Coax abuse and cable losses

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I don't imagine there is such a thing as the DCCS or the Department of Coaxial Cable Services. There is no one actively on the lookout for coaxial cable damage and abuse, and yet it does happen. But what constitutes coaxial cable abuse and what are the penalties? This question has rattled around my head for decades, usually followed with "if I only had a decent VNA…." (Vector Network Analyzer). Then at the times when I did have a really good VNA, I had stuff to do of much higher priority than measuring some cables. Usually designing or tweaking EMI filters for a MIL STD 461 application, validating LISN networks and looking at return loss and gains on project antennas.

First, what coaxial cable is most likely to be abused? Simple. Most anything used in a mobile environment. Slamming doors, movement, vibration, pinching, pulling, abrading. YES! THIS is where coaxial cable damage is most likely. What types of cables are found in this environment? Usually the thinner varieties due to the space claims, bend radius and flexibility required. This boils the solution set down from 10" EIA coaxial hardline used coming out of the broadcast FM combiners to perhaps RG8 mini, RG58, RG142 and cables in the 0.250" OD or less range. I have pulled LMR400 once or twice in a mobile application, but it was a total waste of effort. I've also heard of super cool appliance operators pulling Andrews 7/8" hardline through a mobile environment, which is utterly stupid, I mean why not just run EIA 10" hardline and pressurize it with Argon in the Prius?

What then is abuse? Having serviced and built a lot of equipment of or for these environments, I've found some failure modes to be prevalent.

- Smashing is a terrible coaxial cable abuse. Perhaps a longer length of cable is pulled through a rocker panel and some body work mashes down on the panel compressing a good portion of the run.
- Splicing is perhaps the lowest form. When you just didn't have the time to replace the run, and cobbled up a geometrically reasonable coaxial splice
- Abrasion is common. Perhaps it's a little road rash, or simply constant vibration grinding through the cable jacket up against a rusty or abrasive metal surface?
- Bending is also common. Perhaps the antenna system is mounted on some lip, like perhaps the edge of the trunk. When the trunk slams, the cable is bent into conformance with the abrupt groove around the trunk.

How then do we measure cable damage? This is where a precision RF instrument is needed. Usually the transmit mode is the one we consider when looking at losses. This is where the power is applied to the cable. The place where cable damage will cause a standing wave ratio that will exceed either the current or voltage safe operating area of the output transistors and blow up the transmit chain if the cable is abused too much. The receiver performance may be degraded with a bad cable, but a bad cable won't jeopardize the SOA of the semiconductors in the receiver front end.

S11 Primer

What then are we measuring? We know that energy can only be transmitted, reflected or absorbed by the transmitter, cable and antenna. Again, from the vantage point of the transmitter, we need a good impedance match between the amplifier output, the cable and the antenna. A mismatch causes a high standing wave ratio and reflects a lot of power back to the input. This can be very hard on the output transistors in terms of voltage, current and thermal stress. To measure how much energy is reflected, the common tool is the VSWR bridge or Voltage Standing Wave Ratio meter. This instrument has directional couplers in it. It measures the direction and amplitude of the current and then the voltage. With this information, the standing wave ratio is computed by looking at both the power going out and the power reflecting back to the measurement point. The lower the VSWR, the more energy gets to the load. In the world of S parameter measurements applicable to a VNA, S11 tells us the return loss. This is very similar to VSWR only a backwards. Return loss tells us of the magnitude of the reflected wave directly. More return loss is a lower VSWR; higher return loss is better.

TPO (transmitter power output)	Reflected Power	VSWR	S11 (Return Loss)
(watts)	(watts)		dB(power)
100.00	0.10	1.07	30.00
100.00	0.50	1.15	23.01
100.00	1.00	1.22	20.00
100.00	2.00	1.33	16.99
100.00	5.00	1.58	13.01
100.00	10.00	1.92	10.00
100.00	20.00	2.62	6.99
100.00	50.00	5.83	3.01

Figure 1: Power, VSWR and Return Loss table

As a quick numerical example, let's say we have a transmitter output of 100W. Near the transmitter we install a VSWR bridge and take a couple of measurements. If we measure a VSWR of 1.22:1, we then known that approximately 1W of power is being reflected from the antenna back to the transmitter. In terms of return loss, this is 20dB. If the antenna was broken, perhaps the VSWR would be in the 6:1 range. At this point we know that about 50W is being reflected back to the transmitter. The return loss is then 3dB, and the final output transistors in the amplifier are likely in trouble.

