Application Note

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Installation and Maintenance of Cellular Base Station Antenna and Feeders with the 6820 series Scalar Analyzer

Measurements of Return Loss (VSWR), Insertion Loss and Fault Location using the 6240 series Fault Locators with the 6820 series of Scalar Analyzers

Introduction

The use of digital cellular telephone systems continues to expand world-wide. Analogue networks are increasingly being replaced by digital systems such as DAMPS, GSM, PCS and DCS. These systems work within frequency bands between 800 MHz and 2 GHz. In addition, the traditional Private Mobile Radio (PMR) bands are being updated to trunking networks, such as those based on the MPT 1402 specification and other digital networks such as TETRA.

The quality of service a network operator can provide is heavily dependant on the performance of the antenna and coaxial feeder connected to the radio base station. A degraded antenna installation can result in dropped calls and poor coverage. This leads to irate customers and lost revenue.

Network operators need to verify the feeder and antenna performance when installing and commissioning a system. To ensure continued high quality performance a regular maintenance policy should be implemented. Factors such as corroded connectors, bends and joints, water ingress into the coaxial feeder and a detuned antenna can all cause the system performance to degrade rapidly.

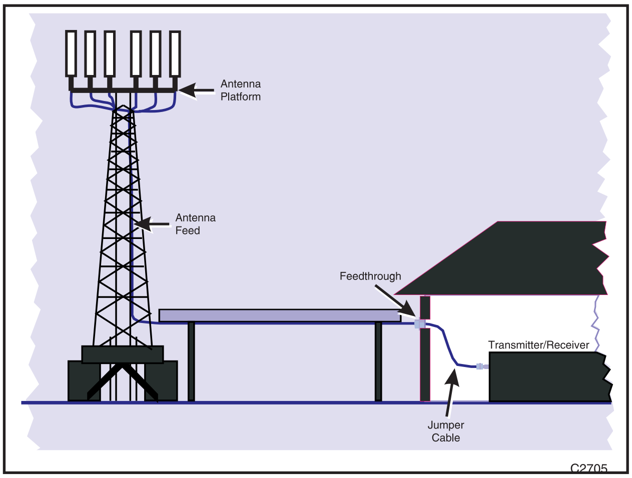
When installing or maintaining an RF feeder, the key measurement to test the quality of the system, is the feeder and antenna return loss (or VSWR).

If the return loss measurement fails to meet specification a fault location measurement can be used to provide a precise identification of the faulty component.

The 6240 series of Fault Locators provide a quick and convenient method of measuring return loss (VSWR) and fault location on coaxial transmission lines. They produce real time, simultaneous measurements of return loss and fault location from a single test port. This leads to a simplification of test procedures and a reduction in the overall test time.

Combined with the versatility of the 6820 series scalar analyzers, the 6240 series of Fault Locators allow full characterisation of transmission line systems in terms of their frequency and distance responses. When commissioned the system performance can be verified and stored. The data can then be used for comparison purposes during future routine maintenance testing. Hence, any degradation can be detected and cured at an early stage, before the system fails.

This article describes the measurements of return loss (VSWR) and fault location from a single test port using a 6240 series Fault Locator and 6820 scalar analyzer.



Reflection Measurements

The measurement of return loss (or VSWR) is a basic measurement used for the characterisation of a system in the frequency domain. The measurement involves applying an RF or microwave signal over the operating bandwidth of the system and measuring the amount of power reflected by impedance discontinuities within the system.

The return loss is simply the ratio of reflected signal to input signal, expressed in dB. Figure 1 shows the measurement set-up.

A directional device is required to separate the input and reflected signals. Calibration is performed by connecting an open and/or a short circuit to the test port. These fully reflecting devices allow correction for losses within the directional device and set the 0 dB reference level on the scalar analyzer display.

For coaxial systems the directional device generally takes the form of a bridge network which offers high directivity, good test port match and operates over extremely wide bandwidths.

In waveguide systems directional couplers are most appropriate. The measurement of waveguide systems has been covered in [1].

The two main figures of merit for the return loss bridge are directivity and test port match. The effect of these is to produce errors in the measurement.

Directivity quantifies the imperfections within the bridge which cause a small amount of the input signal to be reflected before it reaches the test port. Hence, even with a 'perfect' matched load connected to the test port a finite signal will be detected.

