INSTALLING AMATEUR RADIO DUPLEXERS

According to ARRL, 12,600 amateur radio repeaters are in-service in the United States and that includes a lot of duplexers. Duplexers acquired from a manufacturer are tuned to the repeater frequencies and contain the required number of cavities required for that particular repeater. If you have purchased duplexers that are used, they must be tested and retuned which will add to the complexity of the installation. The biggest mistake individuals make, they assume that if the duplexers are tuned, all you need to do is connect the antenna and repeater and it should work.

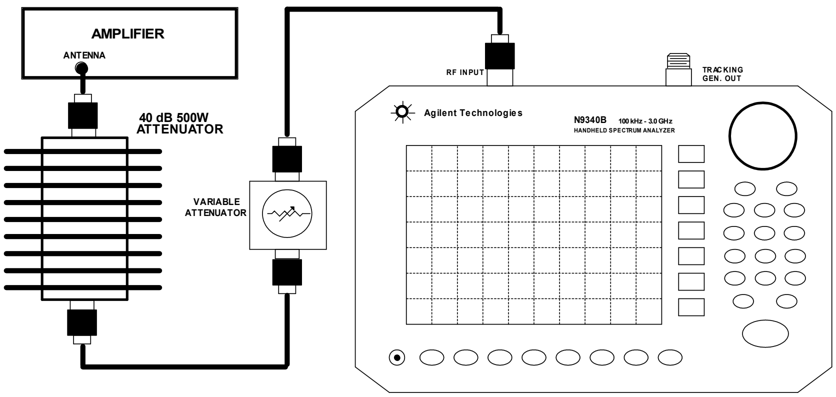
Duplexers are tuned at the factory using Vector Network Analyzers (VNA) that have a high dynamic range (hdr) that exceed 120 dB and cost $40 K to $60 K. 4 cavity duplexers are more common, with 6 cavity being used for the high power repeater systems. The factory tunes every duplexer cavity port to perform properly when connected to a 50 ohm impedance. When you connect any device to a duplexer port that does not have a 50 ohm impedance, it will detune the cavity. If there's not enough margin in your duplexer requirements, the performance of the repeater will suffer.

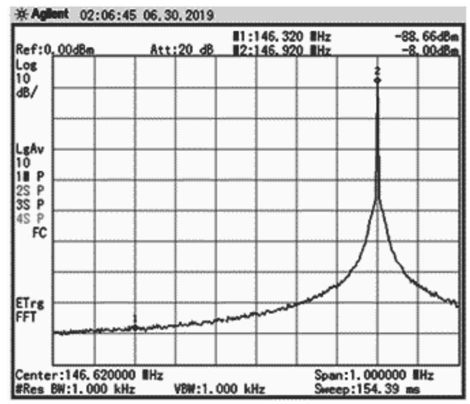
Properly installing duplexers requires test equipment that's not normally found in an amateur's toolkit. You need an instrument that connects directly to the coaxial cable end attaches to the duplexer, measures impedance (Z) and uses an "N" type connector. VNA's are the instrument of choice because they are very accurate when calibrated. Fortunately, you don't need a $40K VNA to perform most of the tests required to install duplexers. The MFJ-226 is less than $400, but is only a single port (S11) VNA and can measure insertion loss (S21) measurements. I used a Mini Radio Solutions (mRS) miniVNA Tiny that was purchased from Ham Radio Outlet for about $500. This is a 2 port VNA that has a frequency range of 1 MHz to 3 GHz. "Beware" China has copied this VNA, but the copy does not equal the accuracy of the Min Radio Solutions instrument. The China model looks exactly like the original, but doesn't have the Mini Radio Solution name on it. The dynamic range of the MiniVNA Tiny is only 70 dB, which means that it can't be used to tune duplexers. Pocket VNA is another company that sells a 2 port VNA that has a frequency range of 1 MHz to 4 GHz and sells for about $450.

