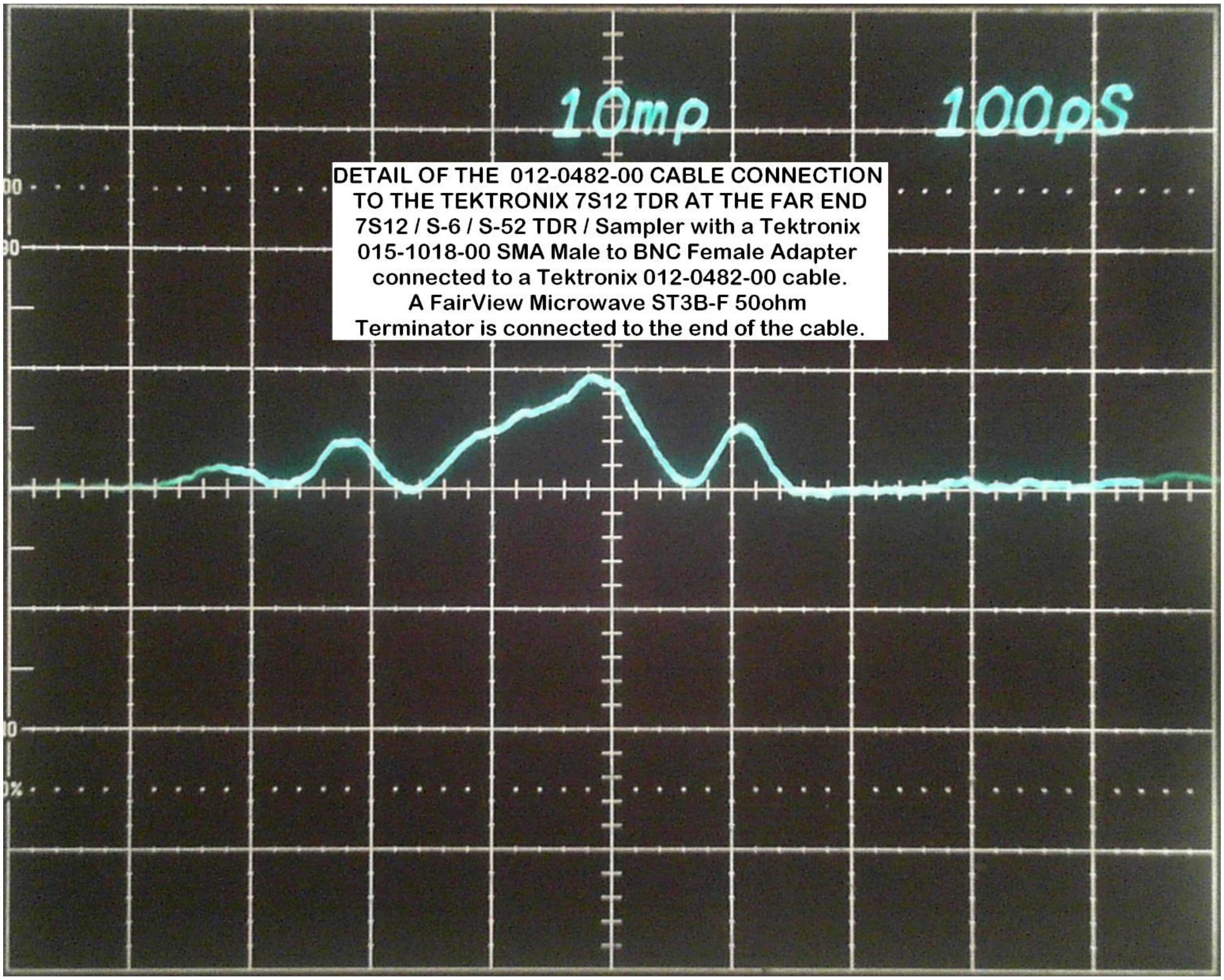

Figure 4 Detailed view of the TDR response at the far end of the 012-0482-00. This is probably due to the BNC connector at that end. The amplitude and duration of the reflection can be reduced slightly by pushing the terminator into the BNC more tightly.

Figure 5 012-0482-00 BNC Male connectors.

TEKTRONIX INC. 012-0057-00 Z0 = 50Ω COAX CABLE ASSEM.

This cable is 43.125 inches long / 1.095 meters. The cable is marked “50 OHM S-300”. There is no reference to S-300 cable on the internet. The diameter of this cable is 0.190-inches and it is as flexible as other coax.so it is not made from the same cable as the 012-0482-00.

Here is the response of this cable. The most notable difference is the slow variation of impedance along the length of the cable. While it isn’t much in absolute terms (5mρ) it is a lot more than the 012-0482-00. Compare this photo to Figure 2. The 5mρ variation means the cable starts out at each end with an effective impedance of 50.5Ω and drops to 50.0Ω at the midpoint.

