Care of Expensive Precision Equipment in Cory 111 Lab

Manual for Qualified User Quiz

Background: The Cory 111 RF Electronics lab has 4 network analyzers and 4 spectrum analyzers which were generously donated by Agilent in 2007. These are precision high-quality pieces of test equipment, and very expensive. Although most students recognize this, they might not realize that the calibration standards and cables are equally precise, critical components of a successful measurement - and they are also quite expensive.

The real problem however, is that a bad cable or connector can get in a lab and ruin the connector it's plugged into ... and that can spread like a virus throughout the lab. By the Fall semester of 2012, of the 13 calibration standards we have in the lab, 7 were broken. A network analyzer was also broken. (Calibration standards come in a kit, which costs upwards of $3000. You can look up prices for any equipment in our lab, on the Agilent web site. Sending a network analyzer back for repair costs $4700.) In addition, of the 20-odd SMA cables, 12 were out of spec (this was the culprit that caused the virus) and 5 were of poor phase stability.

There is no money in the Instructional Labs' budget for repairing equipment. We've asked Agilent for a further donation to fix many of these things, and fortunately they have again been very generous. Also, the company which manufactures the test cables for Agilent, Scotts Valley Magnetics, has also been generous in donating cable and knowledge so that we can make our own cables and keep things working well in the lab.

Plan: Going forward, we are going to institute a training program similar to the procedures used in the Nanofab, where the general strategy is that students pass knowledge of equipment care on to other students in an "each one, teach one" fashion. Anyone who wishes to use the equipment in the Cory 111 lab (i.e. become a Qualified User), must go through this training which consists of:

1) Contacting another Qualified User to get a demonstration of how not to break the equipment
2) Reading this manual & the Agilent Connector Care handout, and then completing a written quiz
3) Contacting a Super User to meet for a hands-on qualification quiz/checkout

As Super Users graduate and leave, Qualified Users are expected to step up and volunteer to become Super Users. Hopefully, passing knowledge on in this manner will keep the equipment in good shape and help everyone who needs to use the equipment.

Topics in How to Not Break the Expensive Equipment

1) The worst: crushed fingers in female 3.5 mm calibration standards
    a) Culprit #1: SMA cables' pin-depth gage measurements out of spec
    b) Culprit #2: Users incorrectly rotating the 3.5 mm standard when attaching SMA cables
2) How to clean the equipment connectors without leaving lint
3) How to "see" broken connectors & crushed fingers under the stereo microscope
4) How to use the pin-depth and dielectric-depth gages to measure SMA cable connectors
5) How to properly use 2 wrenches (torque wrench and open-end wrench) to make connections
6) How to store calibration standards with their red plastic end caps
7) How not to touch the end faces of connectors with oily fingers
8) Why to always use test-port savers
9) How to use the ECal spanner wrench and how to support the ECal when attaching it to the analyzer
10) How not to drop the ECal on the floor (which is probably how it broke last summer)
11) How not to attach a 50 ohm calibration standard to your amplifier's output
12) How to avoid putting too much power from your circuit into the network analyzer (probably how it broke)
13) How to touch the center conductor of any connector to VNA case ground, to protect against static zapping

Topics for How to Fix It If It's Broken

1) How to measure cable stability on the network analyzer to see if your cable is bad
2) How to make your own brand new high-quality SMA cable using semi-rigid coax

Our network analyzers have female N connectors, to which we usually attach male-N-to-female-SMA adapters.

All of our coax cables are male-SMA-to-male-SMA cables.

The calibration reference plane of a male N connector is the plane coincident with the edge face of this metal ground ring surrounding the center signal pin.

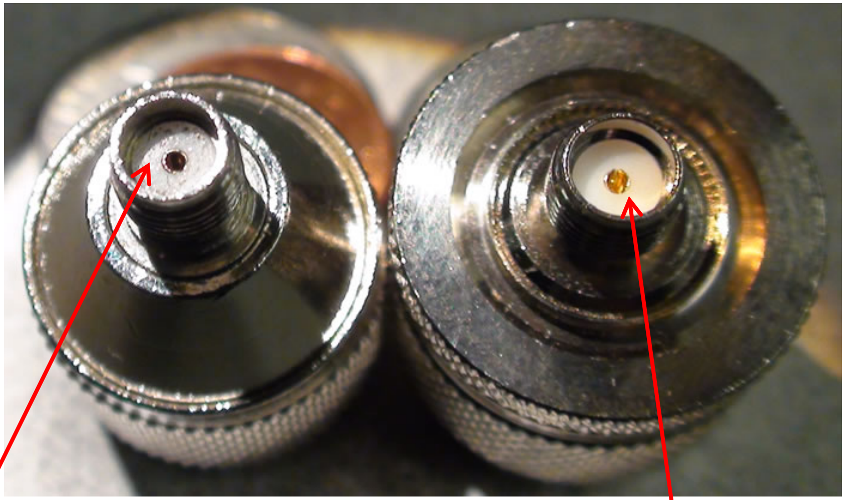
The mating surface on the female connector is another metal ring down at the bottom. However, we won't usually be calibrating directly at this port. We usually want to calibrate so as to move the calibration reference plane from this plane to the far end of our male-male SMA cables.

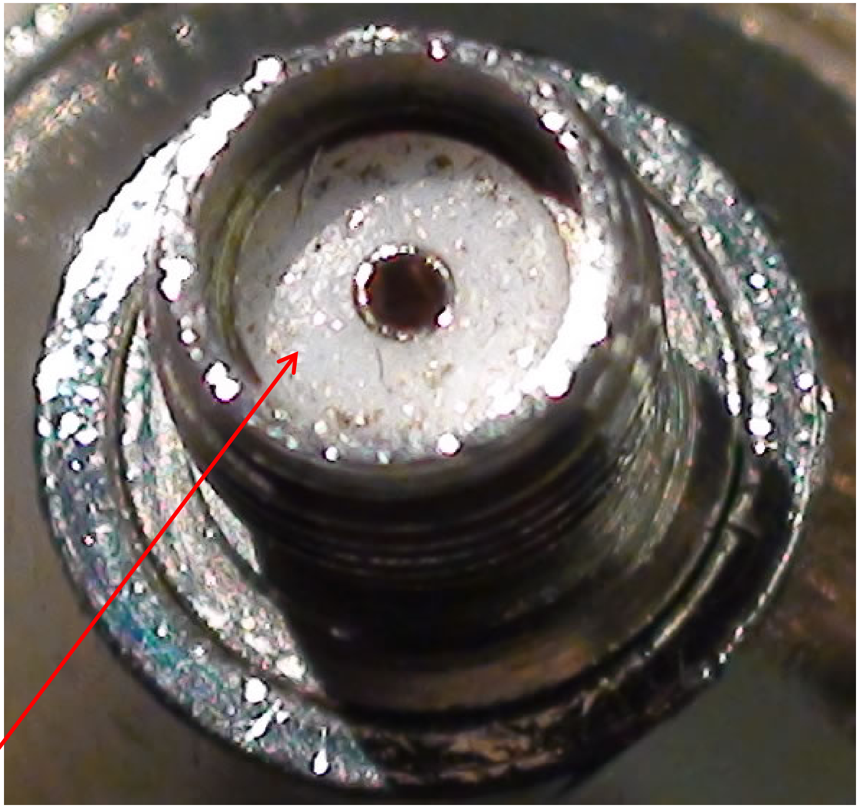
Make sure that none of the adapters have rubber gaskets down at their bottom. Those are made for outdoor applications and require a different torque setting. You can pull the gaskets out with tweezers. If they're left in, and not fully torqued, they make poor (intermittent) connection and don't work.

Inspect both ends of the male-N-to-female-SMA adapters.

Not just this male-N side

...but also the female-SMA side





Here's an old adapter taken off of one of the analyzers in our lab. It's probably been on there since the equipment was donated in 2007 (this picture is taken at the end of 2012). Notice all the bits of metal debris on the surface of the white plastic.

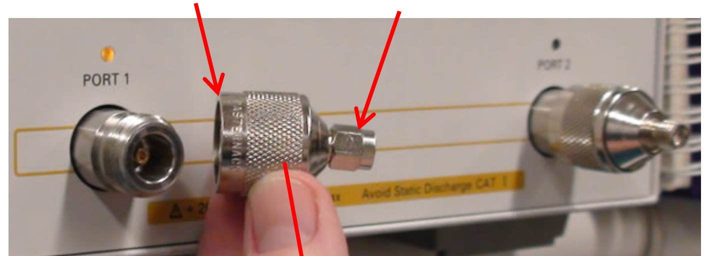
This is a brand new adapter.

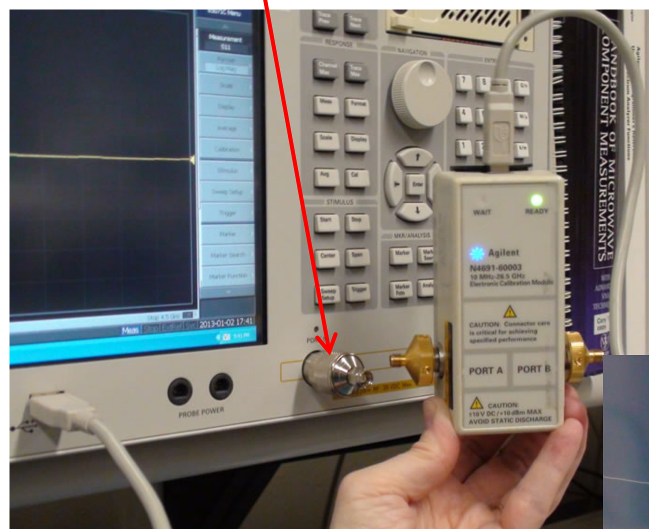
Close-up of the old adapter. Time to clean it. All these metal bits change the electromagnetic environment from what we would assume to be a uniform transmission line of coax cable.

Sometimes however, we use male-N-to-male-SMA adapters ... for instance, when we want to test our test equipment. At bottom right is an ECal (electronic calibrator), which has gold female connectors on each port.

These male-N-to-male-SMA adapters have rubber gaskets on the SMA side too. All SMA connectors have rubber gaskets, but SMA connectors have flats so are easier to tighten to their specified torque.

Specifications on torque:
N connectors: 12 in-lb
3.5 mm connectors: 8 in-lb.
SMA connectors: 5 in-lb.





The ECal can plug directly into the male-N-to-male-SMA adapter. I thought it would be good to test the Ecal this way, as it minimizes the number of cables, adapters and connectors. Unfortunately, I bought some cheap male-N-to-male-SMA adapters and they broke when I torqued them. It's worth it to buy the more expensive male-N-to-male-3.5mm adapters that are made for test applications. Maury Microwave sells them for $80 - $200 each. Otherwise, stick with the male-N-to-female-SMA adapters.

Clean the connectors by first blowing on them with a short burst of clean dry air. Cans are availalbe at Ace Hardware on University Ave. Use sparingly. Let's make the cans last as long as possible.

Then, use a lint-free swab (you can buy them from Texwipes via Amazon) and moisten it with isopropyl alcohol. Look at the connector under a microscrope and brush the swab over the dielectric, around the center conductor.

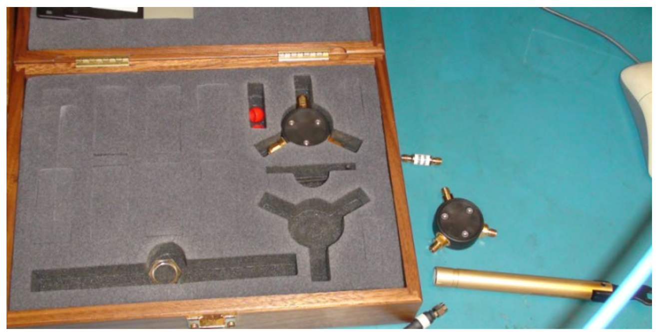
Blow dry. Check again under the microscope to make sure they're clean.

Also, make sure the connectors are dry before you thread them onto anything.

We have 1 electronic calibrator (Ecal) and 2 mechanical calibration kits: 85052D and 85033E. The 2 mechanical calibration standard sets come in both female and male 3.5 mm connectors. The inner diameter of the outer shield is 3.5 mm. These 3.5 mm connectors use air as the dielectric insulator between the center signal pin and the surrounding ground cylinder. 3.5 mm connectors mate with SMA (Sub-Miniature A) connectors. The only difference between the two types of connectors is that SMA connectors use a plastic teflon-like dielectric insulator.

People often use the verbal shorthand of “SMA” when referrring to a 3.5 mm connector, but they’re technically different. Because of their air dielectric, 3.5 mm connectors are rated to 26 GHz and used on test equipment for precision measurements. SMA connectors on the other hand, because of their plastic dielectric, are rated to only 18 GHz. However, SMA connectors are more widely used in commercial applications because they’re cheaper.

85052D 3.5 mm cal standards

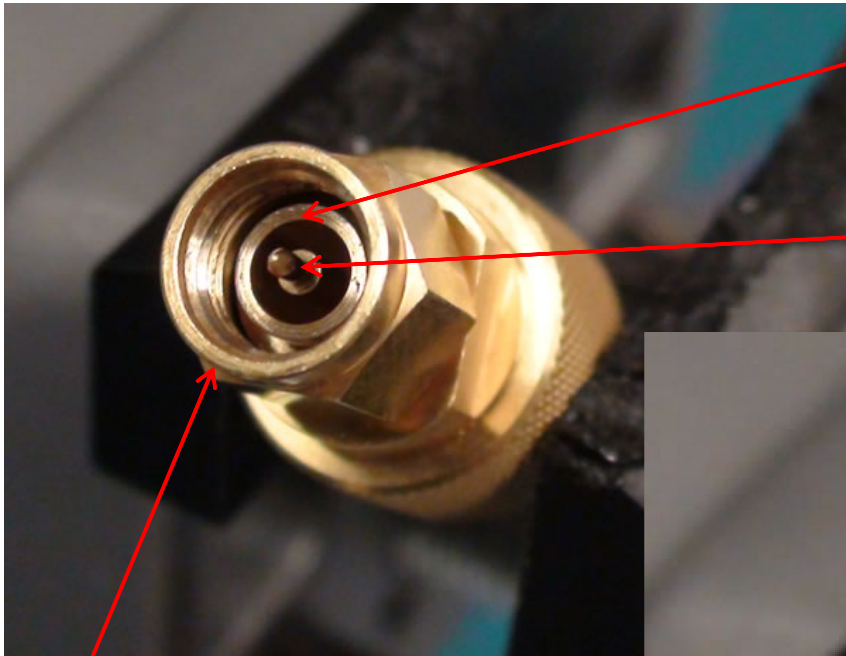


85033E 3.5 mm cal standards

Ecal

(This is Joel Dunsmore’s that he lent us while ours is being repaired. This is model N4691-60003 which is spec’d to start at 10 MHz, whereas ours is the newer N4691-60006 which is spec’d to work as low as 300 kHz.)

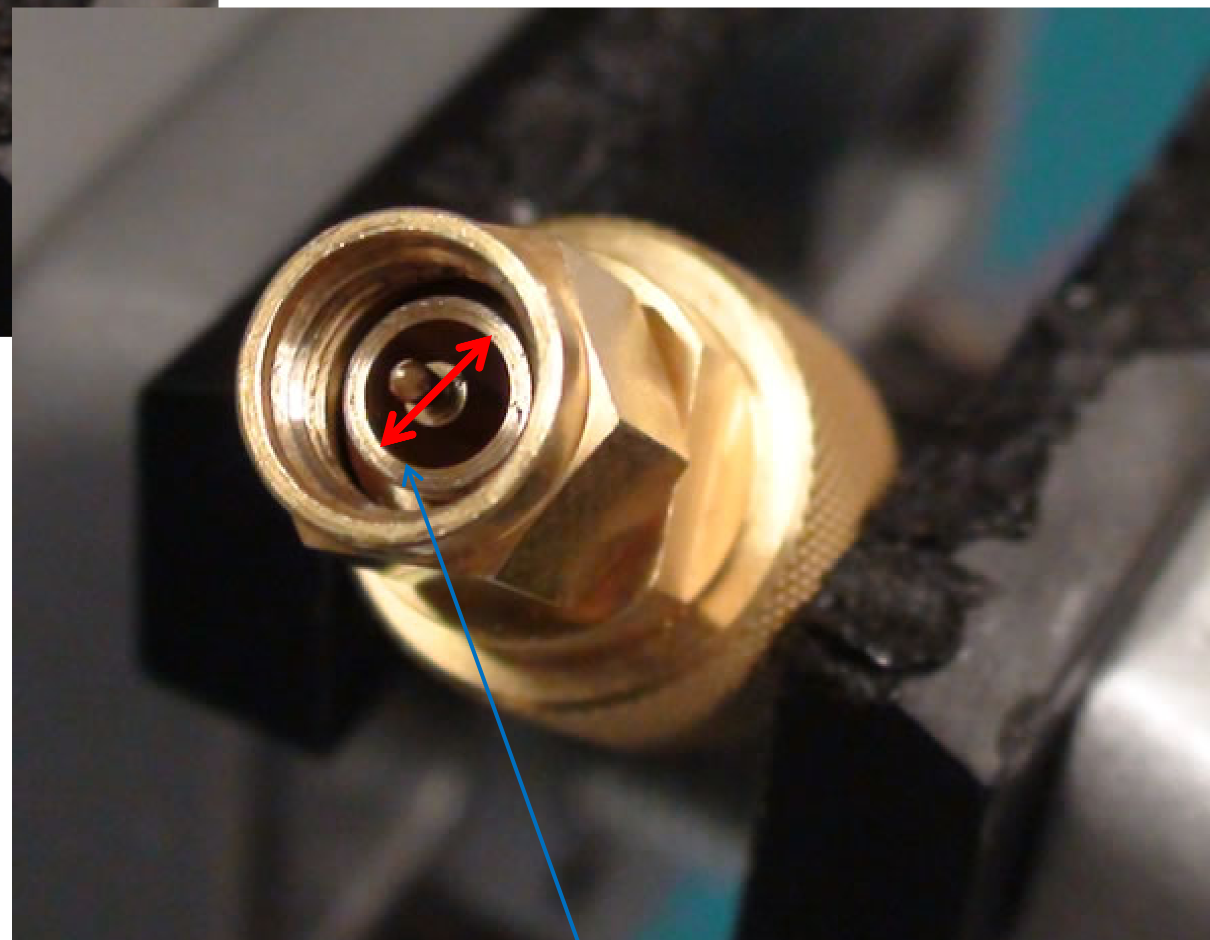
3.5 mm calibration standards



The actual coaxial transmission line consists of this outer ground cylinder here

... and this center signal conductor here. The dielectric between them is air, in a 3.5 mm connector (an SMA connector would have teflon for the dielectric).

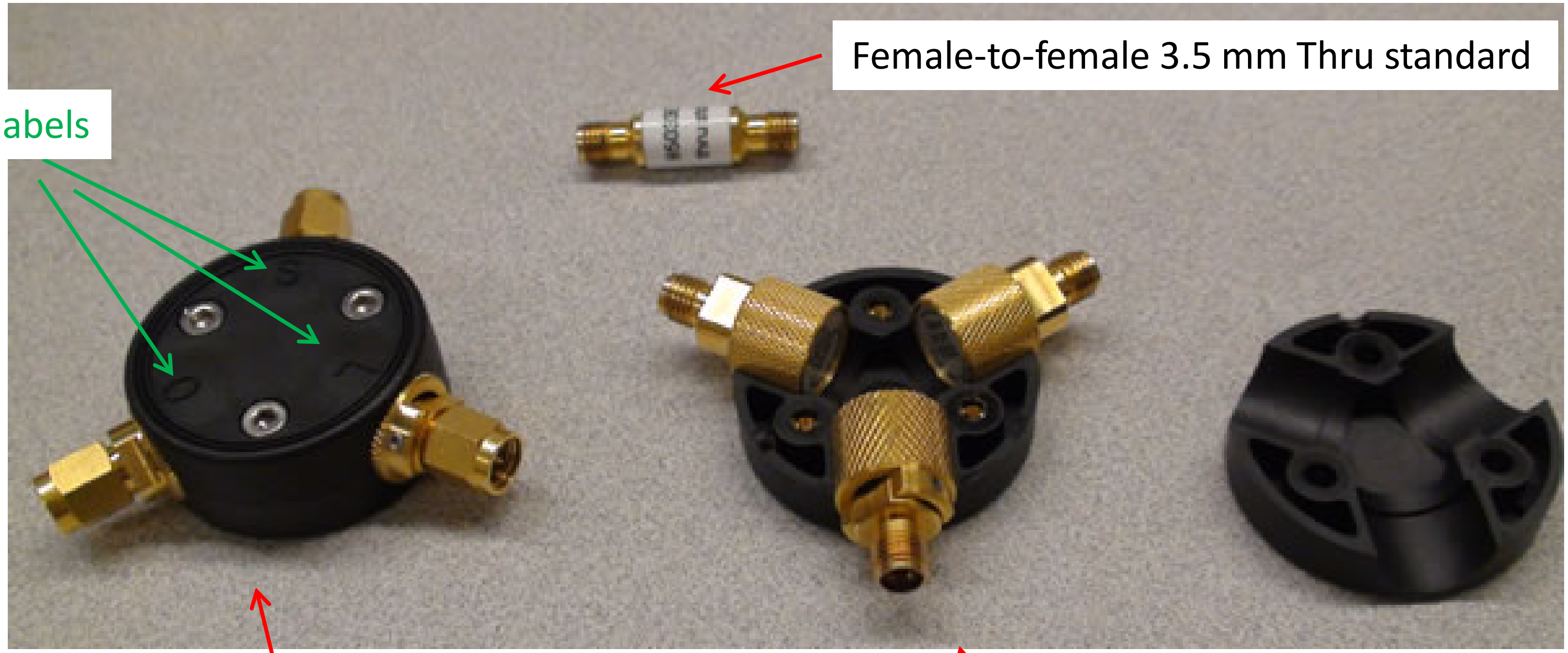
This outer portion is the nut on this male connector. The nut is not actually part of the uniform transmission line (although it does connect electrically to the outer cylinder).



