# RF Filters

## How they work and how to align them for repeaters

*Presented to Calgary Amateur radio Association on January 20,2024*

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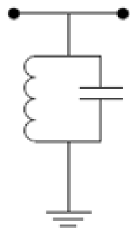
# RF Filters

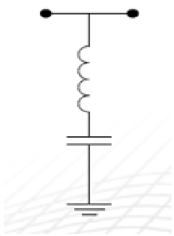
- Filters allow for multiple signals to appear on one antenna
- Through proper filtering an antenna can transmit and receive several signals simultaneously
- Spacing between the transmit and receive frequencies determines the type of filtering required.
    - Along with TX power and other equipment at the site

# Cavity based filter types

- All Cavities are resonant type structures
- Electric and Magnetic energy is “stored” and passed back and forth in a resonant circuit between the electric and magnetic fields.

  - Theoretical Equivalent L-C circuits:
    - Band pass cavity 　　Reject cavity



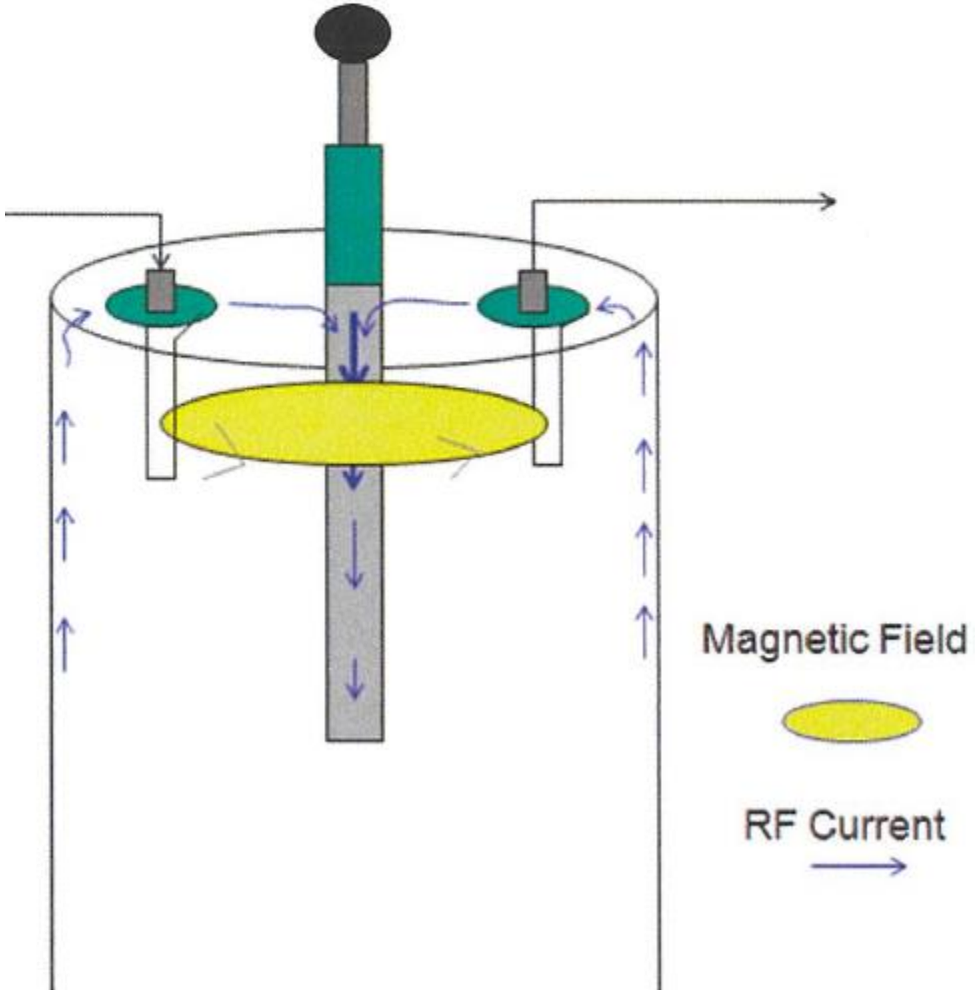


    - Each type has a resonant frequency

$$F = \frac{1}{2\,\pi\,\sqrt{LC}}$$

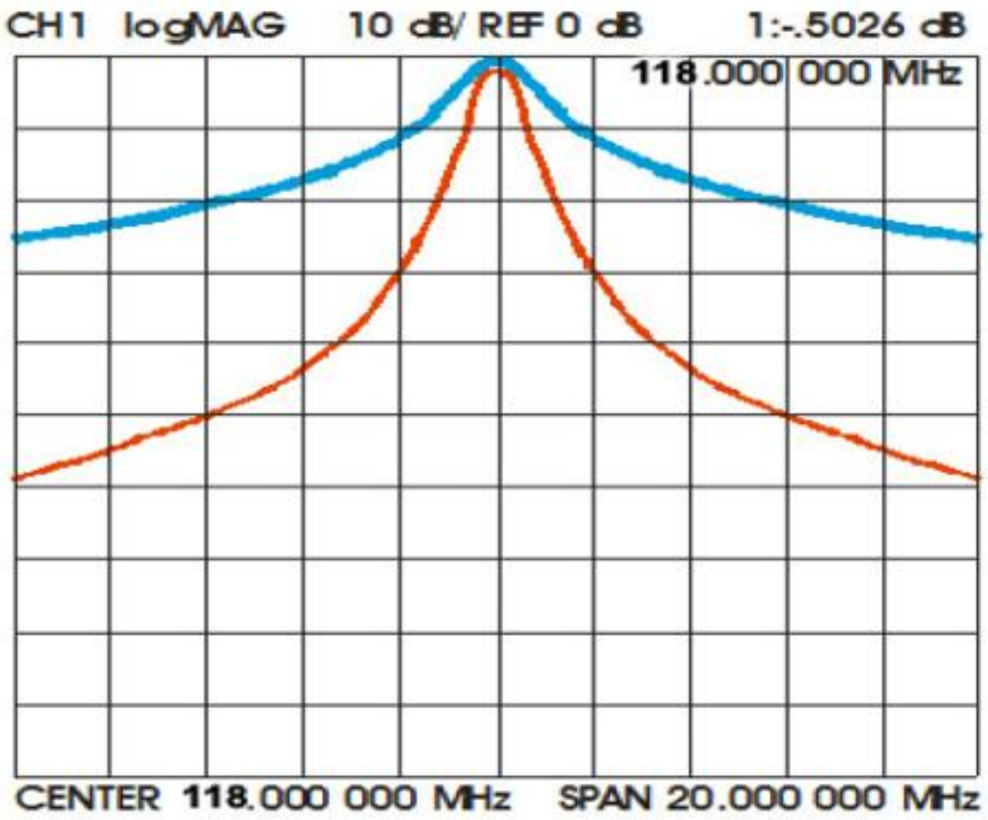
# Electrical View of a Resonant Cavity

- The energy coming in from the loops is coupled thru a magnetic field.
- The current travels from the side of the cavity to the center probe.
- The length of the probe is ¼ wave from the frequency that is presented at the input of the cavity.



# Filter Types

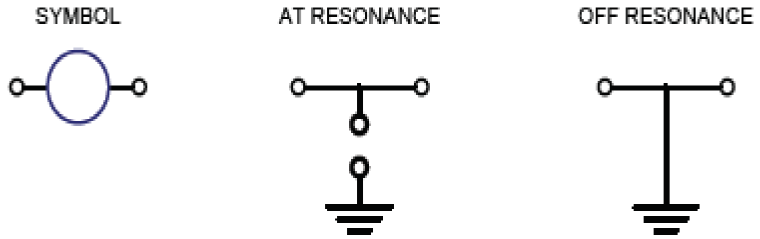
- The sharpness of the notch and bandpass frequency response is referred to as “Q” which stands for the quality factor.
  - The bandpass filter response can range from a very sharp peak with steep slopes around the peak to much smaller slopes on each side of the peak
  - The sharper the peak the higher the Q




- The notch filter response can also range from a very sharp notch to a wide notch.
  - The sharper the notch the higher the Q

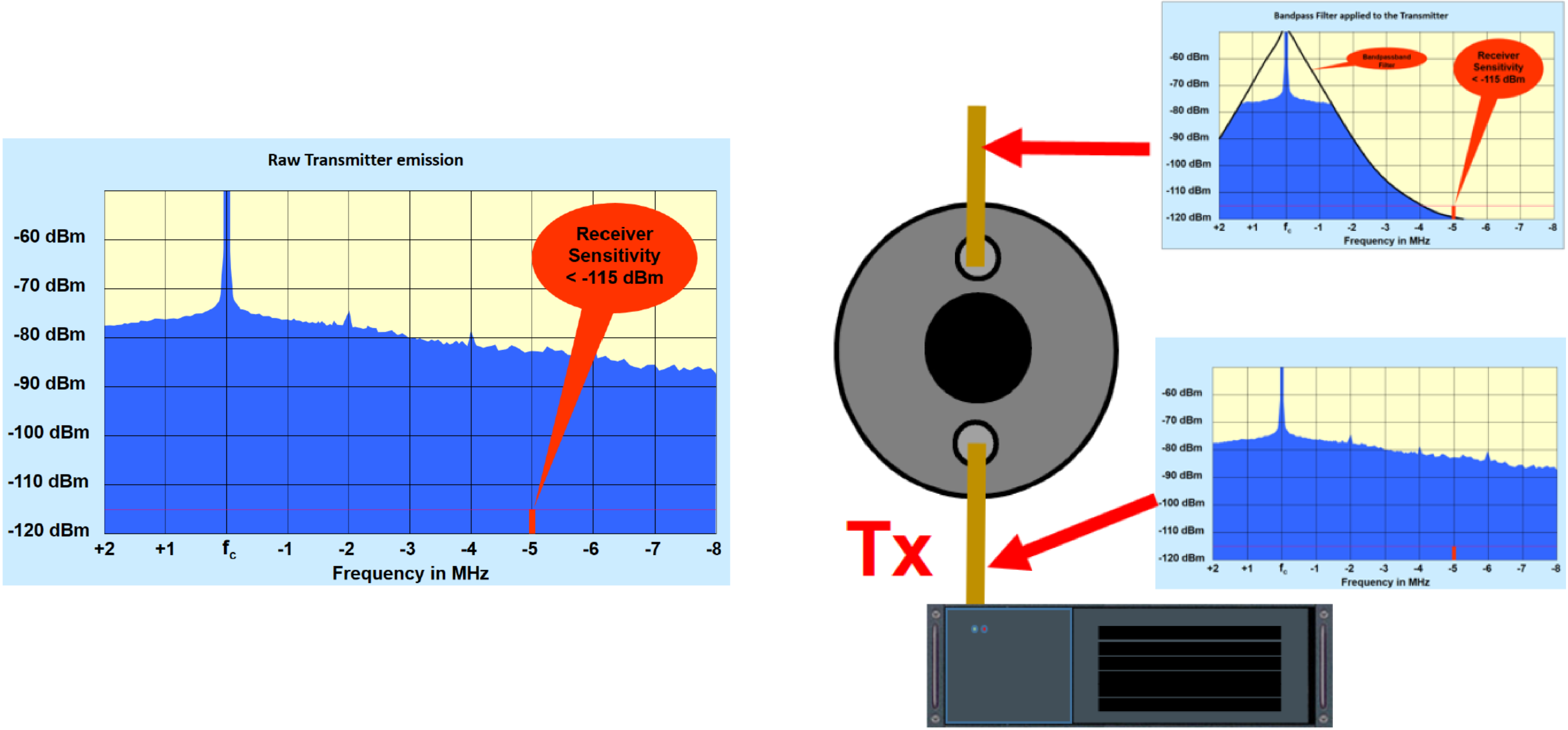
# Band Pass

- The band pass cavity is a two-port device that acts like an impedance to ground.
  - At its resonant frequency it behaves like a very large resistance and is seen as an open circuit to ground and the signal passes through from one port to the other.
  - When a frequency is sufficiently far from resonance, the pass cavity appears as a short circuit to ground and those frequencies do not travel between each port.



