Table of Contents

.

.

Antenna and Feedline Measurements

1.0 Introduction

This application note covers antenna and feedline measurement.

Modern radio equipment is much different than that of even two decades ago. Gone are point to point systems and simple repeater systems using only one frequency. Here now are multiple frequency/multiple site trunking systems. Frequencies extending into low microwaves and multiple site systems e. g. cellular or PCS.

The MSRS, or multiple site radio systems, have many operational advantages over the older single site systems. These include redunancy and better coverage. The disadvantages of these systems are increased problems with intermod and more difficulty in determining a problem site. The two-edged sword of redundancy cuts both ways. A down site means that fewer users can be accommodated, something that is hard to determine. Because of this many system operators have included maintenance test of their sites as standard operating Procedure or SOP. This maintenance usually includes transmitter, receiver, combiners, transmission lines & antennas.

Maintenance tests require the use of a service monitor that contains a good spectrum analyzer, to measure intermod, and a tracking generator, to help test and align filters, etc. This type of service monitor with the addition of a return loss bridge will allow comprehensive antenna and feedline measurements to be accomplished.

This application note covers the different ways used over the years of measuring antennas and transmission lines. These methods include wattmeters, scaler analyzers, and spectrum analyzers. The next section of the note provides more detail on the information contained in a broadly swept return loss curve. The final section covers actual test set ups and how to achieve them. Data is included on some of the more popular communication service monitors that are used for these types of measurements.

This note is designed with the busy technician, or engineer, in mind. Therefor, it does not deal heavily with the why or how. The only math presented here is that which is absolutely necessary to perform measurements or verify performance.

Eagle manufactures a wide variety of bridges that cover from 0.04 MHz to 3.0 GHz. At the present time there are four models in the RLB150 series of bridges. Also included are accessories to assist in the use of these bridges. Please contact the factory for a complete catalog if you do not already have one.

to next column

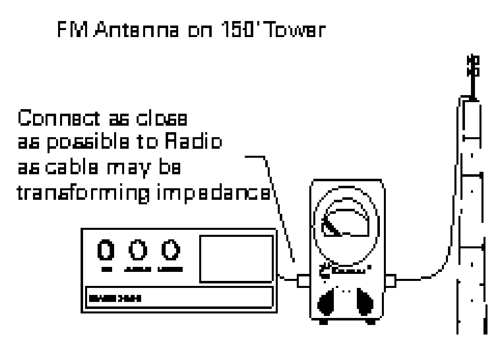
Note: it is not necessary to read sections 2.0 or 3.0 if you are in a hurry to get started skip to section 4.0.

2.0 Measurement Systems

2.1 Wattmeters

The directional wattmeter is the oldest mesasurement system that is still being used in commercial two-way radio systems. The wattmeter is elegantly simple. It consists of a directional separator, usually a coupler, a crystal diode detector and a meter. What could be simpler? There are no batteries to go dead or active electronics to break.

The wattmeter is dead simple to use. Simply connect it in series with the transmission lie and read forward power. Than switch the meter to its reverse power and read the reflected power. By use of a simple table, or memory after using one for a few days, calculate the VSWR. See figure 2.1.1 which illustrates the wattmeter connection.



Typical Directional Wattmeter Connection
Figure 2.1.1

The limitations of the wattmeter in modern sites are now causing this old standby to become inadequate. In a multiple transmitter situation where carriers are present thru a wide spectrum of the band it is necessary to measure the antenna at several frequencies in order to determine correct antenna performance. At some sites it is difficult to get the transmitters to change frequency; therefor it may be necessary to use different transmitters to measure different frequencies.

The other issue with wattmeters is the directivity of 20 to 25 dB is not good enough. Modern sites operating at one GHz are not uncommon anymore. The distance to the antenna from the transmitter may be 300 to 400 feet with a loss of5 or 6 dB. The return loss of the line than is 12 dB or about 6 watts back for 100 watts forward.

to page 2

Antenna and Feedline Measurments-Page 2

2.0 Measurment systems-continued

2.1 Wattmeters-continued

Let's assume the antenna is 2:1 VSWR or return loss of 9.5 dB. This further reduces the reflected power to 2.0 watts. Since the rated directivity of the meter is being approached it is hard to tell what the antenna really looks like.

There is no doubt that at a site with lots of cable loss and broadband antennas the wattmeter is not the instument one shuld be using for analyzing antenna system performance.

2.2 Scaler Analyzers

Scaler analyzers have been around for a long time too. Early models consisted of a sweep generator, diode detector and an oscillioscope. With the addition of a directional coupler or a return loss bridge the unit could be used for return loss measurements.

The sweep generator would sweep thru a range of frequencies and the reflected power could be viewed. The disadvantages are the size of the systems, the screen isn't calibrated directly in dB and they are difficult to use. Improvements were mad over the years and modern instruments contain all of these units in one package. Dedicated scaler analyzers are still somewhat large and can be very expensive.

Because of the limitations of the wattmeter and the desperate need to make swept measurements many two-way operators opted to use scaler analzyers for antenna and feedline measurements. Usually the instruments of choice read out directly in dB and they had highly accurate detectors and accessories. These instruments also had the ability to print the swept data to a plotter, printer or disk. Thus the site could be tested when the equipment was being installed. If problems were suspected the site could be retested and the present data compared to the previous data. This was a big help to find problems without having to experiment by removing antennas, etc.

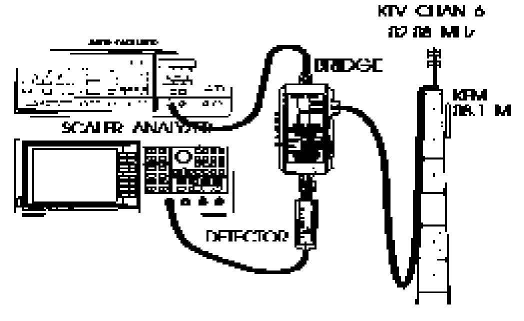
While the larger companies purchased their own scaler systems smaller ones relied upon consultants who specialized in antenna and feedline measurements. At certain intervals the consultant would be contracted to measure the sites and to determine the condition of the antenna system. While this worked it had the disadvantages of being expensive and sometimes not terribly time effective.

to next column

2.2 Scaler Analyzers-continued

As communication sites became crowded and co-location, e.g. other transmitters such as TV FM and AM broadcast at same site, became more prevalent another problem surfaced. The other carriers present would interfere with the measurement process. To understand the problem one must understand how scaler analyzers function.