When purchasing new duplexers, the manufacturer will require you to supply the repeater's frequencies and transmitter's output power. It's up to customer to know if a 4 or 6 cavity duplexer is required for your repeater. When purchasing used duplexers, you will still need to determine the number of cavities needed and have the test equipment to retune the duplexer. The repeater transmitter's "absolute noise" level at the repeaters receive frequency and the receiver's sensitivity determines the number duplexer cavities needed. The repeater specifications will provide the receiver's sensitivity and output power, but the carrier to noise level at the receive frequency will not be included and has to be measured. The formula below can be used to determine the minimum level of rejection needed by the duplexer transmit cavities.

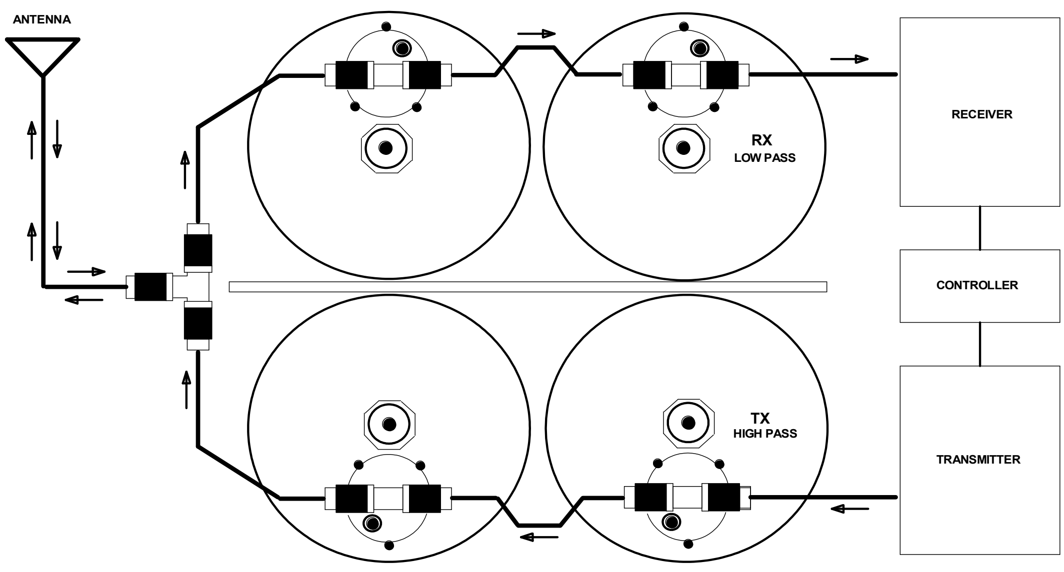
Power	46.34 dBm (43 W)
Carrier to Noise Delta	-88.66 dBm
Absolute Noise Level	-42.32 dB
RX Sensitivity	-127.0 dBm (0.1 µV)
Absolute Noise	-42.32 dBm
	-84.68 dB
RX Cavity Insertion Loss	-1.85 dB
Minimum TX Cavity Rejection	82.83 dB

Carrier to Noise Measurement – All transmitter's generate a degree of noise on each side of the carrier frequency and the noise level at the receive frequency must be rejected by the transmit cavities. The test setup below shows how to measure the carrier to noise level. The carrier to noise level was 88.66 dBm and the formula shows that the minimum transmit cavity rejection needs to be 82.83 dB. 8 inch diameter 4 cavity duplexers provide 80 to 90 dB of rejection and 6 cavity duplexers 110 to 120 dB when "new". Time and environmental conditions cause insertion loss to increase and rejection level change over time. If you have purchased used duplexers, don't be surprised if the cavities do not comply with the manufacturer's specs.





According to the calculations, the transmit cavities need a notch level of 82.83 dB. This notch level would prevent the transmitter noise from desenning the receiver. In reality, this is the minimum amount needed and doesn't leave room for any detuning caused by terminating a duplexer ports with somethiong other than 50 ohms or temperature changes at the repeater site. I normally add an additional 10 dB to this calculated figure to allow for any anomalies.

