PREVIOUS INSTRUMENT STATES

To bring the Data Type Menu (Figure 49) onto the CRT display, first press the **TAPE** key in the AUXILIARY MENUS block. This brings the Tape Menu onto the CRT display. Next press the softkey corresponding to the operation you wish to perform: **STORE**, **LOAD**, or **DELETE**. This brings the Data Type Menu onto the CRT. Pressing **UNDELETE** before any other tape operations occur restores the last file deleted.

Press **INSTRUMENT STATE 1-8** to store a single instrument state previously saved in HP 8510 internal memory using the sequence: **STORE**, **INSTRUMENT STATE 1-8**, then **1**, **2**, **3**, **4**, **5**, **6**, **7**, or **8**.

Press **INSTRUMENT STATES ALL** to save all instrument states 1 through 8 on a single tape file.

In the same way you can select a single memory trace previously stored in HP 8510 internal memory using the **DISPLAY**, **DATA → MEMORY** sequence, or you can record all four memory traces.

Press **CAL SET 1-8** to select a single calibration error coefficient set for recording, or **CAL SETS ALL** to select recording of all cal sets. Press **CAL KIT 1-2** presents a menu to allow selection of either Cal Kit 1 or Cal Kit 2.

The softkeys **DATA: RAW**, **DATA**, and **FORMATTED** refer to measurement data for the currently selected channel at various stages in the digital signal processing steps. **RAW** refers to ratioed and averaged data, **DATA** refers to the data in the corrected data array, and **FORMATTED** refers to data in the formatted array. See Figure 4, Post-Detection Digital Signal Processing.

USER DISPLAY allows recording of any graphics or text written into the user CRT memory via the HP-IB by an external controller. Details for this operation are contained in the HP 8510 Introduction to Programming manual.

MACHINE DUMP records a large file consisting of the complete instrument state, including contents of the various memories for both channels.

After selection of the data type, the File Menu appears. Select any file 1 through 8 and the recording process begins.

TAPE MENU

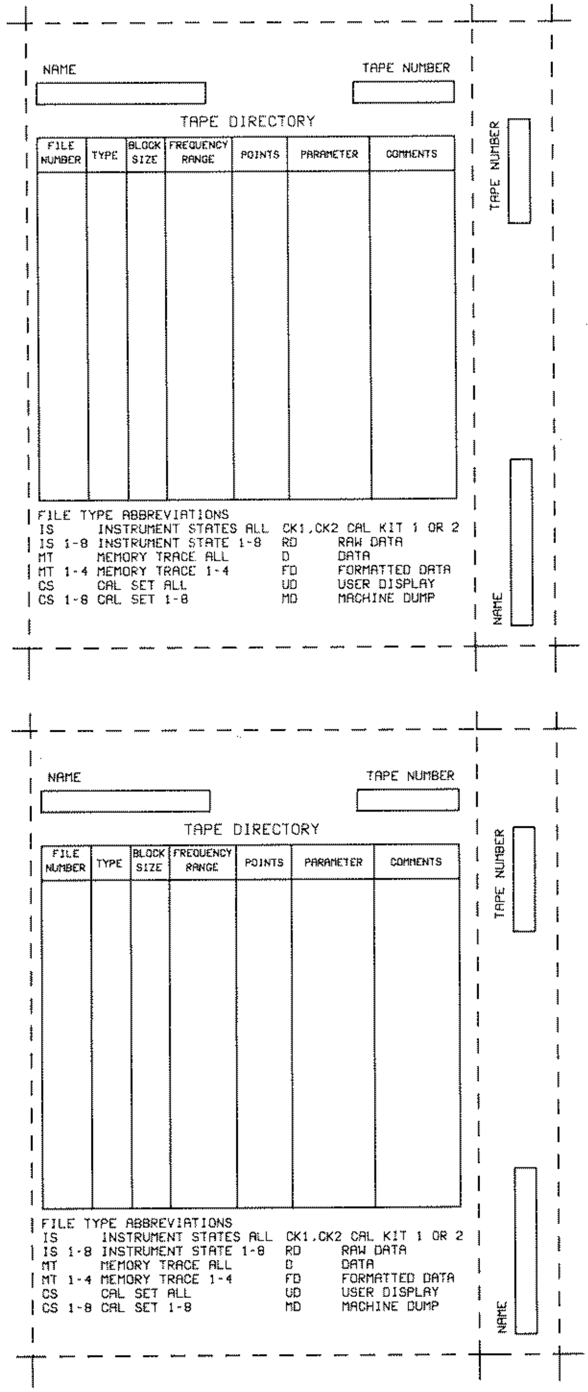
Figure 49 shows the Tape Menu and the associated Data Type Menu. Pressing the softkey **DIRECTORY** displays a list of currently recorded files. Each cartridge holds up to 85 blocks.

STORE, **LOAD**, **DELETE**, and **UN-DELETE** describe operations performed on specified files:

- **STORE** moves the selected data type to the cartridge;
- **LOAD** transfers the data file into network analyzer memory;
- **DELETE** eliminates the specified file from the directory;
- **UN-DELETE** restores the most recently deleted file to the directory listing unless the space has been reallocated to a file recorded after it was deleted or the tape has been removed from the tape drive.

To record a file, press **STORE** to present the Data Type Menu (Figure 49). This menu lists all possible data types which can be recorded. Up to eight files of each data type may be stored, tape space permitting. Details on each of the choices on the Data Type Menu appear on the next page.

Remove the tape cartridge by pressing the eject bar and then pulling the cartridge straight out. *Do not remove the tape cartridge when the tape drive light is on. Serious damage to the tape drive mechanism and to the tape can result.*



NAME

TAPE NUMBER

TAPE DIRECTORY

FILE NUMBER	TYPE	BLOCK SIZE	FREQUENCY RANGE	POINTS	PARAMETER	COMMENTS

FILE TYPE ABBREVIATIONS

IS	INSTRUMENT STATES ALL	CK1,CK2	CAL KIT 1 OR 2
IS 1-8	INSTRUMENT STATE 1-8	RD	RAW DATA
MT	MEMORY TRACE ALL	D	DATA
MT 1-4	MEMORY TRACE 1-4	FD	FORMATTED DATA
CS	CAL SET ALL	UD	USER DISPLAY
CS 1-8	CAL SET 1-8	MD	MACHINE DUMP

TAPE NUMBER

NAME

NAME

TAPE NUMBER

TAPE DIRECTORY

FILE NUMBER	TYPE	BLOCK SIZE	FREQUENCY RANGE	POINTS	PARAMETER	COMMENTS

FILE TYPE ABBREVIATIONS

IS	INSTRUMENT STATES ALL	CK1,CK2	CAL KIT 1 OR 2
IS 1-8	INSTRUMENT STATE 1-8	RD	RAW DATA
MT	MEMORY TRACE ALL	D	DATA
MT 1-4	MEMORY TRACE 1-4	FD	FORMATTED DATA
CS	CAL SET ALL	UD	USER DISPLAY
CS 1-8	CAL SET 1-8	MD	MACHINE DUMP

TAPE NUMBER

NAME

Figure 50. Tape Cartridge Catalog Form

MAKING A BACKUP PROGRAM TAPE

It is strongly recommended that you make a duplicate, backup tape of the HP 8510 operating system software installed in your system. Then put the original away for safekeeping in case the duplicate, working copy is ever lost or damaged.

Use a new, blank tape for the backup, or use a tape that has on it files you no longer want. When the backup is made, all existing files are removed from the tape. The original is not needed in order to make the duplicate: the duplicate is copied from information already stored in the HP 8510 system itself.

First disable the write-protect feature on the tape cartridge that is to be used for the backup, by moving the RECORD tab fully in the direction of the arrow. Then insert the cartridge into the tape drive of the HP 8510 display/processor. Press the Auxiliary Menus key labeled **SYSTEM**. Menu choices will appear on the CRT display.

Press the softkey labeled **SERVICE FUNCTIONS** to display the next menu. When the menu appears, press the softkey labeled **TEST MENU**.

In addition to the menu, this prompt will appear at the bottom of the CRT: **ENTER SELECTION THEN PRESS =MARKER**. Using the entry keys on the front panel of the HP 8510, first enter **21**, then press **=MARKER**. Selection **21** is the **INITIALIZE TAPE** command, and when it is followed by **=MARKER** it prepares the tape to receive the data.

Initialization takes about 1.5 minutes, and you will find that during loading the tape drive starts and stops often. This is normal. Initialization is complete when the number **21** disappears from the CRT display and the tape drive goes out.

When the tape has been initialized, enter **20**, then press **=MARKER**. Selection **20** is the **RECORD PROGRAM TAPE** command, and recording takes about 3 minutes.

Recording is complete when the number **20** disappears from the CRT display and the tape drive light goes out. The system then automatically begins running the main program, and after about 1 minute the graticule will appear.

When the graticule appears, cycle the power once by turning the line switch on the HP 8510 front panel off and then on.

The tape can be removed at any time after the graticule (grid) appears, and it now contains a copy of the operating system software. Move the RECORD tab back to its original position to write-protect the copy. Use this copy and put the original tape away for safekeeping.

Note that as it is installed for the first time the program keys itself uniquely to one HP 8510 system and cannot be used in any other system. You may want to mark the backup tape with the serial number that appears on the original tape to prevent confusion.

MEASUREMENT CALIBRATION

ILLUSTRATIONS

TABLES

INTRODUCTION

Measurement calibration transfers the accuracy of your standards to the measurement of your device. Since the response of the standards is known to a high degree of accuracy, the system can measure one or more standards, then use the results of these measurements to provide data to the error-correction algorithms which process the measured data for display.

This part of the HP 8510 network analyzer system manual explains the theoretical fundamentals of accuracy enhancement, the sources of measurement errors, and the error-correction models used in the HP 8510 system. Then it describes in detail typical measurement calibration sequences using the HP 8510 system. These sequences are then discussed and summarized according to type. Finally, storing calibrations, calibration standards, evaluating calibration data, and adjusting trim sweep are discussed.