This inner diameter of the outer coax ring is 3.5 mm.

Calibration standards (from the 85033E kit): Short, Open, Load and Thru (SOLT)

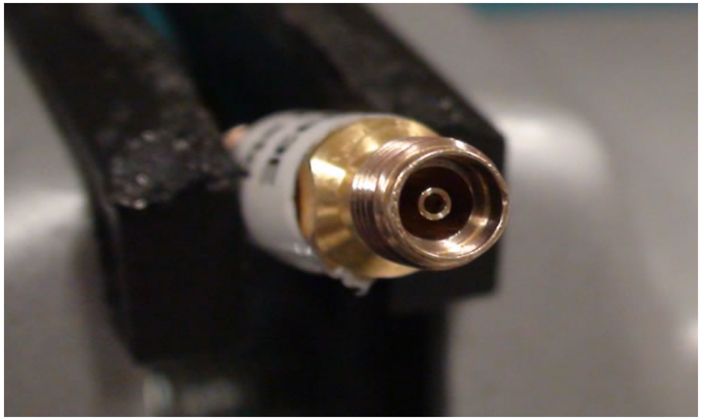
The black plastic thing is just a holder which keeps the short, open and load standards of a kit together. It's called an SOL holder.



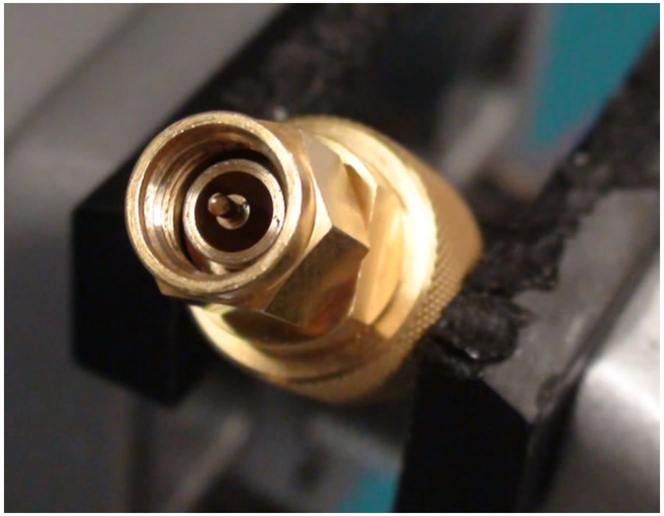
Female Open, Short, Load standards

Female-female Thru standard and male Short standard

Female 3.5 mm connector on one end of a Thru std

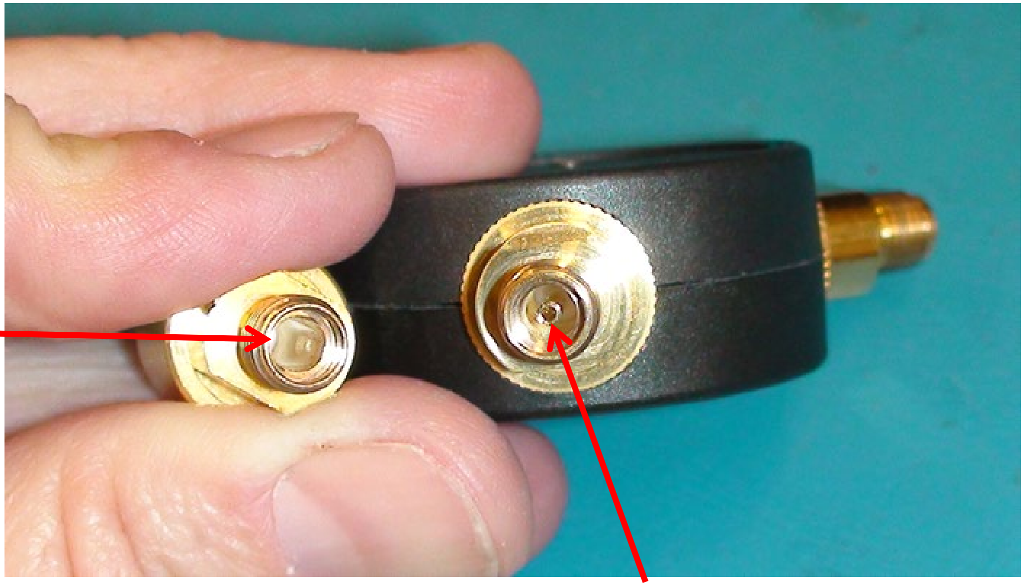


Male 3.5 mm connector on a Short std



Get in the habit of looking carefully at the calibration standards before you use them. Look at them under the stereo microscope, with the microscope light on. Hang the stereo microscope head over the edge of the table so you have plenty of distance to hold the standard and move your hands up and down to change the plane of focus so that you can see all the way to the bottom of these 3.5 mm connectors' insides.

This Open is broken. It's completely missing its insert. We wasted hours and hours trying to calibrate with no success, before we noticed.



A female standard should look like this. It should have this female center insert that accepts the male signal pin from the mating male connector.

From the 85033E service manual: http://cp.literature.agilent.com/litweb/pdf/85033-90028.pdf

Connections

Good connections require a skilled operator. *The most common cause of measurement error is poor connections.*

How to Make a Connection

First, you do a *preliminary connection*, using just your fingers:

Carefully align the connectors. The male connector center pin must slip concentrically into the contact finger of the female connector.

Push the connectors straight together. Do *not* twist or screw them together. As the center conductors mate, there is usually a slight resistance.

Do *not* turn the device body. Only turn the connector nut.

The preliminary connection is tight enough when the mating plane surfaces make uniform, light contact. Do not overtighten this connection.

A connection in which the outer conductors make gentle contact at all points on both mating surfaces is sufficient. Very light finger pressure is enough.

Make sure the connectors are properly supported. Relieve any side pressure on the connection from long or heavy devices or cables.

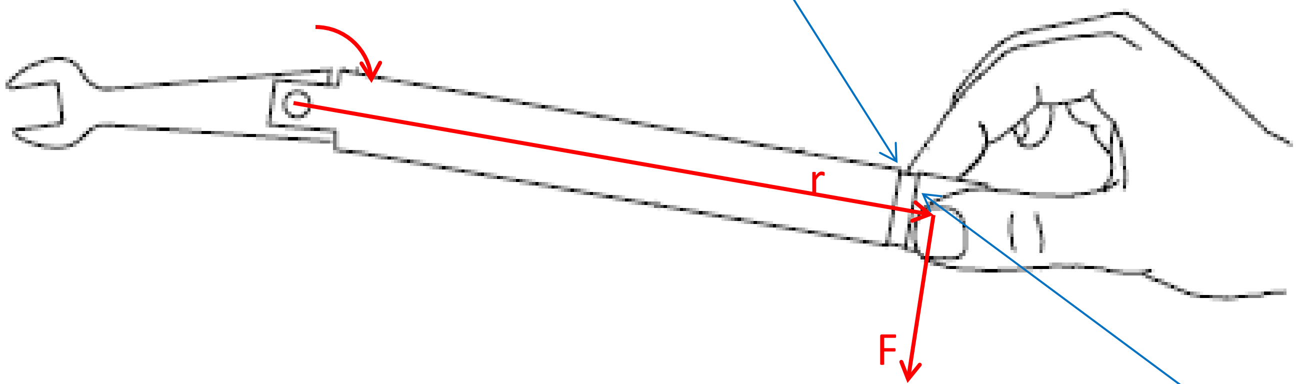
Then you do the *final connection*:

Final Connection Using a Torque Wrench

Open-end 7 mm and 8 mm wrenches

Torque wrench

Always hold the torque wrench past these grooves ...

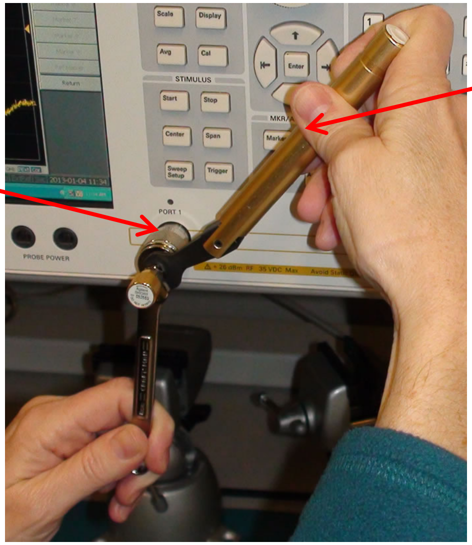


... because torque is the product of force and distance:

$$\tau = F*r$$

The calibration standards are all designed to be torqued to 0.9 Nm (which is 8 inch-lbs.)
The torque wrench supplied with the calibration standards is designed to be held behind these grooves.
The torque wrench will begin to break at 0.9 Nm, which requires only a small force when held at that distance.

male-N-to-male-SMA adapter



Don't hold the torque wrench here. Holding the torque wrench at too short of a radius sometimes leads you to accidentally override the ball joint mechanism that creates the breaking at the torque setting.

Here's an example of busted a male-N-to-male-SMA. It was an old adapter I find lying around the lab (might have been slightly bent or damaged). It required quite a bit of torque to tighten the nut, and made a scraping sound. The male nut came off the SMA end of the adapter because the nut was held on by this retaining ring which couldn't handle the amount of force applied to it when the nut was over-torqued.

wrong

female standard

male-N-to-male-SMA adapter

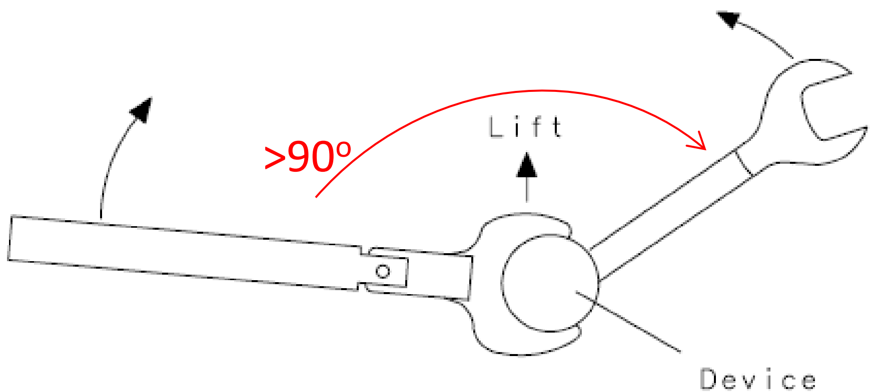
male-N-to-female-SMA adapter

Whenever you have one bad connector in your lab, its effects can spread like a virus and ruin all tje cal standards and cables in the lab. This is because the shoulder on each male pin is supposed to be flush with the outer coax ring (or a little negative below it). If its shoulder sticks out positive, it can compress the mating ring of the female cal standard (pic at upper left). Then your cal standard no longer has the offset length it was calibrated at.

Standards should screw on easily with your fingers. Only the last tiny bit should need the torque wrench.

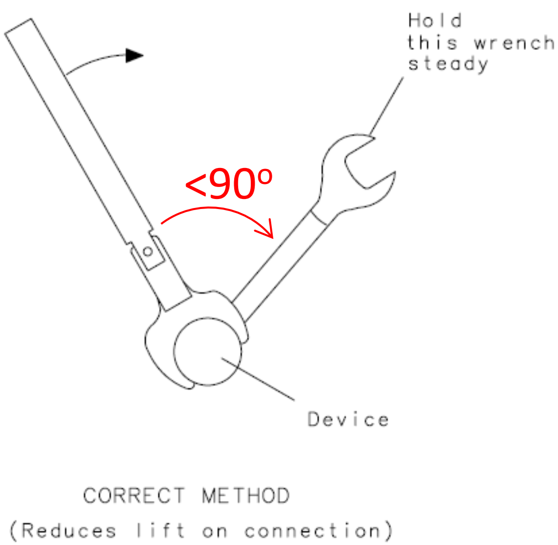
Don’t insert the torque wrench to a starting position >90°. You won’t be applying a pure torque. This scenario ends up also applying a force in the vertical direction:

Don’t do this:



INCORRECT METHOD
(Too much lift on connection)

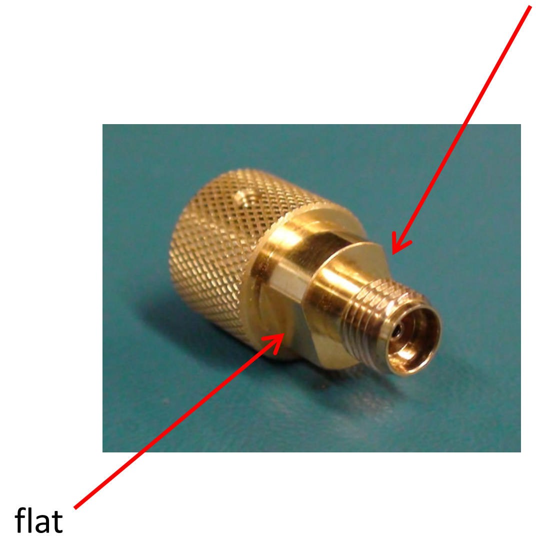
Always use an open-end wrench to hold the standard motionless. Insert the torque wrench on the nut so the starting angle is $<90^{o}$.



The network analyzer is a precision measurement instrument. All connectors and calibration standards need to be tightened precisely with a torque wrench (to keep the length of internal transmission lines fixed to a precise length). Never over-torque the torque wrench – stop just as it starts to break.

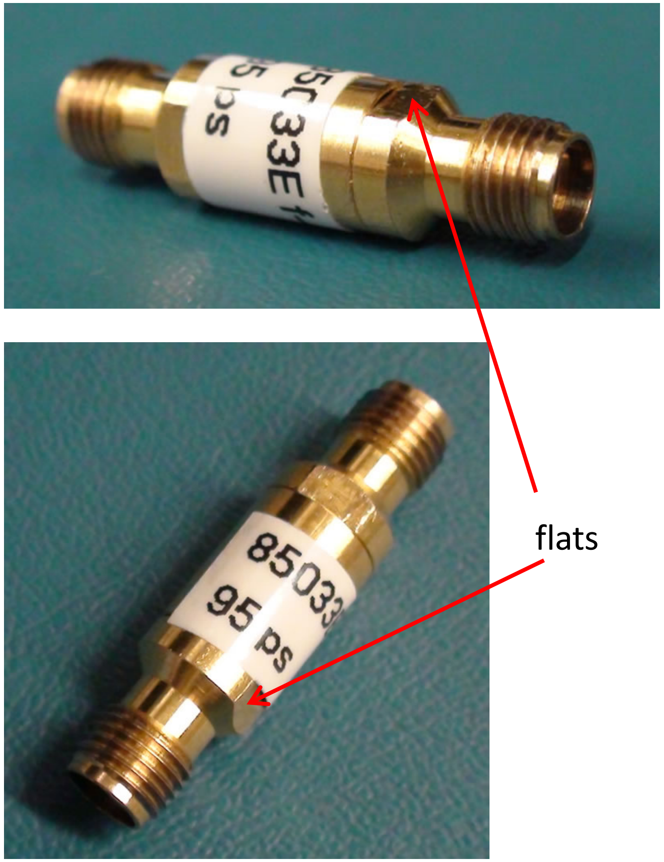
Always use a second open-end wrench to hold the calibration standard. Don't rotate the standard, rotate the nut. If you rotate the standard, the center signal pin's gold plating will wear out.

Calibration standards have flats for an 8 mm open-end wrench:

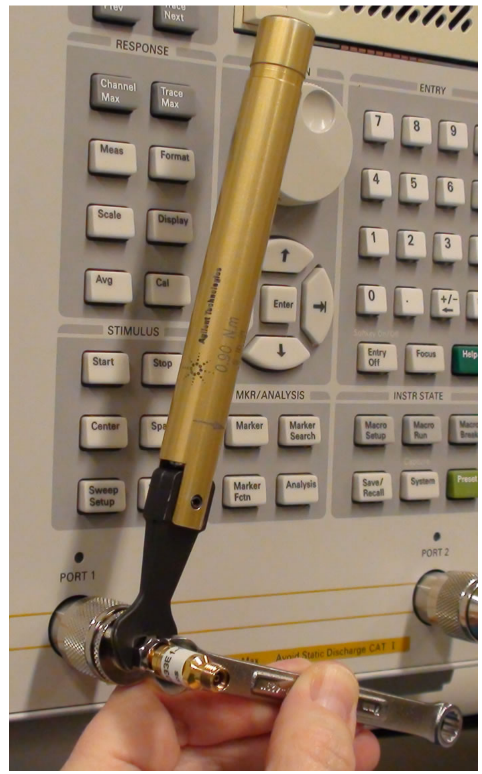


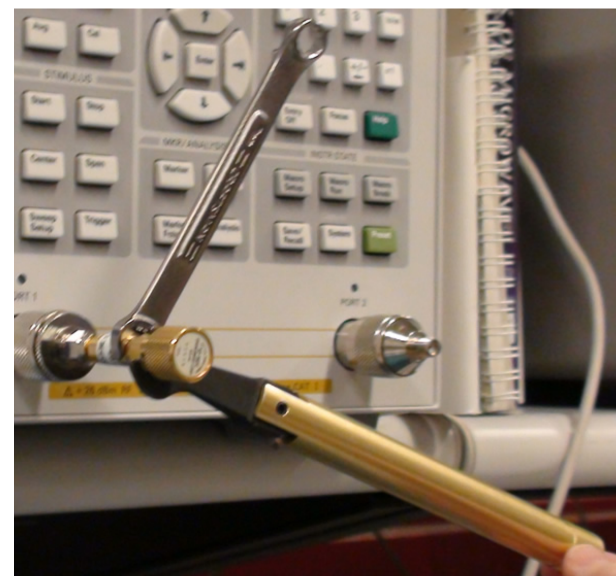
8 mm open-end wrench

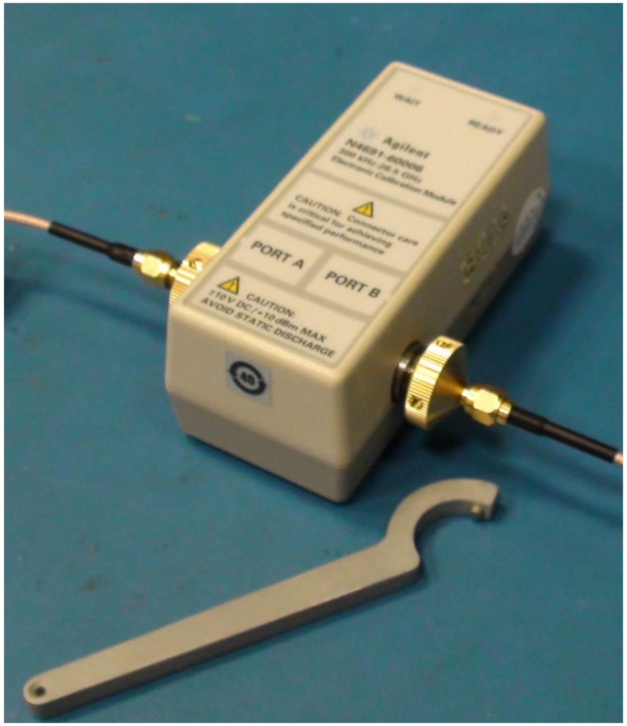
The adapters have flats on both ends for an open-end wrench:

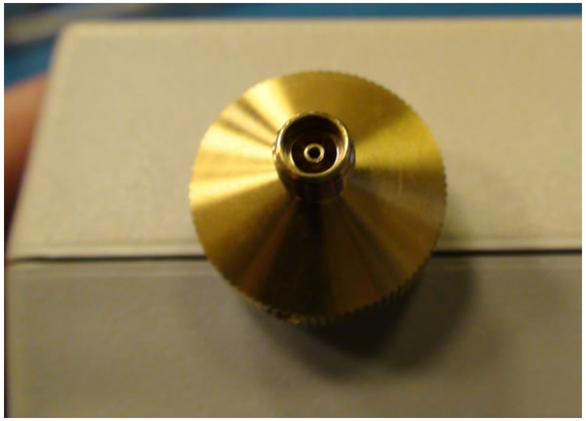


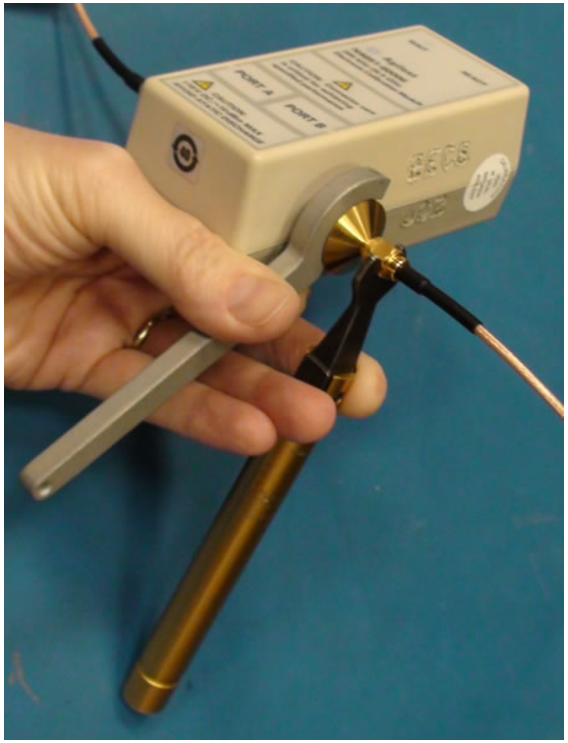
However, you need to use a 7 mm wrench for these adapters. Put the wrench on the flat closest to the end you're connecting to.