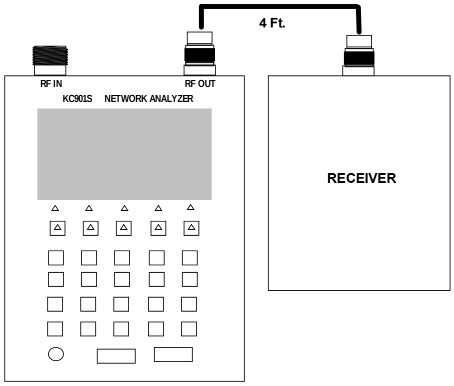


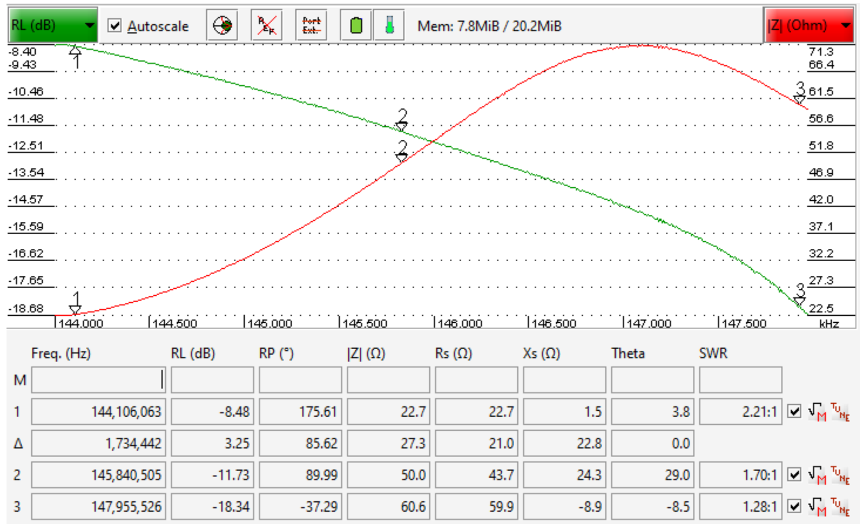
Typical Four Cavity Duplexer

It's very important that each port of the duplexer be terminated with an impedance of 50 ohms and any port terminated with something other than 50 ohms will affect the other ports. An impedance mismatch detunes the cavities and the degree depends on cavity circuit quality (Q).

The following pages will show how to measure the impedance at the coaxial cable end that attaches to the duplexer receiver, antenna and transmitter ports.

Receiver Input Impedance – Receiver specifications never provide the receiver's input impedance, so it must be measured at cable end.