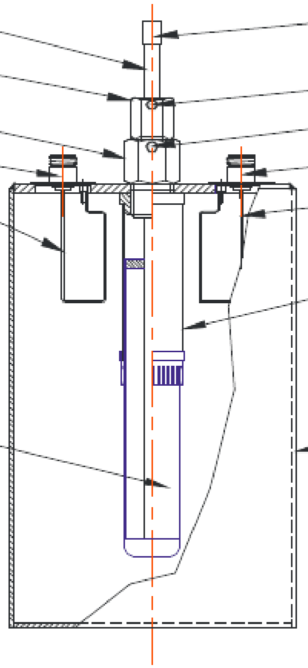

- It purpose is to pass a specific frequency with minimal loss
  - While attenuating off frequency signals
  - It has 2 ports (input & output) which can be reversed

# Pass Filter to Reduce Sideband Noise



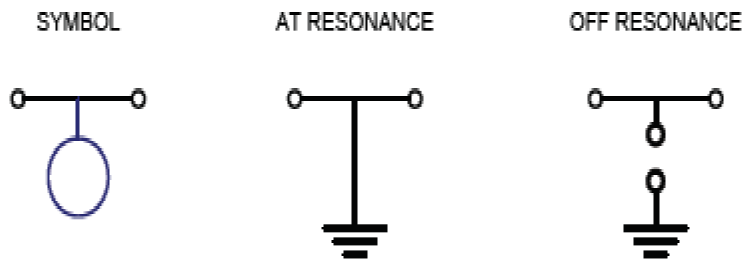
# Band Pass

## Filter Types
### Band Pass (FP)

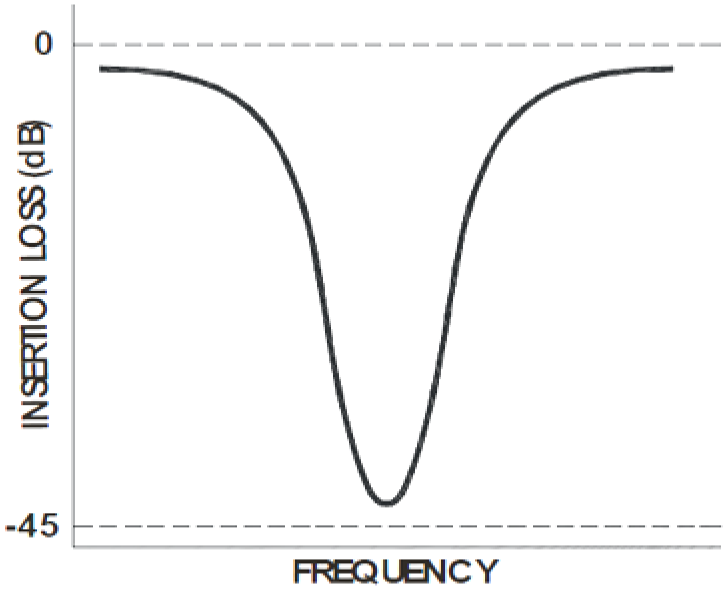



# Band Reject

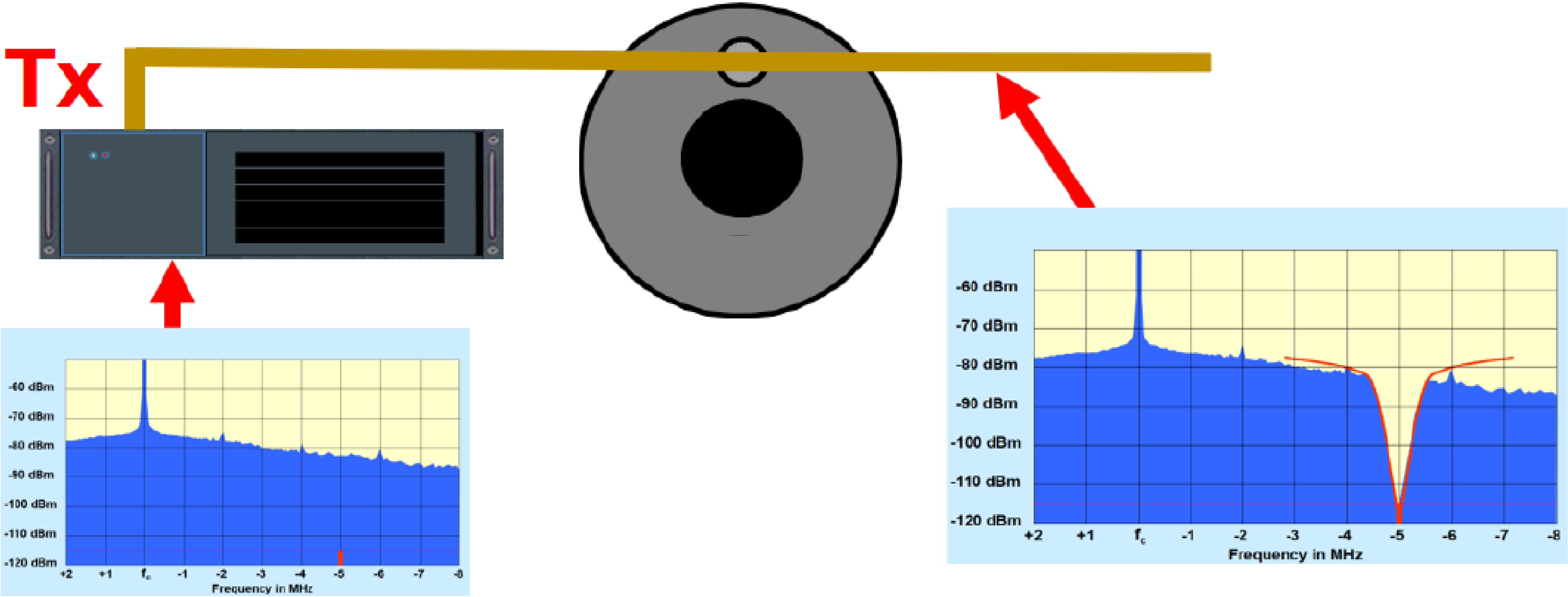
- The Band reject or notch cavity is the reverse of the pass band cavity.
  - It is a short circuit at resonance and an open circuit for all other frequencies




- The purpose is to provide maximum attenuation at a specific frequency
  - while passing all other frequencies with minimal loss.
  - Has only 1 port and acts like a trap to the resonant frequency



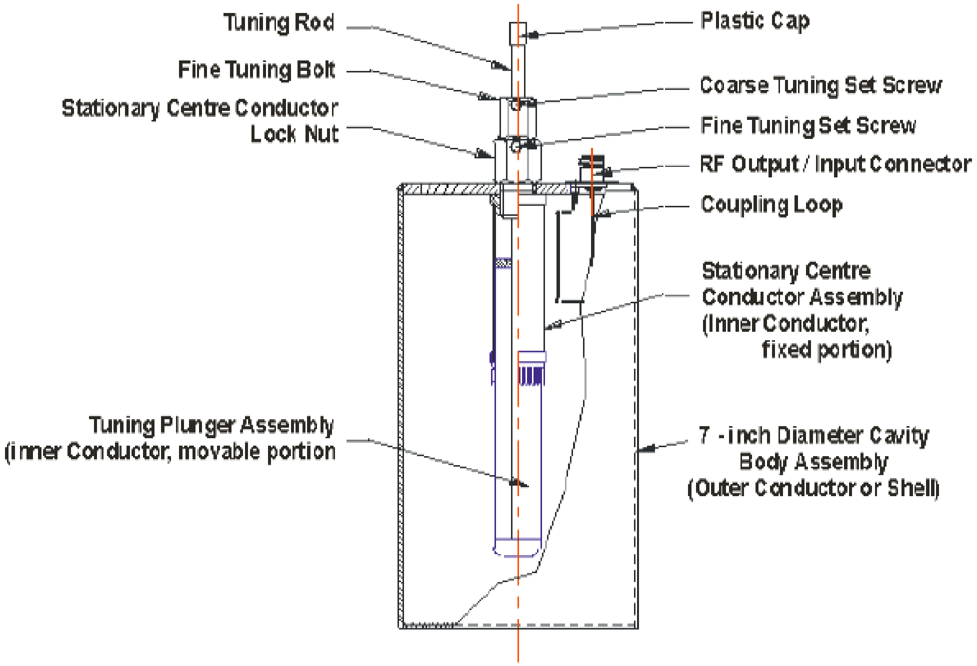
# Notch Filter to reduce Sideband Noise

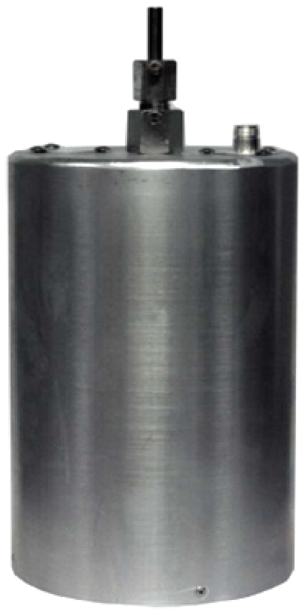


# Band reject

## Filter Types

### Band Reject (FR)

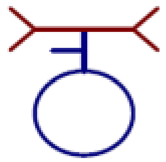


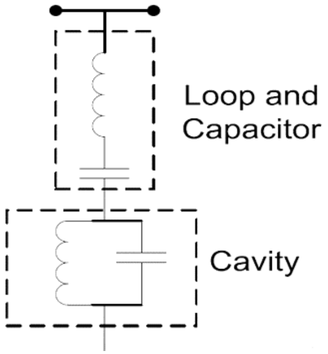



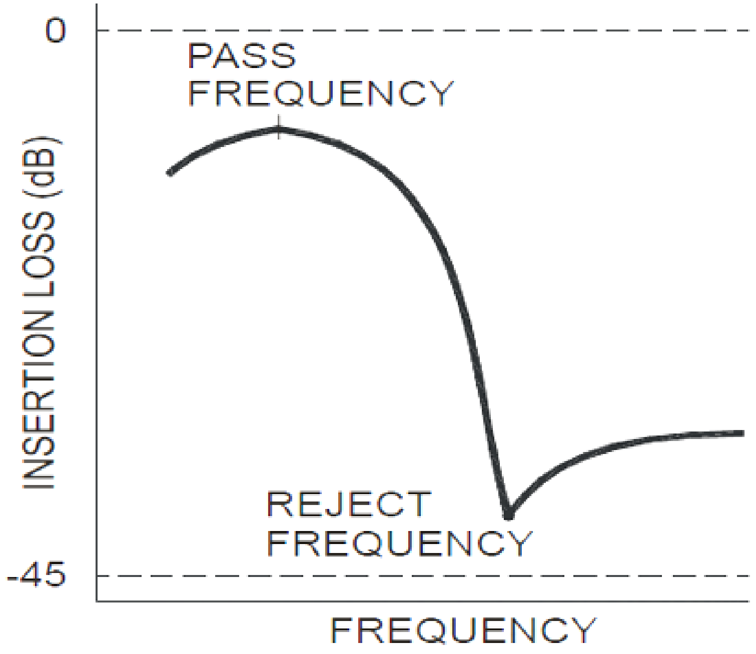
- Position of the coupling loop  determines the notch depth of the cavity.
- Pushing the plunger into the cavity lowers its resonant frequency.

# Q circuit (FQ)

- Advantages of the Q circuit filter:
  - Allows for close spacing of pass/reject frequencies
  - Low insertion loss
  - Broad isolation loss
- Cavity only has 1 (port) loop
- The notch capacitor is placed in series with the loop





# Q circuit

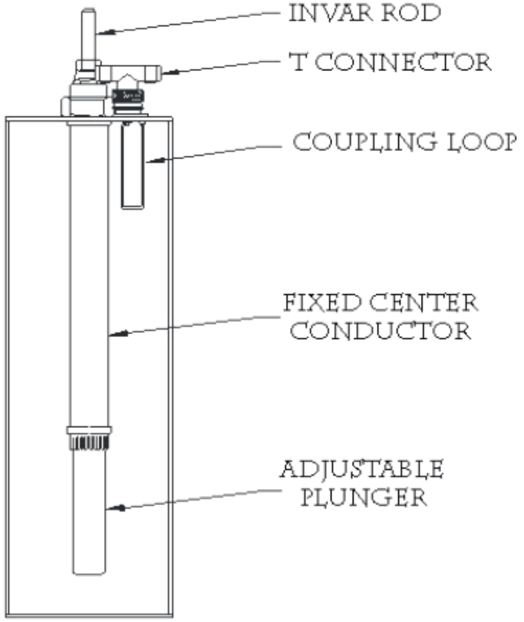
## Filter Types

### Q Circuit (FQ)

Position of the coupling loop determines the pass insertion loss and the notch depth of the cavity.

