This PDF file contains both parts.

Part 1 of 2 - Sinclair R-102G Lowband VHF Band-Reject Duplexer Documentation

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This document is getting too large, so I had to divide it into two parts. Part 1 covers theory and simulations. Part 2 – covers physical hardware modifications and the measured performance of the fully modified duplexer at 6-meters.

I can't find any "how to design a duplexer" articles that go into the actual RF design derivations and technical detail. People know how to tune them based on instructions from others, but there is no deep theory that I can find, so I attempted to create that information. I've been able to gain a lot of insight and "reverse-engineer" a band-reject duplexer by creating computer simulations in LTspice and Agilent ADS, and then comparing them to the real hardware. Out of necessity, this document is at the RF engineering level. It assumes familiarity by the reader with a vector network analyzer (VNA) and other aspects of RF hardware design.

A duplexer must do three things in order for a single antenna to be shared simultaneously by a transmitter and a receiver:

1) Prevent the strong transmitter carrier energy from reaching the input to the receiver and driving it into compression or causing damage. This can only be accomplished in the receiver branch of the duplexer.
2) Prevent the relatively weak transmitter phase noise that falls directly on the receiver channel from reaching the receiver input. This can *only* be accomplished in the transmitter branch of the duplexer. It cannot be eliminated by any form of filtering in the receiver branch because it is directly *on* the receive channel.
3) Combine the transmit branch and the receive branch of the duplexer together using a 50 Ω Tee-connector such that good return loss is preserved at the ANTENNA Port junction for both the TX frequency and the RX frequency. The return loss must be ≥ 20 dB at these two frequencies. This requires the impedance looking into the transmitter branch to look like a high-Z at the *receive* frequency, and the impedance looking into the receiver branch to look like a high-Z at the *transmit* frequency. Note that 50 ohms in parallel with a high impedance is still 50 ohms.

With regard to items 1 & 2, measurements were made on two Motorola Syntor-X 9000™ Lowband VHF Two-Way radios that were linked together using a string of power RF attenuators with one radio transmitting and the other receiving. Test results showed that the minimum attenuation must be 86 dB for absolutely no receiver desense to occur to the weakest possible received signal (−122 dBm, just barely breaking threshold squelch) while transmitting 100 Watts at a 1 MHz carrier offset. Add 10 dB to this number for margin and you have a 96 dB notch rejection requirement. Non-synthesizer channel element radios such as Motorola Micor will have lower phase noise and will not need as much RF isolation. VE3MMX has obtained 117 dB(!) of rejection from his Sinclair duplexer modified for 6-meters, so there is plenty of margin to be had, and this requirement does not pose a problem.

The Sinclair lowband VHF duplexers are of the band-reject variety with a single port on each of the 8 cavities. There are 4 cavities for the transmit branch and 4 for the receive branch. I've been able to model the *entire* duplexer with reasonably good simulation results. This exercise provided a huge amount of insight into how to go about tuning this particular duplexer.

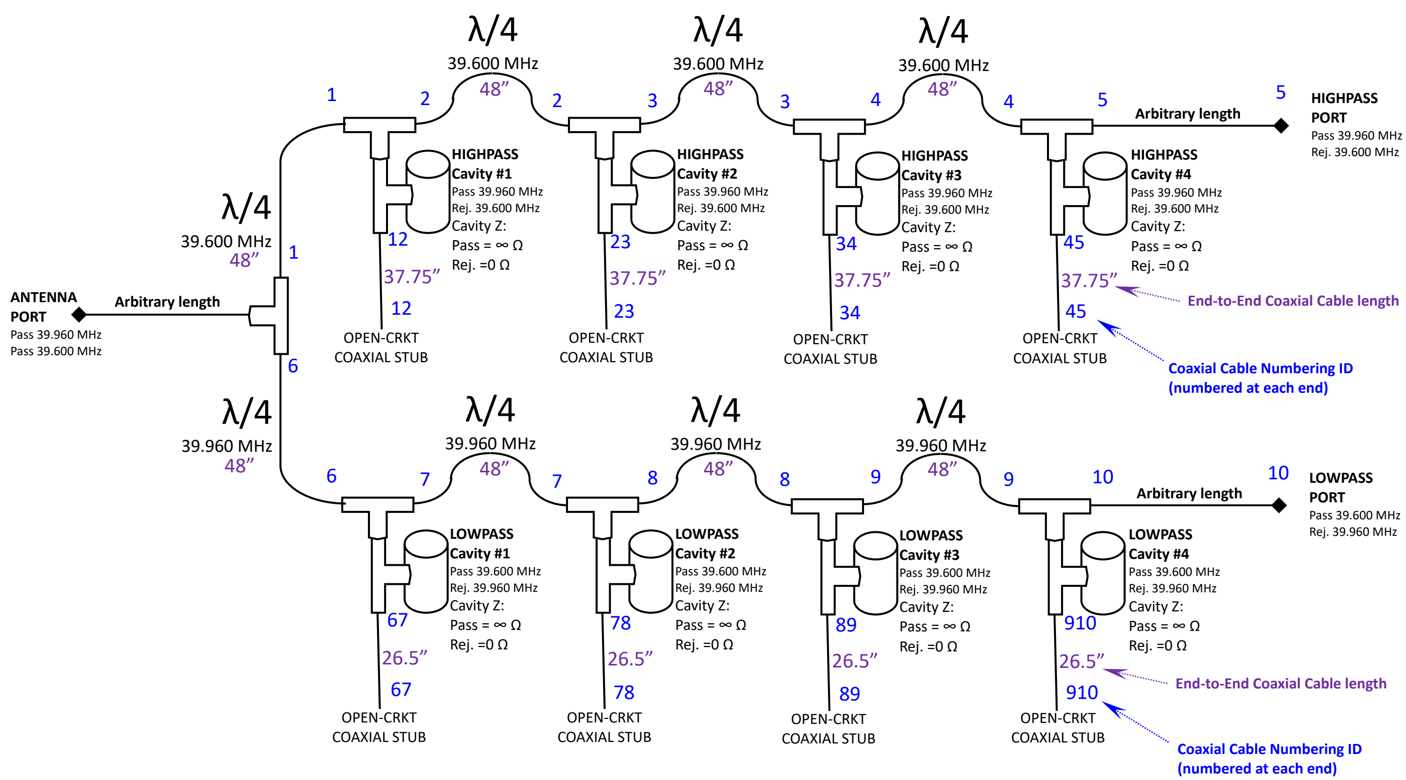
My Sinclair Model # R-102G duplexer came out of service with the railroad industry (in the early 1970s?) and was tuned to these frequencies:
HIGHPASS = 39.960 MHz (railroad repeater TX)
LOWPASS = 39.600 MHz RX (railroad repeater RX)

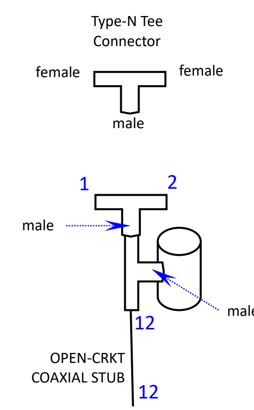
I opened-up a cavity to see what sort of coupling it uses to couple the resonator to the outside world. It uses an inductive coupling loop, although there is no adjustment for the amount of coupling. But more on that in a few pages including some nice photos. There are only two adjustments for each cavity:

1) A tuning rod adjusts the notch (reject) frequency.
2) Each cavity has its own open-circuited coaxial stub (OCS) that can be cut to a new length with some difficulty. They are attached with Type-N T-connectors. The stub length adjusts the Pass-to-Reject frequency spacing and it also determines whether the cavity will be a HIGHPASS or a LOWPASS cavity.

In Part 2 this duplexer is successfully converted to 6-meter operation. The new frequencies are as follows, where RX = 52.150 MHz and TX = 53.150 MHz:
LOWPASS Cavity Frequency (Repeater RX branch) pass 52.150 MHz, reject 53.150 MHz
HIGHPASS Cavity Frequency (Repeater TX branch) pass 53.150 MHz, reject 52.150 MHz

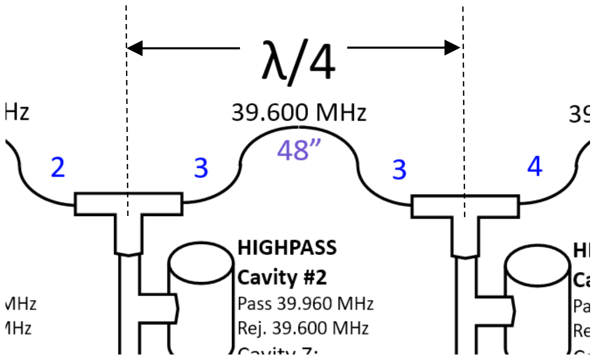
Here is the documentation of the existing Sinclair # R-102G Duplexer with HIGHPASS frequency = 39.960 MHz and LOWPASS frequency = 39.600 MHz:



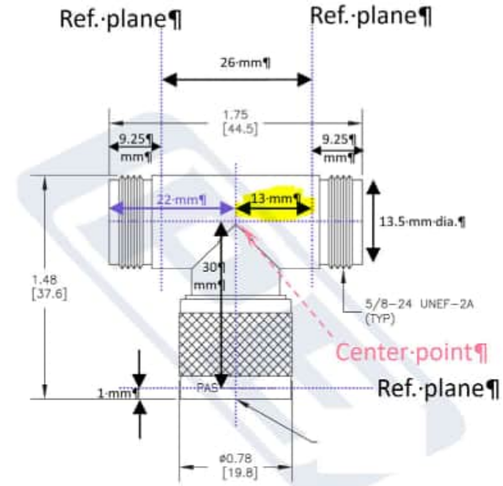


The bench-measured performance is excellent: about 1.3 dB insertion loss and 104 dB rejection after tuning everything up at the railroad frequencies. High-resolution photos of the duplexer with coaxial cable numbering scheme are shown on the last two pages of this document.

For the railroad duplexer, note that all quarter-wavelength coaxial cables are 48” long from male Type-N connector to male Type-N connector. The reference planes that define the end points electrically are as follows:



Frequency [MHz]	velocity of propagation [%]	1/4 wavelength [inches]
39.960	66%	48.8
39.600	66%	49.2



Center line to Center line definition for a quarter-wavelength:

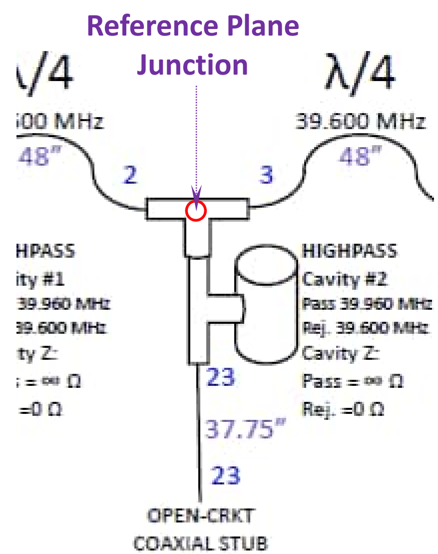
Type-N T-connectors attach at the ends of the 48.0” coaxial cable. This adds another {13mm – 1mm} = 12mm to each end of the cable. Let’s assume that the T-connector uses solid Teflon (PTFE) for the dielectric, which has a velocity of propagation of 69%. This is close enough to the cable’s velocity of 66% to lump them all together and just use 66% for everything. Two times 12mm = 24mm = 0.9 inch. The overall length becomes {48.0 + 0.9} = 48.9 inches. This agrees quite nicely with the table. It shows a quarter-wavelength to be 49 inches for the two railroad duplexer frequencies.

Open-Circuit Coaxial Stubs (OCS):

HIGHPASS Paths - The OCS were measured and found to be 37.75” from tip to the end of their Male Type-N connector.
LOWPASS Paths - The OCS were measured and found to be 26.5” from tip to the end of their Male Type-N connector.
In some cases, the OCS were slightly different in length by maybe 0.5 inch. Note that the OCS are all less than a quarter-wavelength (49”).

HIGHPASS Design Goals:

Refer to the “Reference Plane Junction” (the red circle in the center of the T-connector) as shown on the right. The cavity, the OCS, and the two T-connectors should create an open-circuit at the HIGHPASS frequency, and they should create a short-circuit (0+j0 ohms) at the LOWPASS frequency at the “Reference Plane Junction”.



LOWPASS Design Goals:

Similarly, the cavity, the OCS, and the two T-connectors should create an open-circuit at the LOWPASS frequency, and they should create a short-circuit (0+j0 ohms) at the HIGHPASS frequency at the “Reference Plane Junction”.

I've gone through several iterations in an attempt to model the Sinclair duplexer accurately at the old railroad frequencies (39.600 & 39.960 MHz). For my last attempt at building an accurate model, I opened one of the cavities (Lowpass #2) and made measurements of the individual dimensions inside. Surprisingly, the cavity *does* use inductive coupling, but as designed, the mutual inductance is not intended to be adjusted in the field. The internal coupling loop can be tweaked through a small access hole in the side of the cavity, and this was done only in the factory using a small wooden "hook". Consider the mutual inductance to be fixed and unchangeable. See the photograph on this page and the next page for details. If you know what you are doing, you could increase the loop area by pushing the loop slightly toward the helicoil. This would increase the coupling and would result in more rejection but also greater insertion loss. It's a trade-off.

The cavity's design is simply beautiful. I was able to develop a much more accurate lumped-element model. I calculated the cylindrical capacitance of the tuning rod. I also measured the dimensions of the coupling loop so that I could compute the inductance of the helix accurately. The University of Missouri Rolla has an excellent EMC web page https://emclab.mst.edu/resources/tools/inductance-calculator/ which comes in handy for computing the inductance of various shapes and sizes of wire inductors. It is interesting to note that the helix in the railroad duplexer has 7.125 turns, while the W2GBO modification instructions calls for the number of turns to be reduced to 5. Inductance is proportional to the square of the number of turns, so this has the effect of lowering the inductance by a factor of (7.125/5)^2 = 2. This raises the resonant frequency of the cavity by a factor of the square root of 2 for a fixed tuning capacitance. Note that 52.650 / 39.780 = 1.32 which is close to 1.41; hence, the W2GBO modification instructions make sense. My models include both of the T-connectors, and I matched the HIGHPASS model to the OCS length. The cavity Q is now reasonable and everything fits quite nicely. The model "feels good" and produces reasonable, albeit optimistic results. As mentioned earlier, there is only *one* kind of cavity. The OCS cable length determines whether it becomes a LOWPASS or a HIGHPASS cavity.

Photo of 7-1/8 turn helicoil, which must be shortened to 5 turns **and then stretched to occupy the same overall length!** The cylinder on the right is the outer cylindrical plate of the tuning capacitor. The moveable metal tuning rod (not shown) at GND potential forms the other plate of the capacitor and occupies the interior of the sleeve. The polystyrene rod provides mechanical support and ensures proper alignment inside the cavity. The hollow copper tubing has a 0.25" outer diameter. The helicoil itself has an inner diameter of 2.0". It is brazed to the outer cylindrical plate of the tuning capacitor. The W2GBO modification instructions recommend making two cuts to remove a portion of the turns in the middle to get everything down to 5 turns. This is not a trivial mechanical modification. See the photo on the next page. See Part 2 for a detailed procedure with photos.

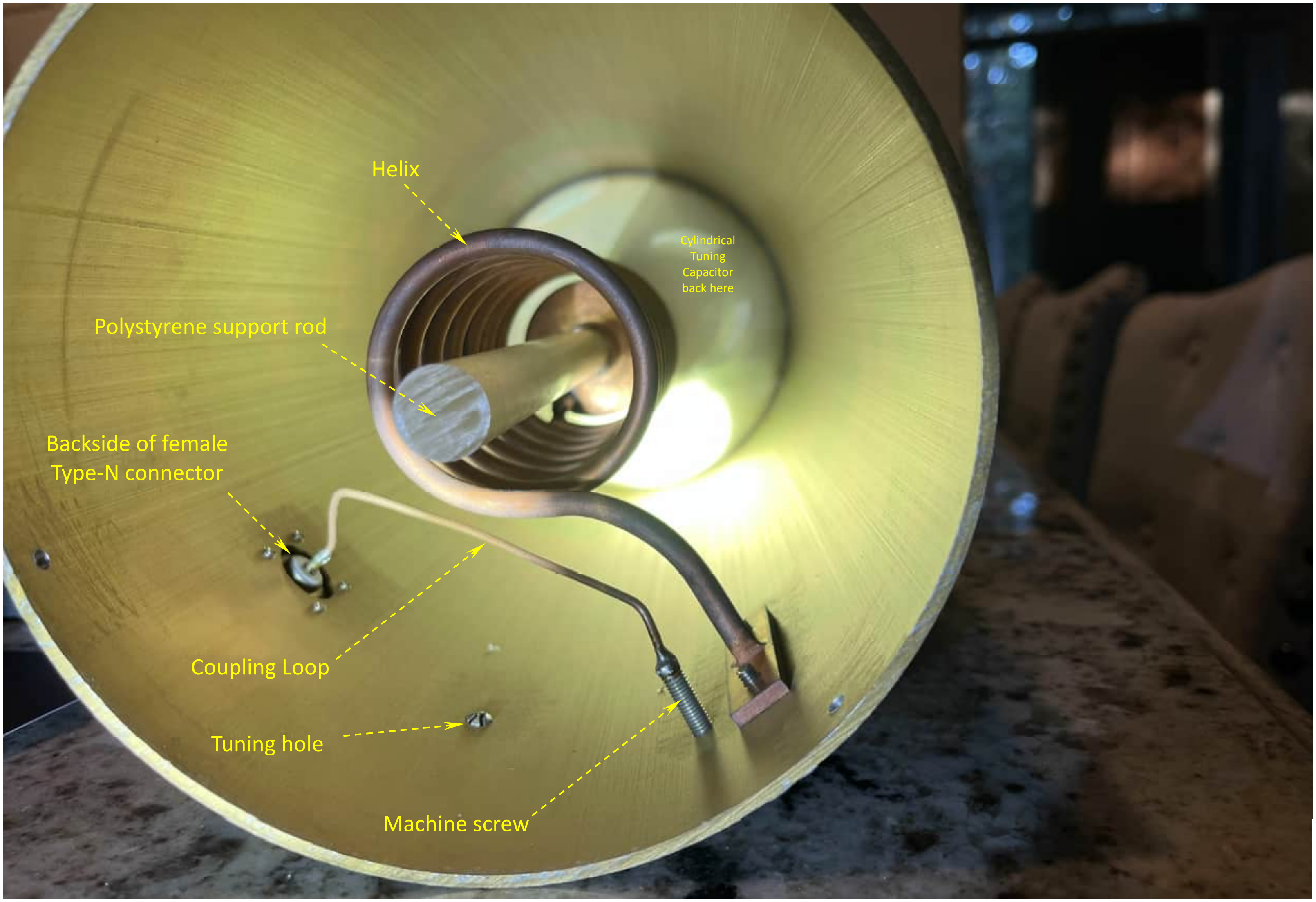


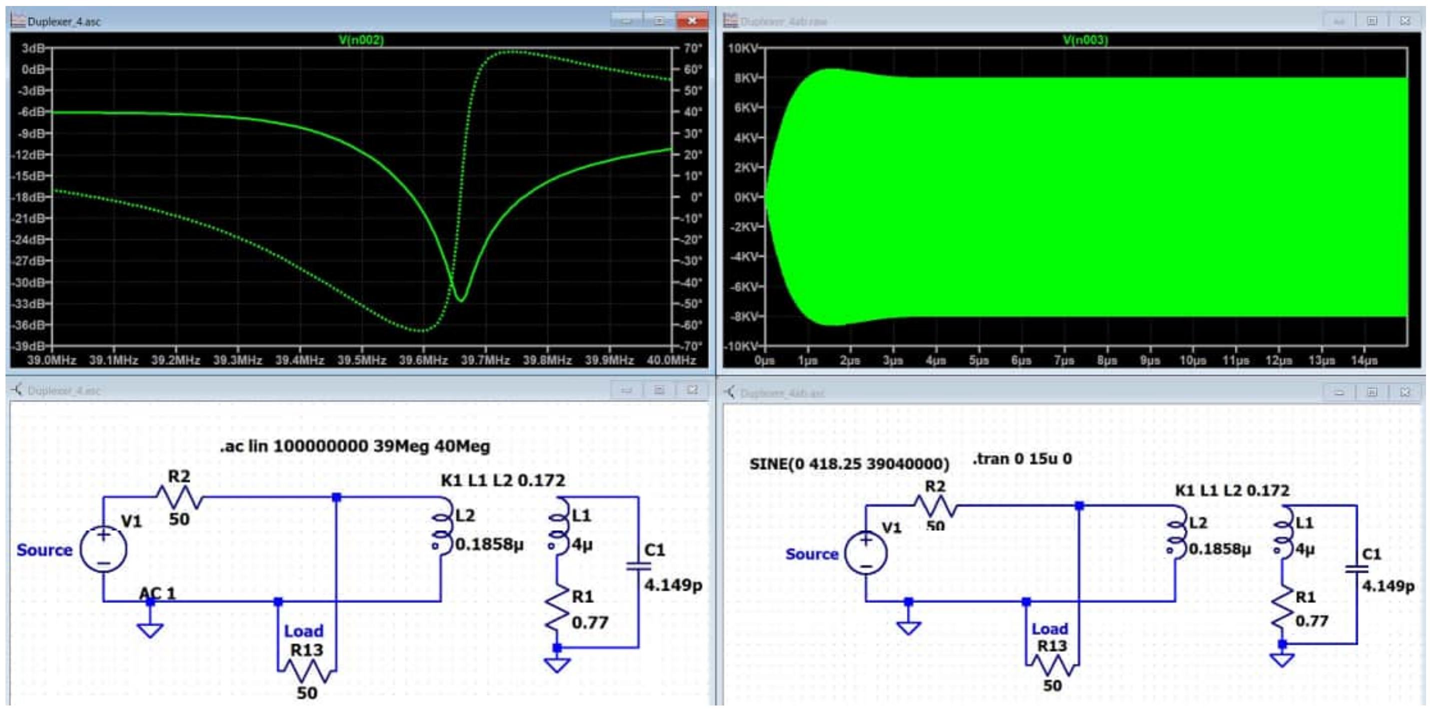
Photo of the end-view of the cavity with the bottom plate removed by drilling out three rivets. Note the coupling loop running from the Type-N connector to the tip of a machine screw. The factory fully inserted and tightened this machine screw in place, and then the copper wire was soldered to the tip of the screw. **This screw is not an adjustment!** This was the only way to solder to the inner wall of the cavity. **Do *not* adjust the machine screw!** A metal brad plugs the tuning hole. A factory worker could insert an insulated tool to tweak the location of the loop slightly. **Do *not* move, bend, or disturb the coupling loop!** It is not intended to be adjusted in the field. I came up with a 17.2% coupling factor (k = 0.172) for the mutual-inductance between the helical inductor and the coupling loop. From a physical geometry standpoint, this looks about right. One-sixth of the magnetic flux produced in the form of a solenoidal magnetic field by the helical resonator is intercepted by the loop area formed by the coupling loop.