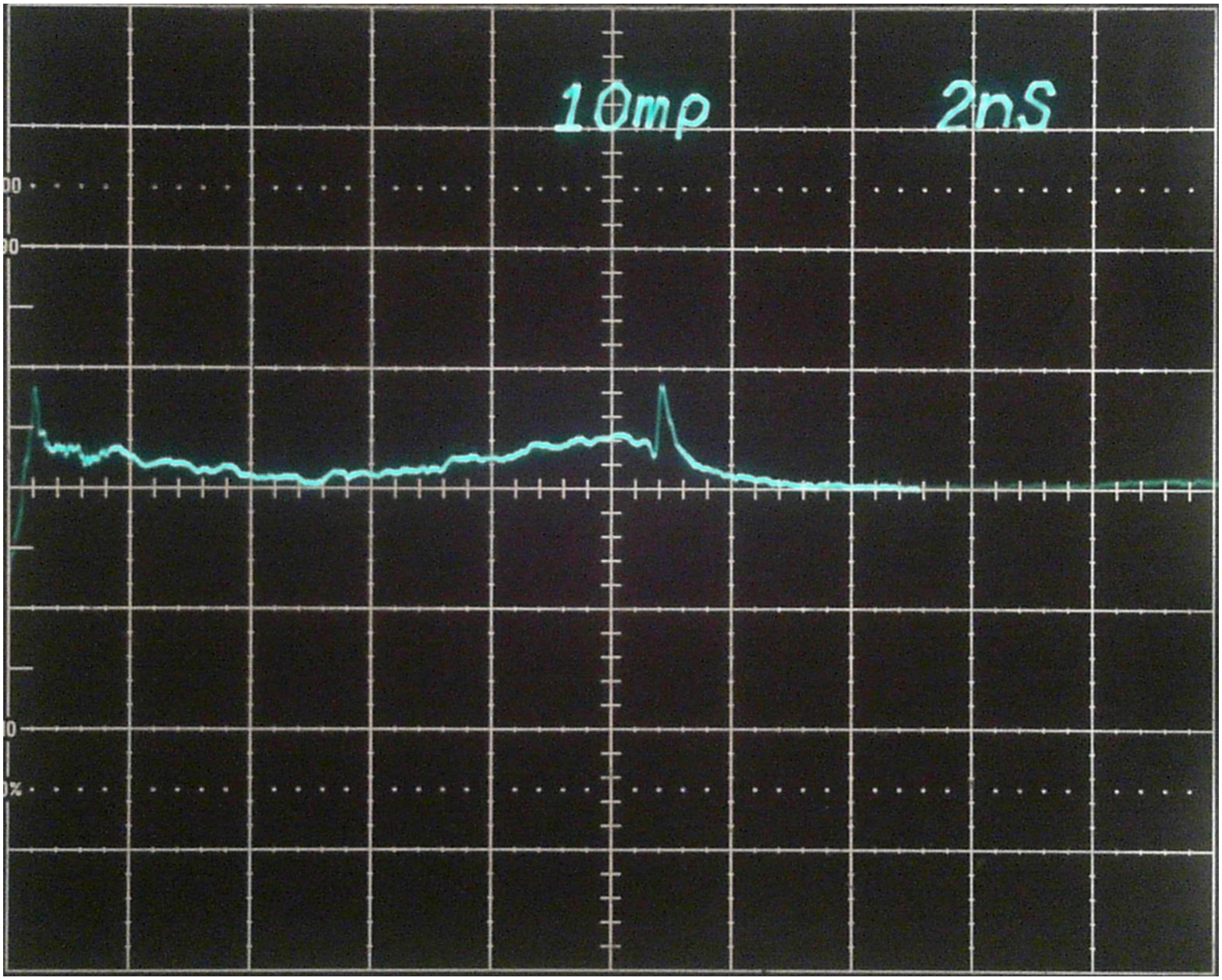

Figure 6   Tektronix 012-0057-00 50Ω coax cable.

POMONA ELECTRONICS #2249-C-36 COMMERCIALLY AVAILABLE 42.5 INCH COAX CABLE

For comparison purposes, I included a commercially made cable from Pomona Electronics, a reputable manufacturer of cables. The coax cable was manufactured by Belden Inc., which says their #8262 RG-58C/U cable impedance is 50Ω, and it is made of 20 AWG Stranded TC, TC Braid, and a Non-contaminating PVC Jacket.

From the TDR response, it is apparent the Belden coax used in this Pomona cable is NOT 50Ω in spite of what the manufacturer of the cable claims. It is actually 50.6Ω. This will result in a VSWR of 1.012.

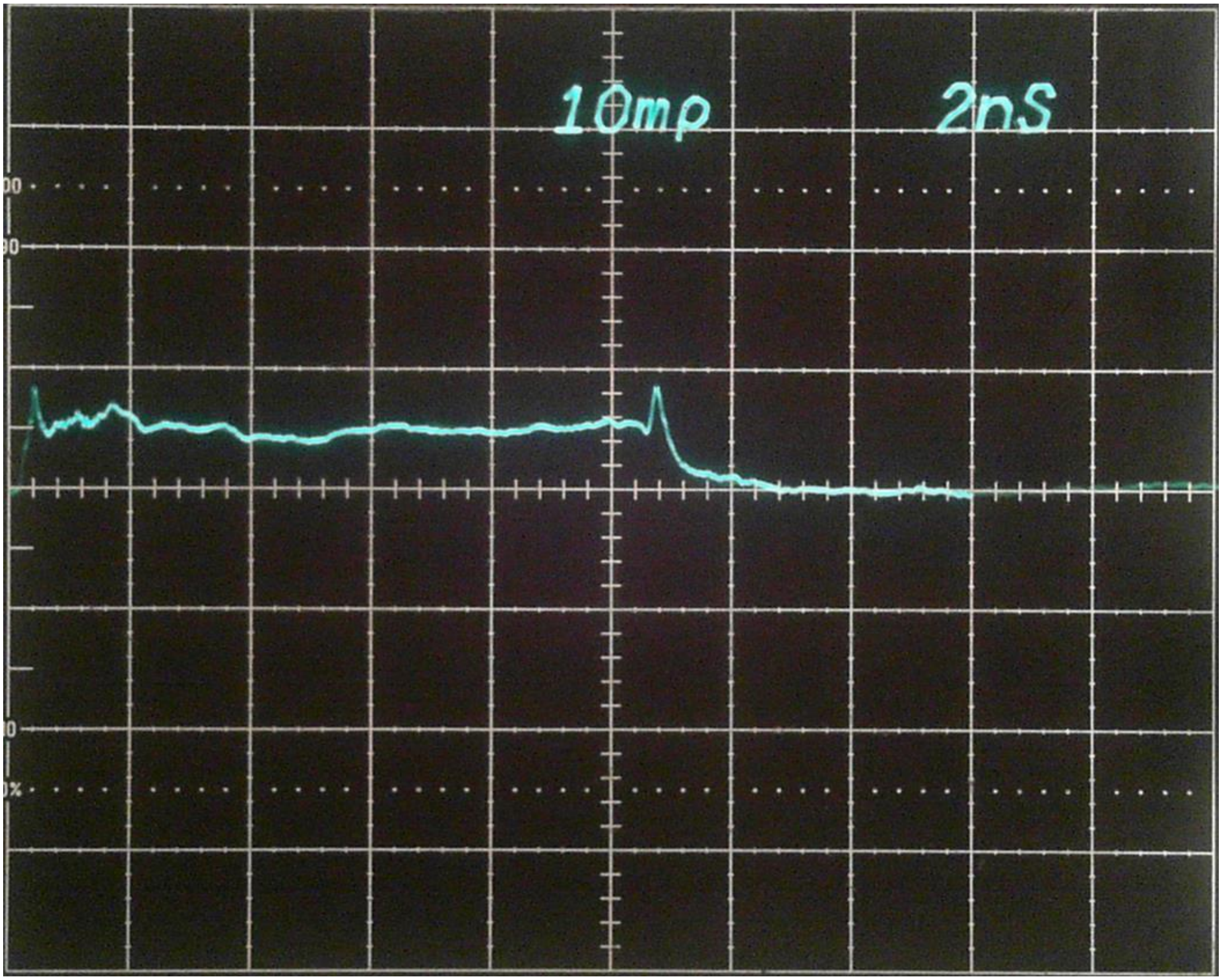

Figure 7 Pomona Electronics #2249-C-36 coax cable made with Belden #8262 RG-58C/U coax. The length is 42.5 inches.