The following figure (Figure 2.2.1) illustrates a typical scaler network analyzer setup:



Typical Scaler Analyzer Hookup
figure 2.2.1

The scaler analyzer consists of a sweep generator to generate a low level signal. This signal is fed into a directional device to which the device under test (DUT) is connected. The output of the directional device is than fed into a detector. This is where a problem comes into play. The detector is basically a diode that simultaneously detects all the signals that are present at the detector input.

Note: Some newer scaler analyzers use a different technique which will be discussed later!

As the figure illustrates the big carrier coming down the antenna is also detected. Let's take a case where the signal coming down is +10 dBm. The signal generator feeds a signal at +0 dBm into the bridge. The antenna and feedline exhibit a return loss of 20 dB. With the bridge loss and the return loss the return signal is -32 dBm. Since the interfering signal is +10 minus 6 dB for cable loss and 6 dB for the bridge loss the interfering signal is -2 dBm. Therefor, the indication will be -2 dB. It does not matter what frequency the generator is on in relation to the scope trace since the detector is receiving all frequencies at the same time. Remember there is no filtering or mixing in front of the diode detector.

Thus as the sites have become more crowded the ability to use a scaler network analyzer has become severely limited because of interference at the site.

to page 3

Antenna and Feedline Measurements-Page 3

2.0 Measurement Systems-continued
2.3 Vector Network Analyzers

Crowded sites sent system engineers and operators in search of some way to do network analysis at these sites. The answer was found in the vector network analyzer. This type of analyzer has been used in RF laboratories for approximately 20 years.

Pictured below, in Figure 2.3.1, is a typical vector network analyzer being used to run a structural return loss test on a reel of cable.

The vector analyzer has two advantages over a scaler analyzer. First, it uses a receiver as a detector rather than a diode. The receiver is designed so that it is looking at only one frequency at a time. This means that the only places the measurement is disturbed, if there are interfering carriers, is on the interference frequency. This also enhances the dynamic range of the measurement from around 50 dB to better than 80 dB. The second advantage is that the vector analyzer gathers and displays phase information about the signal.

With phase information, the impedance of the line can be determined rather than the SWR error. For example, if the scaler analzyer indicates 1.5:1 VSWR, you don't know if the line is 75 ohms or 33.3 ohms. The vector analyzer will tell you exactly the impedance of the line. IN cases where the line is reactive it will give the real and imaginary (j) component of the impedance.

Since the vector analyzers are generally lab-type instruments, they have unparalleled accuracy. They generally contain high performance microprocessors, such as the Motorola 68000 family, and therefor can be error corrected without significantly lowering the display refresh rate. There is no question that if cost is no object the vector network analyzer is the way to go.

to next column

2.0 Measurement Systems-continued
2.3 Vector Network Analyzer-cont.

The downside of the vector analyzer is that care must be exercised in their handling and use. These are large and expensive. They should not be handled like field service equipment. Also, they must be calibrated to insure high accuracy. Electrically, the external power applied to the test ports must be limited. Some sites actually have enough power coming down the line to damage a vector network analyzer. Repairing the test set of a damaged analyzer could run into thousands of dollars.

Another class of network analyzer is a scaler analyzer incorporating a receiver instead of a diode detector. These analyzers operate similarly as the vector, except they do not provide phase information. Since these analyzers use a receiver they are immune to interfering signals, the main drawback of the conventional scaler analyzer. A big advantage to this class of analyzer is the lower cost, size and somewhat increased durability of some units.

2.4 Spectrum Analyzer/Tracking Gen.

As Cellular systems and trunked radios have become increasingly popular there has been trememdous downward price pressure on the service. Airtime costs have gone from several dollars per minute to $.50 in some markets. Some off-peak rates are free. This pressure on price has increased the demand for a low cost system that would provide all, or most of, the benefits of the vector network analyzer.

The following is a list of the essential questions that must be asked when considering equipment to be used for MSRS testing:

1. Is the equipment compact and light?
2. Is the equipment durable?
3. Is the equipment easy to setup and operate?
4. Is the equipment capable of withstanding interference up to +20 dBm?
5. Is the equipment capable of surviving inputs to +33 dBm?
6. Can the equipment sweep over large ranges?
7. Can the equipment provide impedance analysis?
8. Can the equipment yield distance to fault information?
9. Is the equipment inexpensive?

to page 4

Antenna and Feedline Measurements-Page 4

2.0 Measurement Systems-continued
2.4 Spectrum Analyzer-cont.

If a piece of equipment met all of the above parameters it would be perfect for antenna and transmission measurements. At this time there is no piece of equipment that will meet them all.

A solution that comes close is available, and most of it is already on many a technician's bench: This solution consists of using the spectrum analyzer/tracking generator that is a part of the higher grade communications service monitor.

By connecting the tracking generator to the input of a return loss bridge and connecting the bridge output to the spectrum analyzer input we have a network analyzer which uses a receiver. This system yields most of the advantages of the vector network analyzer at a fraction of the cost. It must be pointed out that no vector information is available. Also, internal error correction is not available so the general accuracy is not as good as that of the vector analyzer.

The question arises how good do these measurements have to be? In most cases we are looking for major failures, such as coaxes that have been severely damaged or are full of water, antennas damaged by lightning or hail. Therefor, the accuracy of the test set is not as improtant as the ability to make tests with immunity to interference.

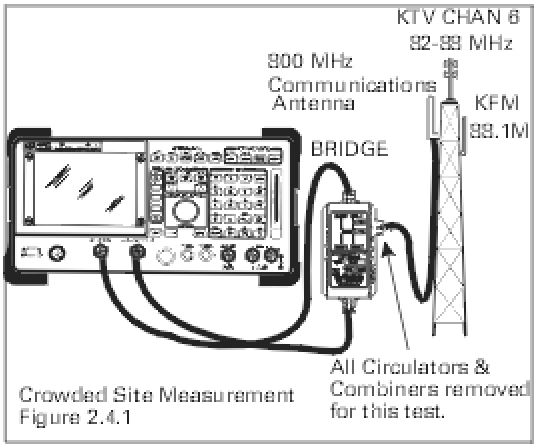


Figure 2.4.1 illustrates the interconnection of a typical CSM (communications service monitor) to a return loss bridge.

to next column

2.0 Measurement Systems-continued
2.4 Spectrum Analyzer-cont.

As we can see this has similar appearance to the scaler hook up diagram. Since the receiver is the spectrum analyzer the immunity to interference is high. On the order of 60 dB, not as good as vector analyzers but adequate.