By definition the unloaded Q of a tuned circuit or a cavity is fo / f3dB. For a lowband VHF duplexer at 6-meters, we want the deep notch to eliminate the transmitter noise that falls on-channel. We also want the modulated carrier to be rejected so that none of the FM modulation reaches the receiver input. The notch should be at least 25 kHz wide, preferably 50 kHz wide; therefore, the Q should be in the neighborhood of (50 MHz / 50 kHz) = 1,000 per cavity. To further develop the ADS models, I was able to accurately measure the unloaded Q of a 39 MHz cavity. The Q is 1,317 and it is set by the helical inductor losses. Per the W2GBO modification instructions, we will be decreasing the inductance by a factor of 2 to push the cavity resonance from 39 MHz up to 52 MHz.

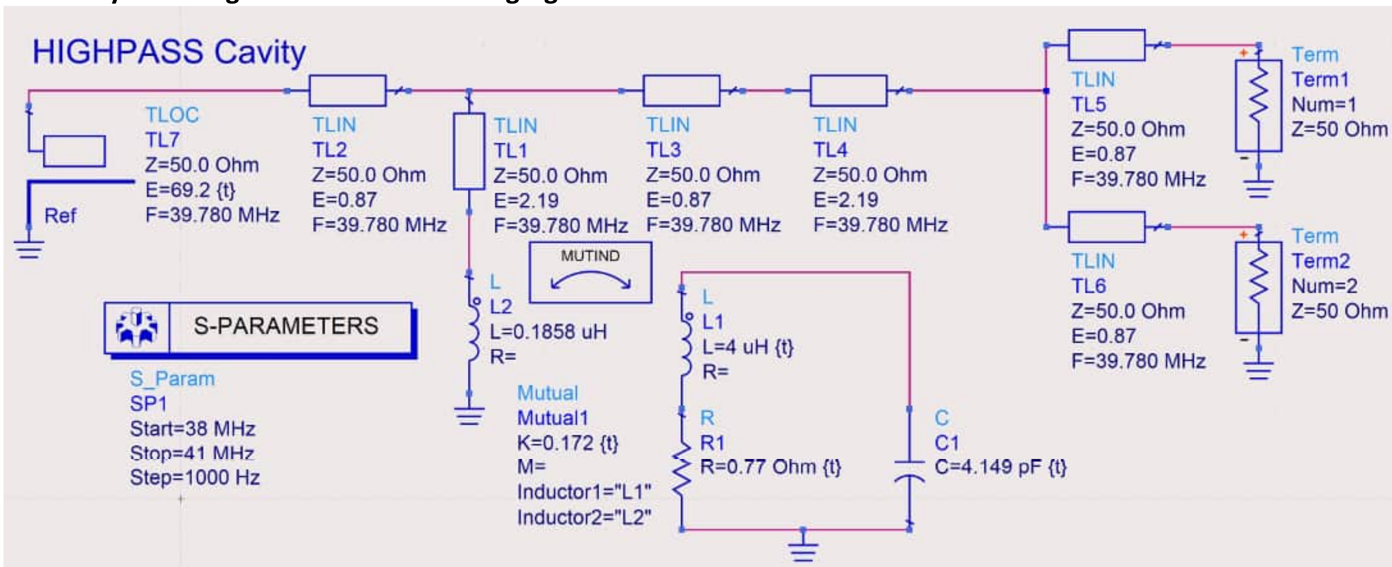
In this case, an alternative but equivalent definition for the unloaded Q would be the helical inductor's reactance divided by its resistance. The reactance increases in proportion to frequency while the resistance increases in proportion to the square-root of frequency (due to the skin depth being inversely proportional to the square root of frequency); hence, the unloaded Q increases as the square root of frequency for an inductor. Note that the inductor's value is being cut approximately in half, from 4 µH down to 2 µH. The series resistance (R1) for the 7.125-turn coil was simulated to be 0.77 ohm. This becomes 0.6216 ohm for the 5-turn coil. (Multiply 0.77 by SQRT(52.65/39.78), and then multiply by (5.0/7.125).

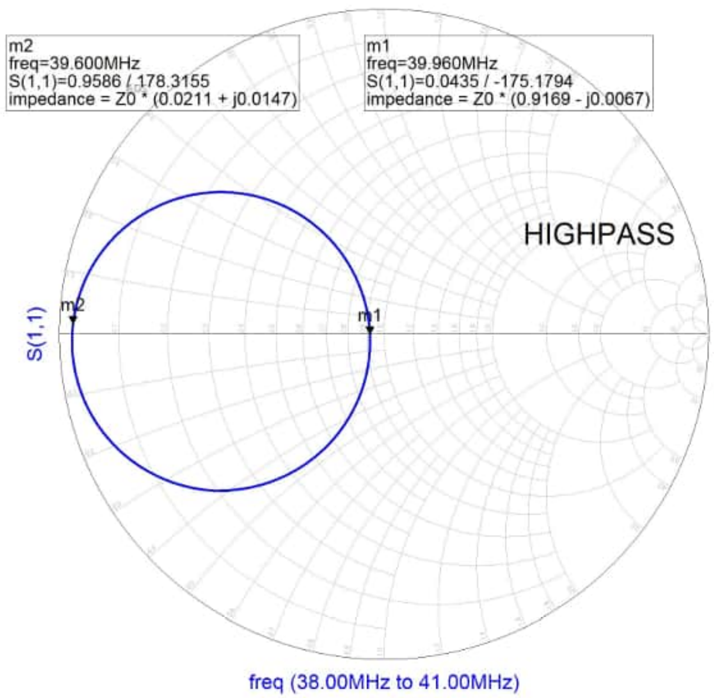
I was not able to measure the *loaded* Q for the cavity. Once it is loaded with 50 ohms (or with 25 ohms), any semblance of a peak in the amplitude response disappears and a deep notch forms. The concept of loaded Q doesn't really apply.

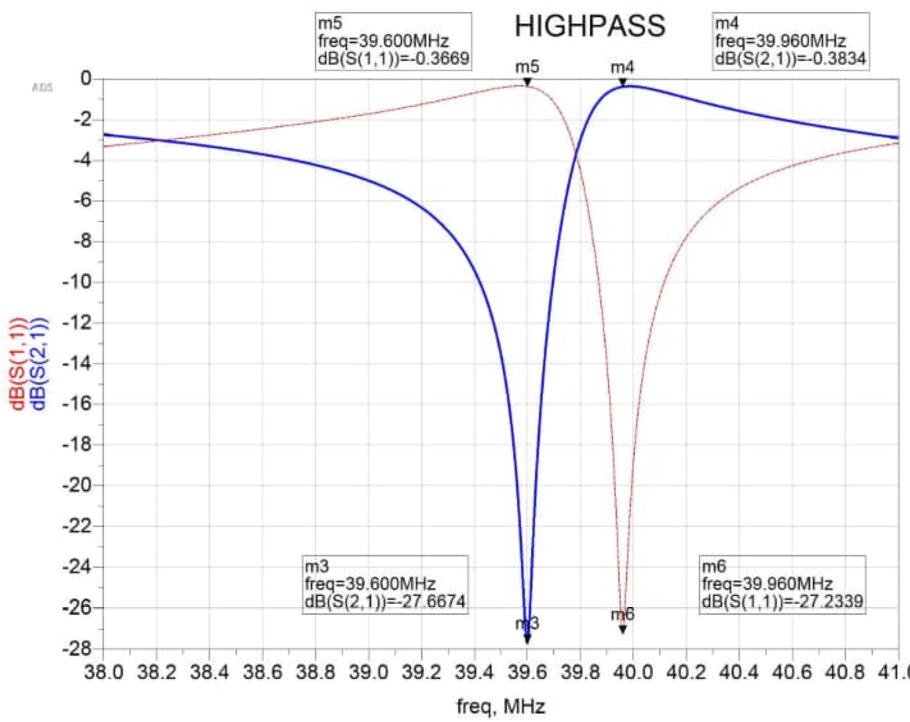
Out of curiosity, I simulated one cavity at the maximum rated RF input power of 350 Watts. The voltage swing across the tank circuit (across C1) is about 5.9 kV peak at the reject frequency and 8.0 kV peak at the pass frequency. The maximum voltage appears at the junction of the helicoil and the cylindrical capacitor sleeve with respect to cavity GND. This is typical of high-Q structures. Adequate spacing is maintained between the cavity components to prevent RF arcing.



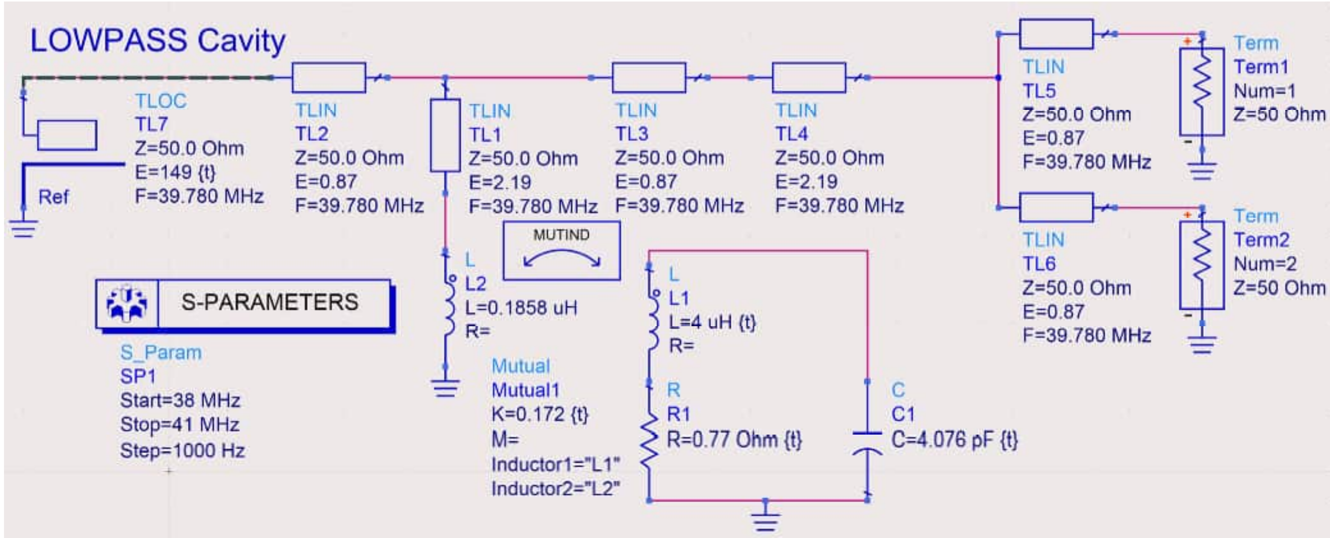
HIGHPASS Model for one cavity including the T-connectors using Agilent ADS:

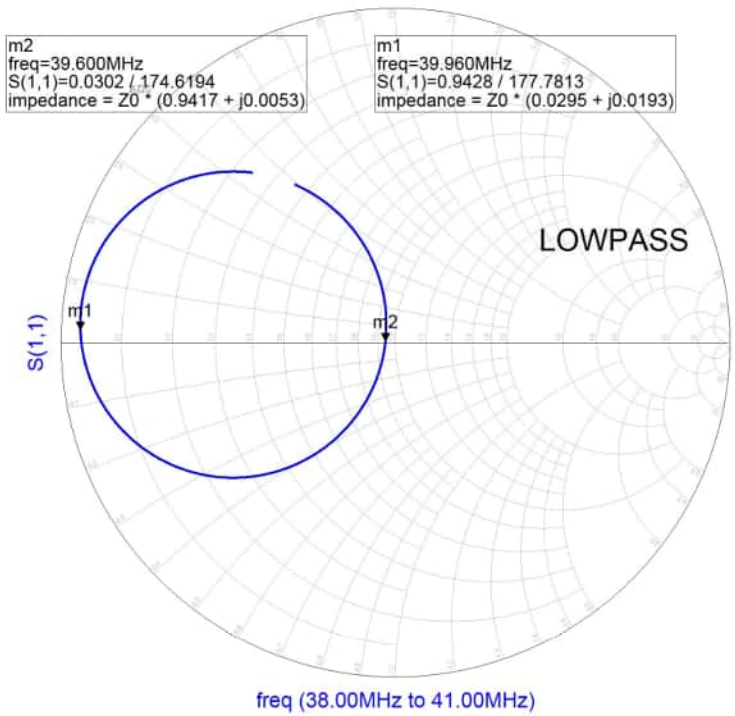


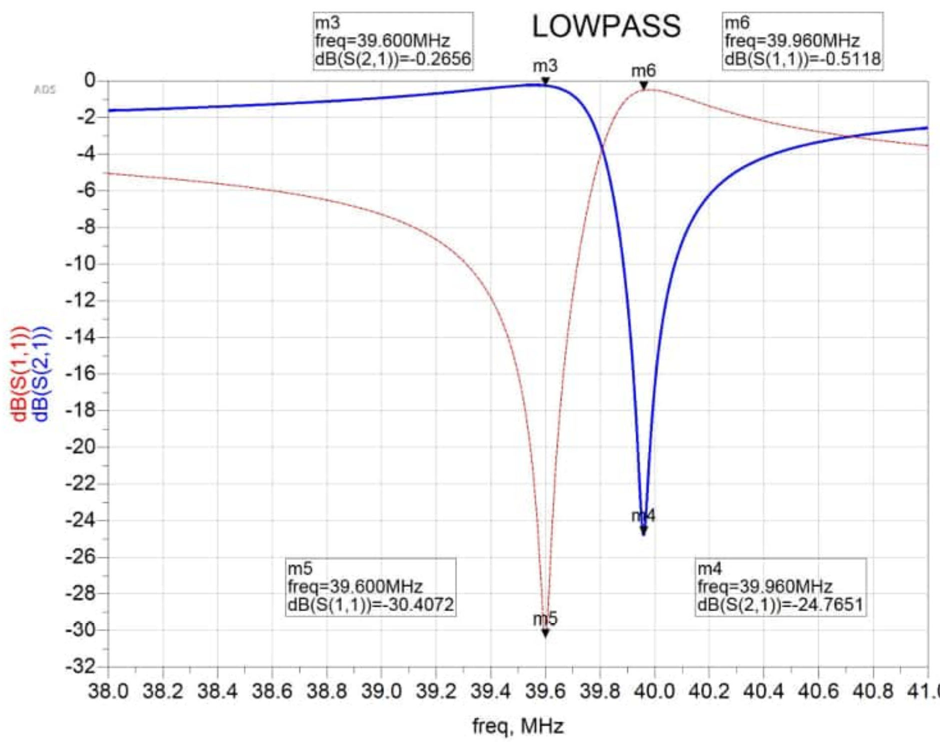




LOWPASS Model for one cavity including the T-connectors using Agilent ADS:







Unfortunately, the same problem remains with this model as for my earlier attempts. When I take the HIGHPASS model as-is and use it to create the LOWPASS model, it works, but the OCS length in the LOWPASS model is incorrect. It has to be 149 electrical degrees for the LOWPASS model to work, yet the actual OCS (hardware) length is much shorter, only 49 electrical degrees. That's a difference of 54 inches of coaxial cable! The models are clearly no good for predicting the OCS lengths. I guess that's not too surprising for an extremely high-Q structure where I do not have an *exact* model.

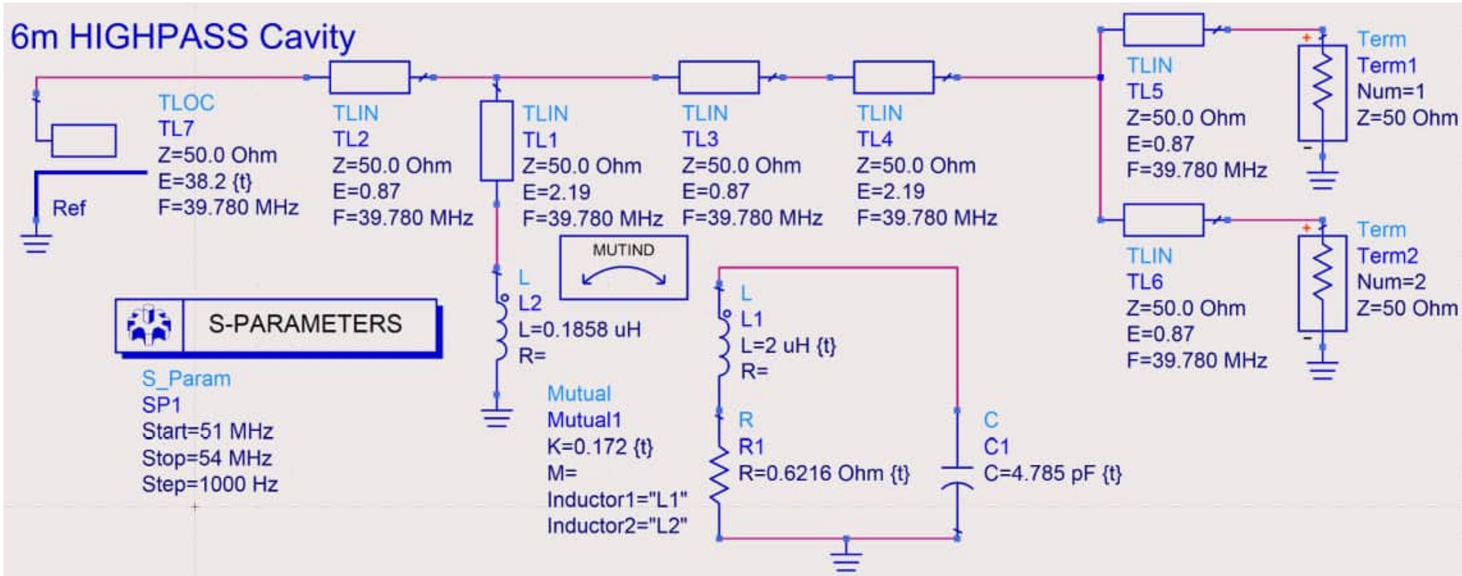
Nevertheless, these models provide a good qualitative feel for how the adjustments work, plus, you can break open the model and simulate s_{11} plotted on a Smith chart for any portion of the hardware. But it's a Catch-22 situation. The most important reason to have a model is to predict the OCS lengths. The OCS lengths are the only unknown quantities. Everything else is known. But you have to know the OCS lengths in advance in order to build an accurate model.

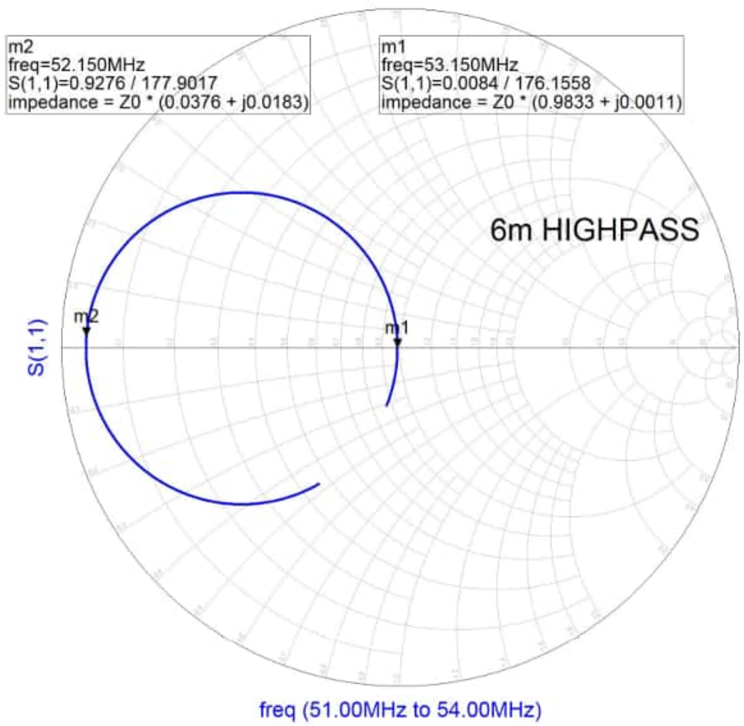
It's obvious that Sinclair had no choice but to use a line-stretcher and/or trial & error methods in choosing the OCS lengths—that and their considerable record keeping database from building a lot of duplexers. Fast forward 60 years and now, we can model the cavity and its internal structure *exactly* using ANSYS HFSS, but that is a mammoth task requiring considerable time and computer resources that I don't have. Instead, I found an old coaxial line-stretcher (trombone) which will come in handy for determining the proper open-circuit stub length for minimum insertion loss from the duplexer. I can adjust the trombone for best performance, measure s_{11} of the trombone on the VNA, and then compute and build an OCS to match it exactly. Easy!

