

Understanding, Maintaining & Re-Tuning Antenna Duplexers

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Forward

A technical bulletin on this subject was prepared in 1990. Since then, antenna duplexers have continued to increase in numbers and many new designs have appeared in the marketplace. This bulletin will review antenna duplexers with emphasis on the theory of operation, methods of tuning and maintenance of them.

Duplexer, Defined:

The terms *duplexer* and *diplexer* have been used interchangeably for many years. The prefix "Di" is defined as "twice, double or two-fold." The prefix "Du" means two or dual. "Plex" from the latin word *plexus* has, among other meanings, the definitions: "An inter-woven arrangement of parts; A network." Thus we can conclude that *duplexer* and *diplexer* have the same literal meaning. It is noted that *duplexer* has been used with regard to wireless (land mobile) systems and *diplexer* has been used in microwave system application. We will stay with *duplexer* to refer to the devices covered in this bulletin.

Duplexer Applications

A duplexer provides the means for simultaneous operation of a mobile relay or repeater station having separate TX and RX frequencies when using a common antenna. The benefits of this include: Saving one antenna and one transmission line, compared with using separate transmit and receive antennas for a repeater, maintaining reciprocal receiving and transmitting signal path characteristics compared with separate, TX

and RX antennas, and providing sufficient filtering to prevent both transmitter carrier power and wide band noise from desensitizing the associated receiver.

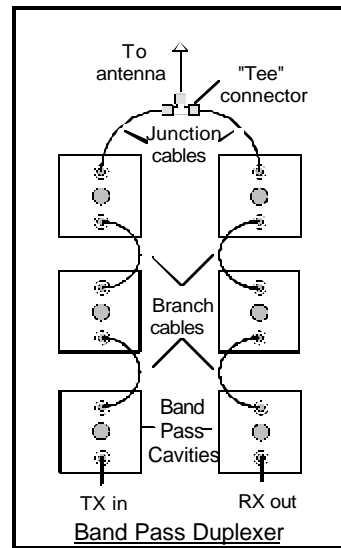


Figure 1

Duplexer Types

There are two basic types of duplexers, Band Pass and Band Reject. The easiest one to understand is the band pass duplexer.

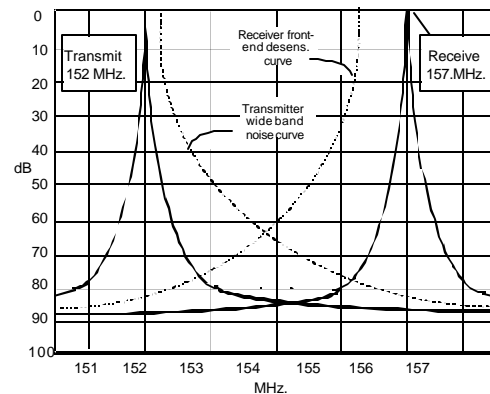


Figure 2 Band Pass Duplexer Response

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A band pass duplexer using six band pass type cavity resonators is shown in schematic form in Figure 1. Note that each branch has three cavities connected together with cables. A "tee" junction and two more cables connects the two branches with the antenna feed line. Sufficient selectivity must be provided by the cavity filters to preclude transmitter carrier power from desensitizing the relatively broad response of the receiver front end and to also reduce transmitter wide band noise to a level below the threshold of receiver sensitivity. In this example we show a VHF duplexer operating at a 5 MHz. transmit-receive frequency offset.

Typical selectivity curves of the three cavity resonator groups in each duplexer branch are shown in Figure 2. Two other curves are shown to represent the transmitter wide band noise spectrum and the desensitization curve of the receiver front end. Note that each filter branch provides attenuation of signal power equal to or greater than the noise and desensitization levels.

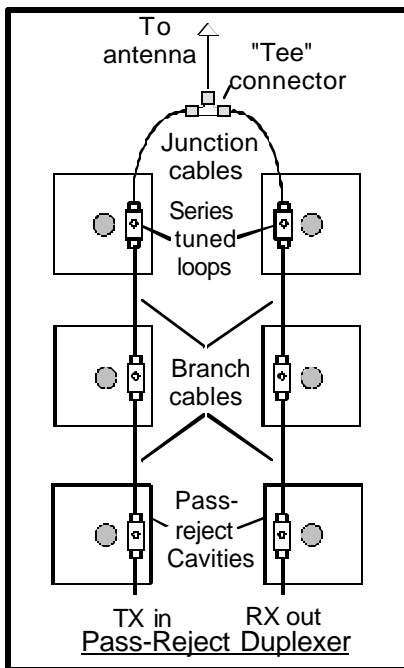


Figure 3

Most duplexers found in land mobile wireless service are pass-reject or pass/notch types, shown schematically in Figure 3. Note that each cavity has only one coupling loop. The loop has a series capacitor, which is adjustable to resonate the loop itself, providing a reject notch when adjusted to a desired frequency.