THE IMPORTANCE OF GOOD ADAPTERS

In the previous photos, I was using the best SMA to BNC adapter I could find. Coincidentally it was made by Tektronix and it is a very unique design. The part number is 015-1018-00. Refer to the leading edge of Figures 2 and 3 for what the performance of the Tektronix adapter looks like.

Unfortunately, there is no way to tell how well an adapter will perform from its appearance. This particular adapter's response, shown in Figure 8, has a severe case of "dribble up". This will happen when an adapter passes high frequency components of a signal with less attenuation than some low frequency components. When testing a coax cable this characteristic shows up as a rapid pulse transition for the first half or more of the step followed by a much slower rate of rise.

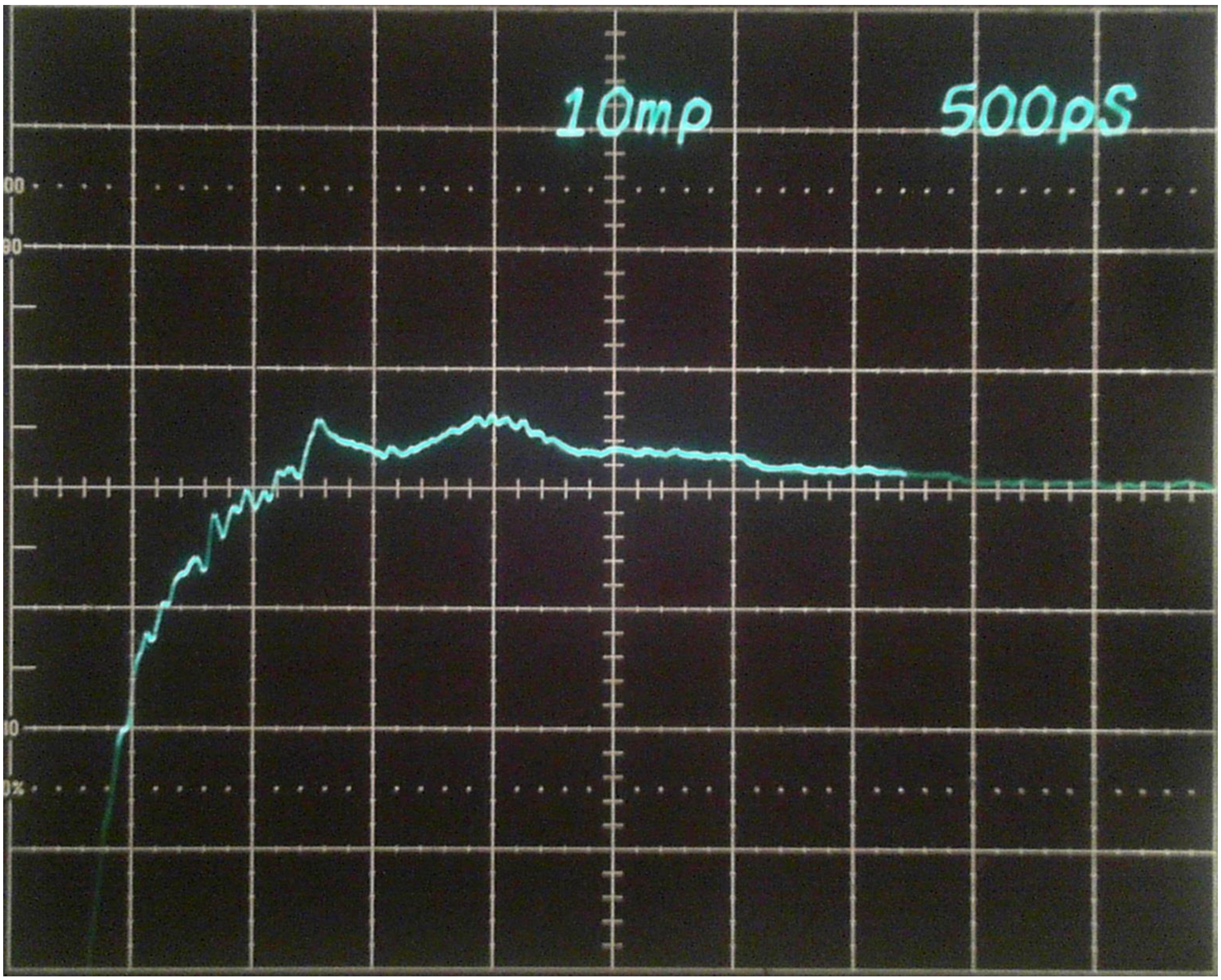

Figure 8 SMA to BNC adapter with significant "dribble up".

0The TDR response shown in Figure 9 indicates that this SMA to BNC adapter has a very large shunt capacitance where it mates with the SMA connector of the S-6 Sampling Head. It would be easy to miss this since it occurs right at the beginning of the TDR's response curve. This is very brief (120pSec) and very large (at least 60mρ or more because the edges are so steep). The impedance at this point is less than 43.5Ω: This will create significant reflections on any transmission line.

$$Z = Z_0 \times \frac{1+\rho}{1-\rho} = 50\Omega \times \frac{1+(-0.07)}{1-(-0.07)} = 50\Omega \times \frac{0.93}{1.07} = 43.5\Omega$$

