# Making Our Own High-Quality SMA Test Cables



Always use a gage kit after making a cable to ensure the pin and the dielectric of the SMA connector are in spec.



AmphenoIRF #901-9808 captivated contact SMA connectors



### Making Our Own High-Quality SMA Test Cables

### Materials (pricing as of October 2013)

AmphenolRF #901-9808 captivated contact SMA connectors Belden #1673A 0.141" o.d. Conformable cable Mouser.com Tallycom.com \$6.07 ea @qty 25 \$4.24/foot

#### Tools

Heat-sink adapter (custom copies of the SanTron assembly adapter #1209-03-P) Maury Microwave #A027A SMA gage kit

We'll use the heat-sink adapter (the secret sauce!) to prevent the dielectric from ooshing out during the step of soldering the outer braid (don't apply more heat than needed). These heat-sink adapters are in the tools case on the GSI desk in the lab.

After assembly, always use the Maury Microwave #A027A gage kit to ensure the pin depth and dielectric depth are in spec. Always inspect under a stereo microscope.

Don't allow any out-of-spec cables to remain in the lab. Out-of-spec cables can crush the fingers in the connectors on the ECal!

# The Reasons to Make Our Own High Quality Test Cables:

- To ensure the ECal, an \$11,000 instrument, and/or the mechanical cal standards, do not get broken
- To ensure our cables have good phase stability, so we can measure accurately
- Commercially available cables of this quality cost \$100s of dollars each

We want to protect the ports on this ECal:



This is a 3.5 mm precision slotless connector (female):



SMA connectors have the same mechanical dimensions as 3.5 mm connectors, but have a plastic dielectric between the inner and outer coaxial conductors (in a 3.5 mm connector, the dielectric is air).

This is a close-up view of a male SMA plug connector that's more or less made correctly:



Here are some close-up views of really bad male SMA plug connectors. These were hand-made in a Cory research lab. There's a learning curve to crimping such cables and assemblying them correctly.

Notice how far out the shoulder of each center pin protrudes from the end face of the surrounding cylinder.





Throw these cables away. If you plug a bad cable such as either of these into an ECal or a mechanical cal standard, or attach this to the test port of a network analyzer, and then torque them tight, you'll ruin the female port connector. The ECal's female center receptor will get its fingers squashed and will no longer make a uniform transmission line.

That means you'll get reflections, or worse, flaky intermittent problems that are hard to debug.

Always inspect a connector or cable under a stereo microscope to make sure it's clean, and then gage it, before plugging it into any equipment. **Crushed fingers:** If your SMA cables are out of spec (the male pin protrudes in the positive direction), then if you connect your SMA cable to a female 3.5 mm ECal port or mechanical calibration standard, you can ruin the ECal or the standard, by breaking the fingers inside the center conductor which are designed to accept the male pin. ECals and mechanical calibration standards are very expensive, so always check your SMA cables (visually under a microscope and with a pin-depth gage) before plugging an ECal.

Here's an example of how an ECal port connector has been destroyed:



3.5 mm connectors use what are called precision slotless connections for the center receptacle. There are fingers which expand, in order to accept the male pin, but they're inside a solid cylinder which doesn't expand. Consequently, the geometry between the inner and outer conductors stays uniform, creating a uniform transmission line through the connection.



The finger is folder over and smushed down in here.