The loop also couples energy into the cavity at the desired coupling factor, producing a relatively broad pass band selectivity. The notch can be placed either above or below the resonant frequency of the cavity, as needed. The typical performance is shown below.

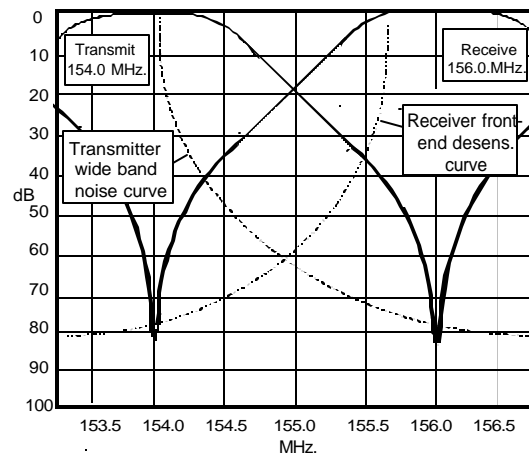


Figure 4 Pass/Reject Duplexer Response Curves

Figure 4 shows responses of a VHF pass-reject duplexer with transmit to receive spacing of 2 MHz. Note that the pass responses are quite broad. The overall notch depths are very sharply defined and sufficient in depth to equal or exceed the noise and carrier "desense" requirements.

Performance Comparisons

There are good reasons for selecting band pass or pass-reject types according to site and/or system requirements. Each type has benefits and shortcomings compared with the

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other type. Some of these are:

Band Pass Type:

- ◆ Generally will have higher branch loss than pass-reject type, 1.5 dB per branch or higher being expected.
- ◆ Far superior for dense site use. The multiple cavity strings provide added selectivity for the receiver and a high order of spurious and harmonic rejection for the transmitter.
- ◆ Requires larger, higher “Q” cavities, and more of them, resulting in higher cost and need for greater site space occupancy.
- ◆ Through use of correct branch cable lengths and careful loop coupling adjustments, this duplexer type can be tuned for a broad “nose” response to accommodate multi-frequency transmitters and receivers.
- ◆ Impractical for closely spaced TX-RX pairs, compared to pass/notch types. Higher costs than pass notch types due to requiring larger cavities.

Band Reject (Pass/Notch) Types:

- ◆ Lower insertion loss than band pass types for same TX-RX spacings.
- ◆ Since pass band is broad, little help is provided in receiver front end selectivity except for the transmit carrier notch. This can be a real problem when placed at high density sites.
- ◆ Can use smaller volume cavities for a given TX-RX spacing, saving space.
- ◆ Lower cost to manufacture; savings in materials and labor.

Special Duplexer Types

At today’s overcrowded land mobile sites, there are often conditions that require unusual pass band and notch responses. The characteristics of the two basic duplexer types may be combined where system needs dictate.

Some examples are:

- ◆ Adding pass-reject cavities to one or both branches of a band pass duplexer to notch out a bothersome transmit frequency that is close to the receiver branch frequency.
- ◆ Adding band pass cavities to a pass-reject duplexer to increase the effective front end *selectivity* of a receiver or to help in the attenuation of transmitter wide band noise.
- ◆ Internal duplexers installed in portable radio and cellular units often employ ceramic resonators. A wide T-R spacing and broad range of transmit and receive sub groups can be covered in this manner mostly due to the low transmit power levels concerned.

Mobile Duplexers

Duplexers are provided for use with low power base stations such as control stations and mobile transceivers. Since they are isolated by distance from multi-use sites the benefits provided by larger fixed station duplexers are not required.

Both small size and economy are possible in these designs. Most of these units employ simple *band reject* operation. Through lighter coupling factors from 20 to 30 dB of notch depth per cavity is secured. This is adequate for the lower transmit power involved in mobile and low power bases.

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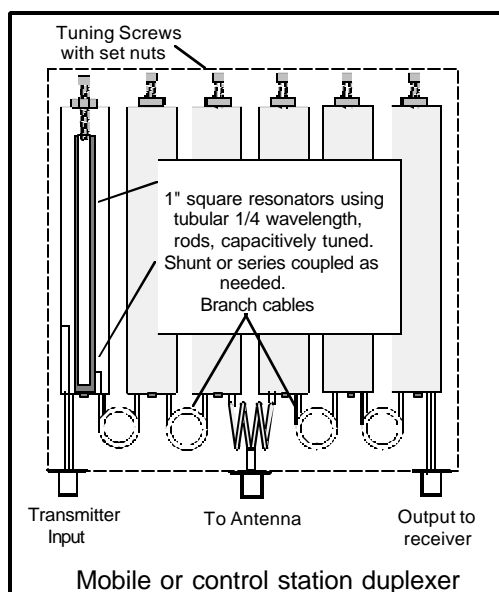


