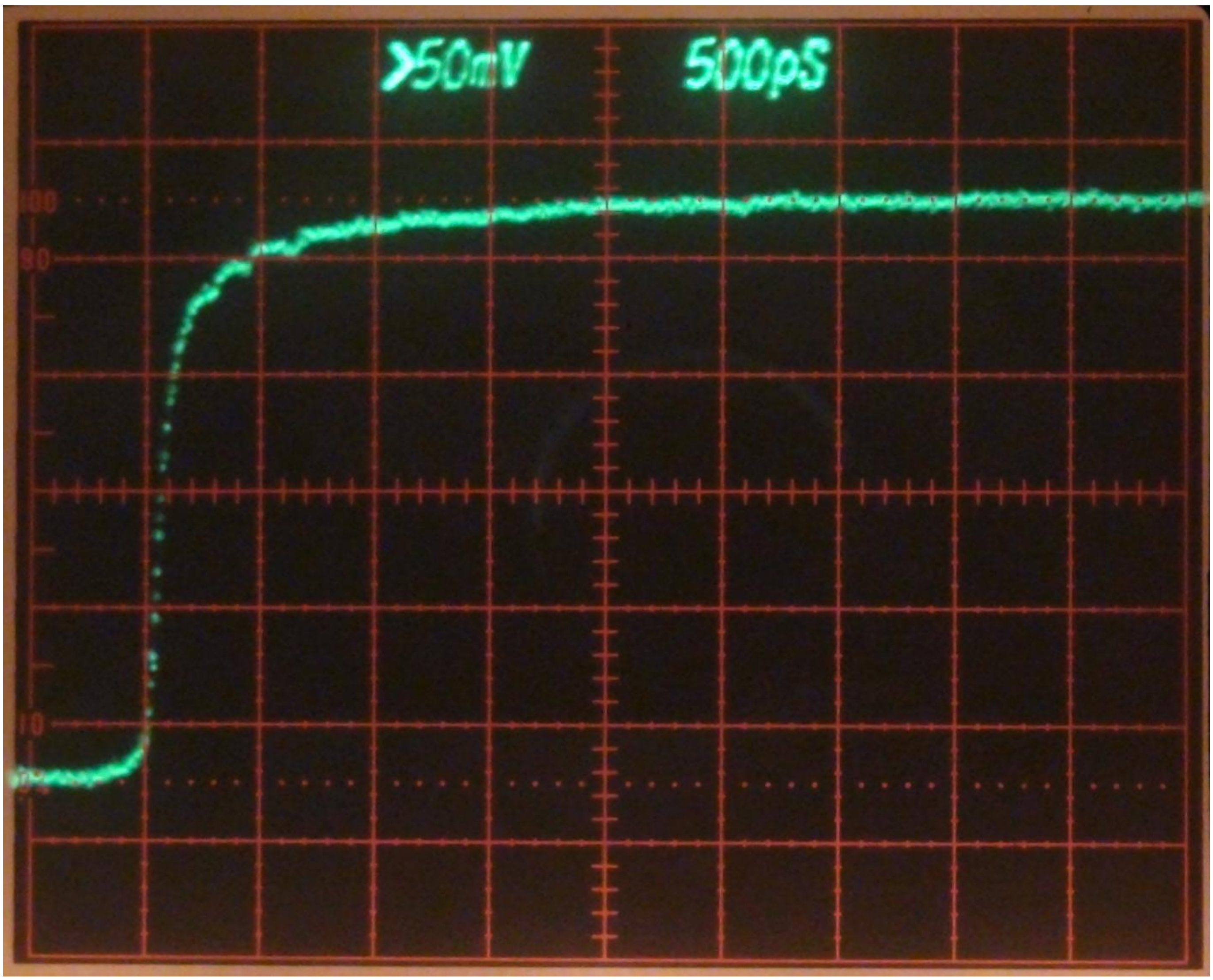
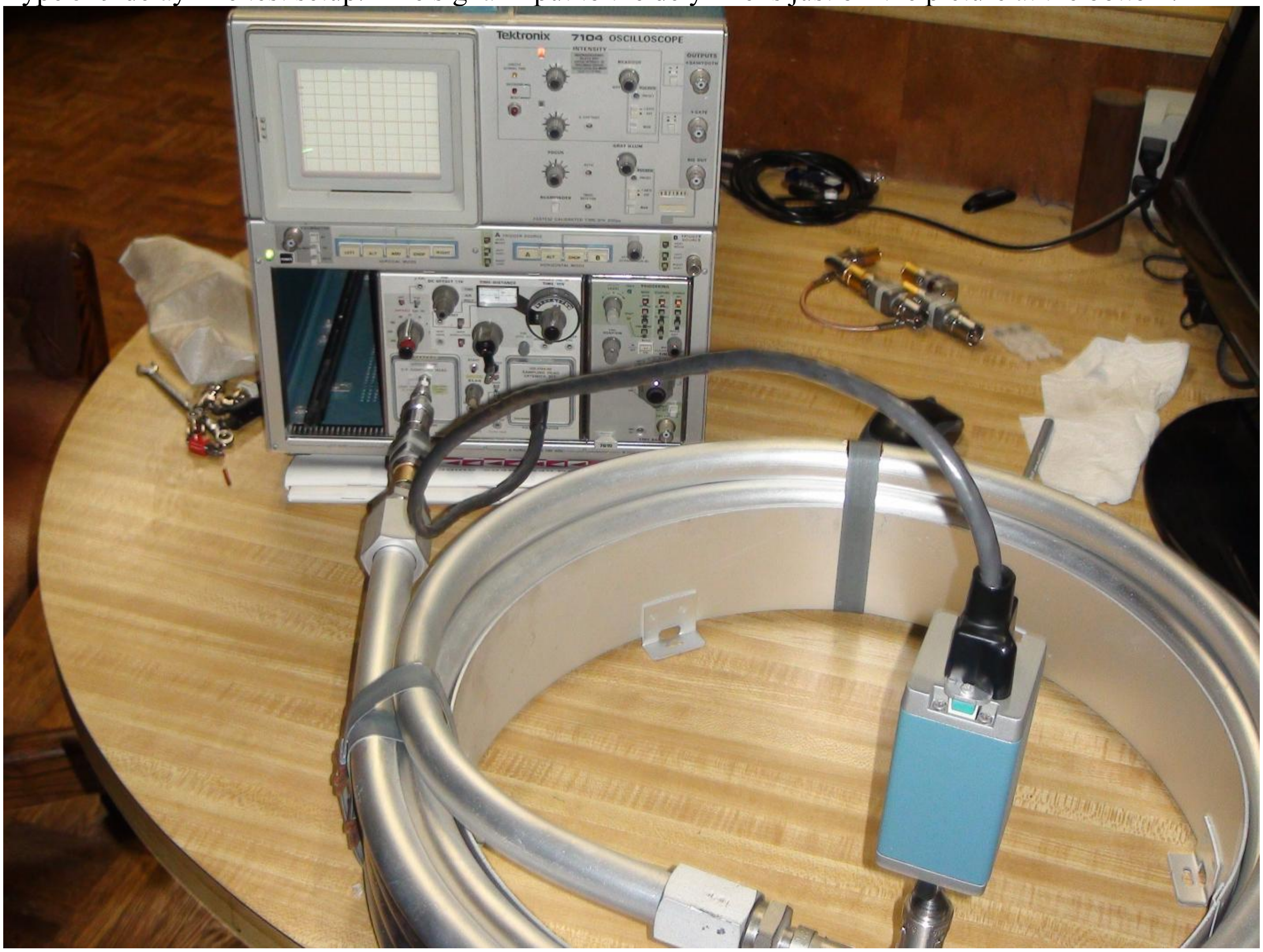
An Explanation of Chirp in High Frequency Transmission Line Transient Response