S21 Primer

We can also measure the insertion loss of the cable. The VNA then takes an exact measurement of the transmit port energy and the energy at the receive port. The loss is then the loss in the cable--the insertion loss, S21. If a cable has a high insertion loss, less power gets from the transmitter to the antenna. Insertion loss measures how much energy is absorbed in the cable. A 3dB insertion loss means that half of the power is being lost in the cable (as heat in the copper and dielectric materials). If the transmitter output is 100W, we would measure 50W at the antenna termination with a 3dB insertion loss. Conversely, if a power amplifier had 10dB of gain, we could drive it with 5W and get 50W output.

TPO (transmitter power output)	dB (power) LOSS	Power at Load
(Watts)	(dB)	(Watts)
100.00	0.10	97.72
100.00	0.20	95.50
100.00	0.30	93.33
100.00	0.50	89.13
100.00	1.00	79.43
100.00	2.00	63.10
100.00	3.00	50.12
100.00	6.00	25.12
100.00	10.00	10.00

Figure 2: Power and dB Loss table

Figure 3: The 4 most common types of cable abuse

The Tests

Is it then possible to test each one of these modes in a before and after context and quantify the impact on S11 and S21 (Return loss and insertion loss respectively)? Of course, it is! To run the tests, I made 4 cables, in RG-8 mini with PL259 connectors and the proper reducers. The OD of the cable hovered around 0.250" OD. I built the cables up to 1 meter in length from shoulder to shoulder of the UG175 adaptors (sans the PL259 pin). Tolerance on the cables wasn't terribly important, but I did measure, stage and strip them carefully, cables came out within about 5mm from shortest to longest.

A Word on Connectors

Al Wolfe, K9SI has a lot to say about the "UHF connector" or the PL259. It starts with "they suck" and gets more graphic from there. But Al is much more than talk. He served in Vietnam, doing impossible communication missions with nearly nothing, he remains incredibly active and devoted to ham radio, broadcast, part 90, and countless other projects related to RF, power and energy. I don't think anyone within 1000 miles of his basement office/shop in Krannert Center at UIUC in Champaign can mention PL259 in any context without acknowledging Al. He was right. It's not a good connector for VHF, it's a REALLY BAD connector for UHF. But dang, I had a drawer full of them and most any mobile installation uses them…..so that's what I chose.

Figure 4: Yup, the ole PL259! Solder type of course. So ugly they are cute! 5/8" x 24 thread!

The instrument:

At this point, I must have a brief instrument discussion. I've used the latest and greatest RF gear from Rhode and Schwarz, Agilent/Keysight and Anritsu over the years. For a passive cable measurement, those instruments have a lot of features that I don't need. My hope was to find a decent little USB operated VNA with a good GUI that used my PC as the data engine. I found countless instruments in the $50 to $200 range, but they all seemed a little lacking in support or substance. Not that "Happy Lucky Shiny Smiling Golden Best Trading Company LLC PRC" hasn't made some great landfill, indeed they have! It's just not for me. Further Google translate does a wonderful job translating the ½ page user's manuals on paper that smells like toxic waste, but I just found the project needing something more. And this is where Array Solutions comes in. I was getting ready to buy the VNA from Pico technologies, but the pain of the bill was causing me to move a little slower than I'd wanted. I had an array solutions 180MHz VNA some years ago and I loved it, but the instrument was traded and this test really needed to cover HF well into UHF. And then I found it. The folks at Array Solutions are now building the *VNA UHF* DC to 1.2GHz VNA again. Wonderful and supportive north Texans that simply couldn't do enough to help you. There is a shortage of this level of support in modern times. If you think I'm kidding, go ahead and call *THE* defacto support line at (most any corporate entity) in perhaps Western Asia, take the cookie, take the spam, take the survey and then tolerate the scams, upsells and gaffs while you are disconnected 11 times on the cheapest possible VOIP line in the path to a lowest level support tech that couldn't care less. That path is so old, so tired, so done—it's absolutely REPULSIVE. On no metric in HBR or elsewhere can this be considered a success….but it's cheap and thereby it lives on.

Array Solutions isn't about this at all. This is an AMERICAN company located in the great state of TEXAS. They take pride in what they do, they answer questions, they call back….I don't think they have as much as MUZAK as a dial in deterrent. The folks that answer the phones and respond are polite and knowledgeable…..the bane of the also-ran. They don't do the "oh, gosh, your question is complicated and I'll just go ahead and not respond" thing that plagues most any post sale support structure. SO REFRESHING!!, SO UNIQUE against the modern backdrop of nonsupport and outsourcing.