Power coming down the antenna is attenuated by the bridge 6 dB in each direction. Plus, the power is divided, which yields another 3 dB of attenuation. Because of the co-located high power VHF sources, power coming down the transmission line is 2 watt(+33 dBm). These signals are attenuated to +24 dBm at each of the analyzer's ports. This would overload the instrument, but probably not cause damage.

By adding a 6 dB precision attenuator at each bridge port, the levels would be further reduced to +18 dBm. Filters could also be added between the bridge reflected port and the analyzer input to reduce unwanted signals. Do not install these filters between the DUT port and the antenna system, as the bridge will also measure the filter as well as the antenna system. This is not desireable because the return loss of the filter would be added into the measurement. With the filter connected to the analyzer input port the only degradation would be to the port match errors which are small.

to page 5

Antenna and Feedline Measurements-Page 5

3.0 Interpreting Return Loss Sweeps

3.1 Introduction

The swept measurement of a feedline and antenna system can tell you much more than just the resonant point of the antenna. The following information may be found in the return loss sweep of an antenna system:

1. Antenna Resonance.
2. Cable Loss.
3. Cable length and distance to fault.
4. Cable impedance.

Antenna resonance and cable loss are derived just by looking at the curve. Cable length, distance to fault and impedance are more difficult. But, it is possible for a skilled operator to determine these by looking at the sweep data. Some spectrum analyzer manufacturers have software which can automatically calculate cable length, fault distance and impedance.

The following sections explain how the sweep curve yields this information.

Note: This chapter explains how to interpret data. For information on how to test please turn to chapter four.

3.2 Antenna Resonance

Figure 3.2.1 below illustrates a typical curve

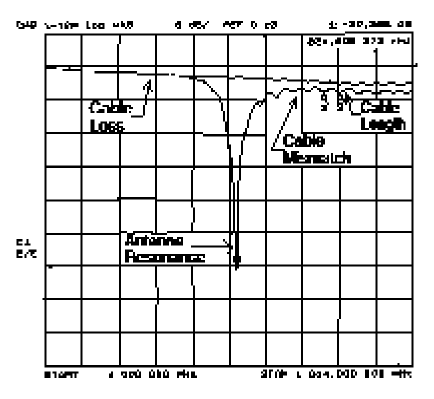


Fig 4.2 Return Loss Curve of Antenna

The dip near the center of the grid is the resonant point of the antenna. The frequency is 524 Mhz and the return loss is better than 30 dB.

Since the cable loss and antenna return loss are combined, the cable loss must be factored out to find the actual antenna return loss as below:

to next column

3.0 Continued-

3.2 Antenna Resonance continued-cont.

$$RL_{antenna}=RL_{indicated}-2 \times cable\text{-}loss$$

On figure 3.2.1 the overall return loss is 30 dB. The cable loss is 0.7 dB at this frequency. We must double the cable loss since the signal from the tracking generator must go up the line, be reflected by the antenna and then return to the spectrum analzyer. Putting these values into the formula we get:

$$RL_{antenna}=30-2x0.7=28.6 \text{ dB}$$

A return loss of 28.6 DB is approximately 1.08:1 VSWR, which is a good antenna. If the cable loss is not known please refer to section 3.3 below.

3.3 Cable Loss

Figure 3.3.1 illustrates a return loss curve for a cable by itself.

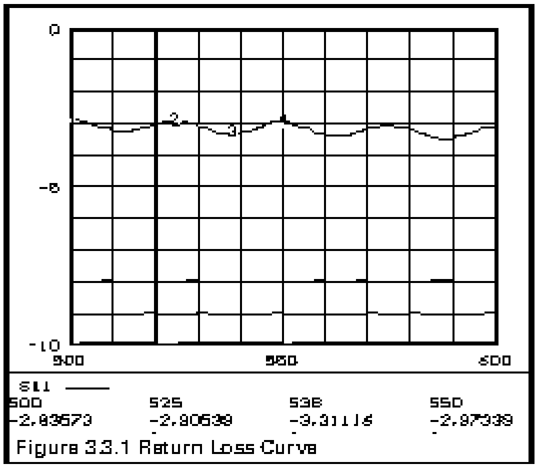


Figure 3.3.1 Return Loss Curve

The peaks and valleys are due to the mismatch between the line and the DUT port of the bridge. To determine the loss, take the reaking at a peak, 2.905 at 525. Next, take a reading at a valley, 3.311 at 538. Add the readings together and divide by two:

$$(2.905+3.311)=6.216/2=3.108$$

This is the average return loss at around 525 Mhz. Now to find the cable loss, divide return loss by 2:

$$3.108/2=1.554 \text{ dB}$$

When this cable was measured the actual loss was 1.537 dB.

to page 6

Antenna and Feedline Measurements-Page 6

3.0 Interpreting RL Sweeps-cont.
3.3 Cable Loss-continued

With perfect equipment it is easy to get very close results. Most field equipment cannot calibrate out all of the errors so don't expect the results to be this good. With practice ±10% error or less is possible. This is close enough to determine if the cable has excessive loss due to water or a failing dielectric.

It is important when making this measurement that the antenna appears to be an open or short. If the antenna is radiating power at the chosen frequency the cable will appear to be more lossy.

During installation of a system it is advisable to sweep the cable with no antennas connected. Make a record of this sweep. Install the antenna and make another broadband sweep and record. Compare the antenna sweep with the no antenna sweep to find a range of frequencies where the antenna did not alter the return loss of the cable.

In the future, should it be suspected that the cable has become more lossy, sweeps centered on these frequencies can be run. Generally cable problems of increased attenuation will show up at all nearby frequencies.

3.4 Cable Length & Distance to Fault

Refer to Figure 3.4.1 below:

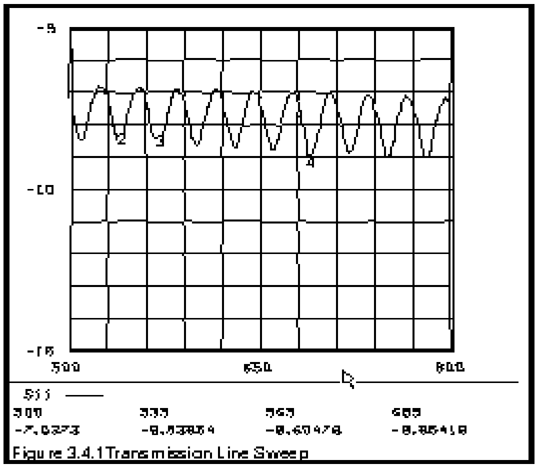


Figure 3.4.1 Transmission Line Sweep

The wave consists of peaks and valleys. The peaks are 1/2 wavelength apart in frequency. The valleys are also 1/2 wavelength apart. Due to other errors the magnitude of frequency difference may very from one point to point. To minimize the effect of these errors it is wise to count several of the peaks or valleys. Usually the peaks or valleys are more pronounced.

to next column

3.0 Continued-
3.4 Cable Length-continued

In this case a transmission line is being swept from 500 MHz to 800 MHz. Markers have been placed at the exact bottom of each valley to aid in determining the frequency and amplitude. The valleys were chosen because they are slightly more pronounced.