ACCURACY ENHANCEMENT FUNDAMENTALS

Vector accuracy enhancement techniques provide the means of reducing network measurement ambiguities. For example, crosstalk due to the channel isolation characteristics of the network analyzer can contribute an error equal to the transmission characteristic of a high loss test device.

Similarly, for reflection measurements the primary limitation of dynamic range is directivity of the test setup. When the magnitude of the test signal equals the leakage signal, the measurement system cannot distinguish the true value of the signal reflected or transmitted by the device from the signal arriving at the receiver input due to leakage in the system. For all measurements, any impedance mismatches within the test setup can cause severe errors.

A perfect measurement system would have infinite dynamic range, isolation, and directivity characteristics, no impedance mismatches in any part of the test setup, and flat frequency response. In practice, this "perfect" network analyzer is achieved by measuring the magnitude and phase response of known standard devices, using this data in conjunction with a model of the measurement system to determine error contributions, then measuring a test device and using vector mathematics to compute the actual test device response by removing the error terms.

The dynamic range and accuracy of the measurement is then limited by system noise and the accuracy to which the characteristics of the calibration standards are known. This is the basic concept of vector accuracy enhancement. The following paragraphs describe the error model, the calibration standards, and the vector mathematics.

SOURCES OF MEASUREMENT ERRORS

Network analysis measurement errors can be separated into two categories:

(1) Random Errors are non-repeatable measurement variations that occur due to noise, environmental changes and other physical changes in the test setup between calibration and measurement. These are any errors that the system itself cannot measure or cannot model with an acceptable degree of certainty.

(2) Systematic Errors are repeatable errors. They include mismatch and leakage terms in the test setup, isolation characteristics between the reference and test signal paths, and system frequency response.

Thus, any measurement result is the vector sum of the actual test device response plus all error terms. The precise effect of each error term depends upon its magnitude and phase relationship to the actual test device response. Random errors cannot be precisely quantified, so they must be treated as producing a cumulative ambiguity in the measured data.

Fortunately, in most microwave measurements systematic errors are the ones which produce the most significant measurement uncertainty. Since each of these errors produces a predictable effect upon the measured data, their effects can be removed to obtain a corrected value for test device response. For the purpose of vector accuracy enhancement, these uncertainties are quantified as directivity, source match, load match, isolation, and tracking (frequency response). When accuracy enhancement techniques are used, the resultant values after correction are termed Effective Directivity, Effective Source and Load Match, Effective Isolation, and Effective Tracking.

Directivity. The vector sum of all leakage signals appearing at the network analyzer test input due to the inability of the signal separation device to absolutely separate incident and reflected waves, as well as residual reflection effects of test cables and adapters between the signal separation device and the measurement plane. The uncertainty contributed by directivity is independent of the characteristics of the test device and it usually produces the major ambiguity in reflection measurements.

The standard test sets typically provide uncorrected directivity of greater than 26 dB. However, the vector accuracy enhancement technique described here will typically produce much greater Effective Directivity.

Source Match. The vector sum of signals appearing at the network analyzer test input due to the inability of the source to maintain absolute constant power at the test device input as well as cable and adapter mismatches and losses outside the source leveling loop. The uncertainty contributed by source match is dependent upon the relationship between the actual input impedance of the test device and the equivalent match of the source, and it is a factor in both transmission and reflection measurements.

Source match error is particularly a problem when measuring very high or very low impedances (large mismatch at the measurement plane). The Effective Source Match can be improved considerably by using vector error correction techniques.

Load Match. The vector sum of signals appearing at the network analyzer test input due to effects of impedance mismatches between the test device output port and the network analyzer test input. The uncertainty contributed by Load Match is dependent upon the relationship between the actual output impedance of the test device and the effective match of the return port, and is a factor in all transmission measurements and in reflection measurements of two-port devices.

Load match effects are analyzed similarly to source match effects and will produce major transmission measurement errors for a test device whose output port is highly reflective. Effective Load match can typically be improved by a factor of 15 to 20 dB using vector accuracy enhancement techniques.

Isolation. The vector sum of signals appearing at the network analyzer detectors due to crosstalk between the reference and test signal paths, including signal leakage within both the RF and IF sections of the receiver. The uncertainty contributed by isolation is a factor in high loss transmission measurements.

The system typically maintains greater than 80 dB of isolation between the reference and test signal paths. Characterization and removal of repeatable cros-stalk and leakage, along with extensive averaging, improves the Effective Isolation to extend the measurement system dynamic range by up to 20 dB.

Tracking. The vector sum of all test setup variations in magnitude and phase frequency response, including signal separation device, test cables and adapters, and variations in frequency response between the reference and test signal paths. This error is a factor in both transmission and reflection measurements.

The magnitude and phase frequency response variations and the resultant measurement errors are reduced using vector accuracy enhancement, making the Effective Tracking typically under 0.02 dB and 0.1 degree.

CORRECTING MEASUREMENT ERRORS

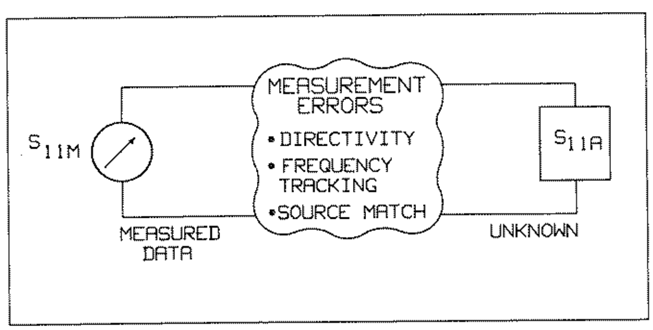
The HP 8510 network analyzer system offers a choice between Frequency-Response-Only, 1-Port, and 2-Port error models. The frequency-response-only error model provides signal path frequency response error correction for the selected parameter. This model may be adequate for measurement of well matched low loss devices where vector normalization of magnitude and phase frequency response errors provides sufficient measurement accuracy.

The 1-Port error model provides directivity, source match, and reflection signal path frequency response vector error correction for reflection measurements. This model is best applied to high accuracy reflection measurements of one-port devices.

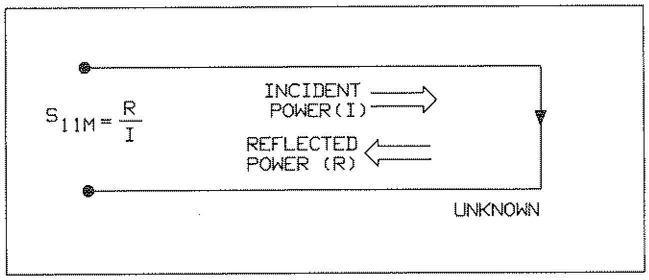
The 2-Port error model provides full directivity, isolation, source match, load match, and frequency response vector error correction for transmission and reflection measurements of two-port devices. This model provides best magnitude and phase measurement accuracy for two-port devices but requires measurement of all four S-parameters of the two-port device.

The following discussion describes these error models in greater detail and, more importantly, explains how they can be characterized and used to reduce measurement uncertainty. In actual system operation, error correction is not always done exactly as this discussion suggests, but the results are in all cases mathematically equivalent.

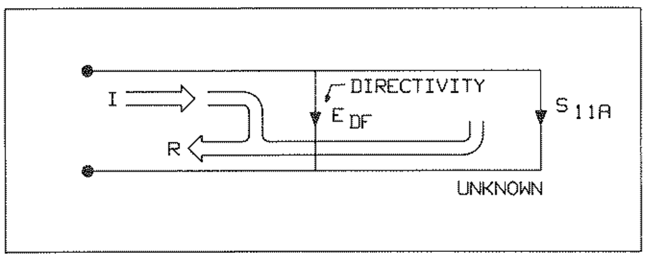
Let's consider measurement of reflection coefficients (magnitude and phase) of some unknown one-port device. No matter how careful we are, the measured data will differ from the actual. Directivity, Source Match, and Tracking are the major sources of error.



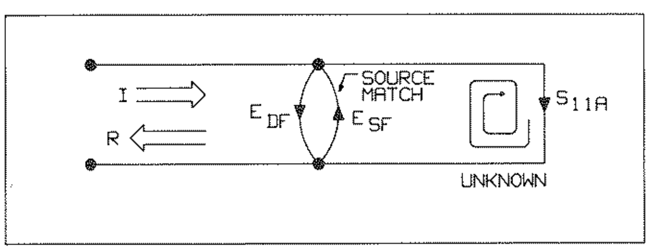
Reflection coefficient is measured by first separating the incident voltage wave (I) from the reflected voltage wave (R) then taking the ratio of the two values. Ideally, (R) consists only of the wave actually reflected by the test device (S_{11A}).



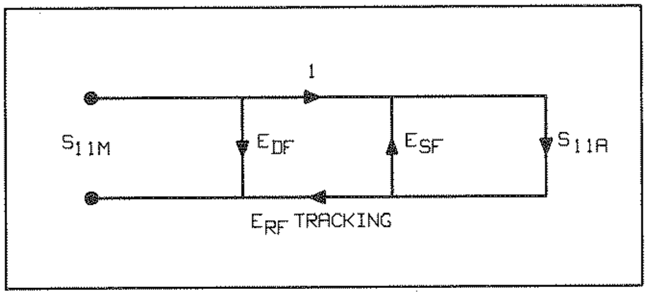
Unfortunately, all of the incident wave doesn't always reach the unknown. Some of (I) may appear at the measurement system input due to leakage through the signal separation device (coupler/bridge). Also, some of (I) may be reflected by imperfect adapters between signal separation and the measurement plane. The vector sum of the leakage and miscellaneous reflections is directivity, E_{DF}. Understandably, our measurement is distorted when the directivity signal combines vectorally with the actual reflected signal from the unknown, S_{11A}.