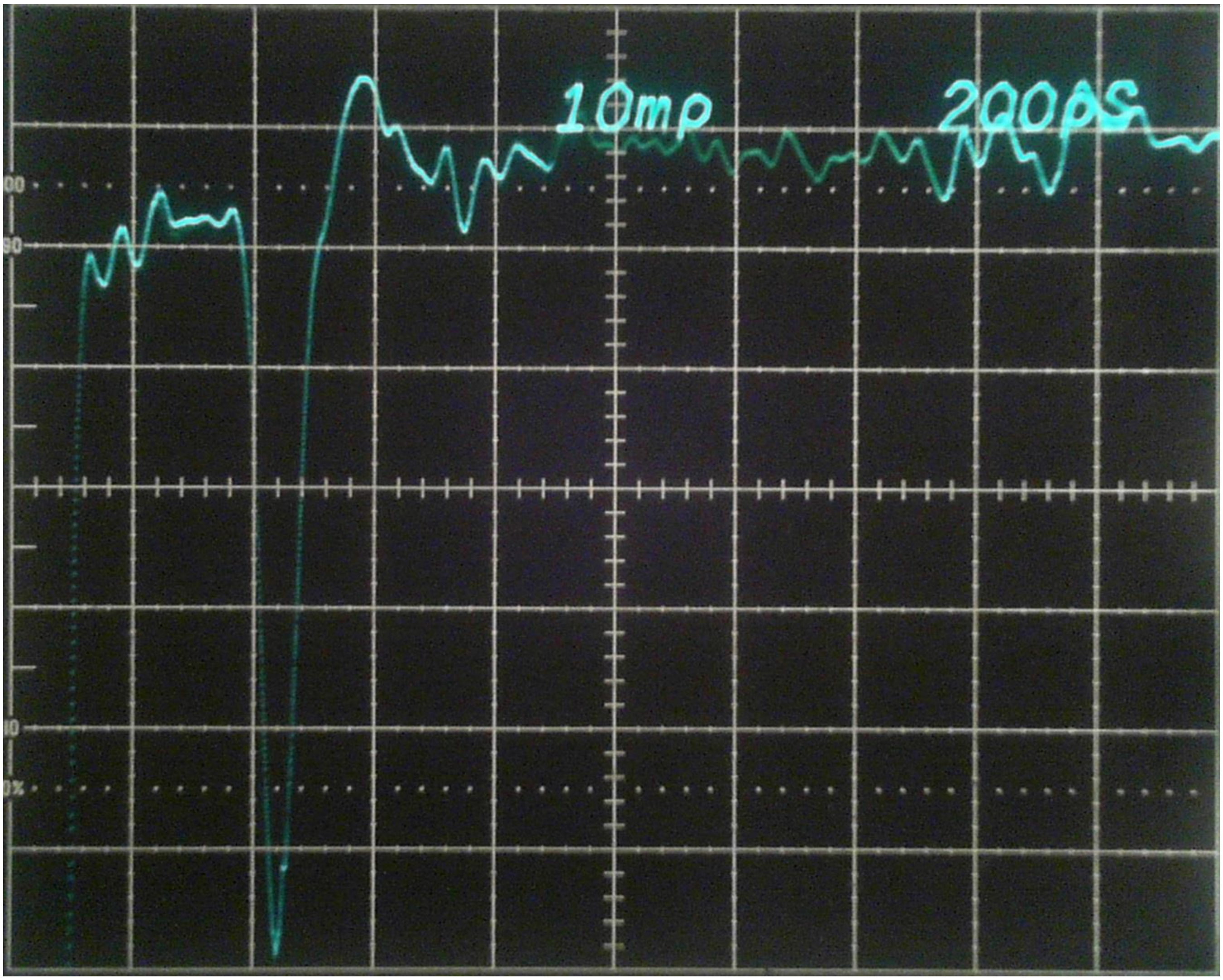

Figure 9 Adapter with a large shunt capacitance mismatch very close to where it meets the sampling head.

THE IMPORTANCE OF GOOD TERMINATORS

Terminators at the end of a cable are just as important as any (optional) adapters you may need elsewhere in a cable. Figure 10 shows what you can expect from a good terminator. This is the Fairview Microwave ST3B-F terminator. Fairview provides a comprehensive 3 page data sheet for this terminator. That alone is highly unusual. This terminator is moderately priced at $25.00. To see what a good terminator's datasheet looks like go to:

https://www.fairviewmicrowave.com/images/productPDF/ST3B-F.pdf

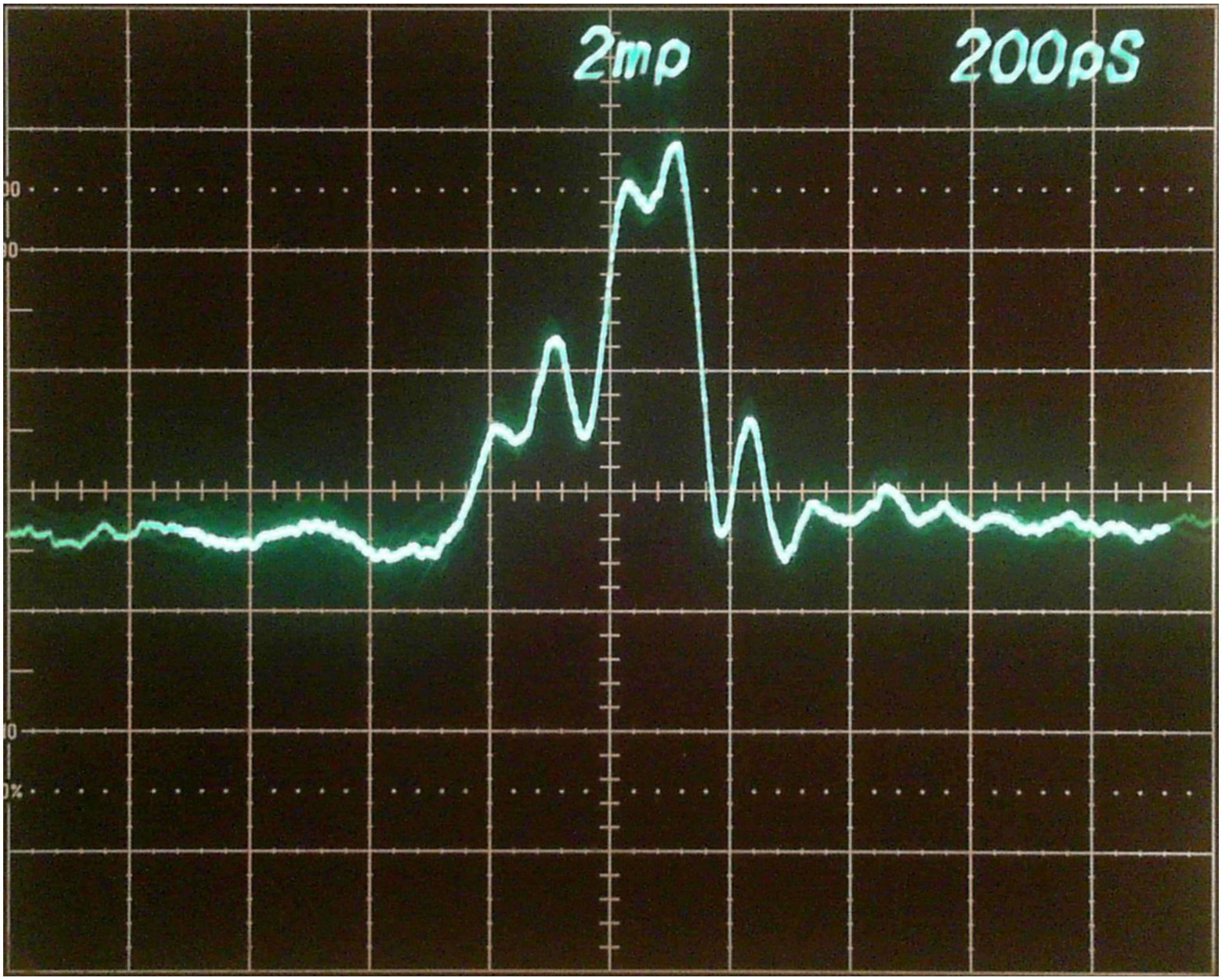

Figure 10 This is the response of the Fairview Microwave ST3B-F 50Ω BNC-Female terminator. The impedance mismatch is slightly capacitive. It reaches a peak of about 8mρ above the midline which corresponds to an impedance of 50.8Ω which is a 1.5% error.