The test port match is also a product of imperfections in the bridge network but it also depends on the match of the source connected to the RF input port. It is desirable to have as good a test port match as possible to reduce the mismatch error signals between the Device Under Test (DUT) and the test port.

Return loss measurement errors are discussed in Appendix A.

Fault location measurements also involve applying an RF signal to the transmission line over the operating bandwidth (as with the return loss measurement). The reflected signals are recombined with the input signal to produce a ripple pattern. This ripple pattern has, encoded within it, amplitude and distance information for all of the reflections occurring within the line. A Fourier transform is required to decode this complex waveform. Calibration is performed by connecting a matched load to the test port and normalising the response to the input signal level.

Fault location theory is discussed in Appendix B.

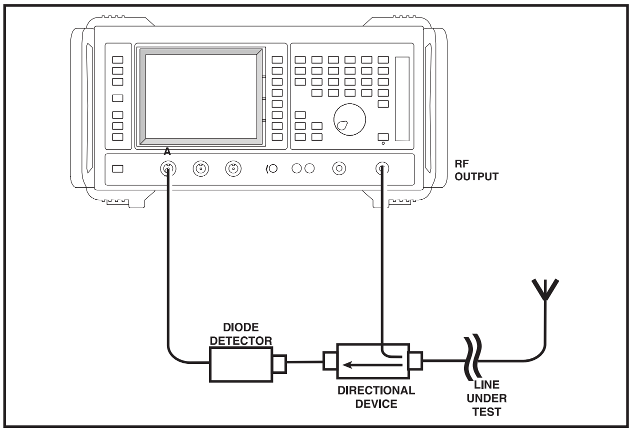


Figure 1 - Reflection Measurement set up

6240 series Fault Locators

The 6240 Fault Locators contain a patented† combination bridge and fault locating network. The combination allows both return loss and fault location measurements to be made from a single test port, hence both measurements can be performed simultaneously.

The 6240 series Fault Locators provide high directivity and a good test port match in 7 versions covering the frequency range from 10 MHz to 26.5 GHz.

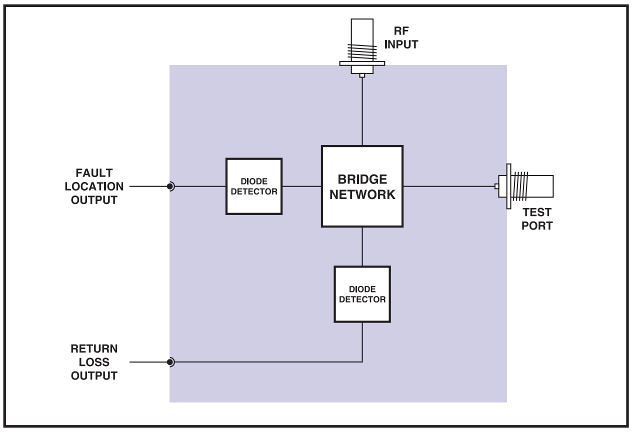


Figure 2 - Fault Locator schematic

Scalar Analyzer set-up

The test set-up for making return loss and fault location measurements using a 6240 series Fault Locator and 6820 series scalar analyzer is shown in Figure 3.

The RF cable connects the Fault Locator to the 6820 series RF output. The detachable detector cables (supplied accessories) are used for connection to the 6820 series inputs. The cables can be connected to any input as the 6820 series identifies the Fault Locator output as either a return loss or a fault location measurement. Calibration is performed using an open and/or short circuit and matched load.

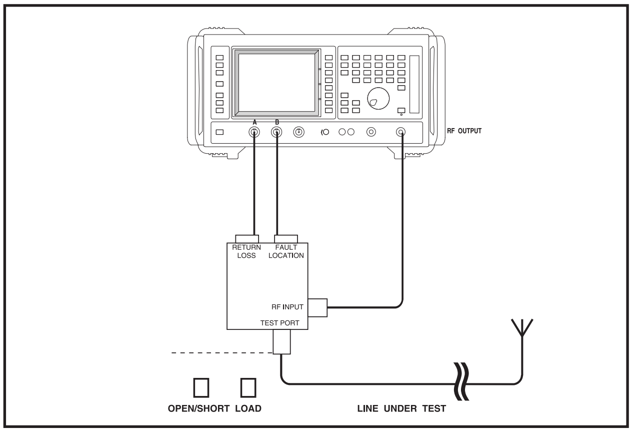


Figure 3 - Test set-up for 6240 series Fault Locators

The following sections use as an example, the measurement of a 1.8 GHz - 1.9 GHz antenna system. The system consists of a 1.5 metre (5ft) coaxial jumper cable, a 25 metre (82ft) coaxial feed and antenna.