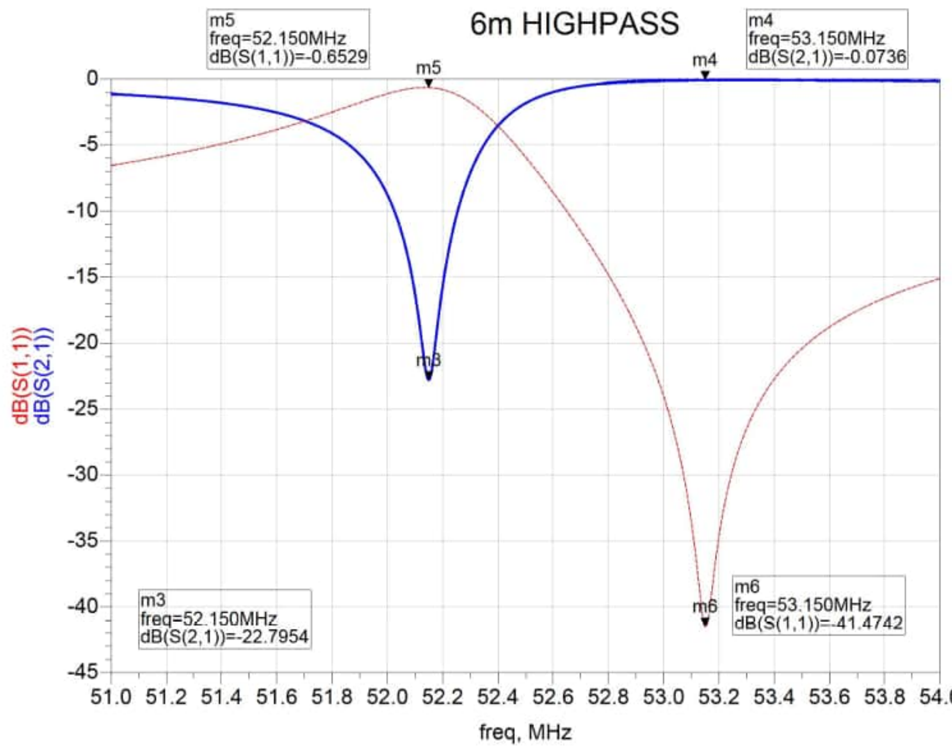
What *exactly* does the OCS do? Its job is to correct the open-circuit impedance produced by the cavity at the PASS frequency by cancelling out any residual reactive component of that impedance. This ideally results in a pure resistance of ∞ + j0 ohms at the PASS frequency. You don't *see* this high resistance because it gets paralleled with the 50 + j0 ohms from the system (50 ohms from the antenna, for example). This is perfect for the "unaffected" PASS frequency. You are using 50 ohm coax terminated in 50 ohms; so no matter what the length of the coax, whether it be a quarter-wavelength or *any* length, the impedance looking into the coax will always be 50 + j0 ohms at the PASS frequency—so long as you get rid of that stray reactance so that it doesn't get rotated around the Smith chart from cavity to cavity and cause a mismatch.

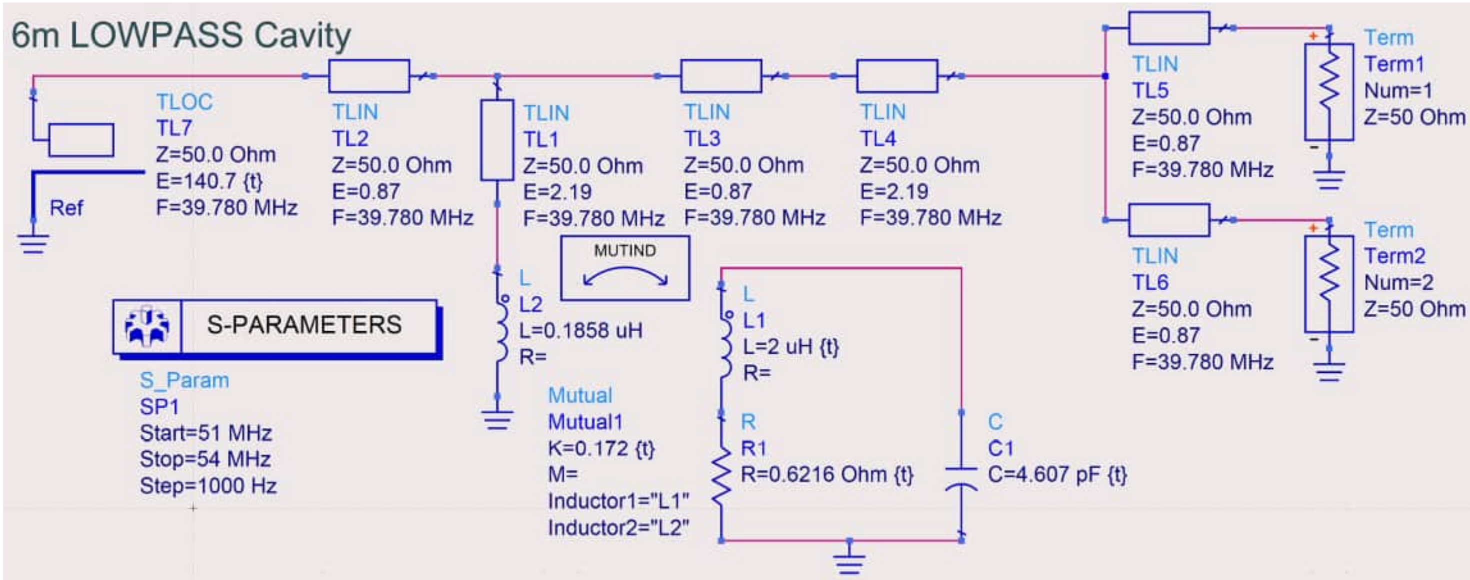
I did do one last thing to the simulation model and that's move it from the railroad frequencies (39.600 & 39.960 MHz which equals an average of 39.780 MHz) up to the 6-meter band with LOWPASS = 52.150 MHz and HIGHPASS = 53.150 MHz. The computer model and simulation results are shown next. The Out-of-Band (OOB) simulation plot is believed to be accurate from 1 to 200 MHz, but I'll definitely measure the actual duplexer once it is converted to 6-meters. Obviously, there is little to no OOB rejection for a Band-Reject Duplexer. Congested antenna sites will probably need to have bandpass filtering added to the Antenna Port. For all plots, the blue traces are the LOWPASS Port, the red traces are the HIGHPASS Port, and the green traces are the ANTENNA Port.

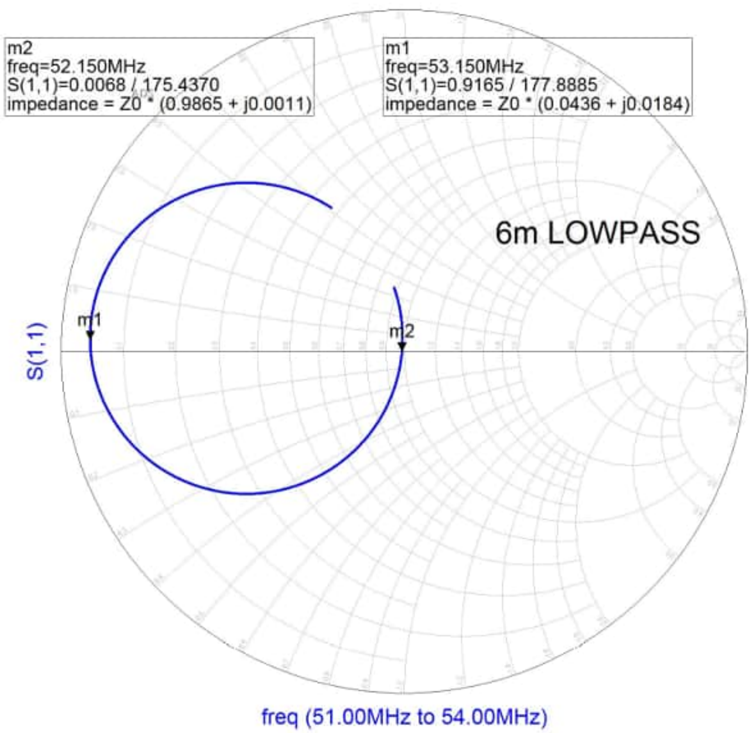
If you look closely at the T-connector models, you will see that they are still referenced to 39.780 MHz rather than to the new 6-meter frequencies. That's okay—specifying a frequency and the number of electrical degrees is the same thing as specifying a physical *length*. The simulation takes this into account when shifting to a new frequency.

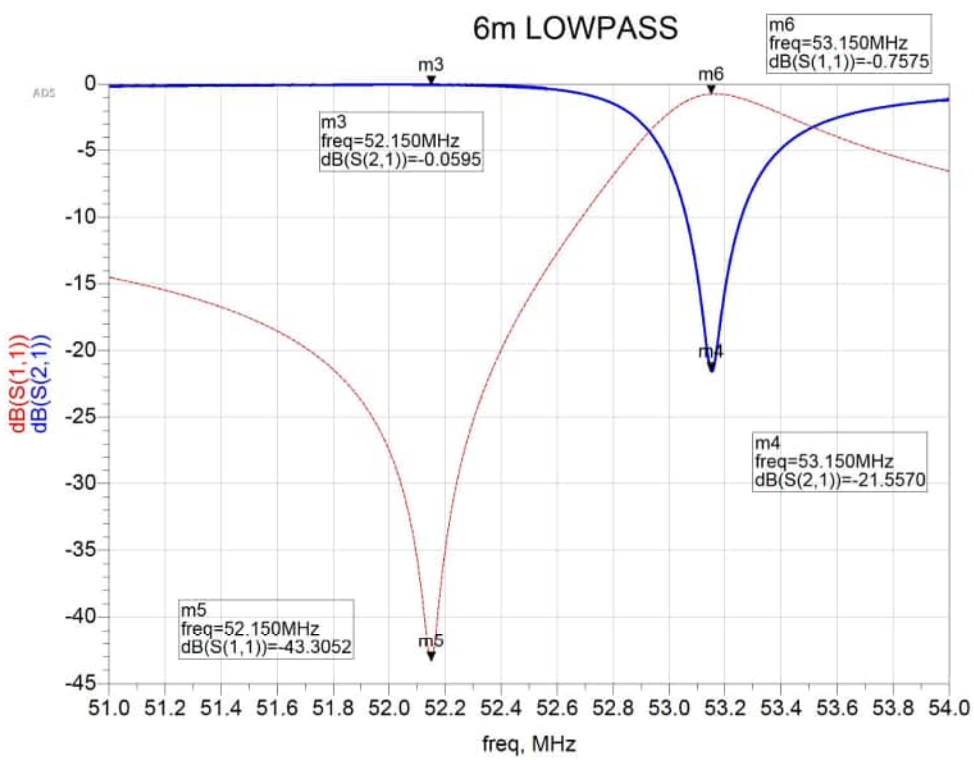

6m HIGHPASS Cavity
TLOC
TL7
Z=50.0 Ohm
E=38.2 {t}
F=39.780 MHz
Ref
TLIN
TL2
Z=50.0 Ohm
E=0.87
F=39.780 MHz
TLIN
TL1
Z=50.0 Ohm
E=2.19
F=39.780 MHz
TLIN
TL3
Z=50.0 Ohm
E=0.87
F=39.780 MHz
TLIN
TL4
Z=50.0 Ohm
E=2.19
F=39.780 MHz
TLIN
TL5
Z=50.0 Ohm
E=0.87
F=39.780 MHz
Term
Term1
Num=1
Z=50 Ohm
TLIN
TL6
Z=50.0 Ohm
E=0.87
F=39.780 MHz
Term
Term2
Num=2
Z=50 Ohm
S-PARAMETERS
S_Param
SP1
Start=51 MHz
Stop=54 MHz
Step=1000 Hz
MUTIND
L
L2
L=0.1858 uH
R=
Mutual
Mutual1
K=0.172 {t}
M=
Inductor1="L1"
Inductor2="L2"
L
L1
L=2 uH {t}
R=
R
R1
R=0.6216 Ohm {t}
C
C1
C=4.785 pF {t}


m2
freq=52.150MHz
S(1,1)=0.9276 / 177.9017
impedance = Z0 * (0.0376 + j0.0183)
m1
freq=53.150MHz
S(1,1)=0.0084 / 176.1558
impedance = Z0 * (0.9833 + j0.0011)
6m HIGHPASS
m2
m1
S(1,1)
freq (51.00MHz to 54.00MHz)

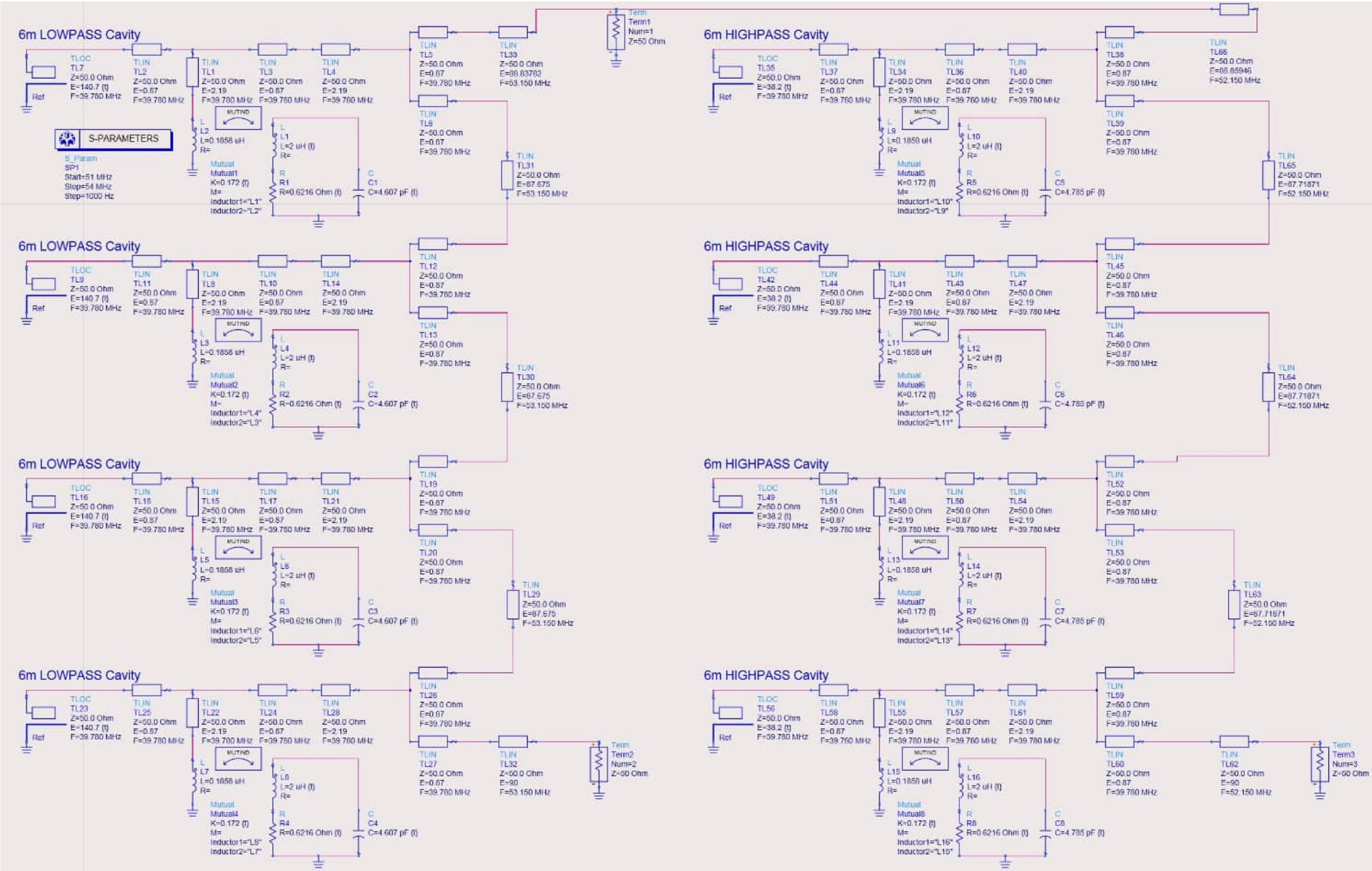

m5
freq=52.150MHz
dB(S(1,1))=-0.6529
6m HIGHPASS
m4
freq=53.150MHz
dB(S(2,1))=-0.0736
m5
m4
m3
m6
m3
freq=52.150MHz
dB(S(2,1))=-22.7954
m6
freq=53.150MHz
dB(S(1,1))=-41.4742
dB(S(1,1))
dB(S(2,1))
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
51.0 51.2 51.4 51.6 51.8 52.0 52.2 52.4 52.6 52.8 53.0 53.2 53.4 53.6 53.8 54.0
freq, MHz


6m LOWPASS Cavity
TLOC
TL7
Z=50.0 Ohm
E=140.7 {t}
F=39.780 MHz
Ref
TLIN
TL2
Z=50.0 Ohm
E=0.87
F=39.780 MHz
TLIN
TL1
Z=50.0 Ohm
E=2.19
F=39.780 MHz
TLIN
TL3
Z=50.0 Ohm
E=0.87
F=39.780 MHz
TLIN
TL4
Z=50.0 Ohm
E=2.19
F=39.780 MHz
TLIN
TL5
Z=50.0 Ohm
E=0.87
F=39.780 MHz
Term
Term1
Num=1
Z=50 Ohm
TLIN
TL6
Z=50.0 Ohm
E=0.87
F=39.780 MHz
Term
Term2
Num=2
Z=50 Ohm
MUTIND
S-PARAMETERS
S_Param
SP1
Start=51 MHz
Stop=54 MHz
Step=1000 Hz
L
L2
L=0.1858 uH
R=
Mutual
Mutual1
K=0.172 {t}
M=
Inductor1="L1"
Inductor2="L2"
L
L1
L=2 uH {t}
R=
R
R1
R=0.6216 Ohm {t}
C
C1
C=4.607 pF {t}


m2
freq=52.150MHz
S(1,1)=0.0068 / 175.4370
impedance = Z0 * (0.9865 + j0.0011)
m1
freq=53.150MHz
S(1,1)=0.9165 / 177.8885
impedance = Z0 * (0.0436 + j0.0184)
6m LOWPASS
m1
m2
S(1,1)
freq (51.00MHz to 54.00MHz)

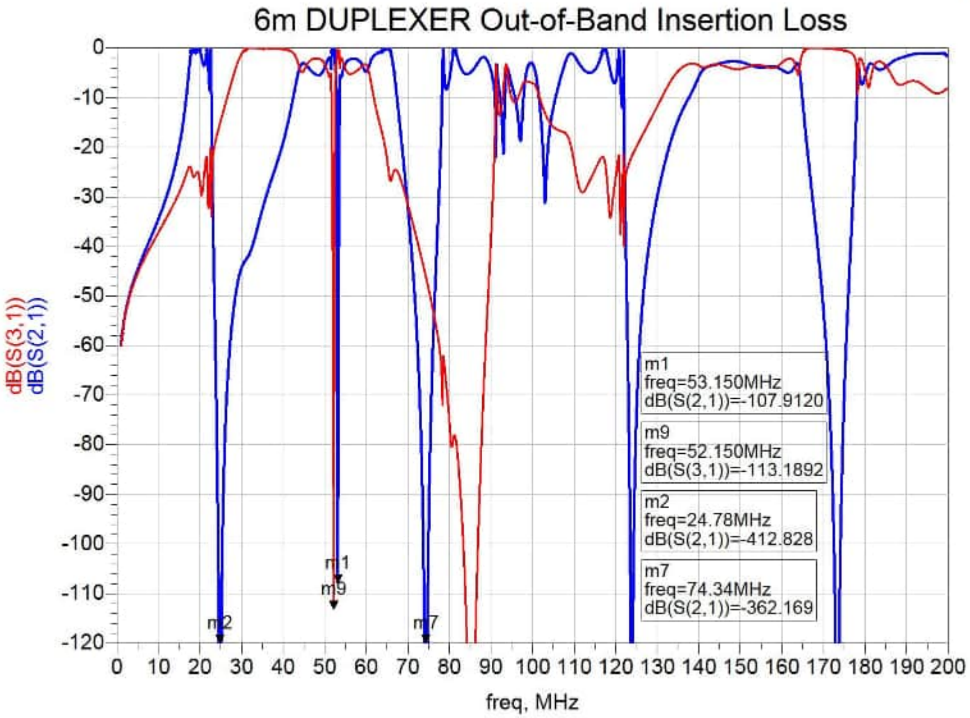

6m LOWPASS
m6
freq=53.150MHz
dB(S(1,1))=-0.7575
m3
freq=52.150MHz
dB(S(2,1))=-0.0595
m4
freq=53.150MHz
dB(S(2,1))=-21.5570
m5
freq=52.150MHz
dB(S(1,1))=-43.3052
dB(S(1,1))
dB(S(2,1))
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
51.0 51.2 51.4 51.6 51.8 52.0 52.2 52.4 52.6 52.8 53.0 53.2 53.4 53.6 53.8 54.0
freq, MHz