The web page for these AmphenoIRF #901-9808 captivated contact SMA male plug connectors we'll be using to make our custom test cables, is here:

www.amphenolrf.com

Then search for 901-9808:

	record.asp?N=0&sid=5137D880401	BBCFF&R=901-9808	
Amphenol <sup>®</sup> R	<b>F</b> Global RF Solutions	901-9808 Part Number O Text	search III RoHS
products site tools rf ma	de simple distributors about	us newsletter contact us log	n Toll Fr Inside
Product Search	product details		
AMC BNC / RP-BNC SAVEA SMP			
EME HD BNC HN MCX	Please note: Images are for reference Amphenol Part Number: Product Series:	e only 901-9808 <u>SMA</u>	
<u>Mini BNC</u> <u>Mini UHF</u> <u>Mini 75 Ω SMB</u> <u>MMCX</u> Precision (APC)	Product Type: Application: Body Plating: Body Termination:	<u>Connectors</u> » <u>Cable</u> <u>Solder</u> <u>Gold</u> <u>Solder</u>	
<u>QMA</u> <u>SC</u> <u>SMA / RP-SMA</u> SMB	Cable Group: Cable Type: Connector Body Style: Connector Material:	<u>L</u> <u>.141 SEMI RIGID</u> <u>Straight</u> Stainless Steel	
<u>SMP</u> SSMB TNC / RP-TNC	Contact Plating: Contact Termination: Gender:	<u>Gold</u> <u>Solder</u> <u>Plug</u>	
<u>Triax</u> <u>True 75 Ω BNC</u> <u>Twin BNC</u> <u>Twinax</u>	Impedance: RoHS Certificate: IGS File Download:	<u>50 Ohm</u> Yes IGS File	Click on Assembly Instructions
<u>Type F</u> <u>Type G</u> <u>Type N</u> <u>UHF</u> Bayaras Balarity	More Information:	Assembly Instructions Sustemer Drawing Distributor Inventory	
Adapters Tools Accessories			

Always measure the pin depth and dielectric depth, using the gages, both before and after assembly. First, zero the MP (male pin) and MD (male dielectric) gages with the gage master:





Then attach the male 901-9808 connector to each of the male pin and male dielectric gages to check that your connectors are within spec. You'll want to compare these measurements to measurements after soldering to see if the connector's pin and/or the dielectric moved due to the heating:





The assembly instructions for the 901-9808 say you'll need to strip the cable 0.125" (3.2 mm):



The manufacturer of the RG-402 conformal cable we'll be using is Belden and the part number is #1673A. One distributer is Talley: www.talleycom.com

It lives here in the Cory 111 lab: Conformable Coax Cable 50 Ohm Microwave Cables

Description	Part No.	UL NEC/ C(UL) CEC Type	Standard Lengths Unit W		idard Veight	Conductor (stranding)	Nominal Core OD		Shielding Materiala	Nominal OD		Nom.	Nom. Vel.	Nominal Capacitance		Nominal Attenuation		
			Ft.	m	Lbs.	kg	Diameter Nom. DCR	Inch	mm	Nom. DCR	Inch	mm	(Ω)	of Prop.	pF/Ft.	pF/m	MHz	dB/ 100 Ft.

RG-402/U Type • 19 AWG Solid .036" Silver-plated Copper-covered Steel Conductor • Copper-Tin Composite Shield (100% Coverage)

TFE Teflo	on® Insu	lation	<ul> <li>Unjac</li> </ul>	keted															
UL AWM Style 10245 (30V 105°C)	1673A* ⊒ີ;	_	50 100 250† 500	15.2 30.5 76.2 152.4	3.3 3.9 8.0 15.0	1.5 1.8 3.6 6.8	19 AWG (solid) .036" SPCCS 20.5Ω/M' 67.3Ω/km	.116	2.95	CT Composite 100% Shield Coverage 4.5Ω/M' 14.8Ω/km	.138	3.51	50	69.5%	29.5	96.8	500 1000 2000 3000 5000 7000 10000 15000 18000 20000	8.0 12.0 18.1 22.9 31.0 37.8 46.6 59.1 65.8 70.0	26.2 39.4 59.4 75.1 101.7 124.0 152.9 193.9 215.9 229.7
							Th	e gag	ge siz	e of the s	solid	inner	r cor	nducto	or is a	AWG	19.		
							Th	at is	it's O	.036" in d	diam	eter,	or 3	6 mils					

1 mil = 0.001"

This is the AmphenolRF 901-9809 captivated-contact SMA connector. With a captivated-contact type of connector, when you buy the connector, the pin is already in the connector and set to the correct depth.