Figure 5

- ◆ Because of the lower circuit “Q” there is very little *band pass* effect, however, more than 60 dB of overall notch depth can be secured by using three cavities in each branch.
- ◆ The relatively small overall dimensions suit vehicular trunk or under dash mounting and there is often space within a control station for a duplexer.
- ◆ Most mobile duplexers are limited to 50 to 75 watts input maximum, and some are limited to intermittent service above 50 watts of power. A few can be found that are rated to 100 watt input, continuous duty rating.
- ◆ Successful designs are “ruggedized” to survive under the vibration, heat, cold and humidity that can be present in vehicular service.
- ◆ Special models have been developed to suit mountings inside the cabinet of desk top control stations that access remote repeaters.

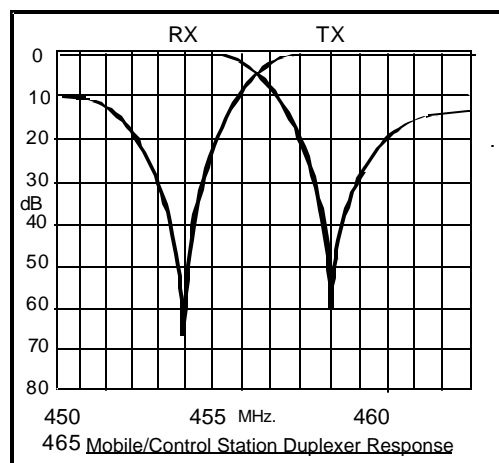


Figure 6

Performance curves for a typical mobile duplexer are shown in Figure 6. Note that the notch in the transmit branch is about 67 dB at the receiver frequency; usually sufficient for 30 to 40 watt mobile transmitter wide band noise rejection. At these transmit powers, the 60 dB notch in the receive branch is usually sufficient to reject transmitter carrier to a usable level.

Where full duplex communications is anticipated, an additional 8-10 dB of notch depth per branch will tend to provide clean, noise free communications. Mobile duplexers are usually designed for a particular T- R split, e.g.: 5, 7, 10, 12 MHz., etc. Due to the sharpness of the response of the notches, modification of branching cables and tap point on the resonators are required to change the T- R split.

Duplexer Maintenance

Most high quality duplexers will give many years of trouble free service after placement at your site “right out of the box” from the manufacturer. The advent of frequency changes or problems due to interference can result in re-tuning on frequency or on new frequencies.

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About Cavity Resonators

Duplexers rely on the characteristics of *cavity resonators* to provide needed filtering performance. Beyond duplexer applications, cavity resonators are used as stand alone filters, in transmitter combiners and various other filter applications.

Cut-away views of typical band pass and pass-reject cavities are shown in Figure 7.

The difference between band pass and pass reject cavity coupling loops are shown in Figure 8. The band pass loop extend down into the

end of the cavity to excite the TEM (transverse electromagnetic) field and to retrieve power in the case of the band pass cavity. A similar loop with a series capacitor is used for the pass-reject version.

Most loops are formed from heavy copper strips, silver plated for reduction of skin effect losses. Loop dimensions, and aspect ratio, e.g.: width to depth, size (volume) of the cavity, operating frequency and degree of coupling will all contribute to the impedance of the loop. For those readers familiar with the use of imaginary number notation, the character of the loop is predominately inductive.