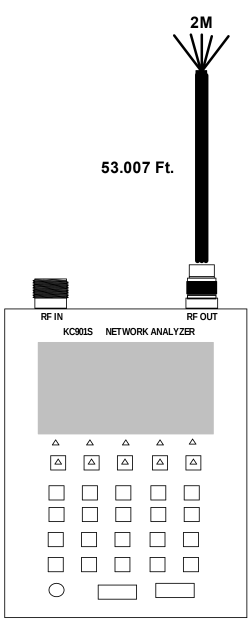


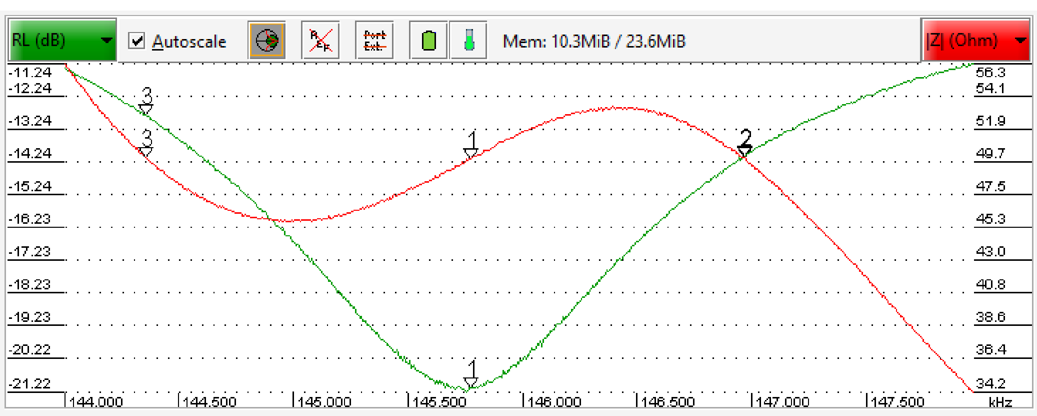


	Freq. (Hz)	RL (dB)	RP (°)	|Z| (Ω)	Rs (Ω)	Xs (Ω)	Theta	SWR
M								
1	144,106,063	-8.48	175.61	22.7	22.7	1.5	3.8	2.21:1
Δ	1,734,442	3.25	85.62	27.3	21.0	22.8	0.0	
2	145,840,505	-11.73	89.99	50.0	43.7	24.3	29.0	1.70:1
3	147,955,526	-18.34	-37.29	60.6	59.9	-8.9	-8.5	1.28:1

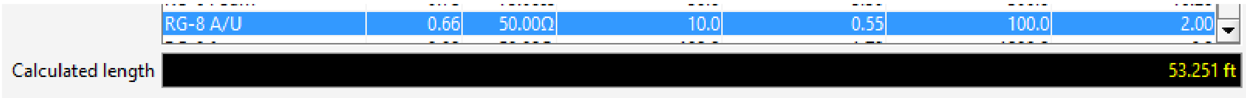
The above VNA chart shows the impedance (Z) and return loss (RL) measured at the end of a 4 foot cable that was connected to a base station Kenwood TR-7950 radio. This chart is a good example of why manufactures don't include the receiver input impedance specification. Base station radio receiver input circuits use fixed bandpass filters to reject out-of-band signals. This Kenwood radio impedance was 50 ohms (RED line) at 154.840 MHz's and return loss (Green line) of -11.73 dB which equals to a match efficiency 93%. I prefer a RL that's better than -15 dB. If you order a repeater from a manufacturer, they will tune the receiver input circuit for an impedance of 50 ohms at your receive frequency. If you purchased a used repeater, you will need to retune the bandpass filter. If you build a repeater using base station radios, the bandpass filter is usually a fixed circuit. In this case, you may need to install a tuner at the receiver or install a preamp that has a 50 ohm ports.

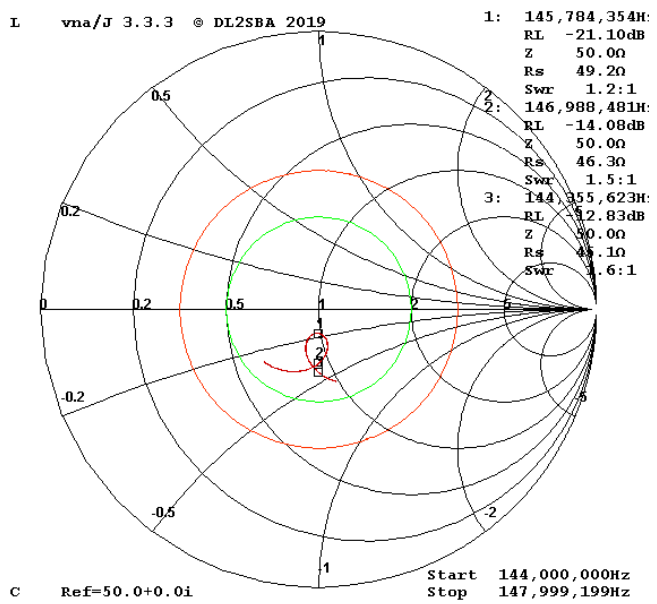
Antenna Impedance – This chart shows a Cushcraft A270 2M antenna impedance and return loss response. The impedance range was 34.2 to 56.3 ohms, with 50 ohms occurring at 144.355, 145.784 and 146.988 MHz's. The VNA calculated the feedline length as being 53.251 feet.