To allow real time simultaneous display of both measurements, different channels are used for return loss and fault location.

Conventions

These conventions are used within this article to indicate an 6820 series keypress.

[**BOLD**] - Hardkey press,
i.e. a dedicated front panel function key.
[*italic*] - Softkey press,
i.e. software menu key.
[●] - ‘toggle function’ enabled.
[○] - ‘toggle function’ disabled

Numeric entries are made using either keypad or rotary control. Keypad entries must be followed by a terminator key.

Return loss

From the [**PRESET**] condition all instrument settings can be set to default values. With the 6820 series operating in SCALAR mode, the source is set to sweep from 1770 MHz to 1815 MHz with an output power of +5 dBm. AC detection is kept on to provide a level of interference suppression.

[**PRESET**]
[*Full*]
[**SOURCE**]
[*Set Start Frequency…*] [1][7][7][0] [**M µ**]
[*Set Stop Frequency…*] [1][8][1][5] [**M µ**]
[*Set Output Power…*] [5] [**ENTER/=MKR**]

Calibration is performed using an open and/or short circuit. Calibration accounts for system losses and sets the 0 dB reference level, the bridge directivity setting the limit on the smallest reflection that can accurately be measured. A detector zero should always be performed before calibration (and at regular intervals thereafter). The zero operation removes any offset volt-

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† The 6240 series Fault Locators are protected by U.S patent no US 5363049 and others.

ages which may exist within the Fault Locator and 6820 series scalar analyzer.

For frequencies below 3 GHz it is generally sufficient to keep the test port unconnected (open) for calibration. However for frequencies above 3 GHz the supplied short/open should always be used.

To calibrate, leave the test port open.

[**SCALAR**]
[*Input Selection*] [*A*]
[**CAL**]
[*Zero Detectors*]
[*Short OR Open Cal*]
[*Continue*]

The 6820 series performs the calibration and displays a normalised response at the 0 dB level. The transmission line can now be connected.

To set a scale of 5 dB per division with a reference level of 0 dB

[**SCALE/FORMAT**]
[Set Scale…] [5] [**ENTER/=MKR**]

The measurement can alternatively be displayed in VSWR. This is applied by selection from within the [**SCALE/FORMAT**] menu.

If required the active marker is moved by using the rotary control and additional markers added using the [**MARKERS**] menu.

Limit checking can be performed automatically by applying a limit specification table. A table is produced by entering the table editor. As an example to set a typical flat limit specification at -22 dB

[**SCALAR**]
[*Limit Checking*][*Edit Spec*][*Limit Type*]
[*Upper Limit Only*][*Return to Limit Editor*]
[*Edit Segments*][*Flat*][⇨]
[1][7][7][0] [**M µ**] [⇨]
[-][2][2] [**ENTER/=MKR**] [⇨]
[1] [8][1][5] [**M µ**]
[*Return to Limit Editor*][*Save As*][*New Store Name*]
[*Erase Text*] Storename…[*Done*][*Save*]
[*Exit*]
Limit checking is applied by
[*Assign Spec*][⇩][*Select*][*Limit Checking* ●].

Figure 4 shows the measurement of the coaxial feed and antenna described above. It meets its 22 dB return loss specification.

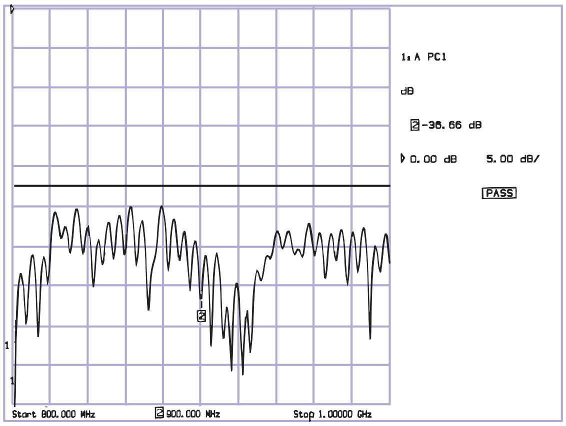

Figure 4 - Return loss measurement of coaxial feed and antenna

Adapters should not be inserted between the test port and the transmission line when making return loss measurements. The adapter reduces the effective directivity to a level below the return loss of the adapter and hence significantly increases measurement errors