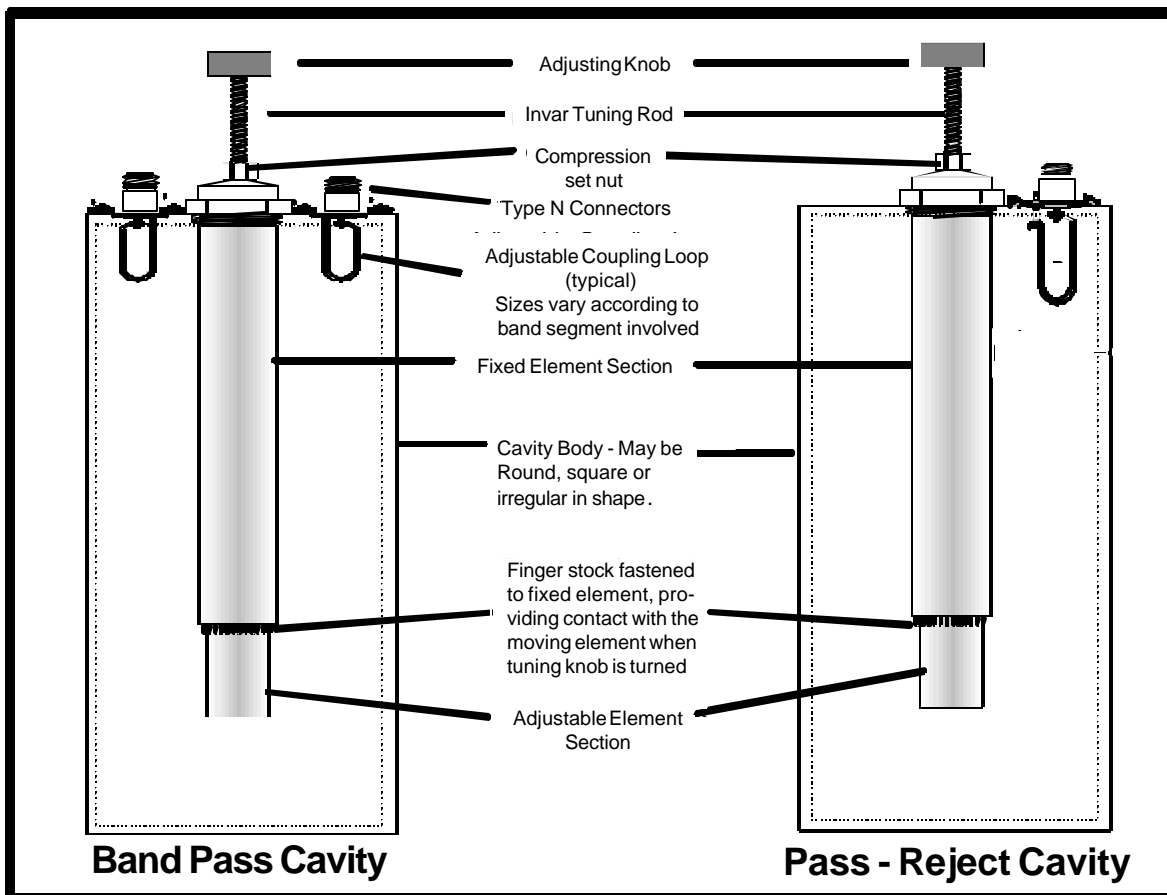


Figure 7

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Admittance will vary from $+j30$ to $+j50$, according to how it is adjusted. Since the loop impedance is not *purely resistive*, all cable lengths between cavities are critical. The lengths of interconnecting cables must be selected to yield a suitable match with the traditional 50Ω system impedance used in land mobile systems.

sided shapes will work fine if properly designed. These can be very space efficient compared to round formats.

EMR Corp. uses square or rectangular format designs exclusively, made from heavy gauge aluminum sheet or extrusions with TIG welded end plates to provide a high order of

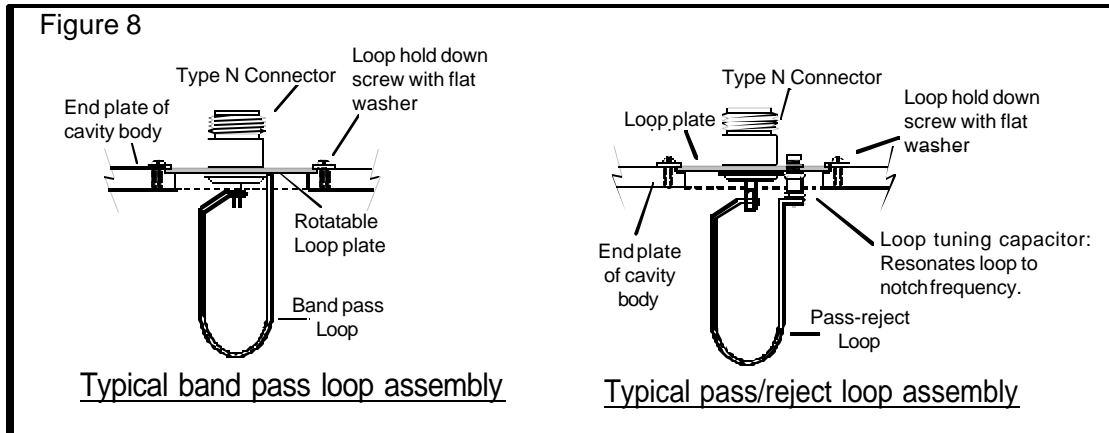


Figure 8, above, shows the two typical loop configurations. Note that the “loop plate” can be rotated to adjust the coupling factor into and out of the cavity. For pass-reject application, either a “T” adapter or a specially constructed loop plate arrangement with a variable capacitor is placed in series with the “grounded” end of the loop. This capacitor is adjusted to position the resulting notch frequency as needed. Cavity tuning as well as notch frequency responses are somewhat interactive, usually requiring several tuning steps, each step bringing the cavity closer to an optimized tuning condition.