This is the Belden #1673A 0.141" outer diameter conformable coax cable. After stripping a longer length, use the calipers to measure 0.125" and cut the inner conductor to 0.125".

Then file off any burrs from the end of the inner conductor.



A wire stripper, calipers and a file are in plastic boxes on the GSI's desk.



Blades for stripping. There isn't one for AWG 19, so try the slot for AWG 18 and inspect under a microscope. The slot for AWG 16 seems to not knick the inner conductor.



Blades for cutting









Yes, the inner conductor does measure as 36 mils in diameter.

Now lock down the jaws at this distance with this knob.



Now transfer to the wire strippers and compare to the AWG 18 slot. The cable inner conductor is spec'd as being AWG 19 gage (higher numbers mean smaller diameter wire), and 36 mils is indeed a bit smaller than the AWG 18 slot. Makes sense.



Try stripping with the AWG 18 slot. Inspect under the microscope. If the center conductor is knicked, cut off the end and try again, using the AWG 16 slot.





The way this would be done at a cable assembly house is that they would use a semi-automatic cable stripping machine:





One of the research labs has such a machine. The resulting stripped cable comes out nicely cut with a very flat, clean face.

We'll clean up our stripped cables with a razor blade ...



You can find razor blades in the blue plastic box also:





Work under the stereo microscope.



Make sure to turn on the light source.

Touch up the stripped face with a razor blade.



Hand stripping leaves the end face ragged.
 Cut it flat with the razor blade.



Use the razor blade to pick out any metal debris:

Slide the calipers to the length you need to strip (125 mils) and lock with the locking knob:



With the calipers locked, you'll have a free hand to cut the stripped end to length with a diagonal cutter:



Next, de-burr the edge of the inner conductor, by filing the end.



De-burring the end means to simply remove any jagged edges, so that the inner conductor will slide easily into the hole in the back of the SMA connector.



De-burring the end of the inner conductor is important because the inner conductor must fit snuggly into the hole in the back of the SMA connector.

After filing and removing any burrs, inspect under the stereo microscope. This cable was stripped with the semiautomatic cable stripping machine, and then the center conductor was manually filed to debur the end. When you strip with a hand stripper and then touch up the end face with a razor blade, it won't come out quite this beautiful.



The inner conductor is neither soldered nor crimped to the SMA connector. It's strictly a press-fit into this #901-9808.

Because there is only a press fit for the inner conductor, you have to ensure that the face of the cable is flat so it will press and mate firmly against the dielectric of the connector in order to make a clean (low mis-match) connection. The length of the stripped inner conductor should also be precisely 125 mils to fit all the way into the center hole.



If you see metal debris on the end face of the insulating dielectric when inspecting under the microscope, get rid of the debris by blowing with air, and/or picking the metal pieces out with a razor blade (also in the plastic box). The goal is to make a clean squared-off interface between the cable and the connector so as to create as uniform of a transmission line as possible.



Then push the connector onto the cable. Push it all the way in.

Next, screw the heat-sink adapter into the SMA connector. It will act as a heat sink during the soldering process.



The heat-sink adapters also live in the blue plastic box:



The heat-sink adapter is actually a SanTron assembly tool, #1209-03-P. This is kept in the plastic box with the cablemaking tools on the GSI's desk in Cory 111. Use it when making these types of cables. The pictures below show each end of the tool. Screw in the end shown on the right into the connector you're assembling onto the conformable cable. When you solder the outer braid of the conformable cable onto the neck of the connector, the heat from the soldering iron can cause the dielectric in the SMA connector to move. This tool prevents that from happening, or tries to. Don't apply more heat than you need to. Use flux (the other secret sauce!). If you apply excessive heat, the dielectric face depth will end up out of spec.