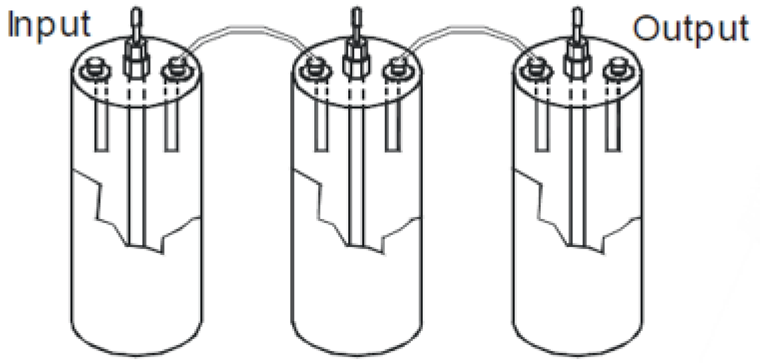
Pushing plunger into the cavity lowers both its pass & notch frequencies

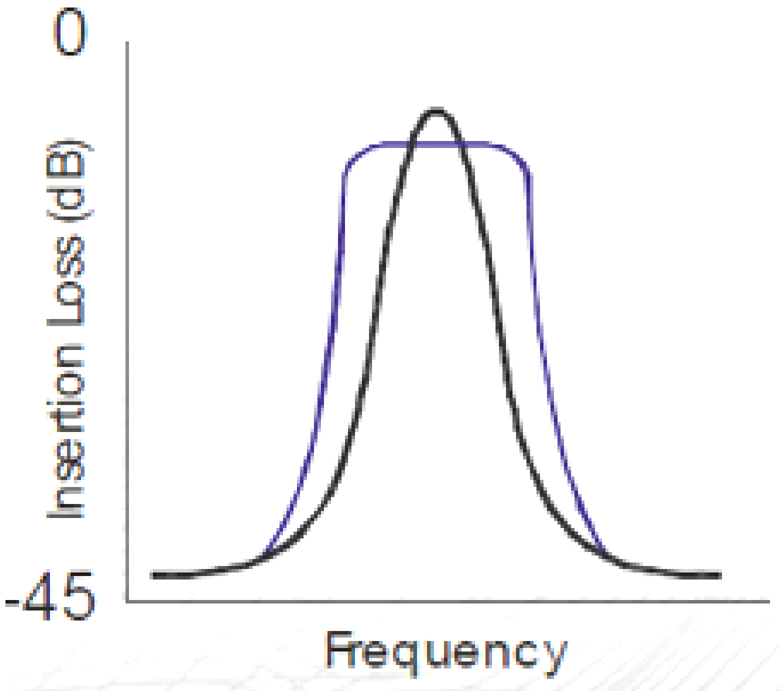
Turning the capacitor changes the notch frequency




# Cascaded Cavities

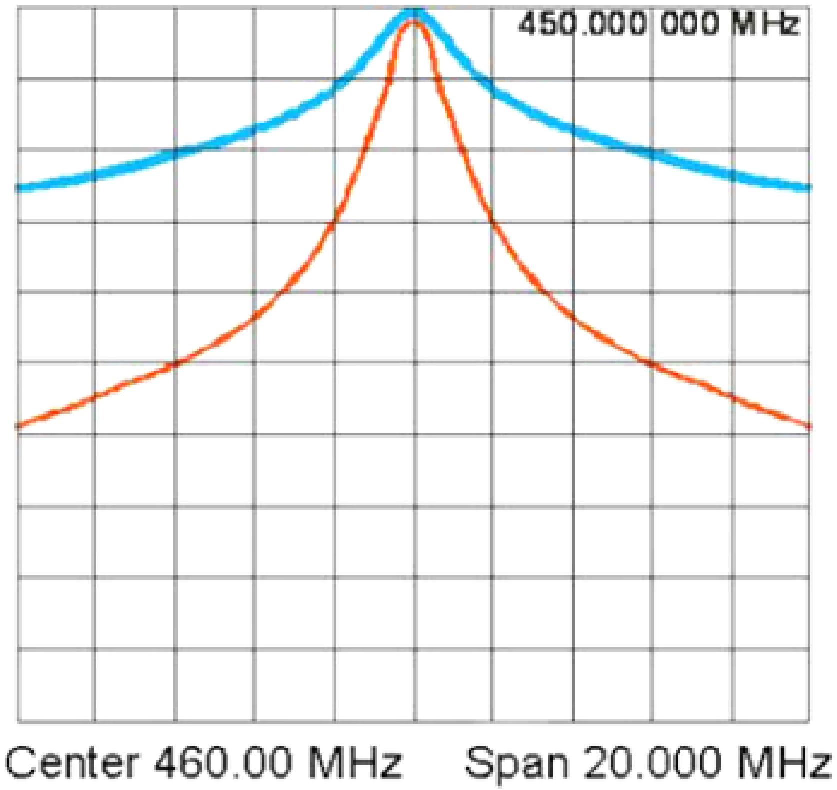
- Multiple Cavities are used to:
  - Increase selectivity at lower insertion loss, as compared to a single cavity
  - Create a wider pass band
  - Used to pass multiple closely spaced frequencies through the same set of cavities such as in a VHF channelized receive system.



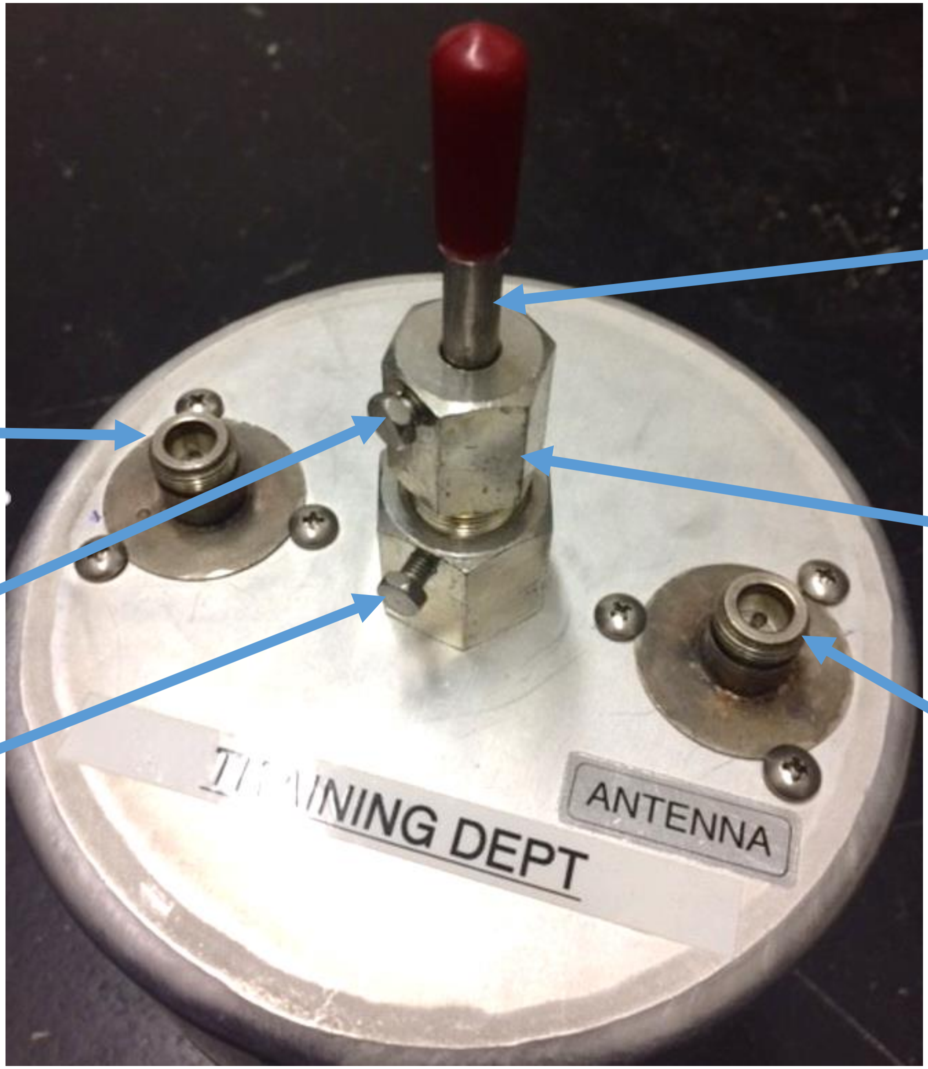



# Response Curves (Cascaded Band Pass Cavities)

- With 1 cavity you will have less selectivity or a lower Q (not as sharp of a peak)
  - By using 2 cavities you will have a sharper peak with the same amount of insertion loss
    - Blue is 1 cavity , 0.5 db insertion loss
      - -10db @1.4 MHz band width
    - Red is 2 cavities, 0.5 db insertion loss
      - -10db @ 500 kHz bandwidth

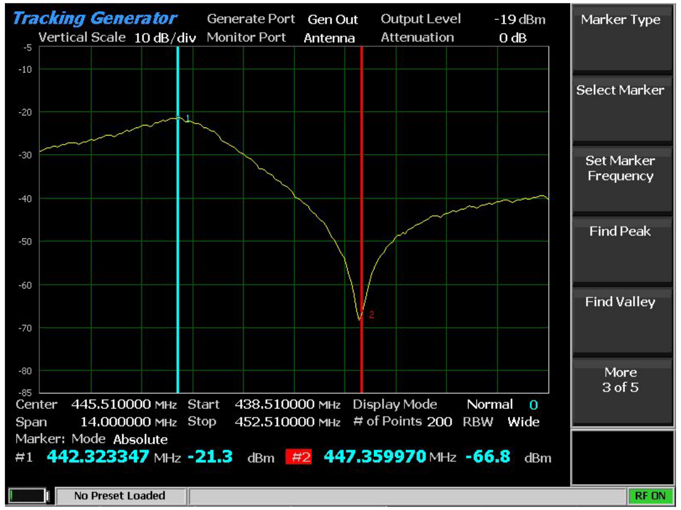


# Pass Filter

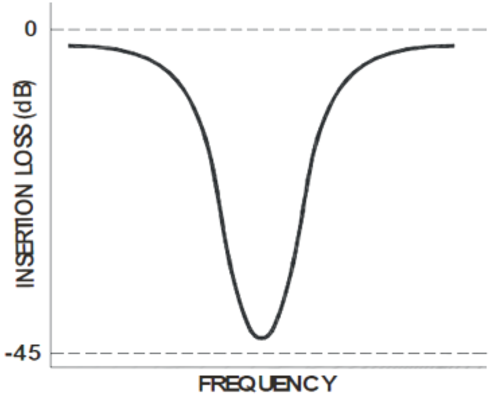

Tuning Rod
RF Port
Fine Tuning Bolt
Tuning Rod Lock Screw
Fine Tuning Lock Screw
RF Port
ANTENNA

# Tracking Generator

- If the response curve doesn't match the filter manufacturer's specification then tuning adjustments are used to align the filter.
  - On combined Duplex pass-reject filters these adjustments interact with each other.
  - So the pass band peak is tuned first, and then followed by the notch frequency adjustment. Working the adjustments back and forth, the response curve peak and valley are aligned to the target frequency points.
  - The filter is considered tuned when the peak insertion loss and notch depth match the manufacturer's specifications at those frequency points.