Cavity Comparisons

Some points of comparison between cavities are as follows:

Many manufacturers build round cavities because round forms of aluminum and copper pipe are plentiful or can readily be roll formed from sheet stock. Rectangular, square or multi-

mechanical integrity. Some of the reasons for using this design concept include:

1. Square or rectangular shapes fit better in cabinets, racks and other enclosures than do round or irregular shapes. We secure a higher “Q” per cubic foot of occupied space using our “Square Q” cavities, yielding better performance vs: site rack or cabinet space occupancy. As an example, a 7” square cavity has performance equal to an 8” round cavity and uses 20% less rack or cabinet space.
2. The square format for our cavities lends itself to a variety of packaging and mounting methods. Many round cavities must use large hose clamps on support rails to mount them. Our UHF and 800-960 MHz square cavities can be panel mounted using their sturdy 1/4” thick bottom plates.
3. The EMR Corp. line of “economical” integrated cavity duplexer bodies employ heavy aluminum parts that are “dip-brazed”

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together to insure absolute mechanical integrity.

These duplexers use “capacitive probe” tuned resonator elements. They provide outstanding performance, stability and reliability at a very attractive cost to the site owner.

4. High power handling cavities for continuous duty operation at 250, 500, 1,000 watts and higher power levels are most often equipped with heat sinks and thermostatically actuated cooling fans to maintain thermal balance.

Tuning or Re-tuning Duplexers

Before attempting to tune a given duplexer to suit a particular transmit and receive frequency pair, you must make several important determinations.

Question: What specifications did the duplexer manufacturer place on the particular model involved? Such as: (A) Input power rating, (B) Minimum T-R spacing, (C) Branch insertion loss vs: T-R spacing.

Answer: Often old catalogs of the duplexer manufacturer will disclose the expected performance capabilities. If this can't be found, measuring performance “as-is” can result in a good opinion as to operating capabilities.

Question: What frequencies were the duplexer factory tuned for? Are these more than 4 to 5% higher or lower than the frequency pair that you want to tune to? Example: Originally factory tuned for 452.250 TX and 457.250 RX. You need a duplexer to work on TX 464.925 TX and 469.925 RX channels. Can the duplexer perform acceptably at the new frequencies?

Answer: Measure and record performance at the old frequencies, then retune. If the T-R split is the same as before and performance

is degraded sharply, you will probably need to modify cable lengths to get proper operation.

Question: What type of duplexer is it? Band pass or pass/reject? A rule of thumb suggestion as to probable performance of various sizes and types of duplexers according to operating band will be found in Appendix #1 of this bulletin. These examples can be used as guide lines to determine whether they can be successfully re-tuned and used for a particular application.

Test Equipment Requirements

The following test equipment is considered necessary to successful duplexer re-tuning:

- ◆ Preferred: A Dynamic Wave Analyzer with dual trace display, 100 dB (or more) in 10 dB steps of vertical log display resolution, 1 dB per division (or less) fine resolution, with integral transmission - reflection bridge or “S parameter” test set.
- ◆ Acceptable: A dual trace spectrum analyzer with integral swept generator and transmission - reflection bridge, having at least 80 dB of vertical resolution in 10 dB and 1 dB steps.
- ◆ Minimum: A spectrum analyzer with 80 dB or greater dynamic range and a stable well calibrated signal generator. If possible, an R. F. bridge should be available.
- ◆ It is possible to retune duplexers using two typical service monitors, one having spectrum display. Generate a calibrated signal with one and use the other to indicate signal amplitude. Usually the accuracy of readings provided are somewhat lacking, making truly accurate adjustments difficult or impossible.
- ◆ Duplexer manufacturers and well equipped

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full service land mobile service shops usually have a range of spectrum and/or wave analysis instruments suitable for filter tuning work.

- ◆ In addition to the basic instrumentation, cables of known integrity, test terminations and various adapters are needed to accomplish the necessary hook-ups and to properly calibrate your set-up.

What Does SWR, VSR And Return Loss Mean?

The term VSWR or simply SWR is used throughout the wireless industry to denote the “quality” of a device relative to a stated impedance. VSWR stands for *Voltage Standing Wave Ratio*. It is expressed mathematically as:

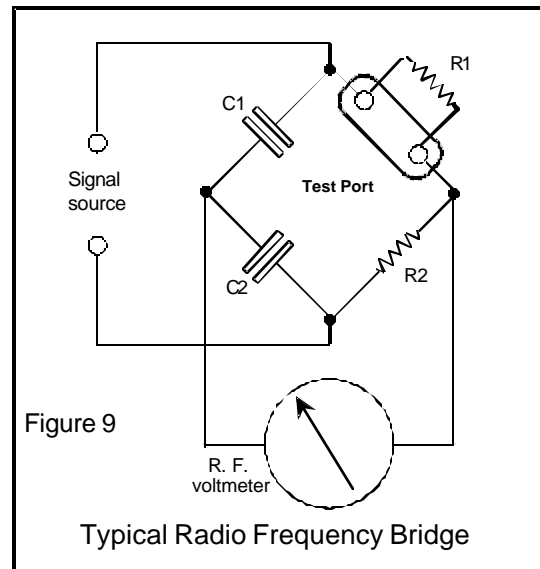
$$VSWR = \frac{V_o + V_r}{V_o - V_r}$$

Where: V_o = incident voltage
 V_r = reflected voltage

VSWR is a ratio between incident (forward) power and reflected power. When none of the power is reflected VSWR = 1:1. If all of the power is reflected, the VSWR will be infinity:1. Direct measurements of VSWR can be made using wave analyzers or using directional couplers with specially calibrated meters. These instruments display reflected power in terms of VSWR in real numbers.

About R. F. Bridges: “Dual sweep, dual trace” wave analyzers have an internal sweep signal generator that drives a R F. bridge having a 50 Ω impedance. If the analyzer does not have this feature, a separate external bridge should be secured and connected such that *return loss* measurements can be made.

A basic R. F. bridge is shown schematically in Figure 9. When R1 and R2 are equal and



C1, C2 are also equal in capacitive reactance the current and voltage flowing in all four legs of the bridge are matched and zero volts will be indicated by the R. F. voltmeter. When all resistances and reactances are 50 Ω , resistor R1 can be removed and its position used as a comparison or test port. When the external circuit impedance is nearing 50 Ω the indicated voltage becomes less and less, becoming zero at a perfect match.

The amount of reflected energy compared with the energy applied to the bridge is then translated directly to dB and is known as *return loss*. Return loss is a most convenient way to measure how well a device matches a standardized system impedance such as 50 Ω .

A mismatched antenna or other device will reflect power in proportion to the degree of mismatch. If no power is reflected, a 1:1 VSWR or perfectly *resistive* match exists. This also represents a return loss of infinity. Conversely, if all of the power is reflected this represents a VSWR of infinity:1 and a return loss of *zero*. The two methods of expressing impedance compatibility are, in that sense, reciprocal.

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Test Accessories.

You will need jumper cables with suitable connectors to connect the analyzer to the DUT (device under test) and back to the analyzer's receive display input. Generally, a set of cables made for each band will suffice. These must be most suitably an electrical half wavelength long. You can calculate this if you know the velocity factor of the cable. Suppose that you are using RG142B/U cable having a velocity factor of 82%:

Example: The constant: $\frac{5.616}{\text{Frequency (MHz)}} = \frac{1}{2}$ electrical wavelength = 36.23"
To correct for cable velocity factor:
 $36.23 \times .82 = \underline{29.7}$ cable length

Be sure to use the cable and connector manufacturer's instructions to determine how much to *shorten* the cable to account for connector electrical lengths.

You can verify your cable lengths by connecting one end directly to the analyzer bridge output and terminating the other end with a known high quality test load termination. If the cable is good for your purpose, a *return loss* of more than 30 dB (40 dB or better preferred) will be indicated at the desired test frequency.

Tuning or Re-tuning Cavities

Figure 10 shows how a wave analyzer can be used to tune either band pass or pass/reject cavities. Prior to doing any tuning, you must set up the analyzer and calibrate it to insure that your measurements will be meaningful.

Suppose that you wish to tune a pass/reject cavity to pass 154.0 MHz and reject 157.0 MHz. First set the center of the instrument swept range to 155.0 MHz and the sweep width to 20 MHz wide.

With the channel "A" reference line set to the vertical *center line* of the display and channel

"A" resolution set for 10 dB per division observe the resulting trace with the test cable unterminated. Set the trace position to show a horizontal line greater at the reference value. Connect the Type N "bullet" adapter between the two free cable ends. Set the "B" trace to full scale reading (top of the graticule).

Now, look at the "A" trace. It should be a horizontal line at least 35 dB down from the "A" reference line. If it is less than 35 dB your cable length should be modified.

Next, connect the cables to the cavity under test. If no notch pattern is seen, expand the horizontal sweep to 20, 50 or 100 MHz until the notch pattern is identified. It will probably look like a distorted "W" response. Adjust the cavity tuning rod position to bring the pattern to screen center. Reduce sweep width to 10 MHz (1 MHz per division).

If your analyzer has markers, place Marker #1 at the pass frequency, in this case 154.0 MHz and set Marker #2 at 157 MHz. Alternately adjust the cavity tuning and the loop notch tuning until minimum insertion loss and maximum notch depth are obtained.