I gladly paid them for the VNA UHF and had it two days later. Happy customer here! When is the last time you said that transacting with big giant corporate structure? The Out of Box Experience (OBE) was simple and straight forward. Why should it require a singin' sock moniker? It's a VNA, hook it up, plug it in, run the calibration. Installation was easy and straightforward.

Figure 5: Picture of Array Solutions VNA UHF kit (Banana, BNC, and SO239 to N adaptors are my own).

Baseline Data

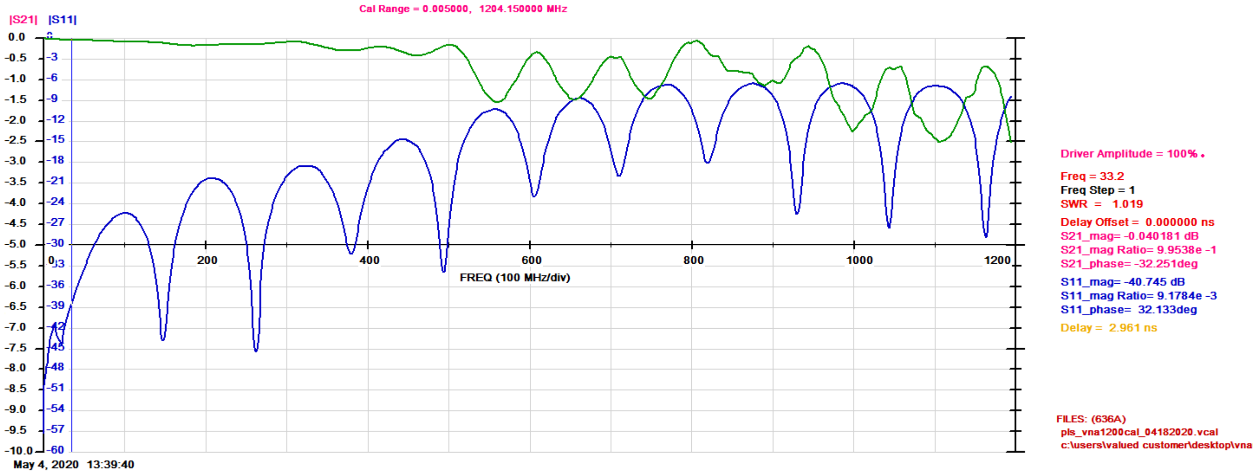

Figure 6: Baseline data for Smash test (cable 4)

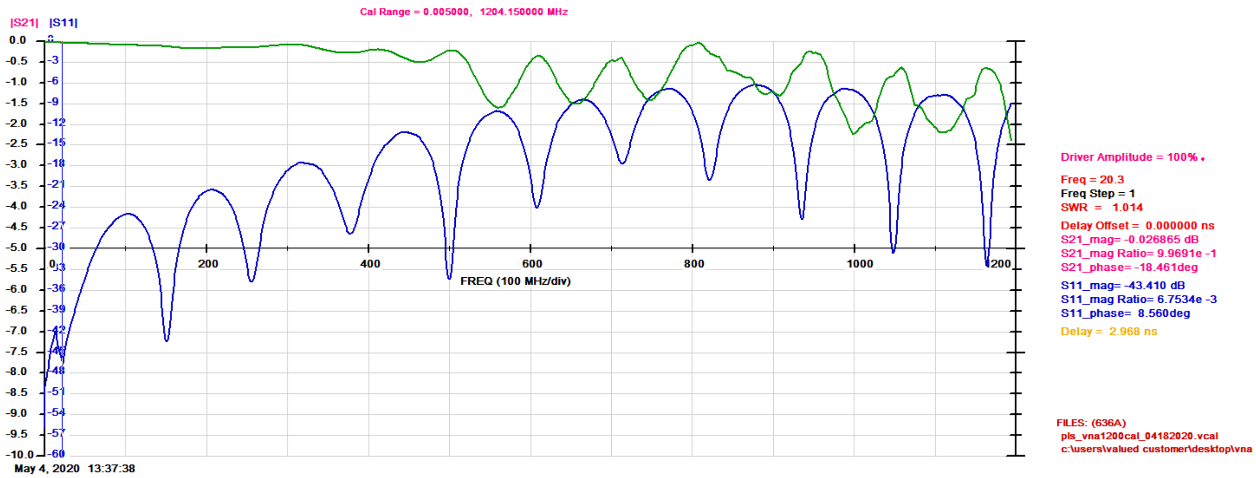

Figure 7: Baseline data for Splice test (cable 3)