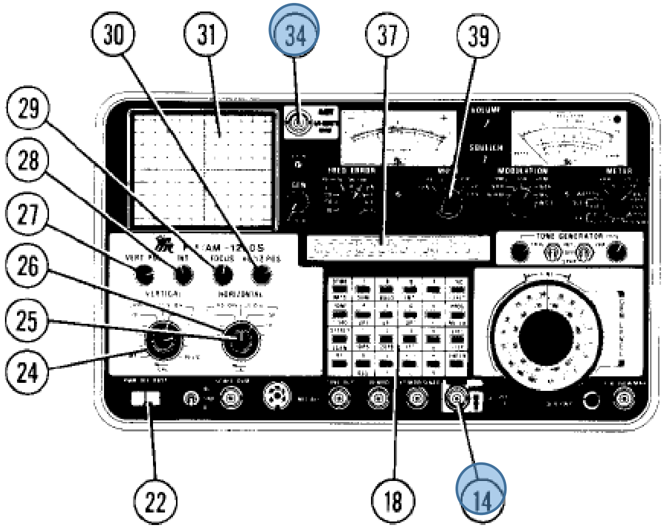






# Setting up Tracking Generator (IFR-1200S)

- The tracking generator option allows operators to accomplish the tuning and alignment of radio communications components such as filters, duplexers, combiners and circulators.
  - The device under test is connected between the **DUPLEX Output Connector (14)** and the input to the Spectrum Analyzer at the **ANTENNA connector (34)**
- Set the front panel controls to the settings listed here.




FM/AM-1200S CONNECTORS AND INDICATORS APPLICABLE TO TRACKING GENERATOR OPERATION:

14 DUPLEX Output Connector
31 CRT Display
34 ANT Connector
37 VFD

| | | |
|---|---|---|
| 18 | Keyboard | "As req'd" |
| 22 | PWR/OFF/BATT Switch | "PWR" or "BATT" |
| 24 | VERTICAL ATTENUATOR Selector Control | Any position except "OFF" |
| 25 | HORIZONTAL Sweep Vernier Control | Fully cw |
| 26 | HORIZONTAL Sweep Selector Control | "1 MHz/Div" |
| 27 | VERT POS Control | "Mid Range" |
| 28 | INT Control | As req'd |
| 29 | FOCUS Control | As req'd |
| 30 | HORIZ POS Control | "Mid Range" |
| 39 | MODE Selector Control | DUP |

# Setting up Tracking Generator (IFR-1200S)

MAXIMUM CONTINUOUS INPUT TO THE ANTENNA CONNECTOR (34) MUST NOT EXCEED 0.25 WATTS.

Enter the center frequency of the UUT using the procedure outlined in paragraph 4-2-1.

Press: [2ND FUNCT] [5 OPT]. One of the following displays will appear on the VFD:

DUPLEX HIGH

DUPLEX LOW

TRACK HIGH

TRACK MED

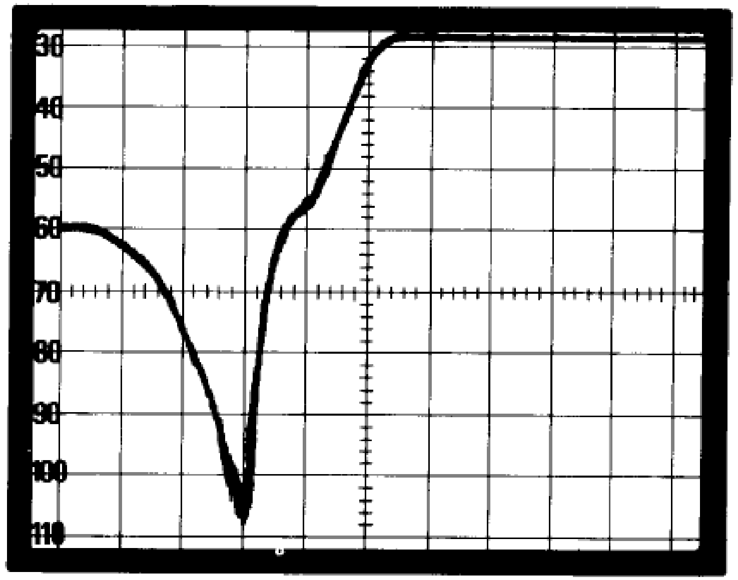
TRACK LOW

ON following one of these displays will indicate the currently selected mode of operation. Use the [ ] and [ ] keys to scroll through the modes until the desired selection appears on the VFD.

Output levels at the DUPLEX Output Connector (14) with the Tracking Generator installed are:

| | |
|---|---|
| Track High: | -3 dBm ±5 dB |
| Track Med: | -15 dBm ±7 dB |
| Track Low: | -40 dBm +5/-10 dB |

Press [ENTER] to select the desired output level.

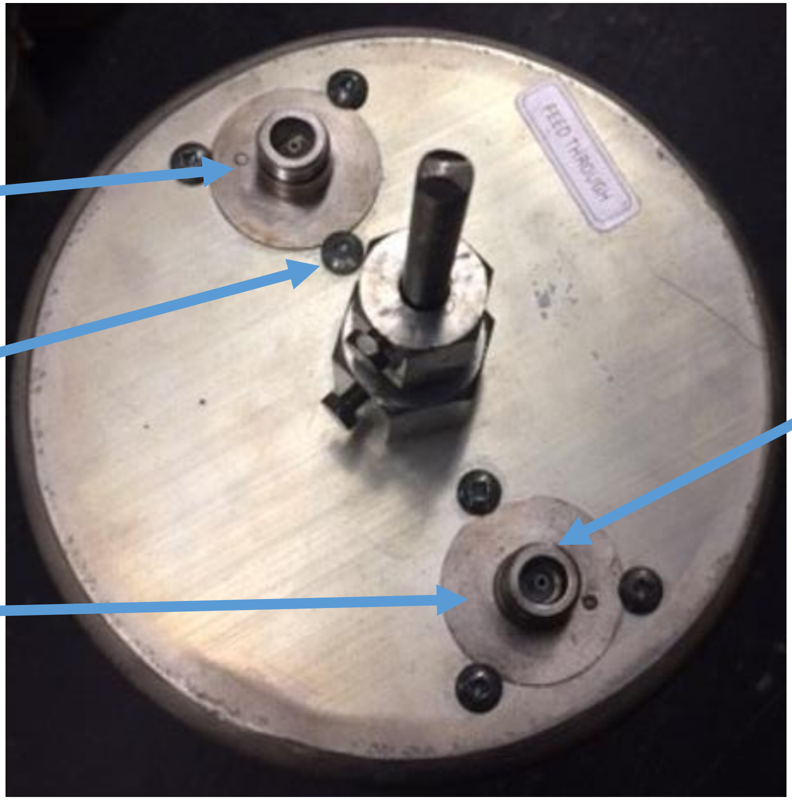


# Tuning of Pass Frequency

1. Connect tracking generator to each port of the filter.
2. Unlock coarse tuning locknut
3. Move rod in to decrease resonant frequency out to increase.
4. Lock coarse tuning bolt,
5. Unlock fine tuning bolt and rotate fine tuning nut to change frequency

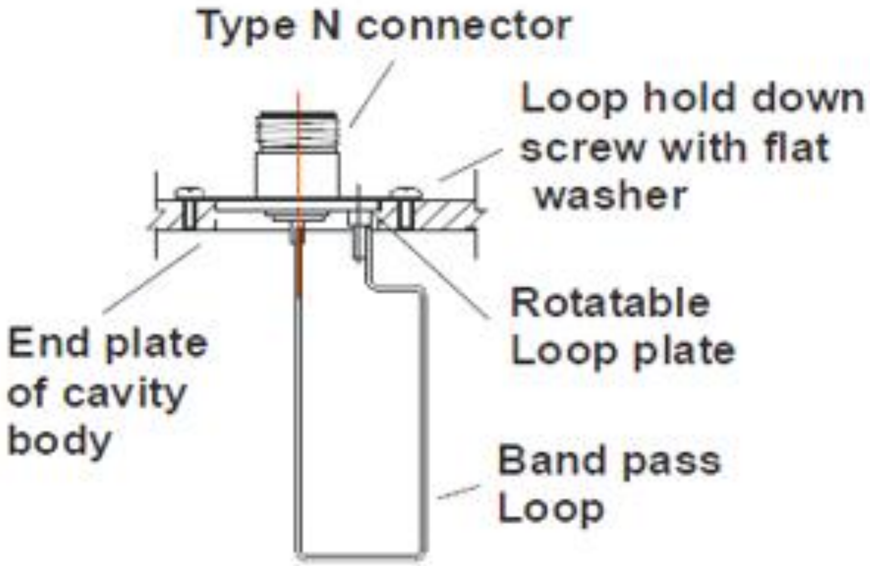
# Coupling Loops

- The cavity filters are equipped with adjustable coupling loops
  - they facilitate insertion loss settings without removal or replacement of the loops.

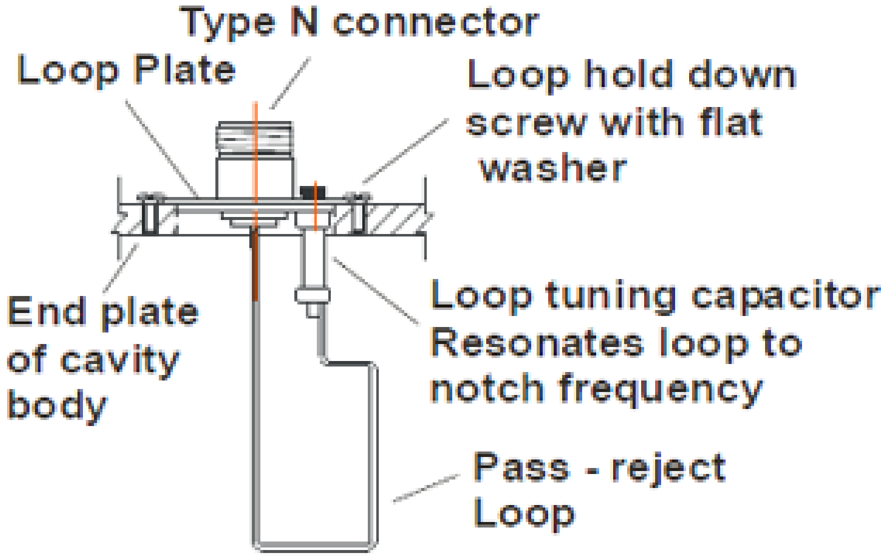


# Coupling Loop assemblies

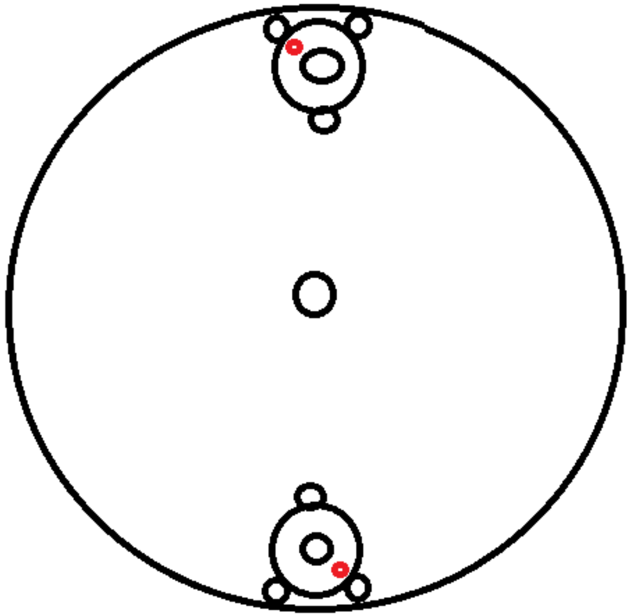
## Typical band pass loop assembly




## Typical pass/reject loop assembly



# Factory Default (Coupling Loops)



**<u>Factory default is position of red dot</u>**

# Adjust insertion loss (method 1)

There are 2 ways to adjust Insertion Loss

**<u>If the loops are set the same (as from factory), then use this method:</u>**

1. Find the existing pass frequency for the cavity.
2. Loosen the plate screws.
3. Turn the loop plates to set the insertion loss for the desired value.
4. Be careful to move the plates in a symmetrical fashion.
   - Moving both loops counter clockwise will increase insertion loss and clockwise will decrease it.
5. When finished both circles should be in the identical position.
6. Tighten the plate screws.
7. The return loss at the two ports must be within 1-2 dB of each other.