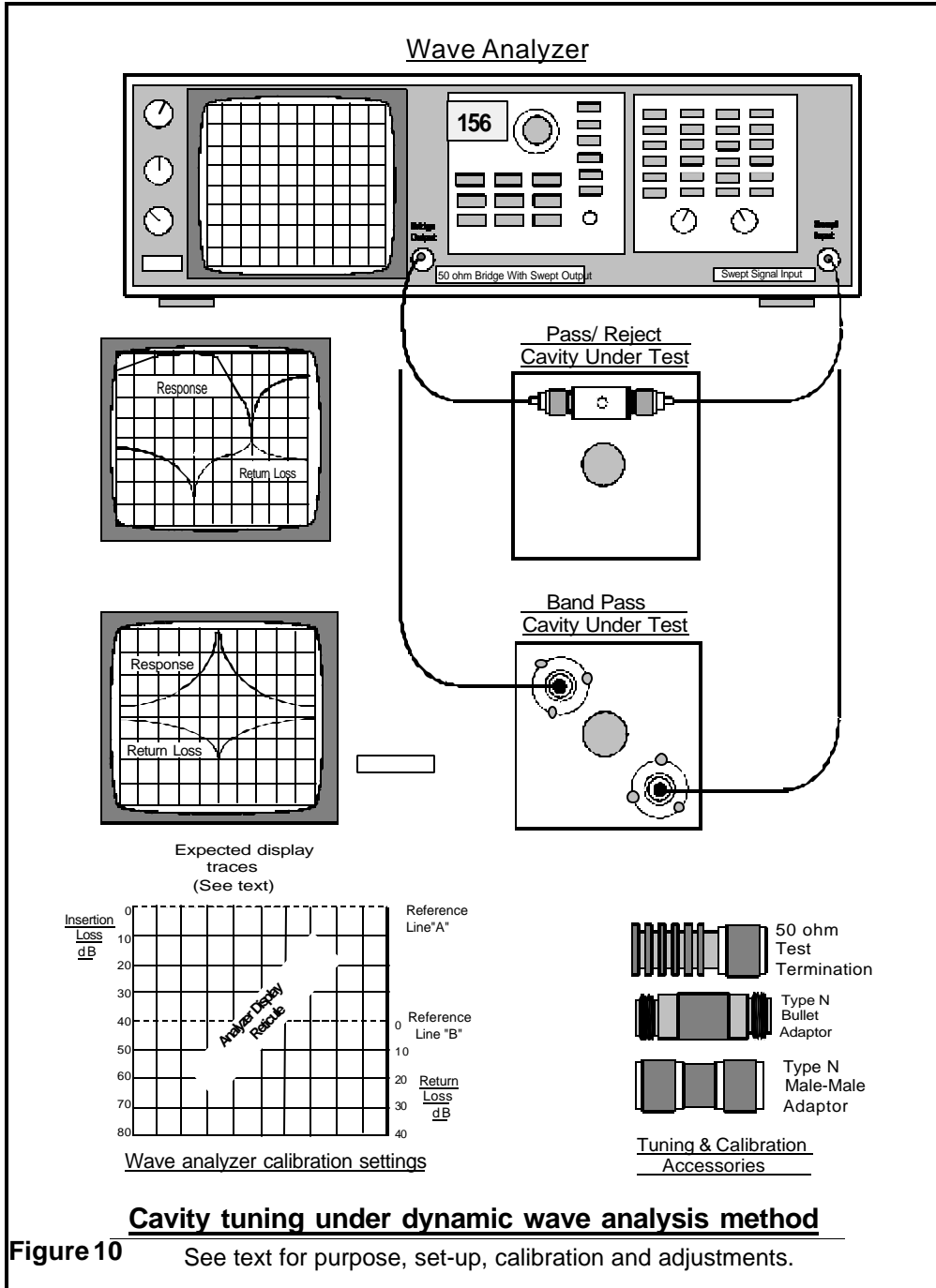
If markers are not available, you can interpolate between the screen divisions to arrive at the desired frequencies with about 100 KHz resolution if you use care. By reducing the resolution of Trace (B) to 0.50, 0.25 or 0.10 dB you can now accurately see the insertion loss with high definition. The response patterns should be similar to those shown in Figure 10.

Tuning band pass cavities is more or less similar. Depending on the particular need, these cavities are tuned for 0.5 dB to 0.75 dB of insertion loss each for duplexer service, although some are tuned for up to 3 dB of loss as stand alone filters. You must be sure that the loop coupling factors are balanced.

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Some manufactures place calibration marks on rotatable loops. Beware: They are simply for guidance and not intended to result in

exact coupling factors. Your cavity is properly tuned when you can reverse the cables to it and both the insertion loss and the return loss are the same in either direction.



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This makes the loop couplings equal through the cavity. Usually this will take several cable reversals and “touch ups” of loop orientation to arrive at the desired insertion loss with acceptable return loss at both ports. Most cavities will show a return loss from 17 to 25 dB when optimized. Remember, the cavity is presenting a predominately inductive characteristic to an inherently resistive leg of the bridge.