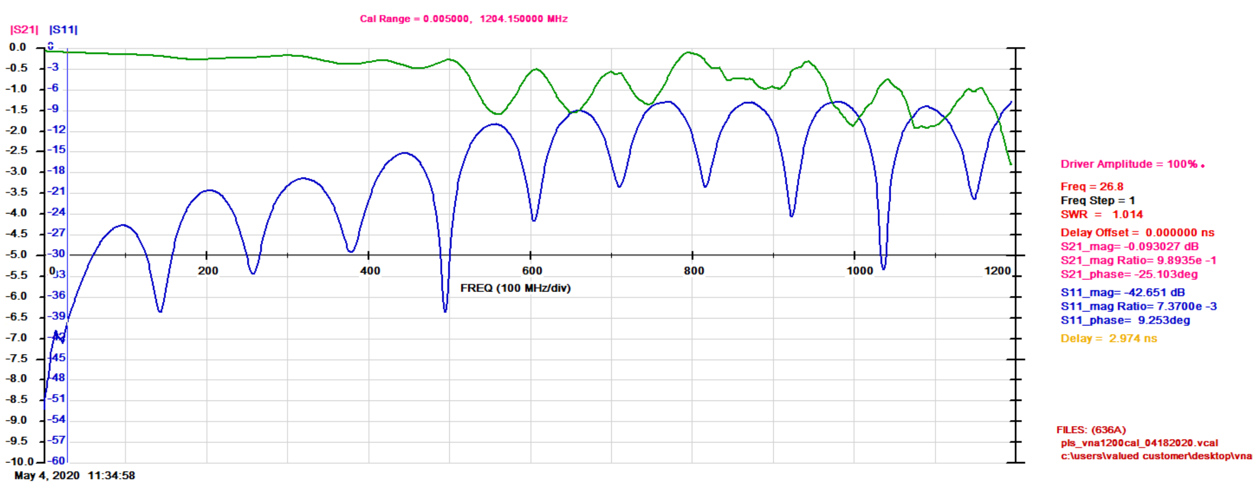

Figure 8: Baseline data for Abrasion test (Cable 1)

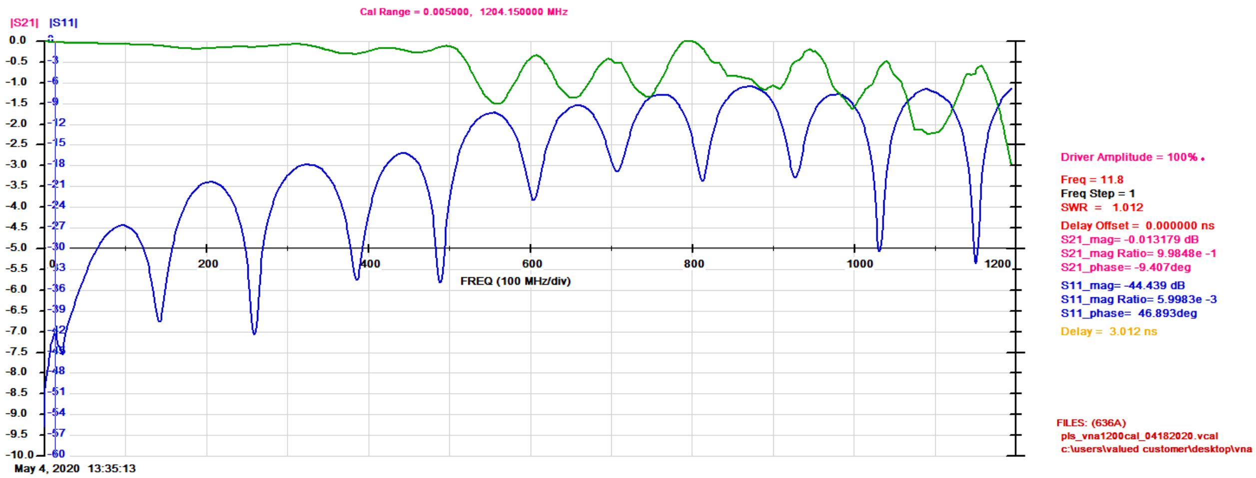

Figure 9: Baseline data for Sharp bend test (Cable 2)