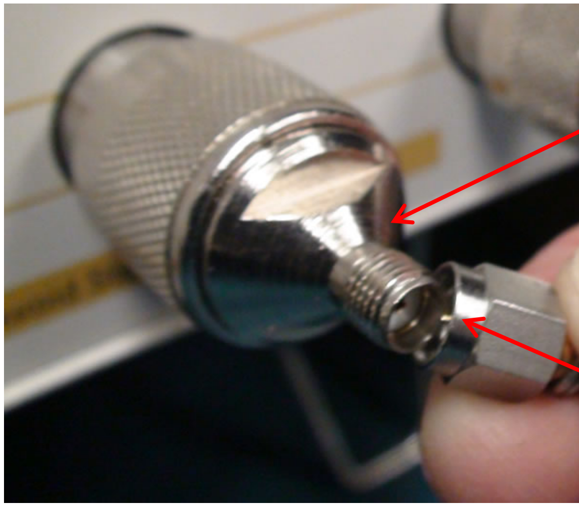

WAIT
READY
Agilent
N4691-60006
Electronic Calibration Module
CAUTION: Connector care is critical for achieving specified performance
PORT A
PORT B
CAUTION:
±10 V DC / +10 dBm MAX
AVOID STATIC DISCHARGE





Prevent Equipment from Getting Zapped!

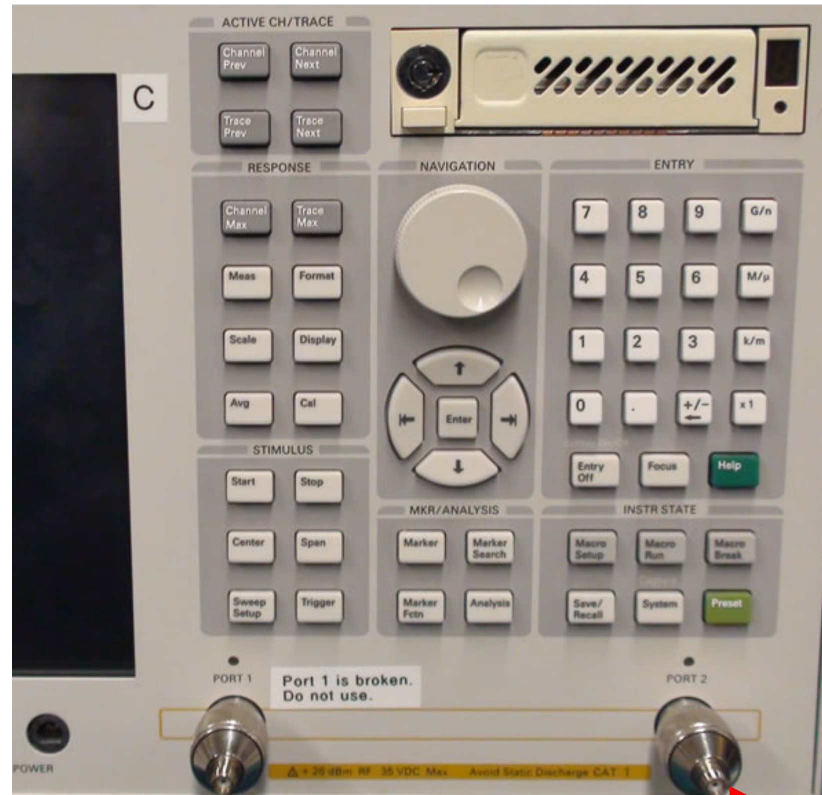
Touch the Center Conductor of Any Cable or Connector to Case Gnd Before Connecting



Case ground

Discharge the center conductor before connecting

Case ground

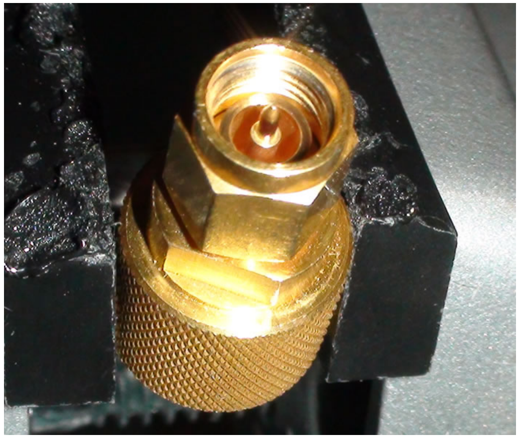


Case ground

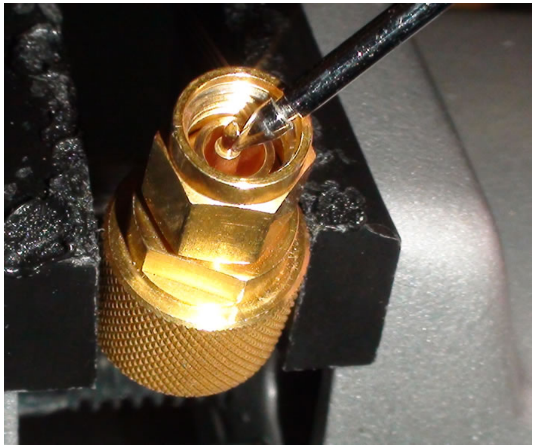
By Fall 2012, both the ECal and Port 1 of this network analyzer had broken. It's possible this was how they broke. Agilent charges $4700 to fix anything, before they even look at it. Our budget is $0.00.

Sometimes you think a connector may be bad, but in this case, it's just the way it's made:

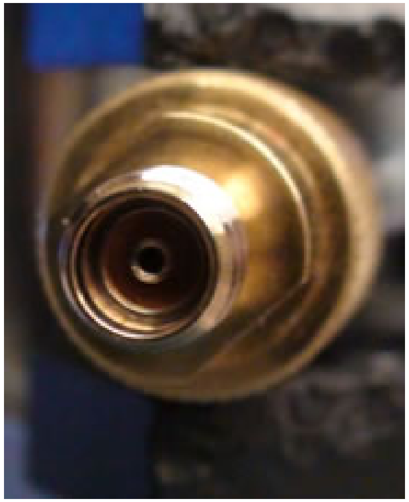
Here's a male Open (85052D standard):



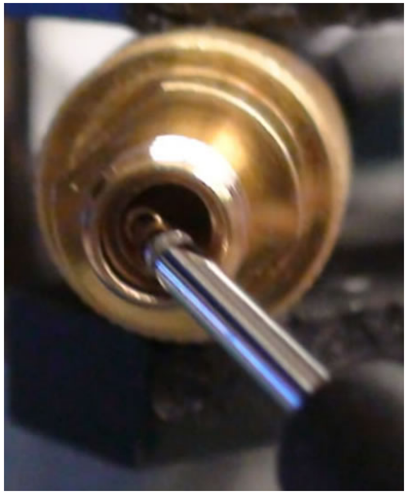
If you just touch the center pin lightly, it moves.



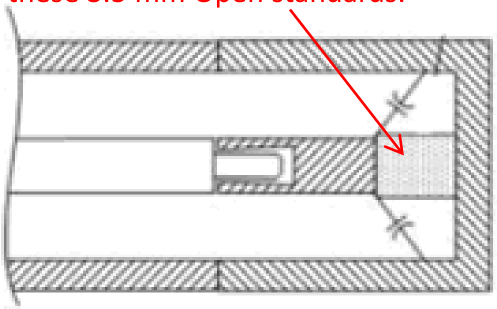
Similarly here's a female Open (85033E standard):



Its center pin moves too.



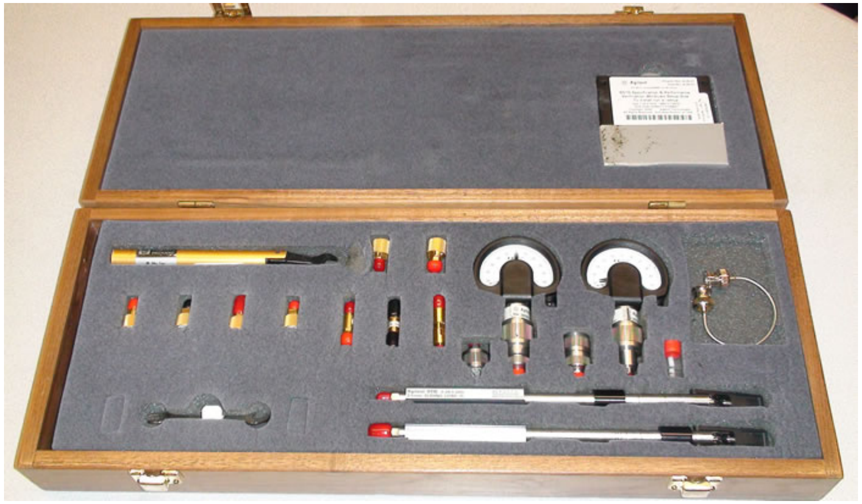
Insulator in an Open standard is a little bit flexible. Be careful with these 3.5 mm Open standards.

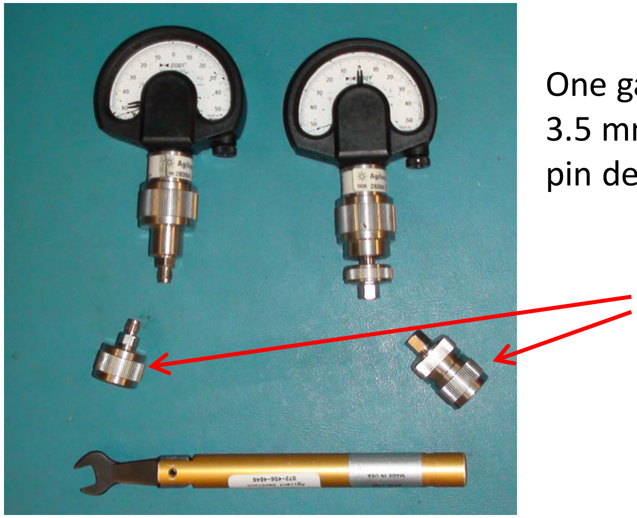


Be very gentle with these 3.5 mm precision connectors. They're expensive and easily broken!

Agilent sells pin-depth gages for verifying that your 3.5 mm standards are good:

This is the 85052B cal kit, which Agilent sent us as a loaner for two weeks in Jan13. This particular cal kit comes with pin-depth gages for 3.5 mm connectors:
http://cp.literature.agilent.com/litweb/pdf/85052-90077.pdf



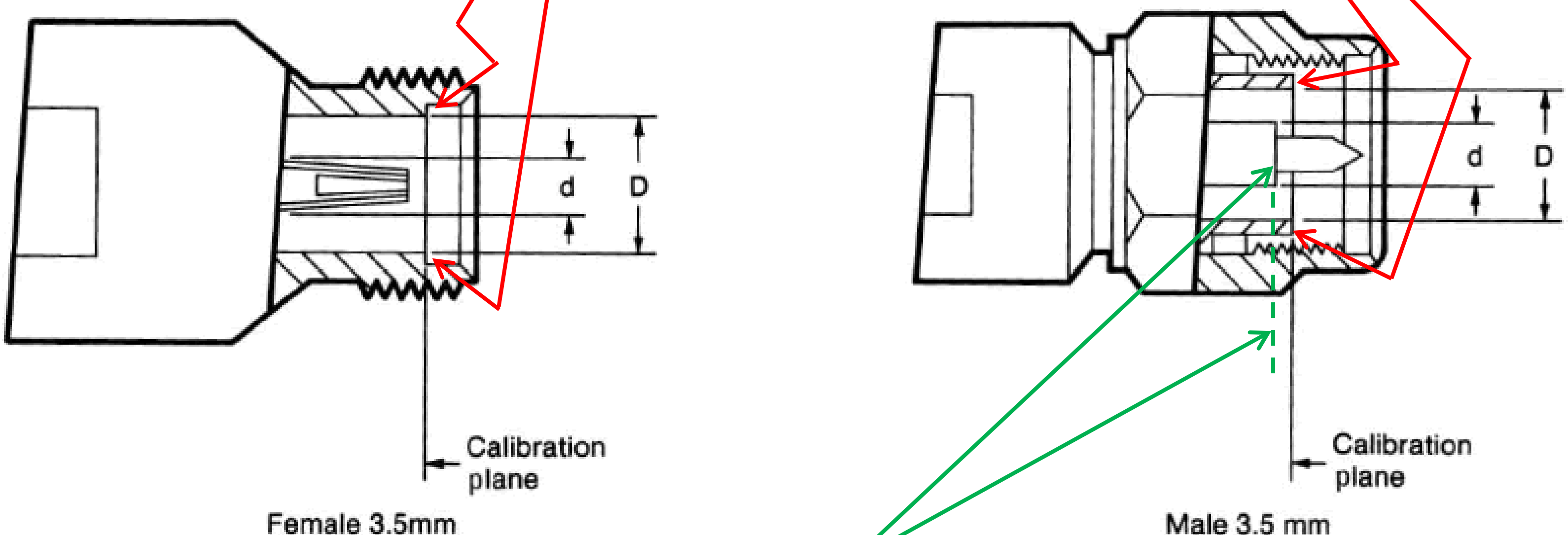


One gage measures pin depth for male 3.5 mm connectors, the other measures pin depth for 3.5 mm females.

First, you connect a gage blocks to the gage and then you zero the gage. Then you connect your 3.5 mm standard and see if its pin depth is within spec.

"Pin depth" refers to the distance the center pin is above or below the plane of the end face of the surrounding cylinder:

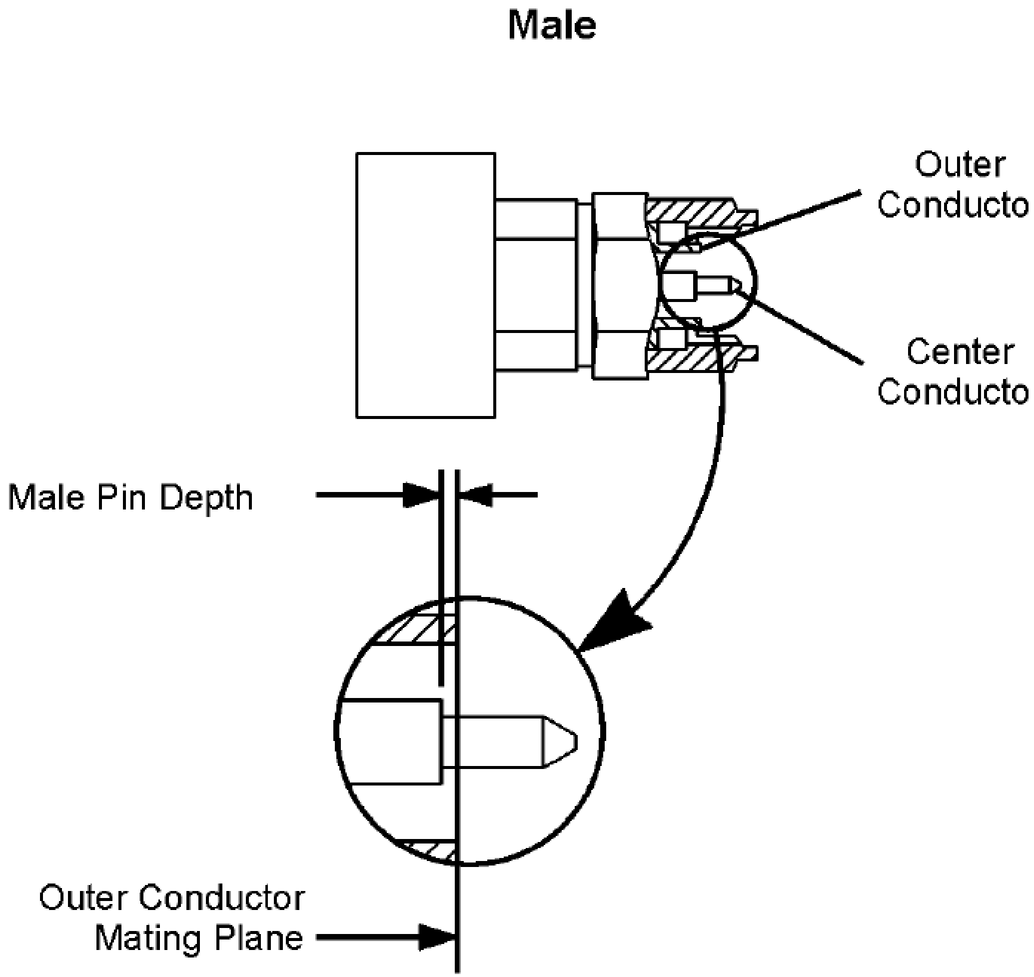
The calibration reference planes on these 3.5 mm male and female standards are here. These planes are where the ground connection will mate to your corresponding opposite-sex test cable connectors.



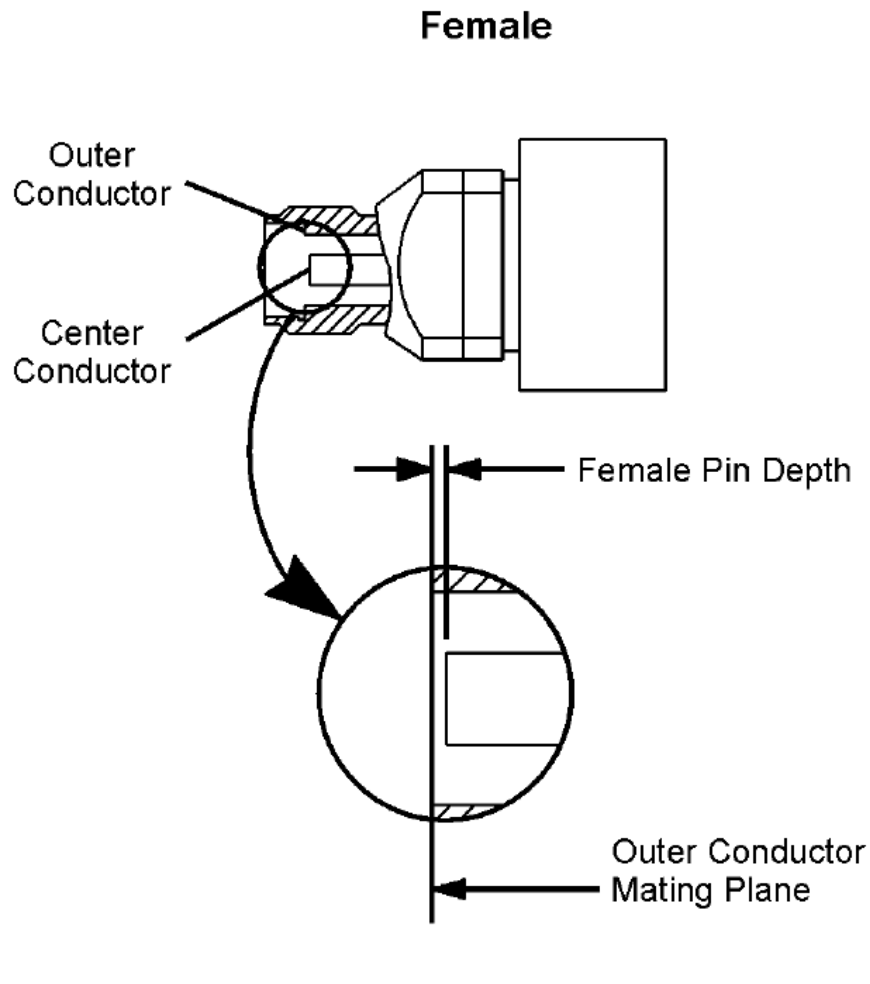
This shoulder of the male 3.5 mm connector's center pin is supposed to be within a specified tolerance distance behind the plane of the end face of the surrounding coax ring (where the red arrows are pointing). The spec is published as a standard and it's a tighter spec for 3.5 mm connectors than for SMA connectors, which is why 3.5 mm connectors are considered "precision" connectors for test and measurement.

Diagram from Agilent App Note 1287-1
http://cp.literature.agilent.com/litweb/pdf/5989-4840EN.pdf

Close-up of the male 3.5 mm connector:



Close-up of the female 3.5 mm connector:



Agilent gives these instructions for understanding the uncertainty of measurements using one of these gages, so that you can determine if your 3.5 mm cal standards are within spec:

The pin depth value of each calibration device in the kit is not specified, but is an important mechanical parameter. The electrical performance of the device depends, to some extent, on its pin depth. The electrical specifications for each device in the kit take into account the effect of pin depth on the device's performance. Table 2-2 lists the typical pin depths and measurement uncertainties, and provides observed pin depth limits for the devices in the kit. If the pin depth of a device does not measure within the *observed* pin depth limits, it may be an indication that the device fails to meet electrical specifications. Refer to Figure 2-1 for a visual representation of proper pin depth (slightly recessed).