For example:

Parameter	**Log unit**	**Linear unit**
Fault Locator directivity	38 dB	0.0126
Adapter return loss	30 dB	0.0316
Fault locator + adapter (effective directivity)	27 dB	0.0126 + 0.0316
Measurement error limits (due to directivity) on 20 dB return loss		
Fault locator only	+1 to -1.2 dB	
Fault locator + adapter	+3.2 to -5.1 dB	

Fault Location

If the return loss measurement of an antenna and feed meets its specification (typically 20 to 25 dB), it is usual to archive the measurement trace for future reference.

When the return loss fails to meet specification it is necessary to identify the cause of the poor performance. This could simply be a loose connector or a more subtle fault, such as water ingress or a kinked cable. In some cases a poor return loss can be the result of a combination of smaller discontinuities.

A typical cellular antenna feed can be over 80 metres long. Clearly a method of quickly identifying the position of the fault along the cable is required.

The fault location measurement of the 6820 series is specifically designed to provide, with pin-point accuracy, the position of cable faults.

Simultaneous return loss and fault location measurement allows real time observation of faults in both the frequency and distance domain. This is particularly useful for determining the position of intermittent faults. The effect and position can be monitored without the need for swapping between test ports and recalibrating.

To allow fault location measurements to be made without losing the return loss set-up, the second measurement channel of the 6820 series is utilised. Selecting and defining the channel as a fault location measurement.

The 6240 series Fault Locators do not require ratio measurement for fault location (c.f. 6581/3 test heads). Measurements are made in single input mode. With the Fault Locator connected to a 6820 series scalar analyzer the selection process is automatic.

[**SWITCH CHANNEL**]

Note that a number 2 appears in the top right hand corner of the display to indicate that channel 2 is now active.

[**FAULT LOCATION**]
[Yes]

There are two options available for setting the measurement bandwidth; frequency entry mode and range entry mode.

Frequency entry mode should be used for bandwidth limited systems, however this may result in an impractiably long range.

In range entry mode the range is entered explicitly with the centre frequency. The 6820 series automatically optimises the bandwidth. The range which is entered should typically be 10% longer than the line under test to prevent aliasing [1].

The source is set to provide maximum output power to the transmission line under test. To enter a range of 30 metres with a centre frequency of 1792 MHz.

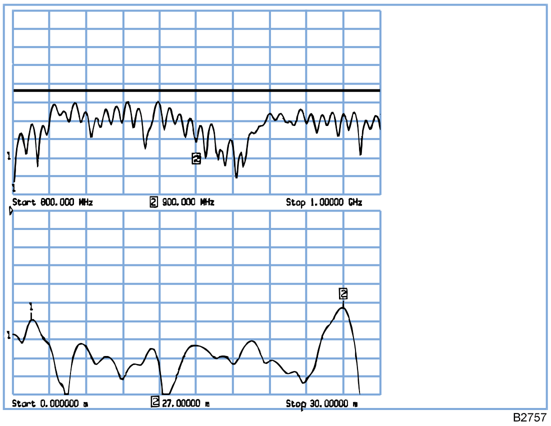

Figure 5 - Fault location measurement of a coaxial RF feed and antenna

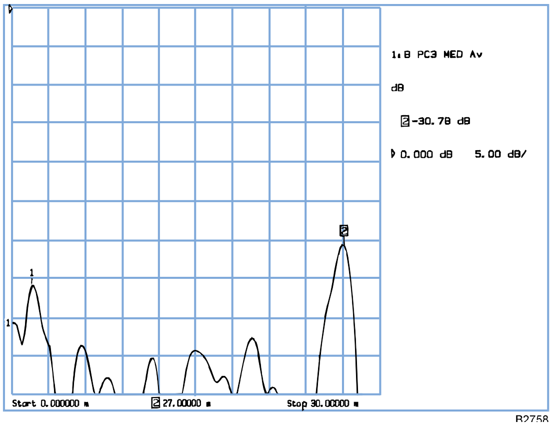

Figure 6 - Simultaneous return loss and fault location measurements of a coaxial RF feed and antenna