The first valley occurs at 539 MHz. The next valley is at 569 MHz and the fifth valley is 689 MHz. The frequency difference will be calculated using one cycle and five cycles.

Using the one cycle method we calculate:

$\text{Freq}_{\text{diff}}=\text{Freq dip1}-\text{Freq dip0}$

$30=569-539$

We arrive at 30 MHz as the frequency difference using that method.

Now let's use the five cycle method to calculate the frequency difference.

$\text{Freq}_{\text{diff}}=(\text{Freq}_{\text{valley}}5-\text{Freq}_{\text{valley}}1)/5$

$(689-539)/5=30$

In this case, the frequency difference was identical, which means the measurement is excellent. This is usually not the case. We will see later that when some error factors are introduced there can be a frequency variance. These errors are: the open/short ratio of the bridge, differences in siganl amplitude and a multiple wave due to faults, among others.

Now that we know the frequency difference, let's proceed with calculating the length of the line. Again a very simple formula does the trick:

$\text{Length}=V_f \times (\text{SOL}/(2\text{x}\text{Fd}))$

In case you think I have gone Greek on you let me explain all of the terms:

Length=physical length of the feedline.

V_f=speed of propagation thru the line as a % of speed on light.

SOL=speed of light in feet per second. We use feet here so let's forget about meters. By the way, SOL in feet is 9.836 x10^8. Use this number and your answer is in feet.

Fd=frequency difference.

to page 7

Antenna and Feedline Measurements-Page 7

3.0 Interpreting RL Sweeps-cont.
3.4 Cable Length-continued

Let's fill in the formula and see what we come up with:

Length=0.8(9.836 10^8/(2 x 30 10^6))
Length=13.11 feet

There we have it, the length of the line to the end is 13.11 feet. If the line is swept when first installed the velocity factor can be compared with the specifications. If the velocity factor is significantly different than specified the cause should be researched. A gross change in velocity factor over time is cause for concern so a record of the initial reading should be saved for reference.

A more important use for the cable length test is that it can also locate faults along the transmission line. Refer to Figure 3.4.2 below:

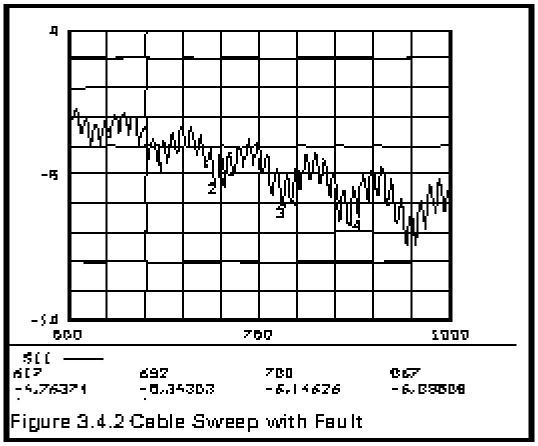


Figure 3.4.2 Cable Sweep with Fault

This figure illustrates the wave when a severe fault has been introduced at a point along the feedline. This is not a short so the wave to the end of the cable is apparent, as a matter of fact, someone has pinned your coax so well you can't even see where they did it.

As can be seen from figure 3.4.2 above, the wave containes a wave of longer periods (higher frequency difference) riding on a wave of shorter periods. The shorter periods represent the overall length of the cable. The longer periods represent the distance to the fault. This wave is harder to analyze because it is possible that the true valley is masked by the undulation of the shorter period wave. Markers have been placed at four of the bottoms of the composite wave, they are:

1. 617 MHz 2. 692 MHz
3. 780 Mhz 4. 867 Mhz

to next column

3.0 Continued-
3.4 Cable Length-continued

With several points we can average out the results which will give a much more accurate reading then just using two points. Now we will calculate the distance between 1 and 2, 2 and 3, and 3 and 4. This yields distances of:

Length=0.8(983.6/(2*692-617))=5.28 feet
Length=0.8(983.6/(2*780-692))=4.46 feet
Length=0.8(983.6/(2*867-780))=4.48 feet

While each one of these is close, by taking the average the answer will be closer. Take the average using the following:

Length=0.8(983.6/(2*((867-617)/3)=4.72'

Like most averages this falls within the parameters of its parts, about 4' 9". The actual distance was 4.7201.

Figure 3.4.3 may prove a little more interesting and more difficult to interpret:

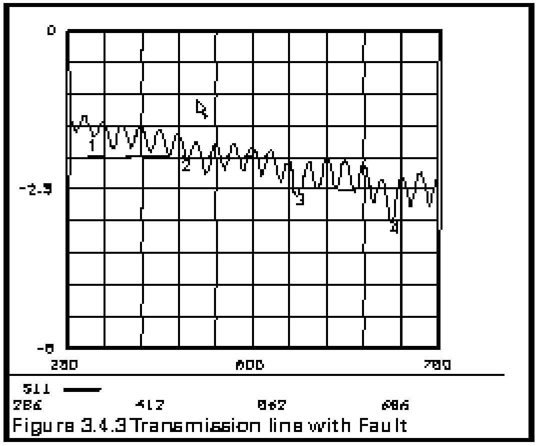


Figure 3.4.3 Transmission line with Fault

As in the previous example, there is a short period riding the long period. It appears that there is a fault that is located some distance from the bridge port that is represented by the short period. Calculating the length based on the long period between marker 3 and 4 we find:

Length=0.8(983.6/(2*((867-617))=3.17'

A careful look at the coax in the region 3 feet from the bridge reveals no problem. Has this method failed? No, what is being seen is a reflection from the far end of the coax. To determine if we are looking at a reflection, always check the main wave and calculate the distance. The other two markers have been set for five repetitions of the shorter period wave(main wave>.