By John Addis

Before testing a Tektronix Type 519 Oscilloscope's delay line, I used the Tektronix 7S12 to test the longest, 25 feet, piece of quality coax I could find to see if it showed any sign of dispersion/chirp. This was to see if the dielectric constant of the polyethylene could readily be blamed for the chirp. It was 75 ohm coax but made of polyethylene foam. That is OK because the foam is air or nitrogen and similar to the polyethylene/air mixture of the Type 519's delay line. I saw no sign of chirp. What I did see is the skin effect on the its transient response. Rise time was about 500 ps. The skin effect likely would obliterate any chirp (an increase in ring frequency over time).

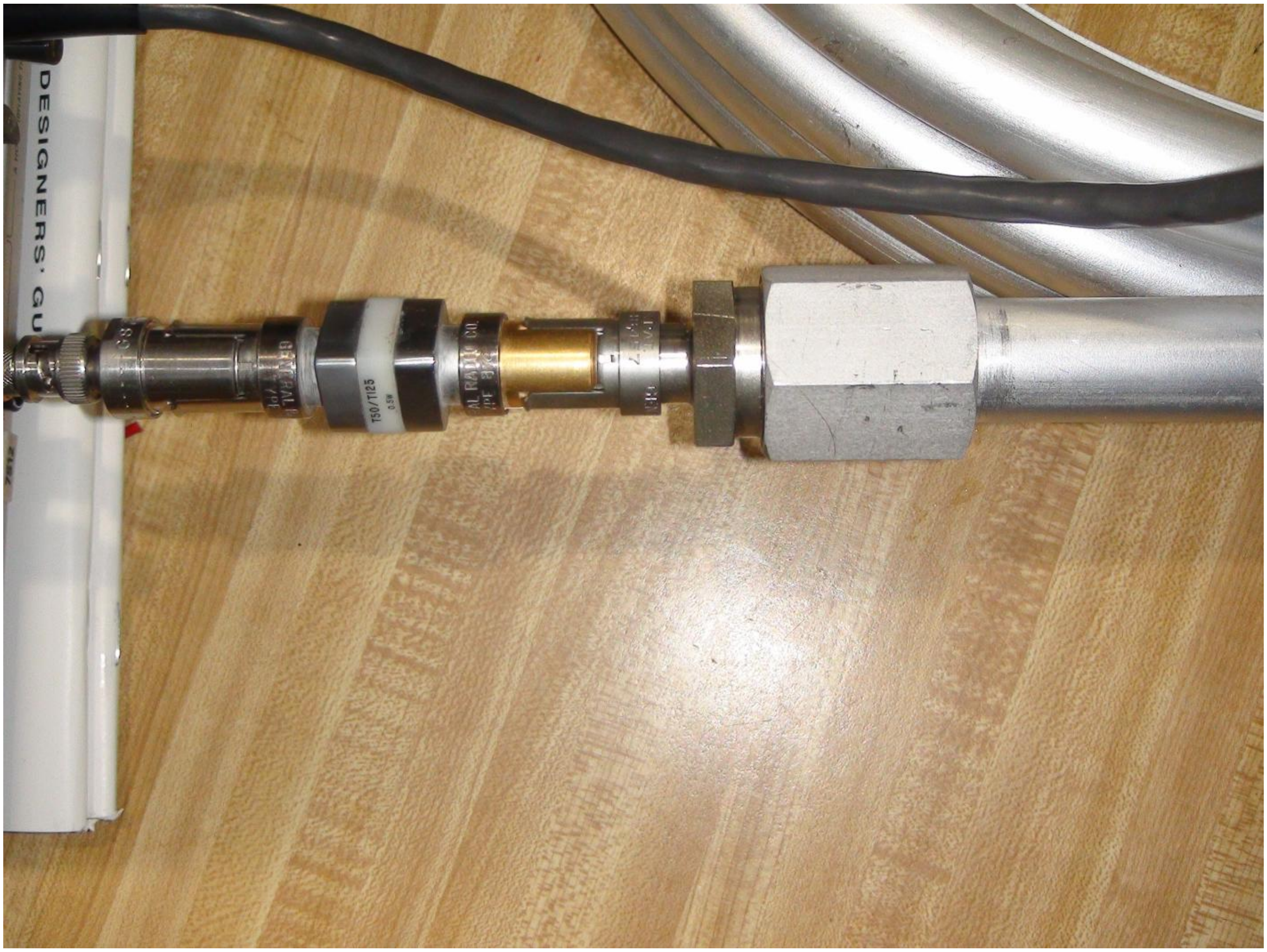


Type 519 delay line test setup. The signal input to the dely line is just off the picture at the bottom.



