AW8920A Return Loss & Cable Fault Test Set

From Airwave Inc.

User's Guide

Revision 4.0



AIRWAVE Communications & Electronics

AW8920A Return Loss And Cable Fault Test Kit User's Guide

By Bryan K. Blackburn

Edition 4.0

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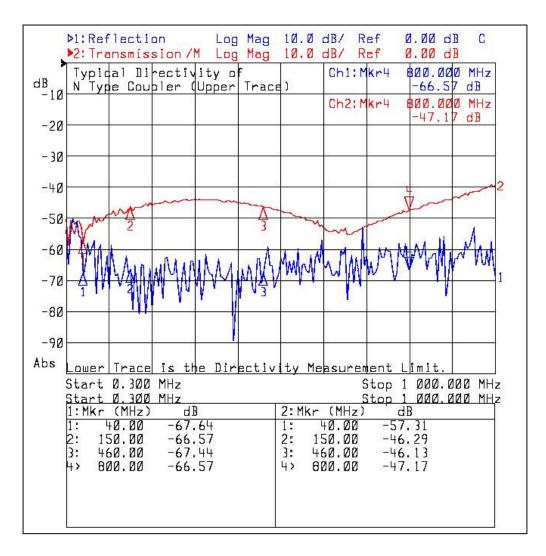
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Typical Directivity of the Coupler (Red Trace), as measured on an HP8714B Network Analyzer (blue trace is calibrated measurement limit of the 8714).

Specifications AW8920A

AW-20-4 Directional Coupler

Impedance	50 Ω
Frequency of Operation.	
Directivity, Typical	
Coupling Factor	
Insertion Loss, Typical	
Maximum Continuous Input Power (at 1 Mhz or more)	
Maximum Intermittent Input Power (1+ Mhz, 10 Seconds On, 1 Minute Off)	
AWR-2050 Resistive Power Divider	
Impedance	50 Ω
Frequency of Operation.	DC-2000 Mhz
Isolation, Typical	6.6 dB
Insertion Loss Above 6 dB, Typical	0.3 dB
Phase Unbalance, Typical	2°
Amplitude Unbalance, Typical	0.2 dB
Matched Power Rating	1 W
Internal load dissipation	0.125 W
Attenuators	
Impedance	50 Ω
Frequency of Operation.	DC-1500 Mhz
Nominal Value	±0.3 dB
Flatness, max. (To 1000 Mhz)	0.6 dB
VSWR, max. (To 1000 Mhz)	1.5:1
Termination's	
Impedance	50 Ω
Frequency of Operation.	DC-2000 Mhz
Return loss, min	
Maximum Input	0.25 W



Unpacking

Kit Contents

The standard AW8920A Return Loss and Cable Fault Test Kit is supplied with the following Items:

- 1. Directional Coupler
- 2. Resistive Power Divider
- 3. Two (2) 6 dB Attenuators
- 4. Precision 50 Ω Termination
- 5. Two (2) Low Loss Test Leads
- 6. Carry Case
- 7. Users Manual and Quick Start Guide

Care and Handling

Every effort has been made to insure durability of all kit components. They remain, however, delicate electronic devices. The directional coupler is by far the most sensitive part in the kit. *NEVER* drop the coupler on a hard surface, and *NEVER* remove the cover. The physical placement of all the internal parts that make up the coupler, the wires, transformers, etc. are *very* critical. A hard shock to the coupler could adversely affect performance. Other components of the kit are far less sensitive to shock, but should be handled with care to prevent damage to their connectors.

NEVER apply DC current to the directional coupler. DC current will destroy the coupler and void your warranty. The minimum frequency of operation for the coupler is 100 Khz, at no more than 0.5 watts below 1 Mhz.

Clean the connectors often using pure TF solvent. The painted surfaces can be cleaned with glass cleaner.

Warranty

All components of the return loss and cable fault test kit are warranted to be free from defects in material and workmanship for a period of one year from the date of shipment, except test leads, which are warranted for a period of 90 days. During the warranty period, Airwave Inc. will at its option, repair or replace at no charge any kit item found to be defective, provided the item is returned, shipping prepaid, to Airwave Inc. Airwave Inc. shall pay return shipping charges to the buyer.

Limitation of Warranty

This warranty shall not apply to any item found to have been subjected to abuse, misuse, or improper care. NO OTHER WARRANTY, EXPRESS OR IMPLIED IS GIVEN. **AIRWAVE** INC. **SPECIFICALLY** DISCLAIMS ANY IMPLIED WARRANTIES OR WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. Repair or replacement of the defective item is buyers sole and exclusive remedy. AIRWAVE INC. SHALL NOT BE ANY DIRECT. FOR INDIRECT. INCIDENTAL, OR CONSEQUENTIAL DAMAGES.



Quick Start Instructions For The AW8920A Test Kit

Connections 0 0 **Setup** Signal Source Analyzer Input Directional Coupler 6 dB Attenuator **Normalizing** Device DUT Under Test **Testing** Terminate All Unused Ports

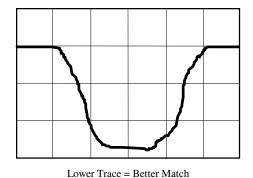
Return Loss

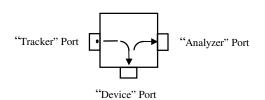
Make connections as shown in the diagram, allowing power reflected from the device under test to be separated and measured independently from the incident signal.

- 1. Set the spectrum analyzer tracking generator controls to sweep the desired frequency range. Smaller span settings are preferred for more exact readings.
- 2. Set RF Amplitude to 0 dBm (or near the high side of the generators ability),
- 3. Set the input reference level, if available, to -20 dB, or set the attenuator, vertical gain or position, and IF gain controls until the displayed line is even with one of the upper graticules.
- 4. Normal Sensitivity at 10 dB per division.

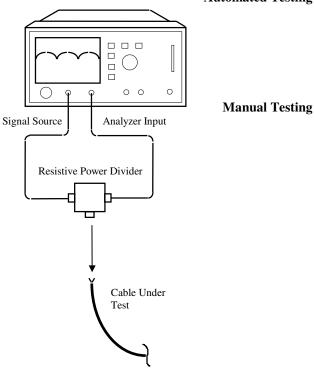
Normalize the analyzer using "Save B" / "A-B" if available, or, use a grease pencil or dry erase marker to trace this reference line on the screen.

Connect the device to be tested to the "Device" test port of the directional coupler. The amount by which the displayed line drops, in dB, is the return loss of the device under test (DUT). This is plotted on the analyzer display as a function of frequency.

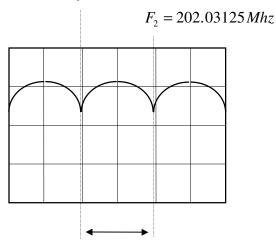




Automated Testing



$$F_1 = 67.625 Mhz$$



 $F_3 = 134.40625 MHz$

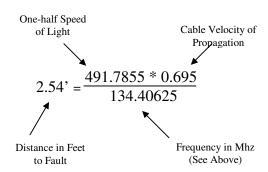
Cable Fault

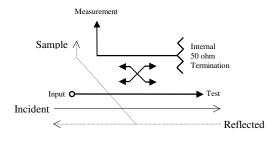
If your monitor offers an automated cable fault test, use the Resistive Power Divider and follow the instructions provided for this test in your manual.

All ports of the Resistive Power Divider are identical and can be interchanged.

- 1) Make connections as shown at left and set tracking generator output at (or near) 0 dBm.
- 2) Connect the cable to be tested to the open power divider port.
- 3) Select analyzer span and input attenuation controls for a standing wave pattern similar to the example. (Short cables require wide span settings.)
- 4) Find the frequency difference between two adjacent "dips".
- 5) Find the velocity of propagation from manufacturer data or from Appendix G.
- 6) Plug these two numbers into the equation below and calculate the distance to the cable end (or fault).

See "Cable Tests," page 25 for more details and how to determine velocity of propagation from a cable sample.





Directional Coupler

Reflection Coefficient

Return Loss

Reflection Measurements

The directional coupler in the AW8920A test kit is a signal separation device. It provides a sample of the power traveling in one direction only. The coupler has three ports, an input port, a test port, and the measurement sample port. A fourth port is internally terminated in a precision 50 ohm load.

An incident signal applied to the input or "Tracker" port of the coupler is passed to the "Device" or test port unattenuated (less the insertion loss). Any signal reflected at this port will be passed back to the input port, with a sample (20 dB down), directionally isolated from the incident signal, also present at the measurement, or "Analyzer" port.

When compared to the incident signal, This directionally isolated reflection sample provides the basis for calculating reflection coefficient, return loss, SWR, and impedance. (See Appendix D for conversions.)

Reflection coefficient is the most basic of reflection measurement values, and is simply the ratio of reflected power to incident power. This number varies from zero for a perfect match to one for a total mismatch. If your spectrum analyzer offers a choice between linear and log displays, you will be able to read this value directly from the screen. The symbol for reflection coefficient is ρ (magnitude only) or Γ (magnitude and phase).

The logarithmic expression of the reflection coefficient is the return loss, and its value is given in decibels. A return loss of 0 dB represents a total mismatch, and one of 40 dB or more, a near perfect match. Since spectrum analyzers are usually calibrated in decibels, reflection measurements are read from the screen directly in return loss. The abbreviation for return loss is RL, R.L. or R/L. Use the equations

$$RL = -20\log_{10}|\rho|$$

$$\rho = 10^{\left(\frac{RL}{-20}\right)}$$

to convert between return loss and reflection coefficient.

Impedance

For every measured value of Γ , there is a corresponding value of impedance. The two are directly related, their relationship in a 50 Ohm system is shown by the equation:

$$Z = 50 \frac{1+\Gamma}{1-\Gamma}$$

To find reflection coefficient from impedance:

$$\Gamma = \frac{\frac{Z}{50} - 1}{\frac{Z}{50} + 1}$$

SWR

Reflected signals on a transmission line form standing waves on the line. Every half-wave along the line, high-voltage and low current points occur. Halfway between the high-voltage points will be low-voltage, high current points. The ratio of these voltages or currents is the Standing Wave Ratio or SWR. SWR is also related to return loss, impedance, and reflection coefficient, as shown by the equations:

$$SWR = \frac{1 + 10^{(-RL/20)}}{1 - 10^{(-RL/20)}}$$

$$SWR = \frac{1+\rho}{1-\rho}$$

and

$$SWR = \frac{Z}{50}$$

Reflected Power

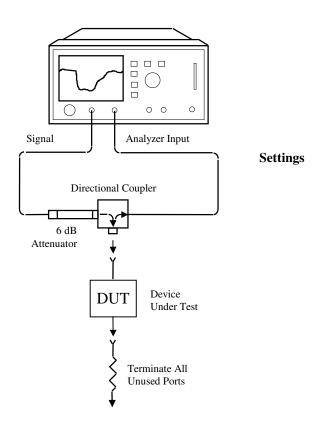
Since power is proportional to I^2 (or E^2), the power reflected will be proportional the square of the reflection coefficient, or:

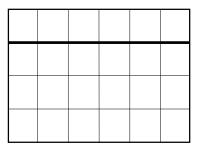
$$P_{reflected} = \rho^2 P_{forward}$$

For example, a source impedance of $50~\Omega$, and load impedance of $100~\Omega$, produces an SWR of 2:1 and a reflection coefficient of 0.3333. The square of 0.3333 is 0.1111, or 1/9, fractional. This means that eight-ninths of the power indicated by an in-line wattmeter would actually be delivered to the load. The remaining one-ninth is reflected from the load. The reflected power is reactive power (volt-amperes), and is not actually dissipated.



Spectrum Analyzer





Normalized Display

Normalizing

Settings Notes

Test Setup

Make connections as shown in the diagram, allowing power reflected from the device under test to be separated and measured independently from the incident signal. The "Tracker" input port of the coupler is connected to the tracking generator output of the spectrum analyzer. The "Analyzer" measurement port is connected to the spectrum analyzer input. The 6 dB attenuator is used to reduce errors caused by mismatches between the directional coupler and the signal source. It should be placed nearest the coupler rather than your measurement instrument. The "Device" test port should be left open at this time.

- 1. Set the spectrum analyzer tracking generator controls to sweep the desired frequency range. Use the smallest span setting that will allow you to see the desired band, set the bandwidth wider for wide span settings and for tests on devices connected by long feed lines. Set the sweep rate quick enough to see rapid changes on the analyzer display. On the HP8920A, for example, sweep rate is a function of the span setting, therefore it is best to use an 18 Mhz span width rather than 10 Mhz, and 1.5 Mhz rather than 800 Khz (see HP8920A owner's manual under "Spectrum Analyzer" for more on span and sweep rate relationships in the HP8920A).
- 2. Set the RF Amplitude to 0 dBm, or near the high side of your tracking generator's output capability. At this point in the setup, you should see a fairly flat trace near the top of the analyzer display.
- 3. Set the input reference level to -20 dBm. If your monitor does not have a reference setting, adjust the input attenuator, the vertical position and IF gain controls until the displayed line is even with one of the upper division lines.
- Set the display range to read decibels at 10 dB per division.

If your spectrum analyzer offers a "Save B" / "A-B" or normalization function, perform that now. Otherwise, use a grease pencil or dry erase marker to trace the line on the screen if desired.