[**FAULT LOCATION**]
[*Configure Measurement*]
[⇩] Range: [3][0] [**ENTER/=MKR**]
[⇩] Centre Frequency: [1][7][9][2] [**M µ**]
[⇩] Tx Line Medium: Coax
[⇩] Relative Velocity:

The relative velocity and attenuation per metre of the transmission line under test can be entered into the table. Alternatively, the parameters of a large number of transmission lines are held in a database within the instrument labelled "Tx Dbase". The values for the transmission line under test can be entered using:

[*Tx Dbase in Use* ●] followed by
[*Select Tx Line from Dbase*][⇩]
Scroll to Tx line required and press
[*Select*] [*Return to Config Meas*]

The number of measurement points can be adjusted from 200 to any value between 51 and 1601 and this will force the instrument to use more measurement bandwidth and hence increase the resolution.

Exit from the configure menu with [Return to Fault Loc]

Calibration is performed by connecting the matched load to the test port.

[**CAL**]
[*Fault Location Cal*]
[*Continue*]

A bar will show the progress of the calibration after which, with the matched load still connected, a noise floor of typically >70 dB should be observed.

The transmission line can now be connected to the test port.

The trace is updated in real time, allowing the user to manipulate the feeder to check for intermittent faults, such as those that can occur with loose connectors.

Setting the scale to 5 dB per division gives the measurement shown in Figure 5.

Marker 1 is positioned at 1.5 metres (5 feet) which is the junction of the jumper cable and feeder. Marker 2 is positioned at 27 metres (88 feet), which is the position of the antenna.

Simultaneous display of return loss and fault location is now possible by choosing a dual channel display:

[**DISPLAY**]
[*Dual Channel Display* ●]
Figure 6 shows the resulting display.

Single Ended Insertion Loss

When installing a base station, it is necessary to minimise the power lost in the antenna feed. Hence, on tall towers, with over 80 metres (262 feet) of feeder, expensive low loss coaxial cable must be used. It is possible to verify the insertion loss of the installed feed with the 6820 series of scalar analyzers. The fast and simple method known as single ended insertion loss can be used.

The single ended measurement involves applying the RF test signal to the feeder that has been short circuited at the far end. The applied signal travels along the line and is totally reflected by the short circuit. The reflected signal then travels back through the line where it is detected by means of a directional device. The detected signal has travelled twice the length of the line and hence the measurement indicates a value which is twice the insertion loss.

The 6820 series of scalar analyzers perform single ended insertion loss measurements and automatically account for the factor of 2 in the path loss. The 6240 series Fault Locators can be used as the directional device. Single ended insertion loss can be performed using the system set up as in Figure 3 except that the antenna must be replaced by a short circuit.

With the source set-up as for the return loss measurement and using input A, perform the calibration by selecting:

[**CAL**]
[*Single Ended Insertion Loss*]
[*Short OR Open Cal*][*Continue*]

The coaxial feeder with a short circuit in place of the antenna is then connected to the 6240 series test port.

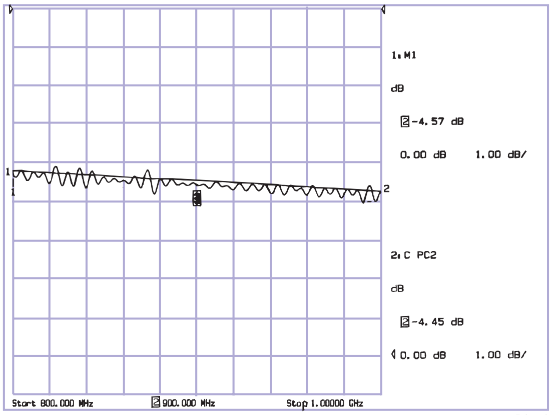

Figure 7 - Single and double ended insertion loss measurements

Figure 7 shows two insertion loss measurements, one single ended as just described, the other a standard two port measurement using a remote detector.

Figure 7 shows that the single ended measurement has a ripple superimposed on the smooth insertion loss response. The ripple is due to multiple reflections within the feeder and indicates a measurement error. This error can be reduced by using a small amount of smoothing, (for example 2% or less). However, smoothing should be used carefully since excessive smoothing factors can distort the response.

Single ended insertion loss measurements should be restricted to systems with low path losses. Systems with losses greater than 6 dB may incur large measurement errors. Single ended insertion loss measurement errors are discussed in Appendix D.