Since the measurement system test port is never exactly the characteristic impedance (normally 50 ohms), some of the reflected signal bounces off the test port (or other impedance changes further down the line) and back to the unknown, adding to the original incident signal (I). This effect causes the magnitude and phase of the incident signal to vary as a function of S_{11A}. Leveling the source to produce constant (I) reduces this error, but since the source cannot be leveled exactly at the test device input, leveling cannot eliminate all power variations. This re-reflection effect and the resultant incident power variation is caused by the source match error, E_{SF}.



Tracking (frequency response) error is caused by variations in magnitude and phase flatness versus frequency between the test and reference signal paths. These are due mainly to imperfectly matched samplers and differences between reference and test signal paths. The vector sum of these variations is the reflection signal path tracking error, E_{RF}.

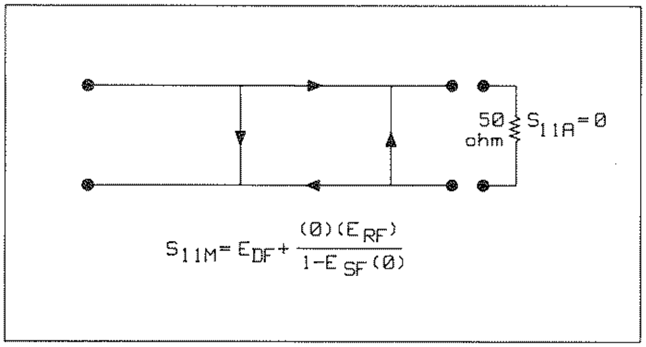


It can be shown that these three errors are mathematically related to the actual, S_{11A}, and measured, S_{11M}, data by the following equation.

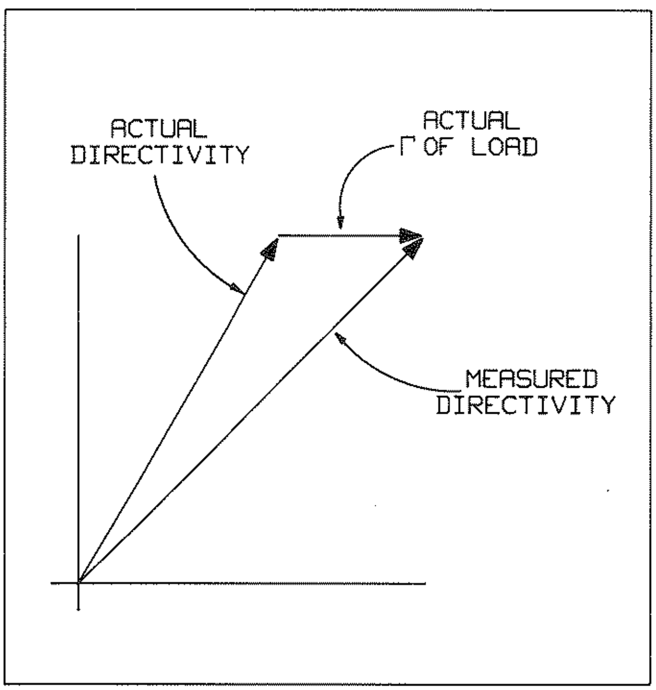
$$S_{11M} = E_{DF} + \frac{S_{11A}(E_{RF})}{1 - E_{SF} S_{11A}}$$

If we knew the value of these three "E" errors and the measured test device response at each frequency, we could simply solve the above equation for S_{11A} to obtain the actual device response. Because each of these errors changes with frequency, it is necessary that their values be known at each test frequency. They are found by measuring (calibrating) the system at the measurement plane using three independent standards whose S_{11A} is known at all frequencies.

The first standard we apply is a "perfect" load which makes $S_{11}A = 0$ and essentially measures directivity. By "perfect" load we mean a reflectionless termination at the measurement plane. All incident energy is absorbed. With $S_{11A} = 0$ the equation can be solved for E_{DF}, the directivity error term. Of course, in practice the "perfect load" cannot be achieved.

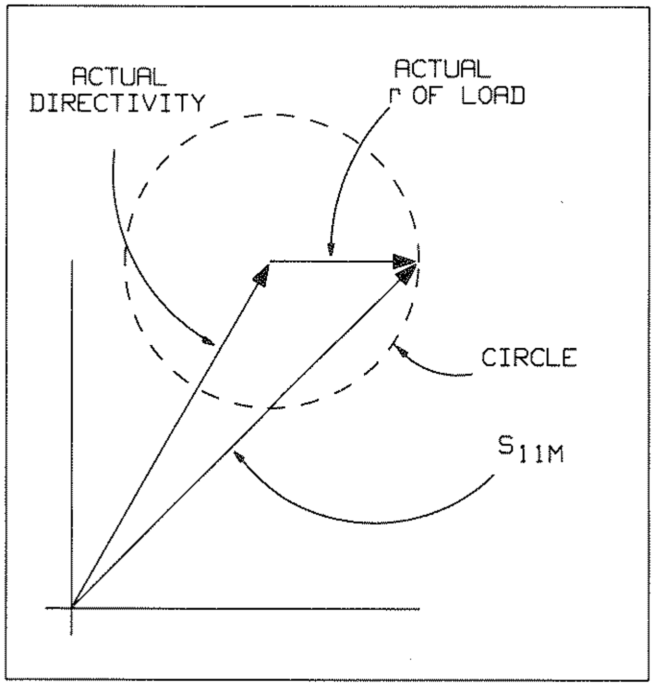


Since the measured value for directivity is the vector sum of the actual directivity plus the actual reflection coefficient of the "perfect" load, any reflection from the termination represents an error. System Effective Directivity becomes the actual reflection coefficient of the "perfect" load. In general, any termination having a return loss greater then the uncorrected system directivity reduces reflection measurement uncertainty.



Due to the difficulty of producing a high quality fixed coaxial termination at microwave frequencies, a sliding load can be used at each test frequency to separate the reflection of a somewhat imperfect termination from the actual directivity.

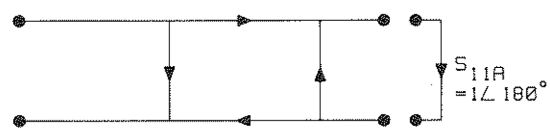
At any single frequency, moving the sliding termination with respect to the measurement plane produces a complete circle when the sliding element is displaced one-half wavelength of the test frequency. Its reflection coefficient magnitude remains constant but the phase of the coefficient changes. The radius of that circle is the actual reflection coefficient of the sliding termination, and the center of the circle is determined by the actual directivity of the test setup and the geometry of the air line within the sliding load.



Thus, the critical specifications for the sliding load assembly are the mechanical dimensions (impedance) of the connector, of the transmission line between the measurement plane and the termination, and that the termination maintains a constant reflection coefficient magnitude at all positions.

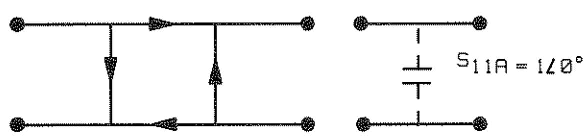
The sliding load calibration sequence used here measures the sliding load at eight or more positions. The firmware can compute the center of the circle with five positions, but more slides (6 to 8 are recommended) increase precision.

Next, a short circuit termination is used to establish another condition.



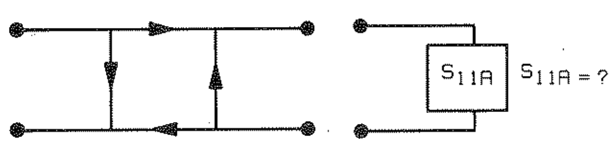
$$S_{11M} = E_{DF} + \frac{(-1)(E_{RF})}{1 - E_{SF}(-1)}$$

The open circuit gives us the third independent condition. Now the values for E_{DF}, directivity, E_{SF}, source match, and E_{RF}, reflection tracking, are computed and stored.



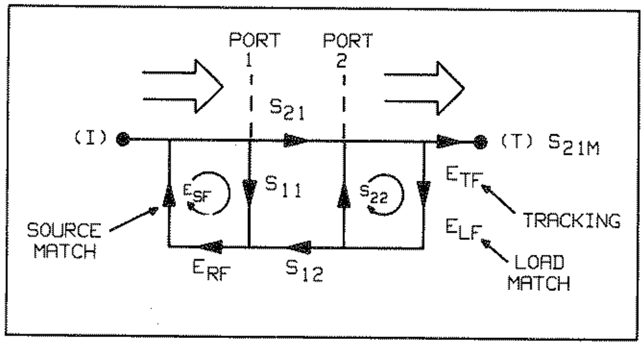
$$S_{11M} = E_{DF} + \frac{(1)(E_{RF})}{1 - E_{SF}(1)}$$

Now we measure the unknown to obtain a value for the measured response, S_{11M}, at each frequency.



$$S_{11M} = E_{DF} + \frac{S_{11A}(E_{RF})}{1 - E_{SF}\, S_{11A}}$$

As in the reflection model, source match can cause the incident signal to vary as a function of test device S_{11A}. Also, since the test setup transmission return port is never exactly the characteristic impedance, some of the transmitted signal is reflected from the test set port 2, and other mismatches between the test device output and the detector, to return to the test device. A portion of this wave may be re-reflected at port 2, thus affecting S_{21M}, or part may be transmitted through the device in the reverse direction to appear at port 1, thus affecting S_{11M}. This error term, which causes the magnitude and phase of the transmitted signal to vary as a function of S_{22A}, is called load match, E_{LF}.