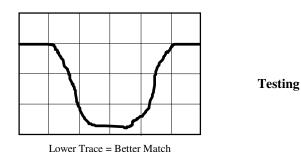
The RF amplitude level is not very critical. Just remember that there is a minimum loss of 26 dB in the system when connected as described (6 dB loss in the attenuator and 20 dB loss in the coupler from the "Device" test port to the "Analyzer" measurement port;

plus any test cables losses). The analyzer must compensate for this by using an increased sensitivity level, or by increasing the generators' output. With a higher output level, the spectrum analyzer has a stronger signal to work with and is easier to use and read. Although the coupler will operate at levels as high as +38 dBm (at 1 Mhz or above), generator levels about 10 to 20 dB below the highest output level obtainable from your tracking source (usually between -20 dBm and +15 dBm,) are preferred as this is usually a more stable and leveled range for the signal generator.

If an adapter or jumper cable must be used between the "Device" test port and the DUT, connect it now. Keep in

Adaptors and Jumpers

mind that the test set will add any mismatch in the adapters or jumpers to your reading, effectively limiting the measurement range of the test setup. A single, average quality adapter can limit the measurement range of the test setup to as little as 20 dB. Jumpers longer than $1/20\lambda$ become *a part of* the DUT, no longer just a jumper! It is always best to avoid using adaptors or jumpers whenever possible.



Once connected and setup as described above, the spectrum analyzer will display the return loss of anything connected to the "Device" test port of the set. Since return loss is a measure of the *reflected* power from the device under test, a lower trace on the analyzer display indicates a better impedance match to 50 ohms. Since spectrum analyzers are calibrated in decibels, and since return loss is a logarithmic expression, the analyzer reads return loss directly.

To see the *approximate* measurement limits of the test setup, connect the 50Ω precision termination to the test port (after following setup procedures as outlined above). The resulting display is an *approximate* limit of measurement. (The actual measurement limit can only be found by using a special calibration termination.)

Network Analyzers

It is assumed that most users of our kit will not have access to an instrument of this class. If you happen to be fortunate, setup as shown in the diagram and perform the calibrations as described in your user's manual. By using a network analyzer, reflection measurements can be made with great precision and accuracy. Enjoy!

Directional Coupler

Airwave Inc.

Device Under Test

Measurement Procedures

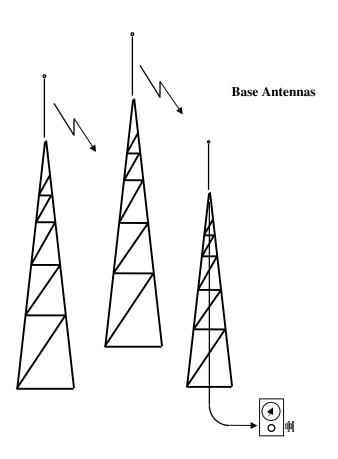
The following are some examples of how the return loss test set can be used to perform some useful tests. Many more uses are possible than are listed here. Generally, any passive network or low power amplifier designed for 50 ohms can be characterized using this return loss test set. When testing a device with more than one port, it is important to terminate all unused ports with a 50 ohm termination. The directional coupler can also act as an isolating combiner, combining two signals into one with the signal sources isolated from each other.

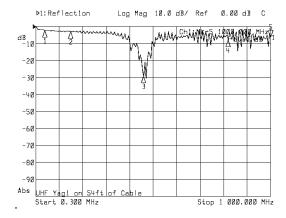
The following examples assume that setup and any calibration(s) as described previously have been performed.

Setup the test set with a 0 dB reference line as described under the section "Improving Accuracy" (page 21). Attach one end of the cable under test to the coupler. The other end should be unterminated or shorted, either way is fine. (Use a shorting termination, not a piece of wire!) Divide the measurement reading by two to find the approximate loss of the attached cable and its connectors. Perform a cable fault check to be sure there are no breaks in the cable, since this measurement would not indicate this except in the possible case of abnormal results.

Before attempting antenna measurements, the location of the antenna to be tested must be considered. If high power transmitters are anywhere within a few thousand feet, it is possible that excessive power may be present at the connector of the antenna to be tested. This must be checked before proceeding. Terminate a wattmeter with a dummy load and connect it to the antenna connector. Any power measured must be less than 2 watts to insure safety of the coupler, 1 watt if using attenuators supplied with the kit, and in most cases, less than 640 mW to insure the safety of most spectrum analyzers (640 mW through the 6 dB attenuator results in 160 mW into the "duplex out" port of the spectrum analyzer). At this level, measurements can safely be made. Be sure that any suspect transmitters are operating when you make this measurement and be sure that your wattmeter is capable of the full frequency range of all the suspect transmitters! If the levels encountered are less than 2 watts but greater than 640 mW, a high power attenuator will be needed. Use a 10 or 12 dB high quality attenuator, one with good flatness across the frequency band of interest. Place the attenuator between the "duplex out" port of the spectrum analyzer and the "tracker" input port of the directional coupler. If your

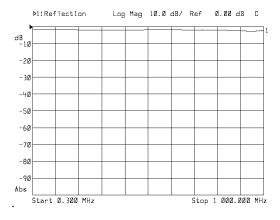
Cables





Wide sweep of a good antenna and cable

Mobile Antennas



Wide sweep of an open or shorted cable

test set is capable of generating the tracking signal through a high power test port, it is possible that this port may be used instead of the attenuator. Usually though, signals generated from this port will be less accurately leveled, causing errors in your readings. Avoid this method if possible. If the levels you encounter are greater than 2 watts, your only options are to turn off the offending transmitter(s), or reduce their output power.

CAUTION: The maximum input power at the "Tracker" or "Device" ports of the bridge is 6 watts under *intermittent* operating conditions. Any sustained use at power levels above 2 Watts could damage the coupler and will void the warranty. For this reason, 2 Watts is listed as the maximum input level for the above tests. The maximum power that may be applied to the "Analyzer" port of the coupler is 125 mW. Also, pay attention to the maximum power ratings of the attenuators. Attenuators supplied with the kit are rated at 1 watt maximum input power.

Once precautions have been taken, the return loss of the base antenna is measured the same as a mobile antenna. See below.

Measure return loss by connecting the test set to the antenna cable of the antenna under test. The reading is the same quality of match the transmitter or receiver "sees" when connected to the transmission line, and is a composite signal of the return loss of the antenna, the cable, any connectors, any losses, and a standing wave pattern related to the length of the cable between the test set and the antenna, and finally, the match at the end of the cable (the antenna). Whew! For most purposes, this reading is enough to determine whether or not you have a problem. If the RL reading seems poor, increase the span of the spectrum analyzer (or vary the center frequency up and down) enough to see the composite wave effect of the antenna and cable. Poor RL with no wave pattern may indicate an open or shorted cable (pattern may be very difficult to see with short antenna cables). It is also possible that if the transmission line is cut to the wrong fraction of a wavelength at the frequency of interest, the standing wave pattern on the feed line can make an acceptable RL from the antenna appear unacceptable at the end of the cable. By just shaving a few inches off the feed line (or by changing the length of a jumper), the RL that the transmitter or receiver "sees" can, in some cases, be improved. A SWR reading of 1.5:1 is equal to a return loss reading of 14 dB. In most cases, this is the value that manufactures specify as a minimum performance level for their antennas. The usable bandwidth of such an antenna, is the span between the 14 dB points.

Portable Antennas

Although portable antennas can be measured using this test set, obtaining an accurate reading is tricky. A test fixture must be made to hold the antenna over a ground plane that simulates a portable radio in real world use. Except for manufacturing, this may not be an economically feasible venture compared to simply replacing a suspect antenna. To do a simple test, connect the antenna to the coupler test port through an adapter, if needed, and watch the analyzer display. Hold the coupler with the antenna near your head, as if it were on a radio in use. Notice the degree of signal variance with only small changes in how the coupler is held in the hand! After testing several known good antennas, you should at least have an idea of what to expect when testing unknowns.

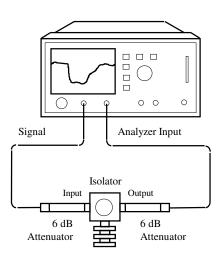
Preamps and receivers

Connect the test set to the input of the preamp or front end to be tested. In the case of the preamp, terminate the unused port with a 50 ohm termination. If the receiver front end is part of a *transceiver*, disable the transmitter before proceeding. It is also important to apply power to the preamp.

The trace on the analyzer display is the plot of return loss versus frequency, tune the front end for a minimum of about 14 dB RL across the entire operating band of the device, or for the best reading possible at the frequency of interest. Usually, only the slugs or trimmers preceding the first amplifier can be tuned with this method. Disconnect the test set and continue tuning the remainder of the device conventionally.

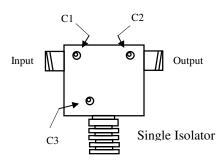
The RL at the output port of a preamp can also be measured if the power levels involved do not exceed the ratings of the test set or the analyzer.

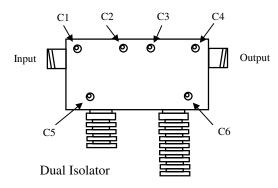
Isolators



Before tuning, test the isolator at the factory tuned frequency and make note of its performance: Measure the insertion loss of the isolator both forward and reversed. Then measure the return loss at the input and output ports. Make sure the isolator load is connected! Compare this performance with the isolator after retuning to be sure performance is acceptable. Also, be sure to perform an RL test of the isolator termination(s) to be sure of their acceptable performance (RL of 26 dB is optimal).

Set up your spectrum analyzer and tracking generator as shown. The 6 dB attenuators serve to move the measurement plane directly to the isolator, and remove the test leads from the measurement. This setup is recommended if the test leads exceed 1/20 λ . Remember to account for the 12 dB loss in your readings, or perform a normalization function with a





Duplexers and Filters

barrel connector in place of the isolator. Set the sweep width to cover both the old frequency and the new frequency, if possible. Tune capacitors C1 and C2 (C1, C2, C3, and C4 for a dual isolator) to move the pass band from the old frequency to the new, tuning for lowest loss. Reduce the sweep width and continue adjusting until no further improvement is noted. The fall off response should be fairly symmetrical above and below the tuned frequency. Reverse the connections at the isolator and adjust C3 (C5, and C6 on a dual) for highest loss.

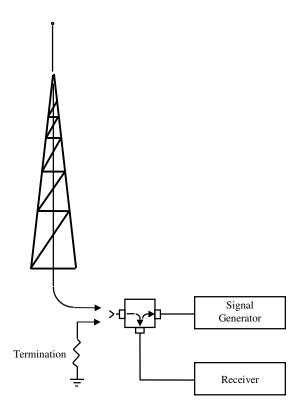
Now terminate the isolator output port with a precision termination. Set up for return loss measurement and measure return loss at the input port of the isolator and tune capacitors C1 and C2 (C1, C2, C3, and C4 for a dual isolator) for best return loss at the transmit frequency. Only minor adjustment should be necessary, and a RL of around 26 dB should be the goal. Now, reverse the connections at the isolator; place the precision termination at the input port, and the measurement set at the output port. Adjust C3 (C5, and C6 on a dual) for best RL at the output port. Again, only minor adjustments here for around 26 dB or better RL.

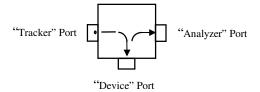
We recommended this method of tuning (conventional first, RL second) because it is possible for an improperly tuned isolator to exhibit a seemingly acceptable RL (the applied signal is dissipated primarily within the isolator). Unacceptable insertion losses and performance would be the result.

Duplexers and Cavity Filters-- Bill Lieske, of EMR Corporation in Phoenix Arizona, has written what may be the most comprehensive guide available on the subject of duplexer retuning. From Mr. Lieskes' manual "Technical Papers," a complete copy of the chapter entitled "Maintenance and Retuning Procedures for Antenna Duplexers" is included in appendix B. We are grateful to Mr. Lieske for his permission to include this work as a part of our user manual.

A complete copy of "Technical Papers," can be obtained by calling EMR Corp. at (602) 581-2875. Also ask for a price list and catalog of products. Some of the best equipment available in the industry is Made at EMR.

Site Noise and Receiver Sensitivity





The sensitivity of a receiver on the "bench" will always be better than the same receiver connected to an antenna, due to "site noise." Power lines, nearby transmitters, sunspots and other sources of noise are everywhere. So how do these noise levels effect receiver sensitivity? To find out, set up the test set as in the diagram. Be sure any associated transmitter(s) on the same line as the coupler are disabled for this test, and it may be wise to measure the received power at the coupler insertion point (see "base antennas" section above for details) before proceeding.

Adjust the generator output for 12 dB receiver SINAD with the *termination* in place, and compare the generator level to that required to obtain a 12 dB SINAD with the *antenna* in place. Remember that the coupler has about a 20 dB loss in-line with the generator, so subtract 20 dB from the measured values to find the actual generator levels, if desired.

The difference between the two noted generator levels is the amount by which the site noise degrades the receiver sensitivity. So, to find the actual receiver sensitivity of the system during use, take the antenna system gain (or loss), minus the site noise as determined above, and subtract the results from (or add them to) the receiver "bench" sensitivity.

Rx Sens. = "Bench" Sens. - (Ant. Gain or Loss - Noise)

Example: An antenna with 10 dB gain is used with a cable having a loss of 3 dB. The measured site noise degradation is 4 dB, and the bench sensitivity of the receiver is -118 dBm. The actual system sensitivity is:

Rx Sens. =
$$-118 \text{ dBm} - (+10 \text{ dB} - 3 \text{ dB} - 4 \text{ dB})$$

= $-118 \text{ dBm} - 3 \text{ dB}$
= -121 dBm

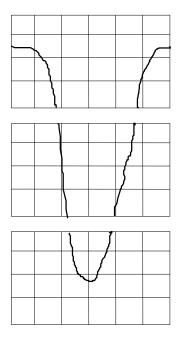
In this example, if the cable is replaced with one having 1 dB loss (instead of the current 3 dB loss), the measured site noise would increase by 2 dB, to 6 dB, (since site noise is also attenuated by cable losses). The resulting system sensitivity would be... -121 dB! Thus, system sensitivity would not necessarily benefit by upgrading the transmission line.