Figures 11 through 13 are typical for the terminators you will find for a few dollars. They show that unless a terminator comes from a reputable dealer there is no way to tell what you are getting. Even low cost brand names like Lcom are questionable. The most important clue about their quality can be found in their data sheet. If there is no data sheet you can't trust the terminator. The more data the manufacturer provides the more likely the terminator will perform as expected.

I was able to make a better terminator in about 15 minutes from four 1206 surface mount 200Ω resistors and a female bulkhead BNC connector. The TDR response of my homemade terminator is substantially better than any of the inexpensive terminators I bought. Figures 14 and 17, near the end of this paper show the response of my home made terminator and Figures 15, and 16 show how I made it and what it looks like.

Here are some examples of typical terminators you will find in the market place.

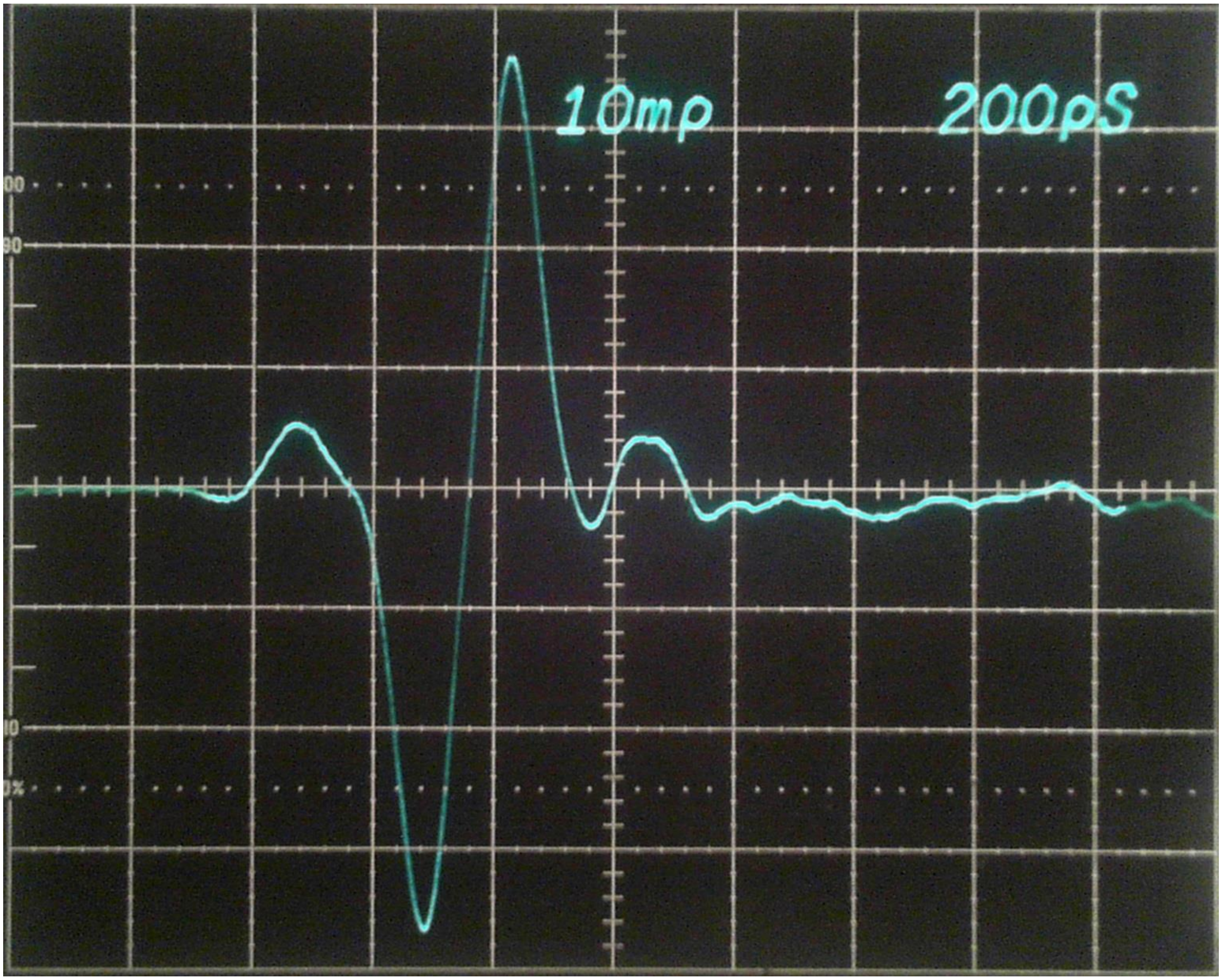

Figure 11 Terminator with a large shunt capacitance mismatch followed by a series inductance before the pulse gets to the terminator resistor. The impedance swings from -37mρ to +37mρ which corresponds to an impedance swing from 46.4Ω to 53.8Ω which is a 13% error.