# Adjust insertion loss (method 2)

**<u>If the loops are not set the same, then use this method:</u>**

1. Attach tee to one loop and leave the other loop open.
2. Loosen the 3 screws that secure the loop down (do one loop at a time)
3. Rotate loop unit the insertion loss trace shows a notch with the depth that corresponds to the desired pass band insertion loss.
    - 14 dB notch = 0.5 dB IL
    - 10 dB notch = 1.0 dB IL
    - 4.5 dB notch = 3.0 dB IL
4. Repeat procedure on second loop.
5. Fine tune each loop until the return loss at each port is equal and the insertion loss is at the desired level.

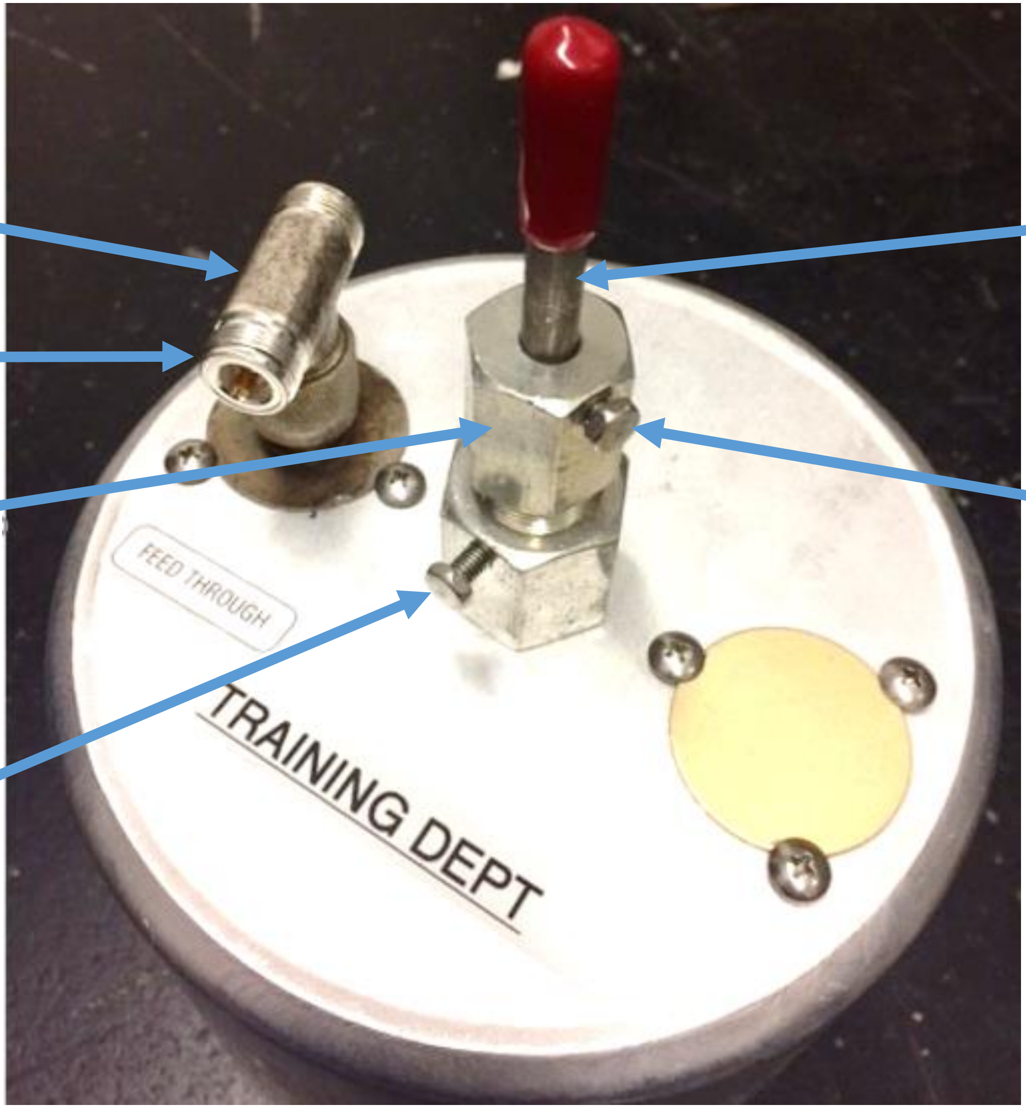
# Reject Filter

T Connector

RF Port

Fine Tuning Bolt

Fine Tuning Lock Screw




Tuning Rod

Tuning Rod Lock Screw

# Tuning of Reject Frequency

1. Connect tracking generator to both ports of the T connector.

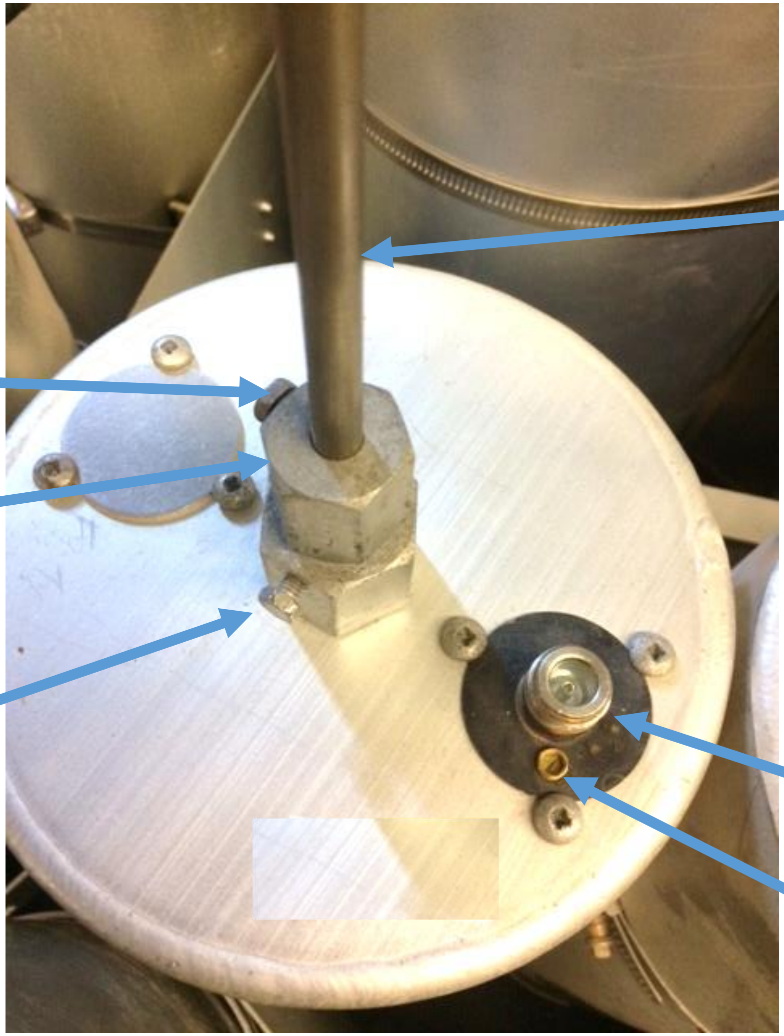
2. Unlock coarse tuning locknut

3. Move rod in to decrease resonant frequency out to increase.

4. Lock coarse tuning bolt,

5. Unlock fine tuning bolt and rotate fine tuning nut to change frequency

# Q Filter


Tuning Rod
Tuning Rod Lock Screw
Fine Tuning Bolt
Fine Tuning Lock Screw
RF Port
Tuning Capacitor (with out cover)

# Q Filter tuning

1. Loosen the upper set screw located on the fine tuning nut and move the **tuning rod** to get the desired **pass frequency**.
2. Tighten the upper set screw to set the tuning rod.
3. Loosen the lower set screw and turn the fine tuning nut with 7/8” wrench to fine tune the pass band.
4. Tighten the lower set screw once the pass band frequency is set.
5. Turn the **capacitor** set screw to position the notch at the desired **reject frequency**.
6. Measure the depth on the notch to ensure it provides a suitable level of attenuation.

7. If a greater level of attenuation at the notch is desired, turn the loop plate counter clockwise to increase the depth of the notch.
   - Note that this procedure will have the effect of increasing the pass band insertion loss as well.
   - This effect is most noticeable when the reject frequency is close to the pass frequency.
   - This procedure has minimal effect with wider spacing of the reject band.

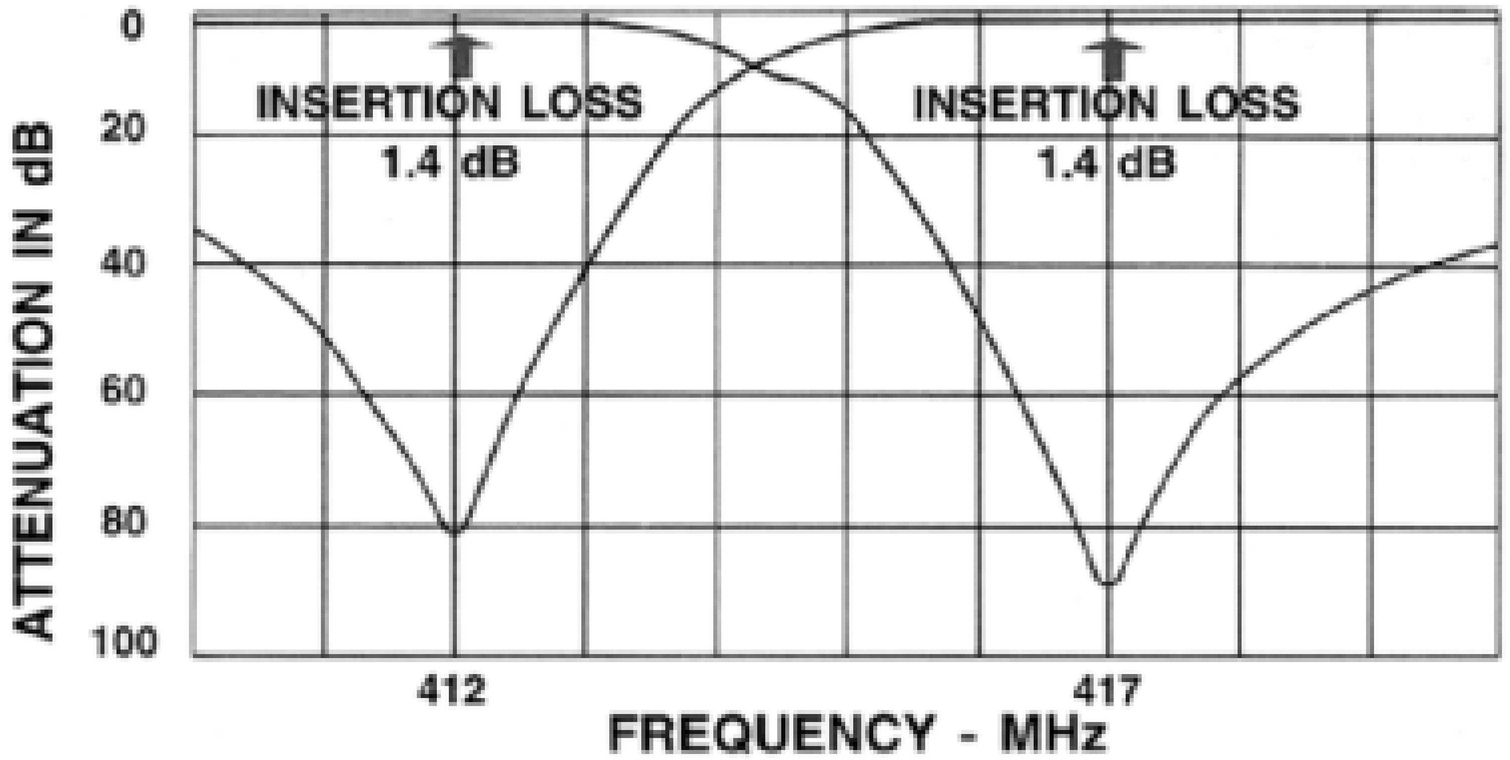
8. Verify that the pass and reject insertion losses and the return loss of the pass band are suitable and the retuning is complete.