As can be seen, this could be a valuable test to perform!

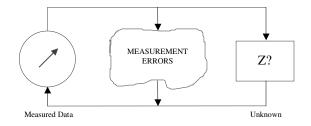
Note also that site noise is not a static value, but is constantly changing, day by day, and varies with the time of day and the time of year. Site noise studies must therefore be conducted over a long enough period of time to be sure the results are true and reliable.



Reliable Measurement Range



Sources of Errors



Improving Accuracy

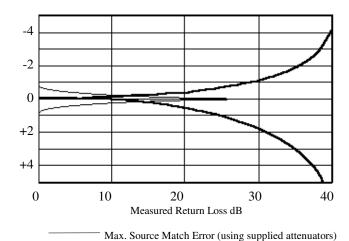
A consideration in the quest for precision is the resolution and accuracy of your display instrument. Most low cost spectrum analyzers (the kind found in communications service monitors, and the kind for which this test set was primarily intended) will yield excellent results when measuring return loss from between 5 to 30 dB -- and will provide reasonable accuracy when measuring from around 1 or 2 dB to as much as 40 or 45 dB, depending on the test frequency. Most spectrum analyzers are inadequate for measurements much outside this range, however. They lack the tracking stability and resolution, and most importantly, the advanced calibration techniques necessary for that latitude of measurement. When the AW8920A kit is used with a network analyzer with vector calibration capability, RL measurements from 0.001 dB to 60 dB or more can be made with great accuracy.

Try to keep in mind real world situations when determining the need for accuracy. In most cases, someone else has already designed the thing, and it's your job to decide if it's still working. Keep the RL to SWR conversion table handy and refer to it often. Note that the difference between a return loss of 30 dB, when compared to one of 40 dB means that only 0.0898% more of the forward power is reflected from the load (reflected power = forward power x reflection coefficient²).

Most of the errors encountered when using a spectrum analyzer with this kit are from:

• Frequency response errors from within the analyzer and the interconnecting cables to the test set. These errors vary, depending on the actual quality of your analyzer (check your analyzer specs,) and the interconnecting cables used with the test set. Their effects are most noticeable with readings between 0 dB to 5 dB RL. The best thing you can do to reduce these errors is use high quality, high frequency low loss test cables.

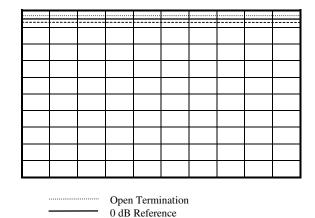
Source match errors result from impedance mismatches between the tracking generator output and the test set input. This is a minor error term. Source match errors affects accuracy of measurements primarily between 0 dB and 5 dB RL, and are minimized by using a 6 dB attenuator at the input of the directional coupler. When the kit



Measurement Uncertainties

Max. Directivity Error (at 40 dB directivity)

Establish a Reference Line



0 dB Reference Line

Shorted Termination

is used with the supplied attenuators, the maximum effect of source match error on an RL reading of 5 dB is about ± 0.5 dB, increasing to about ± 0.75 dB for a reading of 2 dB RL. Experience has shown that these errors are almost always less than the above maximums, and unless you are using a specialized spectrum analyzer or network analyzer, are usually insignificant compared to the frequency response errors almost certain to exist in your measurement instrument.

Directivity error is the collective imperfections within the directional coupler that allow a signal from the source to "leak" directly to the measurement port, and limit the directivity of the test set. Directivity error is the most significant error term for RL measurement. Directivity Error limits the effective measurement range of the test setup and contributes errors to readings primarily beyond 25 dB RL. With an RL reading of 25 dB, directivity error will contribute an uncertainty of about ±1.0 dB, and at an RL of 35 dB, uncertainty of about +3 to -2 dB. As a rule of thumb, if the directivity of the coupler is about 10 dB greater than the reading at the frequency of interest, the measurement will be reasonably accurate.

Be sure to see the measurement comparison test results in the appendix.

- 1) To obtain the highest degree of accuracy possible from the return loss test set, setup as usual, without attaching any adapters or jumper cables (if needed) to the test port just yet.
- 2) Normalize the display by performing the "Save B" / "A-B" analyzer function if available, or by tracing the displayed line on the analyzer with a grease pencil or dry erase marker.
- 3) Next, establish a 0 dB reference as follows. Connect a short circuit termination (not included with the kit) to the test port. One-half the return loss measured for the short circuit termination from the normalized line, is the 0 dB reference.
- 4) If you are using an HP8920A, you can enter this number as the "reference" at the menu field "Lvl" If your spectrum analyzer does not have a reference set function, make a note of the 0 dB reference point, or use a grease pencil to trace a reference line on the analyzer screen. Reference your test results to this line.

Using an Adapter or Jumper

When using an adaptor or jumper at the test port, signal reflections from impedance mismatches and losses within the adaptor or jumper tend to limit the measurement range of the test setup and contribute errors to the measurement. If for instance, the adaptor exhibits a small inductive reactance, and the test device exhibits an equal capacitive reactance, the two will cancel each other out. The result will be either a better than expected reading, or worse depending on the non-reactive element of the DUT impedance.

It is also important to understand that if a jumper is used whose length is a significant portion of a wavelength at the frequency of interest, longer than, say, $1/20~\lambda$, the return loss being measured will *not* be of the intended device. The measurement will instead be of the *test cable*, as terminated with a device of unknown impedance (this information is very useful if the "test cable" also happens to be the feed line to an antenna, for example). In order to obtain an accurate measurement under these conditions, the phase relationships and losses involved must be known. Using this information along with a Smith chart and a little math, the jumper can be "calibrated out" of the measurement.

It is assumed that most users of our test kit will not have easy access to a vector analyzer, and therefore, it is recommended that all test leads at the device port of the bridge be kept to $1/20~\lambda$ or less (This limits the practicable use of jumpers to frequencies of around 50 Mhz or less). It is preferable to lengthen the test leads from the analyzer to the coupler, and then use a high quality adapter at the device port, if necessary. If an adapter is used, have the right one handy and use only one.

If you would like to see the approximate measurement range of the test setup with an adaptor or jumper in-line, attach (using <u>no further</u> adapters) a precision termination to the end of your adapter or jumper. Unless you have a good selection of precision termination's, this is not always possible. The trace displayed is the *approximate* measurement limit of your test setup with the adapter or jumper in-line.

To find the *true* measurement limit of the test setup, a specially made calibration termination must be used. Airwave calibration terminations exhibit a nearly flat RL of about 50 dB. They are available for N, SMA, and BNC connector types, and are priced according to the difficulty involved in construction and tuning (inquire). Calibration terminations are rarely necessary and used mostly for laboratory work. The termination included with the kit is suitable for nearly any application, including most manufacturing situations.



Cable Tests

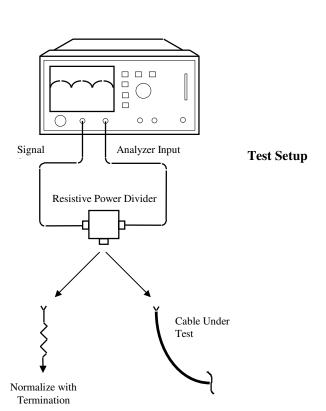
The resistive power divider is used to combine a swept signal from a tracking generator with a reflected signal from the cable under test. The resultant standing-wave trace on the analyzer display can be used to find such information as distance to a fault, velocity of propagation of a known length of cable, and the exact length of cable needed to form $1/4 \lambda$, $1/2 \lambda$, etc. stubs or jumpers. Some service monitors such as the HP8920A, the IFR-1500, the Motorola 2600, and others offer built-in cable fault checking. These monitors use the FFT to find the distance to a cable fault.

When using the HP8920A, run the cable fault test program from the "Tests" screen and follow the instructions provided with the software "System Support Tests." Instructions are provided on screen.

Other service monitors that offer a cable fault test function, such as the IFR-1500 and IFR-1200 Super S may benefit by substituting the resistive power divider in place of a "T" connector specified in the instruction manual. This presents a 50 ohm impedance not only to the service monitor ports, but also to the cable under test, allowing a more accurate pinpointing of the fault.

- 1) Connect the tracking generator output to "Port 1" of the power divider, the analyzer to "Port 2," and a precision termination to the "Source" port (note that all ports of the Resistive Power Divider are identical and can be interchanged, labeling is for convenience).
- 2) Set the tracking generator and spectrum analyzer to the widest sweep possible. The generator output should be as high as possible, but not greater than about 10 dBm.
- 3) If your spectrum analyzer offers a normalization function, set the input attenuation for the analyzer to match the generator output (+10 dBm output, 10 dB attenuation) and normalize the display.
- 4) Now set the analyzer input attenuation to a level 10 to 20 dB higher than the signal generator output. The trace displayed should be relatively flat, and about a graticle or two from the top line.

Fault Location



Testing

Example:

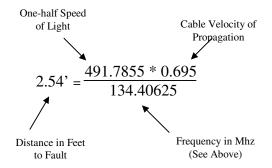
Display Results of a 2' 6.5" Cable.

$$F_{1} = 67.625 Mhz$$

$$F_{2} = 202.03125 Mhz$$

$$Halfwave$$

$$F_{3} = 134.40625 Mhz$$



When an unterminated cable is connected to the "Source" port, a standing wave pattern is displayed on the analyzer screen whose frequency of repetition is related to the length of the cable under test or the distance to a fault. The longer the cable the higher the frequency of repetition. If the span of the spectrum analyzer you are using is too narrow, or the length of cable under test is too short, this pattern may not seem evident at first. Using an IFR 1200 for example (10 Mhz span maximum), any cable less than about thirty-five feet long will be too short to see the standing wave pattern. To view the wave, the center frequency of the generator can be varied to find a "dip" in the analyzer trace. Make a note of this frequency, and find the next adjacent dip, then calculate the frequency difference between the two dips. This is the half-wave frequency. The length of the cable can now be found by the following:

$$D = \frac{.5 c Vr}{f}$$
 (1)

Where:

D = Distance to fault or end of cable

C = Speed of Light,

= 983.571 for ft per second, or

= 299.792 for m per second

.Vr = Velocity of Propagation of the cable

under test

f = Frequency in Mhz determined by

the above test and calculations

The speed of light is expressed in feet or meters per second, and will yield results in the same unit of measure. The Velocity of Propagation can be determined from the table in the appendix, or experimentally as described below.

Example: Consider the example shown at left. This was a section of RG/U 142 cable with a measured length of exactly 2.5417 feet (2' 6.5"), including connectors. The measured frequency of the first dip is 67.625 Mhz; the second dip is at 202.03125 Mhz. The difference between the two is 134.40625 Mhz; this is the half-wave frequency. The published Velocity of

Propagation for RG/U 142 is 69.5%, plugging into the equation:

$$D = \frac{491.7855 * 0.695}{134.40625}$$
$$= \frac{341.790}{134.40625}$$
$$= 2.543 \text{ ft}$$

As can be seen from this example, the results are quite accurate.

Velocity of propagation

The Velocity of Propagation is the speed at which the RF signal travels through a cable. This number is required to find the distance to a cable fault as described in the previous section. It follows then, that if all other quantities are known in the equation above, Velocity of Propagation can be found from the equation:

$$.Vr = \frac{D * f}{.5c}$$

Using the numbers from the previous example:

$$.Vr = \frac{2.543*134.40625}{491.7855}$$

$$= 0.695$$

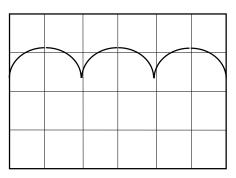
This is the published Velocity of Propagation number for this cable. See appendix for RG/U Velocity of Propagation table.

Once you have found Vr by using a known length sample of the cable to be tested, you can then perform the distance-to-fault test as described previously.

Standing Wave Pattern of Unterminated Cable.

Cutting

Preparation



Same Cable, Terminated in Short Circuit.

Cutting Cable to a Desired Wavelength

Sometimes it is desirable that several cables be trimmed to have a particular electrical length, such as when preparing interconnecting cables for a duplexer or isolator. Half wavelength cables present a well matched source and load with phase relationships delayed but essentially unchanged. A quarterwave stub can be useful for suppressing interference at the tuned frequency, and a length of cable can often serve as an impedance transformer to match a mismatched source and load.

Set up the test set as described in the previous section entitled "Cable Tests".

1. Using the following equation, calculate the approximate length of cable needed for the desired wavelength (λ) of cable at your desired frequency (f).

$$Length_{feet} = (\lambda) \frac{(983.571)(Vr)}{f}$$

or:

$$Length_{Meters} = (\lambda) \frac{(299.792)(Vr)}{f}$$

See Appendix G to find the velocity of propagation (Vr) for many cable types.