Length=0.8(983.6/(2*((412-286)/5)))=15.61'

to page 8

Antenna and Feedline Measurements-Page 8

3.0 Interpreting RL Sweeps-cont.

3.4 Cable length-continued

A careful look at the coax reveals a pin at 15.76'; very close to the predicted spot. The overall length of the coax was 18.88'. Therefore, the length from the antenna end to the pin was 3.12', very close to the 3.17' predicted by the long period wave.

This example illustrates the importance of calculating all of the waves seen before determining where the fault may lie. It is a good idea to analyze a system when it is installed and save the plot. Also, a record of the physical and electrical length of the transmission line is handy to ahve in solving fault distance problems.

Chapter four shows some actual fault waveforms taken using an HP8920 analyzer.

3.5 Cable Impedance

Cable impedance is also presented in the return loss sweep. While impedance can be derived with the antenna in place, it is necessary to have sweeps with the cable open and with the antenna connected. These are to determine which bands of frequencies are not affected by the antenna. Cable impedance is usually tested when the cable is received. This is to verify that the cable is correctly manufactured and that it meets the specification for impedance.

Insure that your measurement is within these limitations or data will be erroneous.

1. The cable impedance must be within the bounds of the terminating pad impedance and what the pad looks like on the end of a 90 degree transformer with a 50 ohm cable. If you are using a 6 dB apd, the impedance is 83.511. The transformation can be found by using the following formula: $Z_{low}=2500/Z_{pad}=2500/83.511=29.934$ ohms

Thus with a 6 dB pad, transmission lines between 30 and 83 ohms could be measured.

2. The value used for cable loss must be very exact. It is advised that the cable loss be determined by the manufacturer's rating. The cable loss can also be determined as outlined in Section 3.3 of this note.

3. The pad loss must be precisely known. It is advised that a pad be used that has a loss graph supplied so that the exact loss at each frequency of interest is known. EAGLE has such pads available. When terminated with a precision 50 ohm load, the pad should have >20 dB return loss. After determining that the pad has acceptable return loss (yes, you can use your bridge to measure the pad and the termination) remove the termination from the pad.

to next column

Set up the bridge to measure return loss. Run a sweep with the DUT port open and use trace memory feature to normalize the trace to 0 dB.

Connect the 6 dB pad to the far end of the cable. Insure that this pad is very accurate. See limitations paragraph 3. above. Sweep the range and determine the valley and peak frequency points.

Figure 3.5.1 below indicates the swept pattern of a cable with mismatch.

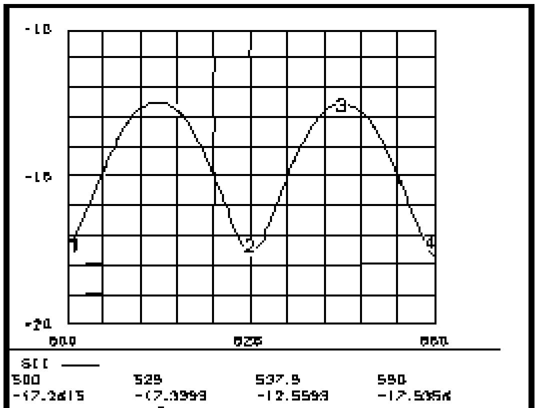


Figure 3.5.1 Cable terminated with 6 dB pad

The following procedure has been broken down into several (13) steps to facilitate understanding of this method.

1. Find the return loss of the pad. Use the actual loss, not the theoretical loss.

RL_{pad}=Padloss x 2=12 dB

2. Find the loss of the cable, use manufacturer's data or measure using Section 3.3 of this chapter. Remember that the cable loss will be increasing with frequency. The only two points of concern are where the valley and peak are located.

Note: the valley should always be the lower frequency of the two points. If required, change the sweep so that a suitable valley will be the lower frequency.

3. Using the following formulas, find the return loss of the valley and peak point if fed with a perfect 50 ohm cable.

$RL_v=RL_{pad}+2*loss_v=12+2x2.049=16.098$

$RL_p=RL_{pad}+2*loss_p=12+2x2.074=16.148$

to page 9

Antenna and Feedline Measurements-Page 9

3.0 Interpreting RL Sweeps-cont.

3.5 Cable Impedance-cont.

Now determine if the valley or peak is closer to the RL reading. The readings were obtained from figure 3.5.1.

The valley is at 17.4 dB, using the formula:

$Dev_v=Read_v-RL_v=17.4-16.098=1.302$

The peak is at 12.56 dB, using the formula:

$Dev_p=Read_p-RL_p=16.148-12.56=3.588$

It is obvious that the valley is the point of minimum deviation. The valley will now be refered to as the min point and the peak will be the max point.

Note: it is very important not to confuse these points during the remaining calculations!

4. Determine the rho of the pad. This can be found by the following formula:

$Rho_{pad}=10^{(-2xPadloss/20)}$

In the case of a 6.00 dB pad this works out to Rho=0.251

5. Calculate the pad impedance from Rho:

$Z_{pad}=((1+rho>/(1-rho))*50$

$Z_{pad}=((1+.251>/(1-.251))*50=83.51$

6. The next step is to calculate out the portion of the loss attributable to the cable. This is because we only want to see the transformation impedance. Since the cable loss adds to the return loss both coming and going it is multiplied by two.

$RL_{mincor}=RL_{min}-2xLoss_{min}$

$RL_{mincor}=17.4-2x2.094=13.301$

Repeat the operation for the max point:

$RL_{maxcor}=RL_{max}-2xLoss_{max}$

$RL_{maxcor}=12.56-2x2.074=8.128$

7. Convert the return loss to rho. Using rho makes the math simpler in the subsequent equations. Use the following formulas:

$Rho_{min}=10^{(-RL_{mincor}/20)}$

$=10^{(-13.301/20)}=.216$

$Rho_{max}=10^{(-RL_{maxcor}/20)}$

$=10^{(-8.128/20)}=.380$

8. Develop a correction factor by subtracting Rho_{min} from the rho of the pad.

$CF=Rho_{pad}-Rho_{min}=0.251-0.216=0.035$

This correction factor corrects for an error term that occurs due to the mismatch losses of the coaxial cable under test.

to next column

9. Now subtract the CF from the Rho_{max}:

$Rho_{cor}=Rho_{max}-CF=.380-.035=.345$

10. Now we find the corrected VSWR of the pad at the DUT port.

$VSWR=(1+Rho_{cor})/(1-Rho_{cor})$

$VSWR=(1+.345)/(1-.345)=1.345/.655=2.053$

11. Now we can find the apparent impedance of the pad by dividing the VSWR into 50 ohms which is the impedance of the return loss bridge port. We know to divide since the cable must be transforming the termination impedance below 83 ohms.