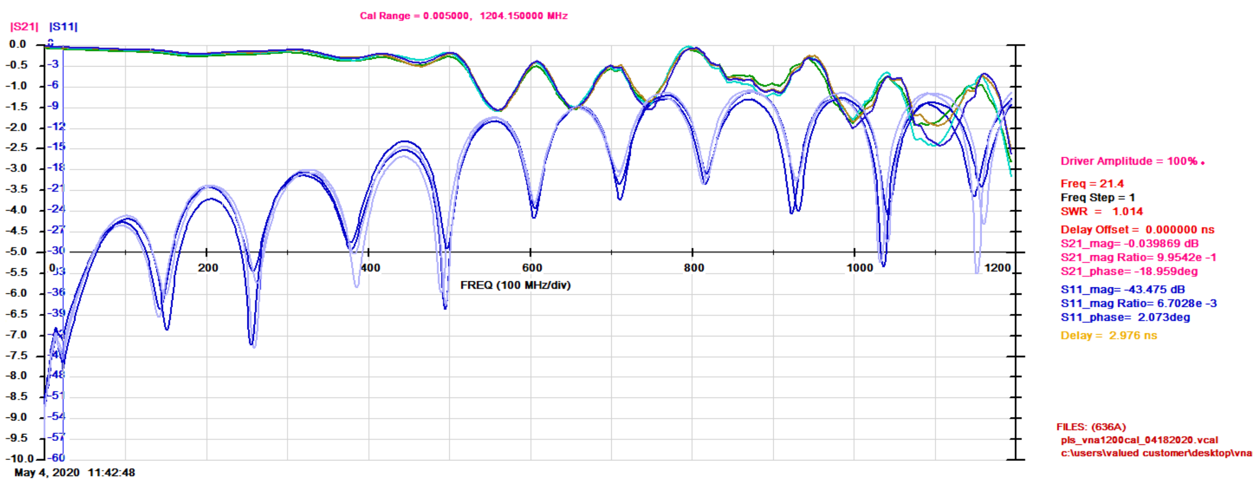

Figure 10: Overlay of all baseline data. Cables were 1m long. Pretty close half wave null points!

Test 1: Smashing Cables (No relation to Billy Corrigan and the Smashing Pumpkins)

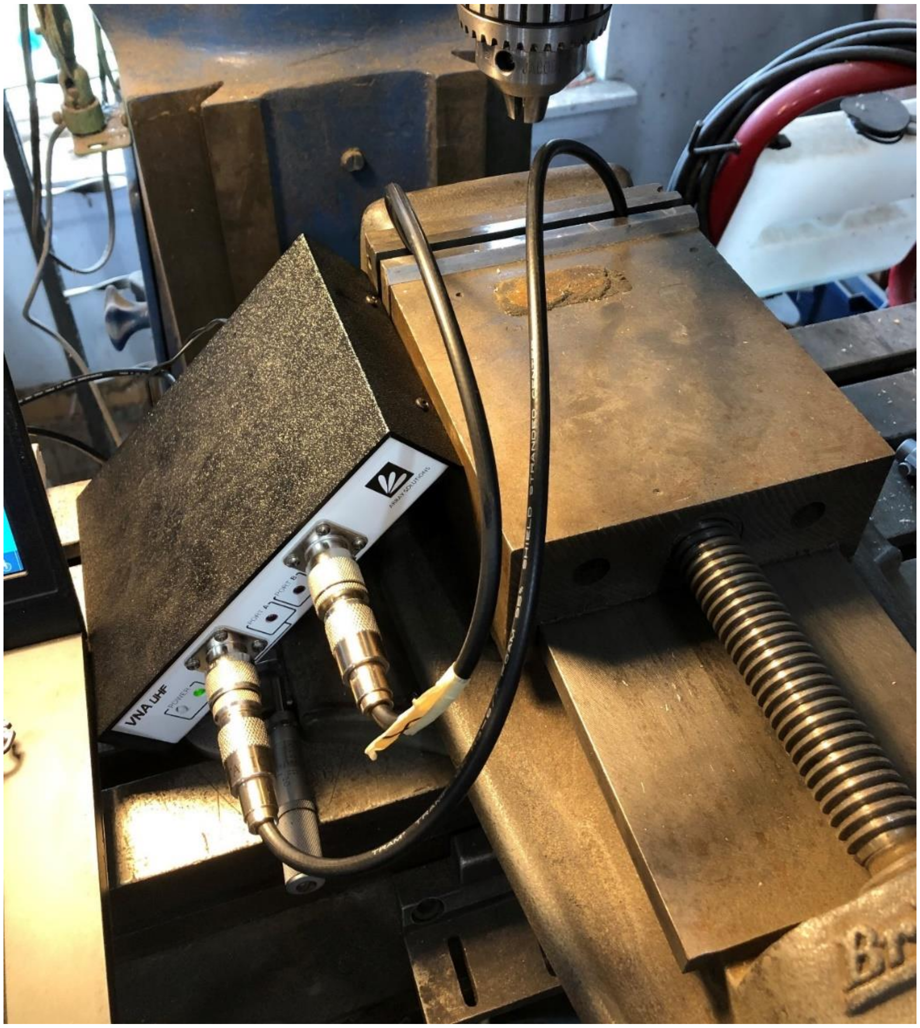

Figure 11: Smash test was done in a milling machine vise because the jaws are absolutely flat, absolutely parallel, coplanar, and it's very easy to measure compression with an ID micrometer.