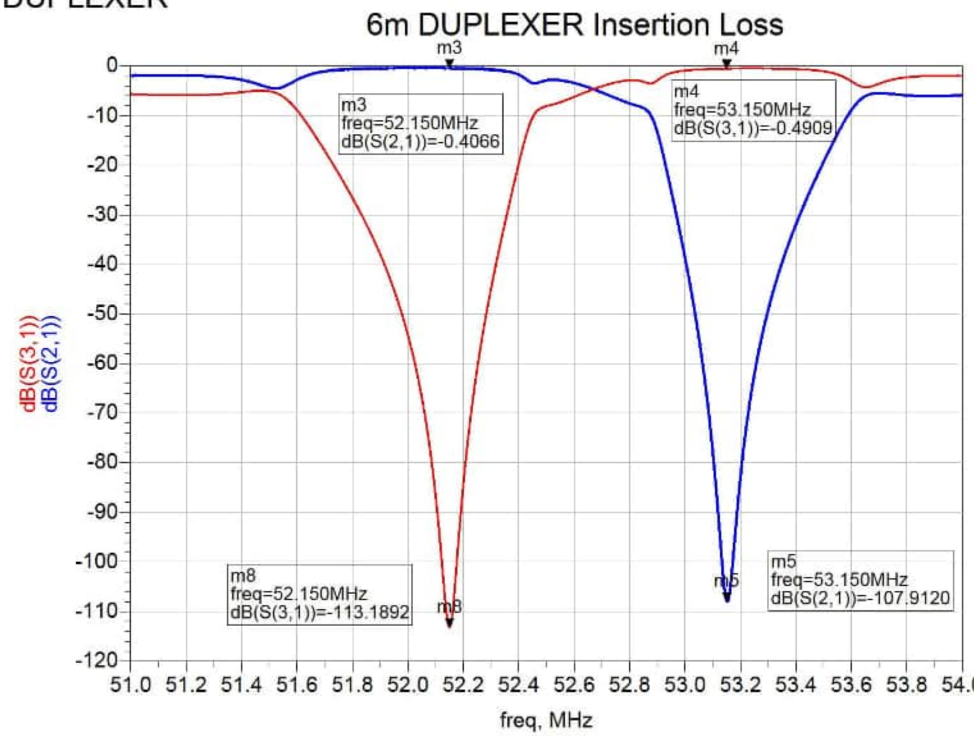
Entire Duplexer Simulation Model tuned for 6-meters

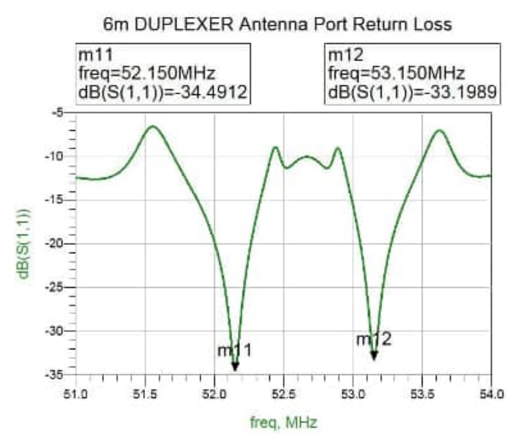


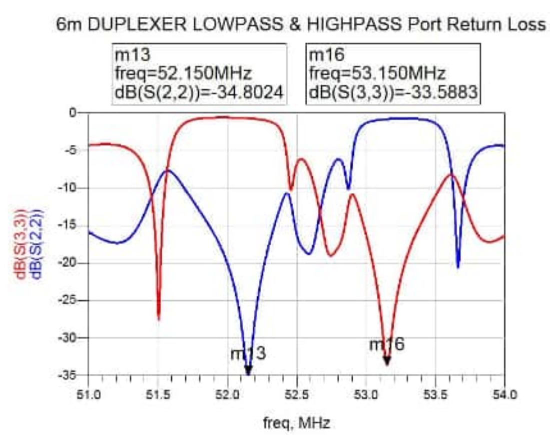
SIMULATIONS

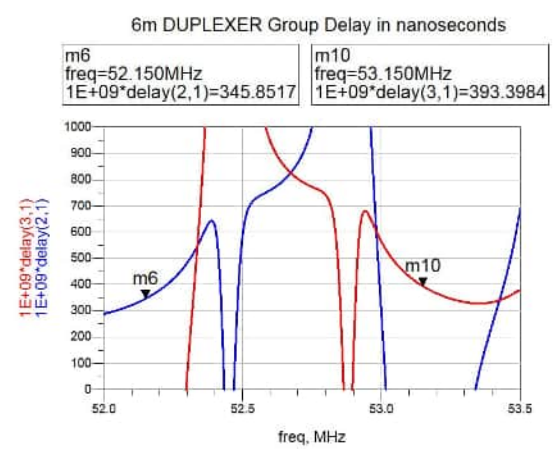
6m DUPLEXER







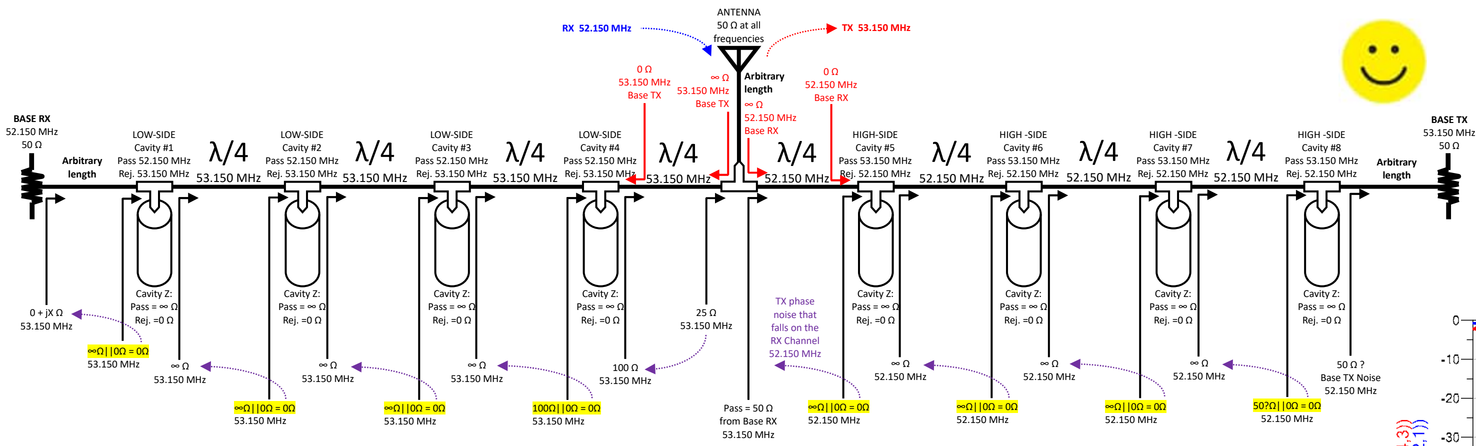


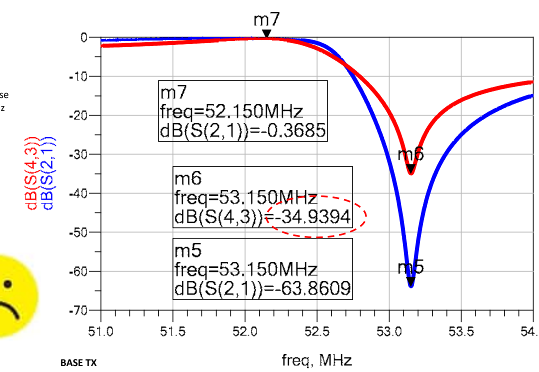


Blue is LOWPASS, Red is HIGHPASS, and Green is ANTENNA Port

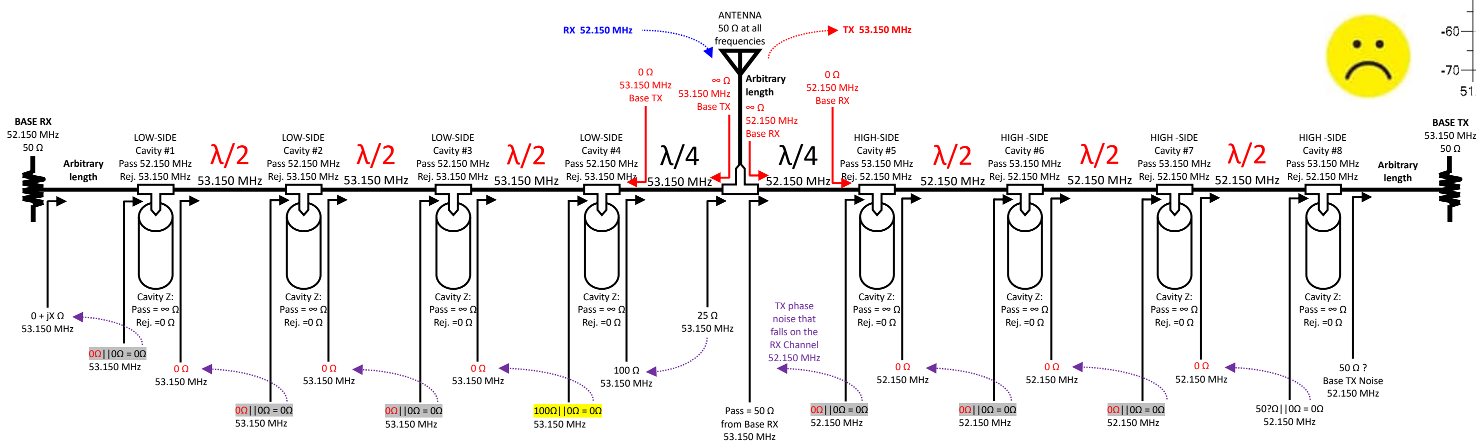
Coaxial cable interconnects between cavities:

There are some videos out there claiming that the interconnects should be a half-wavelength; this is ***wrong***. The interconnects must be a quarter-wavelength at the *reject* frequency, as stated in the W2GBO modification instructions. This is how it works:





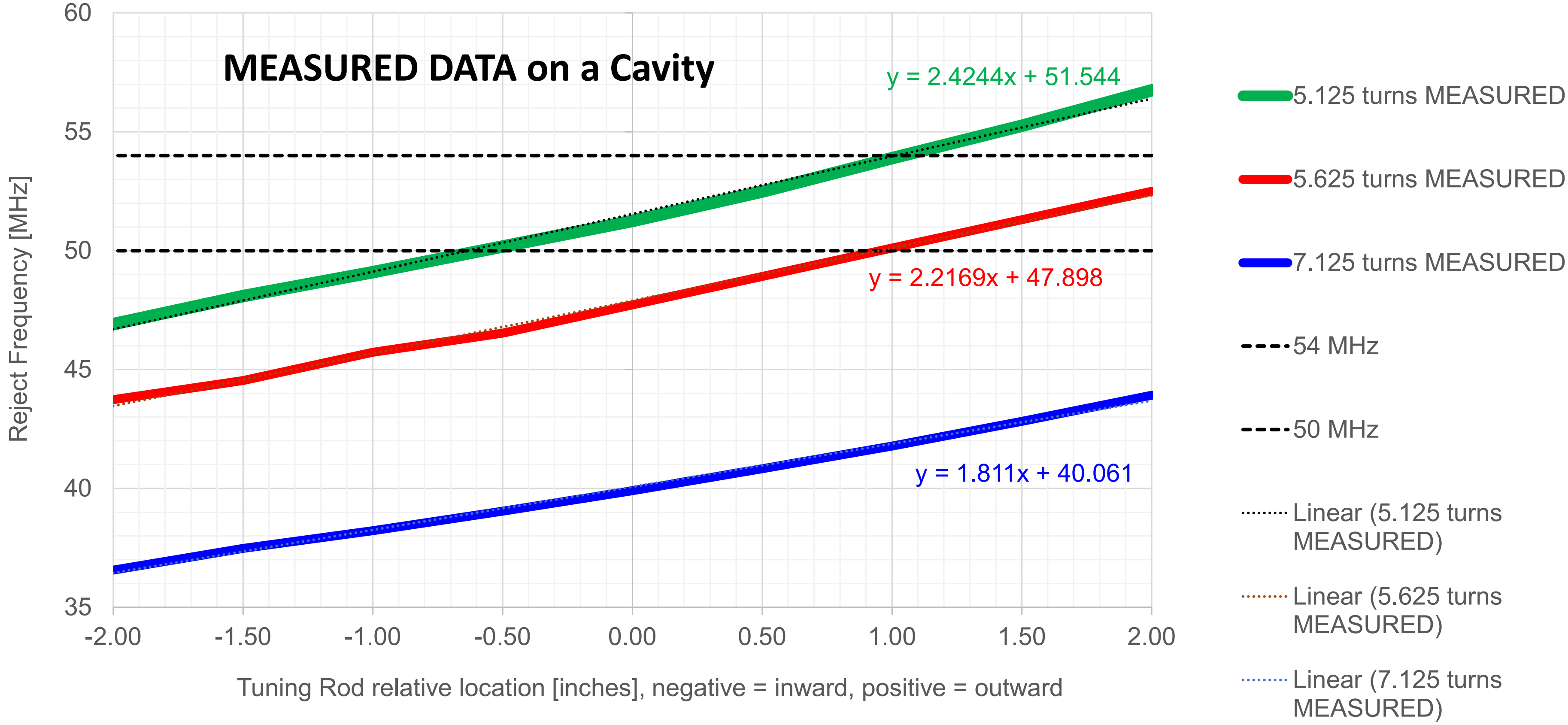
You can compare it to the half-wavelength matching case, which is *incorrect*:



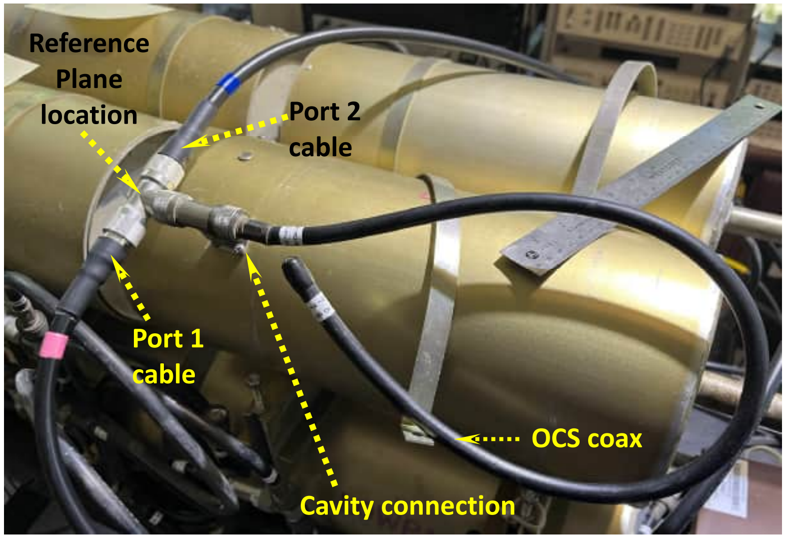
For the half-wavelength matching case, the next cavity in the sequence from right to left looks like a low impedance being parallelled with a low impedance (0Ω||0Ω = 0Ω) due to the lack of transformation by the half-wavelength interconnects. This does not work! In contrast, the quarter-wave interconnects transform a low impedance up to a high impedance before shunting the signal to ground (going right to left) using the low impedance of the next cavity filter (∞Ω||0Ω = 0Ω). This actually works, and provides far more rejection via *deliberate mismatch losses*. We must use quarter-wave interconnects for everything in the cascade as shown at the top of this page. Simulations predict 64 dB of rejection for a quarter-wavelength interconnect between two cavities, versus only 35 dB of rejection between the two cavities using a half-wavelength interconnect. Be very leery of some of the videos out there!

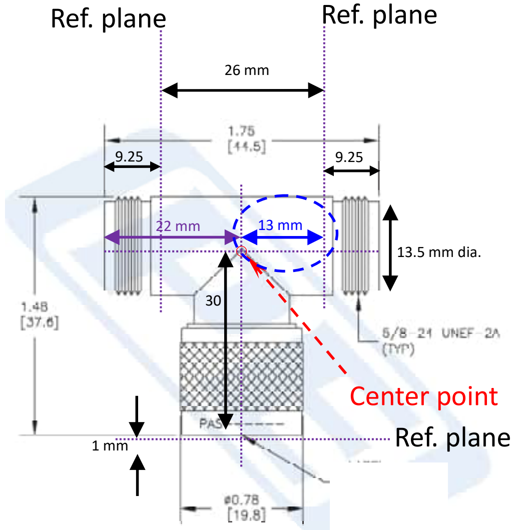
Tuning rod length adjustments:

A few measurements were made to one cavity (Lowpass #2) of the railroad duplexer to record the notch frequency versus tuning rod adjustment length. **Caution!** We do not know if a tuning rod can be pushed in or pulled out too far, such that the silver-plated fingerstock "jump the track", or fall out of position, or some other catastrophe—and we don't want to find out the hard way. I made an adjustment of ± 2.0 inches in increments of 0.5 inch to see how sensitive the notch frequency was to tuning rod adjustments. The Sinclair Model # R-102G duplexer is designed to cover the 37 to 43 MHz range. The tuning rod adjustment sensitivity is 1.8 MHz per inch, meaning that the notch frequency will move by 1.8 MHz when the tuning rod is moved by 1.0 inch. (Measurements were made from 36.6 to 43.9 MHz.) Pushing in the tuning rod increases the cylindrical capacitance inside the cavity and lowers the notch frequency. Pulling it out decreases the capacitance and raises the notch frequency. The helicoil was reduced from 7.125 turns to 5.625 turns and then to 5.125 turns. The unloaded Q was measured after each modification and found to be 1,317 then 1,337 and then 1,329. This is a negligible change in the unloaded Q. (See page 20 for how to measure the unloaded Q of a cavity.) The measured tuning rod results are shown below. The clear winner here is 5.125 turns (removal of 2.0 turns). The tuning sensitivity of an up-ranged 6m cavity is 2.4 MHz per inch, with a tuning range of ~ 46.9 to 56.7 MHz:



Measurement and Adjustment Procedure to obtain VNA Data using a 39 MHz LOWPASS Cavity as a Tuning Example:
Start by measuring one cavity by itself. With the velocity factor set to 0.66, calibrate the VNA over the frequency range of interest. Use at least 801 points, preferably *more*, to get fine resolution for the deep notch. Frequency accuracy is absolutely critical, so the VNA should be running on an external 10 MHz freq standard. After calibration, switch-ON Port Extensions and add 13 mm of positive length to Port 1 and to Port 2. This moves the reference plane location to the center of the T-connector. Connect the VNA for 2-port measurements of |s21|. Connect Port 1 and Port 2 to the cavity duplexer as shown in the photo:





The red-banded cable is Port 1 and the blue-banded cable is Port 2 of the VNA. The OCS is also attached (cable "78") in this photo. The port extension adjustment moves the reference plane to the center of the T-connector as illustrated above. Measure |s21| and adjust the tuning rod for exact resonance at the reject frequency, which is 39.960 MHz in this example:

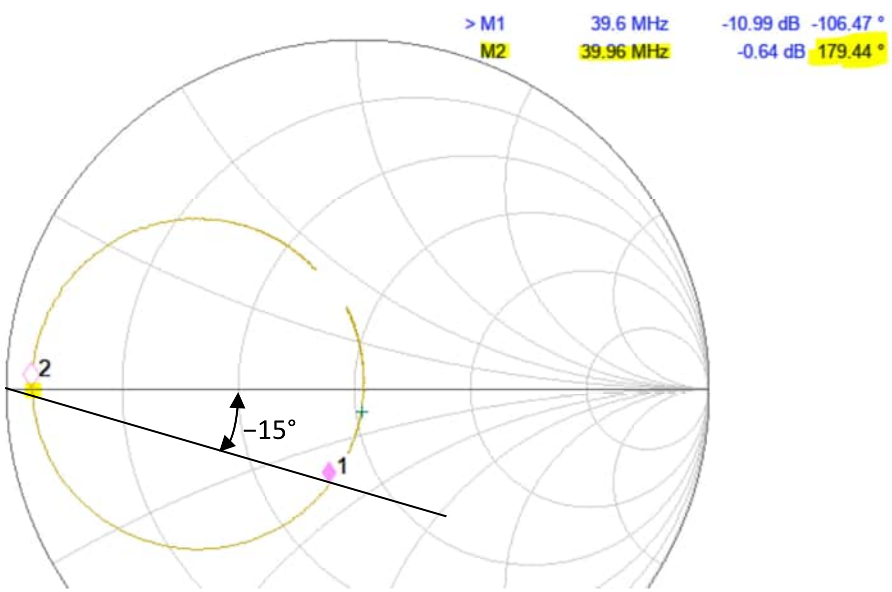
All of these rectangular plots consist of 801 points from 38.0 to 41.0 MHz, which is 300 kHz per horizontal division. Put two markers on the screen, one at the PASS frequency M1 and one at the notch (reject) frequency M2. Regardless of whether the cavity has been tuned, it will need to be *re-tweaked* to the exact notch frequency. This is because the termination impedances seen by the cavity will be slightly different when it is disconnected from the duplexer wiring harness and attached to the VNA cables.

Note that the insertion loss at the PASS frequency is 0.58 dB. This seems high and suggests that the OCS cable may be the wrong length as built by Sinclair! More on this in a moment…

Next, measure s11 on the VNA and display it as a Smith chart using Log / Phase units. (For the rest of these tests, do not change the VNA cabling connections from that shown on the previous page.) This is a VNA plot of 801 points from 38.0 to 41.0 MHz. The reference plane has been moved 13 mm to the center of the T-connector for both Ports 1 & 2 using Port Extensions. Here is measured data on what the OCS cable does to s11 for Lowpass Cavity #2:

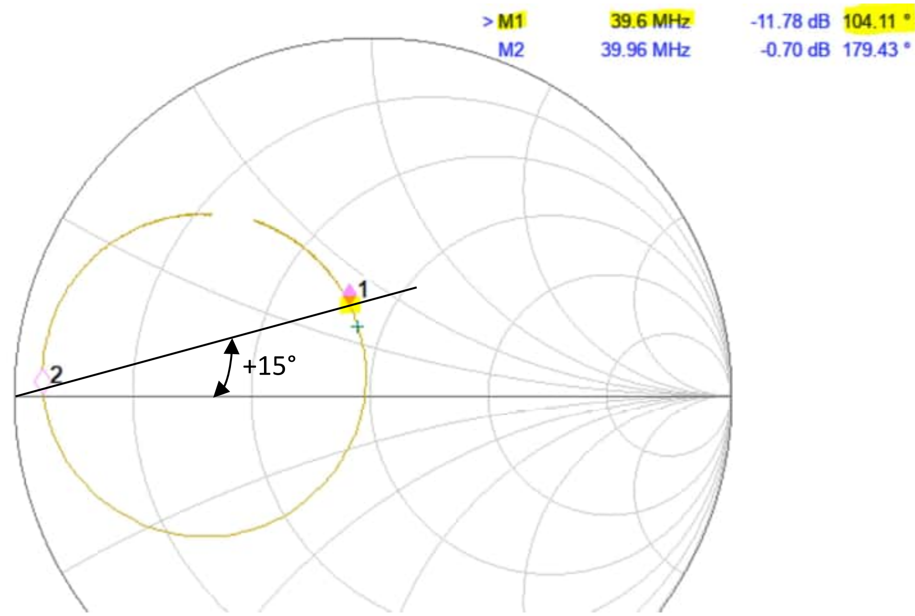
The 26.5” OCS cable is attached for these measurements:
The desired phase angle for the REJECT Freq (M2 at 39.960 MHz) is **180°**
The *measured* angle for the REJECT Freq (M2 at 39.960 MHz) is 179.4°
(Go by the *bottom tip* of the diamond, not by the middle of the diamond.)
This adjustment is controlled by the tuning rod and it’s within 0.6° of ideal. This is plenty good!