It is recommended that single ended insertion is not used as a primary measurement in fault detection. The single ended insertion loss measurement should be made with caution. Under certain conditions it is possible to measure a system to have low loss when in fact a major fault exists. The measurement should always be made after, or in conjunction with, a return loss or fault location measurement.

Floppy disk data storage

Measurements made when the base station is first installed should be archived for reference and comparison at a later date. There may be as many as 12 feeds at a single base station site and a convenient way of archiving results is to store them as trace memories on a 3.5 inch disk. The disk drive is a standard fitting built into the 6820 series of scalar analyzers.

Storing trace data is performed by inserting a formatted disk into the drive and pressing:

[**SAVE/RECALL**]
[*Save Trace*][*Floppy Disk* ●]
[*New Store Name*][*Erase Text*] Filename…[*Done*]
[*Save*]

There are two file formats; a standard 6820 series binary file which can be re-loaded into the 6820 series at a later date as a memory trace.

The Selection of [Spreadsheet Format ●] produces a Comma Separated Variable (*.CSV) file which can be read into a PC spreadsheet for further analysis.

Retrieving and displaying trace data from floppy disk is via

[**SAVE/RECALL**]
[*Recall Trace*][*Floppy Disk* ●]

The up/down arrow keys are used to select the required filename followed by:

[*Select*]
General disk utilities are found under
[**UTILITY**]
[*Store Management*]

The selections are grouped by type of store which includes stores both within the instrument and on floppy disk. Files can be copied between internal and external, floppy disk stores or deleted as required.

Summary

For network operators who need to provide, and maintain, the highest level of performance from their base station feed and antenna. The 6820 series provides a compact portable instrument that, when used with a 6240 series Fault Locator, can accurately characterise the antenna and feed. It is an ideal measurement system for both installation engineers and those responsible for implementing a structured routine maintenance policy.

Bibliography

[1] A.G.Bullock. "Fault Location on Waveguide Antenna Feeds", Marconi Instruments Technical Information sheet, Pub No. 46889-462.

[2] G.Hjipieris, R.MacRae, "Use Scalar Data to Locate Faults in the Time Domain", Microwaves and RF, January 1989.

[3] G.Hjipieris, R.MacRae, S.Thomas. "A Transmission Line Test System", MIOP88. Conference proceedings, March 1988.

Appendix A: Return Loss Theory and Measurement Errors

The return loss bridge network is shown in Figure A1.

The bridge contains 3 balancing resistors R1, R2, R3, a precision reference load R4, against which the unknown impedance Z_x is compared. A diode D1, balanced w.r.t. ground via resistor Rh is AC coupled to the network via capacitors, C1, C2. V_s is a source with an internal impedance R_0.

V_{det} is related to V_s by the relationship:-

$$V_{\det} = \frac{V_s(Z_x - R_0)}{8(Z_x + R_0)}$$

Hence V_{det} is proportional to the reflection coefficient of the unknown Z_x.

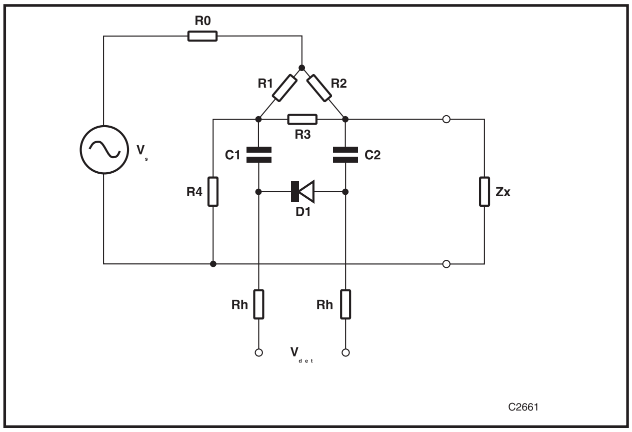

Figure A1 - Return Loss Bridge network

V_{det} is maximum when Z_x is a short or an open circuit. When Z_x=R_0 the diode is balanced across two equal voltages and V_{det}=0, thus showing the directional qualities of the network.

The RF input match is dependant on the load presented at the test port and vice versa. When terminated in Z_0 the port matches are perfect, however even when a port is terminated in an open or short, the port match at the other is -12 dB (1.67 VSWR). This is due to the 6 dB loss produced by the bridge resistors.

Practical realisation of the network results in a finite directivity and test port match. This is due to residual imbalance in the bridge arms, tolerances on the reference load and impedance discontinuities within the test port connector.