No, it's not a pumpkin, but who wouldn't go for dropping perhaps "Dusk to Dawn" onto the turntable platter and giving it a spin. That dude could wail! The smash test was straight forward, carried out in a couple of increments

Smash Test							
	Frequency	50MHz	100MHz	150MHz	450MHz	900MHz	1200MHz
Original Cable (0.245" OD)	S11 (dB)	42	30	30	16	9	12
	S21 (dB)	-0.05	-0.1	-0.2	-0.5	-1	-2.5
0.210" Vise Jaw Distance	S11 (dB)	28	26	16	12	10	10
	S21 (dB)	-0.05	-0.1	-0.4	-0.9	-1	-2.5
0.150" Vise Jaw Distance	S11 (dB)	12	8	16	6	5	7
	S21 (dB)	-0.3	-0.8	-2	-2.7	-3.3	-2.5
0.130" Vise Jaw Distance	S11 (dB)	10	7	12	5	6	8
	S21 (dB)	-0.5	-1.2	-2.7	-2.7	-3.3	-3

Figure 12: Smash test results

Test 2: Cable Splice

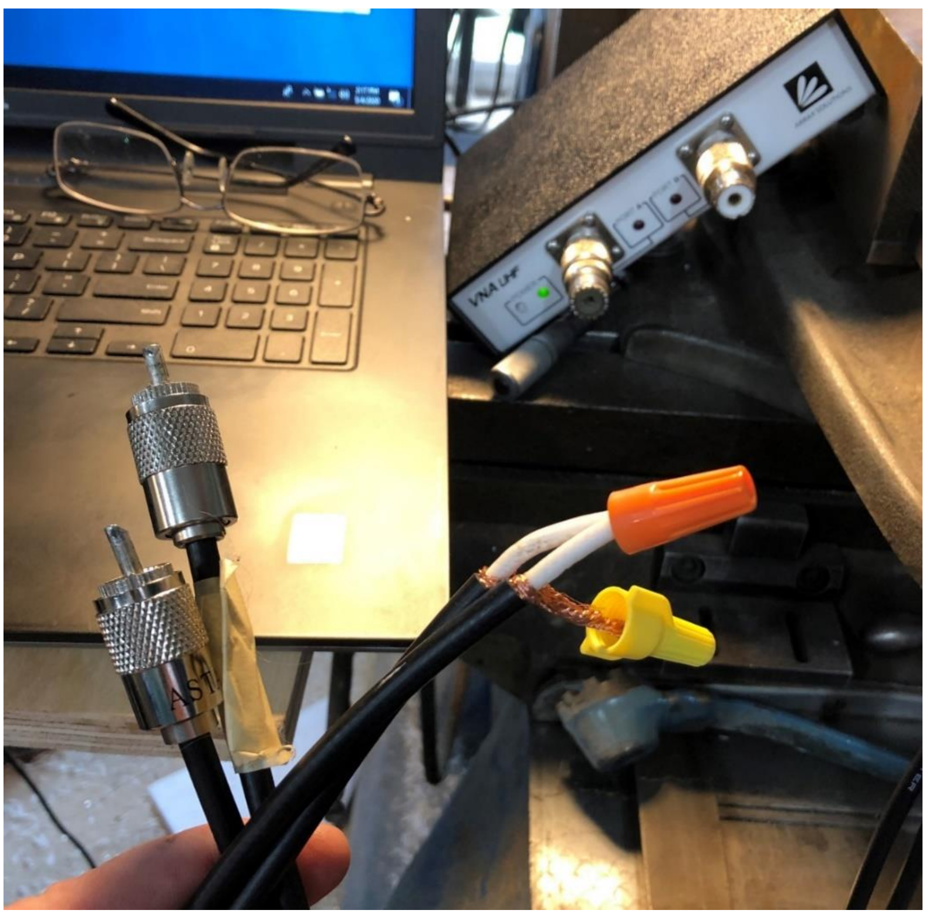

Figure 13: Oh YES, I DID!!! Didn't ya want to know? Have you ever had a coax crisis *without* wire nuts being available?? Glad it's not waveguide or fiber though eh?