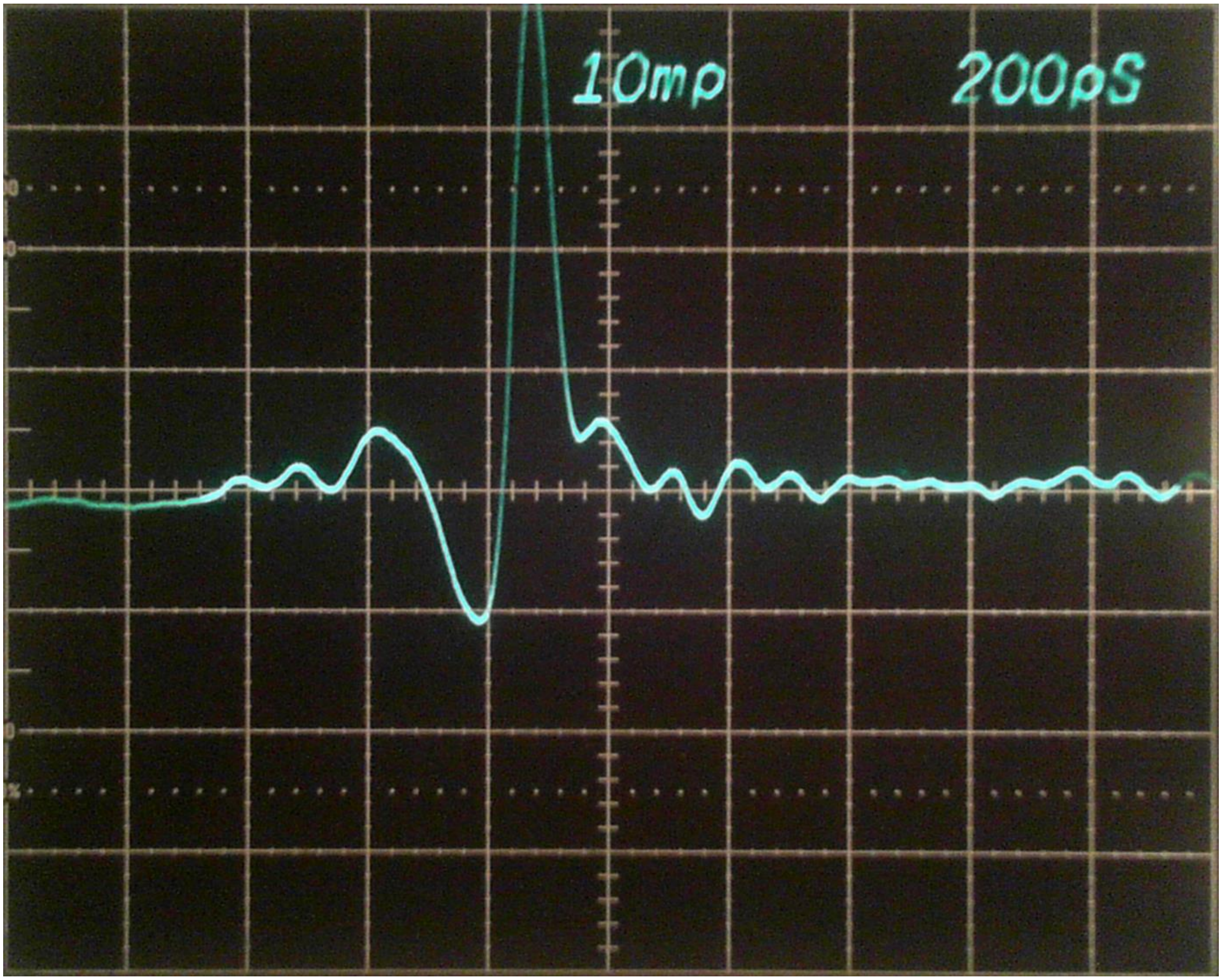

Figure 12 This is an Lcom BIF5F terminator. The response varies from -10ρ to 45ρ. This corresponds to an impedance change from 49.0Ω to 54.7Ω respectively which is a 10% error. The response is dominated by the large inductive mismatch right before the TDR pulse meets the termination's resistance. The cost for this terminator was $6.00.

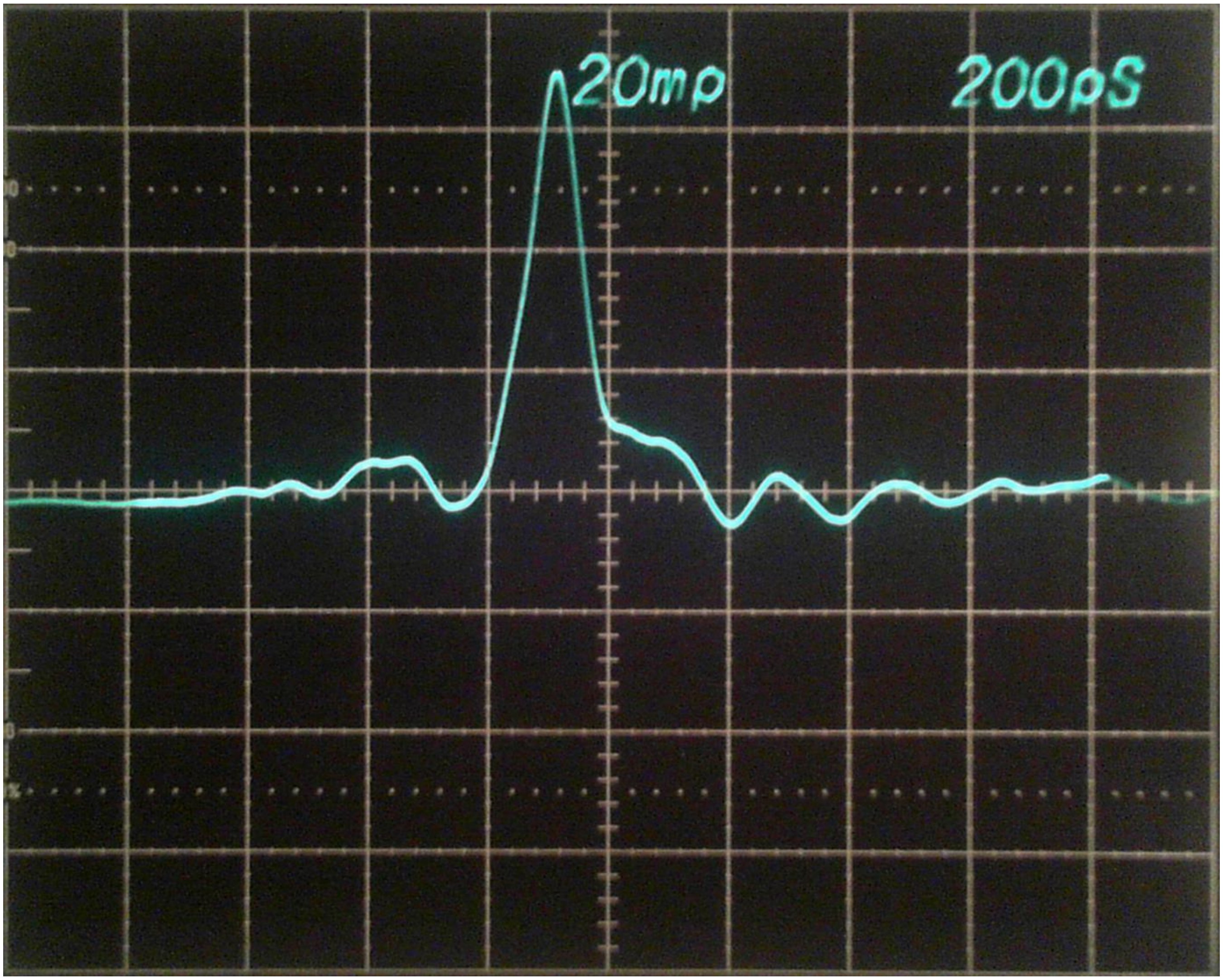

Figure 13 This was purchased on eBay from seller petehooga for ~$5.00. The response is >70mΩ. This corresponds to an impedance of 57.5Ω which is a 15% error. This is the worst terminator I have found so far.