Typically, directivities of >34 dB and test port matches of >20 dB are common.

Measurement Errors

The two major contributors to measurement errors for any directional device are directivity and test port match.

Directivity is the main limitation on the measurement dynamic range. The test port match sets the limit on the accuracy to which a highly reflecting device can be measured. The mismatch between the test port and the DUT sets up multiple reflections which are seen as ripples on the measured response. The error is two-fold since a mismatch ripple is frozen into the measurement by the calibration as well as the mismatch error due to the DUT.

The error E_r when measuring a reflection coefficient Γ_d is:

$E_r = D + M\Gamma_d^2$
where, D = directivity
M = test port match
Γ_d = Reflection coefficient of DUT

Figure A2 shows the measurement error in dB as a function of measured return loss. The analysis assumes a test port match of 20 dB, for directivities of 38 dB and 35 dB.

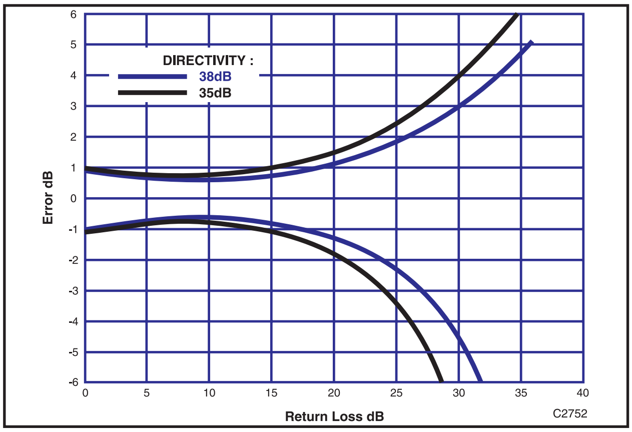

Figure A2 - Measurement error limits on reflection measurements

Appendix B: Fault Location Theory and Measurement Errors

At the heart of time domain measurements using scalar data is the encoding of phase information in an amplitude response. This amplitude response is inverse Fourier transformed to give the required time/distance information. The phase encoding is performed by a symmetrical power divider as shown in Figure B1.

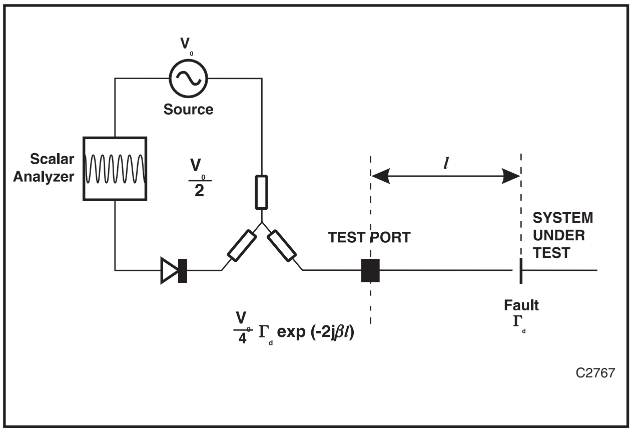

Figure B1 - Phase Encoding Symmetrical power divider

The source power sweeps over the required frequency range, and the divider directs the power to both the scalar detector and system under test. An impedance discontinuity within the system will produce a reflected signal which has incurred a phase delay proportional to the distance from the centre of the divider to the discontinuity. The reflected signal recombines with the reference signal at the divider centre and the detector measures the magnitude of the vector sum of the two. As the frequency is swept, the phase between the reference and reflected signals varies, and the amplitude response produced is a ripple pattern. The ripple amplitude is proportional to the reflection magnitude and has a period which is inversely proportional to the distance.

Assuming square law operation and a single fault, the output voltage V_d from the diode detector is given by:

$$V_d = k|V_0|^2 \{|s_{21}|^2 + |s_{31}s_{23}\Gamma_d|^2 + 2|s_{21}s_{31}s_{23}\Gamma_d|\cos(2\beta l)\}$$

where;-

k is the detector sensitivity,

V_0 describes the wave magnitude incident on the divider input,

Γ_d is the fault reflection coefficient and

l is the distance from divider centre to the fault.