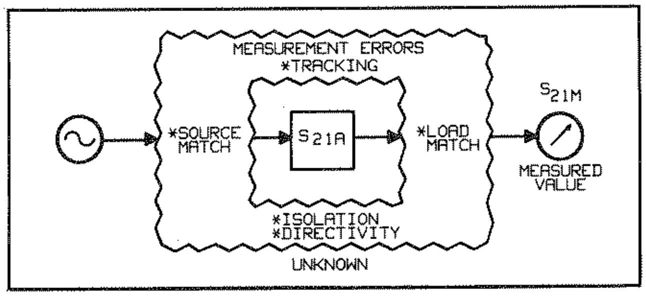


The measured value S_{21M}, consists of wave components which vary as a function of the relationship between E_{SF} and S_{11A} as well as E_{LF} and S_{22A}, so the input and output reflection coefficients of the test device must be measured and stored for use in the S_{21A} error correction computation. Thus, the test setup is calibrated as described above for reflection to establish directivity, E_{DF}, source match, E_{SF}, and reflection tracking, E_{RF}, terms for the reflection measurements.

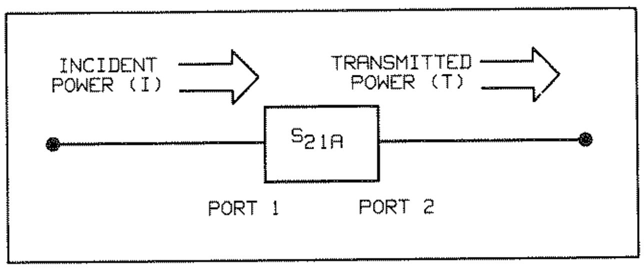
Since we now have a calibrated port for reflection measurements, we connect the thru and determine load match, E_{LF} by measuring the reflection coefficient of the thru connection.

Transmission tracking is then measured with the thru connection. The data is corrected for source and load match effects, then stored as transmission tracking, E_{TF}.

Now consider measurement of transmission coefficients (magnitude and phase) of an unknown two-port device. The major sources of error are Tracking, Source Match, Load Match, and Isolation. These errors are reduced or eliminated using the 2-Port error model.



Transmission coefficient is measured by taking the ratio of the incident voltage wave (I) and the transmitted wave (T). Ideally, (I) consists only of power delivered by the source and (T) consists only of power emerging at the test device output.



Some microwave test sets (HP 8514A and HP 8515A) can measure both the forward and reverse characteristics of the test device without the need to manually remove and physically reverse it. For these test sets, the Full 2-Port transmission and reflection error model shown above includes terms for:

Directivity, E_{DF} (forward) and E_{DR} (reverse),

Isolation, E_{XF} and E_{XR},

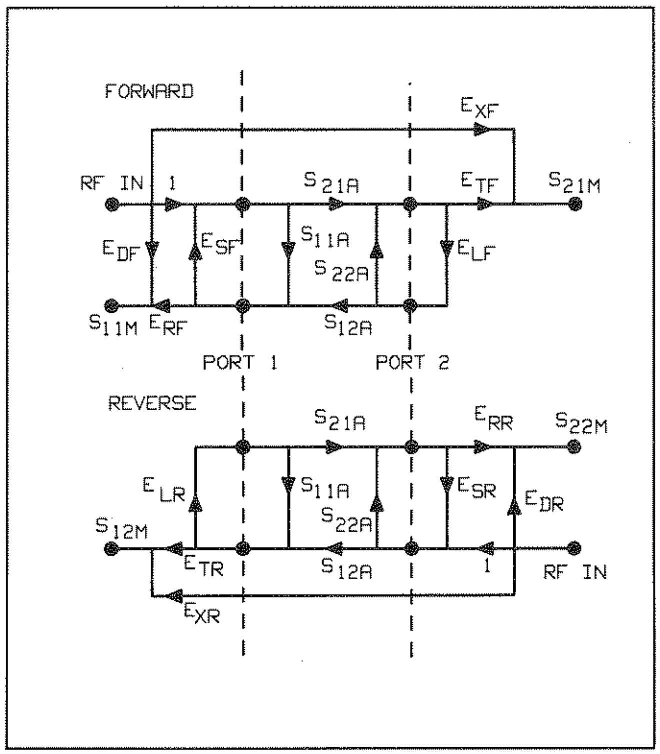
Source Match, E_{SF} and E_{SR},

Load Match, E_{LF} and E_{LR},

Transmission Tracking, E_{TF} and E_{TR}, and

Reflection Tracking, E_{RF} and E_{RR}.

Thus, there are two sets of error terms, forward and reverse, with each set consisting of six error terms.



If the test set cannot switch between forward and reverse (HP 8512A and HP 8513A reflection/transmission test sets), then the reverse terms cannot be measured and the forward error terms are used in their place when the test device is manually reversed. The One-Path 2-Port error model makes this assumption.

These are the 2-Port error model equations for all S-parameters of a two-port device. Note the mathematics for this comprehensive model uses all forward and reverse error terms and measured values. Thus, to perform full error correction, for any one parameter of a two-port device, all four S-parameters must be measured.

$$S_{11A} = \frac{\left[\left(\frac{S_{11M}-E_{DF}}{E_{RF}}\right)\left[1+\left(\frac{S_{22M}-E_{DR}}{E_{RR}}\right)E_{SR}\right]\right]-\left[\left(\frac{S_{21M}-E_{XF}}{E_{TF}}\right)\left(\frac{S_{12M}-E_{XR}}{E_{TR}}\right)E_{LF}\right]}{\left[1+\left(\frac{S_{11M}-E_{DF}}{E_{RF}}\right)E_{SF}\right]\left[1+\left(\frac{S_{22M}-E_{DR}}{E_{RR}}\right)E_{SR}\right]-\left[\left(\frac{S_{21M}-E_{XF}}{E_{TF}}\right)\left(\frac{S_{12M}-E_{XR}}{E_{TR}}\right)E_{LF}E_{LR}\right]}$$

$$S_{21A} = \frac{\left[1+\left(\frac{S_{22M}-E_{DR}}{E_{RR}}\right)\left(E_{SR}-E_{LF}\right)\right]\left(\frac{S_{21M}-E_{XF}}{E_{TF}}\right)}{\left[1+\left(\frac{S_{11M}-E_{DF}}{E_{RF}}\right)E_{SF}\right]\left[1+\left(\frac{S_{22M}-E_{DR}}{E_{RR}}\right)E_{SR}\right]-\left[\left(\frac{S_{21M}-E_{XF}}{E_{TF}}\right)\left(\frac{S_{12M}-E_{XR}}{E_{TR}}\right)E_{LF}E_{LR}\right]}$$

$$S_{12A} = \frac{\left[1+\left(\frac{S_{11M}-E_{DF}}{E_{RF}}\right)\left(E_{SF}-E_{LR}\right)\right]\left(\frac{S_{12M}-E_{XR}}{E_{TR}}\right)}{\left[1+\left(\frac{S_{11M}-E_{DF}}{E_{RF}}\right)E_{SF}\right]\left[1+\left(\frac{S_{22M}-E_{DR}}{E_{RR}}\right)E_{SR}\right]-\left[\left(\frac{S_{21M}-E_{XF}}{E_{TF}}\right)\left(\frac{S_{12M}-E_{XR}}{E_{TR}}\right)E_{LF}E_{LR}\right]}$$

$$S_{22A} = \frac{\left[\left(\frac{S_{22M}-E_{DR}}{E_{RR}}\right)\left[1+\left(\frac{S_{11M}-E_{DF}}{E_{RF}}\right)E_{SF}\right]\right]-\left[\left(\frac{S_{21M}-E_{XF}}{E_{TF}}\right)\left(\frac{S_{12M}-E_{XR}}{E_{TR}}\right)E_{LR}\right]}{\left[1+\left(\frac{S_{11M}-E_{DF}}{E_{RF}}\right)E_{SF}\right]\left[1+\left(\frac{S_{22M}-E_{DR}}{E_{RR}}\right)E_{SR}\right]-\left[\left(\frac{S_{21M}-E_{XF}}{E_{TF}}\right)\left(\frac{S_{12M}-E_{XR}}{E_{TR}}\right)E_{LF}E_{LR}\right]}$$

Applications of these error models, frequency response, 1-port, and 2-port depending on the capabilities of the test sets, are described in the rest of this part of the HP 8510 network analyzer system manual.

MEASUREMENT CALIBRATION

In a typical application, the system is set up for a particular measurement, appropriate measurement calibration is performed for each parameter to be measured, the calibration is saved in a cal set memory, the test device is connected, its response is measured, and then the data is corrected and output. When the device-under-test is to be measured over several different frequency ranges, the appropriate measurement calibration is repeated for each frequency range. After connecting the device, the calibration set for each measurement is recalled in sequence. The eight cal sets and the eight instrument states are used together to choose the appropriate instrument state for the measurement.

- Set Stimulus
- Select Parameter, Format, and Response
- Perform Appropriate Measurement Calibration
- Store Calibration Error Coefficient Set
- Save Instrument State

- Connect Device Under Test
- Recall Instrument State
- Select Parameter
- Select Calibration Error Coefficient Set
- Select Format and Response
- Output Measured Data

When you recall the instrument state, you select the complete stimulus, parameter, format, and response settings used during calibration. Select the parameter to be measured, turn correction On, then make the measurement. If you select an instrument state to which the current cal set does not apply, then correction is turned Off. Since recalling the calibration set recalls a limited instrument state consisting of important stimulus settings, if the appropriate parameter is already selected it is only necessary to recall the calibration set in order to achieve the correct instrument state for measurement.

Always calibrate using the same adapters and cables that will be used for the measurement. If the adapters or cables are changed between calibration and measurement, unpredictable errors will result due to the fact that the error coefficients determined during calibration do not apply to the altered setup. If you change the setup, you must perform the measurement calibration procedure again to find appropriate error terms for the new setup.

When the test setup must be changed between calibration and measurement (as in measuring non-insertable devices), you can minimize errors by switching between components which have equal loss and length. But since no two components exhibit exactly equal magnitude and phase response, the measurement uncertainty is greater.