The desired plot angle for the PASS Freq (M1 at 39.600 MHz) is **the real line**
The *measured* plot angle for the PASS Freq (M1 at 39.600 MHz) is −15°
This is off by a considerable amount. I don’t know if this was caused by inaccurate tuning in the factory or if aging has somehow taken place.



The 26.5” OCS cable has been disconnected for these measurements:
Let’s disconnect the OCS cable and figure out what the heck is going on.
The desired phase angle for the REJECT Freq (M2 at 39.960 MHz) is **180°**
The *measured* angle for the REJECT Freq (M2 at 39.960 MHz) is 179.4°
(Go by the *bottom tip* of the diamond, not by the middle of the diamond.)
This adjustment is controlled by the tuning rod. Notice that it did not change even though we disconnected the OCS. Nice!

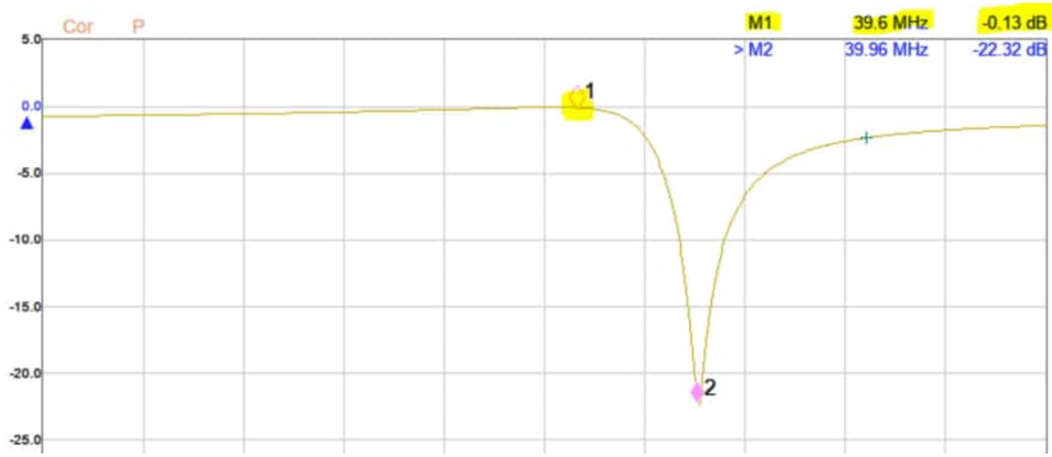
The desired plot angle for the PASS Freq (M1 at 39.600 MHz) is **the real line**
The *measured* plot angle for this configuration is +15°
We now have enough information to compute the proper length for the OCS.

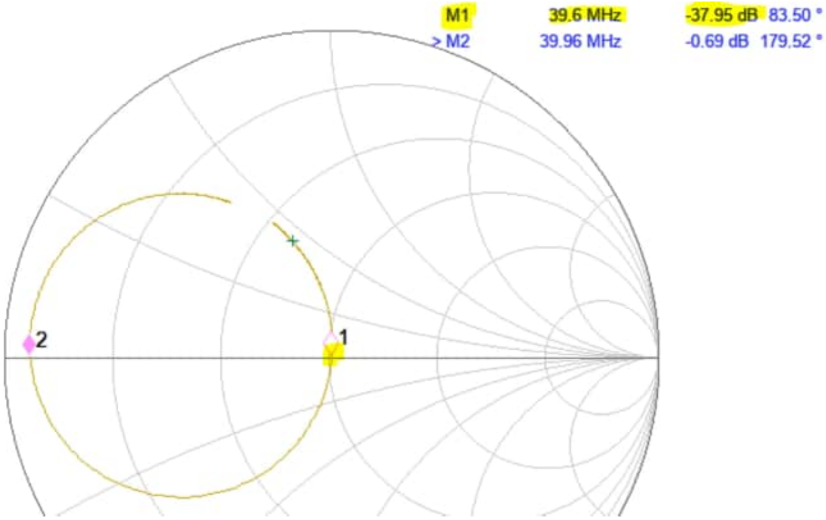


Adding a longer and longer open-circuited coaxial stub (OCS) causes a clockwise rotation from the inductive top-half of the Smith chart to the capacitive bottom-half of the Smith chart. (You can’t use the complex angle measurements of the markers for M1. Those angles are based off of the center of the Smith chart.) The 26.5 inches of open-circuited coaxial cable rotates the M1 frequency point by a total of {15° − −15°} = 30°. We want to rotate only 15° to stop on the real line of the Smith chart. This requires an OCS length of {26.5*(15/30)} = ~ 13.25 inches. The existing OCS cable is double the length that it ought to be!

To get a better feel for the situation, we can also plot |s21| **without the OCS cable attached** and see the effect. The PASS frequency at M1 now has less insertion loss, about 0.32 dB, and the shape of the response looks better than before:

Next, **we add a scrap Type-N coax that I had lying around, a ~ 13" OCS cable** to the cavity. We plot |s21| again and it looks even better. The measured insertion loss drops to 0.13 dB. Compare this to the |s21| plot at the bottom of page 16:





This is what you want to see when you have the cavity and its OCS properly tuned. For s11 we pretty much hit the center of the Smith chart for the PASS frequency at 50 + j0 ohms by adding the ~ 13" OCS. The return loss at the PASS frequency is an incredible 38 dB. (The degree number of 83.50° is a *radial* angle from the center of the Smith chart. That's why you can't really use the angle information from the Marker on the previous page.)

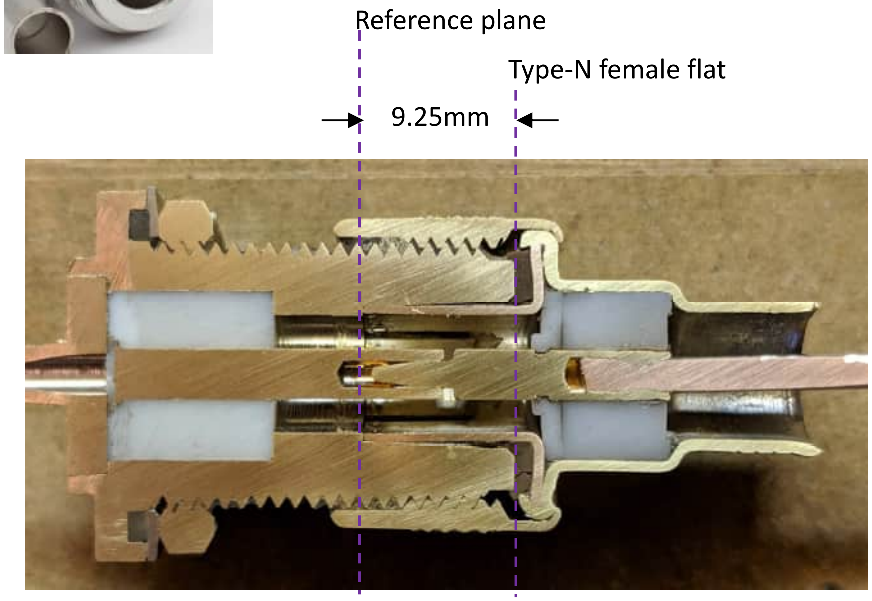
I'll have to go back and check my model to see if this OCS build discrepancy is the cause of my model not predicting the proper OCS length. The factory's choice of 26.5" seems to be incorrect, based on actual measurements. 13" looks great! But perhaps there was some other reason for choosing a longer OCS cable.

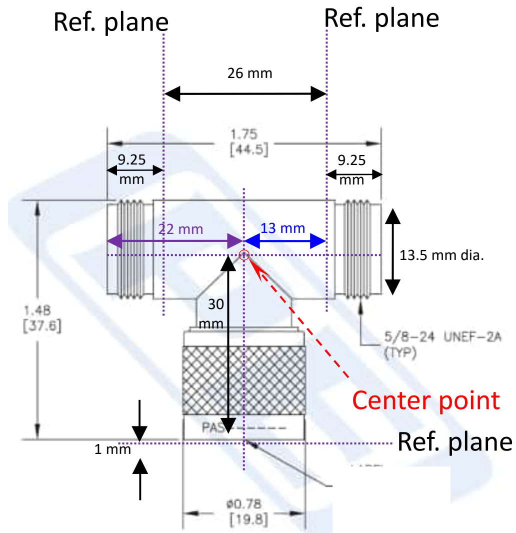
Reference Plane definitions for VNA measurements:

The key to an easy frequency conversion process is to make accurate reference-plane-shifted VNA measurements while tuning the cavities.

On a Type-N connector, the reference plane is at the edge of the inner ring on the male connector.

According to my calipers, the reference plane is recessed from the front flat portion of the female connector by 9.25 mm:





Electrical length = 13mm from center point (solid PTFE?) to Type-N (female) reference plane for cavity measurements.

Cleaning the copper helicoil:

Does the copper oxide need to be cleaned off of the helicoil per the W2GBO modification instructions? Our duplexer repair expert, K5SXK, says no, not unless it is *really* corroded. Normally, copper oxide is not a problem. Keep in mind that I measured an unloaded Q of 1,317 for the cavity shown in the photos on pages 4 and 5, and the duplexer has good performance as-is.

But… if you want to clean it, my chemistry expert, WD0HWV, advises to do this:

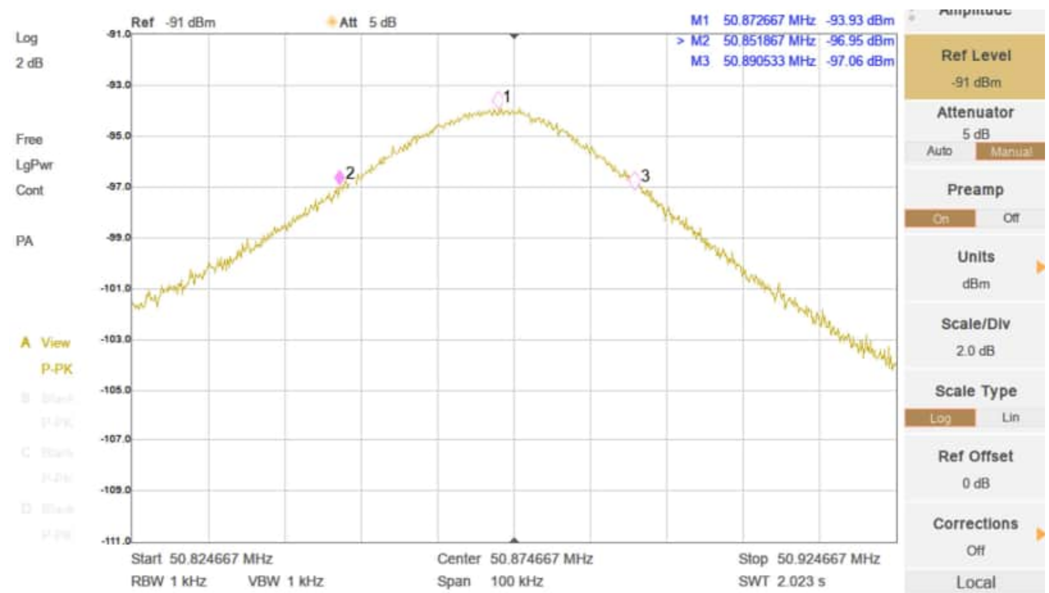
Instead of taking grit to the copper helicoil, take 1/4 cup of vinegar, and dissolve 1 teaspoon of salt into it. Take a cotton ball or clean cotton rag, dip it in this solution, and gently scrub the coil. You'll see the CuO_2 coming off. It will dissolve copper oxide and not interfere with the shape or surface texture of the coil. When done, wash with copious amounts of water, followed by distilled water to titrate out the minerals in the water. Dry with a hair-dryer, or if you use compressed air, make sure the air stream doesn't bend the coil, as it can be forceful.

If you *really* want to remove 100% of the water, go somewhere safe and douse it with gasoline. This will remove the water and evaporate quickly in the sun, leaving no residue. (This is dangerous, but very effective. Never do this around an idiot who might light up a cigarette.) You could also use isopropanol 91%, but be aware that it is hydroscopic and you can end up with more water than you started with. You just have to work quickly and use a fan to dry it fast. Do it in the sun on a dry day.

Measuring the unloaded Q with a tracking spectrum analyzer:

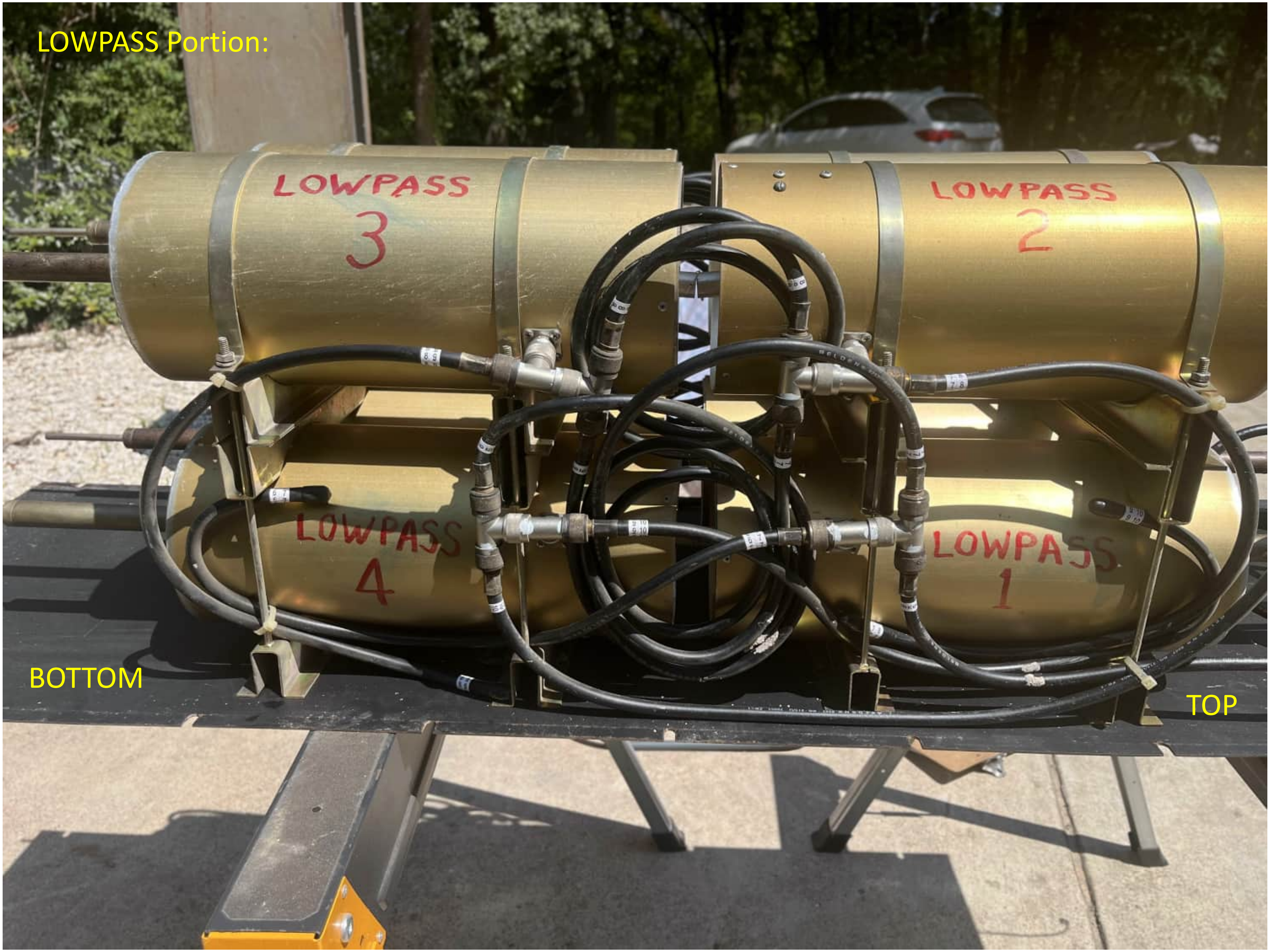
This can be tricky if you haven't done this before. Use a T-connector to connect both the tracking source cable and the RF input cable of the spectrum analyzer directly to the cavity. Disconnect *both* Type-N connectors from the T-connector so that the center pins do not touch! Only the GND shells of the Type-N connectors will make partial contact to the T-connector. The Type-N connectors are on the verge of falling off and no threads are engaged whatsoever. You are *very weakly* coupling into the cavity with both cables. This lack of center pin connection creates about a 0.1 pF capacitance in series with the 50 ohm source and the 50 ohm load from the tracking spectrum analyzer so that they do not load down the cavity and ruin the measurement. You should see the noise floor and nothing else.

Next, turn on the Spectrum Analyzer's preamplifier and lower its internal Attenuator setting so that you can seek out a very weak noisy signal peak in the noise level. It will be within a few MHz of the frequency to which the cavity is tuned to reject. Once you find it, center it, reduce the span, and change the vertical scale to 1 dB per division. You will see a response similar to that shown on the right.



Measure the frequency of the peak and divide it by the 3dB bandwidth, which is found by looking 3 dB down from the peak on either side and taking the difference frequency to get the 3 dB bandwidth. In this example, *by definition,* the unloaded Q is {50.872667 / (50.890533 – 50.851867)} = **1,316**.

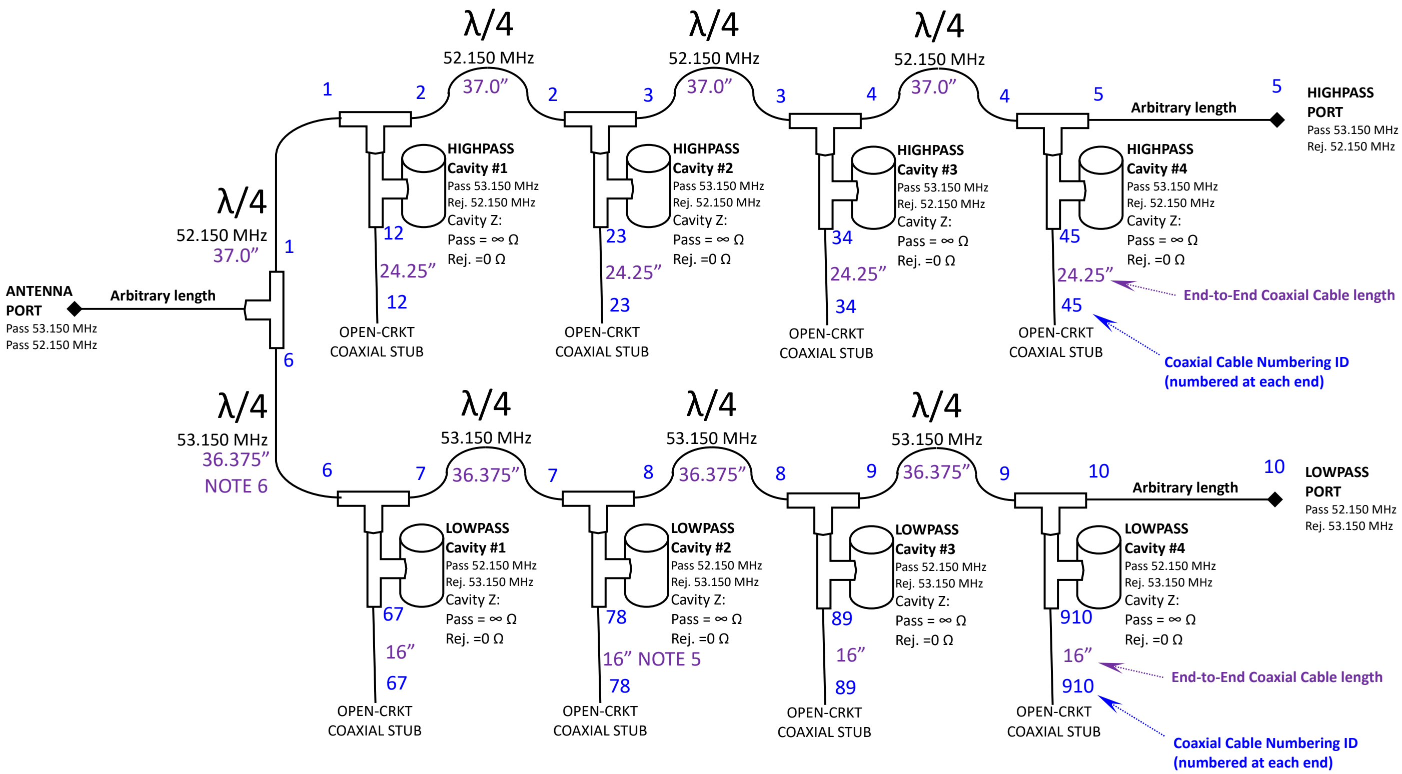

HIGHPASS Portion:
TOP
BOTTOM
HIGHPASS 3
HIGHPASS 1
HIGHPASS 4

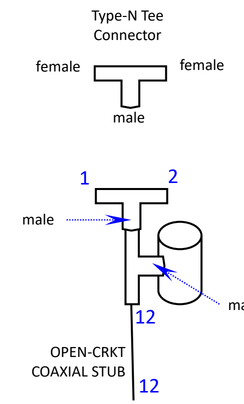

LOWPASS Portion:
LOWPASS
3
LOWPASS
2
LOWPASS
4
LOWPASS
1
BOTTOM
TOP

Part 2 of 2 - Sinclair R-102G Lowband VHF Band-Reject Duplexer Documentation

W. H. (Bill) Cantrell, Ph.D.   WD5CVG   10/17/2024

This document is getting too large, so I had to divide it into two parts. Part 1 covers theory and simulations. Part 2 covers physical hardware modifications and the **measured** performance of the fully modified 6m duplexer with detailed coax lengths for LOWPASS = 52.150 MHz and HIGHPASS = 53.150 MHz:





The length-modified cables have the (same) numbering scheme shown above, and a green band of tape is added to each end. This indicates that they have been shortened and tested for accuracy using a VNA.