- 2. Measure your cable length from the above equation, plus a little extra to account for Vr variations. If you are making a jumper, and the length of cable you will need is longer than your calculated length; cut in multiples of the calculated length, plus a small amount to allow trimming.
- 3. Install one connector to the cable and connect to the test setup. Set the center frequency of the monitor to the "dip" frequency found from the following:

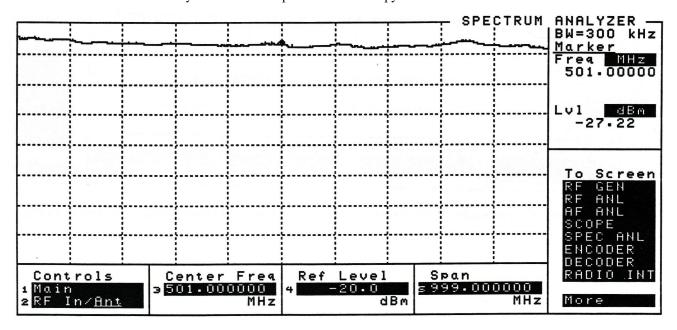
$$frequency_{cut} = 0.25 \frac{f}{\lambda}$$

4. Trim the cable for a "dip" on the display, making sure that the cut end remains open (not shorted) during measurements. Keep in mind that the length of any adapters used at the test port, or connectors not yet installed will add length to the cable. These lengths are more significant at higher frequencies.

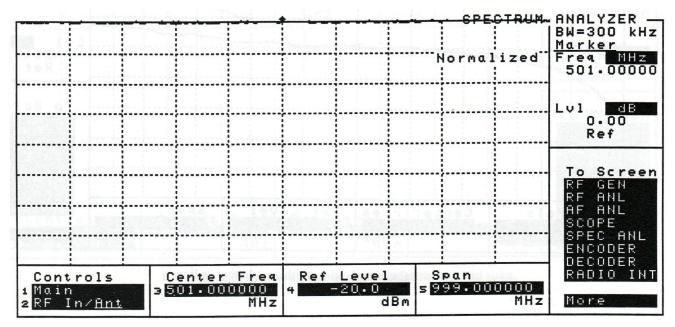
Appendix A

Test Examples

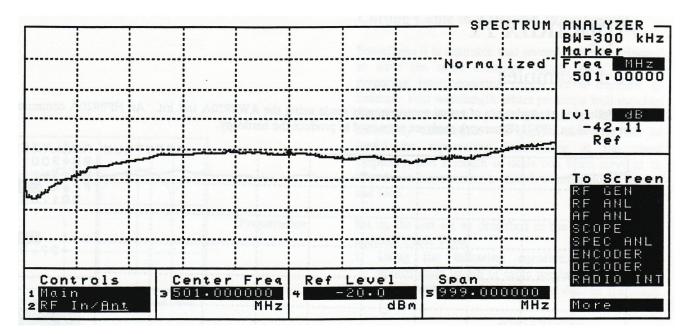
The following examples are of actual measurements made using the AW8920A test kit. An HP8920A communications test set and an HP8714B network analyzer were used to produce the hardcopy.



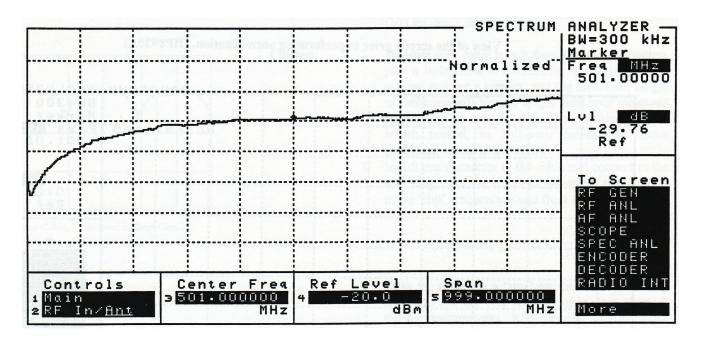
View of the screen prior to performing normalization, (HP8920A).



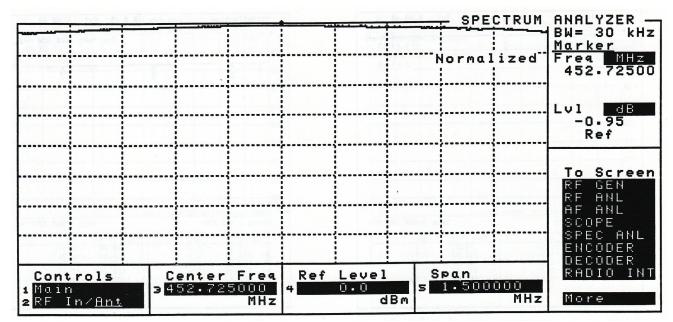
Same test setup after performing a "Save B" / "A-B" normalization function.



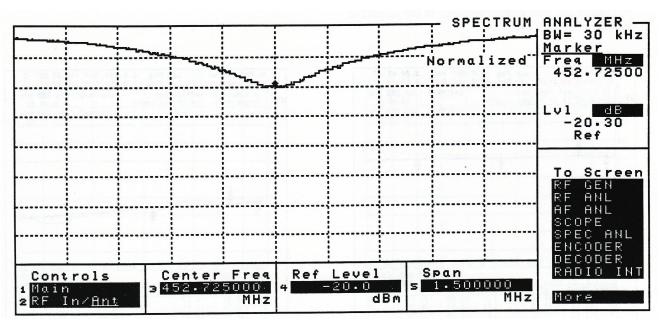
Test set is terminated with a precision termination, showing the approximate measurement range.



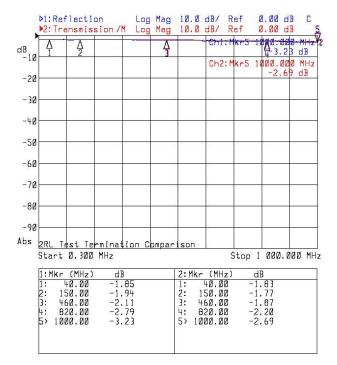
Same termination, with an adaptor in-line.



Transmission characteristics of a band-pass filter.



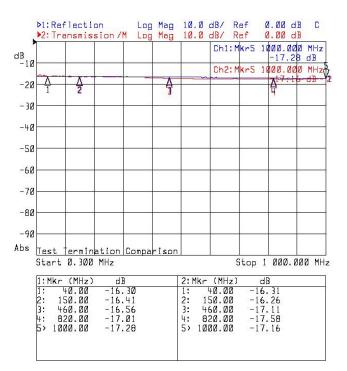
RL reading of the same filter at the same frequency and span.



Above is a comparison plot of a 2.0 dB test termination performed with an HP8714B network analyzer. The blue trace is of the termination through a vector calibrated channel of the network analyzer. The red trace is of the termination through the directional coupler, normalized but uncalibrated (identical to the reading that would be obtained with a tracking generator and spectrum analyzer). This plot shows the comparative accuracy of the coupler at low-level RL readings.



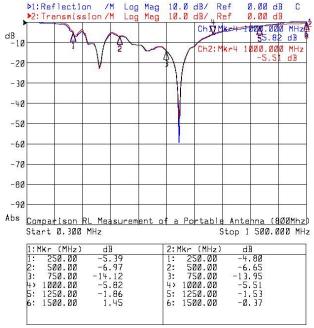
Comparison plot of a 39.8 dB test termination. This plot shows the comparative accuracy of the coupler at high RL readings.



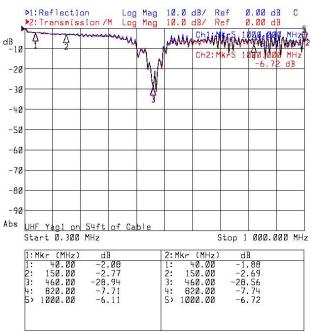
Another comparison plot, this time of a 16.3 dB test termination. This plot shows the comparative accuracy of the coupler at mid-level RL readings.



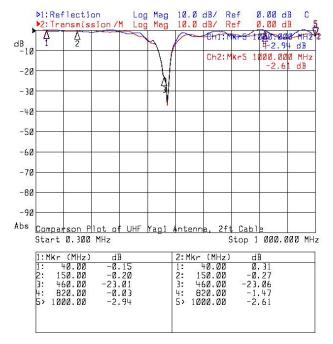
Expanded scale comparison plot of a 16.3 dB test termination. Notice the scale of the reading, and how closely the coupler (red) trace matches the vector calibrated (blue) trace.



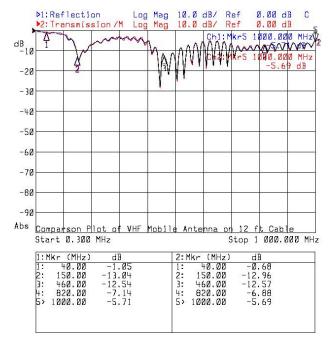
Comparison plot of a 800 Mhz portable antenna, measured in a test fixture. Notice that the span width has been increased to center the traces.



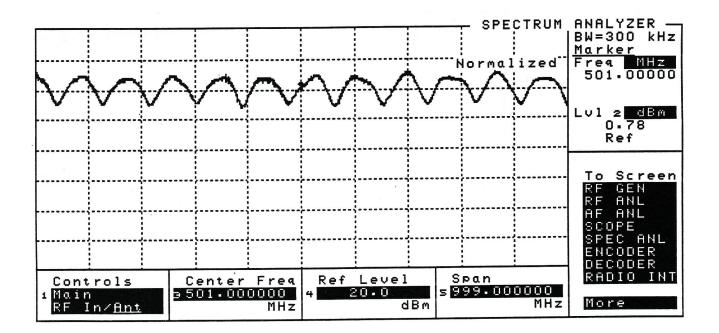
Comparison plot of a UHF yagi with a 54 ft feed line. The interference pattern seen is related to the length of the cable.



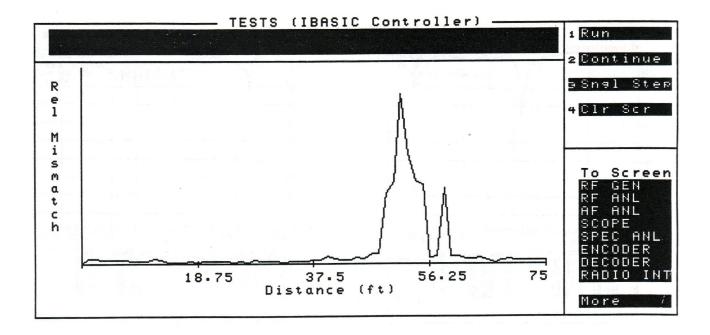
Comparison plot of a UHF yagi antenna with a 2ft feed line.



Comparison plot of a VHF mobile antenna on a mag-mount base with 12 ft of cable.



Cable test standing wave pattern.



Automated test of fifty foot cable. Measurement made on the HP8920 running "System Support Tests" software.

Appendix B

Maintenance and Retuning Procedures for Antenna Duplexers

By Bill Lieskie of EMR Corporation, Phoenix, AZ. © EMR Corp., Used by permission.

EMR Corporation manufactures a broad line of antenna duplexers for fixed repeater station applications. The following information is offered for the systems engineer or applications technician: Duplexer type descriptions, comparisons of duplexer types, application notes, system impedance matching, testing, tuning, re-tuning and trouble shooting.

Duplexer Types and Operating Frequency Bands

Four distinct types of duplexers are manufactured by EMR Corporation: Band Pass, Band Reject, Pass Reject and Pass Reject - Band Pass. The distinguishing features of each type are as follows:

Band Pass Type

This duplexer type consists of two or more band pass cavity resonators with suitable connecting cables in the transmit and receive branches to secure desired rejection of transmitter carrier and noise powers as required for full duplex operation. The two branches are connected to two ports of a three way "tee" connector using selected cable lengths. The antenna is connected through its coaxial cable feed line to the third port of the "tee" connector.

The size and number of the cavity resonators, coupling loop design and adjustment and cables lengths between the cavities are determined by the operating frequency band and the frequency spacing between the transmitter and receiver frequencies. Where multi-frequency, or multicoupled receivers, multi-frequency or combined transmitters are to be served by a single duplexer, special coupling and tuning methods along with critical cable lengths permit duplexing of expanded pass bands within certain limits.

Standard EMR Corporation duplexers are available for single frequency TX and RX stations in the 66-68 Mhz, 88-108 Mhz, 118-136 Mhz, 136-150 Mhz, 406-450 Mhz, 450-512, 806-896 Mhz and 896-960 Mhz bands. Standard expanded pass band duplexers are available for the 806-821/851-866 Mhz and 896-901/935-940 Mhz SMR system bands. Special model broad band, band pass models capable of serving multiple transmitter-receiver system in all bands are available where uniform T-R channel pairings are present.

The characteristics of the band pass duplexer are such that sufficient rejection of transmitter wide band noise, harmonic and spurious emissions are provided along with narrow pass band responses to protect the receiver not only from its associated transmitter emissions but from all other undesired signals. Transmitter spurious and harmonic radiation's are also controlled by the highly selective band pass characteristics. Branch losses are generally higher than other duplexer types since each cavity must be set for at least 0.5 dB of coupling factor to secure required branch selectivity's. The minimum T to R spacing that can be used is determined by cavity "Q." More cavity elements are required for a given T-R spacing than for the other duplexer types, resulting in higher costs to manufacture.

Band Reject Duplexers

This duplexer type employs one or more notch type cavity resonators in each branch, depending on T-R frequency spacing, operating frequency band and transmitter power level. In this design, a single loop is used to excite each cavity, using the resonant response of the cavity to define a rather broad selectivity characteristic, centered on the transmit and receive frequencies. The coupling loop is resonated by a series capacitance to form a notch element. The notch in the receiver branch is tune to reject transmitter in the transmitter branch is used to trap out residual transmitter wide band noise existing at or near the receiving frequency.

With a given cavity size, the spacing between transmit and receive frequencies decreases, the notch depth becomes less and throughput losses become greater. As T and R frequencies are brought closer together more cavities are required to provide needed rejection of transmitter noise and carrier powers as needed to yield interference free duplex isolation, and resulting branch losses increase.