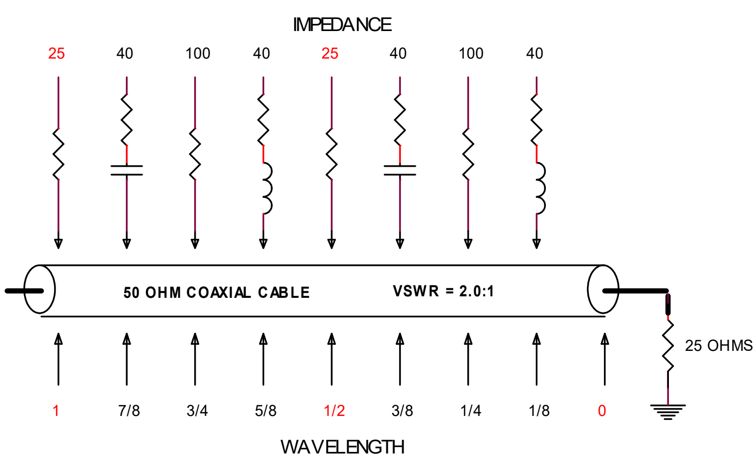
	Freq. (Hz)	RL (dB)	RP (°)	|Z| (Ω)	Rs (Ω)	Xs (Ω)	Theta	SWR
M								
1	145,784,354	-21.10	-90.17	50.0	49.2	-8.7	-10.1	1.19:1
Δ	1,204,127	7.02	0.24	0.0	2.9	10.3	0.0	
2	146,988,481	-14.08	-89.93	50.0	46.3	-19.0	-22.4	1.49:1
3	144,355,623	-12.83	-89.93	50.0	45.1	-21.7	-25.7	1.59:1