The bench-measured performance is excellent: < 0.9 dB insertion loss, 104 dB typical rejection and > 27 dB return loss. (For both branches, the rejection will vary from 100 to 110 dB over time, mostly staying around 104 dB. The insertion loss stays mostly around 0.85 dB.) See page 14 for a measured data summary for the entire 6-meter Duplexer. High-resolution photos of the original duplexer with coaxial cable numbering scheme are shown on the last two pages **of Part 1**.

Keeping track of coaxial cable modifications:

Cable Number	Function Quarter-wave (QW) or Open-Circuit Stub (OCS)	Old Railroad Length [inches]	HP or LP	Coax New Length [inches]	Coax Design Frequency [MHz]	Coax Measured Round-trip Phase Error [degrees]	Coax Actual Measured Error (divide by 2) [degrees]	Coax Measured Insertion Loss [dB] NOTE 3	Coax Measured Return Loss [dB] with 50 ohm termination	Cavity Measured Unloaded Q NOTE 2	Repeater Path TX or RX	Cavity PASS Frequency Measured Insertion Loss [dB]	Cavity REJECT Frequency Measured Rejection [dB]	Modification Date	Cable Number
0 - Antenna Port	Arbitrary	-	**ANTENNA**	eliminated	-	-	-		-	-	BOTH	-	-	9/30/2024	**0 - Antenna Port**
1	QW	48.0	HIGHPASS	37.0	52.150	0.3	0.15	0.06	52	-	TX	-	-	9/30/2024	1
2	QW	48.0	HIGHPASS	37.0	52.150	0.7	0.35	0.15	40	-	TX	-	-	9/25/2024	2
3	QW	48.0	HIGHPASS	37.0	52.150	1.1	0.55	0.06	44	-	TX	-	-	9/30/2024	3
4	QW	48.0	HIGHPASS	37.0	52.150	0.3	0.15	0.05	52	-	TX	-	-	9/30/2024	4
5 - Highpass	Arbitrary	48.0	**HIGHPASS**	48.0	-	-	-	0.10	42	-	TX	-	-	9/30/2024	**5 - Highpass**
12	OCS	37.75	HIGHPASS #1	24.25" NOTE 1	53.150	-	-	-	-	1229	TX	0.12	18.2	9/30/2024	12
23	OCS	37.75	HIGHPASS #2	24.25" NOTE 1	53.150	-	-	-	-	1267	TX	0.12	20.0	9/30/2024	23
34	OCS	37.75	HIGHPASS #3	24.25" NOTE 1	53.150	-	-	-	-	1218	TX	0.12	18.8	9/30/2024	34
45	OCS	37.75	HIGHPASS #4	24.25" NOTE 1	53.150	-	-	-	-	1150	TX	0.12	19.0	9/30/2024	45
6	QW	48.0	LOWPASS	**NOTE 6**	53.150	1.4	0.70	0.05	50	-	RX	-	-	9/30/2024	6
7	QW	48.0	LOWPASS	36.375	53.150	0.1	0.05	0.06	47	-	RX	-	-	9/30/2024	7
8	QW	48.0	LOWPASS	36.375	53.150	0.7	0.35	0.15	38	-	RX	-	-	9/25/2024	8
9	QW	48.0	LOWPASS	36.375	53.150	1.1	0.55	0.05	50	-	RX	-	-	9/30/2024	9
10 - Lowpass	Arbitrary	48.0	**LOWPASS**	48.0	-	-	-	0.10	40	-	RX	-	-	9/30/2024	**10 - Lowpass**
67	OCS	26.5	LOWPASS #1	16" NOTE 4	52.150	-	-	-	-	1177	RX	0.08	19.8	9/30/2024	67
78	OCS	26.5	LOWPASS #2	14.75" **NOTE 5**	52.150	-	-	-	-	1261	RX	0.09	21.3	9/30/2024	78
89	OCS	26.5	LOWPASS #3	16" NOTE 4	52.150	-	-	-	-	1270	RX	0.09	21.3	9/30/2024	89
910	OCS	26.5	LOWPASS #4	16" NOTE 4	52.150	-	-	-	-	1250	RX	0.08	20.5	9/30/2024	910

NOTE 1 - OCS cable is 24.25" from tip of Type-N connector to tip-end of coax center conductor (excludes insulating cover). Braided shield is pulled back 1/8th of an inch from cut end to prevent RF arcing at high power.
(For a comparison, the OCS length in the W2GBO modification instructions was 22.2 inches.)

NOTE 2 - Tracking Spectrum Analyzer measurement made using a modified T-connector with the receptacle pins broken off of both female sockets to simulate 0.1 pF coupling both ports. See Part 1 page 20 for measurement details.

NOTE 3 - Insertion loss of cables is difficult to measure accurately due to small reflections. Insertion Loss is probably more like 0.10 dB per cable.

NOTE 4 - OCS cable is 16.0" from tip of Type-N connector to tip-end of coax center conductor (excludes insulating cover). Braided shield is pulled back 1/8th of an inch from cut end to prevent RF arcing at high power.
(For a comparison, the OCS length in the W2GBO modification instructions was 16.9 inches.)

NOTE 5 - OCS Cable #78 was length-tweaked for better return loss for the ANTENNA Port.

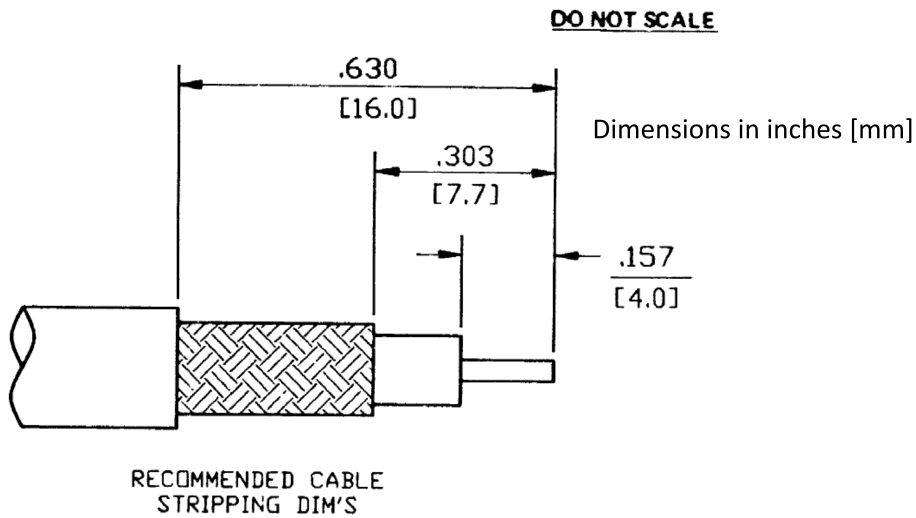
NOTE 6 - Cable #6 was length-tweaked for better return loss for the ANTENNA Port. It consists of a normal 36.375" coax *plus* two Type-N right-angle connectors added in cascade to lengthen it. See photo on page 16.

The lengths shown in this table are measured from Type-N connector tip to Type-N connector tip. The old existing cables can be cut to length and reused because all of the cable lengths are shorter for 6-meter operation when compared to the old 39 MHz railroad lengths. This involves cutting the cable to the new proper length and adding one Type-N connector to the end of the quarter-wave coaxial cables. (Discard the least attractive end of the cable and keep the rest for modification.)

Attaching RF Connectors:

You can use Amphenol # 082-4426-11RFX crimp-on male Type-N RF connectors for RG-213/U coax. They are $9 each from Mouser Electronics. You should also use an RF connector crimping tool, Amphenol # 47-10230, same as the old Model # CTL-3. I bought one for $125 from Mouser. It should come with the proper die punch for the # 082-4426-11RFX crimp-on male Type-N RF connectors. (If not, the die punch part number is 47-20029.) Note that you do *not* have to do any soldering! This crimper crimps the center conductor pin as well as the outer shield—and it does an excellent job. Per the table, I measured better than 38 dB return loss at 6 meters for these connectors.

Pay close attention to *how* to get the exact coax length that you want: Cut 0.5" of coax off of each end that has to have a crimp-on connector installed. For example, in order to obtain a 37.0 inch cable measured tip-to-tip when a Type-N connector is already installed on one end, cut the cable to 36.5" and strip it to the exact specifications shown below. After the crimp-on Type-N connector is added, the total length will be 37.0" tip-to-tip. (Each Type-N connector adds 0.5 inch to the overall length of the coaxial cable.)

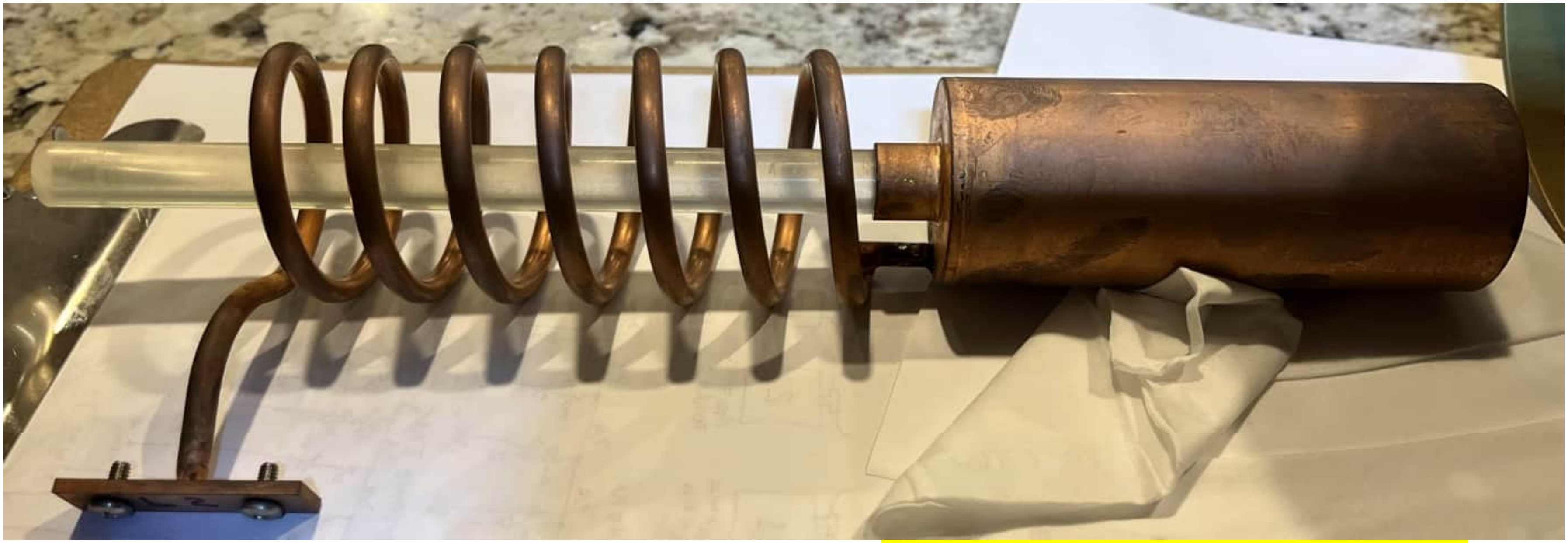


You can also purchase a coax stripper to get the cuts correct for crimping-on the RF connectors. I purchased a "HT-322S3 Coaxial Cable Stripper RG-8/11/213 (3 Blade Model)" for $16 on eBay. It did not work well at all. After quite a bit of experimentation on a scrap piece of RG-213/U coax, I was able to use it to cut the outer jacket cleanly. But I used other tools to do the rest of the cable prep work.

As you go along, inspect *all* of your Type-N T-connectors. Take all of them apart and look at them carefully. If you discover any with damaged center pins or bad threads, replace them with Amphenol UG-107B/U RF Coaxial Tee Connector Adapters N(f) N(m) N(f), or with Amphenol Part # 172125, which is $27 each. Both part numbers are equivalent to each other. These are available from Mouser and they can be found on eBay. Beware of the cheap Chinese knock-offs. They are not the same electrical length or quality.

A simple streamlined helicoil modification process:

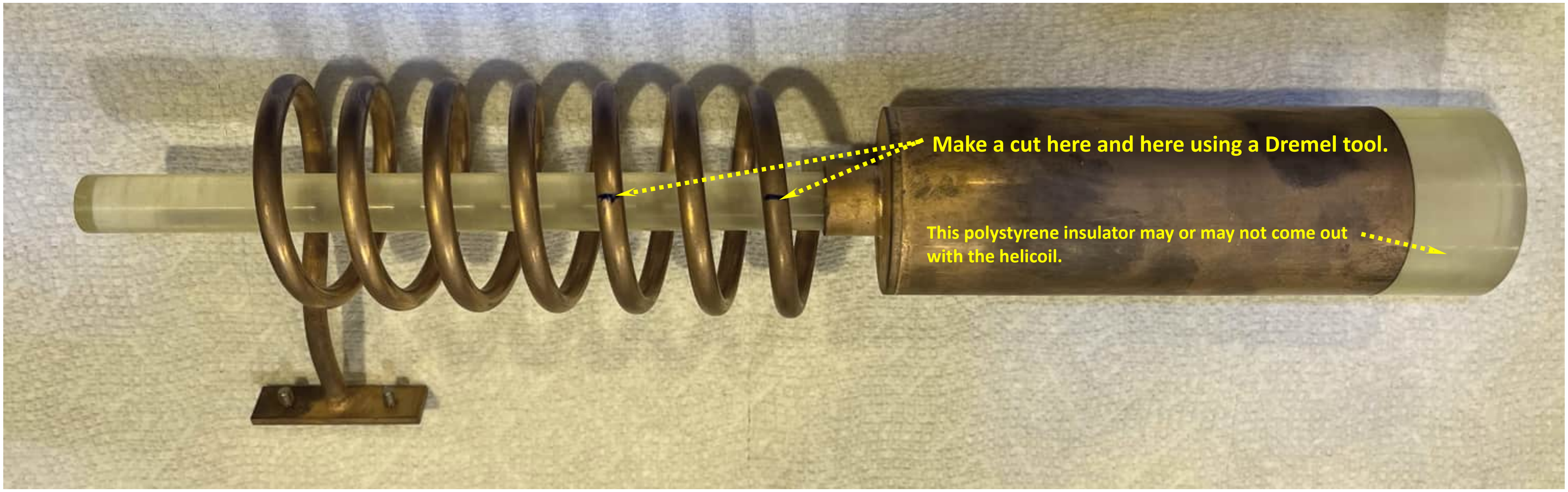
First, a word of caution: We have no reason to believe that beryllium was used in this product from Sinclair. The Sinclair drawings for the copper coils do not indicate any use of beryllium; *however,* we do not know this with absolute certainty. Inhalation of a slight amount of beryllium dust can be lethal. You should wear a suitable mask, eye protection and gloves when cutting, grinding or soldering on this copper helicoil material.



Overview - Photo of 7-1/8 turn helicoil, which must be shortened to 5-1/8th turns **and then stretched to occupy the same overall length!** The cylinder on the right is the outer cylindrical plate of the tuning capacitor. The moveable metal tuning rod (not shown) at GND potential forms the other plate of the capacitor and occupies the interior of the sleeve. The polystyrene rod provides mechanical support and ensures proper alignment inside the cavity. The hollow copper tubing has a 0.25” outer diameter. The helicoil itself has an inner diameter of 2.0”. It is brazed to the outer cylindrical plate of the tuning capacitor. The W2GBO modification instructions recommend making two cuts to remove a portion of the turns in the middle to get everything down to 5-1/8th turns. This is not a trivial mechanical modification.

Here is the simplest procedure to remove 2.000 turns from the 7.125 turn helicoil to get 5.125 turns. ***Read these instructions thoroughly before you begin!***

1) Start by marking the cavity number on the round aluminum bottom cover plate. Also mark the *orientation* of the bottom plate with respect to the cavity cylinder. This is not mandatory, but Sinclair didn’t always get the 120-degree spacing exactly correct between rivets, so this will speed reassembly.
2) Remove the bottom plate by drilling out the three rivets. The bottom plate is spring-loaded and will come off quite easily. Be ready for it to pop out!
3) Remove the two Phillips screws that connect the end of the helicoil to cavity GND. Carefully and slowly wiggle the polystyrene rod back and forth slightly until it comes loose. Carefully remove the helicoil assembly from the cavity, being careful to NOT bump the coupling loop. Screw the two screws back into the helicoil so that they don’t get lost. Mark the bottom of the two-screw plate with the cavity number, in this example, L2 for LOWPASS #2.
4) Mark off exactly two turns to be removed as shown in the photo on the next page.

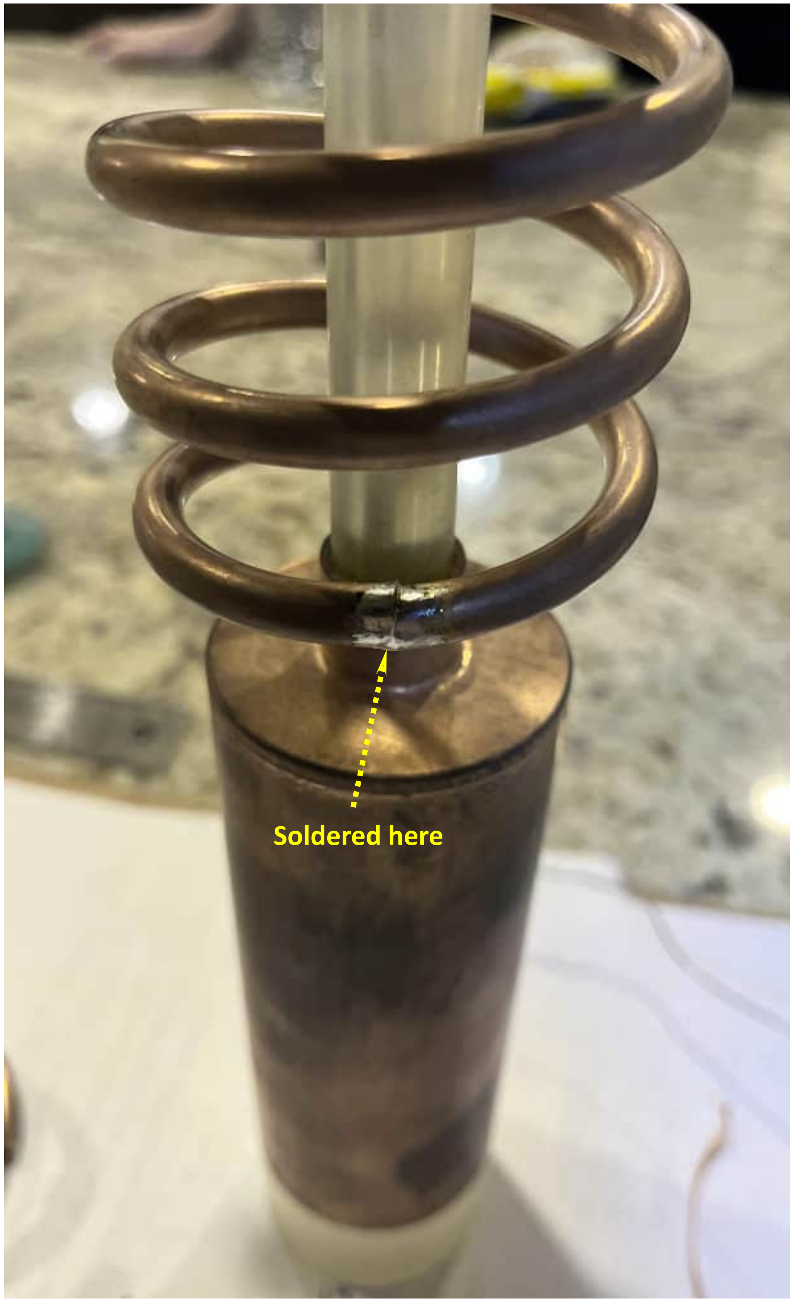


5) Make the two cuts as clean and orthogonal as you can. You can discard the 2 turn segment or turn it into a wind-chime:

Be sure to gently tap-out any accumulated copper dust from inside the tubing. Use a polishing tip on the dremel tool to clean up the cut ends so that they are smooth and clean of oxidation.