CAL MENU

Pressing the CAL MENU key brings the Cal Menu (Figure 51) onto the CRT display. Choices on this menu offer you a wide range of calibration options.

CORRECTION ON and **OFF** provides selection of vector error-corrected or measured data for display.

Pressing **CORRECTION ON** brings the Cal Set Selection menu onto the CRT display and the message SELECT CALIBRATION SET onto the CRT display. An asterisk (*) next to the cal set number indicates that calibration error coefficients are already stored in that cal set. Selecting a cal set recalls a limited instrument state of important stimulus values. If the selected cal set applies to the presently selected parameter, the stimulus values are set to the defined values and the Cal menu is displayed with **CORRECTION ON**.

In the general sequence for performing a measurement calibration, first select the parameter, then press **CORRECTION OFF**.

Pressing **CAL 1 (<kit name>)** or **CAL 2 (<kit name>)** allows you to select the appropriate cal kit depending upon the category of calibration standards to be used. Pressing either of these softkeys brings the accuracy enhancement error model selection menu, known as the Cal Type menu (Figure 51), onto the CRT display.

Now select the calibration model, frequency **RESPONSE**, **S_{11} 1-PORT**, **S_{22} 1-PORT**, **ONE-PATH 2-PORT**, or **FULL 2-PORT**. Selections from this menu branch to procedures involving connection and measurement of calibration standards.

The **RESUME CAL SEQUENCE** key allows you to interrupt the calibration procedure currently in progress, for example to change the averaging factor, then return to the same point in the sequence.

If the TIME DOMAIN LOW PASS mode will be used for measurements, set the STOP frequency and number of points, then press **SET FREQ. (LOW PASS)** before proceeding with measurement calibration.

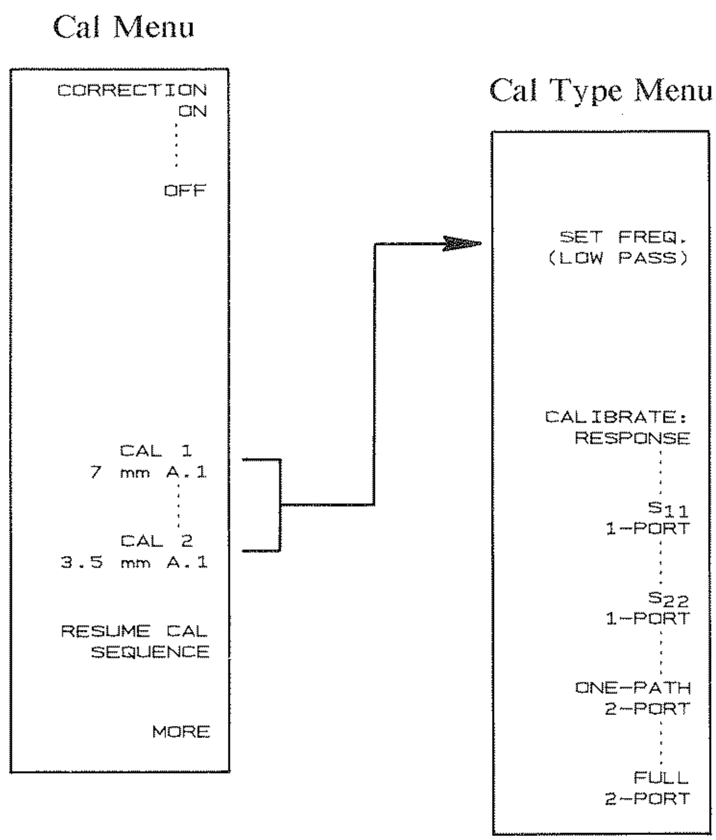
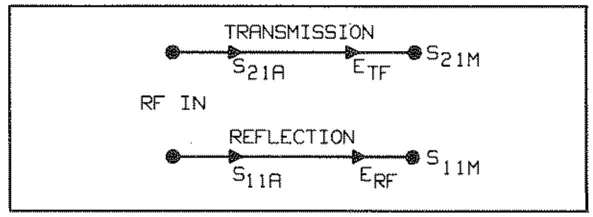
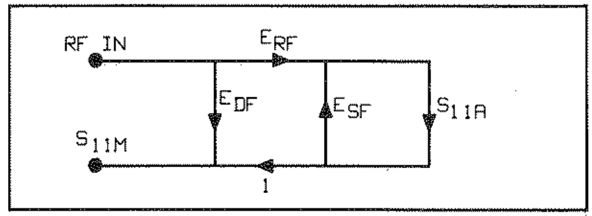


Figure 51. Cal and Cal Type Menus

RESPONSE — Selected signal path frequency response.



S_{11} 1-PORT — S_{11} Directivity, Source Match, Frequency Response.



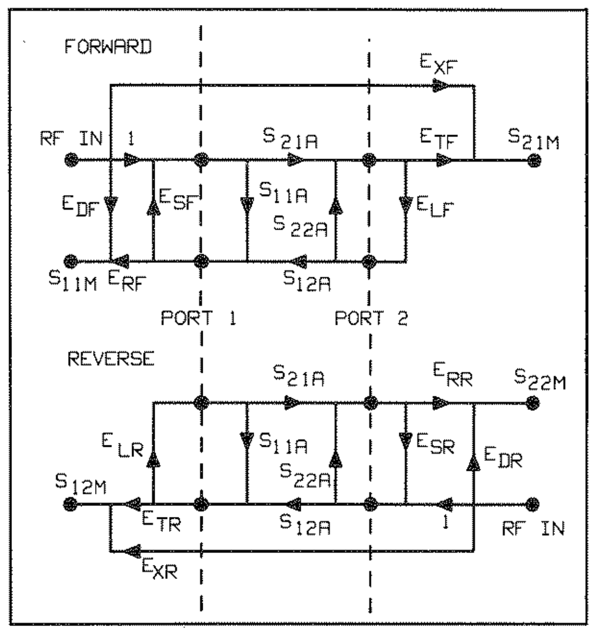
S_{22} 1-PORT — S_{22} Directivity, Source Match, Frequency Response.

All error terms with respect to PORT 2.

FULL 2-PORT

(S-Parameter Test Sets)

S_{11}, S_{21}, S_{12}, S_{22} Directivity, Source Match, Frequency Response, Load Match, Isolation.



ONE-PATH 2-PORT

(Reflection/ Transmission Test Sets)

S_{11}, S_{21} Directivity, Source Match, Frequency Response, Load Match, Isolation.

All error terms with respect to PORT 1, FORWARD model only.

Figure 52. Cal Type Selections

STANDARDS AND CALIBRATION TYPES

Select an appropriate standard from the list, connect the standard, and press the key. The message WAIT-MEASURING CAL STANDARD appears while the standard is being measured. Do not press any front panel key while this message is displayed unless it is your intent to stop the measurement process. When the standard has been measured, the standard name will be underlined to indicate measurement is complete.

If the standard label includes an (M), for male, or an (F) for female, the reference is to the test port connector sex. For example, in the Type-N calibration kit, the standard labeled SHORT (F) would be selected when the appropriate short circuit is connected to the Type-N female test port.

The **RESPONSE** measurement calibration sequence requires a single standard: the SHORT or OPEN for reflection, or the THRU for transmission. If more than one standard is measured, the last standard pressed is used to compute the frequency response correction term.

The S_{11} **1-PORT** and S_{22} **1-PORT** measurement calibration sequences require a minimum of three standards, an OPEN, a SHORT, and at least one standard from the LOADS menu. For some calibration kits, the standards on the LOADS menu are specified as to the frequency range covered:

> The LOWBAND selection is specified from the lowest frequency up to 2.001 GHz.
>
> The SLIDING load is specified from 1.999 GHz up to the highest frequency.
>
> The BROADBAND load is specified over the full frequency range.

Thus, for sweeps that cross 2 GHz, calibration using such a kit requires that you use both the LOWBAND and SLIDING loads, or the BROADBAND load.

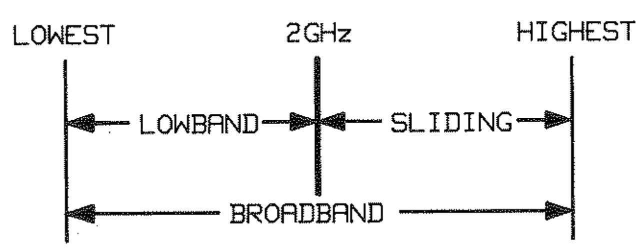


Figure 53. LOADS Frequency Ranges

If the standards thus far measured are not specified over the full frequency range being swept, then pressing **SAVE** causes the message ADDITIONAL STANDARDS NEEDED to appear.

Selecting **FULL 2-PORT** brings the Full 2-Port measurement calibration menu onto the CRT display. Select **REFLECTION**, **TRANSMISSION**, then **ISOLATION** in any sequence to bring these menus (Figure 54) onto the display. Parameter selection is automatic during these sequences.

Select **REFLECTION** then measure at least three standards, just as in the 1-Port sequence. Connect the appropriate S_{11} standards at Port 1 and the appropriate S_{22} standards at Port 2, then press **REFLECT'N DONE**.

For **TRANSMISSION**, connect the thru, then press the four standard selection softkeys to measure transmission frequency response and the terminating impedance.

The standard for the **ISOLATION** calibration step is to disconnect the Thru connection, then install appropriate Z_0 terminations (fixed loads) at Port 1 and Port 2. For best isolation cal, select an averaging factor of at least 128 by pressing RESPONSE MENU, AVERAGING ON, 256 x1, CAL, RESUME CAL SEQUENCE. If a large averaging factor is not used, the error may greater than if the isolation cal were not performed. To skip isolation cal, press OMIT ISOLATION, then ISOLATION DONE.

When all necessary standards on the list have been measured, press the bottom softkey labeled **DONE** or **SAVE**. You may measure the standards in any order. Until you press **DONE** or **SAVE** you may remeasure any standard on the currently displayed list and the last measurement on any particular standard will be used.