Table 2-2 Pin Depth Limits

Device	Typical Pin Depth	Measurement Uncertainty[a]	Observed Pin Depth Limits[b]
Opens	0 to –0.0127 mm 0 to –0.00050 in	+0.0064 to –0.0064 mm +0.00025 to –0.00025 in	+0.0064 to –0.0191 mm +0.00025 to –0.00075 in
Shorts	0 to –0.0127 mm 0 to –0.00050 in	+0.0041 to –0.0041 mm +0.00016 to –0.00016 in	+0.0041 to –0.0168 mm +0.00016 to –0.00066 in
Fixed loads	–0.0025 to –0.0254 mm –0.0001 to –0.0010 in	+0.0041 to –0.0041 mm +0.00016 to –0.00016 in	+0.0016 to –0.0295 mm +0.00006 to –0.00116 in
Adapter	–0.0025 to –0.0254 mm –0.0001 to –0.0010 in	+0.0041 to –0.0041 mm +0.00016 to –0.00016 in	+0.0016 to –0.0295 mm +0.00006 to –0.00116 in
Sliding loads	0 to –0.0076 mm 0 to –0.00030 in	+0.0041 to –0.0041 mm +0.00016 to –0.00016 in	+0.0041 to –0.0117 mm +0.00016 to –0.00046 in

a. Approximately +2 sigma to –2 sigma of gage uncertainty based on studies done at the factory according to recommended procedures.

b. Observed pin depth limits are the range of observation limits seen on the gage reading due to measurement uncertainty. The depth could still be within specifications.

Cables

Quote from Dunsmore book (p. 197):

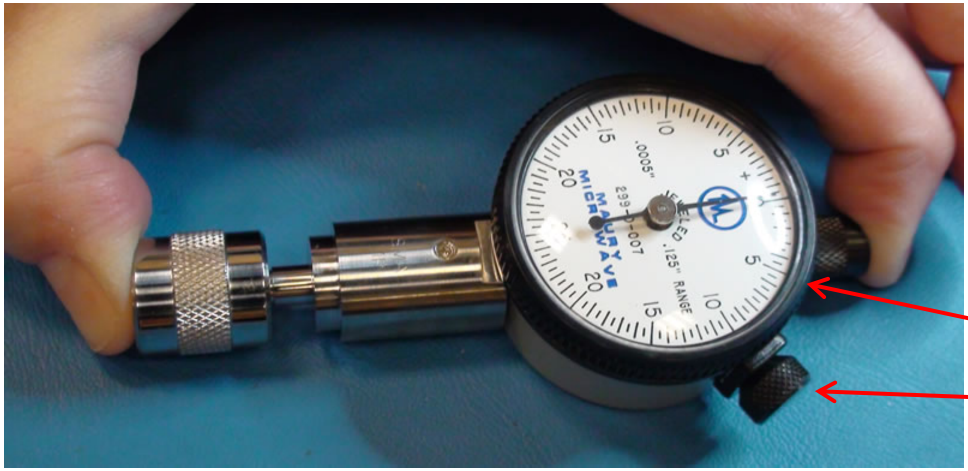
“Cables are like dogs; either they are bad, they’ve been bad or they are going to be bad, and when they’re good, they only stay good with great care.”

Agilent tech support says that you need a separate gage kit to measure SMA connectors. They recommended Maury Microwave (maurymw.com). This is the A027A kit ($1300) which has 4 gages so that you can measure the depth not only of the male and female pins, but also the depth of the dielectric.

A027 SMA Precision Connector Gage Kit

We recently purchased one of these sets. Also shown is a cable we made which passes both the dielectric depth and pin depth tests. Look at the manual for this A027A set on the www.maurymw.com web site.

Use the gage master to zero each gage first. One end of the gage master is for the 2 gages that measure male connectors. The other end of the gage master is for the 2 gages that measure female connectors. The gages themselves are inscribed with either MD, MP, FD or FP for male or female and dielectric or pin, respectively.



Hold the gage and gage master like this, so that you apply purely axial forces.

Untighten this black knob, so that you can rotate the display's outer black ring. Adjust the ring to line the 0 on the display with the needles. Then re-tighten the black knob.

This gage is inscribed “MP” which means it’s the gage for measuring a male SMA connector’s pin depth.

Your measurements on your cables should never be on the minus side of zero. Don’t let any such cables be in the lab!

MP

Note here, that this says that the distance between the 2 smallest divisions on the dial represents 0.0005”, or half a mil. A mil is 0.001”. The way to remember how long a mil is, is that a sheet of paper is 4 mils thick, and a sheet of paper is 100 um thick. So 1 mil = 25 um. So what is this gage reading? It’s reading 3 mils. That means the shoulder of the pin is 3 mils recessed lower than the SMA’s mating plane. Good.

SMA connector specification:

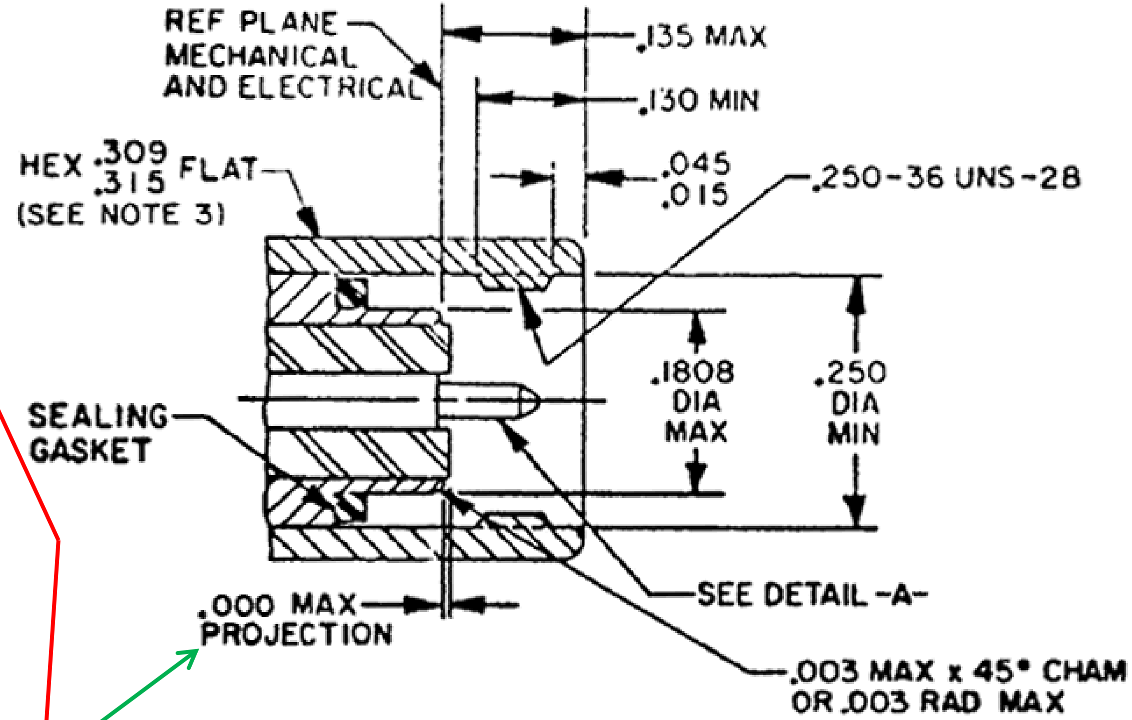
SMA connectors have much looser specifications than 3.5 mm connectors.

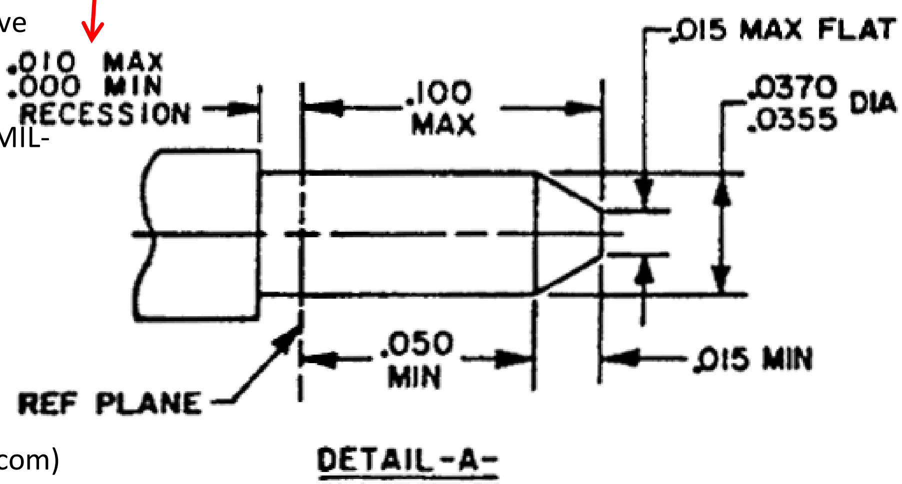
This set of drawings is from MIL-STD 348A which is the standard for SMA connectors. The tolerance spec for the pin depth is +0.000", -0.010". This means the shoulder can't stick out at all and it can only be inset less than 10 mils. The gages in the 85052B kit only read to +-0.005" (+- 5 mils).

I bought some Emmerson cables which are so far negative, they don't even read on the scale of the 85052B gage (but they could be within spec).

Also, all SMA connectors have a dielectric which the 3.5 mm connectors don't, and so there is a spec in this SMA standard for the tolerance on the distance the dielectric face can be with respect to the reference plane (+0.000"). Actually, you're supposed to buy special gages for SMA connectors (Maury Microwave sells such gages).

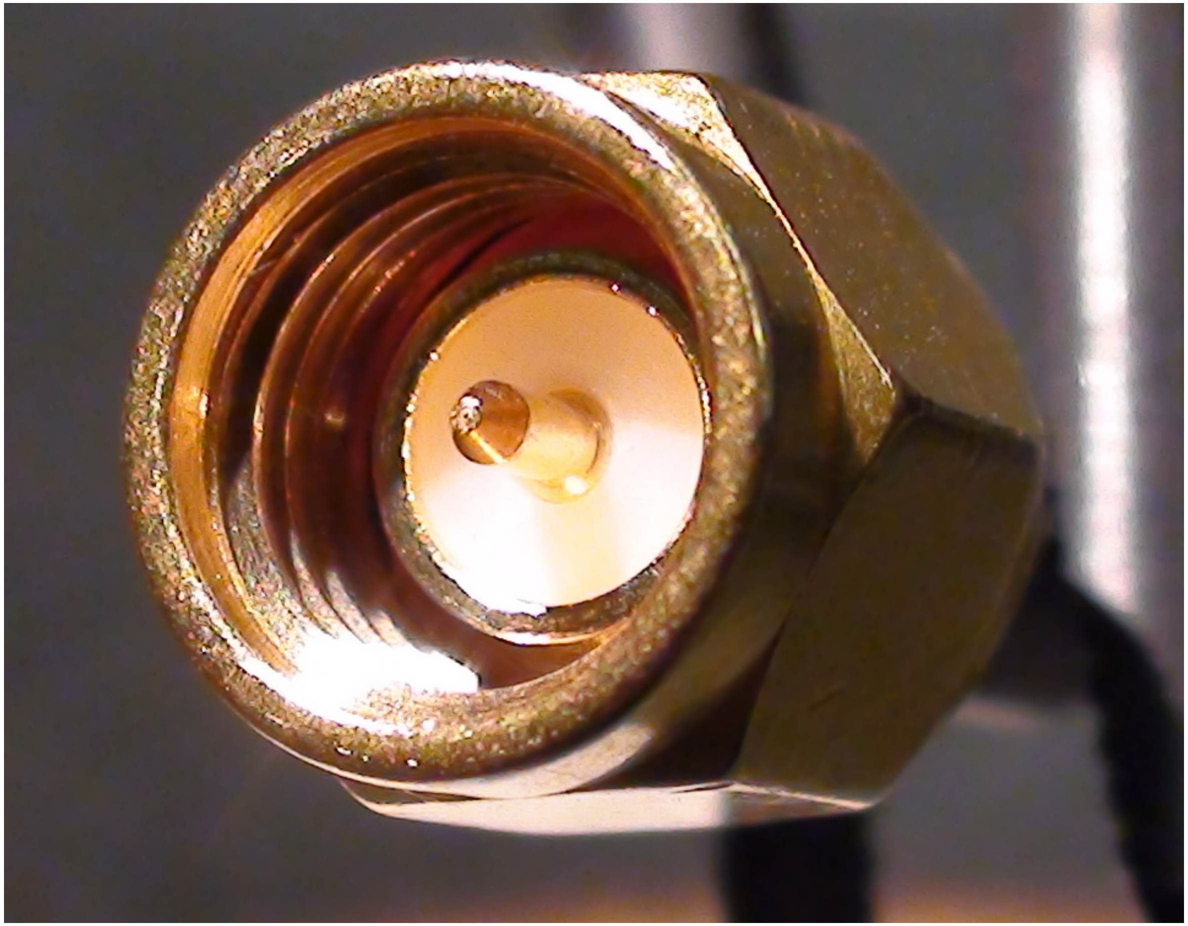
Note that the rubber gasket is actually part of the MIL-STD 348A SMA connector spec.





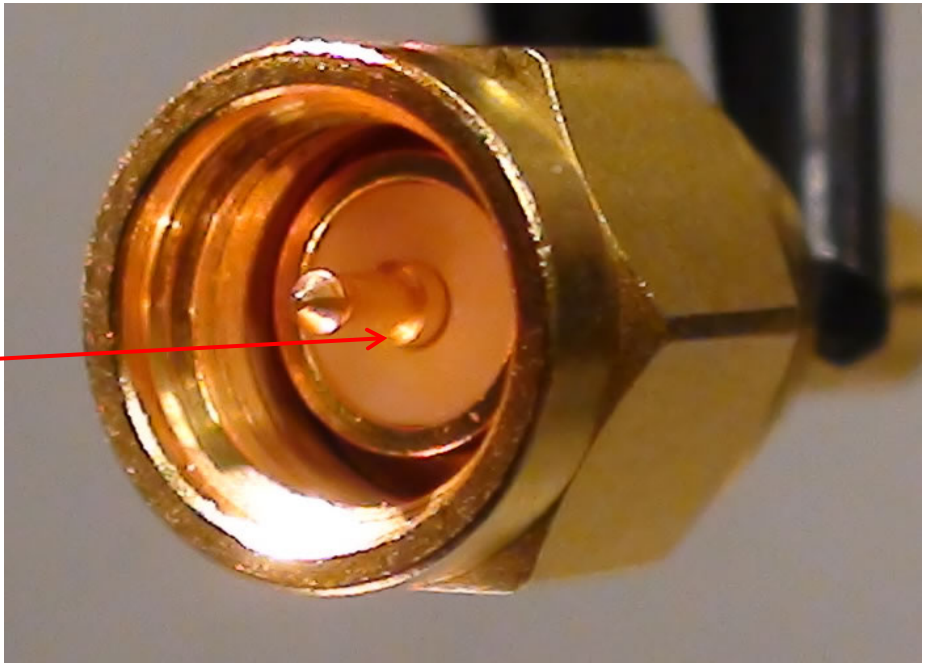
MIL-STD 348A
(Google it. I found this copy at carlsonmfg.com)

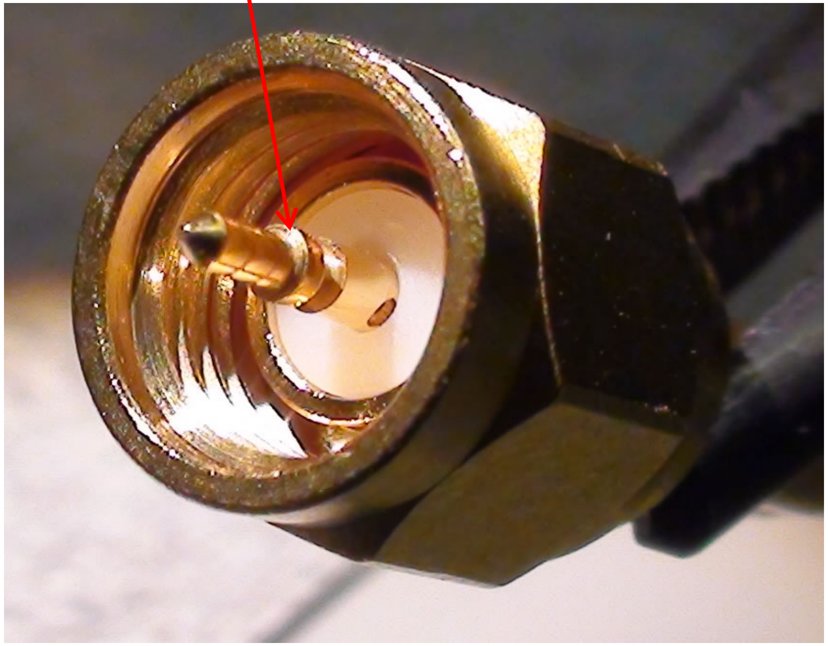
This is a close-up view of an SMA connector that's more or less made correctly:



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

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



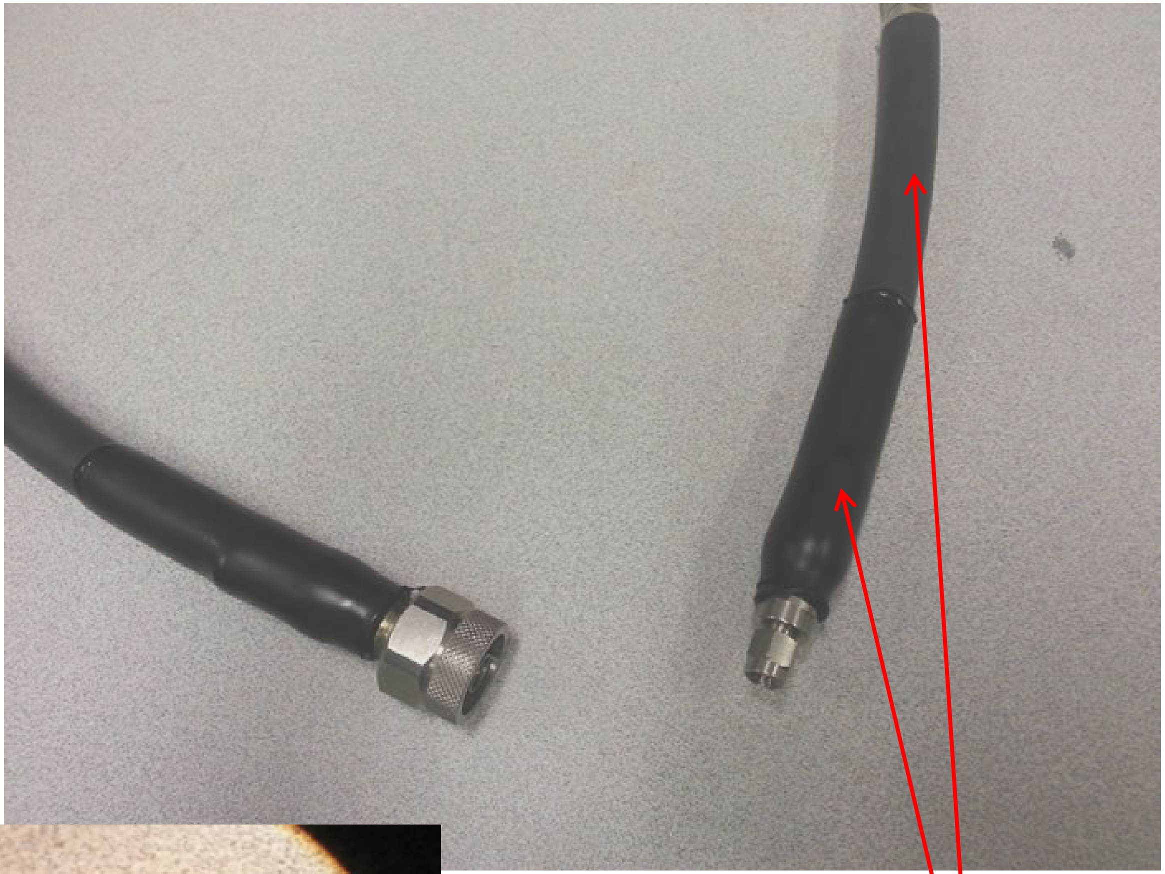


Throw these cables away. If you screw cal standards into one of these, or attach one to the test port of a network analyzer, and then torque them tight, you'll ruin the mating connector. The mating connector's female center receptor will get squashed and won't be the proper length to make a uniform transmission line.

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

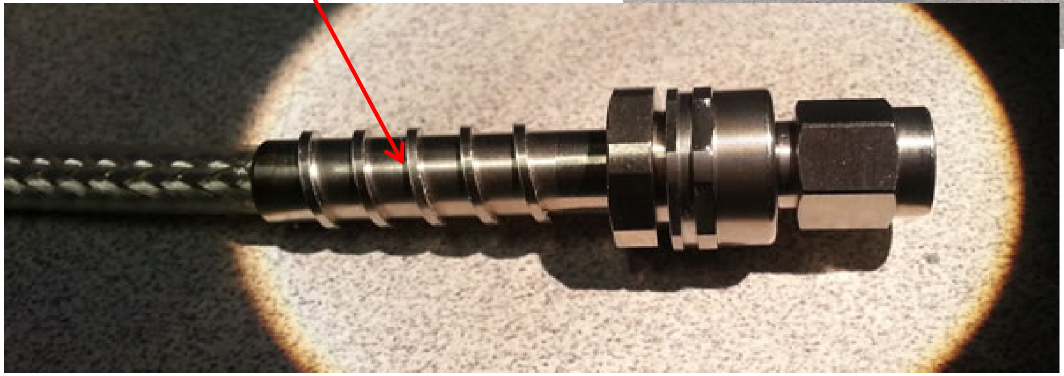
Always inspect a connector or cable under a stereo microscopre before you attach anything to it.