$Z_{appr}=PORT/VSWR=50/2.067=24.349$

12. We can now find the cable impedance because we know that it is at the logarithmic center of the original pad impedance and the apparent impedance because the line is exactly 90 degrees from the valley and the peak of the curve.

The formula for finding the center is:

$Z_{cable}=(Z_{pad}xZ_{appr})^{.5}$

$Z_{cable}=(83.511*24.349)^{.5}=45.10$

Thus the cable impedance is indicated at 45.10 ohms. In this case the curve was made from a cable that was set at 45.00 ohms. The illustrates that if care is taken, to accurately take the data and measure the pad, this method cab be very accurate.

Figure 3.5.2 illustrates a second cable.

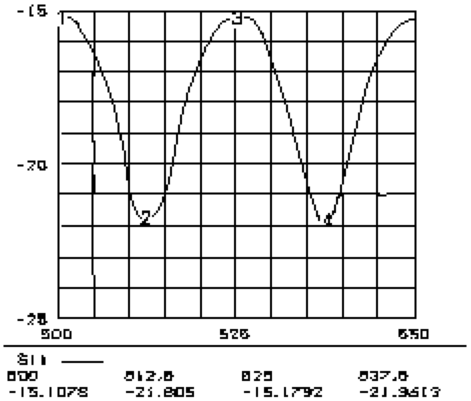


Figure 3.5.2 Return Loss Sweep Cable 2

When checking the peak and valley it is found that the valley has the max deviation and the peak has the min deviation. The reason for this is that the impedance of the cable this time is above 50 ohms.

to page 10

Antenna and Feedline Measurements-Page 10

3.0 Interpreting RL Sweeps-cont.
3.5 Cable Impedance-cont.

The following illustrates that there is not much difference in handling this case:

1. RL_{pad}=Padloss x 2=12 dB

2. Cable Loss:

$Loss_v$=2.025@512.5 MHz
$Loss_p$=2.049@525 MHz

3. Corrected return loss (if cable 50 ohm).

$RL_v=RL_{pad}+2*loss_v=12+2x2.025=16.050$

$RL_p=RL_{pad}+2*loss_p=12+2x2.049=16.098$

Readings:

Valley: 21.805
Peak: 15.179

$Dev_v=Read_v-RL_v=21.8-16.05=5.750$

$Dev_p=Read_p-RL_p=16.098-12.179=.0919$

In this case the peak is closest from the corrected return loss. Therefor, the peak will be used at the min point and the valley will be the max point.

Note: As before it is very important not to confuse these points during the remaining calculations! Remember this time the peak is the min point!

4. Determine pad rho:

$Rho_{pad}=10^{\wedge(-2xPadloss/20)}=$
10^(-2x6/20)=.251

5. Impedance of pad:

Z_{pad}=((1+rho>/(1-rho))*50

Z_{pad}=((1+.251>/(1-.251))*50=83.51

6. Factor cable loss out of reading

$RL_{mincor}=RL_{min}-2xLoss_{min}$

$RL_{mincor}=15.179-2x2.094=10.992$

Repeat the operation for the max point:

$RL_{maxcor}=RL_{max}-2xLoss_{max}$

$RL_{maxcor}=21.805-2x2.049=17.702$

7. Convert the return loss to rho. Using rho makes the math simpler in the subsequent equations. Use the following formulas:

Rho_{min}=10^(-RL_{mincor}/20)=
10^(-10.992/20)=.282
Rho_{max}=10^(-RL_{maxcor}/20)=
10^(-17.702/20)=.130

to next column

8. Find correction factor:

$CF=Rho_{pad}-Rho_{min}=0.251-0.282=-0.031$

9. Find corrected Rho:

$Rho_{cor}=Rho_{max}-CF=.130-(-.031)=.161$

10. Find apparent VSWR of pad at bridge port

$VSWR=(1+Rho_{cor})/(1-Rho_{cor})$

VSWR=(1+.161)/(1-.161)=1.161/.839=1.384

11. Find apparent impedance at port

Z_{appr}=PORT/VSWR=50/1.384=36.111

12. Find impedance of cable:

$Z_{cable}=(Z_{pad}xZ_{appr})$^.5

Z_{cable}=(83.511*36.111)^.5=54.91 ohms

The cable impedance is calculated at 54.91 ohms, in actuality it was an even 55.0 ohms. Again, this method comes up with a very close answer.

A reminder that it is very important to take careful measurements of the actual attenuation of the terminating pad and to know the cable loss accurately in order to achieve good results with this method.

4.0 Test Setups Using Service Monitors

4.1 Basic Hookup

In order to use a return loss bridge with a service monitor the monitor must have at least the following equipment. A signal generator to provide a signal. The generator may be a single frequency, but ideally it should be capable of sweeping over a range of frequencies. The analyzer must also contain a spectrum analyzer. Both of these functions must operate simultaneously. Not all service monitors have this capability.

Refer to figure 4.1.1.

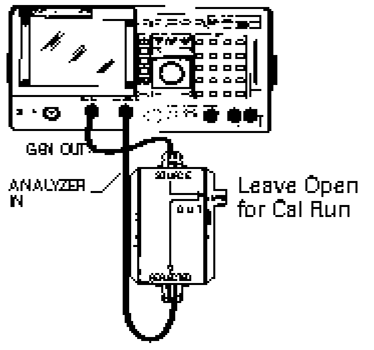


fig 4.1.1 Basic Connections

to page 11

Antenna and Feedline Measurements-Page 11

4.0 Test Setups Using Service Monitors

4.1 Basic Hookup-cont.

This figure illustrates a typical analyzer and the interconnections to the bridge. The following is a list of the connections and what they do:

1. Connect the output of the generator to the input of the source port of the bridge. This provides the driving signal to the bridge.

2. Connect the reflected port of the bridge to the spectrum analyzer input. This supplies the signal coming back from the bridge to the analyzer.

3. Initially the DUT or device under test connector is not connected to anything. This is to provide a reference trace. The level of this trace is 0 dB return loss since all of the signal must be reflected back from an open connector. After this trace is established, the device under test is connected and the actual return loss is measured.

The following are instructions for the exact ports to use with some of the communications service monitors that are available:

4.1.1 IFR 1200S

1. Connect 1200S duplex (BNC) to bridge source (N).

2. Connect bridge reflected (N) to the 1200S ANT (BNC).

Note: The optional tracking generator is required to make swept measurements using the 1200S.