Calibration is performed using a matched load ($\Gamma_d = 0$), and results in a detector response V_{dl} where:

$$V_{dl} = k|V_0 s_{21}|^2$$

Normalising all subsequent measurements by V_{dl} and subtracting 1 gives:

The Fourier transform of the above result yields:-

An impulse at zero distance, magnitude

An impulse at distance 2l, magnitude

The fault location and its associated reflection coefficient have been found to within a scaling factor defined by the scattering parameters of the divider. In practice the divider scattering parameters are characterised, and are accounted for in the MTS firmware.

Fault location measurement errors fall into two main categories namely distance and amplitude errors. These errors have been covered in detail in [1,5].

Appendix C: The Fault Locator

The 6240 series Fault Locators incorporate the features of the return loss bridge network (Figure A1) and the fault location network (Figure B1), to produce a unique circuit. Both networks rely on the accurate power division of an input signal to a test and reference plane. Figure C1 shows the fault locator circuit.

This novel arrangement is capable of performing both measurements, simultaneously, from a single test port.

V_s is the RF input source. Plane AA' defines the test port measurement plane, BB' defines the reference plane. Resistors R1, R2, R3 form the common power dividing network. Each of these resistors is 50 Ω to produce a well matched input port and test port. Diodes D1 and D2 perform the return loss and fault location measurements respectively. The resistor network formed by Ra, Rb, Rc performs a dual function. Firstly, they produce a 50 Ω reference impedance against which the unknown, Z_x is compared. Secondly, they limit the power incident on diode D2 such that it operates in square law.

Measurement errors when using a 6240 series Fault Locator are as described in Appendices A and B.

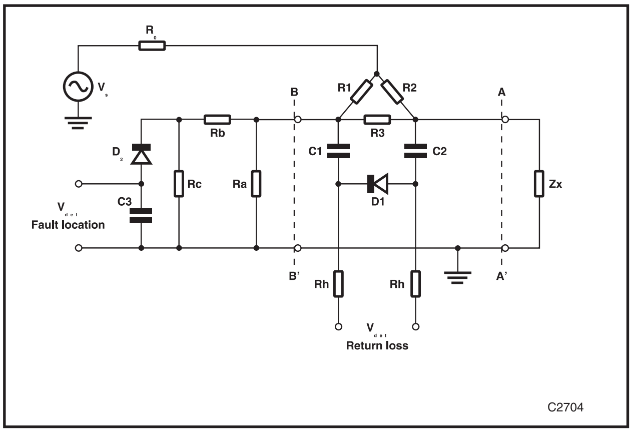

Figure C1 - Fault Locator Circuit

Appendix D: Single Ended Insertion Loss Measurement Errors

The magnitude of the error ripple, seen on single ended insertion loss measurements, is similar in origin to the errors seen when making return loss measurements. However, they do not just depend upon the bridge directivity *D* and test port match *M*. The input match s_{11} and the insertion loss L of the line under test also need to be considered.

The input match of the line under test modifies the directivity and test port match in a way that is similar to the effect of using an adapter on the test port when making a return loss measurement. An example is given in the main text.

Figure D1 shows a graph of peak error in dB as a function of line loss and input match. The calculations use typical fault locator directivity and test port match values.

The plots show that the errors become large when high losses are measured. The technique should be restricted to lines with losses <6 dB to prevent excessive measurement error being encountered.

For line losses <3 dB the effective test port match error term dominates and the peak error on the displayed measurement can be approximated by:

$$\text{Peak Error} = \left|\sqrt{1 + ML^2}\right|$$

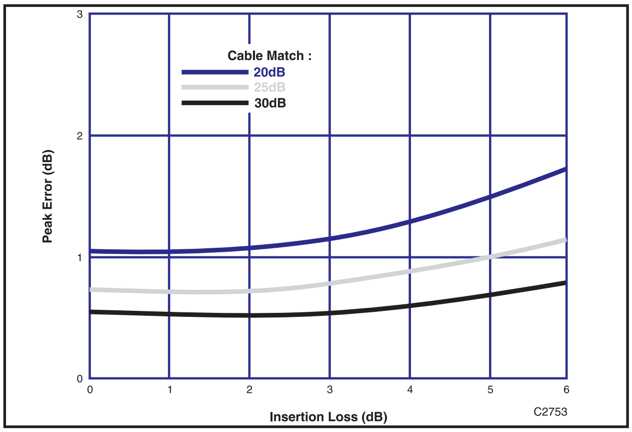

Figure D1 - Peak Error on single ended insertion loss measurements

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