# Duplexer (Mobile & Res-Lok)

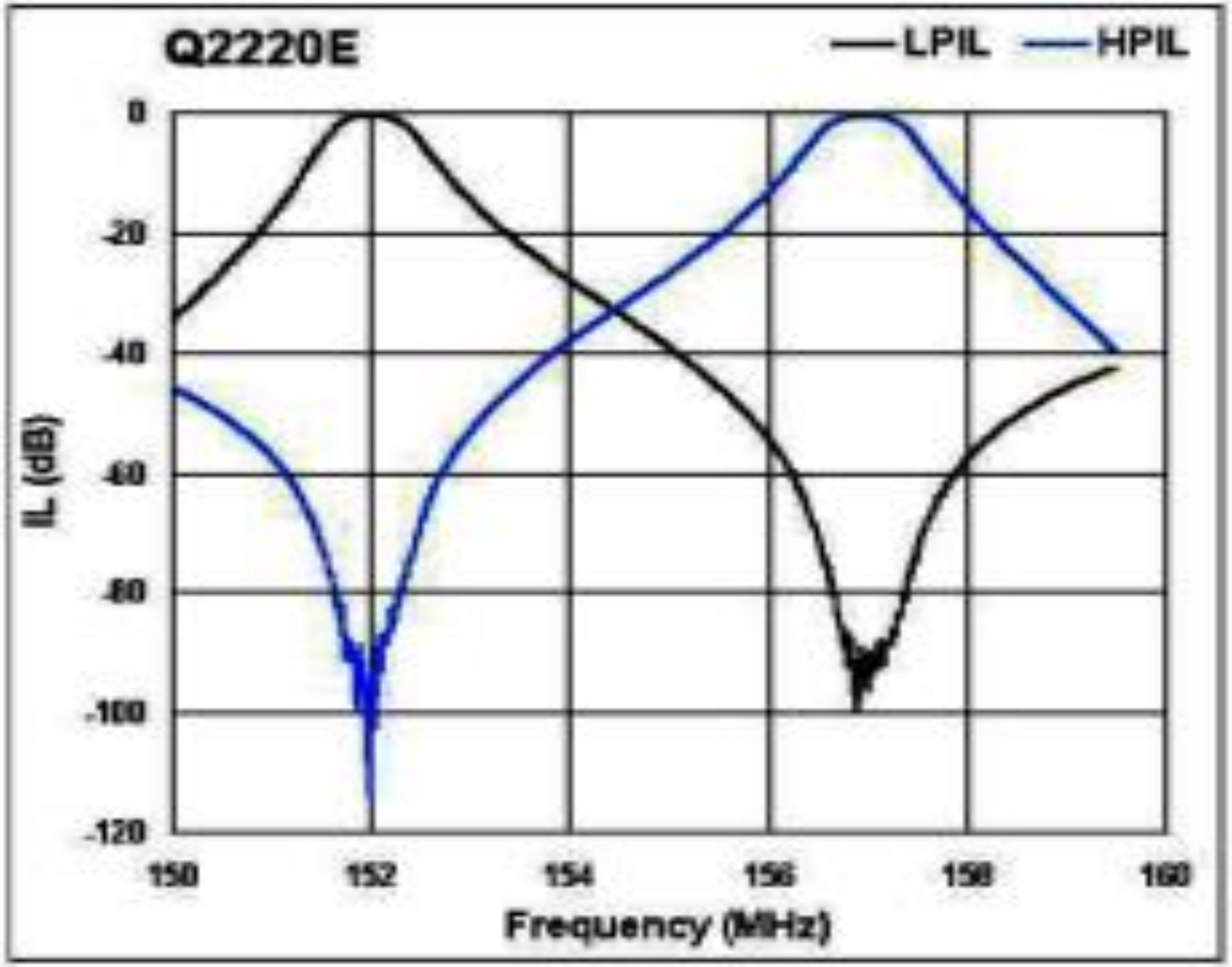
- Basically 2 sets of reject filters only in mobile type
  - Res-Lok has a set of reject and pass filters

# Response curve (mobile duplexer)

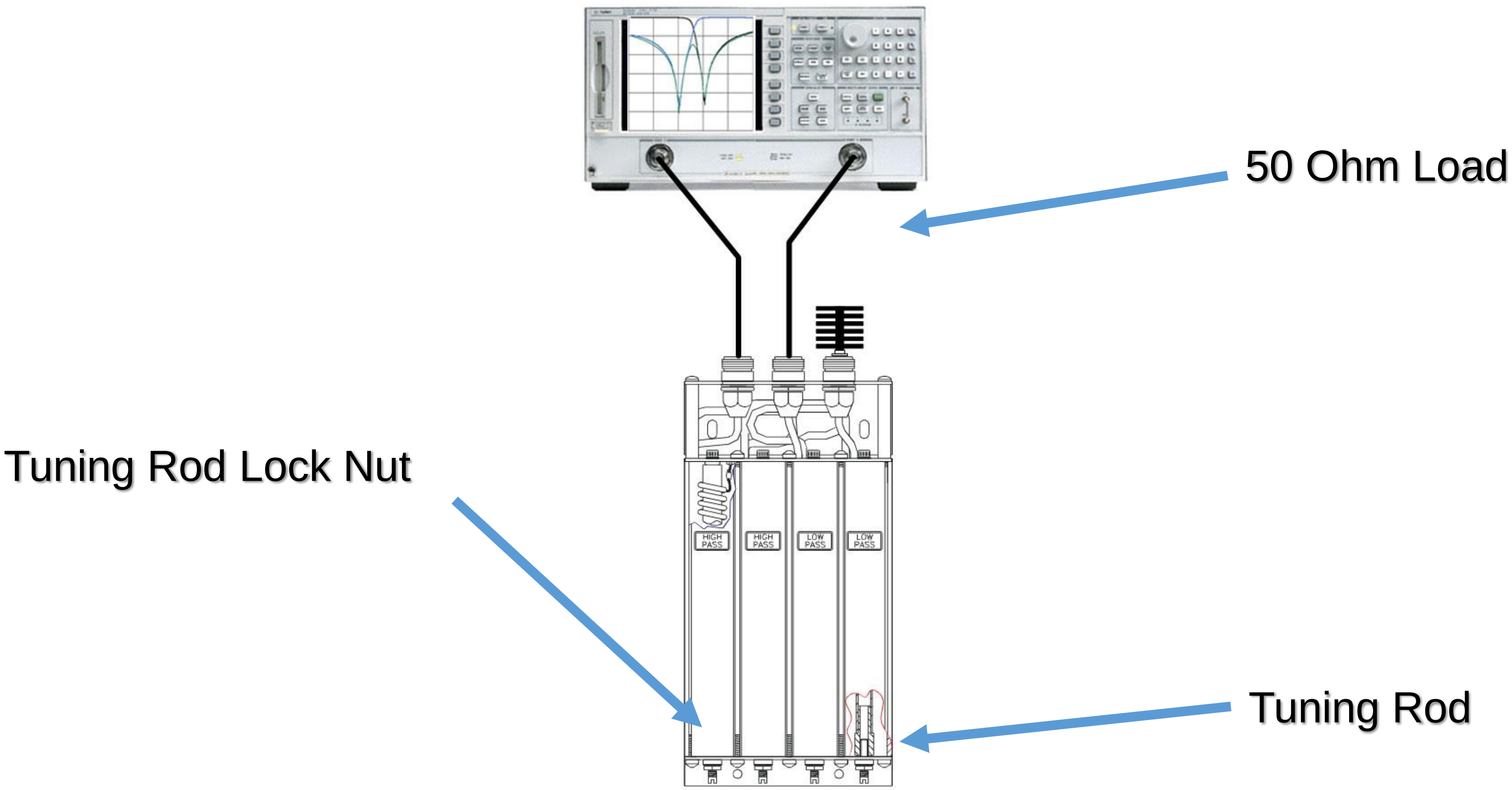
Typical Response Curve ay 5 MHz Spacing



# Response curve (Res-Lok duplexer)



# Duplexer (Mobile) tuning



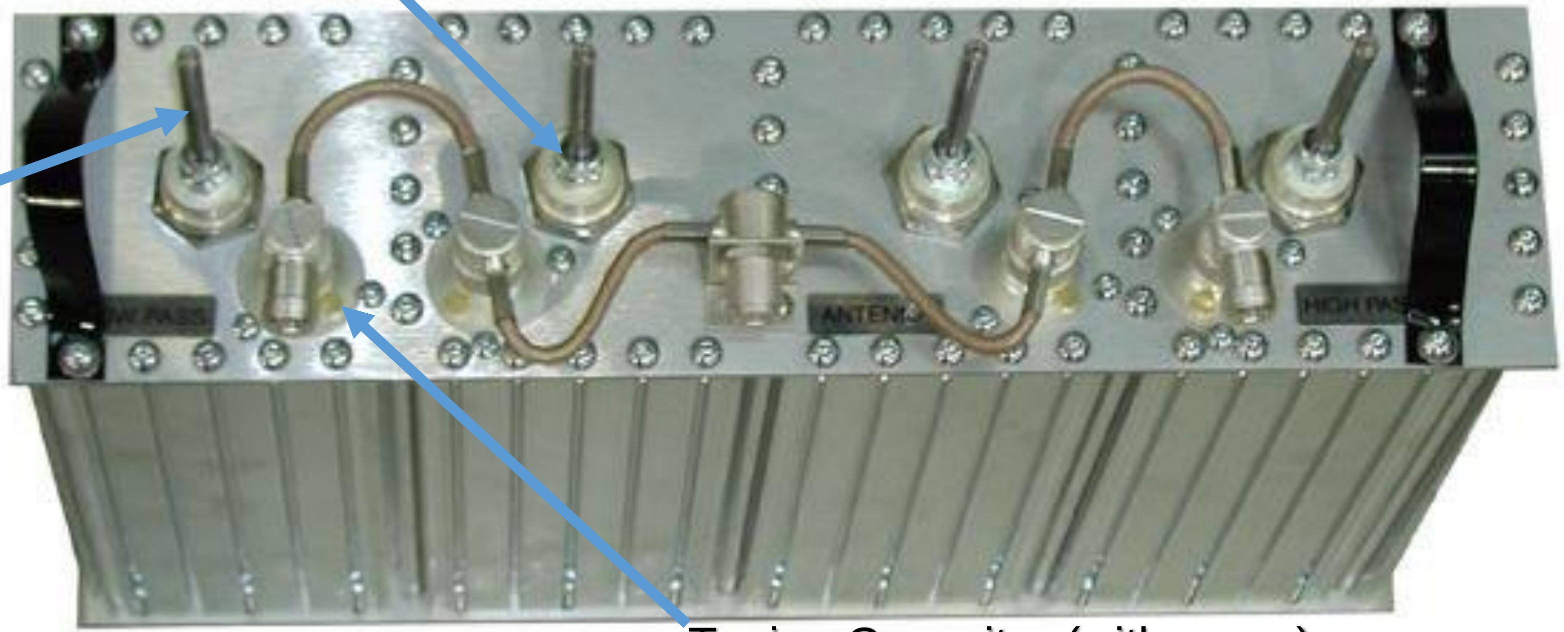
# Duplexer (Mobile) tuning Procedure

## **Retuning Procedure**

1. Unlock the tuning rod lock nuts
2. Tune the signal generator to the receiver frequency. Adjust the tuning screws of the transmitter channel for minimum signal in receiver "A". Lock the tuning lock nuts.
3. Tune the signal generator to the transmitter frequency. Adjust the tuning screws of the receiver channel for minimum signal in receiver "B". Lock the tuning lock nuts securely.
4. A final check that both high and low pass are tuned to the new frequencies is done, and VSWR is checked to be better than 1.5:1 at both frequencies.
5. Repeat steps 3-5 if required for final check.
6. The duplexer is now ready for operation.

WARNING: Do not tune the duplexer with the transmitter keyed into the duplexer.