The input of the signal path detail shows the S-52 pulse generator on the end of an extension cable. From the S-52, the signal goes through an SMA to GR 50 ohm adaptor, then to an elbow 50 ohm to 125 ohm adaptor and into the test cable. Gold outer conductor means the connector is a 125 ohm impedance. However, in this case, there is no matching resistor inside the elbow, so there is a reflection at this junction, but the signal amplitude is not attenuated.

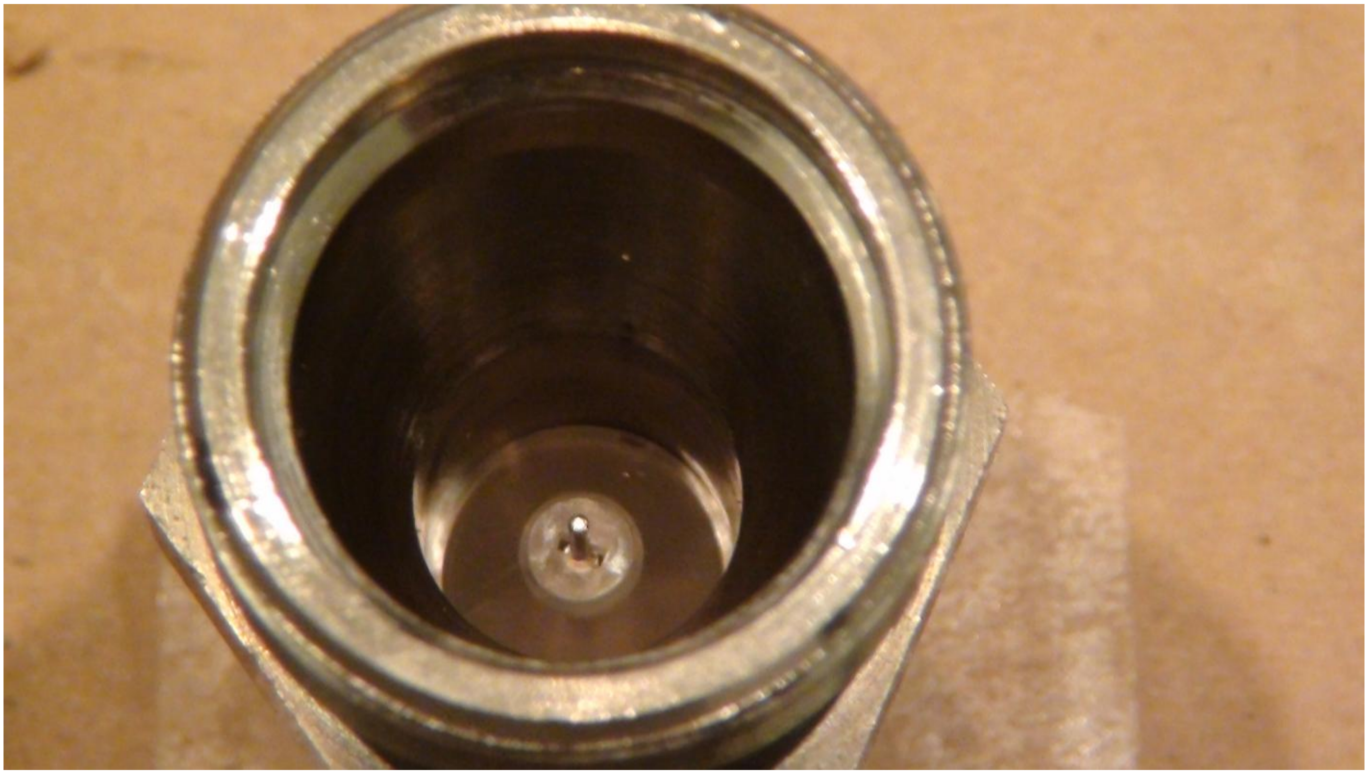
The output of the signal path detail shows a GR 150 ohm to 50 ohm impedance match unit connected to the delay line. To its left is a 50 ohm GR to BNC adaptor and off to the left is a BNC to SMA connector to the S-6 sampling head's SMA input.