Good test cables can range from $150 to $400 each. They're expensive because the dielectric has been melted/flattened so that it doesn't stick out beyond the mating plane, and because they usually have armor with many layers of jacketing near the ends so they can't get kinked.



Multiple layers of heat-shrink jacketing over the armor.

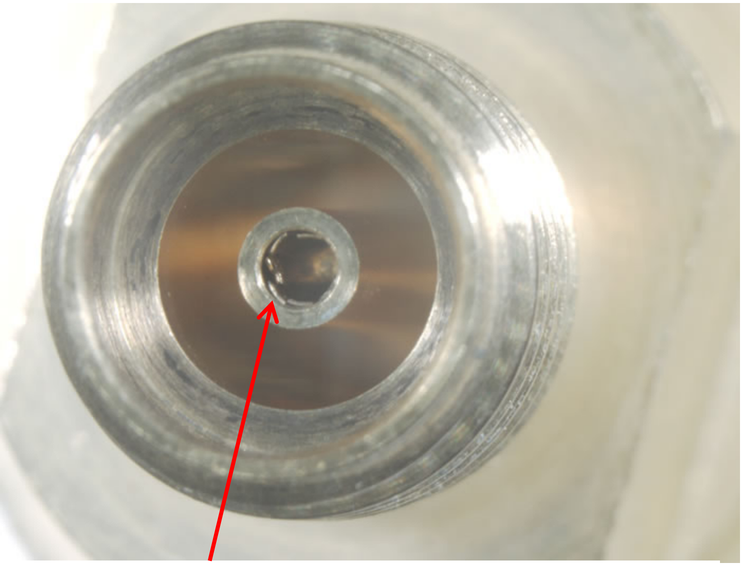
armor



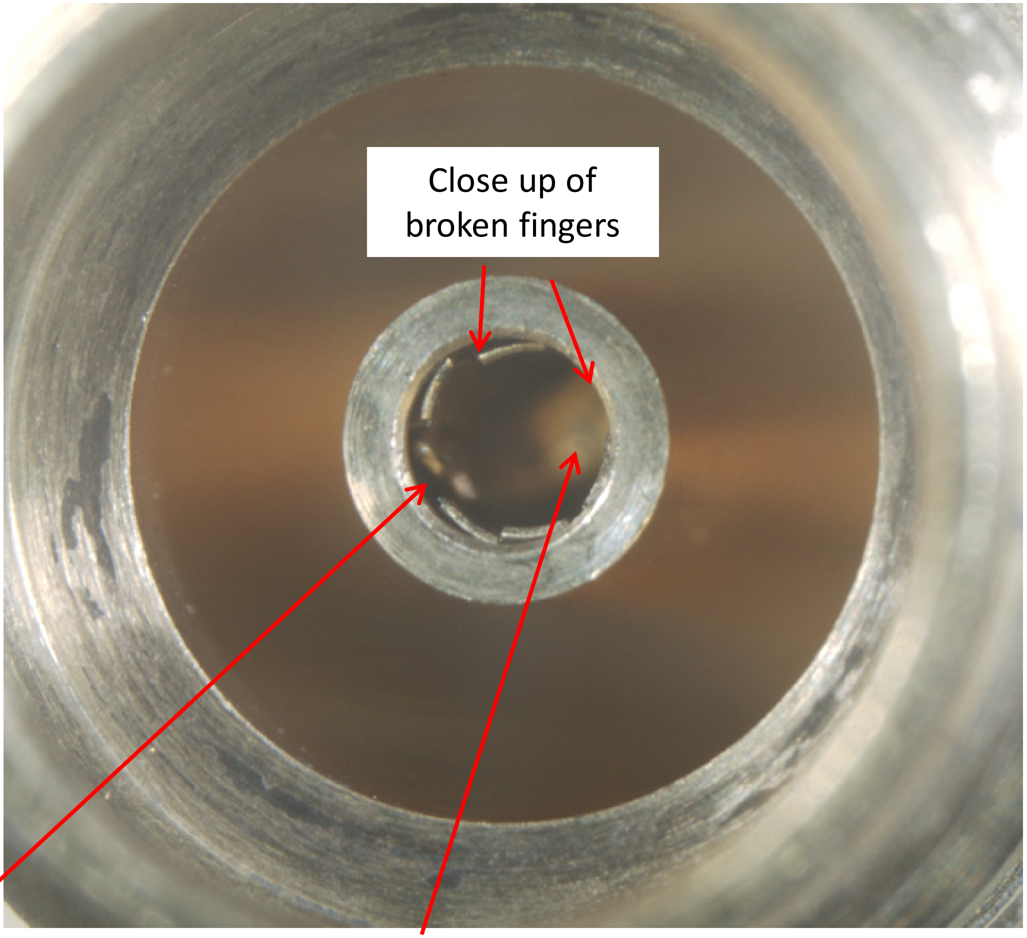
These connectors looked to be of high quality. The center pin's shoulder looked even with the surrounding gold cylinder's end face, but after measuring with the gage set, they turned out to be out-of-spec. I threw this cable in the garbage.

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 calibration standard, you can ruin the standard, by breaking the fingers inside the center conductor which are designed to accept the male pin. Calibration standards are very expensive, so always check your SMA cables (visually under a microscope and with a pin-depth gage) before attaching to a calibration standard.

Here's a female calibration standard that's been destroyed:



3.5 mm female calibration standards use what are called precision 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 of the electric and magnetic fields to propagate along the air dielectric stays uniform in the region of the air dielectric.



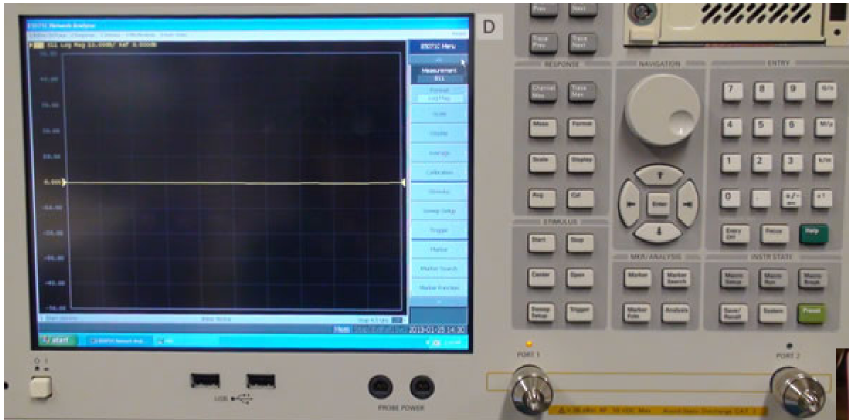
This finger has been broken because a male pin's shoulder which protruded too far hit it and when the two mating connectors were tightened, they squished the finger down into the hole.

The finger is folder over and smushed down in here.

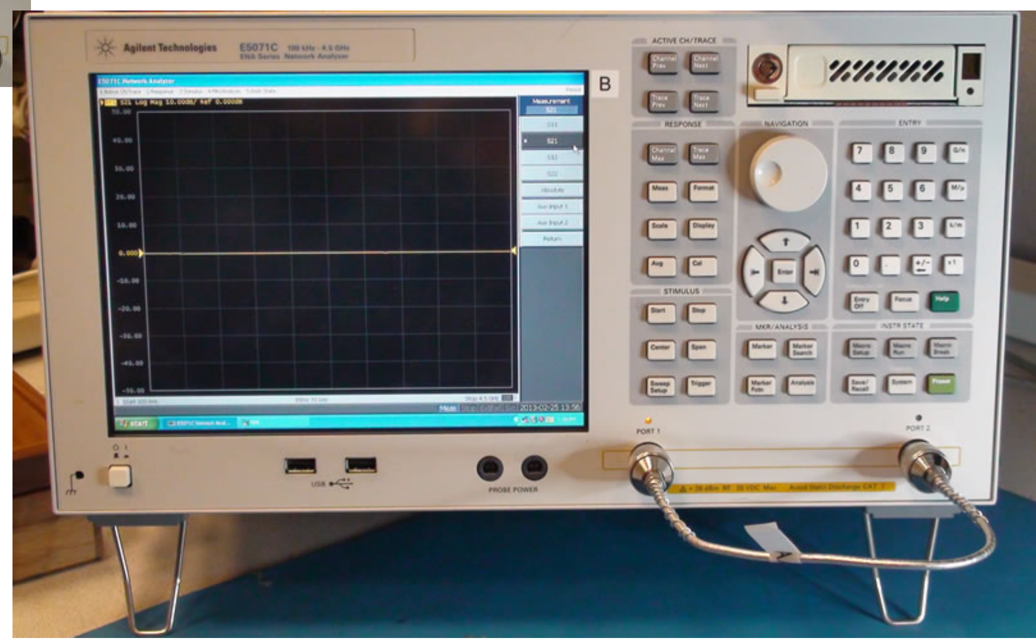
Pre-testing: Checking Your Cables' Phase Stability Before Starting a Calibration

But before that ... Check that your network analyzer isn't broken!

Hit the Preset button. Select OK. Displays LogMag S11.
Repeat for LogMag S11, S12 and S21.

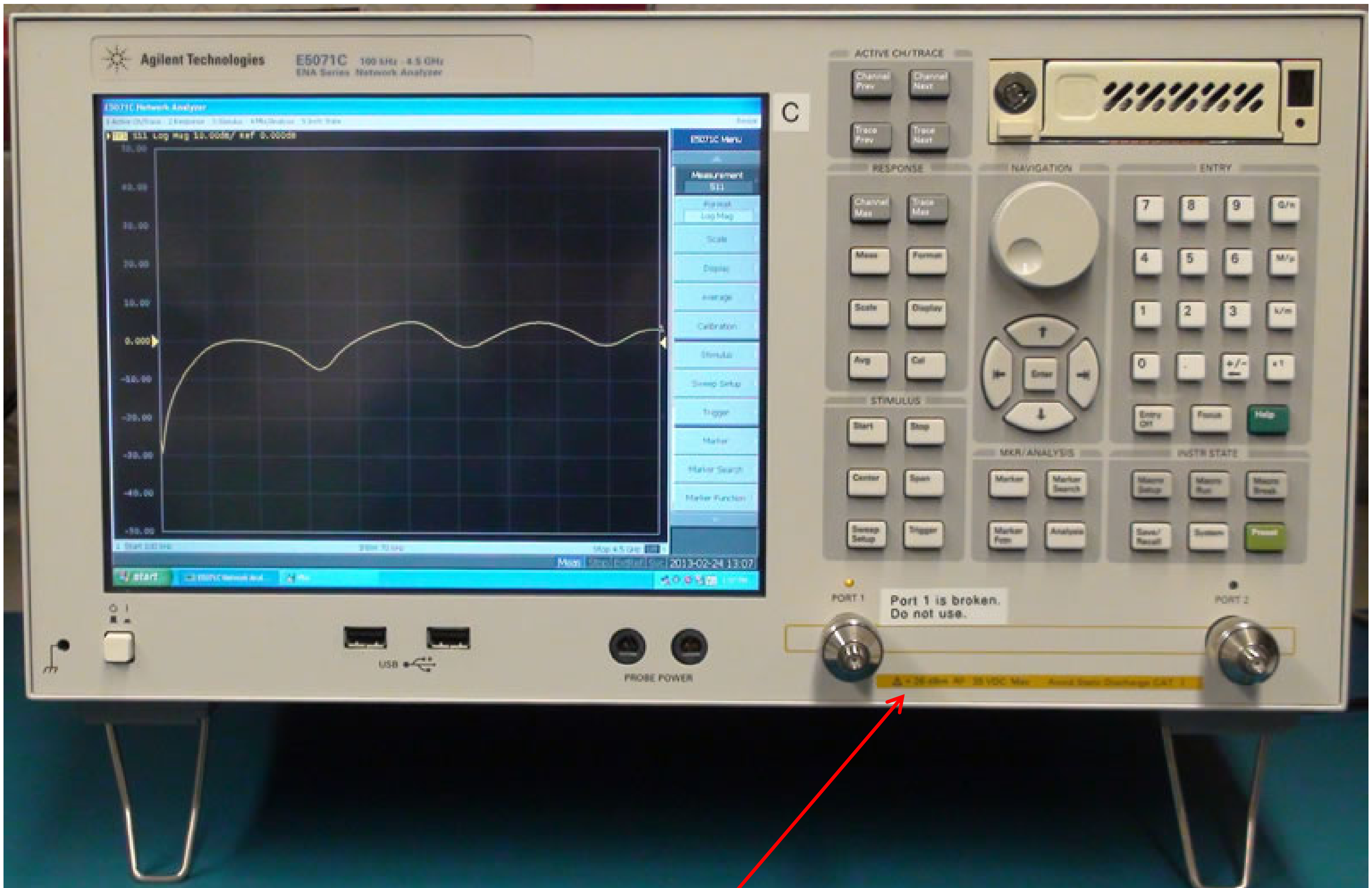


For S12 and S21, make sure to hook up a cable between Port 1 and Port 2. For example, hit the Meas key, and choose S21. LogMag S21 looks like this (very close to 0 dB for all freqs) as nearly all the signal from Port 1 makes its way to Port 2:



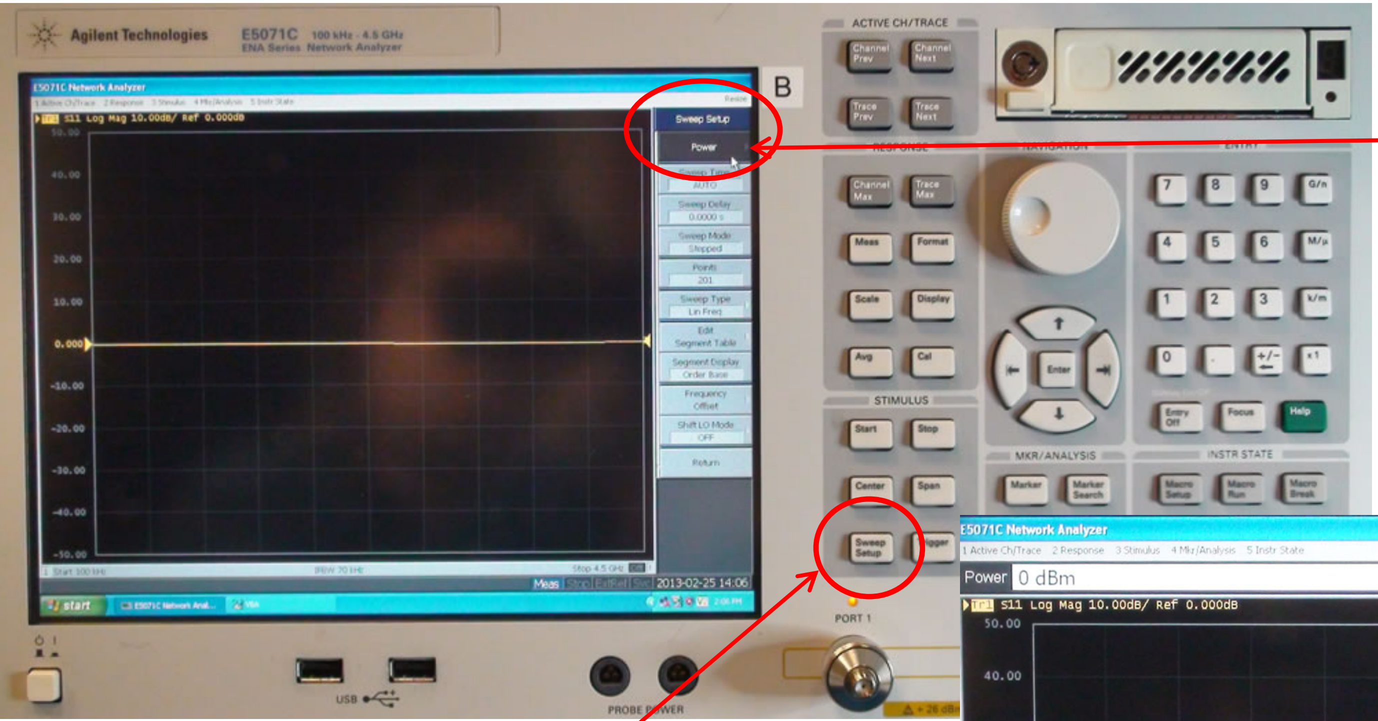
We have 1 broken network analyzer in the lab: Network Analyzer C

On this one, if you hit the Preset button and then select OK, it comes up saying that LogMag S11 is greater than 0 dB for some frequencies, even though nothing is connected to Port 1! It also says there is 30 dB of loss at 100 kHz. If you display LogMag S22, you'll see that Port 2 is not broken.   Someone probably put too much power into Port 1. This can happen if you hook up the output of your amplifer to Port 1, where you have too much input power to your amp.



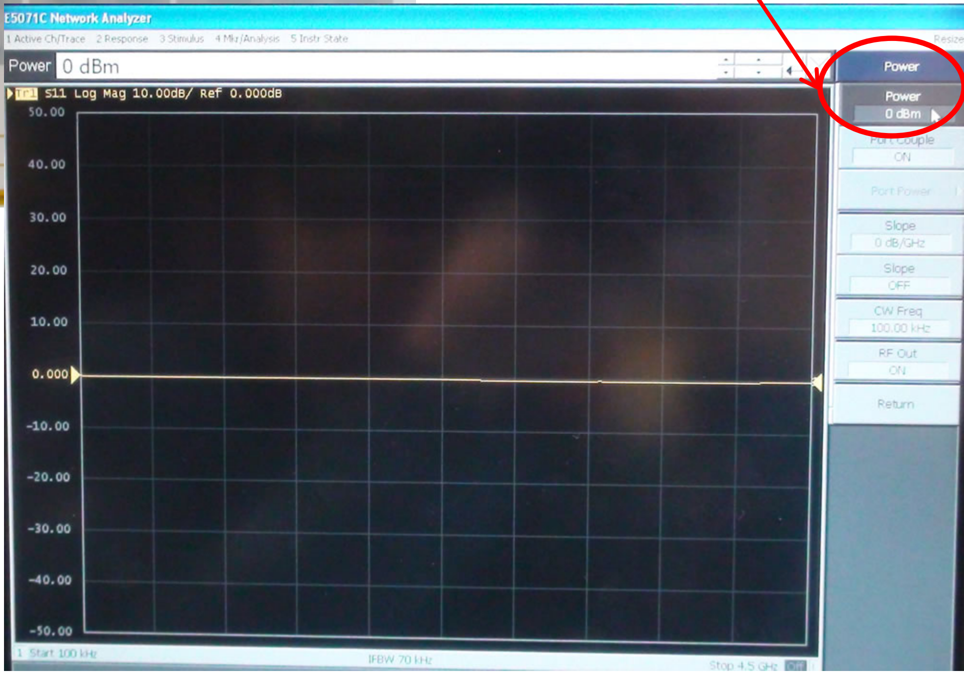
It says here: max input power is 26 dBm. How many watts is 26 dBm?

When testing an amplifier set the output power from the network analyzer (which will be your input power to your amplifier), from the Sweep Setup menu. Hit the Sweep Setup hard key to get to the Sweep Setup menu:



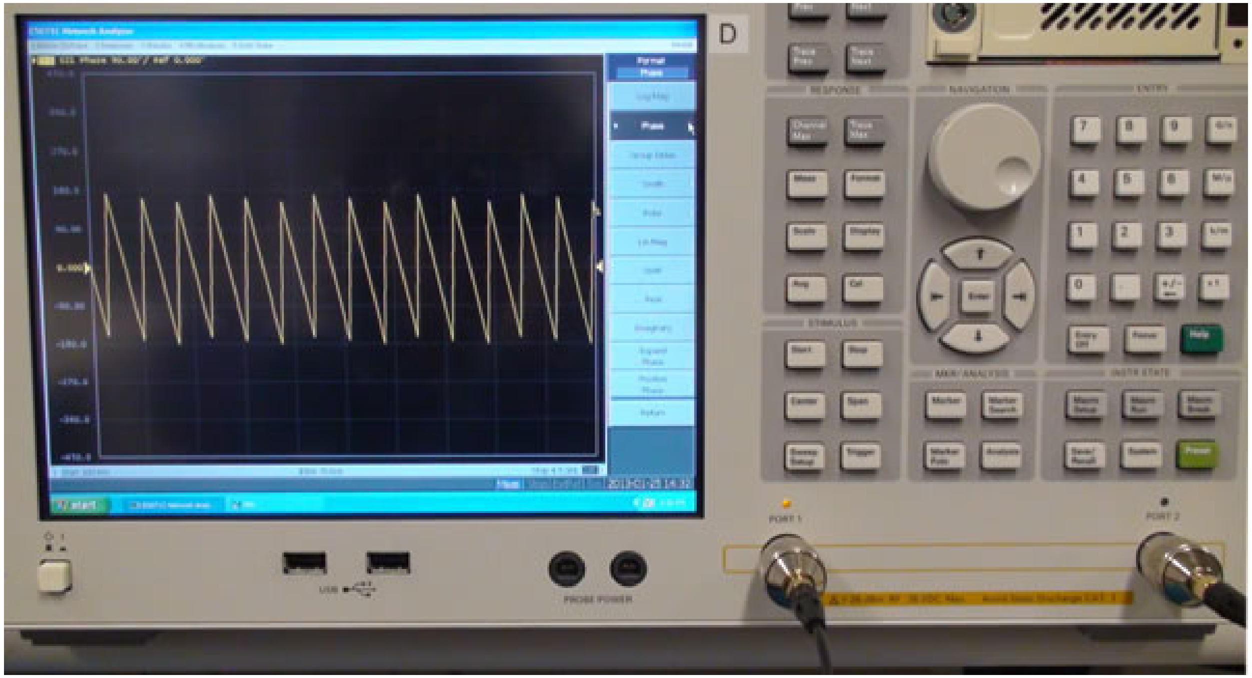
In the Sweep Setup menu, select the Power soft key item:

The default is 0 dBm (fine for testing passives). Type in a lower power setting, based on your amplifier's gain.