The red masking tape is to make them easy to spot when left on the lab benches. If you see one left on a bench, please put it back in this box. The machine shop made up some more of these heat sink adapters (Nov. 2013). They live here in the Cory 111 lab:





Hold the cable in a vise and solder the neck, using the heat sink to suck the heat away from the dielectric.



Use flux, and solder the outer braid to the connector neck. You don't need to use huge amounts of solder, but you must solder all sides of the cable in order to get solder all the way around. Again, you're trying to make a uniform coaxial transmission line, so you want the outer braid to make good contact circumferentially around the neck of the SMA connector.



Note: Solder is brittle! If/when this cable breaks, it will break here.

The point of failure will always be at the solder joint at the neck, so you never want to bend the cable in such a way as to induce stress at the neck.

Solder is brittle, which is why most really high quality connectors are crimped. However, crimper tools cost \$100s of dollars and can walk away, so they're not a viable solution for the Cory 111 lab. Hence this solution for making our own high-quality test cables.

Uses the gages to make sure the pin depth and dielectric depth are still within spec after soldering:





Never allow your cables to bend at the solder joint.

You can bend conformal cable as much as you want in any way you want, just remember to not let it bend at the neck.

Also, after you cal, you don't want to move them too much. The calibration is for a certain configuration of your cables.



The general strategy in working with these cables is to first make sure the network analyzer is sitting flat on the lab bench where you want to work. Then bend the cables to fit the ECal. Make sure no stress is applied at either neck. Keep the cables straight at each neck.



After calibration, you'll only bend the cables just enough to attach to your device under test. If you tape the cables down, your test setup should be nice and stable while you make measurements.



At some point during the term, you will notice a cable is broken at the neck. Don't throw the entire cable away. Instead, fix it.

Cut off the bad connector (the top one in the picture below, the other one is fine) and throw that away. Then re-strip the cable and solder on a new connector, following the instructions just outlined.



Gage the new connector before and after soldering, and also test the phase stability when you finish.

Network Analyzer Quality Tests to Verify Cable Performance

# Cable Stability Tests

- Phase S21 test
- LogMag S11 test
- SWR test

# Pre-testing: Checking Your Cables' Phase Stability Before Starting a Calibration

Hit the Preset button. Select OK. Displays LogMag S11.



Hit the Meas key, and choose S21. LogMag S21 looks like this (close to 0 dB) as almost all the signal from Port 1 makes its way to Port 2:



Hook up a cable between Ports 1 & S. Why does LogMag S11 look like this? Because there are always slight impedance mismatches at connections, so we see reflections and re-reflections, albeit 30 dB down.



To test our cables, we want to look at the Phase of S21. Hit the Format key and choose phase. The sweep here is up to 4.5 GHz, so phase wraps around about 14 times at that frequency for this particular length of cable.



90.00'/ Ref 0.000' LD/M

Hit the Display hard key. Choose: Data->Memory

Under Dat Math, choose:

Data/Memory



That will make the Phase S21 trace become zeroed:



Zoom in. Hit the Scale hard key. Set the scale to 1 degree/division:



Now stop touching the cable. Wait for the trace to settle. Now the phase goes a bit negative by the time the sweep reaches 4.5 GHz. Check how far off the phase is from zero at your frequency of interest.

Once you calibrate, and start moving the cables all around, this different bit of phase each time you change calibration standards and move the cables around during a calibration procedure, is going to get incorporated into the calibration's error-correction coefficients.



Expensive cables are usually expensive because they have good phase stability.

Try it again. Wiggle the cable around some more, then take your hands away and see where it settles. This time we see a bit of positive phase at the upper frequencies.