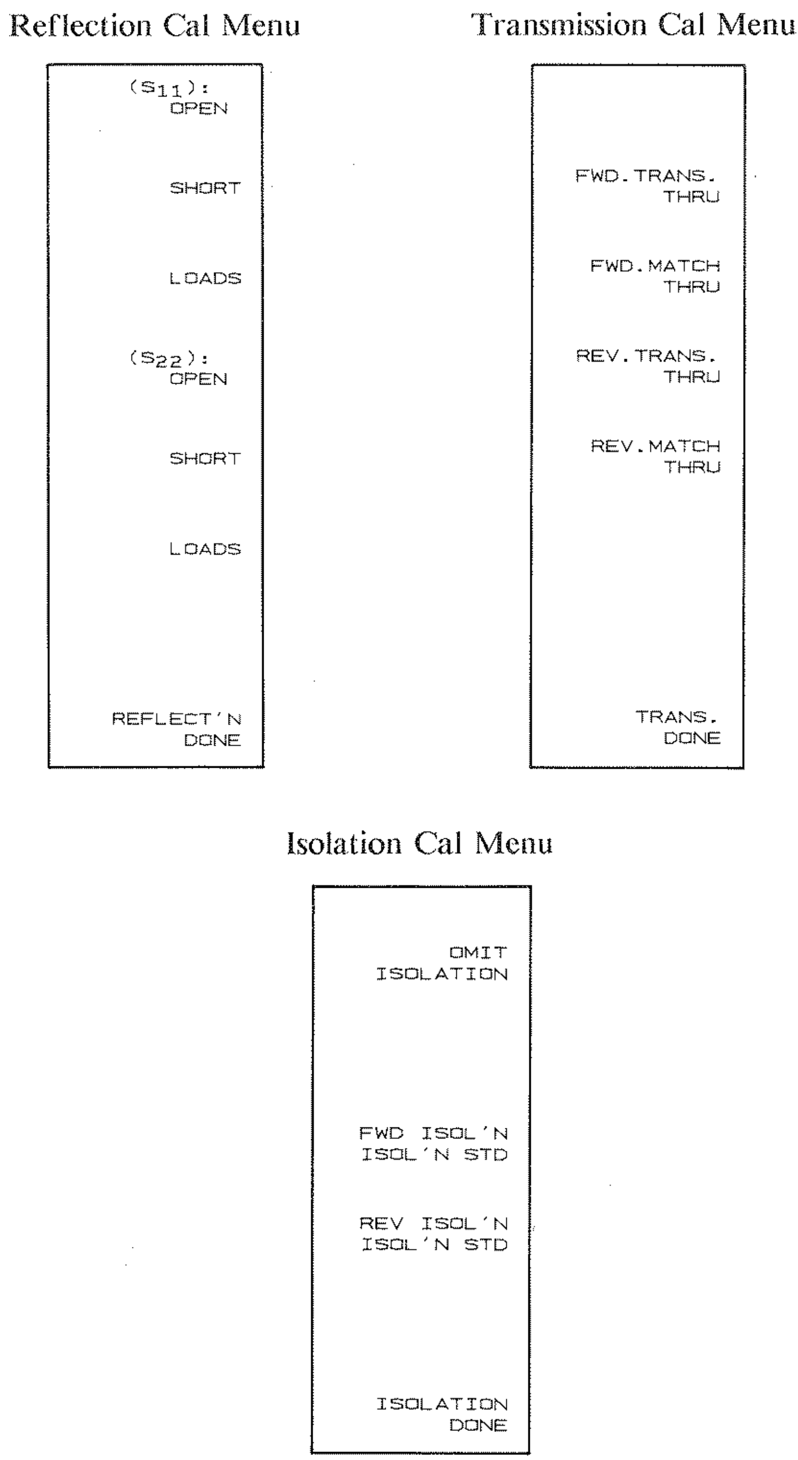


Figure 54. Reflection, Transmission, and Isolation Cal Menus (Full 2-Port Cal)

STORING CALIBRATIONS

At this point the Cal Set Selection menu and the message SELECT CALIBRATION SET are displayed. A * next to the cal set number indicates that calibration error coefficients are already stored in that cal set. If you select a cal set which is already marked by an *, that cal set will be deleted and replaced by the new calibration coefficients.

When you press a key, the error coefficients are stored in the selected cal set, an underline appears under the cal set number to indicate that the cal set is currently selected, then the Cal Menu is displayed with **CORRECTION ON**.

The cal set includes a limited instrument state (Table 11) describing the parameter to which the cal set applies and important stimulus settings in effect when the calibration was saved. If a parameter is selected to which the cal set does not apply, the message **THIS PARAMETER NOT IN COEFFICIENT SET** will appear, indicating that correction cannot be turned on for this parameter using this calibration set. If the Frequency Range or Number of Points is changed, the message **CORRECTION RESET** is displayed and correction is automatically turned off. (If this is done when time domain low pass mode is selected, the message **CORRECTION AND DOMAIN RESET** appears, correction is turned off, and the domain is changed back to the frequency domain.) Other changes that may affect error correction result in the display of the message **CAUTION: CORRECTION MAY BE INVALID.**

Table 11. Cal Set Limited Instrument State

Parameter(s) Corrected turns Correction Off if changed and new parameter is not included; will not turn Correction On if parameter is not included;
Frequency Range Number of Points both turn Correction Off if changed; will not turn Correction On if changed;
Source Power Sweep Time Power Slope Ramp/Step/Single Point Trim Sweep Sweep Mode **CAUTION: CORRECTION MAY BE INVALID** displayed if any of these is changed.

Note that the current ATTENUATOR PORT: 1 .. 2 settings (under STIMULUS **MENU, SOURCE POWER**) are not saved with the cal set. If you change these functions during measurement calibration, or during measurement, error correction is not turned off even though the displayed data may be in error.

With COUPLED CHANNELS selected, when you turn correction on for a parameter on one channel, it is also turned on for that parameter on the other channel. Selecting UNCOUPLED CHANNELS allows you to apply a different cal set to the same parameter on the other channel.

For example, to display real time responses of corrected and uncorrected data:

- Press **DISPLAY, DUAL CHANNEL, OVERLAY**
- Select the same parameter for display on both channels.
- Press **CAL, CORRECTION OFF**
  Correction is turned off for both channels.
- Press STIMULUS **MENU, MORE, UNCOUPLED CHANNELS**
- Press **CHANNEL 1, CAL, CORRECTION ON, CAL SET n**
  Correction is turned ON only for Channel 1.

When UNCOUPLED CHANNELS is selected, correction off/on and cal set must be selected independently for each channel.

MESSAGES DURING MEASUREMENT CALIBRATION SEQUENCE

Various messages appear on the CRT during the measurement calibration sequence.

CONNECT STD THEN PRESS KEY TO MEASURE. Connect the calibration standard to be measured, then press the softkey corresponding to the name of the standard. Pressing a standard selection key causes Measurement Restart. In Ramp sweep, n+1 sweeps are taken where n is the averaging factor. In Step sweep, 1 sweep is taken.

WAIT--MEASURING CAL STANDARD. This message appears after the calibration standard is selected; a beep sounds when the measurement is complete. Pressing any key stops the sequence. In Ramp sweep, n+1 sweeps are taken where n is the averaging factor. In Step sweep, one sweep is taken.

PRESS 'DONE' IF FINISHED WITH STD(s). This message appears when enough standards have been measured to satisfy the error model and to cover the required frequency range. If the calibration for the listed standards is complete, press the bottom 'DONE' key (label may vary depending upon the class of standards used) to proceed to the next step in the calibration sequence.

PRESS 'SAVE' IF FINISHED WITH CAL. This message appears when measurement of the last standard in the calibration sequence has been accomplished. When all the standards required for the calibration type have been measured, press 'SAVE' (the label varies depending upon the calibration type) to compute the error coefficients to be stored.

SELECT CALIBRATION SET. Press a CAL SET 1 though 8 key to select storage of the calibration error coefficients.

ADDITIONAL STANDARDS NEEDED. This message appears if you press 'DONE' or 'SAVE' when all standards required for the calibration have not been measured. Look at the standard selection menu presently displayed. The underlined standards have been measured. You will need to measure one or more of the remaining non-underlined standards to complete the sequence.

This message will also appear if the standards thus far measured are not specified over the full frequency range being swept. For example, the 7mm cal kit includes three loads, the LOWBAND (up to 2 GHz), the BROADBAND (0 to 18 GHz), and the SLIDING (2 to 18 GHz). If the sweep crosses 2 GHz and only the LOWBAND load was measured, then this message would appear.

MORE SLIDES NEEDED. For best accuracy, measure the sliding load at up to eight (or more) randomly spaced positions covering the entire range of the sliding load. If fewer than five slides are used, this message will appear.

NO SPACE FOR NEW CAL; DELETE A CAL SET. Even though all cal sets 1 though 8 are not marked by an asterisk (*), when this message appears it indicates

S-PARAMETER TEST SET (TWO-PATH) CALIBRATION ERROR MODELS

Three calibration error models exist for S-Parameter test sets:

Frequency Response: S_{11}, S_{21}, S_{12}, or S_{22}

1-Port: S_{11} or S_{22}

Full 2-Port

These measurement calibration sequences are described in the next several pages.

FREQUENCY RESPONSE

This calibration error model provides vector error correction for the selected parameter signal path frequency response using a single standard (usually a thru for transmission, a short or an open for reflection). The nominal calibration kit designations are **CAL 1** for 7mm and **CAL 2** for 3.5mm: thus if a 3.5mm calibration kit is used, instead of **CAL 1** and **CAL SET 1** in the following procedures substitute **CAL 2**. Calibration kit designations may be changed by the user, for example to define **CAL 1** as 3.5mm and **CAL 2** as Type-N.