Sweep Setup hard key

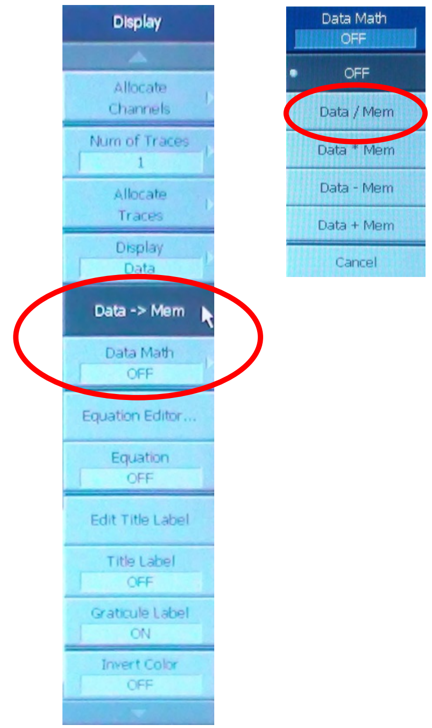
To test our cables, we want to look at the Phase of S21. Hit the Format key and choose phase. The sweep here is up to 4.5 GHz, so phase wraps around about 14 times at that frequency for this particular length of cable.



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

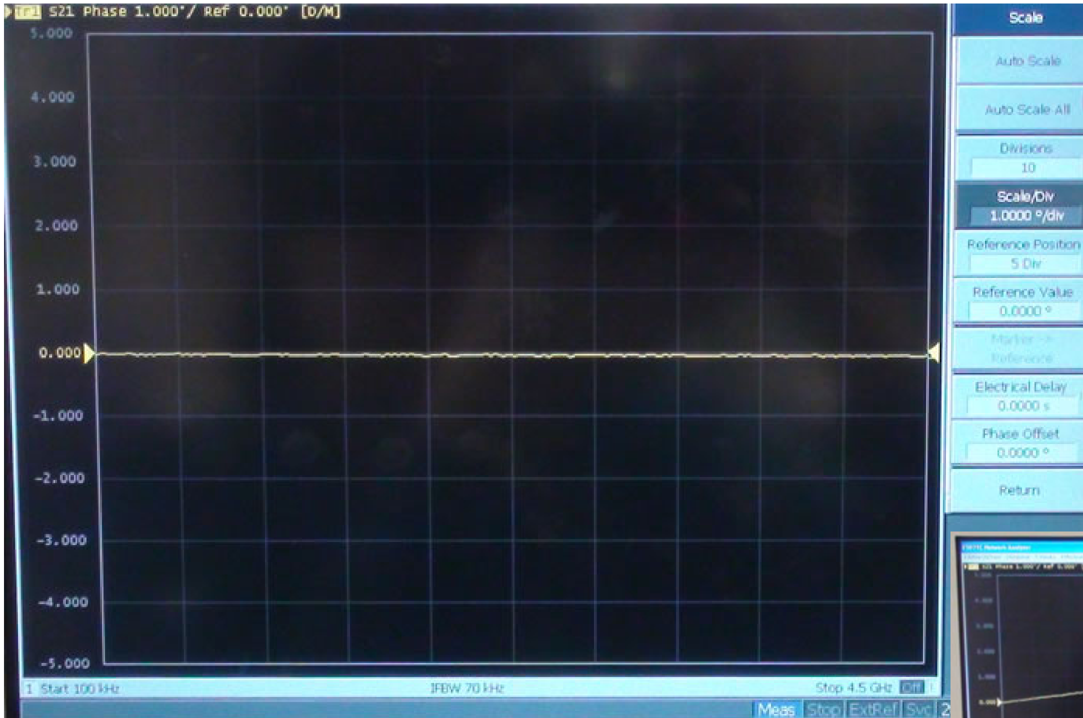
Under Dat Math, choose:

Data/Memory

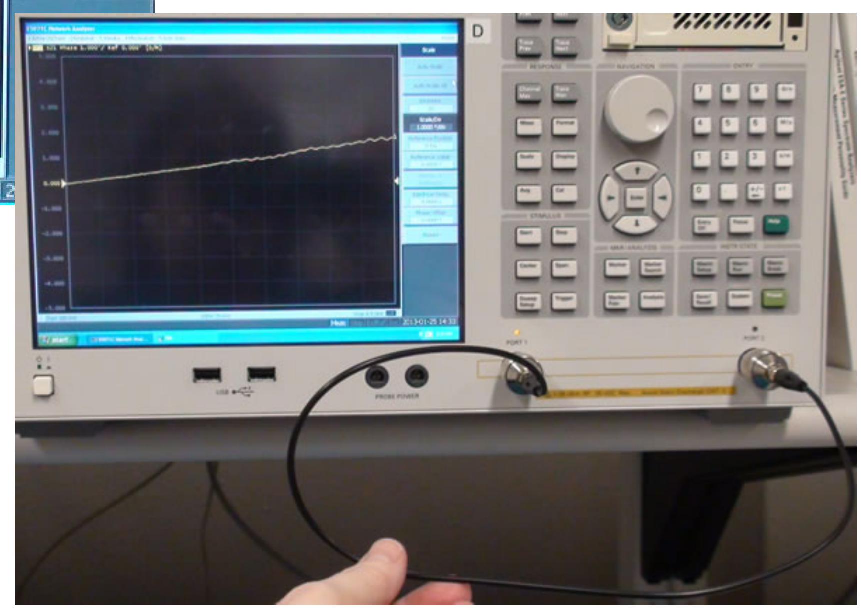


That will make the Phase S21 trace become zeroed:

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

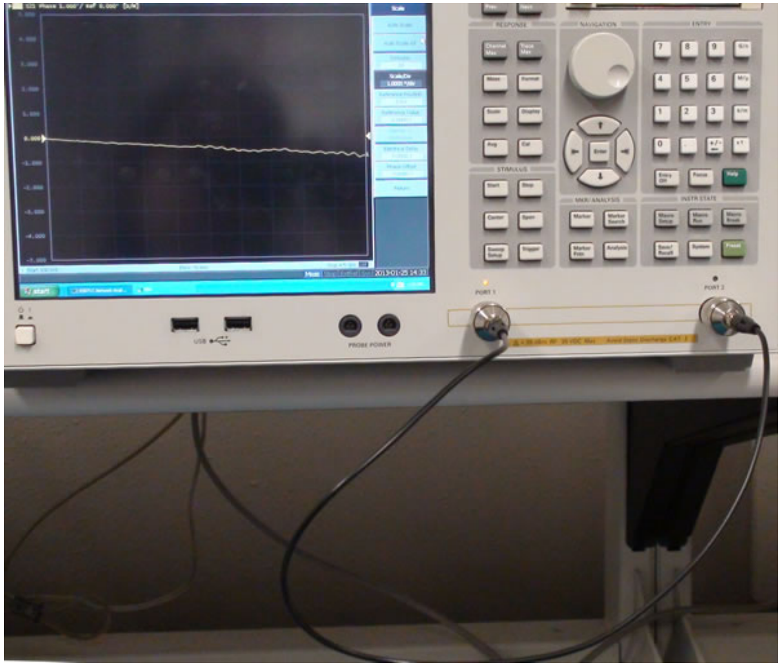


Now wiggle and bend the cable. The phase changes as you bend or stretch the cable.

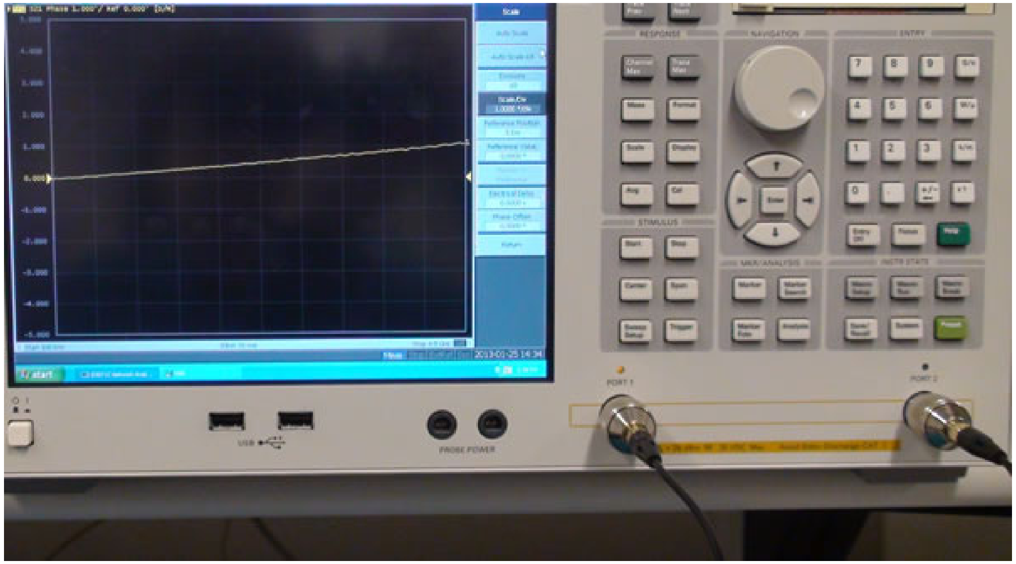


Now stop touching the cable. Wait for the trace to settle. Now the phase goes a bit negative by the time the sweep reaches 4.5 GHz. Check how far off the phase is from zero at your frequency of interest.

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.



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.



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

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...

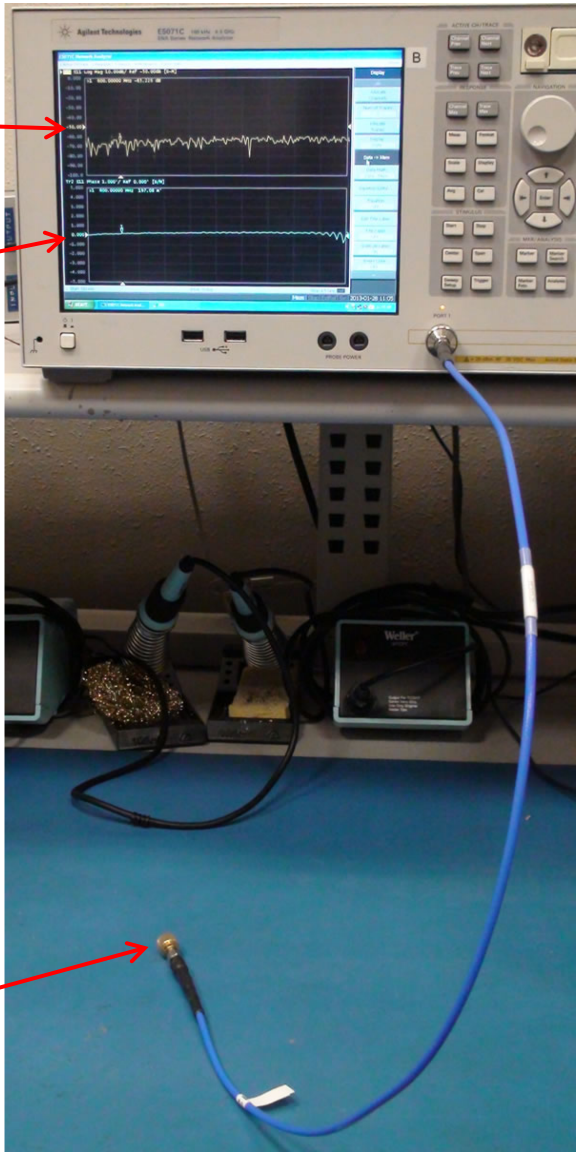
Cable #12

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)

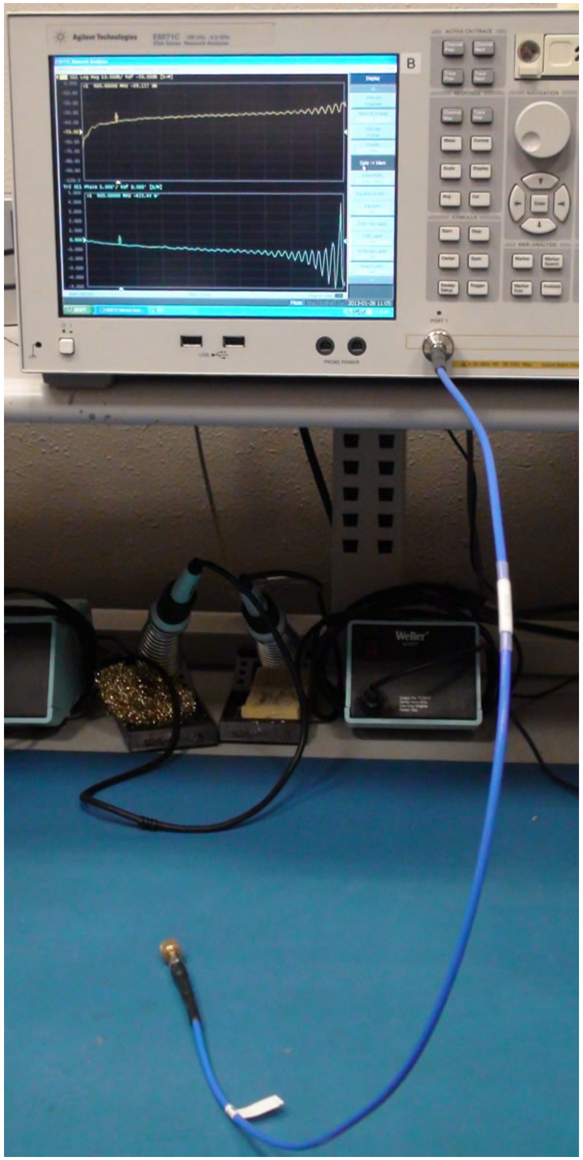
Short standard

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



Now after wiggling and letting it settle.

This cable is really bad.



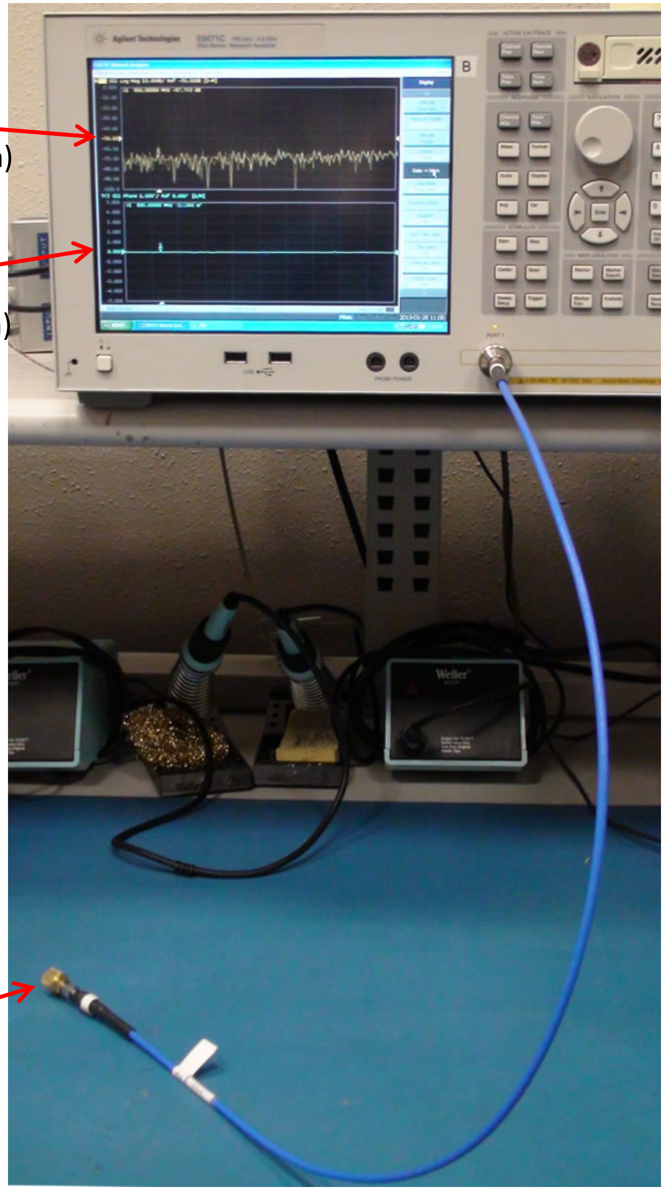
Cable #2

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)

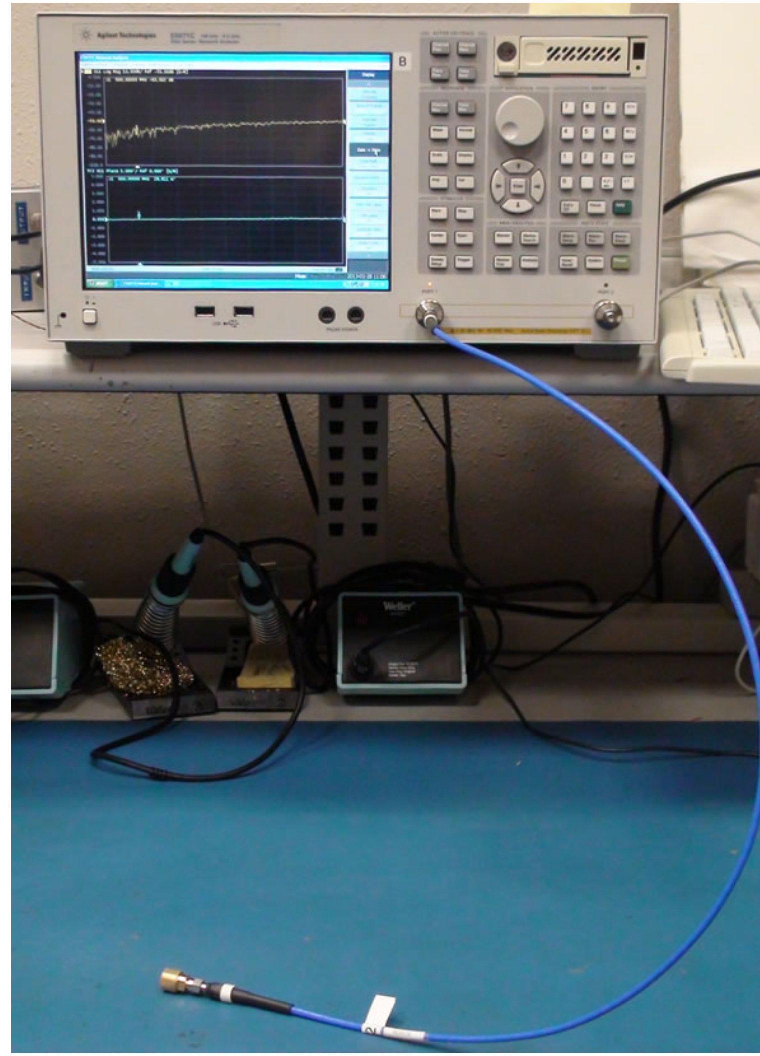
Phase S11
(ref set to 0 dB,
scale set to 1 deg/division)

Short standard



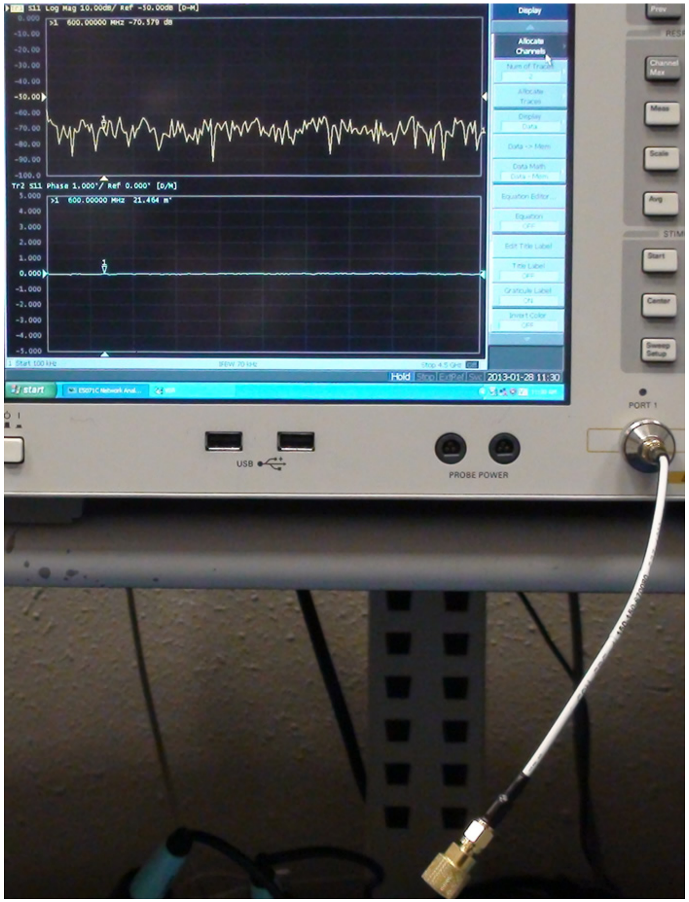
Now after wiggling and letting it settle.