Cable Stability Tests

- Phase S21 test
- LogMag S11 test
- SWR test

## **Dunsmore Advice on Pre-Testing Cables**

(from the Agilent web forum)

"To test the cable: Place the cable on one port of the VNA, attach a Short or Open standard from a calkit on the other end. Don't cal. Just do Data->Mem and Data-Mem (that's right, Data -Minus- Memory). Look at the result in dB. Immediately after that, the trace should show -70 or -80 dB return loss. Now flex the cable back and forth and up and down. The trace for a "GOOD" cable should be -50 dB. If the highest spot on the trace is above -30 dB it is a "BAD" cable. Take a wire cutter and immediately cut the cable in 20. For me, I would not use a cable that is worse than -40 dB."

Let's do this test on a few cables in our lab...

### Cable #12

Just after Data->Mem for each window, and Data-Mem for the top, and Data/Mem for the bottom

LogMag S11 (ref set to -50 dB, \_\_\_\_\_ scale set to 10 dB/division)

Phase S11 (ref set to 0 dB, scale set to 1 deg/division)

Short standard

Alternatively, you can modify a female SMA jack. Cut the center signal pin flat against the face and solder copper tape to make a low inductance short.





Now after wiggling and letting it settle.

This cable is really bad.



### Cable #2

LogMag S11

(ref set to -50 dB,

Just after Data->Mem for each window, and Data-Mem for the top, and Data/Mem for the bottom

gin ESCITC man and

Now after wiggling and letting it settle.

This cable is pretty good.



scale set to 10 dB/division) Phase S11 (ref set to 0 dB,



Short standard

Here's a very good cable (brand new, \$50, came with a sheet showing its factory test).

Just after saving into memory, before wiggling:



After wiggling and letting it settle. Below -50 dB for all freqs up to 4.5 GHz. Good.



Cable Stability Tests

- Phase S21 test
- LogMag S11 test
- SWR test

## A Third Cable Test – the SWR Test

This is probably the best test. The SWR test is the way Scotts Valley Magnetics and SanTron, two high-end cable assemblers, test their cables:

- Attach your cable to Port 1 of the network analyzer
- Attach a 50 ohm cal standard or any 50 ohm load to the other end
  - A perfect cable and 50 ohm load would show an SWR of 1.00
- Under the Format menu (Format hard key), select SWR
- If the SWR measurement is under 1.22, SanTron says it's a good cable (albeit they measure to 20 GHz)

You shouldn't need to calibrate the network analyzer to do your cable pre-testing. The default factory setting (hitting the Preset hard key) should be a good enough calibration setting to test your cables for whether you should throw them in the garbage or not.



The yellow triangle marks the Reference Position for the yellow48trace. Here, the Reference Position is at the 0<sup>th</sup> division.

Of course, if you do this test with the exact same cable, on the broken network analyzer (Network Analyzer C), you'll get some crazy results.



Network Analyzer C's Port 1 says that this same cable has an SWR of 3.4!

If you calibrate this network analyzer before you test the cable, you won't get such a bad reading. However, the calibration will work so hard to "fix" the errors, that subsequent measurements will always have dynamic range degraded.



# When are "bad" cables okay to use? When do you need to re-calibrate?

Cables are really bad if the male pin's shoulder sticks out beyond the reference plane, since that can damage cal standards or test port savers. Don't use those.

Other cable problems can be calibrated out to some extent. That is, as long as the trace is stable, then any mismatch, phase delay and loss can be calibrated out. But if they cables aren't stable, they've probably been crimped or have cracked, and consequently make intermittent connections.

When you've achieved a "good" calibration, it can last for a week or two because the network analyzer itself is a fairly precise instrument, but we often change our setups, so this is moot.

Re-calibration should be done if you dis-connect and re-connect cables, or if you change the frequency sweep settings such that the sweep is over a larger range than when calibration was done.

Calibration does not have to be re-done however, when simply changing the output power level of the analyzer (e.g. for amplifier measurements). Older analyzers used to require re-calibration after a power level change, but our E5071Cs don't need to be re-calibrated after changing the power level.

Final caveat: if you're in a room with air conditioners turning on and off, very precise measurements can sometimes detect that temperature change.