The benefits of this duplexer type include lowest possible loss in each branch, use of smaller cavity resonator dimensions, smallest overall duplexer size and lowest cost to manufacture. The disadvantages are that the pass responses are very broad, providing very little protection against the radiation of harmonics or spurious emissions present in the transmitter's output and little or no improvement in the receiver's "front end" selectivity.

EMR Corporation manufactures band reject duplexers for all bands from 136 Mhz through 960 Mhz as standard models and for frequencies below 136 Mhz on special order.

Pass Reject Duplexer Types

This duplexer design is similar to the straight band reject type except that lighter coupling into the cavity field is provided by smaller loop geometry's and placements. When properly designed, above and below resonant loop notch responses are used to yield a "pseudo band pass" effect. Excellent isolation notch depths are provided along with notches above and below the desired pass bands.

Although a slightly higher branch loss results, compared with the strict band reject type, the pass bands of both branches provide valuable selectivity to help attenuate the radiation of transmitter noise, harmonics and spurs and improve effective receiver front end selectivity. For application at moderately and highly populated sites, this duplexer provides the desired aspects of the band reject type in terms of small size, low loss and low cost to manufacture with some of the benefits of the bandpass type in terms of selectivity. EMR Corporation manufactures pass reject type duplexers in all frequency bands from 136 through 960 Mhz as standard models and special models for 50 through 136 Mhz ranges.

Pass Reject - Band Pass Duplexers

This type of duplexer is suited for the most difficult site installation. Generally, a pass-reject type arrangement followed by one or more band pass cavities in each branch. The benefits of deep notch response is further enhanced by the use of band pass elements to provide the ultimate in protection for both receivers and transmitters. Relatively close T-R spacings can be accommodated and maximum receiver selectivity enhancement is provided, with a reasonable amount of branch losses. Although the cost to manufacture and physical size of this duplexer type increases, it is often the only type that will permit a given repeater to operate on highly populated, high I.M. level sites. EMR Corporation manufactures pass reject - band pass duplexers for all of the popular land mobile frequency bands.

Duplexer-Isolator Combinations

The addition of an RF isolator between the transmitter and the input port of a duplexer provides several system advantages. These include:

- 1. Protecting the system from intermodulation problems through attenuation of signals from other nearby transmitters they may mix in the transmitter power amplifier stage to produce intermodulation products.
- 2. Providing a "resistive" match for the power amplifier compared to the somewhat inductively reactive characteristic of the duplexer cavity resonator input.
- 3. Added isolation between the transmitter and receiver operating with the duplexer.

The cover of this booklet shows an EMR Corporation duplexer with an added dual stage RF isolator. Isolator-duplexers, or "Isoplexers", are supplied in all frequency ranges, with either single or dual stage isolators, according to the character of the site in terms of equipment density. For best performance, the jumper cable between the isolator and the duplexer's TX cavity port must be optimized for correct matching. While isolators can be added to duplexers already in service, it is best to order the complete "isoplexer" at the onset, as random cable lengths between isolator and duplexer can lead to impedance matching problems.

Adding an isolator will improve the overall performance of any of the four duplexer types with only a small increase in transmitter power loss (under 0.3 dB for a single stage isolator and under 0.5 dB for a dual stage isolator). In the band reject and pass reject type duplexers the isolator should be followed by a 2nd harmonic or low pass filter since 2nd harmonic rejection characteristics of these duplexers are usually insufficient to suppress the 2nd harmonic responses which contribute to 3rd and 5th order intermodulation products.

Application of Duplexers

Unless specially manufactured and supplied in a weather resistant or weather proofed enclosure, all EMR Corporation duplexers are intended for indoor, protected installation. Most models are arranged for mounting in standard EIA relay racks or cabinets. Unless specially ordered, all models use Type N female input and output connectors because of critical cable lengths, duplexers in 1296 Mhz range have BNC or TNC connectors).

For best performance, the duplexer should be placed as near to the associated transmitter and receiver as possible. Use of double shielded flexible or solid outer conductor high quality cables for connection between the duplexer and repeater is recommended. Receive and transmit lines should be strung at least 6 inches apart since T to R port isolations from 75 to more than 120 dB are provided by the duplexer and cable-to-cable coupling can nullify these isolations. Each EMR Corporation duplexer is factory tuned using wave analysis techniques to specified frequencies and supplied with a test data sheet showing losses in each branch, transmitter carrier rejection or isolation at receiver frequency, transmitter noise rejection or isolation at receiver frequency, VSWR's at all ports at all frequencies and mid-band isolation between T and R frequencies. No field adjustment should be required or attempted at time of installation. All components used in manufacture are of high quality and cavity resonators are designed with inherent temperature compensation. Unless damaged in shipment or tampered with, every duplexer may be expected to provide a high level of system performance for an indefinite period, since all elements are passive and fixed.

Impedance Match Between the Duplexer, Transmitter and Receiver

Often, it will be found that the loss through a duplexer seems higher than expected. This is usually due to the fact that the power amplifier output does not meet a true 50 ohm impedance at the desired system power level. Modern solid state power amplifiers are designed to match 50 ohm systems at their rated power output, and if driven or adjusted for power levels other than their rated output level, the actual output impedance will vary, exhibiting a lower output impedance at higher than rated level or a higher output impedance at below rated power level. Further where a mismatch exists and the jumper cable from the P.A. to the duplexer happens to be at or near an electrical 1/4 wavelength any mismatch may be made worse. The effect is that even though the duplexer was designed for a 50 ohm match, the combination of P.A. and cable mismatch will cause power to be reflected instead of conducted toward the antenna. This situation may also exist when long, random lengths of cable are used with isolator-duplexer combinations.

One way to correct this situation is through experimenting with cable lengths between the transmitter and duplexer until an optimum of signal power transfer is found. The quickest and most effective way of accomplishing this is through the use of an adjustable impedance correction network. EMR Corporation manufactures such units, called *line matchers*, which are actually adjustable "Pl" networks having an impedance transformation ratio of 2:1 or greater for each of the popular land mobile frequency bands. The recommended method for using line matchers is as follows:

- 1. First, adjust the amplifier output to desired level using a through line watt meter and suitable 50 Ohm test load termination.
- 2. Next, install the line matcher right at the transmitter's output jack (with an adapter or short jumper cable, is necessary) and connect the jumper cable from the line matcher to the duplexer.
- 3. Place the in-line wattmeter between the *duplexer antenna port* and the 50 ohm test load termination.
- 4. Key the transmitter up and alternately adjust the line matcher capacitors until maximum power is obtained. The duplexer branch loss may then be calculated. For example: If the transmitter is set 100 watts output and 80 watts is measured out of the duplexer, loss calculates to 1 dB through the duplexer (see chart at end of the booklet. To use the chart, divide power out of the duplexer by the input power and compare the nearest loss ration to find loss through the duplexer in dB).
- 5. Connect the antenna feedline to the wattmeter and check the power reading. It should be within a watt or two if the antenna system VSWR is 1.2:1 or better.

A line matcher can also be used in the receiver branch to secure best receiver sensitivity. To accomplish this, a 12 dB SINAD measurement should be used, feeding the duplexer antenna port with the signal generator and adjusting the matcher *and the receiver input tuning* to secure best available sensitivity.

Duplexer Retuning

The occasion may arise through system frequency changes, equipment transfers to meet customer needs, etc., that a duplexer must be retune. Before attempting to retune any duplexer, several things must be determined, including:

- 1. Suitability of the duplexer for service at the new frequencies, and under the site density conditions to be experienced.
- 2. Transmitter power handling rating of the duplexer.
- 3. Ranges of the cavity resonator tuning, and loop adjustment methods if a band reject or pass reject type.
- 4. Range over which the duplexer may be tuned without modification of jumper cables, loop sizes, etc.
- 5. Availability of proper test equipment in terms of frequency stability, display measurement range, both maximum and minimum.
- 6. The correct procedure to be used to most effectively accomplish the retuning procedure.

The following points might be of help in determining these variables:

A. If the duplexer is to be moved to frequencies within no more than 1% of its nominal frequency range (e.g.: 1.5 Mhz. in the 150 Mhz. range, 4.5 Mhz. in the 450 Mhz. range, or 7-8 Mhz. in the 800 Mhz. band) and the T - R spacing is the same as originally supplied, it can probably be retune successfully. (Note that broad banded duplexers are usually optimized with loops and cables required for the exact band pass and T-R spacing as factory tuned. Such models are best returned to the factory for retuning).

- B. Attempts at retuning a duplexer with inadequate test equipment, proper instructions and knowledge of how the particular duplexer functions will usually result in failure. We regularly retune duplexers of our own manufacture or those made by other companies and can attest to their condition of tuning when received if such has been attempted under improper procedures.
- C. Before trying to retune or even to "touch up" the tuning of any duplexer, be sure that it's operation is understood, both in theory and in application.

D. When following tuning instructions, don't try any short cuts. In the instructions to follow, we will describe the procedure that we would follow either in-plant or in the field. It is important that these are followed exactly if the full performance capabilities of the duplexer are to be secured.

Test Equipment Requirements

Although skilled technicians have tuned duplexers for years using receiver responses and other tricks the availability of modern highly stable service monitors, field portable spectrum analyzers and similar equipment have simplified bench or field tuning of duplexers of all types. Few two-way shops have true wave analyzers, having the measurement accuracy and dynamic range of those used in manufacturing, in their test equipment inventory.

To tune even the simplest form of duplexer you must be able to generate a signal that is very accurate in frequency and level adjustment. Since you will be dealing with insertion losses as low as 0.5 dB and signal response rejections of 75 to 120 dB, according to duplexer type and application, it is rather pointless to attempt tuning duplexers with equipment incapable of displaying the results of adjustments to these limits, and with reasonable accuracy.

Accordingly, we offer the following test equipment types as those required to properly retune duplexers to factory specifications:

1. A wave analyzer, preferably with a transmission-reflection test set or an accurate R. F. bridge source of 50 ohms and a return loss measurement range capability to 40 dB or greater. Suitable analyzers are manufactured by Hewlett Packard, Wiltron, Textronix, Rhode & Schwartz, General Instruments and others. Models with dynamic ranges of 80 dB are suitable for tuning and optimizing most duplexers, however, a range of 100 dB or more is needed to correctly adjust the more high performance duplexer models.

Most such analyzers have, in addition to 10 dB per division major range resolution, expanded ranges with resolution down to as exacting as 0.1 dB per display graticule division, built in step attenuators, polar display capability and other desirable capabilities. Wave analysis equipment of this class cost from \$25,000 to as high as \$75,000 per setup on today's market depending on ranges, capabilities, added features such as S-Parameter measurement, pen or digital recorders, etc. It is a rare two-way shop that has this class of equipment on hand!

2. Barring the availability of a suitable wave analyzer, the next best choice is a spectrum analyzer with an integral swept signal source, often called a "tracking generator." If the frequency source is not provided by a synthesized, crystal oscillator reference that is accurate to 50 Hz. or better, an accurate frequency source such as a good quality service monitor can be used to check calibration by injecting "birdie" markers

The addition of an accurate 50 ohm bridge source and optimized cable types and lengths are definite assets. The spectrum analyzer must have a dynamic measurement range of at least 80 dB, for signal reject measurements and should also have a resolution of 2 dB or less on expanded ranges.

- 3. Several high quality service monitors on today's market have highly accurate signal generation capability along with swept source or tracking generator options and integral spectrum analysis capabilities. Several have 80 dB or greater dynamic display ranges, however, only one or two have expanded resolution ranges of 1 dB or lower. A reasonably good job of duplexer tuning may be done with these instruments, particularly if a good R. F. bridge is used for measurements that may be translated to VSWR.
- 4. The very minimum equipment should include a spectrum analyzer with an 80 dB dynamic range plus a stable signal source such as a good service monitor. Again, a suitable RF bridge is most valuable to observe VSWR (using return loss measurement) during the tuning procedures.
- 5. In every case high quality double shielded test cables with Type N or BNC connectors, as applicable, and high grade adapters to meet other duplexer connector types such as UHF or TNC types will be needed. Each cable set must be optimized for the band in which the duplexer is to operate. Accurate 50 ohm test loads having a VSWR of 1.05:1 or better are a must. Random cable lengths and types may cause erroneous readings and single shielded cables may inadvertently have sufficient leakage to cause improper results.
- 6. Many duplexers currently manufactured or built during past years for use at VHF and UHF frequencies are equipped with "UHF" (PL-258 or SO-239) connector types. Good quality adapters or optimized cable sets equipped with UHF connectors will be needed to tune these along with test loads having "UHF" connectors. Occasionally, duplexers equipped with RCA "phono type," TNC, SMA and special connectors are found, particularly in mobile duplexer designs. Cables, adapters and test loads must be secured to suit.

Tuning Band Pass Duplexers

This type of duplexer is the easiest to tune, particularly if it is set up for single transmit, single receiver operation. As stated earlier, this duplexer performs by virtue of pure band pass cavity selectivity. Their tunable ranges are generally restricted to less than 0.5% of originally set frequencies due to the critical nature of loop adjustment and cable lengths.

Obviously, major changes of frequency can be accomplished through complete re-adjustment of all loop settings and making up new cables as required. We caution against attempting this, as loop setting and cables lengths are interactive and overall adjustment procedures are lengthy and tricky at best.

Remember, for low signal loss and interference free duplex operation, the duplexer must do several things:

- 1. Through sufficient selectivity of cascaded band pass cavity branches the carrier power of the transmitter must be reduced below the threshold sensitivity of the receiver.
- 2. The wide band noise generated in the transmitter must also be reduced to a level below the receiver's threshold.
- 3. The lowest possible loss should exist in both branched to keep transmitter power loss down and to preserve receiver sensitivity.
- 4. Co-incident with low loss is the electrical match between each port of the duplexer and transmitter output impedance, receiver input impedance and the antenna impedance. A measured return loss of at least 26 dB, (a VSWR of 1.1:1 or better) should be attained. Lower return losses (higher VSWR's) simply indicate a mismatch with the associated devices, meaning that power will be reflected, causing higher losses.