This cable is pretty good.

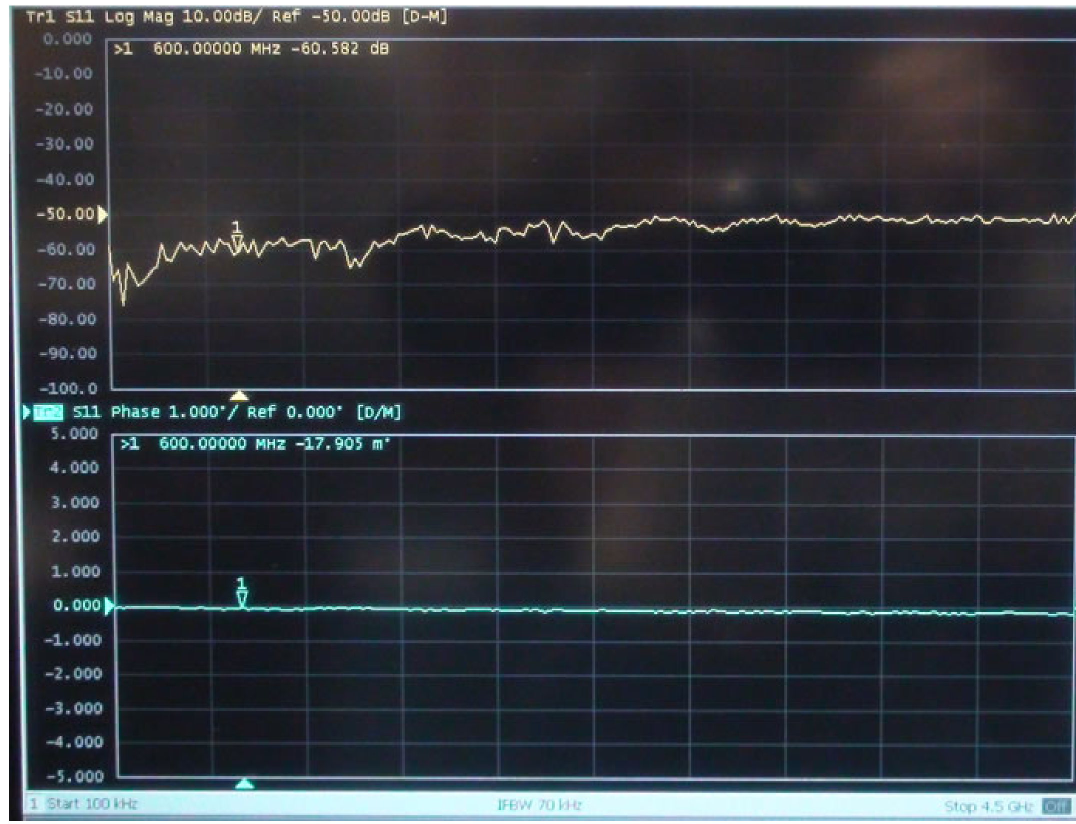


Here's a very good cable (brand new, $50, came with a sheet showing its factory test).

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.

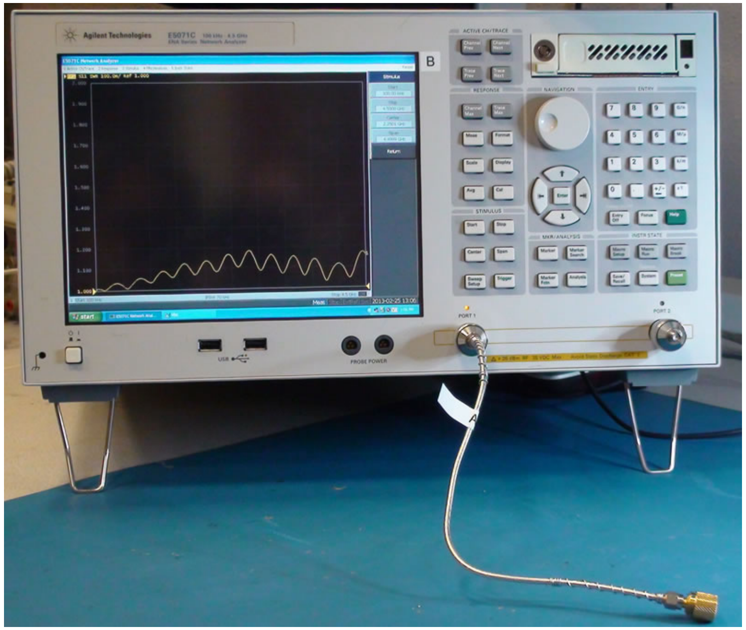


A Third Cable Test – the SWR Test

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:

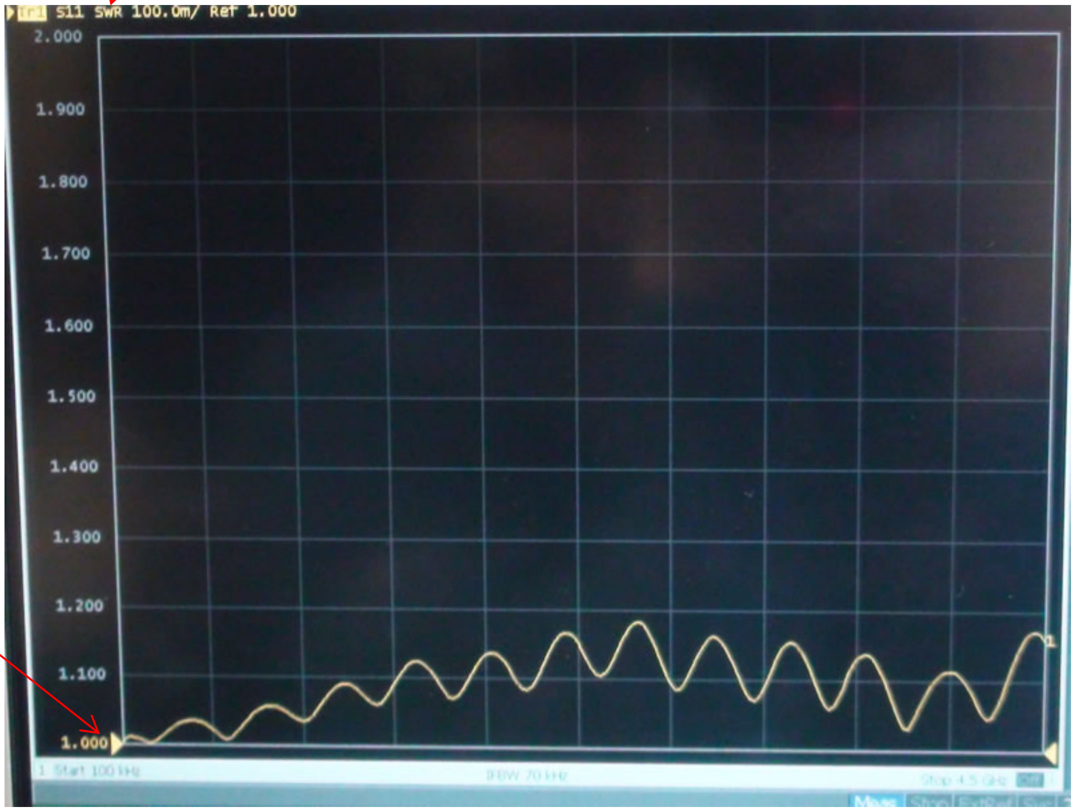
- Attach your cable to Port 1 of the network analyzer
- Attach a 50 ohm cal standard to the other end
    - A perfect cable and 50 ohm load would show an SWR of 1.00
- Under the Format menu (Format hard key), select SWR
- If the SWR measurement is under 1.22, SanTron says it’s a good cable (albeit they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



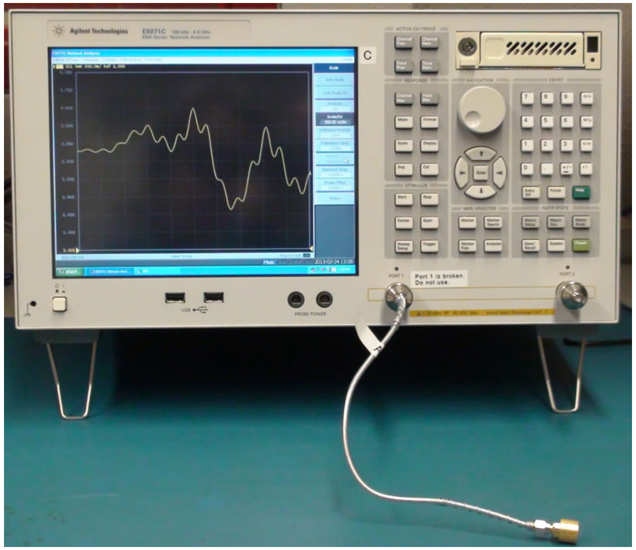
Should say "SWR".

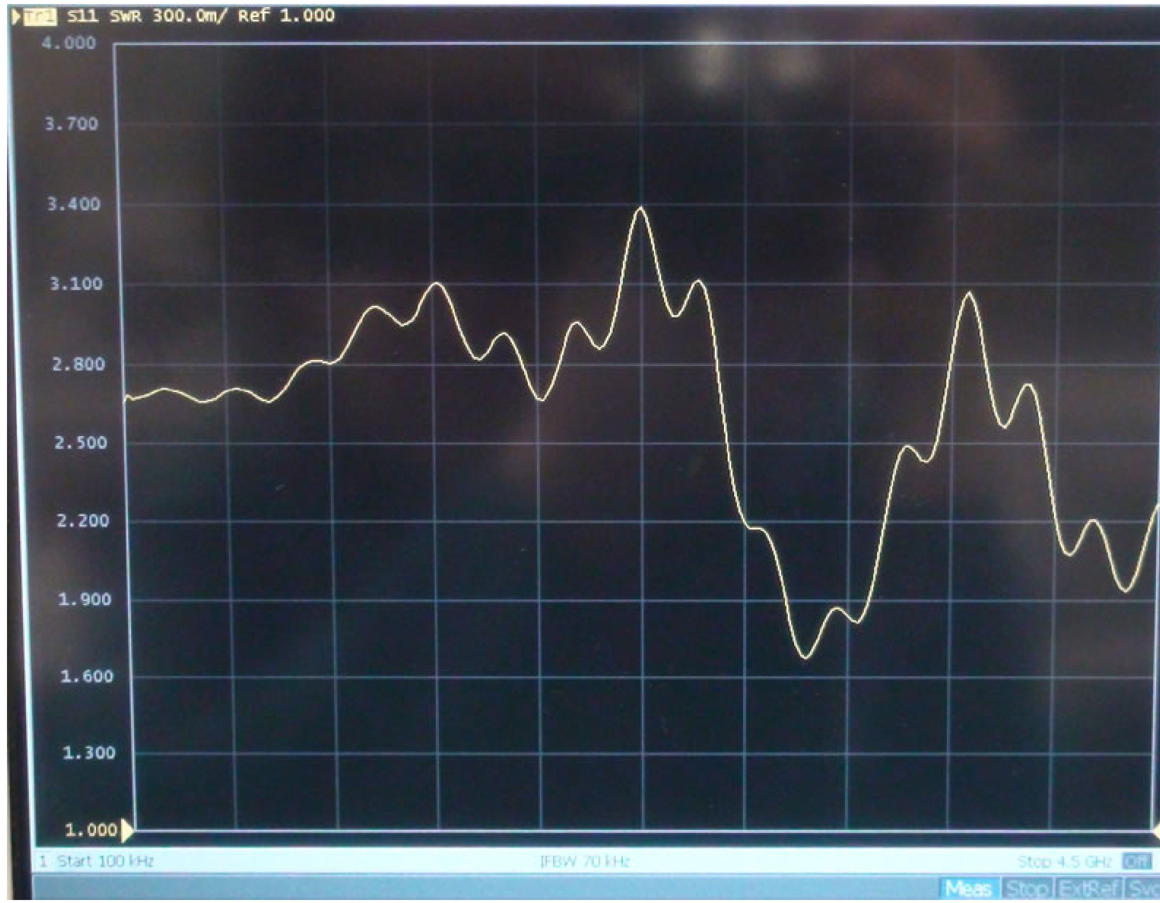
Hit the Scale hard key. You'll see the defaults for an SWR format are: the Reference Position is set to the 0th division. The Reference Value is 1.00. Then set the Scale/Div to 0.1:



The yellow triangle marks the Reference Position for the yellow trace. Here, the Reference Position is at the 0th 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 cracked and have 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.

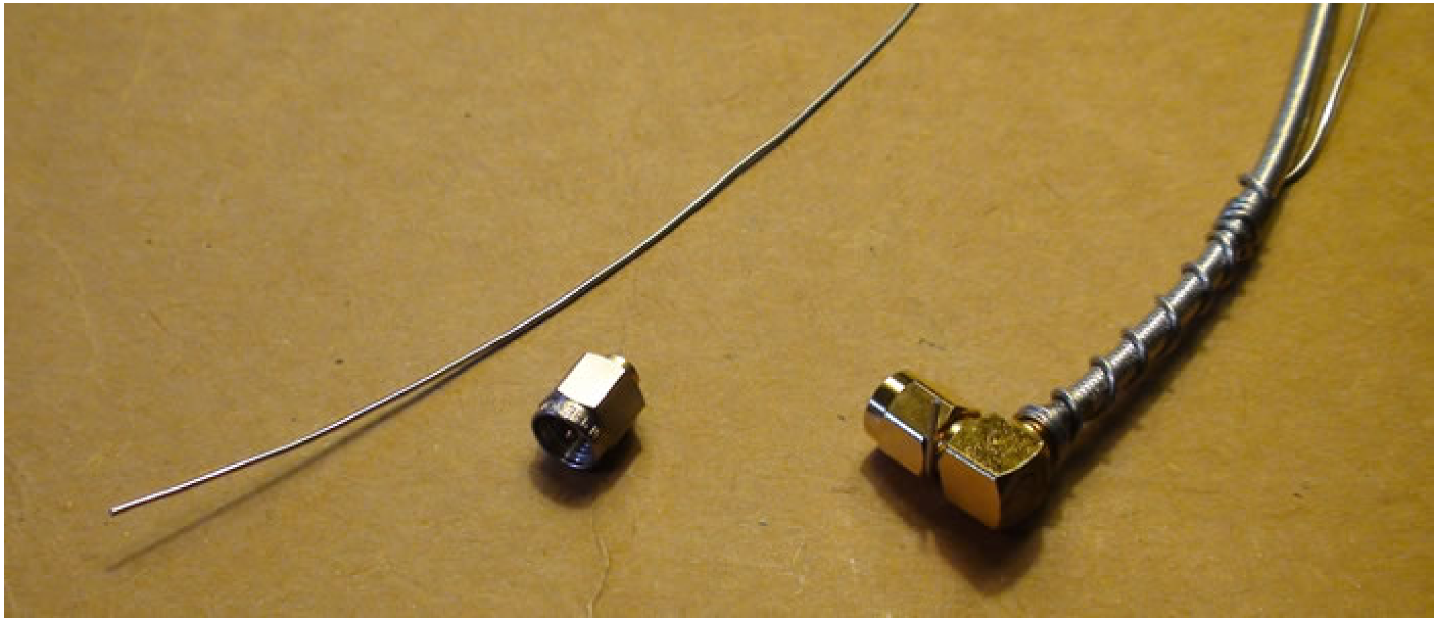
Making Our Own High-Quality Cables

Buy these captivated contact connectors from Amphenol RF: #901-9808 (from Rfdepot.com)
They're to be used with 0.141" diameter conformable cable. Buy Belden #1673A (from Tallycom.com).
Buy bend-and-stay wire from McMaster.com: #8872K75

Tools to put these together are now in the Cory 111 lab.

Use the SanTron assembly tool: #1209-03-P to prevent the dielectric from ooshing out during the step of soldering the outer braid (don't apply more heat than needed). The #1209-03-P is in the tools case on 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. Don't let any out-of-spec cables get in the lab. Out-of-spec cables can crush the fingers in the connectors on the ECal!

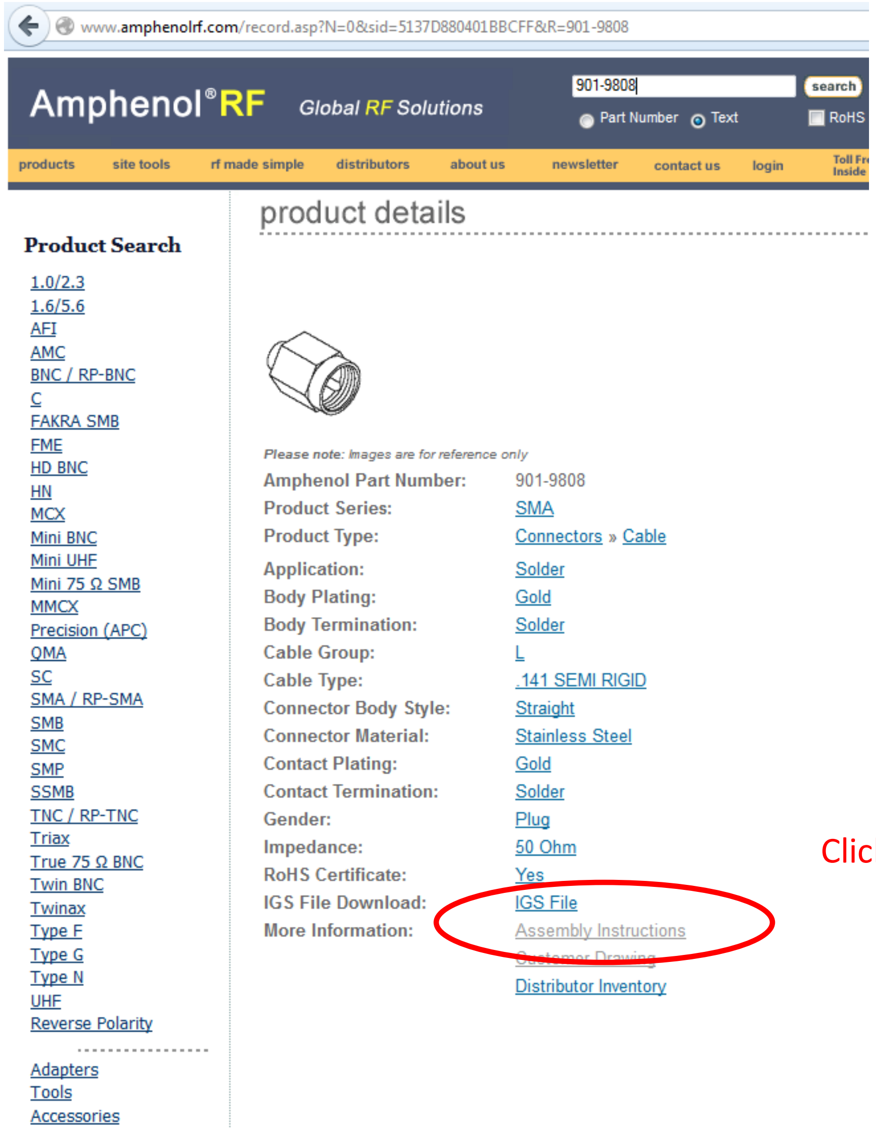


Note: Amphenol RF is different than Amphenol Connex. Look on www.amphenolrf.com.

The web page for these AmphenolRF #901-9808 captivated-contact connectors we're using is here:

www.amphenolrf.com

Then search for 901-9808:



Click on Assembly Instructions

Clicking on Assembly Instructions will take you to this web page. It says you'll need to strip the cable 0.125" (3.2 mm):

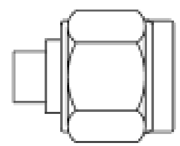
www.amphenolrf.com/pdf/318.pdf

Page: 1 of 1 Automatic Zoom

Assembly Instructions-C48 SMA

Amphenol®

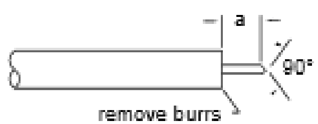
SOLDER TO BODY/PRE-ASSEMBLED CENTER CONTACT FOR SEMI-RIGID CABLE



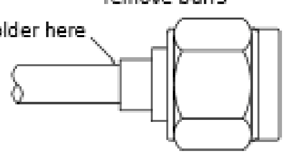
connector as shipped
(contains pre-assembled center contact)

Amphenol Number	Connector Type	Cable S/R	Dim a
901-9723	SMA Plug	.085(2.2)	.125(3.2)
901-9723-10	SMA Plug	.085(2.2)	.125(3.2)
901-9805-HP	SMA Plug	.085(2.2)	.125(3.2)
901-9808	SMA Plug	.141(3.6)	.125(3.2)
901-9808-1	SMA Plug	.141(3.6)	.080(2.0)
901-9808-2	SMA Plug	.141(3.6)	.125(3.2)

Step 1



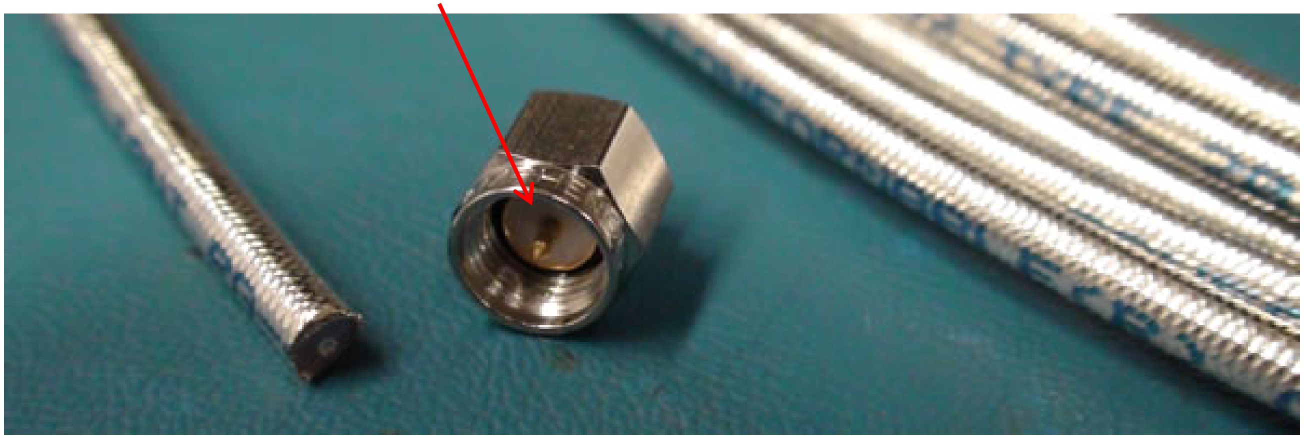
Step 2



Step 1 Clean cable end for .625"(16mm) min. length. Trim cable jacket and dielectric to dimension shown. Do not nick center conductor. Remove burrs from cable jacket. File blunt end of center conductor to a 90° cone.