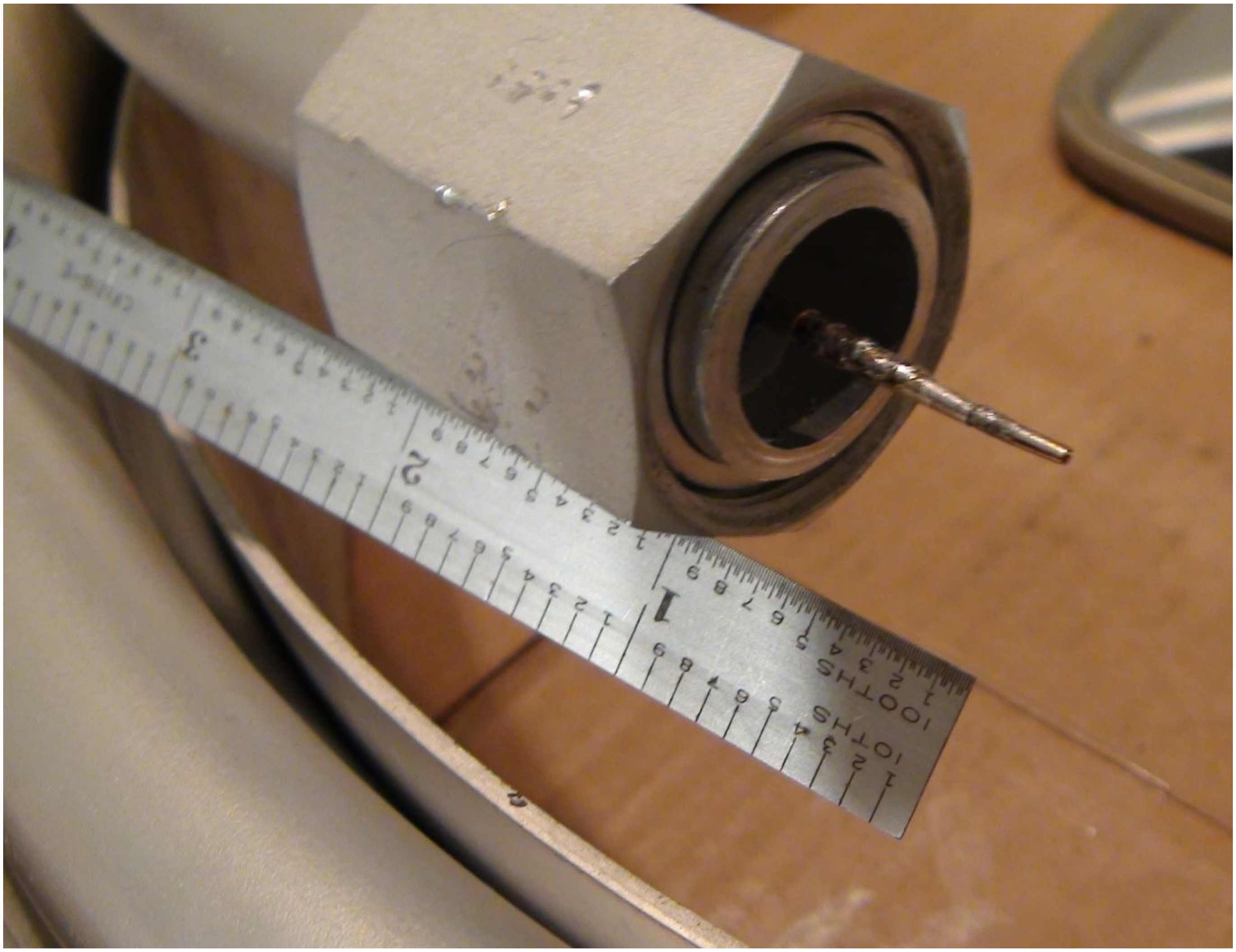
Upon making all of these connections, I got no signal displayed on the scope.