Other things can also happen. Certain amplifiers may become spurious if connected to a poor match, or through integral protective circuitry reduce the amplifier's output power where a bad match exists. Obviously a poor match between the receiver's input circuits and the duplexer means that less signal will be transferred, reducing effective receiver sensitivity. Note that many manufacturers specify VSWR's as 1.5:1 (a return loss of 14 dB) or better, as an acceptable matching impedance. Consider that a 1.5:1 VSWR represents a mismatch in which 20% of the power will be reflected. If properly designed and properly tuned, we find that most duplexers will provide return losses of at lest 26 dB at all ports, which translates to a VSWR of about 1.1:1, a reflection coefficient of only 5%.

It is for these reasons that we stress that measuring return loss is most important in duplexer tuning. Even though a measure loss appears to be low through a transmit or receive branch a bad match between that port and the radio equipment can, and often will, result in lowered system performance.

The following procedure is recommended for tuning a band pass duplexer:

- 1. Normalize the test equipment such that display indication is set to top of scale with a calibrated generator signal output. For most analyzers and many swept type measurement systems, 1 milli-watt (0 dB) is available. (We assume here that the duplexer to be tune or retuned has been operating satisfactorily.)
- 2. Terminate the receive port with a test termination.
- 3. Set the generator center frequency to the present frequency of the transmit branch to verify insertion loss as originally tuned.
- 4. Drive the transmit port with generator signal output and monitor at the antenna port. Measured loss should be close to the duplexer's rated loss.
- 5. Expand the analyzer bandwidth if necessary and measure the response at the originally tuned receive frequency. This defines the rejection of transmitter noise rejection at the receiver's frequency. For transmitters under 100 watt output power, this should be at least 75 dB. For 125 watt or higher transmitter powers at least 95 dB of noise rejection is needed, and up to 120 dB where T R spacings are close (under 1 Mhz in VHF, 3 Mhz in UHF and 6 Mhz in 800 960 Mhz band.)
- 6. If equipment for return loss measurement is available, you should see a R/L of 26 dB or higher at the transmit frequency. Reverse the drive and monitor leads to check the R/L at the antenna port, at the TX frequency.
- 7. Reverse the leads again. Adjust the frequency source and display to the new transmit frequency. Now tune all cavity adjustments sequentially until a peak or overall response is achieved. If equipped for expanded range measurement, check the nose of response to see if it meets rated insertion loss.
- 8. Observe the R/L at the new frequency. Carefully adjust all cavity tuning for best attainable return loss, consistent with lowest branch insertion loss. Where two, three or more cavities are used in each branch, go through the cavities several times to find the optimum. Note that it may be possible to secure and excellent return loss, but with a higher insertion loss than the duplexer's rating. Note also, that the pass band geometry should be a smooth "skirt" dropping symmetrically on either side of the peak of response. If other "bumps" in the response pattern or a marked difference in skirt slope exists, improper tuning is usually indicated. Keep going through the string of cavities over and over until the desired responses are obtained.
- 9. Drive the RX port and terminate the TX port.
- 10. Using the same procedures as given in steps 1 through 8, tune the RX branch. The skirt response is the rejection of the transmitter carrier and must meet or exceed system requirements according to transmitter power. When accomplished, go to the next step.
- 11. If equipped for return loss measurement, drive the antenna port at a frequency about midway between the transmit and receive channel frequencies. Expand analyzer frequency range to permit viewing both frequencies. You can now monitor the loss toward the T and R ports by monitoring one of them and terminating the other. You can also see the return loss that the antenna port at each frequency. It should be at least 26 dB. If either or both are less, you must go through each branch procedure again to find the optimum of loss, reject and return loss at all ports.

It will be found that most bandpass duplexers will tune readily if the frequency change is small. If a significant change in either or both frequencies is made and poor performance results, loop setting cable lengths may have to be changed. We recommend returning the duplexer to its original manufacturer for this level of retuning. The required cable lengths and loop setting procedures vary from one manufacturer to another according to design philosophy, making it the least problem for the original manufacturer to affect such changes. We also recommend that all expanded band pass duplexers are returned to manufacturer for retuning or repair and tuning, for the same reasons.

Tuning Band Reject and Pass Reject Duplexers

As previously mentioned, these duplexer types function by placing the notches of one or more cavities in each branch such that the transmitter carrier is notched out in the receive branch and transmitter noise at receiving frequency is notched out in the transmit branch. Simple two cavity duplexers can be used for low power transmit systems with wide T - R spacings. Where 65 dB or so is sufficient for duplex operation, this can be secured with two carefully coupled and tuned cavities.

Where higher transmitter power and narrower T - R spacing are present, two, three or even four cavities and large cavities providing higher "Q" may be needed in each branch. This is particularly true where T - R spacings are very narrow, such as down to 180 - 200 Khz. in the 150 Mhz. range, and in similar special situations. Notch depths required for interference free duplex operation increase as transmitter power (yielding more noise) increases, and the receive frequency is brought closer to the transmitter carrier where the amount of noise power increases sharply.

Before attempting to tune a duplexer of these types for a T - R spacing closer that it was factory tuned, you must consult the manufacturer's data sheets or contact the manufacturer's engineering department to determine whether or not it can function at closer spacings.

The recommended procedure for tuning band reject and pass-reject duplexers is as follows:

- 1. Normalize your test setup as covered under band pass duplexer tuning.
- 2. Drive the duplexer transmit port, monitor at the duplexer antenna port and terminate the receiver port with a 50 ohm load. Adjust the cavity tuning rods for lowest insertion loss and best return loss at the desired transmit frequency.
- 3. Drive the receive port at the receive frequency with the transmit port terminated and adjust the cavities for lowest insertion loss and best available return loss.
- 4. While driving the receiver port and monitoring at the antenna port, tune to the transmit frequency and adjust the notch tuning of the receive cavities to place the notches exactly on the transmit frequency.
- 5. Now, drive the transmitter port again and adjust the transmit cavity notch capacitors to place the notches on the receive frequency.
- 6. Repeat steps 2 through 5. Note that the cavity main tuning and notch tuning are somewhat inter-relative. With fairly close spaced duplexers three or four times through the procedures may be needed to secure best overall performance. The return loss at both the transmit and receive ports should be 26 dB or better. If not, some compromise in cavity tuning may be required to secure this, even at some slight expense of insertion loss. Note that any time a cavity is adjusted, it's loop must again be adjusted to re-position the notch.
- 7. Now, terminate the antenna port, drive the transmit port and monitor at the receive port. Expand the swept width to view both the receive and transmit frequencies. This will display the two notches and the mid-band isolation curve between the receive and transmit frequencies.
- 8. Drive the antenna port, monitor the transmit port and terminate the receive port. Observe the return loss at both transmit and receive frequencies. It should be 26 dB or better, at either frequency.

Tuning Pass-Reject with Added Band Pass Element Duplexers

The recommended procedure for tuning this type duplexer is similar to the pass reject type, tuning the pass cavities during the pass-reject cavity sequences as covered. As noted earlier, this type of duplexer is used generally at high density communications sites and can provide reject notches of 120 dB or greater in addition to enhanced receiver protection and transmitter spurious, harmonic and intermodulation protection. Great care must be used in tuning procedures to secure the best operation characteristics.

Tuning Duplexers ("Isoplexers") with Isolators in Transmit Branch

First retune the duplexer according to the instructions for the duplexer type, with the isolator disconnected. After the duplexer has been tuned satisfactorily, re-connect the isolator and retune as follows:

- 1. Drive the isolator input at the transmitter frequency with the signal source and monitor the antenna port. Alternately adjust the input, inter-stage (if a dual type) and output tuning capacitors of the isolator for lowest indicated overall insertion loss (do not adjust the load port capacitor(s) at this time).
- 2. Now, drive the antenna port and monitor the isolator input port. Adjust the isolator load port capacitor(s) for the greatest isolation.
- 3. If the isoplexer is equipped with a 2nd harmonic filter, drive the isolator input at 2X the transmit frequency while monitoring this frequency at the duplexer antenna port. Adjust the filter tuning capacitor to place it's notch at the harmonic frequency.

Note: If the isolator is broadband or fixed-tuned device, check losses and tune the harmonic filter as in step #3, above.

Hints and Kinks, Errata

Often, if a duplexer has been seriously detuned, cables damaged, etc. it will be best to pretune each cavity separately for pass or passreject characteristics. Care must also be used to avoid exchanging cables since all cables are critical in length. If a cable must be replaced use the exact cable type and connector types and make sure that the cable is the exact length as the original.

Cavities having rotatable, adjustable loops should not be changed under frequency change procedures, since these adjustments can be very critical and the effective electrical length changes as the loop coupling factor is changed. Note that it is rare that calibrations placed on rotatable loops are accurate over a range of loop coupling adjustment. Should it be necessary to adjust a band pass cavity resonator for a given loss (coupling) factor, the availability of an impedance bridge is most desirable.

The procedure to adjust band pass cavity coupling loss is as follows:

- 1. If the loops have calibrations in dB of loss, set them to the indicated coupling factor desired, e.g.: 0.5 dB, 1 dB, 1.5 dB, etc., as a starting point.
- 2. Set the equipment to the desired pass frequency, drive one loop and monitor at the other loop. Observe the loss through the cavity and the return loss at the driven loop. It should be 18 dB or better. Now, reverse the test cables and check the return loss at the other port.
- 3. It will be necessary to carefully adjust each loop alternately to finally secure the desired coupling factor and at the same time have identical return losses at both ports. Often, three or four reversals of the cables will be required to arrive at this optimum point of tuning. The return losses with most cavities will be from 16 to 25 dB, depending on the cavity design, the "Q" and the coupling factor desired.

Other suggestions include making certain that all connector barrels are properly tightened, cables are tied down and the cavities are properly secured to their mounting bars or brackets. When retuning a duplexer, do yourself and the next technician a favor by labeling the unit with its operating frequencies. Also, a record of the performances as measured is most valuable in the even of system problems or if the duplexer is to be placed in storage for later use.

Summary

Antenna duplexers currently provide many thousands of repeaters with the system isolations needed for successful duplex operation. Most duplexers manufactured during the past ten to fifteen years are capable of long term operation without maintenance. The EMR Corporation line of antenna duplexers was developed over several years of design work. Our choice of square format cavities was determined by looking for an optimum of physical size versus performance requirements in today's land mobile system market. The square shapes and cavity lengths are optimum for the frequency ranges of the traditional land mobile band allocations and package very well for relay rack and in-cabinet mounting.

Every effort is made to use the best materials, careful attention to internal resonating element construction and use of silver plating to reduce losses of the elements and loop assemblies. High quality double shielded cable is used with high grade cable connectors. We use Type N connectors primarily for their constant impedance characteristics, extremely low loss and low signal leakage. Every cavity is carefully temperature compensated to ensure stable, long term and trouble free performance under wide extremes of ambient temperature and transmit duty cycles up to 100%.

Appendix C

Equations / Conversions

The following mathematical equations allow one to convert between SWR, Reflection Coefficient, and Return Loss.