ONE-PORT DEVICE: REFLECTION FREQUENCY RESPONSE CALIBRATION

- Press S_{11}, **CAL, CAL 1, CALIBRATE: RESPONSE.**
- At Port 1, connect either a short or a shielded open circuit.
- When the trace is correct, press **SHORT** or **OPEN.**

  Data is measured.
- Press **DONE: RESPONSE**, then select a **CAL SET 1** through **8.**

  Error coefficients are computed and stored;

  Cal Menu is displayed with **CORRECTION ON.**

  A Corrected trace is displayed.
- Connect the test device, and measure S_{11}.

TWO-PORT DEVICE: TRANSMISSION AND REFLECTION FREQUENCY RESPONSE CALIBRATION

This procedure performs frequency response calibrations for all four S-parameters. If the test set being used has 3.5mm test port connectors, instead of CAL 1 use CAL 2.

- At Port 1, connect either a short circuit or a shielded open circuit.
- Press S_{11}, **CAL**, **CAL 1**, **CALIBRATE: RESPONSE**.
- When the trace is correct, press **SHORT** or **OPEN**. (S_{11} data is measured.)
- Press **DONE: RESPONSE**, then select **CAL SET 1**. (Error coefficients are computed and stored; Cal Menu is displayed with **CORRECTION ON**.)
- Corrected S_{11} data is displayed.

- Connect Port 1 to Port 2 Thru.
- Press S_{21}, **CAL 1**, **CALIBRATE: RESPONSE**.
- When the trace is correct, press **THRU**. (S_{21} thru data is measured.)
- Press **DONE: RESPONSE** then select **CAL SET 2**. (Error coefficients are computed and stored; Cal Menu is displayed with **CORRECTION ON**.)
- Corrected S_{21} data is displayed.

- Press S_{12}, **CAL 1**, **CALIBRATE: RESPONSE**.
- When the trace is correct, press **THRU**. (S_{12} thru data is measured.)
- Press **DONE: RESPONSE**, then select **CAL SET 3**. (Error coefficients are computed and stored; Cal Menu is displayed with **CORRECTION ON**.)
- Corrected S_{12} data is displayed.

- At Port 2, connect either a short circuit or a shielded open circuit.
- Press S_{22}, **CAL 1**, **CALIBRATE: RESPONSE**.
- When the trace is correct, press **OPEN** or **SHORT**. (S_{22} data is measured.)
- Press **DONE: RESPONSE**, then select **CAL SET 4**. (Error coefficients are computed and stored; Cal Menu is displayed with **CORRECTION ON**.)
- Corrected S_{22} data is displayed.

- Connect the test device.
- Measure any parameter.

1-PORT

This calibration error model provides the best accuracy for measurement of a one-port device, providing full vector error correction for directivity, source match, and reflection signal path frequency response. The procedure uses three standards, usually a shielded open circuit, a short circuit, and a load.

During the S_{11} 1-Port calibration, all standards are connected at Port 1 (the point at which the test device input port will be connected). During the S_{22} 1-Port calibration, all standards are connected at Port 2 (the alternate point at which the test device output port will be connected). This model also can be used to measure S_{11} and S_{22} of a two-port device.

To obtain greater accuracy in measurement of a one-port device, perform the S_{11} 1-Port and S_{22} 1-Port calibration sequences described on the next page instead of the S_{11} and S_{22} frequency response calibrations described above.

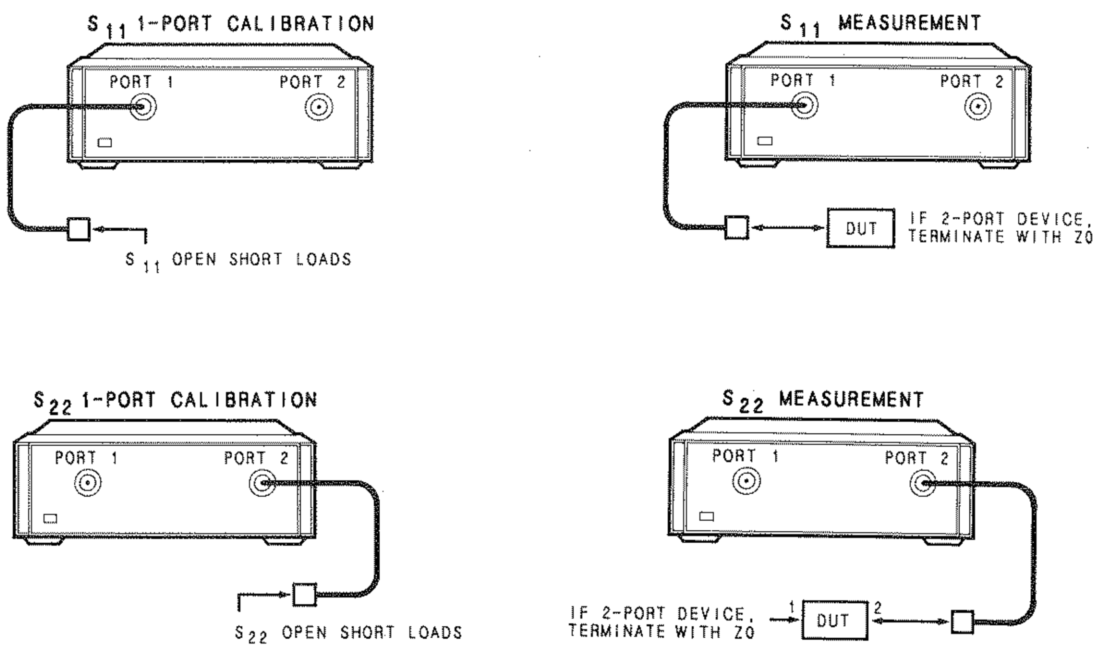


Figure 56. S-Parameter Test Set 1-Port Calibrations

1-PORT CALIBRATION SEQUENCE (7 mm)
S-PARAMETER TEST SETS

- Press S_{11}, CAL, CAL 1, S_{11} 1-PORT.
- At Port 1, connect a shielded open circuit.
- When the trace is correct, press S_{11} OPEN.
  Open circuit data is measured.
- At Port 1, connect a short circuit.
- When the trace is correct, press **SHORT**.
  Short circuit data is measured.
- Press **LOADS** to present the Standard Selection Menu.
  If the frequency sweep crosses 2 GHz, then both the **LOWBAND** and **SLIDING** loads, or the **BROADBAND** load must be used.)
- At Port 1 connect a fixed load.
- When the trace is correct, press **LOWBAND**.
  Load data is measured.
- At Port 1, connect a sliding load.
- Move sliding element to the first index mark; then, when the trace is correct, press **SLIDE IS SET**.
  Load data is measured.
- Repeat 5 to 8 times, each time moving the sliding element to the next index mark, then pressing **SLIDE IS SET** each time.
- Press **SLIDING LOAD DONE**.
  If the message MORE SLIDES NEEDED appears, measure at more slide positions.
- Press **DONE: LOADS**.
  If the message ADDITIONAL STANDARDS NEEDED appears, then the loads were not specified for the current frequency range (for example, only the LOWBAND load was used for a sweep that crossed 2 GHz).
- Press **SAVE 1-PORT CAL**, then select a **CAL SET 1** through **8**.
  (Error coefficients are computed and stored;
  old cal set 1 is replaced with the new error coefficients,
  Cal Menu is displayed with **CORRECTION ON**.)
- Corrected S_{11} trace is displayed.

- Press S_{22}, CAL 1, S_{22} 1-PORT.
- Perform the S_{22} 1-Port calibration procedure,
  use S_{22} **OPEN**, **SHORT**, and **LOADS**,
  connect all standards at Port 2,
  press **SAVE 1-PORT CAL**, then
  store the error coefficients using another
  CAL SET 1 through **8**.

- Connect the test device.
- Measure S_{11} or S_{22}.

FULL 2-PORT

The Full 2-Port measurement calibration procedure can be used only with the S-parameter test sets. This calibration error model provides the best accuracy when measuring two-port devices. Four standards are used, usually a shielded open circuit, a short circuit, a load or loads, and a thru. This model provides full error correction of directivity, source match, reflection and transmission signal path frequency response, load match, and isolation for S_{11}, S_{21}, S_{12}, and S_{22}.

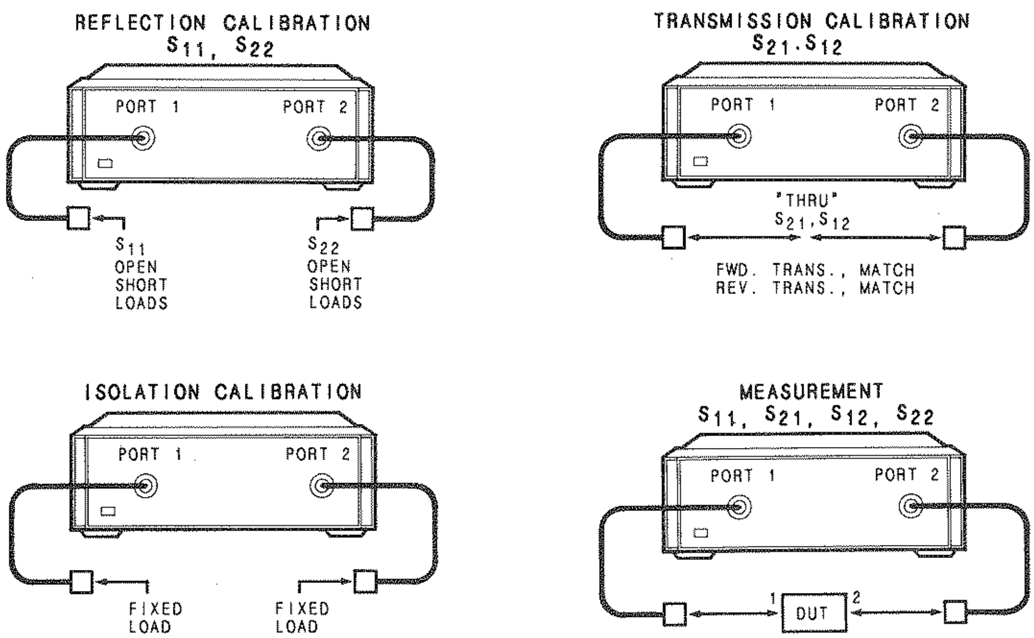


Figure 57. S-Parameter Test Set Full 2-Port Calibration

FULL 2-PORT CALIBRATION SEQUENCE (7 mm)
S-PARAMETER TEST SETS

NOTE - If the test set being used has 3.5mm test port connectors, instead of **CAL 1** use **CAL 2**.