After testing each of the interconnections and confirming that the S-52 works into a 125 ohm load, I checked the very last part of the signal path, the 519 delay line, which turned out to be open. But where? Oh, wait, I have the perfect equipment to find out exactly where it is open! And the output end was open at the connector, so I disassembled the connector. (The output end refers to the output in this setup, although it is actually the input end of the line when installed in the 519.)

The center conductor had moved/shrunk by something like a ¼ inch and the sliding center conductor was no longer reaching the short pin inside the GR connector, shown below.



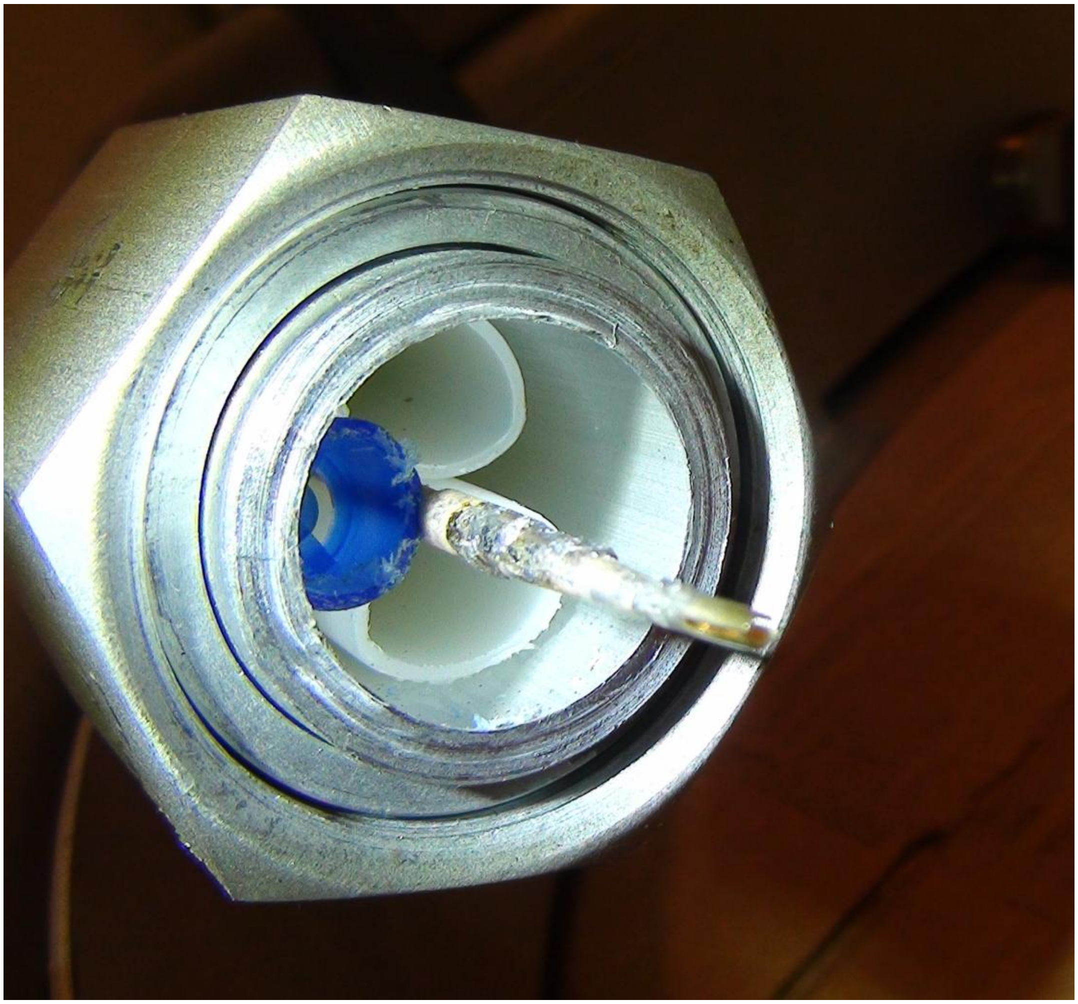
Below: The center conductor is soldered to a 1 inch long piece, tapered in diameter to match the connector’s tiny part of the GR’s 125 ohm diameter (at right) which slid into the one inch long piece (center) that had a tiny spring socket at its end (extreme right).



I heated up the 1 inch long piece and pulled on it. It came out about ¼ inch but still stayed soldered to the center conductor.