Step 2 Assemble cable into connector body. Make sure center conductor is straight. Use care in pushing center conductor into spring contact. Make sure jacket bottoms in connector. Maintain end pressure while soldering. Avoid excessive heat which may distort dielectric.

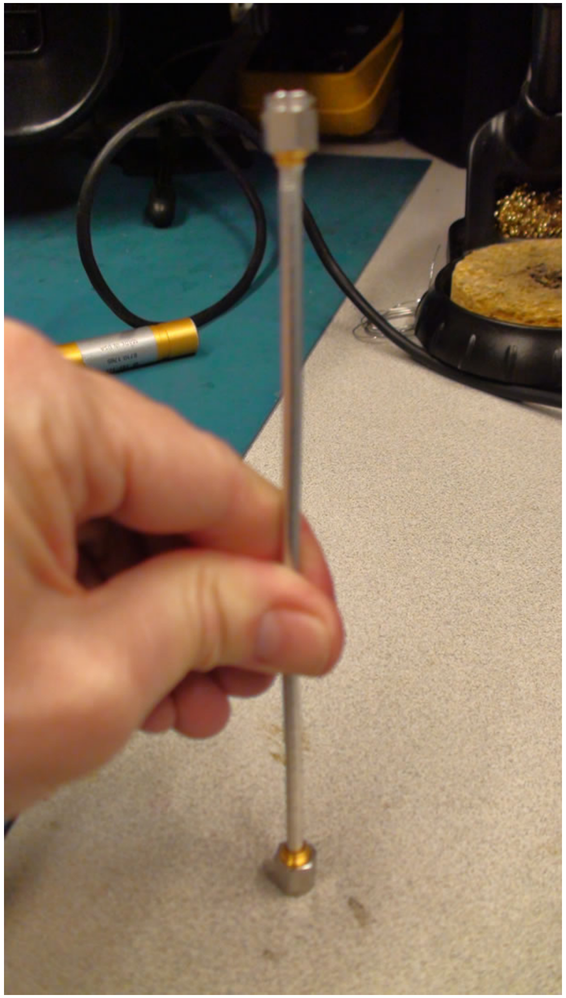
AmphenolRF 901-9809 captivated-contact SMA connector. With a captivated-contact type of connector, when you buy the connector, the pin is already in the connector and set to the correct position. Check the AmphenolRF web page for assembly instructions.



Belden #1673A 0.141" outer diameter conformable coax cable. The web page for the 901-9808 connector should have a link to assembly instructions, which will tell you the distance to strip the conductor. After stripping, push the center conductor into this hole on the backside of the connector. Then solder the outer braid to the connector neck.

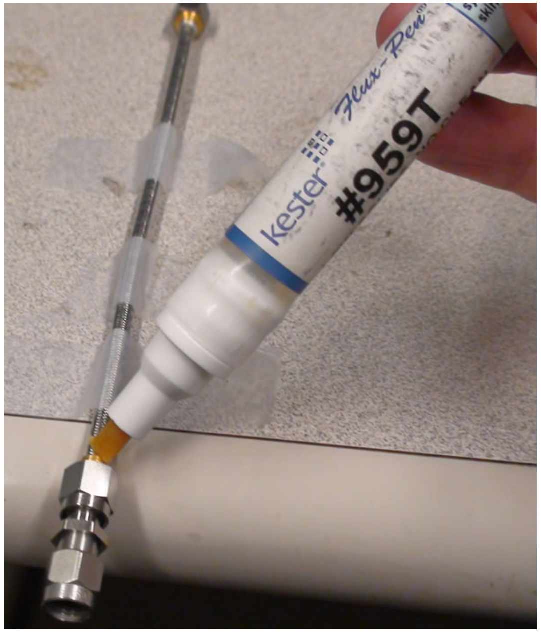
SanTron assembly tool, #1209-03-P. This is kept in the plastic box with the cable making tools on the GSI's desk in Cory 111. Use it when making these types of cables. The pictures below show each end of the tool. Screw in the end shown on the right into the connector your assembling onto the conformable 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 to move. This tool prevents that from happening, or tries to. Don't apply more heat than you need to. If you do, the dielectric face will end up out of spec. Always measure the pin-depth and dielectric-depth, using the gages, both before and after assembly.

Strip the cable to the appropriate length, then file the tip of the inner conductor to take off any burrs (while looking under the stereo microscope). A wire stripper and a file are in the plastic box on the GSI's desk. Check it under the stereo microscope for any metal debris sitting on the insulator's face. Get rid of them by blowing with air, or picking them out with a razor blade (also in the plastic box). The goal is to make a clean interface between the cable and the connector so as to create as uniform of a transmission line as possible.

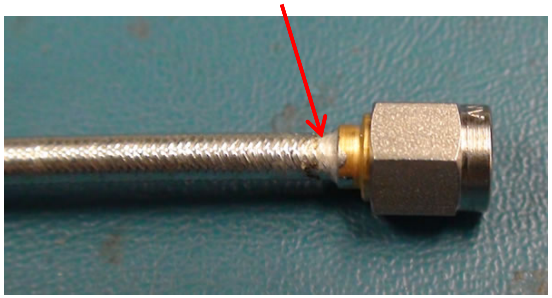


Then push the connector onto the cable. Push it all the way in.

Next, screw the Santron 1209-03-P tool into the SMA connector. The Santron tool acts as a heat sink during soldering.

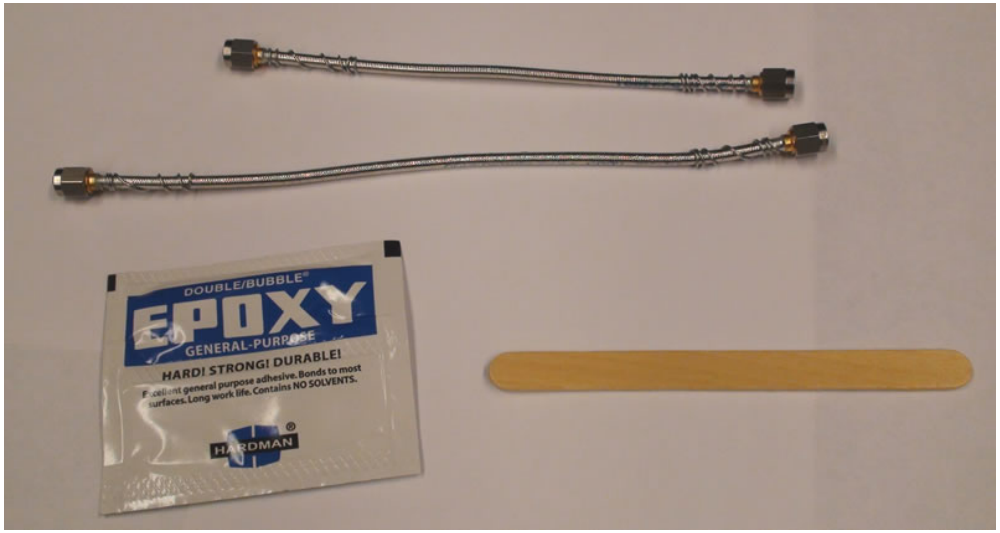


Use flux and solder the outer braid to the connector neck. You don't need to use huge amounts of solder, but you do need to do both sides to get solder all the way around. Again, you're trying to make a uniform coaxial transmission line, so you want the outer braid to make good contact circumferentially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



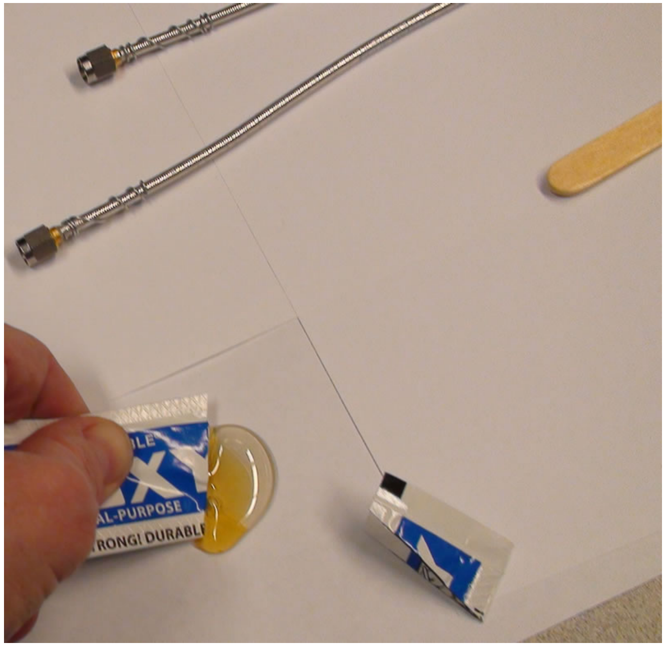
After soldering the outer braid to the connector neck, use needle-nose pliers and bend some Bend-and-Stay wire to add rigidity to the cable. The point of failure will always be at the solder joint at the neck, so you never want to bend the cable there when you're doing measurements on the VNA. Wrap bend-and-stay wire tightly at the neck, with wider-spaced wraps for the next two inches, followed by several tight turns at the end.

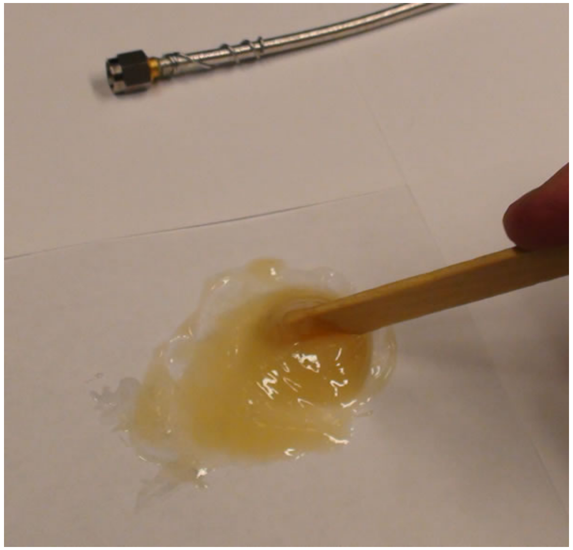
Now get the 2-part epoxy and a mixing stick from the plastic box on the GSI's desk.



Fold the pack in half, cut through both parts with scissors, and squeeze out the entire contents of both packs.

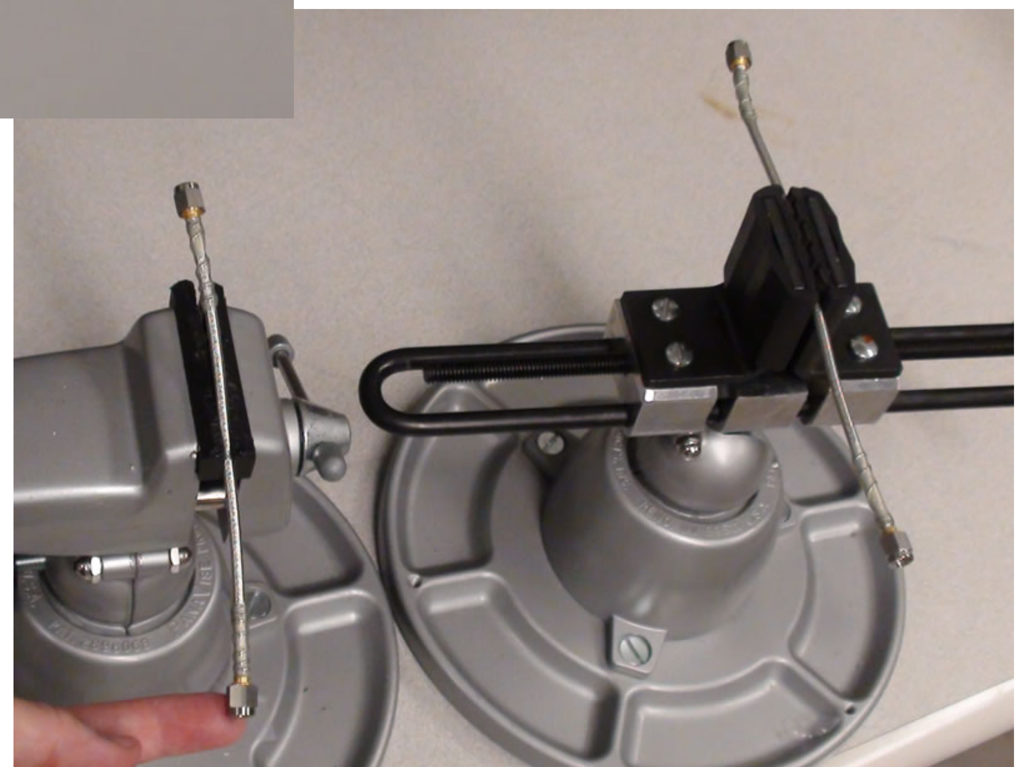
Mix thoroughly.





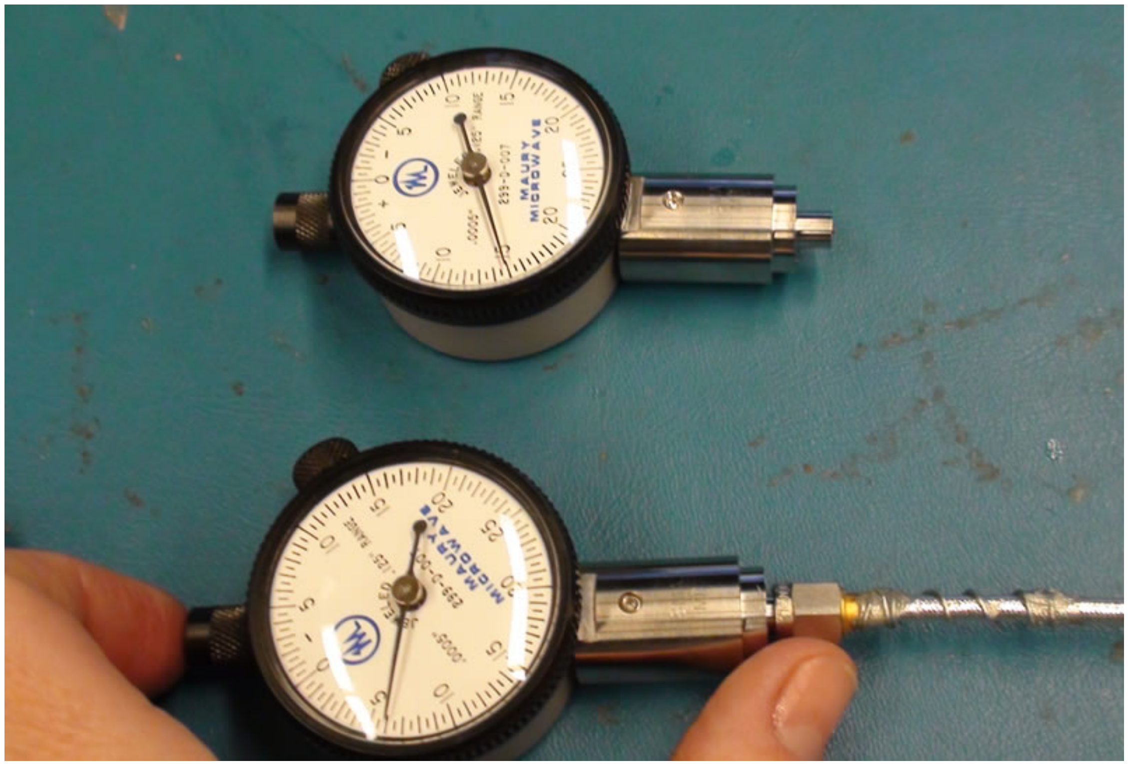
Put a small amount of epoxy on your mixing stick and apply a thin layer of epoxy over the Bend-and-Stay wire.

Make sure not to get any epoxy in this rotary joint.



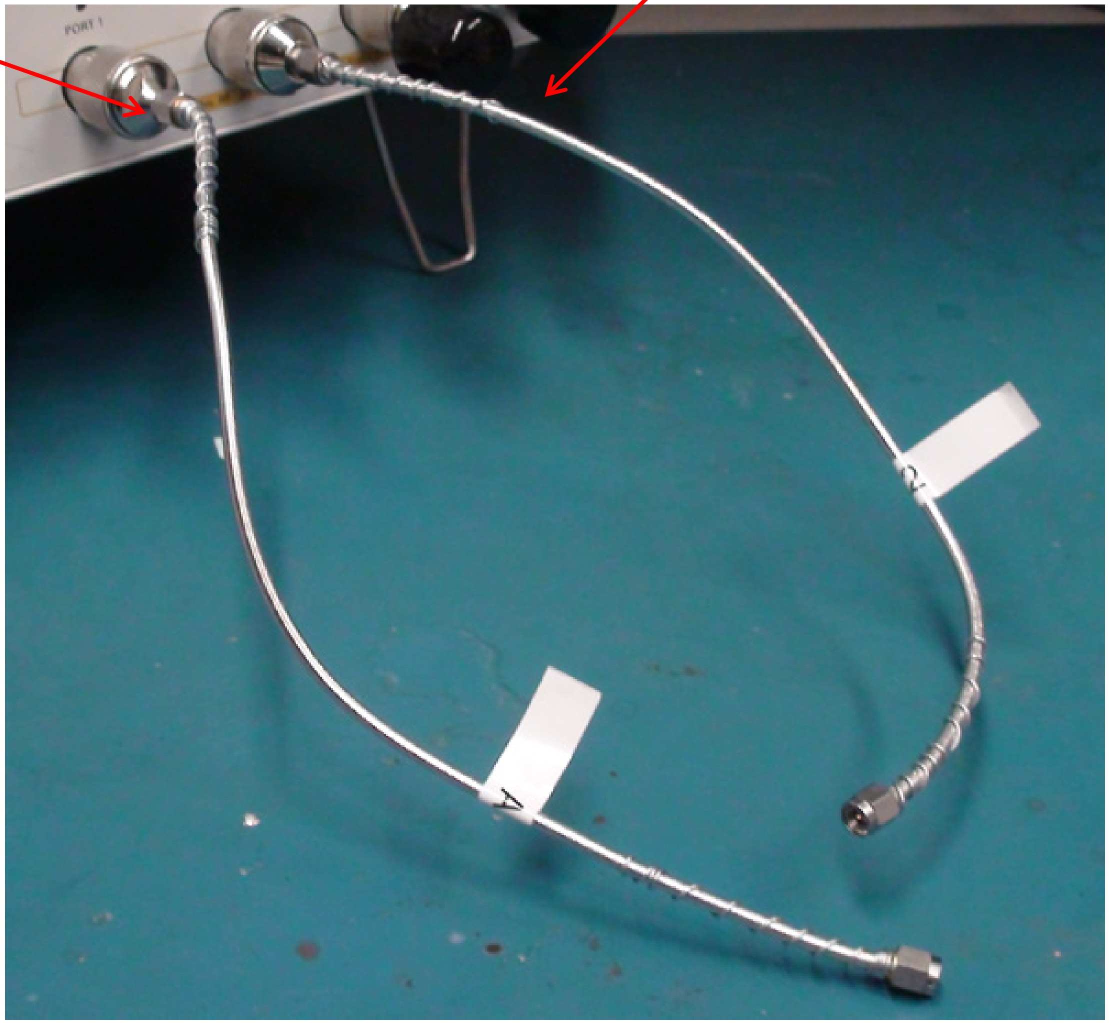
Hold in a vise at the middle of the cable and let dry overnight. Check that the nut rotates freely and that you didn't get any epoxy in the joint.

Uses the gages to make sure the pin-depth and dielectric depth are within spec:



Never bend these cables like this at the solder joint.

Keep them straight up until this point.



When done assembling, test the cable on the network analyzer. Use the 3 tests for cable stability: 1) the LogMag test 2) the SWR test and 3) the Phase test.