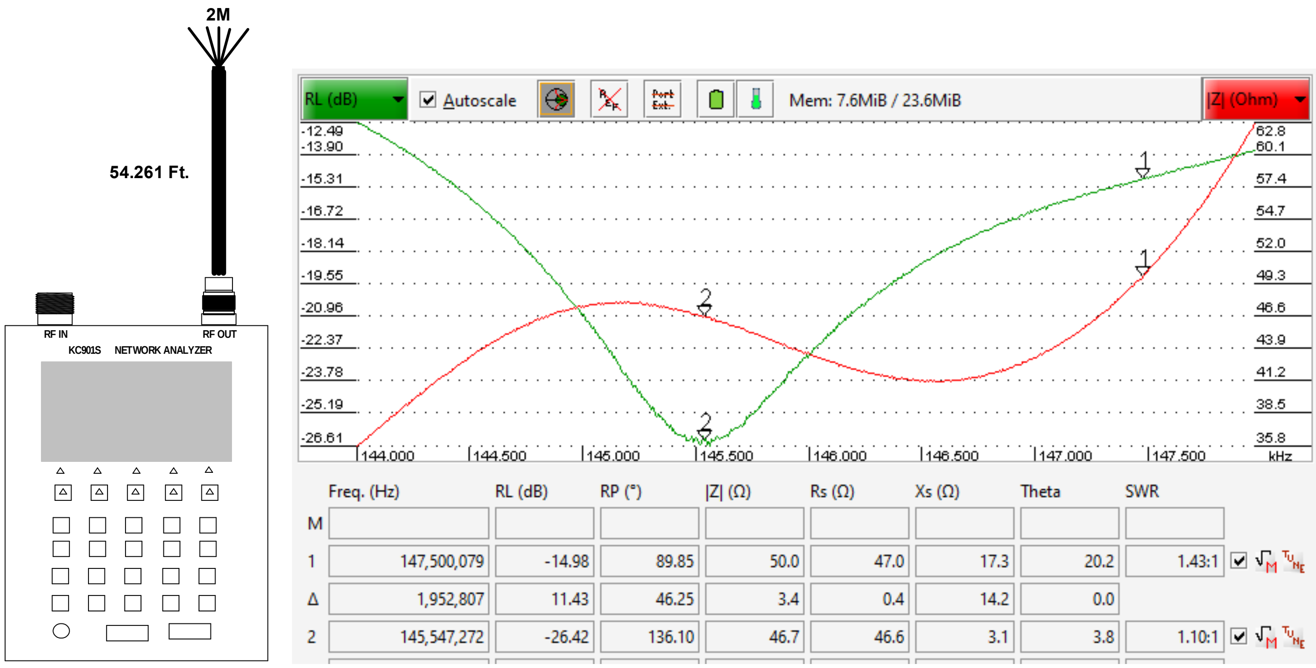


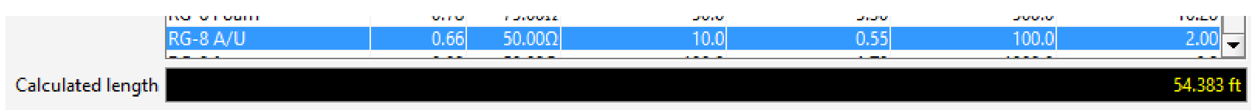


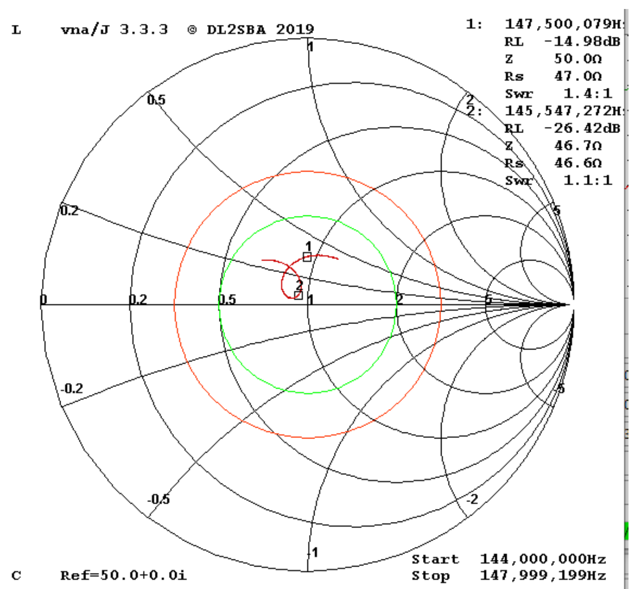
Although this antenna has three frequencies that would provide a 50 ohm impedance for the duplexer, your repeater frequency pair may not match one of these frequencies. If this occurs, the antenna would have to be re-tuned and this could be a problem if the antenna is mounted on the tower. As a last resort, you can change feedline length to match the 50 ohm impedance required for your repeater frequencies. The minimum amount reflected power (RL) -21.10 dB occurred at 145.784 MHz's which results in a match efficiency of 99 %. The Smith Chart shows that that the antenna is non-resonant and the line impedance is capacitive at 53.251 feet.

The VNA chart on the next page shows the results of increasing the cable length to 54.383 feet. This caused the minimum amount of RL to move from a frequency of 145.784 MHz to 145.547 MHz's and RL level to -26.42 dB. Normally, changing the line length would not change the frequency or the return loss (RL) level, but in this case, the feedline is acting a part of the antenna. This antenna does not include any type of RF choke at the antenna port. The Smith Chart shows that the impedance at this line length (54.383 ft.) is inductive. Most antennas designed for base station use will not provide a 50 ohm impedance over the repeaters 600 kHz bandwidth. Repeater antennas like the DB224-E and DB516 have a bandwidth of 12 MHz's and are not adjustable. The drawing below shows how the impedance can be resistive, capacitive or inductive.