# Duplexer (Res-Lok)



# Duplexer (Res-Lok) tuning Procedure

1. Loosen the tuning rod lock nuts
2. Set the frequency to be passed into the high pass terminal and detect it at the antenna terminal with the low pass terminal terminated with 50 Ohms. Adjust the high pass tuning rods for maximum signal.
3. Set the frequency to be passed into the low pass terminal and detect it at the antenna terminal with the high pass terminal terminated with 50 Ohms. Adjust the low pass tuning rods for maximum signal.
4. Set the frequency to be rejected into the high pass terminal and detect at the low pass terminal. Adjust the capacitors at the high pass cavities for minimum signal.
5. Set the frequency to be rejected into the low pass terminal and detect at the high pass terminal. Adjust the capacitors at the low pass cavities for minimum signal.
6. Repeat steps 2-5, and then tighten the tuning rod lock nuts securely into position. Finally check that both high and low are tuned to the new frequencies and VSWR (return loss) is 1.5:1 or greater at both frequencies.

# Repeater Desense

- Record 12db Sinad of repeater receiver (should be about -115 dbm). To verify that receiver is functioning and no excessive loss through filters.

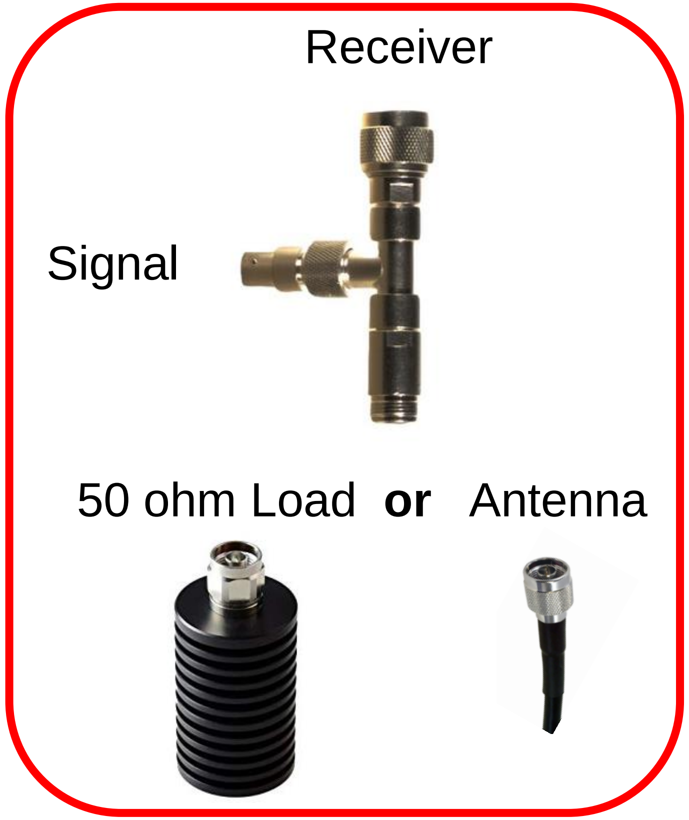
- Inject a signal through an 40db isolated T connector and record Sinad level (usually around -75dbm)

- Turn on repeater TX and record degradation of signal in receiver (should be less than 3dbm)

RF Sampler RFA-4059-A1

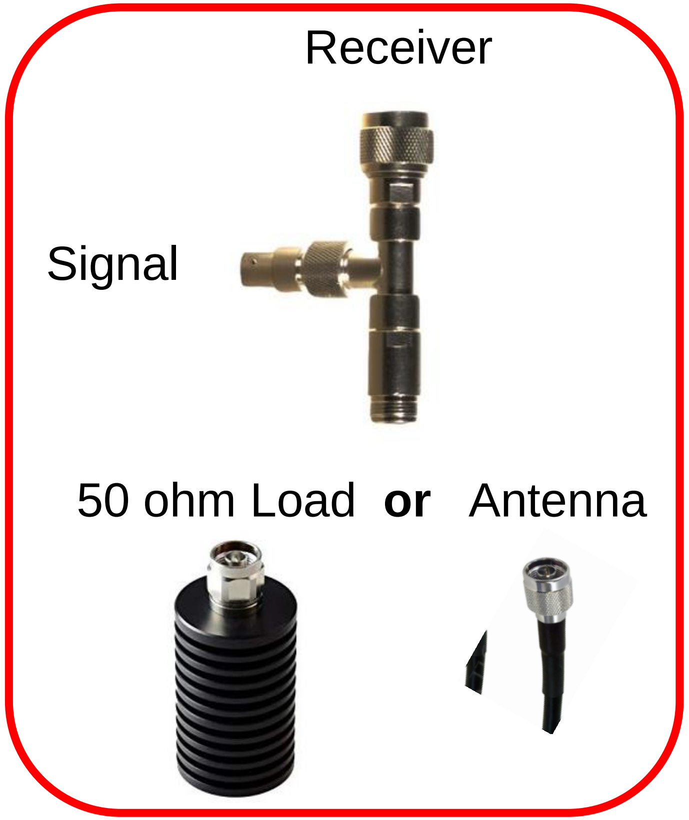
# Site noise - Analog

- Record 12db Sinad of repeater receiver (should be about -115 dbm) To verify that the receiver is functioning and no excessive loss through filters.
- Inject a signal through an 40db isolated T connector with the antenna port terminated with a 50 ohm load and record Sinad level (usually around -75dbm)
- Replace load with antenna (and filters) and record the 12 db Sinad level
- The degradation of signal due to site noise should be less than 5 dbm



# Site noise - Digital

- Put radio into RX BER test mode with laptop to perform the following test
- Record 5% BER (should be about -121 dbm) To verify that the receiver is functioning and no excessive loss through filters.
- Inject a signal through an 40db isolated T connector with the antenna port terminated with a 50 ohm load and record 5% BER level (usually around -81dbm)
- Replace load with antenna (and filters) and record the 5% BER level
- The degradation of signal due to site noise should be less than 5 dbm



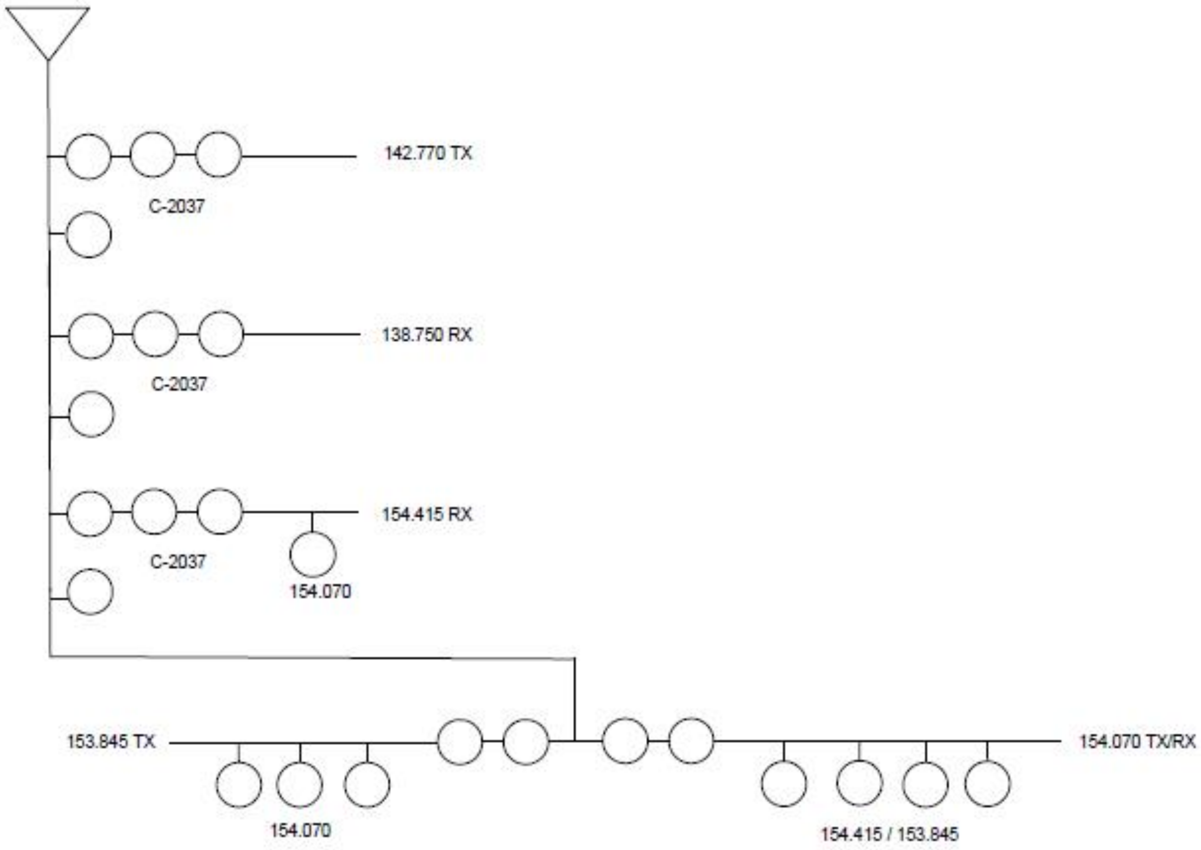
# Effective receive sensitivity

- If your receiver has a 12db Sinad reading of -116 dbm (.35 uv) and you now have 8 db of site noise your effective receive sensitivity is now -108 dbm (.89 uv)

**dBm TO MICROVOLTS CONVERSION CHART (For 50 Ω System)**

| dBm | uV | dBm | uV | dBm | uV |
|---|---|---|---|---|---|
| 0 | 224,000 | -47 | 1,000 | -94 | 4.47 |
| -1 | 200,000 | -48 | 891 | -95 | 3.99 |
| -2 | 178,000 | -49 | 795 | -96 | 3.55 |
| -3 | 159,000 | -50 | 709 | -97 | 3.17 |
| -4 | 141,000 | -51 | 633 | -98 | 2.82 |
| -5 | 126,000 | -52 | 563 | -99 | 2.52 |
| -6 | 112,000 | -53 | 501 | -100 | 2.24 |
| -7 | 100,000 | -54 | 447 | -101 | 2.00 |
| -8 | 89,100 | -55 | 399 | -102 | 1.78 |
| -9 | 79,500 | -56 | 355 | -103 | 1.59 |
| -10 | 70,900 | -57 | 317 | -104 | 1.41 |
| -11 | 63,300 | -58 | 282 | -105 | 1.26 |
| -12 | 56,300 | -59 | 252 | -106 | 1.12 |
| -13 | 50,100 | -60 | 224 | -107 | 1.00 |
| -14 | 44,700 | -61 | 200 | -108 | 0.891 |
| -15 | 39,900 | -62 | 178 | -109 | 0.795 |
| -16 | 35,500 | -63 | 159 | -110 | 0.709 |
| -17 | 31,700 | -64 | 141 | -111 | 0.633 |
| -18 | 28,200 | -65 | 126 | -112 | 0.563 |
| -19 | 25,200 | -66 | 112 | -113 | 0.501 |
| -20 | 22,400 | -67 | 100 | -114 | 0.447 |
| -21 | 20,000 | -68 | 89.1 | -115 | 0.399 |
| -22 | 17,800 | -69 | 79.5 | -116 | 0.355 |
| -23 | 15,900 | -70 | 70.9 | -117 | 0.317 |
| -24 | 14,100 | -71 | 63.3 | -118 | 0.282 |
| -25 | 12,600 | -72 | 56.3 | -119 | 0.252 |
| -26 | 11,200 | -73 | 50.1 | -120 | 0.224 |
| -27 | 10,000 | -74 | 44.7 | -121 | 0.200 |
| -28 | 8,900 | -75 | 39.9 | -122 | 0.178 |
| -29 | 7,950 | -76 | 35.5 | -123 | 0.159 |
| -30 | 7,090 | -77 | 31.7 | -124 | 0.141 |
| -31 | 6,330 | -78 | 28.2 | -125 | 0.126 |
| -32 | 5,630 | -79 | 25.2 | -126 | 0.112 |
| -33 | 5,010 | -80 | 22.4 | -127 | 0.100 |
| -34 | 4,470 | -81 | 20.0 | -128 | 0.0891 |
| -35 | 3,990 | -82 | 17.8 | -129 | 0.0795 |
| -36 | 3,550 | -83 | 15.9 | -130 | 0.0709 |
| -37 | 3,170 | -84 | 14.1 | -131 | 0.0633 |
| -38 | 2,820 | -85 | 12.6 | -132 | 0.0563 |
| -39 | 2,520 | -86 | 11.2 | -133 | 0.0501 |
| -40 | 2,240 | -87 | 10.0 | -134 | 0.0447 |
| -41 | 2,000 | -88 | 8.91 | -135 | 0.0399 |
| -42 | 1,780 | -89 | 7.95 | -136 | 0.0355 |
| -43 | 1,590 | -90 | 7.09 | -137 | 0.0317 |
| -44 | 1,410 | -91 | 6.33 | -138 | 0.0282 |
| -45 | 1,260 | -92 | 5.63 | -139 | 0.0252 |
| -46 | 1,120 | -93 | 5.01 | -140 | 0:0224 |