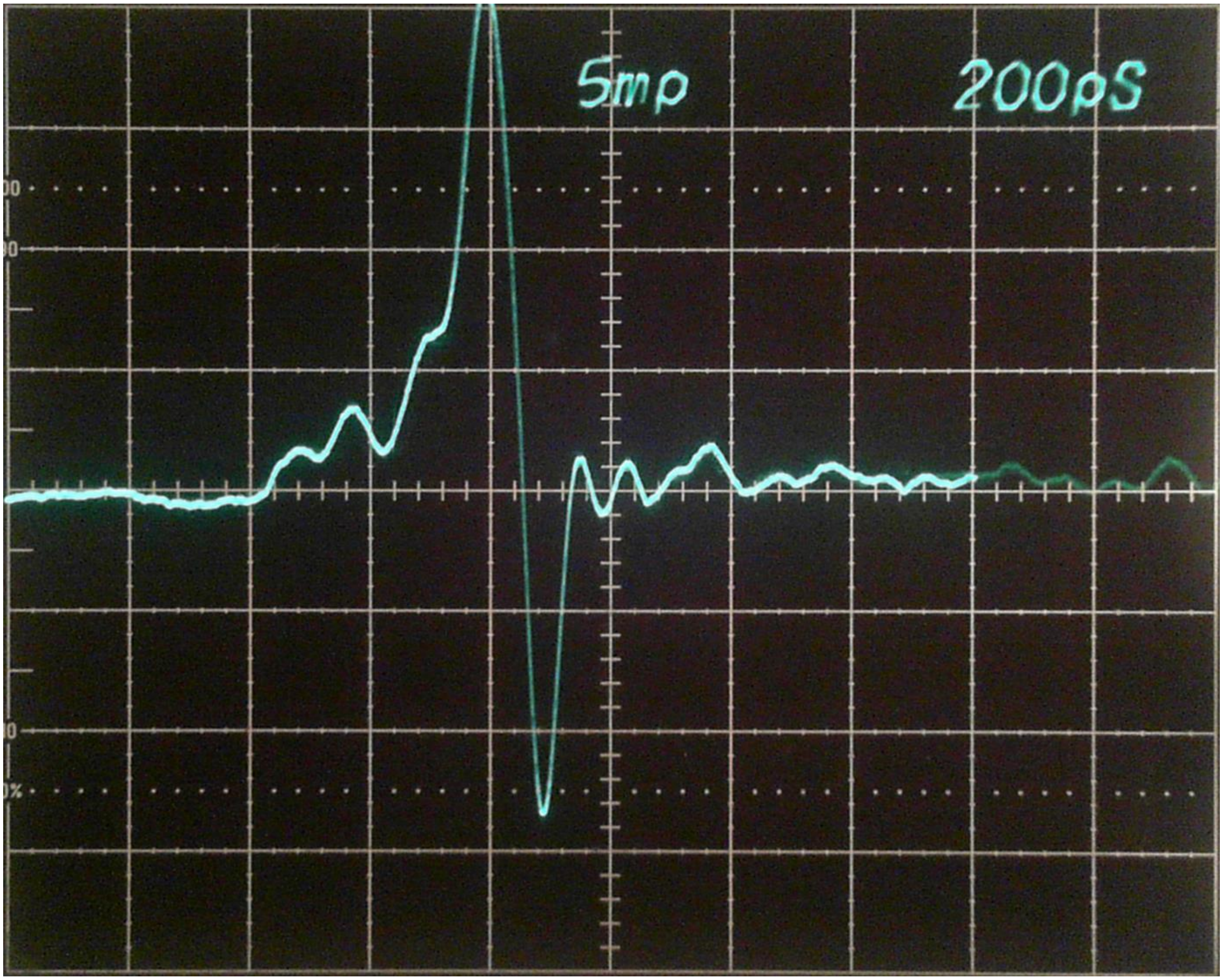

Figure 14 The response of my homemade terminator goes from +22ρ to -14ρ. This corresponds to an impedance of 52.25Ω to 48.6Ω which is a 4.5% error. This is much better than any of the inexpensive terminators I have. The rising edge of the response is due in part to the bulkhead connector itself. This connector is fairly massive which would give it a lot of capacitance.