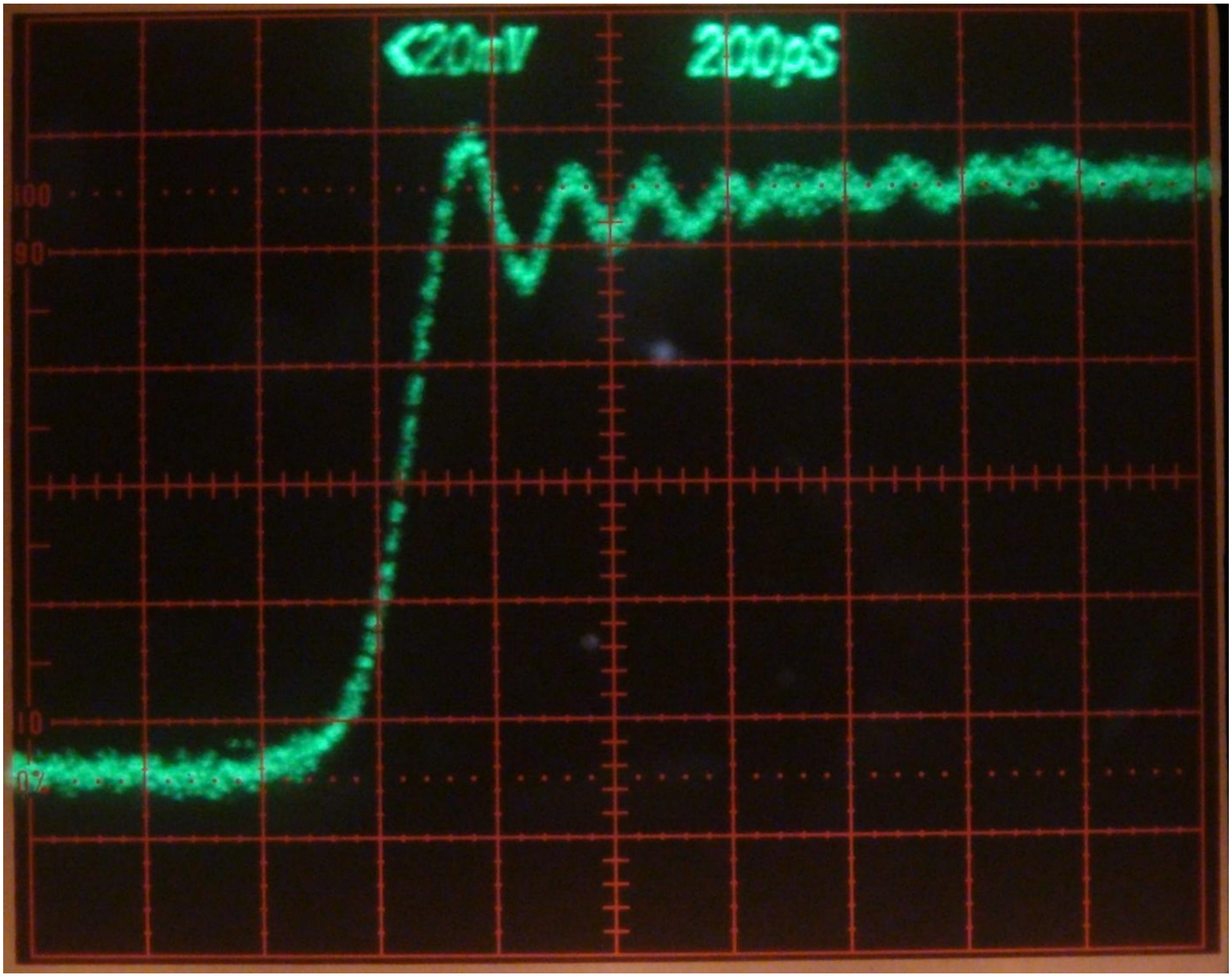
I reassembled the connector and tested the connection with the Time Domain Reflectometer (TDR) configuration of the 7S12/S-52/S-6. It worked.

Then I looked at the other end of the 519 delay line with the TDR and found that it too had shrunk, but by even more. Furthermore, the cable was no longer centered. One of the three polyethylene tubes had shrunk more in length than the others, allowing the center conductor to move off center. I cut the top off a blue ball point pen cover and shoved it down in place of the shortened tube, as seen in the picture below.


It took hours (and 130V input to the soldering iron) to pull the one inch adapter piece out about 3/8”. With each attempt, I made detailed measurements of the amount of the center conductor’s extension and the distance the GR’s center pin was recessed using calipers until I got the two to match and contact. This took days!

I was ready to make measurements on the 519’s delay line.

With both ends matched (a second 50 ohm to 125 ohm impedance matcher now inserted between the S-52 pulser and the delay line), this is the observed transient response, with a 165 ps rise time:

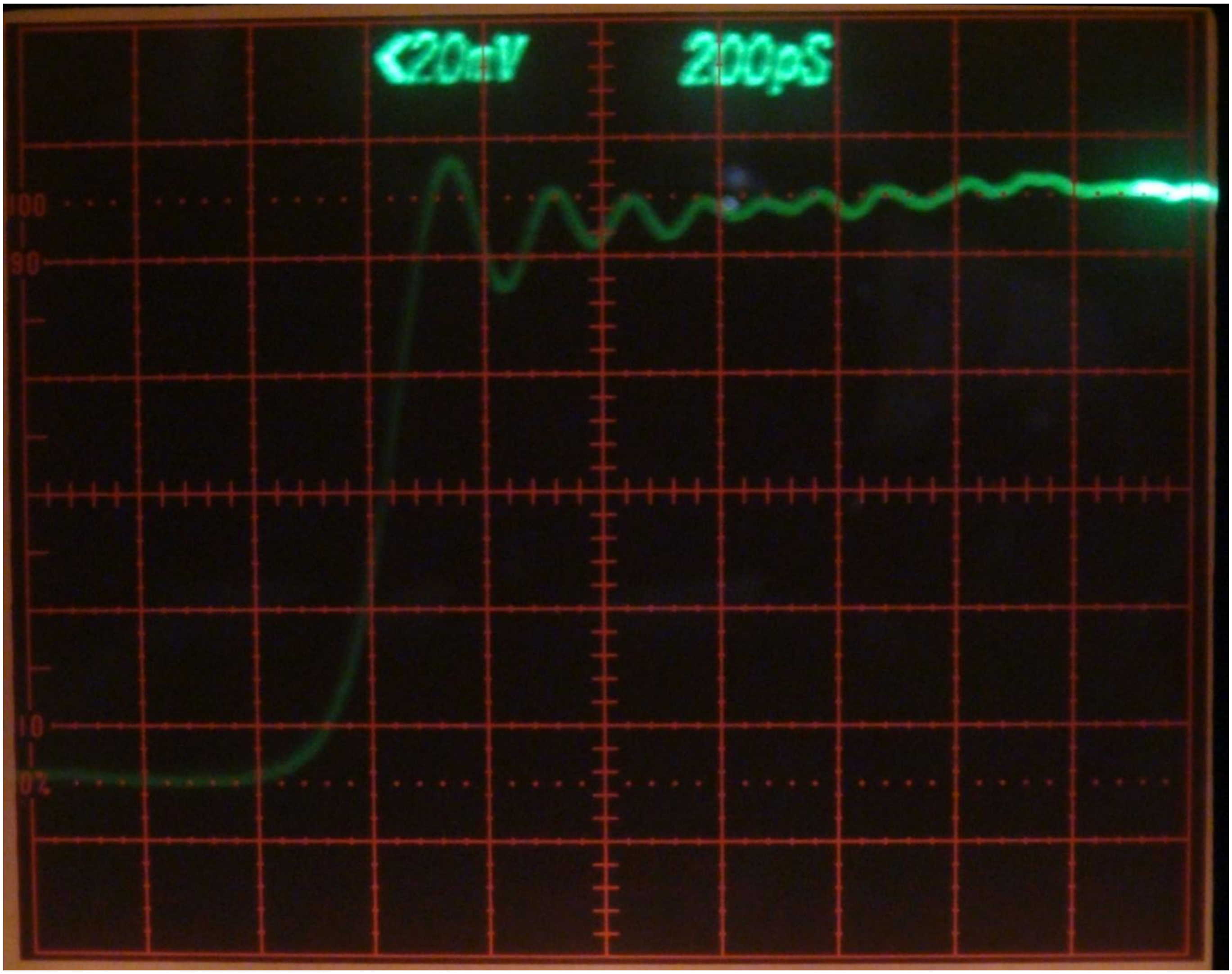


There is an obvious ring, but is there a chirp (ring frequency change from left to right)? A careful count of the period of successive rings does appear to show a chirp. The fact that the chirp does not last long should not be too surprising. The higher skin effect loss in the Type 519 delay line attenuates the ring much more quickly than that of the Type 113 suitcase transmission line. The skin effect loss is apparent in the slow rollup of the pulse's vertical center (about half a division from the initial pulse to the right side of the picture.

The trace's blur between the fourth and fifth cycles seems to imply that the line's ring frequency interferes with and cancels a ring in the transient response. This is apparently the reflection off the line (or the elbow) and back to the S-52, that is not a very clean reverse termination.