$$RL = -20\log_{10}|\rho|$$

$$RL = -20\log_{10}\frac{SWR - 1}{SWR + 1}$$

$$RL = -20\log_{10} \frac{\frac{Z}{50} - 1}{\frac{Z}{50} + 1}$$

$$SWR = \frac{1+\rho}{1-\rho}$$

$$SWR = \frac{1 + 10^{(-RL/20)}}{1 - 10^{(-RL/20)}}$$

$$SWR = \frac{Z}{50}$$

$$SWR = \frac{1 + \sqrt{\frac{P_r}{P_f}}}{1 - \sqrt{\frac{P_r}{P_f}}}$$

$$\rho = \frac{SWR - 1}{SWR + 1}$$

$$\rho = 10^{(-RL/20)}$$

$$\rho = \sqrt{\frac{P_r}{P_f}}$$

$$\Gamma = \frac{\frac{Z}{50} - 1}{\frac{Z}{50} + 1}$$

$$Z = 50 \frac{1+\Gamma}{1-\Gamma}$$

$$Z = 50SWR$$

$$Z = 50 \frac{1 + 10^{(-RL/20)}}{1 - 10^{(1RL/20)}}$$

Appendix D Return Loss to SWR, Reflection Coefficient, and Impedance

RL	SWR	ρ	Z∠?°	Z∠?°	RL	SWR	ρ	Z∠?°	Z∠?°	RL	SWR	ρ	Z∠?°	Z∠?°
40.0	1.020	0.0100	51.01	49.01	26.6	1.098	0.0468	54.91	45.53	13.2	1.560	0.2188	78.00	32.05
39.8	1.021	0.0102	51.03	48.99	26.4	1.101	0.0479	55.03	45.43	13.0	1.577	0.2239	78.84	31.71
39.6	1.021	0.0105	51.06	48.96	26.2	1.103	0.0490	55.15	45.33	12.8	1.594	0.2291	79.72	31.36
39.4	1.022	0.0107	51.08	48.94	26.0	1.106	0.0501	55.28	45.23	12.6	1.612	0.2344	80.62	31.01
39.2	1.022	0.0110	51.11	48.92	25.8	1.108	0.0513	55.41	45.12	12.4	1.631	0.2399	81.56	30.65
39.0	1.023	0.0112	51.13	48.89	25.6	1.111	0.0525	55.54	45.01	12.2	1.651	0.2455	82.53	30.29
38.8	1.023	0.0115	51.16	48.86	25.4	1.114	0.0537	55.68	44.90	12.0	1.671	0.2512	83.54	29.92
38.6	1.024	0.0117	51.19	48.84	25.2	1.116	0.0550	55.81	44.79	11.8	1.692	0.2570	84.60	29.55
38.4	1.024	0.0120	51.22	48.81	25.0	1.119	0.0562	55.96	44.68	11.6	1.714	0.2630	85.69	29.17
38.2	1.025	0.0123	51.25	48.78	24.8	1.122	0.0575	56.11	44.56	11.4	1.737	0.2692	86.83	28.79
38.0	1.025	0.0126	51.27	48.76	24.6	1.125	0.0589	56.26	44.44	11.2	1.760	0.2754	88.01	28.41
37.8	1.026	0.0129 0.0132	51.31 51.34	48.73 48.70	24.4 24.2	1.128 1.131	0.0603	56.41 56.57	44.32 44.19	11.0 10.8	1.785 1.811	0.2818 0.2884	89.24 90.53	28.01 27.62
37.6 37.4	1.027 1.027	0.0132	51.34	48.67	24.2	1.131	0.0617 0.0631	56.73	44.19	10.8	1.837	0.2864	90.33	27.02
37.4	1.027	0.0133	51.40	48.64	23.8	1.138	0.0646	56.90	43.94	10.4	1.865	0.3020	93.27	26.81
37.0	1.029	0.0130	51.43	48.61	23.6	1.141	0.0661	57.07	43.80	10.4	1.894	0.3020	94.72	26.39
36.8	1.029	0.0145	51.47	48.58	23.4	1.145	0.0676	57.25	43.67	10.0	1.925	0.3162	96.25	25.97
36.6	1.030	0.0148	51.50	48.54	23.2	1.149	0.0692	57.43	43.53	9.8	1.957	0.3236	97.84	25.55
36.4	1.031	0.0151	51.54	48.51	23.0	1.152	0.0708	57.62	43.39	9.6	1.990	0.3311	99.51	25.12
36.2	1.031	0.0155	51.57	48.47	22.8	1.156	0.0724	57.81	43.24	9.4	2.025	0.3388	101.25	24.69
36.0	1.032	0.0158	51.61	48.44	22.6	1.160	0.0741	58.01	43.10	9.2	2.062	0.3467	103.08	24.25
35.8	1.033	0.0162	51.65	48.40	22.4	1.164	0.0759	58.21	42.95	9.0	2.100	0.3548	104.99	23.81
35.6	1.034	0.0166	51.69	48.37	22.2	1.168	0.0776	58.42	42.80	8.8	2.140	0.3631	107.01	23.36
35.4	1.035	0.0170	51.73	48.33	22.0	1.173	0.0794	58.63	42.64	8.6	2.182	0.3715	109.12	22.91
35.2	1.035	0.0174	51.77	48.29	21.8	1.177	0.0813	58.85	42.48	8.4	2.227	0.3802	111.34	22.45
35.0	1.036	0.0178	51.81	48.25	21.6	1.181	0.0832	59.07	42.32	8.2	2.274	0.3890	113.68	21.99
34.8	1.037	0.0182	51.85	48.21	21.4	1.186	0.0851	59.30	42.16	8.0	2.323	0.3981	116.14	21.53
34.6	1.038	0.0186	51.90	48.17	21.2	1.191	0.0871	59.54	41.99	7.8	2.375	0.4074	118.74	21.05
34.4	1.039	0.0191	51.94	48.13	21.0	1.196	0.0891 0.0912	59.78	41.82	7.6	2.430	0.4169	121.49	20.58
34.2 34.0	1.040 1.041	0.0195 0.0200	51.99 52.04	48.09 48.04	20.8 20.6	1.201 1.206	0.0912	60.04 60.29	41.64 41.46	7.4 7.2	2.488 2.549	0.4266 0.4365	124.39 127.47	20.10 19.61
33.8	1.041	0.0204	52.04	48.00	20.4	1.211	0.0955	60.56	41.28	7.0	2.615	0.4467	130.73	19.12
33.6	1.042	0.0209	52.13	47.95	20.2	1.217	0.0933	60.83	41.10	6.8	2.684	0.4571	134.19	18.63
33.4	1.044	0.0214	52.18	47.91	20.0	1.222	0.1000	61.11	40.91	6.6	2.758	0.4677	137.88	18.13
33.2	1.045	0.0219	52.24	47.86	19.8	1.228	0.1023	61.40	40.72	6.4	2.836	0.4786	141.80	17.63
33.0	1.046	0.0224	52.29	47.81	19.6	1.234	0.1047	61.70	40.52	6.2	2.920	0.4898	145.99	17.12
32.8	1.047	0.0229	52.34	47.76	19.4	1.240	0.1072	62.00	40.32	6.0	3.010	0.5012	150.48	16.61
32.6	1.048	0.0234	52.40	47.71	19.2	1.246	0.1096	62.32	40.12	5.8	3.106	0.5129	155.28	16.10
32.4	1.049	0.0240	52.46	47.66	19.0	1.253	0.1122	62.64	39.91	5.6	3.209	0.5248	160.44	15.58
32.2	1.050	0.0245	52.52	47.60	18.8	1.259	0.1148	62.97	39.70	5.4	3.320	0.5370	166.00	15.06
32.0	1.052	0.0251	52.58	47.55	18.6	1.266	0.1175	63.31	39.49	5.2	3.440	0.5495	172.00	14.54
31.8	1.053	0.0257	52.64	47.49	18.4	1.273	0.1202	63.67	39.27	5.0	3.570	0.5623	178.49	14.01
31.6	1.054	0.0263	52.70	47.44	18.2	1.281	0.1230	64.03	39.05	4.8	3.711	0.5754	185.54	13.47
31.4	1.055	0.0269	52.77	47.38	18.0	1.288	0.1259	64.40	38.82	4.6	3.864	0.5888	193.22	12.94
31.2	1.057	0.0275	52.83	47.32	17.8	1.296	0.1288	64.79	38.59	4.4	4.032	0.6026	201.61	12.40
31.0 30.8	1.058 1.059	0.0282 0.0288	52.90 52.97	47.26 47.20	17.6 17.4	1.304 1.312	0.1318 0.1349	65.18 65.59	38.35 38.11	4.2 4.0	4.216 4.419	0.6166 0.6310	210.82 220.97	11.86 11.31
30.6	1.061	0.0288	53.04	47.13	17.2	1.320	0.1349	66.01	37.87	3.8	4.644	0.6457	232.21	10.77
30.4	1.062	0.0302	53.11	47.07	17.0	1.329	0.1413	66.45	37.62	3.6	4.894	0.6607	244.72	10.22
30.2	1.064	0.0309	53.19	47.00	16.8	1.338	0.1445	66.90	37.37	3.4	5.174	0.6761	258.72	9.66
30.0	1.065	0.0316	53.27	46.93	16.6	1.347	0.1479	67.36	37.11	3.2	5.490	0.6918	274.50	9.11
29.8	1.067	0.0324	53.34	46.87	16.4	1.357	0.1514	67.84	36.85	3.0	5.848	0.7079	292.40	8.55
29.6	1.068	0.0331	53.42	46.79	16.2	1.367	0.1549	68.33	36.59	2.8	6.258	0.7244	312.89	7.99
29.4	1.070	0.0339	53.51	46.72	16.0	1.377	0.1585	68.83	36.32	2.6	6.731	0.7413	336.56	7.43
29.2	1.072	0.0347	53.59	46.65	15.8	1.387	0.1622	69.36	36.05	2.4	7.284	0.7586	364.21	6.86
29.0	1.074	0.0355	53.68	46.57	15.6	1.398	0.1660	69.90	35.77	2.2	7.938	0.7762	396.92	6.30
28.8	1.075	0.0363	53.77	46.50	15.4	1.409	0.1698	70.46	35.48	2.0	8.724	0.7943	436.21	5.73
28.6	1.077	0.0372	53.86	46.42	15.2	1.421	0.1738	71.03	35.19	1.8	9.686	0.8128	484.28	5.16
28.4	1.079	0.0380	53.95	46.34	15.0	1.433	0.1778	71.63	34.90	1.6	10.888	0.8318	544.40	4.59
28.2	1.081	0.0389	54.05	46.26	14.8	1.445	0.1820	72.24	34.60	1.4	12.435	0.8511	621.76	4.02
28.0	1.083	0.0398	54.15	46.17	14.6	1.458	0.1862	72.88	34.30	1.2	14.500	0.8710	724.98	3.45
27.8 27.6	1.085 1.087	0.0407 0.0417	54.25 54.35	46.09 46.00	14.4 14.2	1.471 1.484	0.1905 0.1950	73.54 74.22	34.00 33.68	1.0 0.8	17.391 21.730	0.8913 0.9120	869.55 1086.50	2.88 2.30
27.4	1.087	0.0417	54.46	45.91	14.2	1.499	0.1930	74.22	33.37	0.6	28.964	0.9120	1448.22	1.73
27.4	1.091	0.0427	54.56	45.82	13.8	1.513	0.1993	75.66	33.04	0.4	43.437	0.9550	2171.86	1.75
27.0	1.094	0.0447	54.68	45.72	13.6	1.528	0.2089	76.41	32.72	0.2	86.863	0.9772	4343.14	0.58
26.8	1.096	0.0457	54.79	45.63	13.4	1.544	0.2138	77.19	32.39	0.0	∞	1.0000	∞	0.00

Appendix E

dBm to Power or Voltage at 50 ohms

dBm	Power	***	Voltage		dBm	Power		Voltage		dBm	Power	***	Voltage	
53	199.53	W	99.88	V	-10	100.0	uW	70.71	mV	-73	50.1	pW	50.06	uV
52	158.49	W	89.02	V	-11	79.4	uW	63.02	mV	-74	39.8	pW	44.62	uV
51	125.89	W	79.34	V	-12	63.1	uW	56.17	mV	-75	31.6	pW	39.76	uV
50	100.00	W	70.71	V	-13	50.1	uW	50.06	mV	-76	25.1	pW	35.44	uV
49	79.43	W	63.02	V	-14	39.8	uW	44.62	mV	-77	20.0	pW	31.59	uV
48	63.10	W	56.17	V	-15	31.6	uW	39.76	mV	-78	15.8	pW	28.15	uV
47	50.12	W	50.06	V	-16	25.1	uW	35.44	mV	-79	12.6	pW	25.09	uV
46	39.81	W	44.62	V	-17	20.0	uW	31.59	mV	-80	10.0	pW	22.36	uV
45	31.62	W	39.76	V	-18	15.8	uW	28.15	mV	-81	7.9	pW	19.93	uV
44	25.12	W	35.44	V	-19	12.6	uW	25.09	mV	-82	6.3	pW	17.76	uV
43	19.95	W	31.59	V	-20	10.0	uW	22.36	mV	-83	5.0	pW	15.83	uV
42	15.85	W	28.15	V	-21	7.9	uW	19.93	mV	-84	4.0	pW	14.11	uV
41	12.59	W	25.09	V	-22	6.3	uW	17.76	mV	-85	3.2	pW	12.57	uV
40	10.00	W	22.36	V	-23	5.0	uW	15.83	mV	-86	2.5	pW	11.21	uV
39	7.94	W	19.93	V	-24	4.0	uW	14.11	mV	-87	2.0	pW	9.99	uV
38	6.31	W	17.76	V	-25	3.2	uW	12.57	mV	-88	1.6	pW	8.90	uV
37	5.01	W	15.83	V	-26	2.5	uW	11.21	mV	-89	1.3	pW	7.93	uV
36	3.98	W	14.11	V	-27	2.0	uW	9.99	mV	-90	1.0	pW	7.07	uV
35	3.16	W	12.57	V	-28	1.6	uW	8.90	mV	-91	794.3	fW	6.30	uV
34	2.51	W	11.21	v	-29	1.3	uW	7.93	mV	-92	631.0	fW	5.62	uV
33	2.00	W	9.99	v	-30	1.0	uW	7.07	mV	-93	501.2	fW	5.01	uV
32	1.58	W	8.90	V	-31	794.3	nW	6.30	mV	-94	398.1	fW	4.46	uV
31	1.26	W	7.93	v	-32	631.0	nW	5.62	mV	-95	316.2	fW	3.98	uV
30	1.0	W	7.07	v	-33	501.2	nW	5.01	mV	-96	251.2	fW	3.54	uV
29	794.3	mW	6.30	v	-34	398.1	nW	4.46	mV	-97	199.5	fW	3.16	uV
28	631.0	mW	5.62	v	-35	316.2	nW	3.98	mV	-98	158.5	fW	2.82	uV uV
27	501.2	mW	5.01	v	-36	251.2	nW	3.54	mV	-99	125.9	fW	2.51	uV uV
26	398.1	mW	4.46	v	-37	199.5	nW	3.16	mV	-100	100.0	fW	2.24	uV uV
		mW		v	-38	158.5						fW	1.99	u V uV
25	316.2		3.98				nW	2.82	mV	-101	79.4			
24	251.2	mW	3.54	V	-39	125.9	nW	2.51	mV	-102	63.1	fW	1.78	uV
23	199.5	mW	3.16	V	-40	100.0	nW	2.24	mV	-103	50.1	fW	1.58	uV
22	158.5	mW	2.82	V	-41	79.4	nW	1.99	mV	-104	39.8	fW	1.41	uV
21	125.9	mW	2.51	V	-42	63.1	nW	1.78	mV	-105	31.6	fW	1.26	uV
20	100.0	mW	2.24	V	-43	50.1	nW	1.58	mV	-106	25.1	fW	1.12	uV
19	79.4	mW	1.99	V	-44	39.8	nW	1.41	mV	-107	20.0	fW	1.00	uV
18	63.1	mW	1.78	V	-45	31.6	nW	1.26	mV	-108	15.8	fW	0.890	uV
17	50.1	mW	1.58	V	-46	25.1	nW	1.12	mV	-109	12.6	fW	0.793	uV
16	39.8	mW	1.41	V	-47	20.0	nW	1.00	mV	-110	10.0	fW	0.707	uV
15	31.6	mW	1.26	V	-48	15.8	nW	890.19	uV	-111	7.9	fW	0.630	uV
14	25.1	mW	1.12	V	-49	12.6	nW	793.39	uV	-112	6.3	fW	0.562	uV
13	20.0	mW	1.00	V	-50	10.0	nW	707.11	uV	-113	5.0	fW	0.501	uV
12	15.8	mW	890.19	mV	-51	7.9	nW	630.21	uV	-114	4.0	fW	0.446	uV
11	12.6	mW	793.39	mV	-52	6.3	nW	561.67	uV	-115	3.2	fW	0.398	uV
10	10.0	mW	707.11	mV	-53	5.0	nW	500.59	uV	-116	2.5	fW	0.354	uV
9	7.9	mW	630.21	mV	-54	4.0	nW	446.15	uV	-117	2.0	fW	0.316	uV
8	6.3	mW	561.67	mV	-55	3.2	nW	397.64	uV	-118	1.6	fW	0.282	uV
7	5.0	mW	500.59	mV	-56	2.5	nW	354.39	uV	-119	1.3	fW	0.251	uV
6	4.0	mW	446.15	mV	-57	2.0	nW	315.85	uV	-120	1.0	fW	0.224	uV
5	3.2	mW	397.64	mV	-58	1.6	nW	281.50	uV	-121	0.794	fW	0.199	uV
4	2.5	mW	354.39	mV	-59	1.3	nW	250.89	uV	-122	0.631	fW	0.178	uV
3	2.0	mW	315.85	mV	-60	1.0	nW	223.61	uV	-123	0.501	fW	0.158	uV
2	1.6	mW	281.50	mV	-61	794.3	pW	199.29	uV	-124	0.398	fW	0.141	uV
1	1.3	mW	250.89	mV	-62	631.0	pW	177.62	uV	-125	0.316	fW	0.126	uV
0	1.0	mW	223.61	mV	-63	501.2	pW	158.30	uV	-126	0.251	fW	0.112	uV
-1	794.3	uW	199.29	mV	-64	398.1	pW	141.09	uV	-127	0.200	fW	0.100	uV
-2	631.0	uW	177.62	mV	-65	316.2	рW	125.74	uV uV	-128	0.250	fW	0.100	uV
-3	501.2	uW	158.30	mV	-66	251.2	рW	112.07	uV uV	-129	0.136	fW	0.079	uV
-3 -4	398.1	uW	141.09	mV	-67	199.5	рW	99.88	uV uV	-130	0.120	fW	0.079	uV uV
-5	316.2	uW	125.74	mV	-68	158.5	рW	89.02	uV uV	-131	0.100	fW	0.063	uV uV
-5 -6	251.2	uW uW	112.07	mV	-69	125.9	рW	79.34	u v uV	-131	0.079	fW	0.065	u v uV
	231.2 199.5	uW uW	99.88	m v mV	-69 -70				u v uV		0.063		0.050	
-7 -8					-70 -71	100.0 79.4	pW pW	70.71		-133 -134		fW		uV
-8 -9	158.5	uW	89.02	mV mV			pW	63.02	uV		0.040	fW	0.045	uV
4	125.9	uW	79.34	mV	-72	63.1	pW	56.17	uV	-135	0.032	fW	0.040	uV