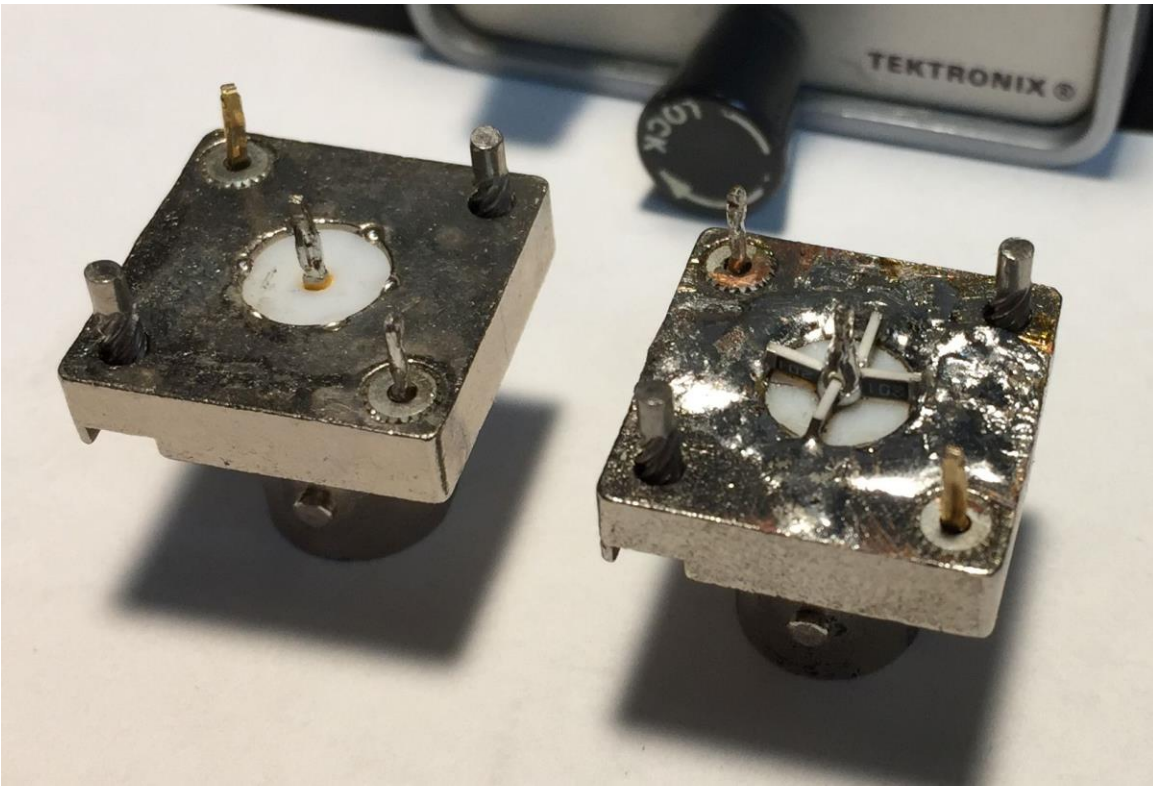

Figure 15 My homemade terminator consists of four 1206 surface mount 200Ω resistors arranged around the center pin of the bulkhead connector so they are in parallel. The BNC at the left is what it looked like before I started. The finished terminator is on the right. This took about 15 minutes to make and it had better performance than the inexpensive terminators I bought from several sources.

I removed some of the bulkhead because I thought it would improve the +20mρ spike which I believe was due to capacitance from the physical size and mass of the connector

Figure 16 Bulkhead connector after removing some of its mass.

The response of my homemade terminator improved a little after I removed some of the mass of the bulkhead connector. This is the final result:

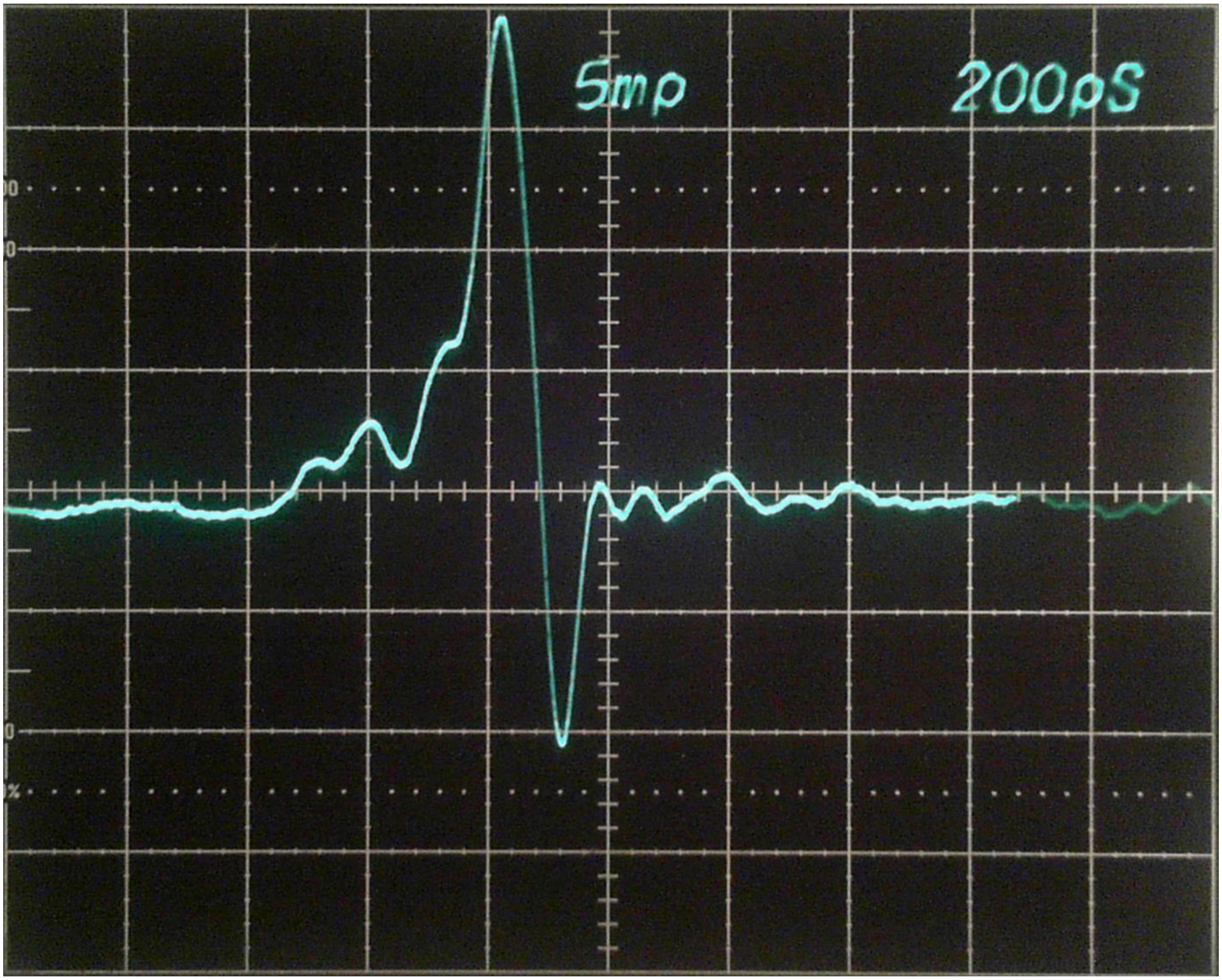

Figure 17 The response of my homemade terminator after the final change I made is +20ρ, -11ρ which corresponds to 52.04Ω and 48.91Ω respectively. This is an error of 4% which is at least 2½ times better than the low cost terminators I bought.

TEST SETUP

Figure 18 The test setup consists of a 7603 scope, 7S12 TDR plugin, S-52 Pulse Generator, S-6 Sampling Head, SMA-Male to BNC Female Adapter, 50Ω ST3B-F Precision BNC-Female Terminator, and others, 012-0482-00 Reference Cable, custom built Microsoft LifeCam Studio webcam based scope camera.

The scope camera shown in the photo above was used to capture all of the screen shots in this paper. At its highest resolution it takes 3840 x 2180 (8MPixel) photos.