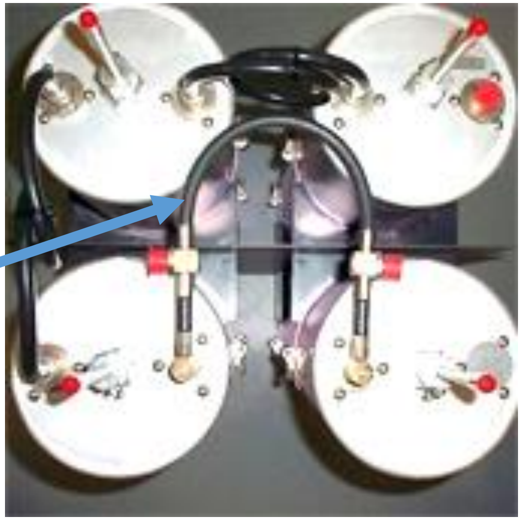
# Multicoupler




# Multicoupler Tuning

- Each “C” Series can be retuned through the system, but if major changes are to be made, it is recommended that each cavity in the system should be tuned individually.
  - Follow tuning procedures for each filter as shown earlier in this training.

- In either case the **Critical Cable** lengths in each “C” Series should not be altered.
  - The cables between the series are not critical length but should be kept as short as possible in order to keep insertion losses low.
  - Place a 50 ohm load on unused port when tuning



Critical cable

# Critical Cable Lengths

Critical Cable Lengths - Between VHF Cavities in a C-Series
132 - 140 MHz. 23" RG214 23 x 1.073 = 24.7" RG142
140 - 146 MHz. 22" RG214 22 x 1.073 = 23.6" RG142
146 - 150 MHz. 21" RG214 21 x 1.073 = 22.5" RG142
150 - 155 MHz. 20" RG214 20 x 1.073 = 21.5" RG142
155 - 160 MHz. 19" RG214 19 x 1.073 = 20.4" Rg142
160 - 167 MHz. 18" RG214 18 x 1.073 = 19.3" RG142
167 - 174 MHz. 17" RG214 17 x 1.073 = 18.2" RG142

Critical Cable Lengths - Between UHF cavities in a C-Series
406 - 420 MHz. 17.125" RG214 or 18.375" RG142
450 = 470 MHz. 15.155" RG214 or 16.26" RG142
These cable lengths are odd multiples of an
electrical quarter wavelength

Critical Cable lengths - Between the 'Tee's in a UHF C-Series
406 - 420 MHz. 14.125" RG214 or 15.155" RG142
450 - 470 MHz. 12.5" RG214 or 13.41" RG142
These cable lengths are odd multiples on an
electrical half wavelength

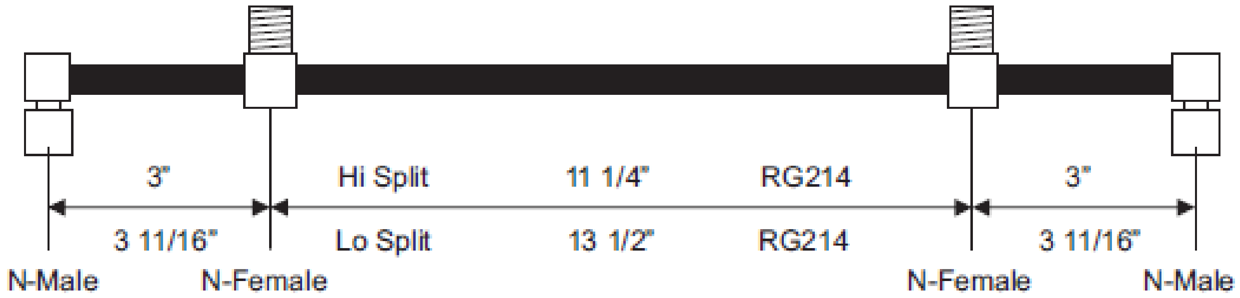
Critical Cable Lengths between hub and cavities for Star Combiner
406 - 420 MHz. 9 5/8" RG214 or 10 7/8' RG142
450 - 470 MHz. 9" RG214 or 10 1/8" RG142
Un-Used port stub is 1/4 wavelength
These cable lengths are an electrical half wavelength
**NOTE: Each connector adds 5/8" to the length of the cable!**

High UHF length x 1.13 = Low UHF length

RG214 length x 1.073 = RG142 length

Q-Filters use the same critical length jumpers as C-Series

Hi Split: 160 – 174 MHz
Lo Split: 138 – 160 MHz

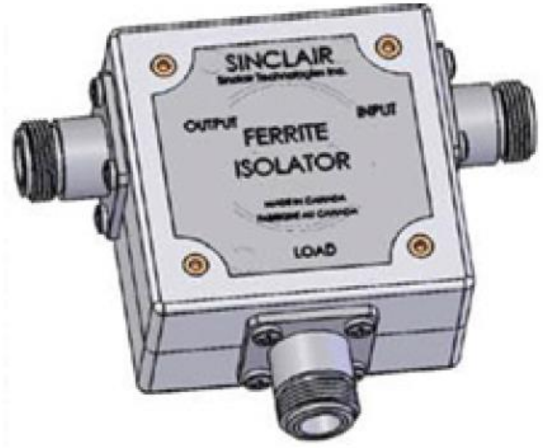


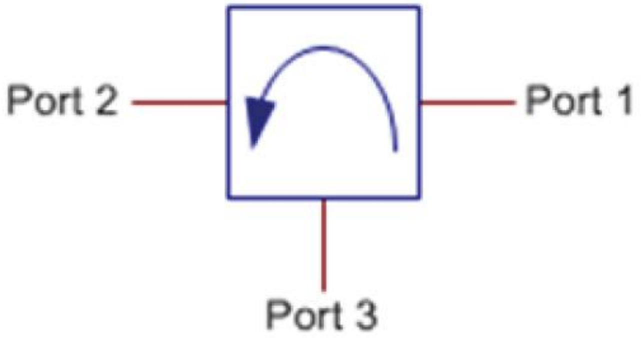
# Isolators and Circulators

- The most popular use of an isolator is to control interference from intermodulation.
  - It also protects its transmitter's power from overheating by keeping reflected power from flowing back toward the transmitter.
  - Shown here is a single stage Isolator

# Circulator

- A circulator is a three-port device which allows one to route signals in a specific direction.
  - When a signal is applied to port 1 it will be output on port 2
  - Similarly, any signal on port 2 will travel through the circulator and will be output on port 3
  - Finally any signal which enters port 3 will be output on port 1

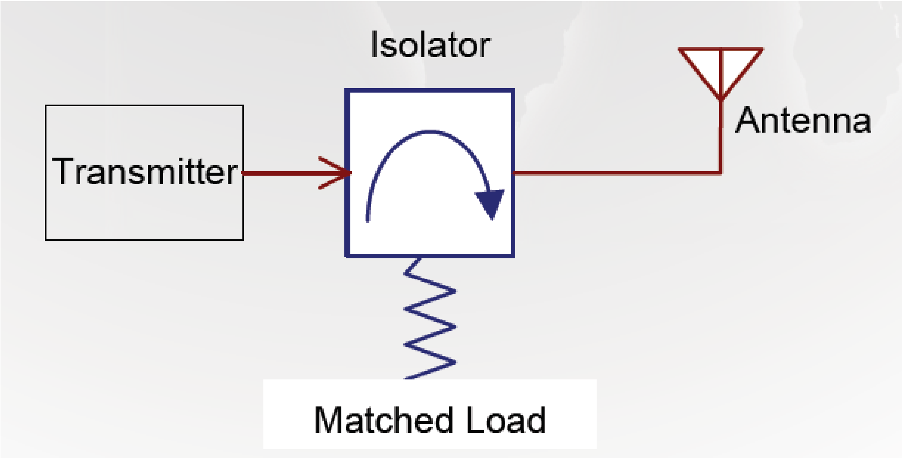



  - When you add a 50-ohm load to port 3 it now becomes an Isolator

# Isolator use

- The transmitter is connected to an antenna through an isolator.
  - When everything is functioning properly, the transmitted signal reaches the antenna through the isolator.




  - One such scenario might be when an antenna is bent by high wind or the antenna-feedline becomes an open circuit.
  - An open circuit on the antenna-feedline will cause a total reflection of the TX power.
    - The signal enters the isolator which is routed to the load and dissipated as heat.

# Isolator use (cont'd)

- Another way the transmitter is isolated from the load is in impedance matching.
  - If the transmitter output impedance is not matched to the load, then a reflection will occur
- The system may start matched, varying conditions, such as antenna icing, may change the load impedance.
  - Without the isolator, the transmitter will then see different impedances, probably affecting its output power
- Using the isolator means that the transmitter power is always entering a matched 50-ohm load.
  - Therefore what ever happens beyond the isolator is not visible to the transmitter

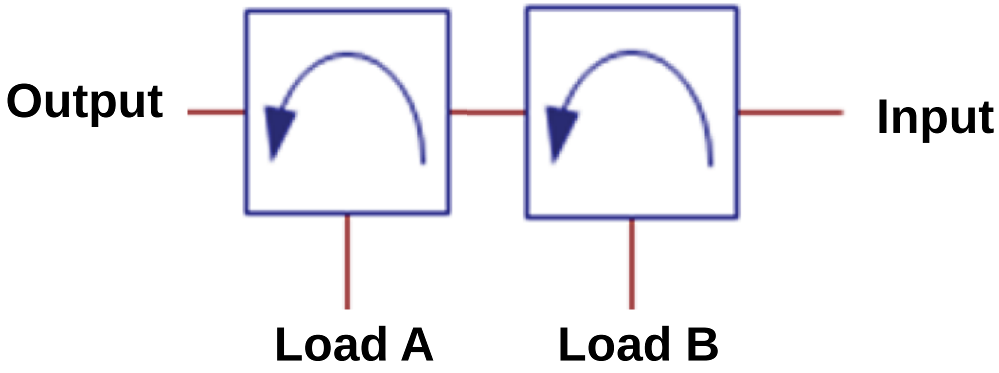
# Dual-Stage Isolator

- In the real world, no isolator is perfect. A single-stage isolator will typically have 35 db of isolation which may not be enough.
  - If system power levels are high, a dual-stage isolator may be required

# Dual-Stage Isolator (cont'd)

- The input signal enters the first isolator at the input port and passes through the first stage.
  - Then it enters the second stage where it passes through to the output port.

- A reflected signal entering the output port is routed through to the larger load attached to the load port of the second stage.
  - Since no match is perfect, a small amount of power will enter the first stage of the dual isolator after being reflected from the larger load




  - As a result, the dual isolator will supply an assured higher-degree of isolation than the single.

# Main Isolator Application

- The use of isolators is highly recommended whenever two or more transmitter's are combined into a single antenna.
  - It may also be needed when other transmitters in the same frequency band are co-located on the same or nearby antenna structure

- There are no perfect combining methods.  Some of a transmitters signal will get through the combining equipment to other transmitters.
  - The signal if not stopped can enter the final output stage of the transmitter power amplifier
  - It will mix with the desired signal and produce intermodulation products
  - The intermodulation products have the potential to occur on receive frequencies and produce interference