Figure 14: But surely we can do better than wire nuts. Core soldered up in telegrapher's splice

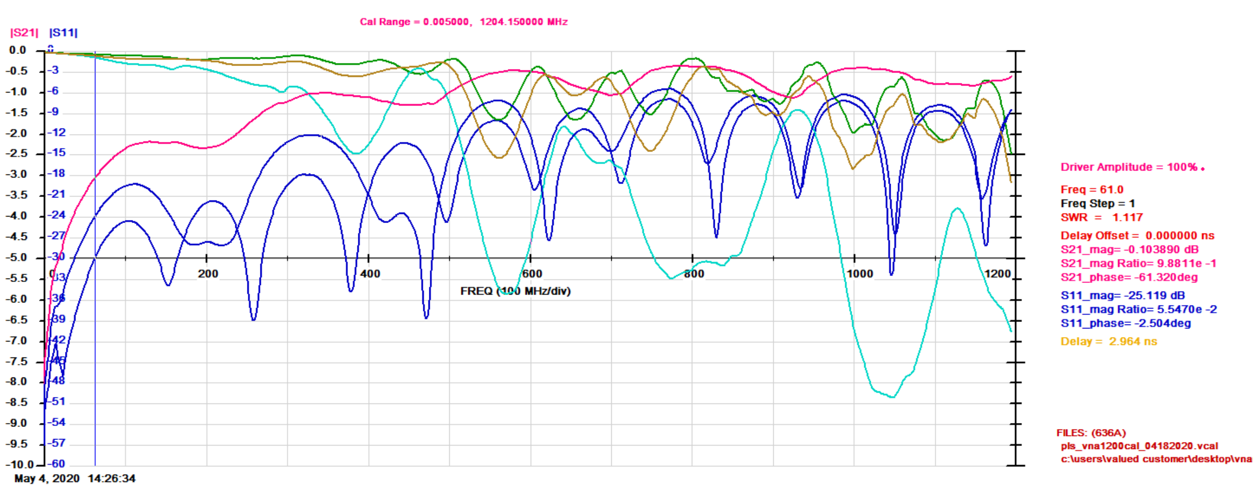

Figure 15: Splice data. Shows original S11, S21, then wire nut splice, then improved splice. Hard to read without cursors…

Figure 16: Taped over the telegrapher's splice, wrapped it up in lots of copper braid. If you've ever had the misfortune of "makin' it work" it might have looked like this. Then you went over it with splicing tape hoping the water would stay out.

Splice Test							
	Frequency	50MHz	100MHz	150MHz	450MHz	900MHz	1200MHz
Original Cable	S11 (dB)	30	24	33	13	8	9
	S21 (dB)	-0.05	-0.1	-0.2	-0.5	-1.3	-2.5
Wire Nut Splice	S11 (dB)	18	14	13	8	6	4
	S21 (dB)	-0.1	-0.3	-0.4	-0.5	-2.4	-6.7
Improved Splice	S11 (dB)	24	19	21	24	9	9
	S21 (dB)	-0.05	-0.2	-0.2	-0.4	-1.5	-3