4.1.2 IFR COM 120

1. Connect COM 120 Aux in/out (BNC) to bridge source(N).
2. Connect bridge reflected to COM120 antenna.
3. Select center frequency desired.
4. Set tracking generator to -13 dBm.

4.1.3 IFR 1600

1. Connect duplex out to bridge source port(N)

2. Connect bridge reflected port(N) to the antenna port.

3. Adjust tracking generator to -13 dBm for best results

4.1.4 HP8920/8921

1. Connect the duplex out(BNC) to bridge source port(N)

2. Connect the bridge reflected port(N) to the ant in port(BNC).

3. Refer to page 3-158 of HP8920 applications handbook.

to next column

4.1.5 Wavetek/Schlumberger 4015

1. Connect the 4015 RX-HIGH(BNC) to the bridge source port(N).

2. Connect the bridge reflected port(N) to the RX/TX port(BNC).

3. Set up per instructions supplied with 4015 to do VSWR measurements.

4.1.6 Wavetek/Schlumberger 4031/4032

1. Connect the 4031 RF-direct(TNC) to the bridge source port(N).

2. Connect the bridge reflected port(N) to the 4031 RF port(N).

3. Set up per instructions supplied with 4031 to do VSWR measurements.

4.2 Calibration Procedure

Connect the service monitor as shown in figure 4.2.1

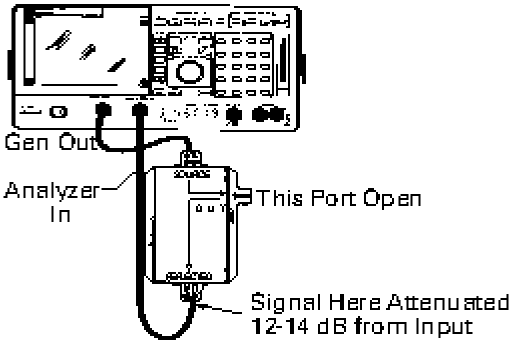


figure 4.2.1 Calibration test Open

1. Adjust the generator to provide the desired frequency coverage.

2. The DUT port should not be connected to anything

3. The output of the reflected port should be 12 to 14 dB lower than the input level. If the input level is 0 dBm, the output should be -12 to -14 dBm.

Note: If this is not so, replace the bridge with an "N" barrel connector. This will test the cable loss and analyzer reading. Subtract this reading from what you get with the bridge to see if it is within -12 to -14 dB less than the input.

After making the corrections above, if the reading is still out of range the bridge is suspect.

The above assumes you are using an EAGLE RLB150x3 or x4 series return loss bridge.

to page 12

Antenna and Feedline Measurements-Page 12

4.0 Test Setups Using Service Monitors

4.2 Calibration Procedure-cont.

4. If your analyzer has a normalization feature, save the present trace and subtract it from the live trace. This will give a reading of 0 dB, since the live trace is equal to the saved trace. If the service monitor does not have normalization, then adjust the generator and analyzer to put the trace on the 0 dB graticle.

This completes the open test and setup of the bridge. The system is now ready to test the bridge directivity.

Refer to figure 4.2.2.

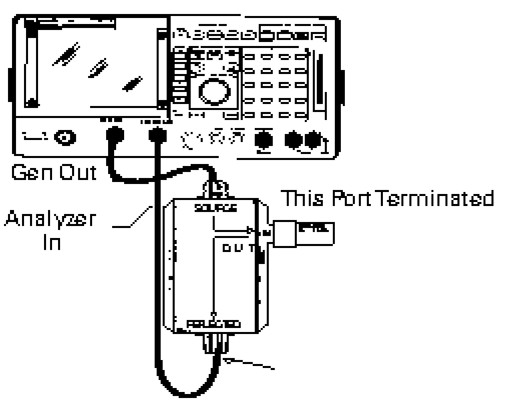


Figure 4.2.2 Calibration Tests-Terminated

This shows the bridge with a precision termination connected to the DUT port. The precision termination used should have a rated directivity of 40 dB. The EAGLE RFT050NM2was designed specifically for this purpose. Connect the termination as shown in the figure to the DUT port.

With the termination connected, the trace should drop at least 40 dB at all frequencies between 50-1000 MHz. The bridge directivity is rated at 45 dB or better over this range. In some cases the indication may be much greater than 40 dB. This is due to the fact that the bridge error and the termination error are cancelling each other out. The case of two wrongs making a right!

If the drop is substantially less than 40 dB, first check to insure that the signal is not in the noise of the analyzer. If it is in the noise, then increase the signal level from the generator or use a lower IF bandwidth on the spectrum analyzer. After checking that, if the drop is not 40 dB, then the load or the bridge is suspect. Repeat the test with another load or another bridge.

to next column

If the drop is 40 dB or more the bridge is verified; you can now make return loss measurements with confidence.

Verify open/short performance. Calibrate with the open, then place a short on the DUT port. The difference in the trace is the open/short ratio. If the open short ratio is more than 2 dB, the port match may be suspect.

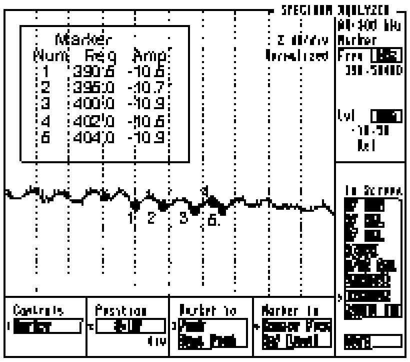
4.3 Making Return Loss Measurements

This section explains how to make certain types of return loss measurements. Section 3.0 explains how to interpret the data that is collected from the following measurements. These measurements are made using a swept technique. In other words, a range of frequencies and the amplitude values are displayed simultaneously. While it is possible to make these measurements one point at a time and then plot the data on a graph, the author believes that this technique would introduce many errors and be too time consuming to be cost effective. There are many fine spectrum analyzer/tracking generator combinations that are available at low cost. Therefore, single point techniques are not discussed here.

These measurements are not all inclusive. There are many more measurements that can be made with the return loss bridge. For example, combiners can be tuned, or the front end of radios and isolators can be set to new frequencies.