6) Next, wind a ~ 2 ft length of #6 AWG round copper wire around a 2.0 inch O.D. wooden dowell or equivalent. Note that this is #6 AWG, *not* #8 AWG, counter to the information in the W2GBO modification instructions. #8 AWG is way too small and even #6 AWG fits too loosely.
7) Cut out a 1.5 inch segment of this wire. It now has the proper bend radius to slide inside the hollow copper tubing to help hold it together long enough to be soldered.
8) All soldering uses standard Sn-Pb electrical solder. Silver solder is NOT required! A torch is NOT required!! All soldering can be accomplished with a 260 Watt Weller soldering gun or preferably, a 40 to 100W large chisel soldering iron.
9) **Change of procedure! Pre-stretch the helicoil *now*, per Step #12, then come back to Step #10.**
10) Next, stand the helicoil up on end and temporarily affix the upper helicoil section to the poystryrene rod so that it is properly centered and so you don't have to hold it in place. (You will need both hands for soldering.) Make sure it is properly aligned axially before soldering:

11) Here is a reasonable looking solder connection using regular solder. The copper does *not* need to be cleaned except around the solder joint:



SOLDERING NOTE: I did not do this particular step, but I *would* if I had it to do over again. I will explain: It is not clear exactly how much solder is wicking into the interior of the copper tubing and adhering to the #6 AWG solid round copper wire segment. You want solder to flow inside for greater strength. The goal is to not have any forces pulling on the copper helicoil; but sometimes, it can't be helped. I had one Cavity that was put together by someone having a bad day at Sinclair. It started with an out-of-round aluminum bottom cover and went downhill from there. To make a long story short, there will be pulling forces on that particular helicoil.

I suggest drilling a single small hole a few millimeters next to the outer perimeter of each cut end of the tubing. This will allow you to feed solder into the little hole so that there is plenty of solder going inside to hold the two segments together. (Recall that RF currents flow on the outer surfaces of the helicoil. There is no RF current in the interior. This is being done *purely* for mechanical rigidity.)

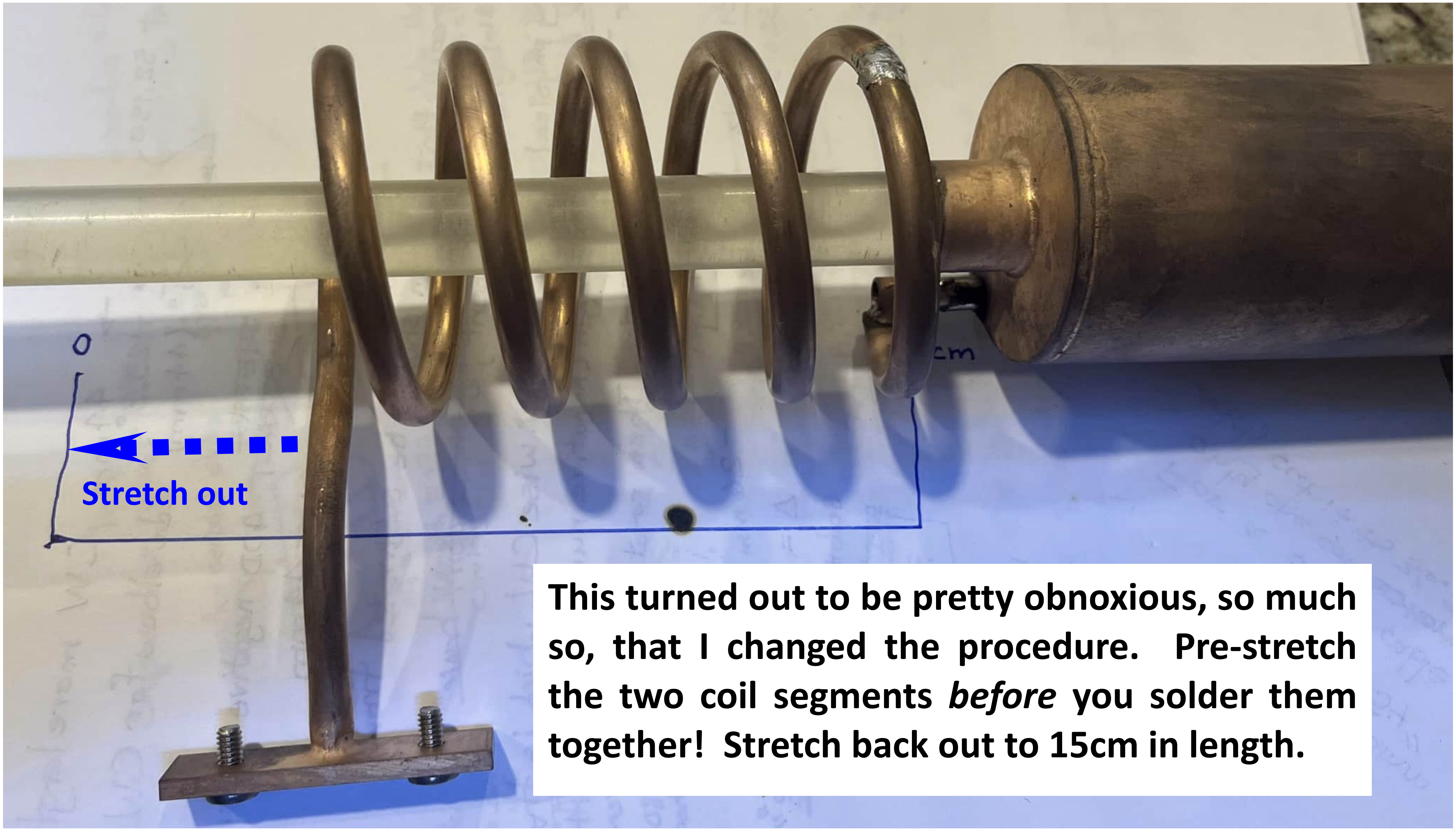
Note also that if a solder connection should fail, the helicoil would not likely come apart, but it would probably de-tune itself. If the failure occurs in the HIGHPASS (transmitter) path, the result would be more phase noise into the receiver and poor sensitivity. Even worse, if enough failures occur in the LOWPASS (receiver) path, the receiver could be burned-out by the transmitter.

Fortunately, this product is not subjected to motion or vibration. It is intended for stationary applications only. I also plan to keep it indoors, so it should not be subjected to large temperature swings that might cause a sketchy solder joint to fail.

Another consideration is power dissipation. If operated at a near continuous-duty of 330 Watts (the maximum rating is 350 Watts), the duplexer will dissipate 74 Watts assuming 1.1 dB insertion loss for the HIGHPASS (transmitter) path. Coax losses account for about 40% of this, so the remaining 44 Watts will be divided between the four HIGHPASS cavities as shown in the table below. That's just 10 to 12 Watts per cavity, which is negligible. As simulated in Part 1, the voltage swing in the cavity tank circuit will be as high as 8,000 volts peak, so the design is voltage arc-limited and not power dissipation-limited.

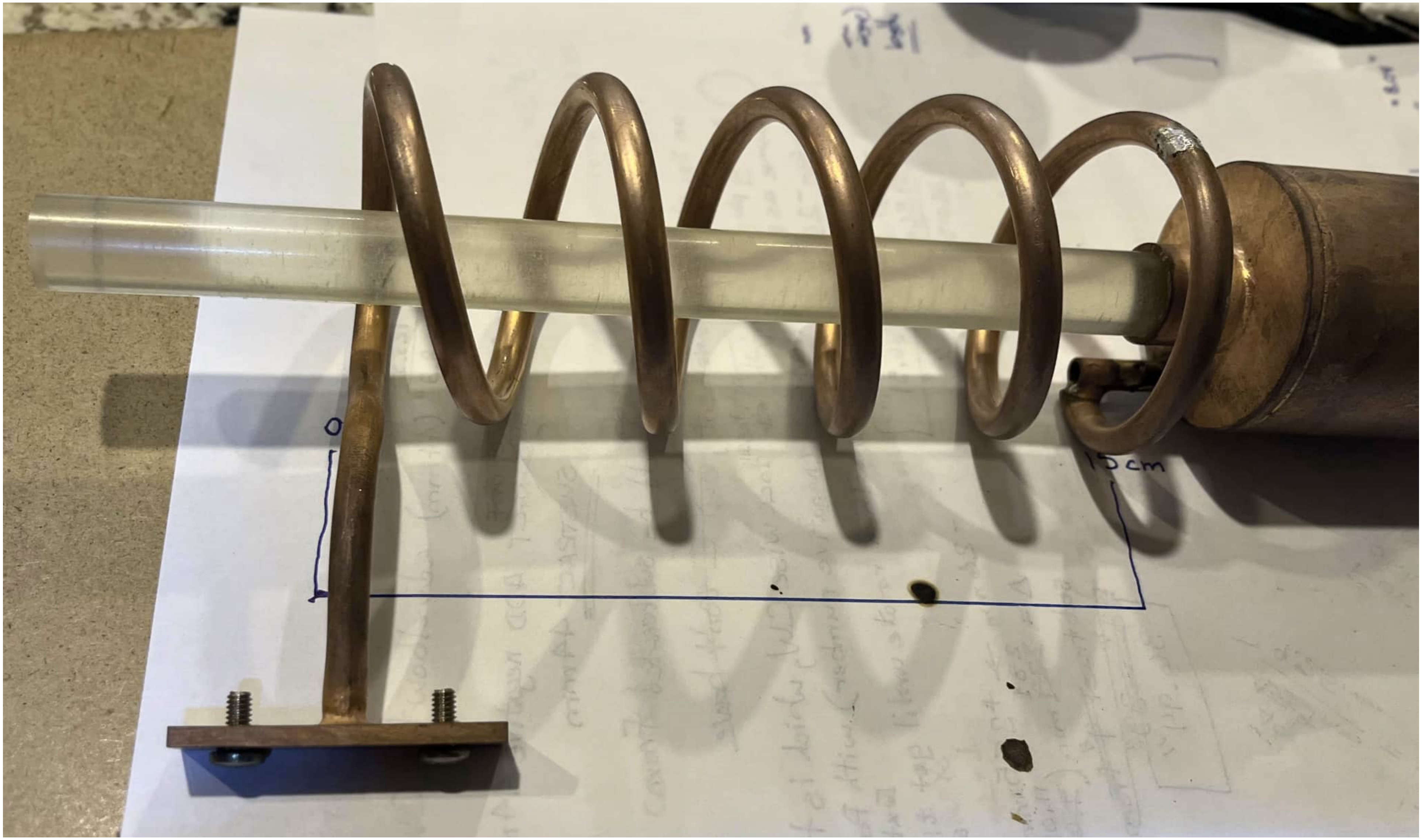
Duplexer Heat Dissipation		**Pin [W]**	**Pout [W]**	**Item Disp [W]**
Item	Loss [dB]	**330.0**	**256.2**	**73.8**
QW Coax	0.09	330.0	323.2	6.8
Highpass Cavity #4	0.1625	323.2	311.4	11.9
QW Coax	0.09	311.4	305.0	6.4
Highpass Cavity #3	0.1625	305.0	293.8	11.2
QW Coax	0.09	293.8	287.7	6.0
Highpass Cavity #2	0.1625	287.7	277.2	10.6
QW Coax	0.09	277.2	271.5	5.7
Highpass Cavity #1	0.1625	271.5	261.5	10.0
QW Coax	0.09	261.5	256.2	5.4

12) This is *the* most difficult step: You **must** stretch out the coil turns so that they occupy the same overall length that it had *before* the two turns were removed. That distance is 15 cm from coil turn outer top edge to coil turn outer bottom edge. This is shown below:



~~This task is made all the more difficult because we have elected to NOT de-solder the cylindrical capacitor sleeve on the right. It stays attached to the helicoil at all times.~~ The trick is to use your thumbs and forefingers to grasp either side of two whole turns and slightly stretch that portion a fraction of a centimeter. You go back and forth at different turns and rotational angles and keep doing this until you finally and *very very very slowly* get it to a length of 15 centimeters. You want this stretching to be as evenly distributed as possible so that the turns look natural and are not bunched-up or asymmetrical.

13) End result of stretching the coil back out to 15 cm. It's not perfect but it works beautifully:



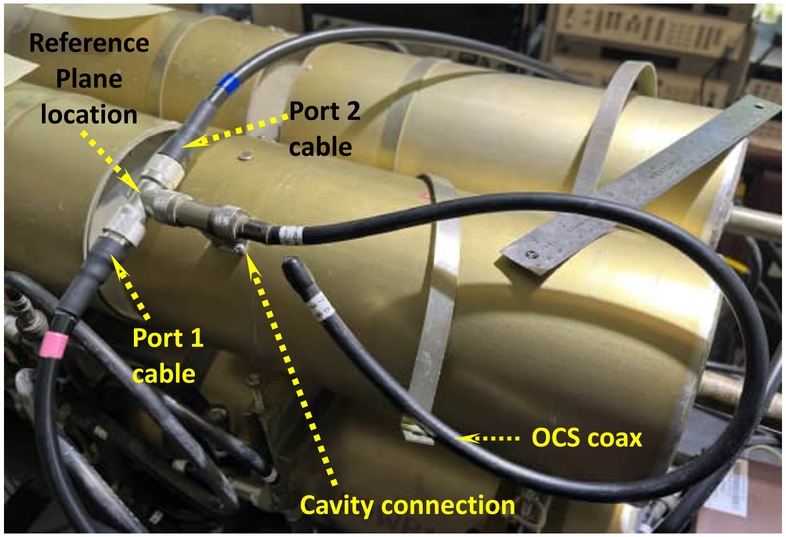
14) Reheat and apply solder to the joint, if needed, to ensure a good solid solder joint. Don't leave any sharp edges that could arc under high RF power.

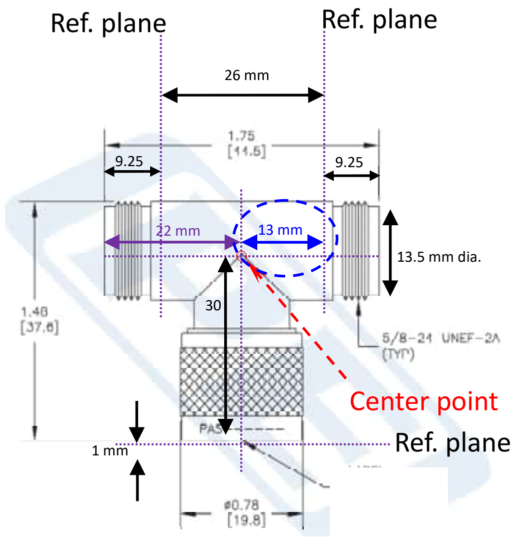
15) Carefully replace the helicoil assembly back into the cavity housing. Do not bump the coupling coil! The two screw post support should line up almost perfectly with the holes in the housing. Reattach and tighten the two screws. Do not force things! Re-bend as needed so that the helicoil fits back in naturally, the same as before the modifications were made. This is how it looks, post-modification:

16) Reattach the bottom cover plate, taking care to get the polystyrene rod into the spring-loaded compression hole. Use 6-32 hardware (6-32 by 5/8" long screws and nuts) in lieu of the three rivets. **NOTE:** You don't need to do this, but I added another three screws and nuts so that there is a fastener every 60 degrees around the perimeter of the bottom cover plates. This reduced the near-field RF leakage by 20 to 30 dB from the bottom seams of the cavities. This has resulted in more consistent RF rejection measurement results.

17) The cavity is ready to be tested. (See the next section of this report.)

Measurement of LOWPASS and HIGHPASS Cavity in the 6-meter band:
Start by measuring the cavity by itself that has been modified to have 5.125 turns instead of 7.125 turns for the helicoil. With the velocity factor set to 0.66, calibrate the VNA over the frequency range of interest. Use at least 2001 points to get fine resolution for the deep notch. Frequency accuracy is absolutely critical, so the VNA should be running on an external 10 MHz freq standard. After calibration, switch-ON Port Extensions and add 13 mm of positive length to Port 1 and to Port 2. This moves the reference plane location to the center of the T-connector. Connect the VNA for 2-port measurements of |s21|. Connect Port 1 and Port 2 to the cavity duplexer as shown in the photo:





The red-banded cable is Port 1 and the blue-banded cable is Port 2 of the VNA. The OCS (cable "78") is shown attached for illustrative purposes, but this is not the correct cable. The port extension adjustment moves the reference plane to the center of the T-connector as indicated above. Measure |s21| and adjust the tuning rod for exact resonance at the reject frequency, which is 53.150 MHz in this example.

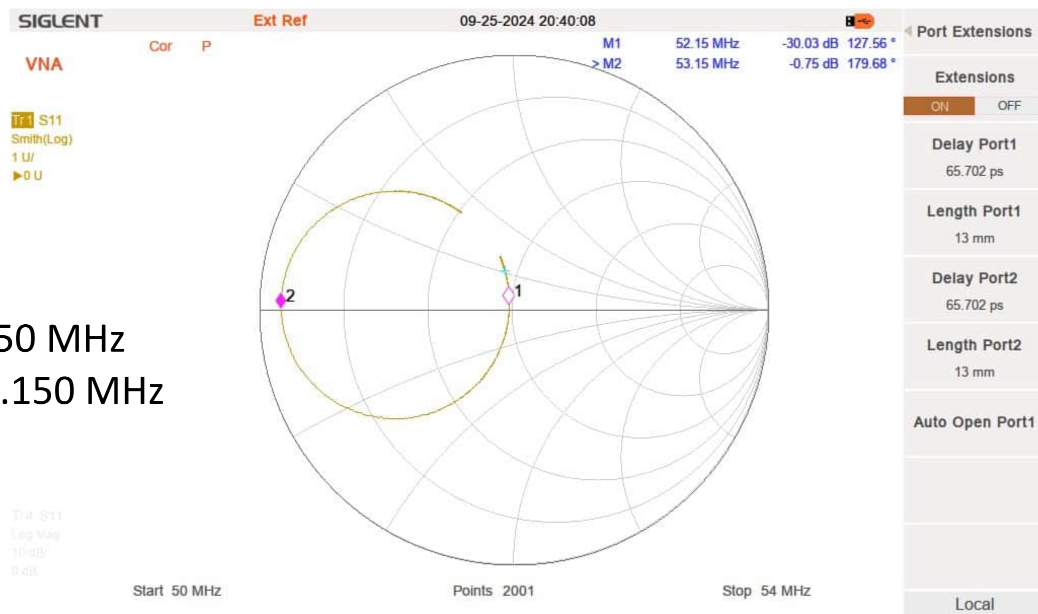
All of these rectangular plots consist of 2001 points from 50.0 to 54.0 MHz, which is 400 kHz per horizontal division. Put two markers on the screen, one at the PASS frequency M1 and one at the reject (notch) frequency M2. Regardless of whether the cavity has been tuned, it will need to be re-tweaked to the exact notch frequency.

Measured data is shown next for a modified 6-meter cavity. Then we'll show the data for the whole assembled 6m Duplexer.

The LOWPASS cavity looks like this for |s21|:

Measured Data on the Bench

and like this for s11:



LOWPASS

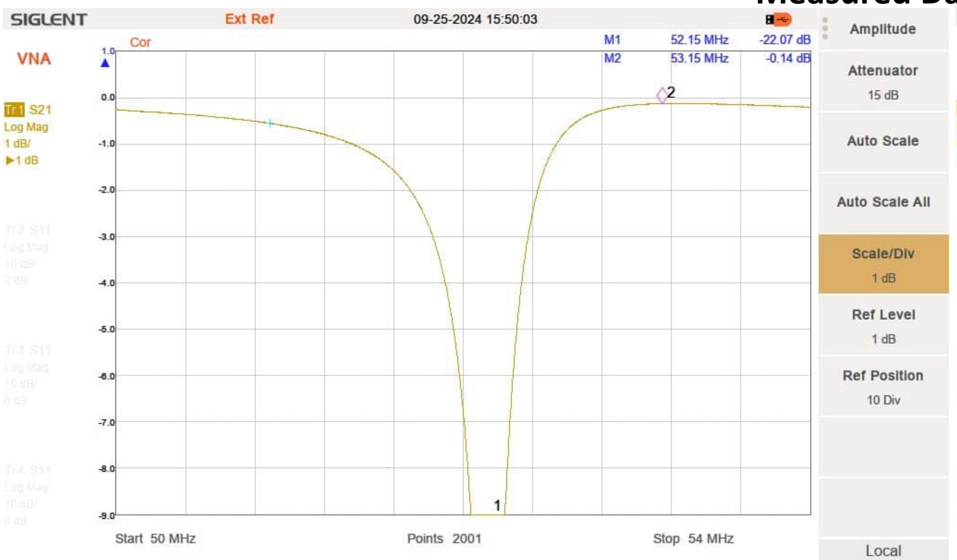
Marker M1 - PASS 52.150 MHz

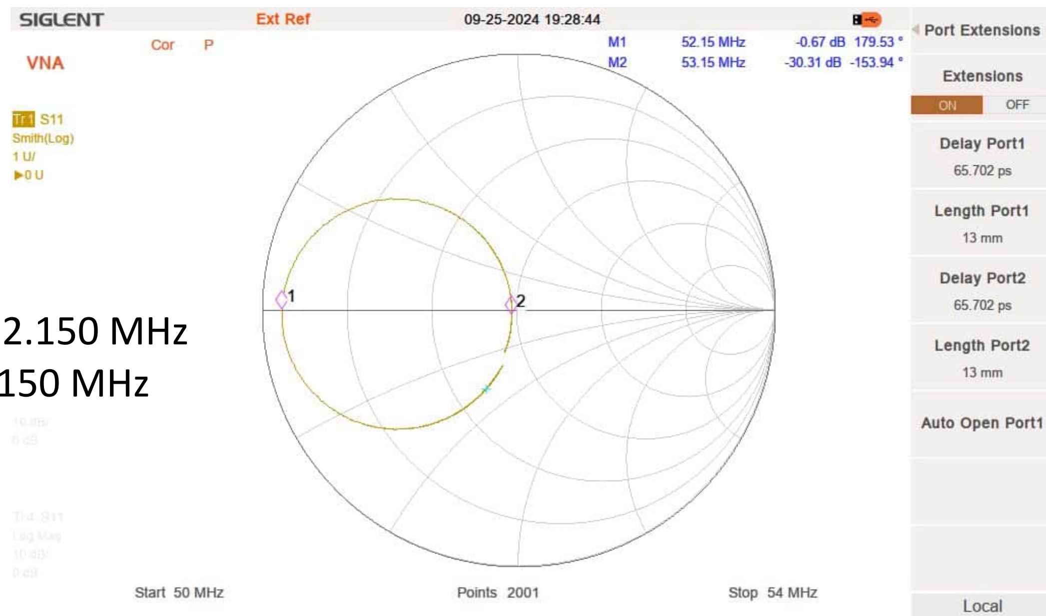
Marker M2 - REJECT 53.150 MHz

The bottom tips of the diamonds are sitting on the real-axis, which is where they should be. The OCS is 16 inches of coax. I could probably get it a little closer for M1 by adding just a little bit more coax length to the OCS. This looks very good.