Figure 17: Splice results

Test 3: Abrasion

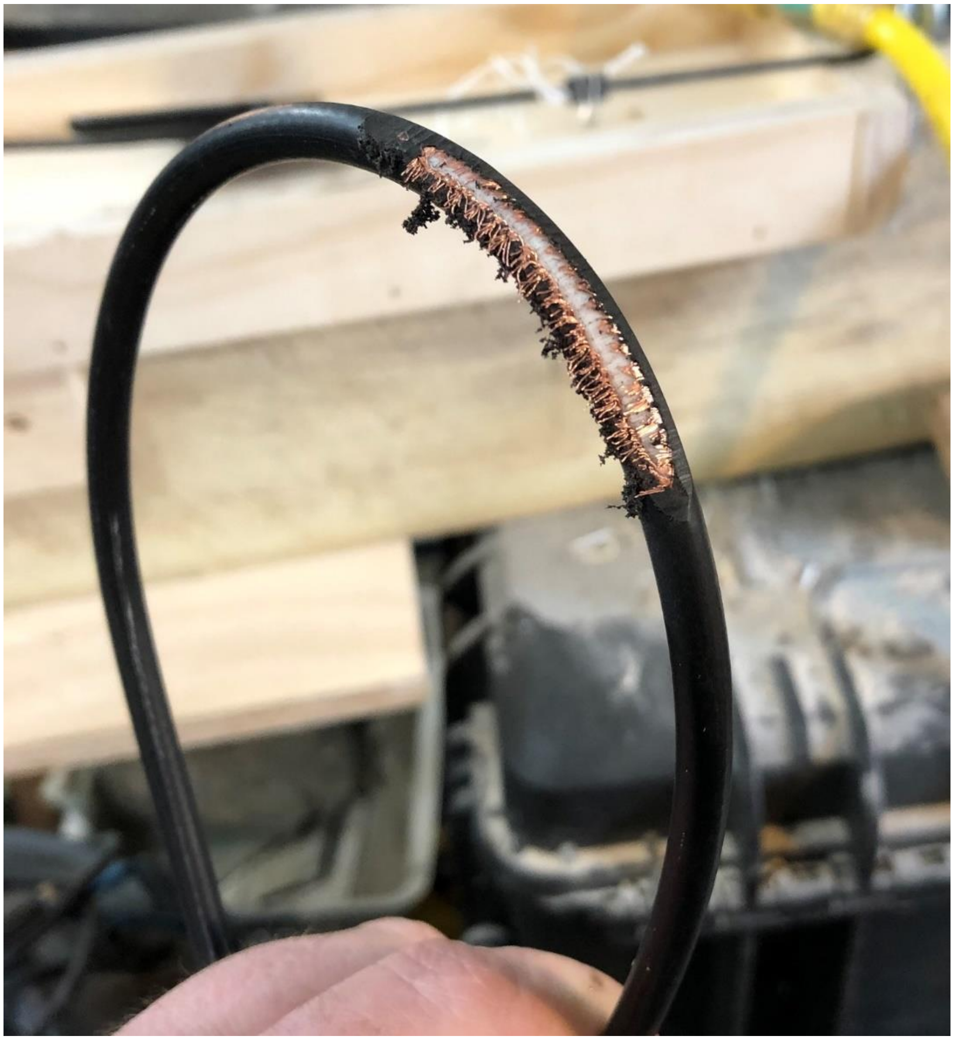

Figure 18: Bench grinder to simulate perhaps a little abrasion. ”[we dragged it] over the hills and through the woods to grandma’s house!”

Figure 19: And then we dragged it back too!!

Abrade Test							
	Frequency	50MHz	100MHz	150MHz	450MHz	900MHz	1200MHz
Original cable	S11 (dB)	27	23	39	14	8	8
	S21 (dB)	-0.05	-0.1	-0.2	-0.5	-1.3	-2.7
Abrasion	S11 (dB)	27	24	39	14	8	8
	S21 (dB)	-0.05	-0.1	-0.2	-0.5	-1.5	-2.7
More Abrasion	S11 (dB)	24	22	33	17	9	8
	S21 (dB)	-0.05	-0.1	-0.2	-0.5	-1.5	-2.7

Figure 20: Abrasion results

Test 4: Sharp Bend

Figure 21: WAY tighter than the recommended 4.5” bend radius for RG8U. This is more like 0.01” bend radius! About like the door or trunk slam…

Bend Test							
	Frequency	50MHz	100MHz	150MHz	450MHz	900MHz	1200MHz
Original cable	S11 (dB)	30	26	42	16	9	8
	S21 (dB)	-0.05	-0.1	-0.2	-0.4	-1.2	-3
Soft bend (0.2" Radius)	S11 (dB)	34	31	30	16	13	6
	S21 (dB)	-0.05	-0.1	-0.2	-0.5	-0.8	-4.5
Hard Bend (0.1" Radius)	S11 (dB)	34	30	18	10	9	3
	S21 (dB)	-0.05	-0.1	-0.2	-1	-1.7	-7.5

Figure 22: Sharp bend results

Conclusions

I found the splice surprising. Wire nuts, lousy, non RF compliant, barnyard variety wire nuts can splice a cable for reasonable performance on HF. Clearly at VHF and UHF frequencies wire nuts don't work at all, but the insertion loss at HF was a lot less than I expected it to be. I don't recommend splicing coaxial cable at all, but the improved splice was also surprising well into UHF. I thought the abrasion test would be worse. Most everytime I've scraped up a cable, I just guessed I was losing at least 3 or 4dB. Not true. The bend or pinch test fell apart at UHF, and from experience, this makes sense. Crease that cable once and UHF isn't the same.

The Array Solutions VNA UHF vector network analyzer is a real treat. The good folks at Array Solutions have built a wonderful product and they stand behind it.

PS: Should one be so inclined, Array Solutions can be reached at:

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