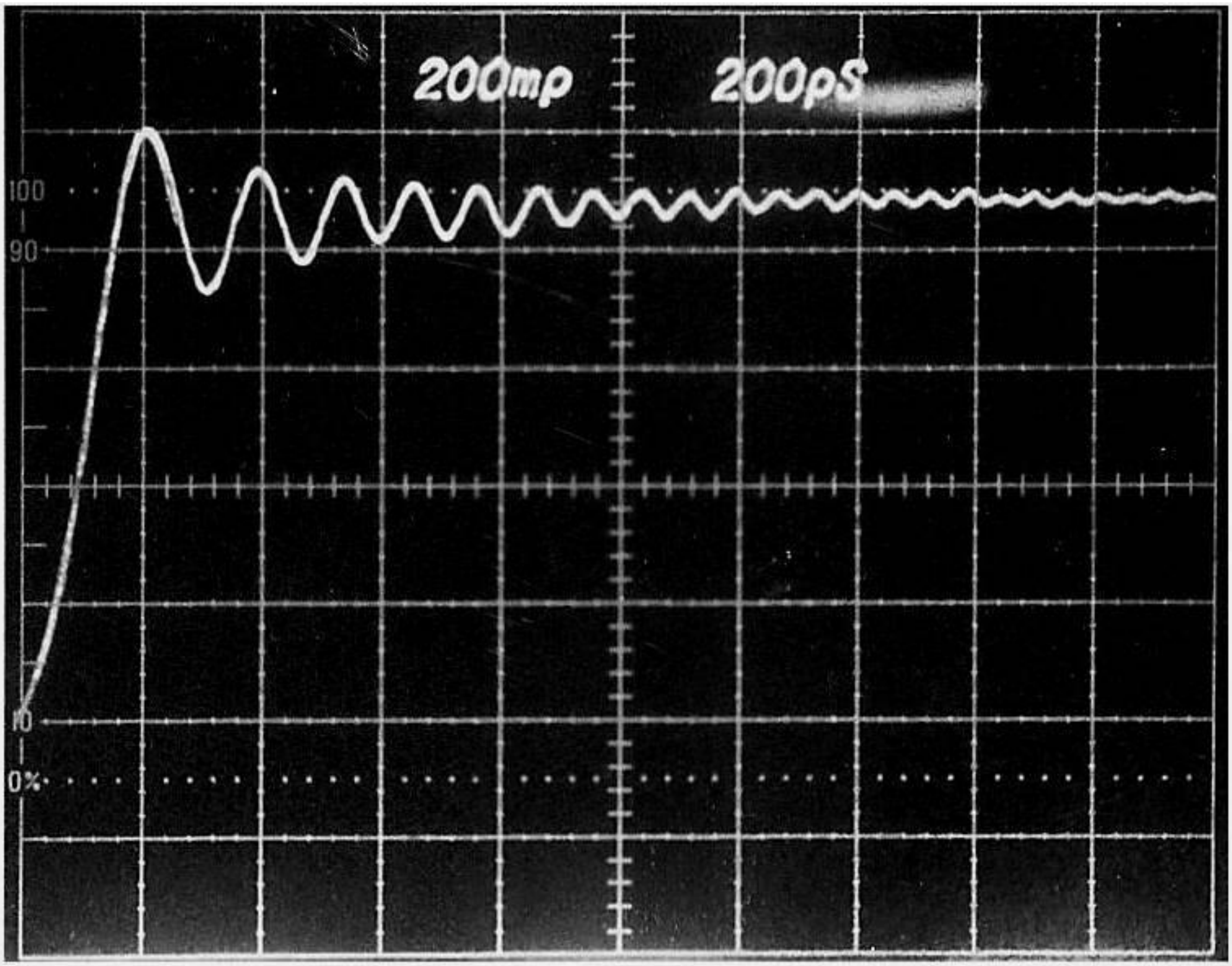
The noise in the trace is due to the significant signal attenuation of the two impedance matching units.

An additional photo was take without any matching network installed between the S-52 and the delay line. This produces less noise and does not seem to change the signal significantly. (The sensitivity is less even though the readout still indicates "<20mV" per division.) The rise time is still about 165 ps



20mV
200pS
100
90
10
0%

The purpose of this experiment was to determine the cause of the chirp seen in the Type 113 transmission line's transient response. Why does the ring frequency change with time?:



Tektronix Type 113 Delay Line ("Suitcase") transient response in S52/S6 Sampling System (using cable extenders). System BW is about 11GHz (32ps). The ring, never known until samplers and perhaps never measured until this photo, is most likely due to moding in the large diameter line. Skin effect is barely detectable (due again to 7/8" diameter line). Chirp is about 16GHz at right and 8.3 GHz at left. John Addis 9/27/1989

There were several possible explanations:

Moding (excitation of non-transverse electro-magnetic (TEM) waves. These are generated by mechanical structures comparable in size to the wavelength of the signal. For example, as a pulse travels down a transmission line, the pulse does not discover the existence of a ground plane until the pulse has moved on by about two radii of the transmission line (once out to the outer conductor, and the second back to the center conductor).

Dispersion(dielectric constant of the insulation variation with frequency). This causes the lower frequency content of the delay line to arrive after the high frequency content. Dispersion is a known characteristic of plastics caused by motion of the constituent molecules excited by the electric field.

The Type 113 delay line has a spiral plastic center conductor support. Does the spiral cause an added delay of the signal dependent on the frequency content of the signal? It was not known when this was written that the dielectric in the 113 is not a spiral.at all. It is four or possibly five hollow tubes similar to the 519's three support tubes. The difference is that the three 519 tubes, a greater distance from the center conductor to the outer conductor's inner diameter and the thinner tube walls made the amount of polyethylene in the 113 considerably greater. This made the dispersion greater in the 113 and increased the chirp's magnitude. - Mar 23, 2026.

The advantage of the comparison between the Type 113 (four or five thick walled tubes supported center conductor) and the Type 519 delay line (three thin walled polyethylene tubes) is that the differences are limited to the different impedance and the amount of polyethylene. If the Type 519 delay line has no chirp, the cause could be attributed to the 113's extra polyethylene.

Conclusion: Although there is less chirp in the Type 519 delay line, this can be explained by the much (≈6 times) greater skin effect loss in the Type 519 line that has a much smaller diameter center conductor essential to obtaining the 125 ohm characteristic impedance. Although less apparent, there is still a chirp in the Type 519 delay line. I conclude that the chirp is caused by the polyethylene's dispersion.

John Addis
March 4, 2026
March 23, 2026 (after a Type 113 was disected and found to have no spiral support)

I thank Dave Brown for removing the delay line from the Type 519 Oscilloscope on display in the vintageTEK Museum vestibule. That was a huge help in being able to measure its characteristics.