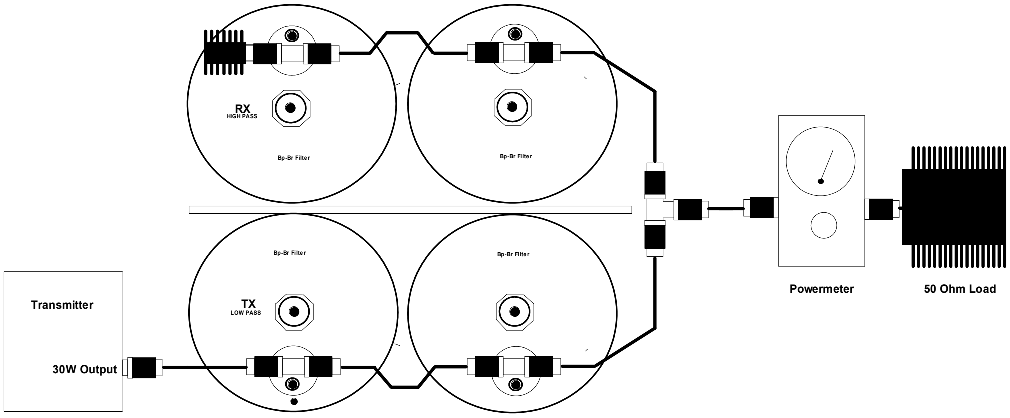




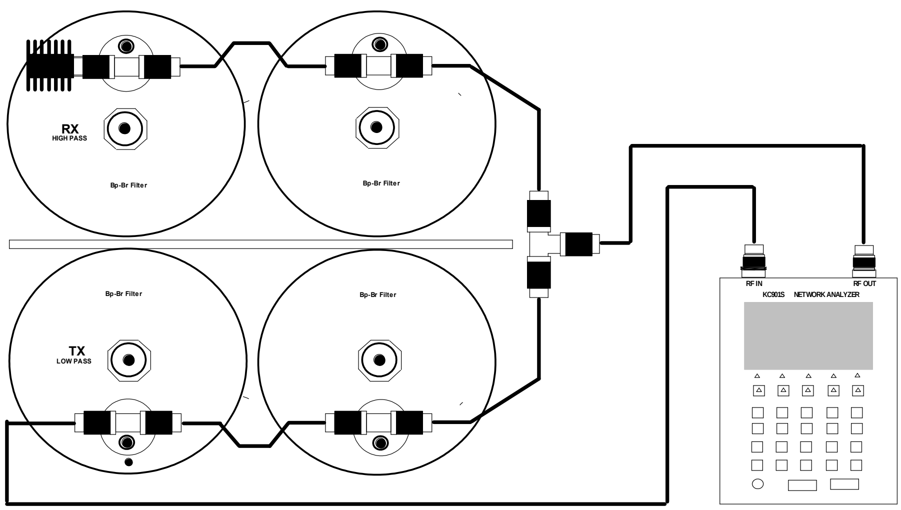


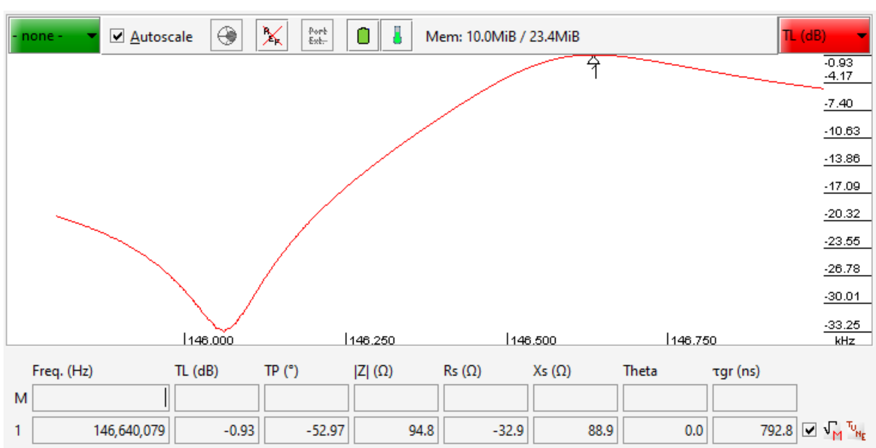


Transmitter Impedance – The test setup on the next page shows how to determine if the transmitter impedance is detuning the duplexer cavities. Connect the power meter directly to transmitter terminated with a 50 ohm load and record the output power. Reconnect the cable to the transmit cavity and then measure the power at the duplexer antenna port. Make sure the receiver port is terminated with a 50 ohm load. **Do not** measure the power by inserting the power meter in-line with the antenna. Using the manufactures insertion loss (IL) spec, determine what the output power should equal. Example: 30W (44.9 dBm) – 1.8 dB I.L. = 43.1 dBm (20.4W).



If the insertion loss is unknown, use the VNA's S21 mode and the test setup below to determine the insertion loss (I.L.).