Appendix F

Decibels to Percentage Gain or Loss

dB Change	Gain	Loss	dB Change	Gain	Loss	dB Change	Gain	Loss
0.10 dB	2.33%	2.28%	1.34 dB	36.14%	26.55%	4.90 dB	209.03%	67.64%
0.12 dB	2.80%	2.73%	1.36 dB	36.77%	26.89%	5.00 dB	216.23%	68.38%
0.14 dB	3.28%	3.17%	1.38 dB	37.40%	27.22%	5.10 dB	223.59%	69.10%
0.16 dB	3.75%	3.62%	1.40 dB	38.04%	27.56%	5.20 dB	231.13%	69.80%
0.18 dB	4.23%	4.06%	1.42 dB	38.68%	27.89%	5.30 dB	238.84%	70.49%
0.20 dB	4.71%	4.50%	1.44 dB	39.32%	28.22%	5.40 dB	246.74%	71.16%
0.22 dB	5.20%	4.94%	1.46 dB	39.96%	28.55%	5.50 dB	254.81%	71.82%
0.24 dB	5.68%	5.38%	1.48 dB	40.60%	28.88%	5.60 dB	263.08%	72.46%
0.26 dB	6.17%	5.81%	1.50 dB	41.25%	29.21%	5.70 dB	271.54%	73.08%
0.28 dB	6.66%	6.24%	1.52 dB	41.91%	29.53%	5.80 dB	280.19%	73.70%
0.30 dB	7.15%	6.67%	1.54 dB	42.56%	29.85%	5.90 dB	289.05%	74.30%
0.32 dB	7.65%	7.10%	1.56 dB	43.22%	30.18%	6.00 dB	298.11%	74.88%
0.34 dB	8.14%	7.53%	1.58 dB	43.88%	30.50%	6.10 dB	307.38%	75.45%
0.36 dB	8.64%	7.96%	1.60 dB	44.54%	30.82%	6.20 dB	316.87%	76.01%
0.38 dB	9.14%	8.38%	1.62 dB	45.21%	31.13%	6.30 dB	326.58%	76.56%
0.40 dB	9.65%	8.80%	1.64 dB	45.88%	31.45%	6.40 dB	336.52%	77.09%
0.42 dB	10.15%	9.22%	1.66 dB	46.55%	31.77%	6.50 dB	346.68%	77.61%
0.44 dB	10.66%	9.64%	1.68 dB	47.23%	32.08%	6.60 dB	357.09%	78.12%
0.46 dB	11.17%	10.05%	1.70 dB	47.91%	32.39%	6.70 dB	367.74%	78.62%
0.48 dB	11.69%	10.46%	1.72 dB	48.59%	32.70%	6.80 dB	378.63%	79.11%
0.50 dB	12.20%	10.87%	1.74 dB	49.28%	33.01%	6.90 dB	389.78%	79.58%
0.52 dB	12.72%	11.28%	1.76 dB	49.97%	33.32%	7.00 dB	401.19%	80.05%
0.54 dB	13.24%	11.69%	1.78 dB	50.66%	33.63%	7.10 dB	412.86%	80.50%
0.56 dB	13.76%	12.10%	1.80 dB	51.36%	33.93%	7.20 dB	424.81%	80.95%
0.58 dB	14.29%	12.50%	1.82 dB	52.05%	34.23%	7.30 dB	437.03%	81.38%
$0.60 \mathrm{dB}$	14.82%	12.90%	1.84 dB	52.76%	34.54%	7.40 dB	449.54%	81.80%
0.62 dB	15.35%	13.30%	1.86 dB	53.46%	34.84%	7.50 dB	462.34%	82.22%
0.64 dB	15.88%	13.70%	1.88 dB	54.17%	35.14%	7.60 dB	475.44%	82.62%
$0.66 \mathrm{dB}$	16.41%	14.10%	1.90 dB	54.88%	35.43%	7.70 dB	488.84%	83.02%
0.68 dB	16.95%	14.49%	1.92 dB	55.60%	35.73%	7.80 dB	502.56%	83.40%
0.70 dB	17.49%	14.89%	1.94 dB	56.31%	36.03%	7.90 dB	516.60%	83.78%
0.72 dB	18.03%	15.28%	1.96 dB	57.04%	36.32%	8.00 dB	530.96%	84.15%
0.74 dB	18.58%	15.67%	1.98 dB	57.76%	36.61%	8.10 dB	545.65%	84.51%
0.76 dB	19.12%	16.05%	2.00 dB	58.49%	36.90%	8.20 dB	560.69%	84.86%
0.78 dB	19.67%	16.44%	2.10 dB	62.18%	38.34%	8.30 dB	576.08%	85.21%
0.80 dB	20.23%	16.82%	2.20 dB	65.96%	39.74%	8.40 dB	591.83%	85.55%
0.82 dB	20.78%	17.21%	2.30 dB	69.82%	41.12%	8.50 dB	607.95%	85.87%
0.84 dB	21.34%	17.59%	2.40 dB	73.78%	42.46%	8.60 dB	624.44%	86.20%
$0.86 \mathrm{dB}$	21.90%	17.96%	2.50 dB	77.83%	43.77%	8.70 dB	641.31%	86.51%
0.88 dB	22.46%	18.34%	2.60 dB	81.97%	45.05%	8.80 dB	658.58%	86.82%
0.90 dB	23.03%	18.72%	2.70 dB	86.21%	46.30%	8.90 dB	676.25%	87.12%
0.92 dB	23.59%	19.09%	2.80 dB	90.55%	47.52%	9.00 dB	694.33%	87.41%
0.94 dB	24.17%	19.46%	2.90 dB	94.98%	48.71%	9.10 dB	712.83%	87.70%
0.96 dB	24.74%	19.83%	3.00 dB	99.53%	49.88%	9.20 dB	731.76%	87.98%
0.98 dB	25.31%	20.20%	3.10 dB	104.17%	51.02%	9.30 dB	751.14%	88.25%
1.00 dB	25.89%	20.57%	3.20 dB	108.93%	52.14%	9.40 dB	770.96%	88.52%
1.02 dB	26.47%	20.93%	3.30 dB	113.80%	53.23%	9.50 dB	791.25%	88.78%
1.04 dB	27.06%	21.30%	3.40 dB	118.78%	54.29%	9.60 dB	812.01%	89.04%
1.06 dB	27.64%	21.66%	3.50 dB	123.87%	55.33%	9.70 dB	833.25%	89.28%
1.08 dB	28.23%	22.02%	3.60 dB	129.09%	56.35%	9.80 dB	854.99%	89.53%
1.10 dB	28.82%	22.38%	3.70 dB	134.42%	57.34%	9.90 dB	877.24%	89.77%
1.12 dB	29.42%	22.73%	3.80 dB	139.88%	58.31%	10.00 dB	900.00%	90.00%
1.14 dB	30.02%	23.09%	3.90 dB	145.47%	59.26%	10.10 dB	923.29%	90.23%
1.16 dB	30.62%	23.44%	4.00 dB	151.19%	60.19%	10.20 dB	947.13%	90.45%
1.18 dB	31.22%	23.79%	4.10 dB	157.04%	61.10%	10.30 dB	971.52%	90.67%
1.20 dB	31.83%	24.14%	4.20 dB	163.03%	61.98%	10.40 dB	996.48%	90.88%
1.22 dB	32.43%	24.49%	4.30 dB	169.15%	62.85%	10.50 dB	1022.02%	91.09%
1.24 dB	33.05%	24.84%	4.40 dB	175.42%	63.69%	10.60 dB	1048.15%	91.29%
1.26 dB	33.66%	25.18%	4.50 dB	181.84%	64.52%	10.70 dB	1074.90%	91.49%
1.28 dB	34.28%	25.53%	4.60 dB	188.40%	65.33%	10.80 dB	1102.26%	91.68%
1.30 dB	34.90%	25.87%	4.70 dB	195.12%	66.12%	10.90 dB	1130.27%	91.87%
1.32 dB	35.52%	26.21%	4.80 dB	202.00%	66.89%	11.00 dB	1158.93%	92.06%

Appendix G

Velocity of Propagation for RG/U Cable Types

RG/U	Vr	RG/U	Vr	RG/U	Vr	RG/U	Vr
5	.659	74	.659	174	.659	235	.695
6	.659	79	.84	177	.659	293	.659
7	.659	84	.659	178	.695	294	.659
8	.659	85	.659	179	.695	295	.659
9	.659	87	.695	180	.695	302	.695
10	.659	94	.695	183	.91	303	.695
11	.659	108	.659	187	.695	304	.695
12	.659	111	.659	188	.695	306	.8
13	.659	115	.695	195	.695	307	.8
14	.659	116	.695	196	.695	316	.695
17	.659	117	.695	211	.695	323	.8
18	.659	118	.695	212	.659	324	.8
19	.659	119	.695	213	.659	332	.8
20	.659	120	.695	214	.659	333	.8
21	.659	122	.659	215	.659	334	.8
22	.659	130	.659	216	.659	335	.8
29	.659	131	.659	217	.659	336	.8
34	.659	140	.695	218	.659	360	.8
35	.659	141	.695	219	.659	376	.8
54	.659	142	.695	220	.659	388	.659
55	.659	143	.695	221	.659	393	.695
57	.659	144	.695	222	.659	397	.695
58	.659	147	.659	223	.659	400	.695
59	.659	159	.695	224	.659	401	.695
62	.84	161	.695	225	.695	402	.695
63	.84	164	.659	226	.695	403	.695
70	.659	165	.695	227	.695	404	.695
71	.84	166	.695	228	.695		

Other Cable Types

If the type of cable you are testing is not listed here, keep in mind the following; The velocity of propagation for Teflon dielectric cables is typically 0.695, and for typical cables with polyethylene dielectric, 0.659. Some foam dielectric cables have Vr ratings from 0.78-0.88, and air dielectrics from 0.90-0.93.