Remember that all cavities can be either HIGHPASS or LOWPASS. You just change the OCS length and tune the cavity's notch to the proper frequency. I've taken the same *exact* cavity that we just tested as a LOWPASS and changed it to a HIGHPASS cavity. The OCS changes to 24.25 inches of RG-213/U coax and the notch frequency is tuned to 52.150 MHz. Here are the results:

Measured Data on the Bench





HIGHPASS

Marker M1 - REJECT 52.150 MHz

Marker M2 - PASS 53.150 MHz

The bottom tips of the diamonds are sitting on the real-axis exactly where they should be. The OCS is 24.25 inches of RG213/U coax.

Measured Data on the Bench

Measured Results for the entire Modified 6-meter Duplexer 52.150 / 53.150 MHz:

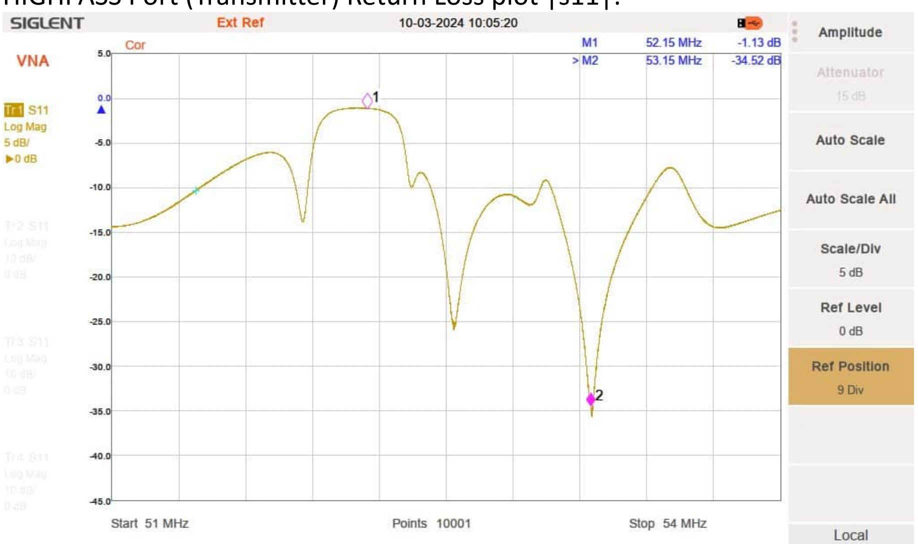
HIGHPASS Path (Repeater TX 53.150 MHz)
Insertion Loss at 53.150 MHz = 1.10 dB
Rejection at 52.150 MHz = 100 dB
Return Loss at 53.150 MHz = 34 dB

LOWPASS Path (Repeater RX 52.150 MHz)
Insertion Loss at 52.150 MHz = 0.89 dB
Rejection at 53.150 MHz = 104 dB
Return Loss at 52.150 MHz = 35 dB

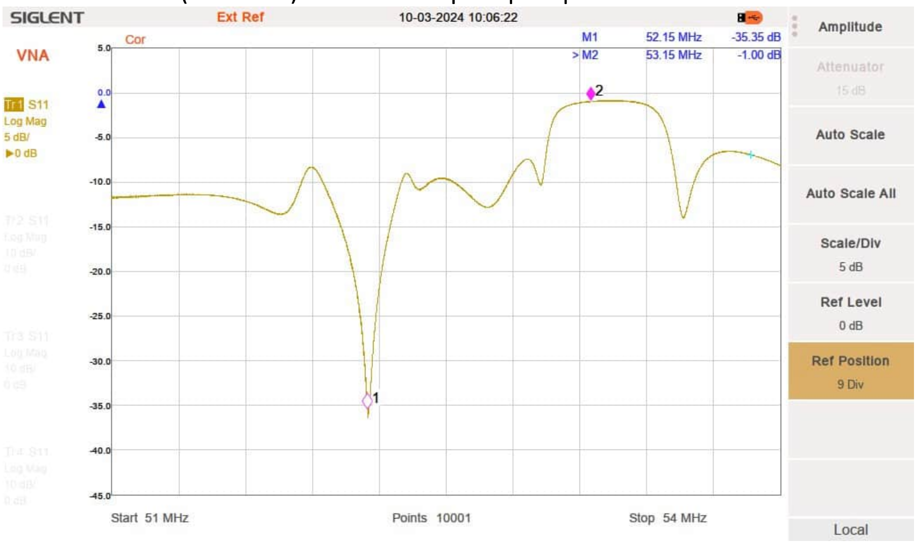
ANTENNA Path Return Loss
at 53.150 MHz = 29 dB
at 52.150 MHz = 27 dB

Insertion Loss and Rejection were measured using an HP8648B RF Signal Generator and an Agilent E4402B ESA-E Series Spectrum Analyzer with low phase noise and preamplifier option. (My Siglent SVA1015X VNA doesn't have adequate dynamic range to measure this level of rejection.)

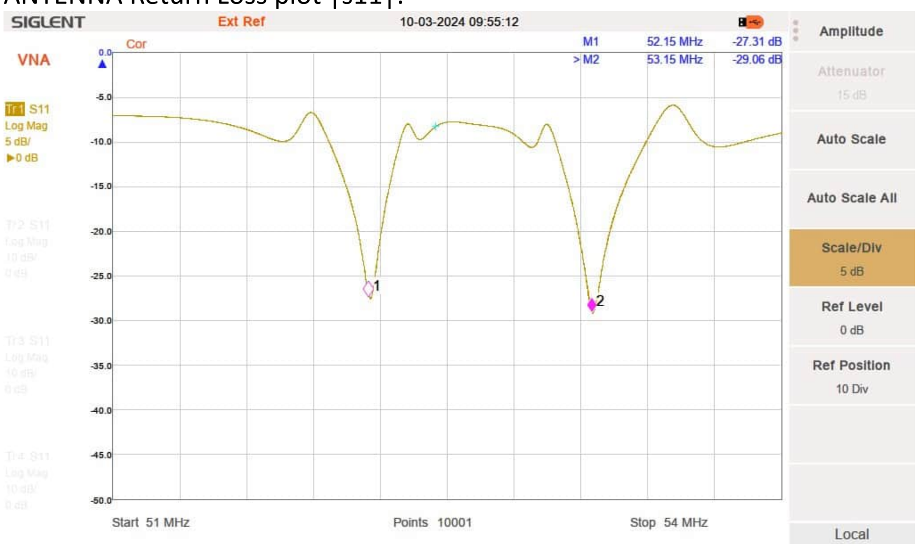
HIGHPASS Port (Transmitter) Return Loss plot |s11|:



LOWPASS Port (Receiver) Return Loss plot |s11|:



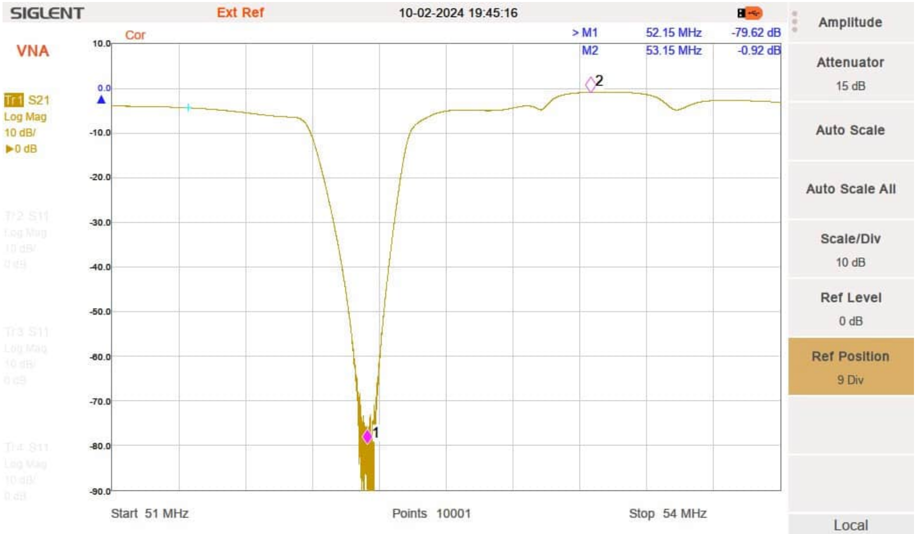
ANTENNA Return Loss plot |s11|:



See page 16 for some last-minute tweaks that were made to improve the return loss to what is shown on this page.

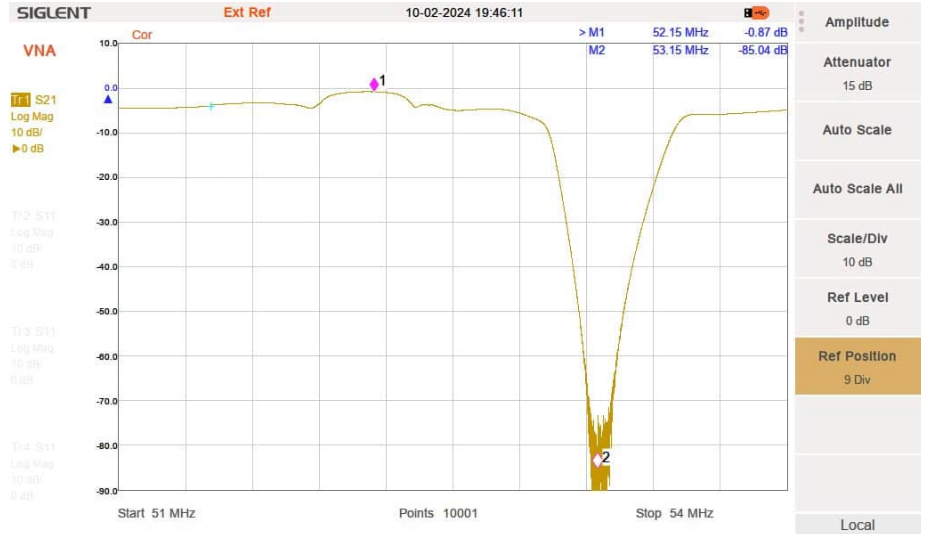
Measured Data - 51 to 54 MHz Duplexer Attenuation Plots |s21|

HIGHPASS (Transmitter) to ANTENNA Port Insertion Loss plot |s21|:



10 dB/vert div & 300 kHz/horiz div

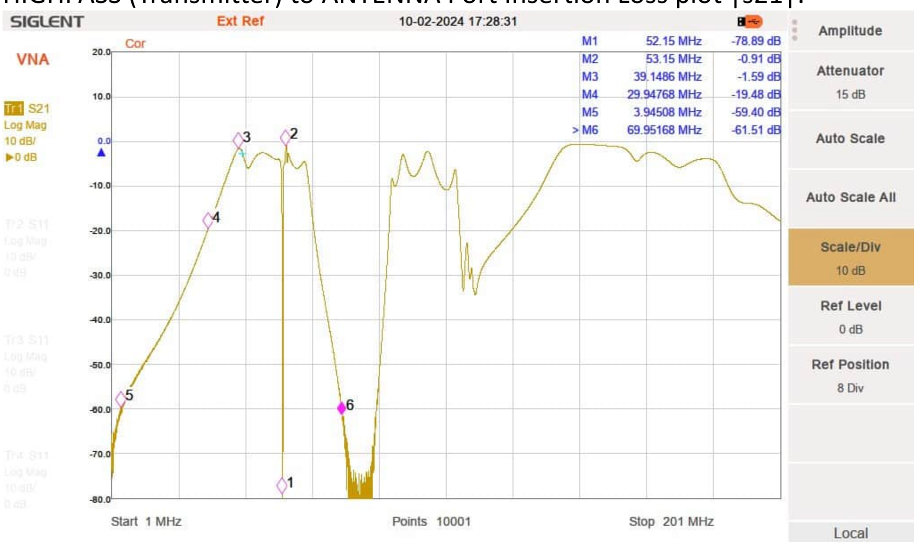
ANTENNA to LOWPASS (Receiver) Insertion Loss plot |s21|:



10 dB/vert div & 300 kHz/horiz div

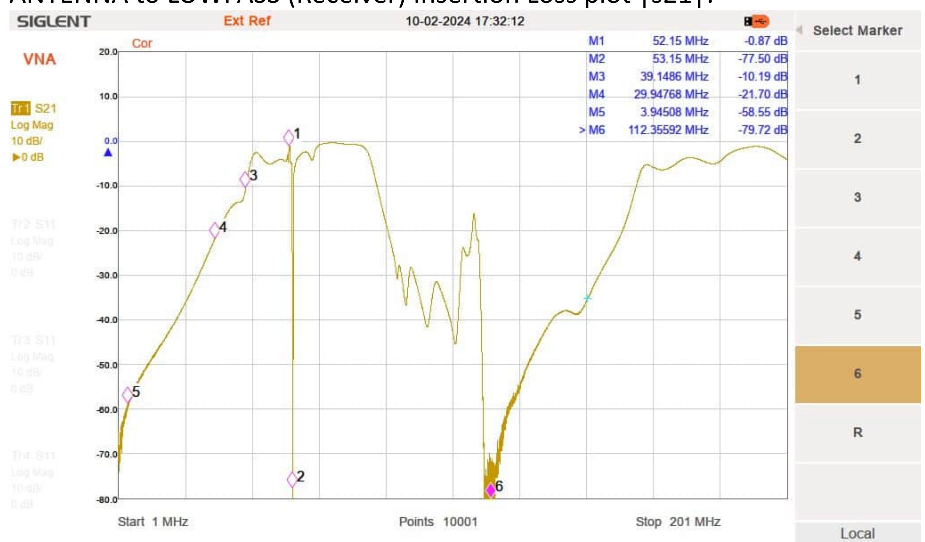
Measured Data - 1 to 200 MHz Wideband (Out-of-Band) Duplexer Attenuation Plots |s21|

HIGHPASS (Transmitter) to ANTENNA Port Insertion Loss plot |s21|:



10 dB/vert div & 20 MHz/horiz div

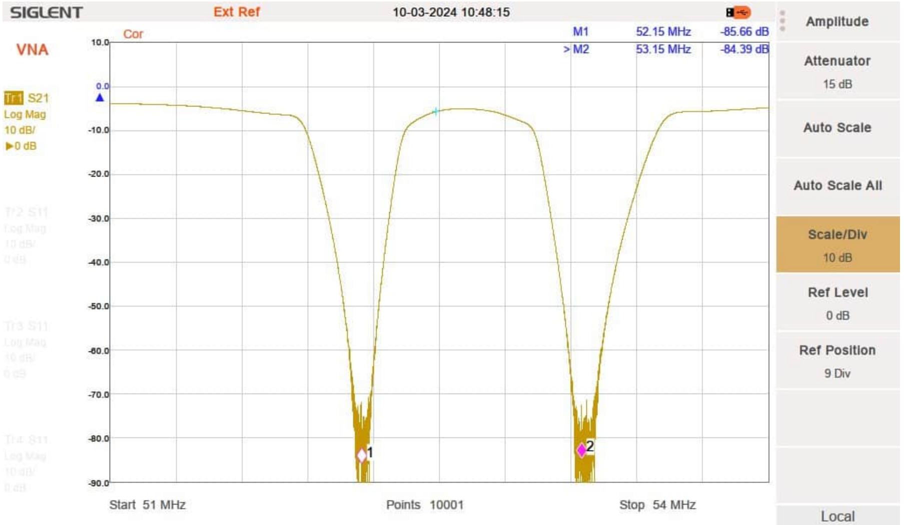
ANTENNA to LOWPASS (Receiver) Insertion Loss plot |s21|:



10 dB/vert div & 20 MHz/horiz div

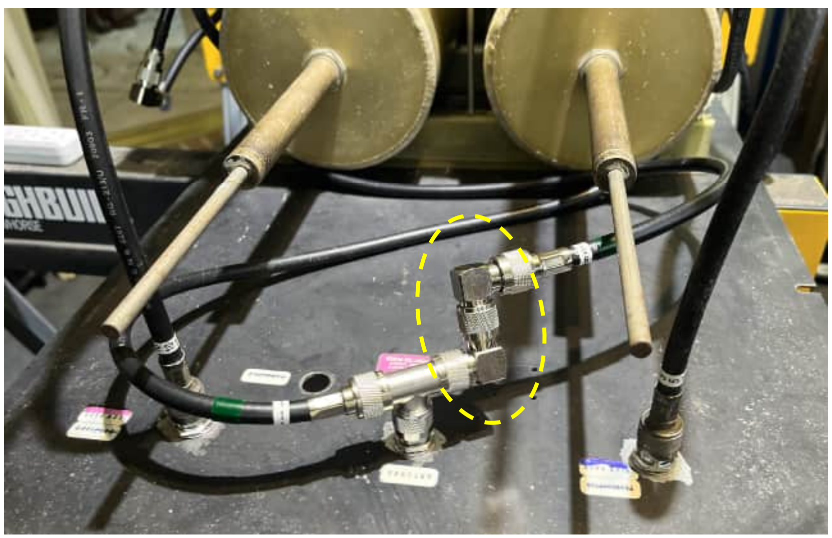
Measured Data on the Bench

TX to RX (HIGHPASS to LOWPASS) RF Isolation:

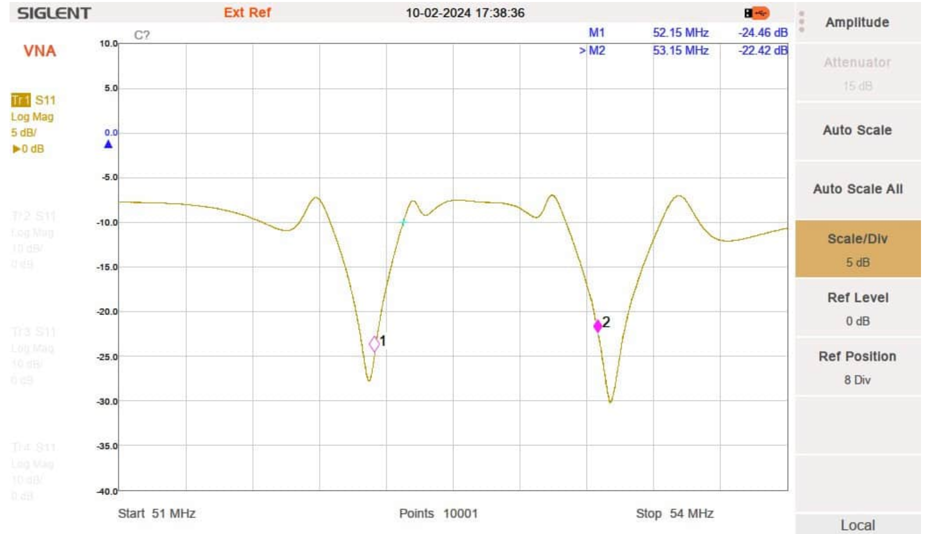


This measurement is dynamic range-limited by the VNA. The actual isolation is per the blue box on page 14.

In order to achieve optimal performance for return loss, a last-minute tweak was made, based on some computer modelling trends. Coaxial cable # 6 was lengthened by about 3 inches by adding two right-angle connectors as shown in the photo:



This improved the return loss considerably. Before the change to cable #6, the return loss looked like this:



After the change to cable #6, the return loss looks like this:

My guess is that some reactance was not cancelled out fully by the LOWPASS OCS cables and this change to cable #6 rotates the residual reactance to land at the open-circuit (∞ + j0) location on the Smith chart.

Measured Data on the Bench

As an interesting sidenote, K5AB will be modifying an identical Sinclair Model # R-102G (railroad) duplexer for 52.050 & 53.050 MHz operation. That's only 100 kHz lower in frequency than mine, so it looks like the cable lengths in the table shown on page 2 can remain the same. I tuned my duplexer to his frequencies and this is the measured performance (*tuning rod changes only / no cable changes*):

Measured Results for the entire Modified 6-meter Duplexer tuned down by 100 kHz to 52.050 / 53.050 MHz:

HIGHPASS Path (Repeater TX 53.050 MHz)
Insertion Loss at 53.050 MHz = 0.98 dB
Rejection at 52.050 MHz = 98 dB
Return Loss at 53.050 MHz = 33 dB

LOWPASS Path (Repeater RX 52.050 MHz)
Insertion Loss at 52.050 MHz = 1.08 dB
Rejection at 53.050 MHz = 104 dB
Return Loss at 52.050 MHz = 34 dB

ANTENNA Path Return Loss
at 53.050 MHz = 29 dB
at 52.050 MHz = 25 dB

The numbers are almost identical to the measured values for 52.150 / 53.150 MHz in the next column.

End of Documentation.

Measured Results for the entire Modified 6-meter Duplexer Tuned to 52.150 / 53.150 MHz:

HIGHPASS Path (Repeater TX 53.150 MHz)
Insertion Loss at 53.150 MHz = 1.10 dB
Rejection at 52.150 MHz = 100 dB
Return Loss at 53.150 MHz = 34 dB

LOWPASS Path (Repeater RX 52.150 MHz)
Insertion Loss at 52.150 MHz = 0.89 dB
Rejection at 53.150 MHz = 104 dB
Return Loss at 52.150 MHz = 35 dB

ANTENNA Path Return Loss
at 53.150 MHz = 29 dB
at 52.150 MHz = 27 dB