Line loss measurements

Refer to Figure 4.3.1 below:



Marker

Num	Freq	Amp
1	390.6	-10.6
2	395.0	-10.7
3	400.0	-10.9
4	402.0	-10.6
5	404.0	-10.9

Figure 4.3.1 Cable Loss & Length

to page 13

Antenna and Feedline Measurements-Page 13

4.0 Test Setups Using Service Monitors
4.3 Making RL Measurements-cont.

This figure is a picture of an actual screen of an HP8920 analyzer running a return loss curve. The return loss is around 10 dB so the 2 dB/div scale is used to give better resolution. Since the trace is normalized, 0 dB return loss is at the top of the screen.

This measurement was set up as described in calibration section 4.1.

The transmission line was connected to the DUT port. The far end was left open, causing all of the power to be reflected. Since this line is not a perfect 50 ohms, the trace has peaks and valleys in it.

To determine the insertion loss, take the reading at one peak (use marker 4). This reading is 10.5. Then take the reading of an adjacent valley. Let's use marker 5 which gives 10.9 dB. Use the following formula to find the average:

$RL_{avg}=(RL_1+RL_2)/2=(10.5+10.9)/2=10.7$

As discussed previously, the cable loss is 1/2 the return loss, so use the following to calculate line loss:

$Loss=RL_{avg}/2=10.7/2=5.35$ dB

The loss of the line is calculated to be 5.35 dB. This line, a piece of RG-214/U that is 75 feet long, was measured with an HP8753C. This measured the loss at 5.39 dB @ 400 Mhz. The calculated loss of RG-214/U is 4.12 dB maximum. Some of the additional loss may be due to connectors and the fact that this cable is 20 years old and has been kicked around quite a bit.

Line loss measurements

The setup and reading is the same as in the line loss measurements above. As a matter of fact, we can use the same curve from figure 4.3.1.

Refer to chapter 3.4 for more details on how to process the data from this measurement.

First, find the average frequency difference at the valleys. Use the valleys since they are slightly more pronounced than the peaks.

$Freq_{diff}=(404.0-390.5)/3=4.5$ MHz

$Length=vel\ fac(SOL/(2xFreq_{diff})$

$Length=.66(9.836\ 10^8\ fps/9.0\ 10^6)=72.13$ feet

This is the same 75 foot cable used in the loss measurement. The error than is 72.13/75 or 3.83% short of the actual value. This is a reasonably close measurement using this type of equipment.

to next column

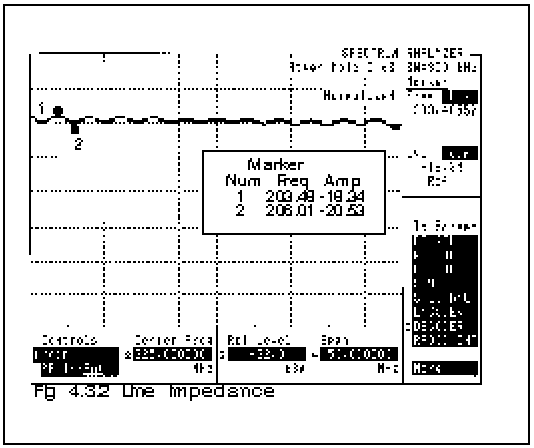
Cable fault measurements

These use the same setup as line length. The difference is that there may be an additional period, or many additional periods, if the fault is not a dead short or open. If a fault is suspected but only one period is seen, as in fig 4.3.1 above, go ahead and calculate the distance anyway. If the distance found is significantly shorter than the length of the cable, then there is some type of fault at that point.

If many periods are present it may be impossible to sort them out without an analysis program.

Line impedance measurements

Refer to figure 4.3.2 below:



Marker		
Num	Freq	Amp
1	203.49	-19.34
2	206.01	-20.53

Fg 4.32 Line Impedance

This is an actual sweep of a line. The setup is the same as for loss except that the scale is 10 dB/div. The line is terminated in a pad at the far end. Please refer tosection 3.5for more information on this measurement.

The return loss of the pad was measured at 12.3 dB.

1. $RL_{pad}=12.3$ dB
2. $Loss_{line}=3.528$ dB
3. $RL_{cor}=19.355$ dB

$Dev_{valley}=20.53-19.355=1.175$

$Dev_{peak}=19.355-17,340=1.015$ dB

Note: Peak is the closest to the corrected return loss.

4. $Rho_{pad}=0.242$
5. $Z_{pad}=81.944$ ohms

6A. $RL_{mincor}=18.34-2x3.528=11.284$

6B. $RL_{maxcor}=20.53-2x3.528=13.474$

to page 14

Antenna and Feedline Measurements-Page 14

4.0 Test Setups Using Service Monitors

4.3 Making RL measurements-cont.

7A. $Rho_{min}=10^{(-11.284/20)}=.273$

7B. $Rho_{max}=10^{(-13.474/20)}=.212$

8. CF=.242-.273=-.031

9. $Rho_{cor}=.212-(-.031)=.243$

10. $VSWR_{appr}=1.641$

11. $Z_{appr}=50/1.641=30.469$

12. $Z_{line}=(81.944x30.469)^{.5}$

The above equations are organized as in the example in Section 3.5 if any questions arise. The finding was that the cable was very close to 50 ohms. The actual impedance of this cable was 49.6 ohms, as measured using a vector network analyzer. With care, measurements within ±0.5 ohms are possible.

Antenna resonance

This is done using the identical setup as line loss, except the far end of the line is terminated with the antenna. The point of maximum dip is the resonant point of the antenna.

Antenna bandwidth

This is set up exactly the same as antenna resonance. Determine what is the minimum return loss that is acceptable, for example, 10 dB or about 2:1 VSWR. Find the low frequency point at 10 dB + cable loss, and the high frequency point at 10 dB + cable loss. Then subtract the low frequency from the high frequency and the answer would be the acceptable bandwidth.

to next column

4.4 Using Computers

The use of computers is becoming more and more popular. As you can see, if you worked through the above problems, some of these can become very tedious.

The author has put the appropriate formulas into a spreadsheet. This allows easy input of the data and automatically does the calculations. If the formulas are correct, the correct answers will be realized.

Another use of the computer is to normalize the trace. Because a computer could actually calculate the results of several traces, some very fancy things can be done. For example, you can run an open trace, a short trace and a data trace. Then average the open/short trace and normalize the data trace with the average.

Another common use is to run plots of antenna systems when they are new, and at a periodic rate thereafter, and save these traces for future reference. This aids in finding a deteriorating system, maybe even before it fails.

A final use is to feed in a complex hyperbolic curve, the curve you see when doing the length and fault analysis, and let the computer find all of the periods using a Fourier transform.