Tuning Multiple Cavities, Tuning Duplexers

It is possible to develop a filter to pass a range of frequencies and having steep sloped responses above and below the desired pass band. The curves shown in Figure 11 displays the performance of four, 10” square cavities properly phased together in a series configuration.

To secure broad band “nose” responses from two or more cavities in series, the connecting cables between them must be of optimum length. Before trying to tune a cavity “string” you must first tune each cavity individually, setting its pass or pass/reject to suit system needs. Usually the connecting cables between cavities are close to $\frac{1}{2}$ wavelength in electrical length, corrected to allow for the effective lengths of connectors and loop configurations. Shorter lengths are often found to yield the desired performance, according to band of operation.

If the “chained” cavities are to be used as branches of a duplexer, one branch (or chain) will be tuned for the receive pass frequency and the notch set for the transmitter frequency. The transmit branch is tuned opposite. The junction cables must be adjusted in length to effectively maintain the reject characteristics between the two branches while maintaining correct impedance matching with both branches and the antenna port.

Note that through critical coupling, the desired pass band is essentially flat over a 1 MHz. range and the return loss is about 28 dB over the range. Careful cable length adjustments and considerable tuning time is required to accomplish superior filter performance. This insures protection for a group of closely spaced multicoupled receivers at a high density site.

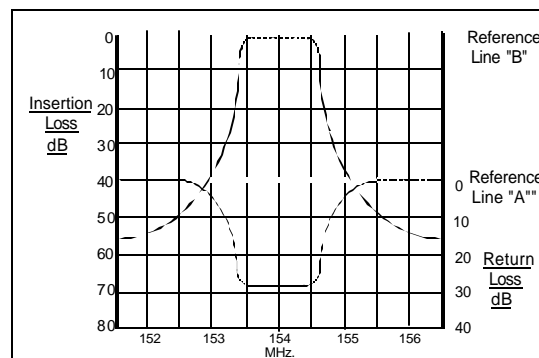


Figure 11

Summary:

For the reader who wishes to become proficient at tuning or re-tuning antenna duplexers, it is hoped that this bulletin has provided enough insight to be of assistance to you.

Appendix #1 lists expected performances of typical cavity combinations in the VHF, UHF and “High UHF” bands. These are to be considered average, some makes and types showing better and some not as good as these numbers.

Errata

It is important that you have correct cable lengths between the duplexer cavity resonators and that proper tuning has been accomplished.

We are often asked for a list of generic cable

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lengths to connect cavities together. Often, the user will be trying to make a filter or duplexer out of a set of mis-matched cavities as a duplexer or filter. Unfortunately, we can only guess at the lengths, drawing from past experience.

We trust that this bulletin will be the basis for a better understanding of antenna duplexers, and bring out the reasons why care must be used in tuning them if acceptable performance is to be secured.

Hopefully, this discussion of duplexers has provided enough insight to be of assistance to you.

We will be pleased to assist you with any duplexer problem. Call, FAX or E-mail us with your duplexer type(s) and operating frequency information.

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Appendix #1

Cavity Types vs: Performance in Duplexers

Duplexer Type	Band MHz.	No. Cavities Per Branch	Cavity Size & Format	Minimum T-R Spacing, MHz.
Band Pass	150-170	3	4" Sq., 5" Round	4.0
Band Pass	150-170	3	7" Sq., 8" Round	3.0
Band Pass	150-170	3	10" Sq., 11" Round	2.2
Pass Reject	150-170	2	4" Sq., 5" Round	0.8
Pass Reject	150-170	3	7" Sq., 8" Round	0.5
Pass Reject	150-170	3	10" Sq., 11" Round	0.3
Band Pass	450-470	3	4" Sq., 5" Round	10.0
Band Pass	450-470	3	7" Sq., 8" Round	7.0
Band Pass	450-470	3	10" Sq., 11" Round	5.0
Pass Reject	450-470	2	4" Sq., 5" Round	5.0
Pass Reject	450-470	3	7" Sq., 8" Round	3.5
Pass Reject	450-470	3	10" Sq., 11" Round	3.0
Band Pass	806-960 (1)	1	4" Sq., 5" Round	45.0
Band Pass	806-960 (2)	2	4" Sq., 5" Round	30
Band Pass	806-960 (3)	6 RX, 4 TX	Special modular filters	15
Pass Reject	806-960	1	4" Sq., 5" Round	45.0
Pass Reject	806-960	2	4" Sq., 5" Round	20.0
Pass Reject	806-960	2	7" Sq., 8" Round	12.0

(1) Single frequency repeaters, only under 30 watts power.

(2) Extended band pass, up to 15 MHz. wide, each response.

(3) EMR Corp. Broad band SMR Duplexer, up to 15 MHz. per TX and RX response.