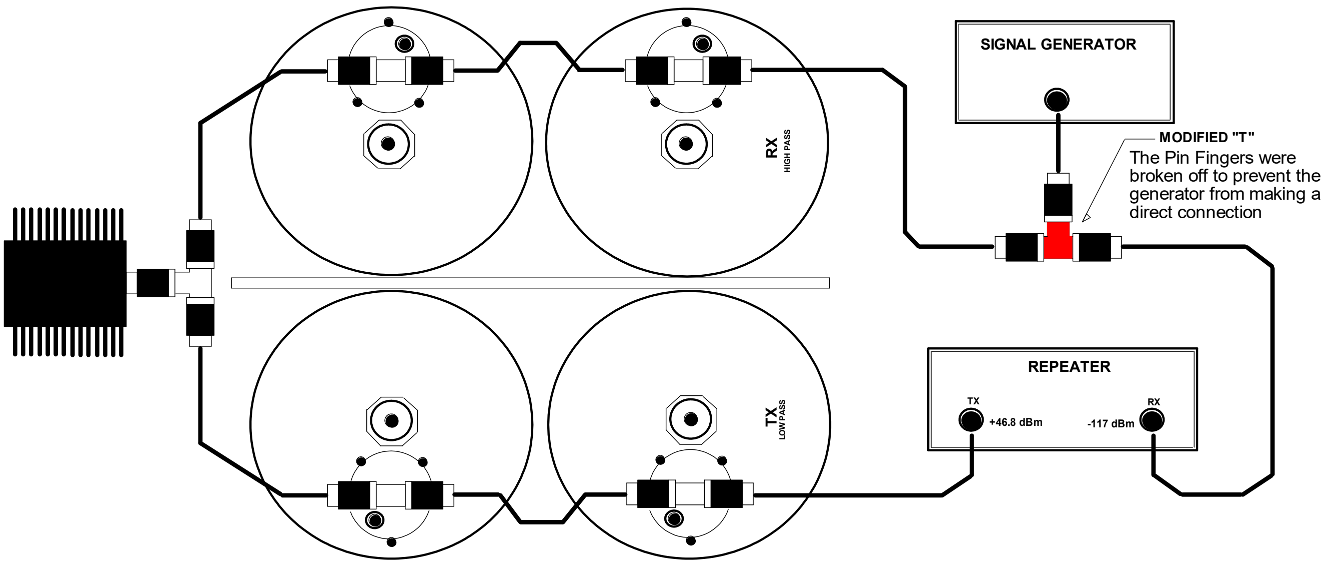


This chart shows the high pass band insertion loss was 0.93 dB for a single Wacom cavity.

If the transmitter output power is lower than calculated "**Do Not**" adjust the cavities!! Try changing the coax length between the transmitter and duplexer. If this does not work, install a tuner at the transmitter output and adjust the tuner until the output power is correct.

Receive Desensitization Test – This test ensures that the transmit cavities are providing adequate attenuation to the receive signal noise generated by transmitter. Note: The “Tee” connector port that the signal generator is attached to has the pin fingers broken off to prevent a direct connection. This requires a higher generator output level, but prevents the generator 50 ohm impedance from interfering the normal flow of RF.

This test procedure requires that the transmitter be disabled and the receiver squelch open. The signal generator output is adjusted so that the signal is barely heard in the squelch noise. The transmitter is enabled at its normal output power and the signal + noise heard by the receiver’s speaker should not change. If a change does occur, it indicates that the transmit cavities are not providing enough rejection to the transmitter noise. To correct this this type of problem, the transmitter output power can be reduced or an additional cavity can be added to the transmit side.



An alternate way to test for receiver desense problem is for the repeater technician to catch a stationary station that’s noisy into the repeater. Disable the repeater transmitter, the in-coming noisy signal should still be noisy when listening to the repeater speaker. If the noisy signal clears up, the transmitter’s noise is not being attenuated by the transmit cavities. If your repeater does not provide a method to disable the transmitter or have a speaker, have the noisy station make a long test transmission and connect the repeater antenna cable to a HT. If the in-coming station is clear, then either your receive cavities have too much attenuation or the transmit cavities are not attenuating transmitter sideband receive noise.

Note: Receive desense problems usually go unnoticed unless radio operators start complaining about hearing the repeater noise free, but they require additional output power to reach the repeater.

Summary – Of the more than 12,000 repeaters in-service, how many groups payed $2000 to $3000 for duplexers and spent 30 minutes installing them? Too many.

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