- Press **CAL**, **CAL 1**, **FULL 2-PORT**, **REFLECT'N**.
- Proceed as for the S_{11} 1-PORT calibration sequence, already described; connect standards at Port 1, use S_{11} **OPEN**, **SHORT**, and **LOADS**, do not press **REFLECT'N DONE**.
- Proceed as for the S_{22} 1-PORT calibration sequence, already described; connect standards at Port 2, use S_{22} **OPEN**, **SHORT**, and **LOADS**.
- Press **REFLECT'N DONE**.
  Reflection error coefficients are stored.
- Press **TRANSMISSION**.
- Connect Port 1 to Port 2 Thru.
- When the trace is correct, press **FWD. TRANS. THRU**.
  S_{21} frequency response is measured.
- Press **FWD. MATCH THRU**.
  S_{21} load match is measured.
- Press **REV. TRANS. THRU**.
  S_{12} frequency response is measured.
- Press **REV. MATCH THRU**.
  S_{12} load match is measured.
- Press **TRANS. DONE**.
  Transmission error coefficients are stored.
- Press **ISOLATION**.
- Connect a load at Port 1 and a load at Port 2.
- When the trace is correct, press **FWD. ISOL'N ISOL'N STD**.
  S_{21} noise floor is measured.
- Press **REV. ISOL'N ISOL'N STD**.
  S_{12} noise floor is measured.
- Press **ISOLATION DONE**.
  Forward and reverse isolation error coefficients are stored.
- Press **SAVE 2-PORT CAL**, then select a **CAL SET 1** through **8** to save the error coefficients.
  Error coefficients are computed and stored; Cal Menu is displayed with **CORRECTION ON**.
- Corrected trace is displayed.

- Connect test device.
- Press any PARAMETER key, S_{11}, S_{21}, S_{12}, or S_{22}, to display corrected data for that parameter.

REFLECTION/TRANSMISSION TEST SET (ONE-PATH) CALIBRATION ERROR MODELS

You may choose S_{11} Frequency Response, S_{21} Frequency Response, S_{11} 1-Port, or One-Path 2-Port calibration error models. Reverse calibration may also be performed (S_{12} and S_{22} frequency response and S_{22} 1-Port), but in this case,the standards (open, short, and load) are still conncted to port 1 and during measurement you must use care to physically reverse the test device and select the appropriate parameter (S_{11} or S_{22}).

FREQUENCY RESPONSE. This model provides vector error correction for selected parameter signal path frequency response using a single standard (usually a thru for transmission; a short circit or a shielded open circuit for reflection). The S_{11} and S_{21} frequency response calibrations are performed using the same basic procedures as described previously for the S-parameter test set.

S_{11} 1-PORT. This model provides the best accuracy for measurement of a one-port device, providing full vector error correction for directivity, source match, and reflection signal path frequency response. The procedure uses three standards, usually a shielded open circuit, a short circuit, and load, in the same sequence as described for the 1-Port calibration on the S-parameter test set described previously. If the S_{22} 1-PORT procedure is used with the reflection/ transmission test set, the test device must be manually reversed.

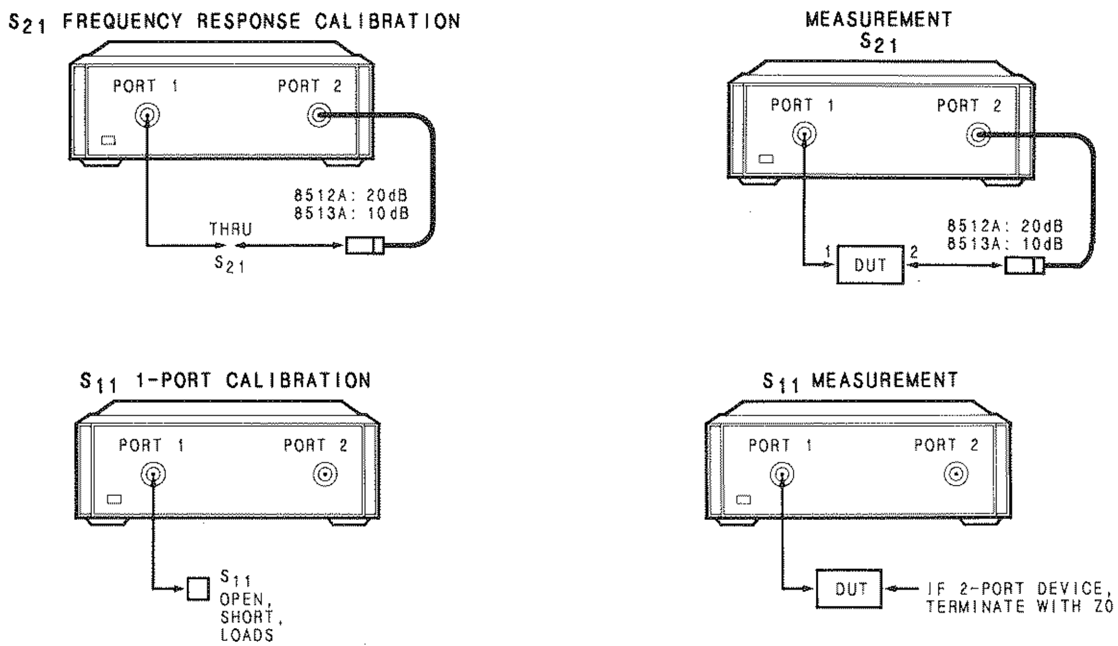


Figure 58. Reflection/Transmission Test Set Frequency Response and 1-Port Calibrations

TWO-PORT DEVICE: TRANSMISSION AND REFLECTION FREQUENCY RESPONSE CALIBRATION

This procedure presents a calibration sequence for measurement of a two-port device using a combination of S_{21} and S_{12} frequency response and S_{11} and S_{22} 1-Port error models. Since the reflection/transmission test set cannot produce real-time error corrected measurements using the One-Path 2-Port error model (the device under test must be manually reversed), this sequence is usually the quickest way to measure a two-port device on a reflection/transmission test set where source and load match effects are not an important factor in the accuracy of the measurement.

NOTE - If the test set being used has 3.5mm test port connectors, instead of **CAL 1** use **CAL 2**.

- Press **S_{11}**, **CAL**, **CAL 1**, **S_{11} 1-PORT**.
- Perform the **S_{11} 1-PORT** calibration sequence, already described; use **S_{11} OPEN**, **SHORT**, and **LOADS**, connect standards at Port 1.
- Press **SAVE 1-PORT CAL**, then select **CAL SET 1**.
- Corrected S_{11} data is displayed.

- Connect Port 1 to Port 2 Thru.
- Press **S_{21}**, **CAL 1**, **FREQUENCY RESPONSE**.
- When the trace is correct, press **THRU**.
  S_{21} thru data is measured.
- Press **DONE: RESPONSE**, then select **CAL SET 2**.
- Corrected S_{21} data is displayed.

- Press **S_{12}**, **CAL 1**, **FREQUENCY RESPONSE**.
- When the trace is correct, press **THRU**.
  S_{12} thru data is measured.
- Press **DONE: RESPONSE**, then select **CAL SET 3**.
- Corrected S_{12} data is displayed.

- Press **S_{22}**, **CAL 1**, **S_{22} 1-PORT**.
- Perform the S_{22} 1-PORT calibration sequence, already desribed; use **S_{22} OPEN**, **SHORT**, and **LOADS**, connect standards at Port 1.
- Press **SAVE 1-PORT CAL**, then select **CAL SET 4**.
- Corrected S_{22} data is displayed.

- Connect the test device for forward measurement.
- Measure S_{11} and S_{21}.
- Reverse the device and adapters.
- Measure S_{22} and S_{12}.

ONE-PATH 2-PORT

The One-Path 2-Port calibration error model is designed specially for the reflection/transmission test set. It provides vector error correction of directivity, source match, reflection and transmission signal path frequency response, load match, and isolation errors for S_{11}, S_{21}, S_{12}, and S_{22}. This procedure is similar to the Full 2-Port calibration procedure described previously for S-parameer test sets, except that all calibration takes place with respect to Port 1, and the device under test(and possibly the adapters if used) must be manually reversed in the process of measuring any S-parameter.

This manual reversal makes it impossible to obtain fully error-corrected data in real time. Instead, pressing the softkey labeled **PRESS TO CONTINUE** controls a measurement process that includes operator prompts to connect the test device for forward and reverse measurements, finishing with the corrected data for the selected parameter displayed and ready for data output. Pressing another parameter key either displays the corrected data for the new parameter choice immediately, or restarts the measurement process.

When load and source match effects are not major error contributors in the measurement, or when you wish to view the real time response of the device under test and are not concerned with absolute measurement accuracy, use a combination of S_{11} 1-Port and S_{22} 1-Port reflection calibrations with S_{21} and S_{12} frequency response transmission calibrations, instead of this One-Path 2-Port sequence.

Averaging may be used during measurement calibration, but in the ramp mode due to the fact that the One-Path 2-Port model takes only one sweep for each S-parameter, averaging cannot be used with correct results during measurement, unless the test device is repeatedly reversed.

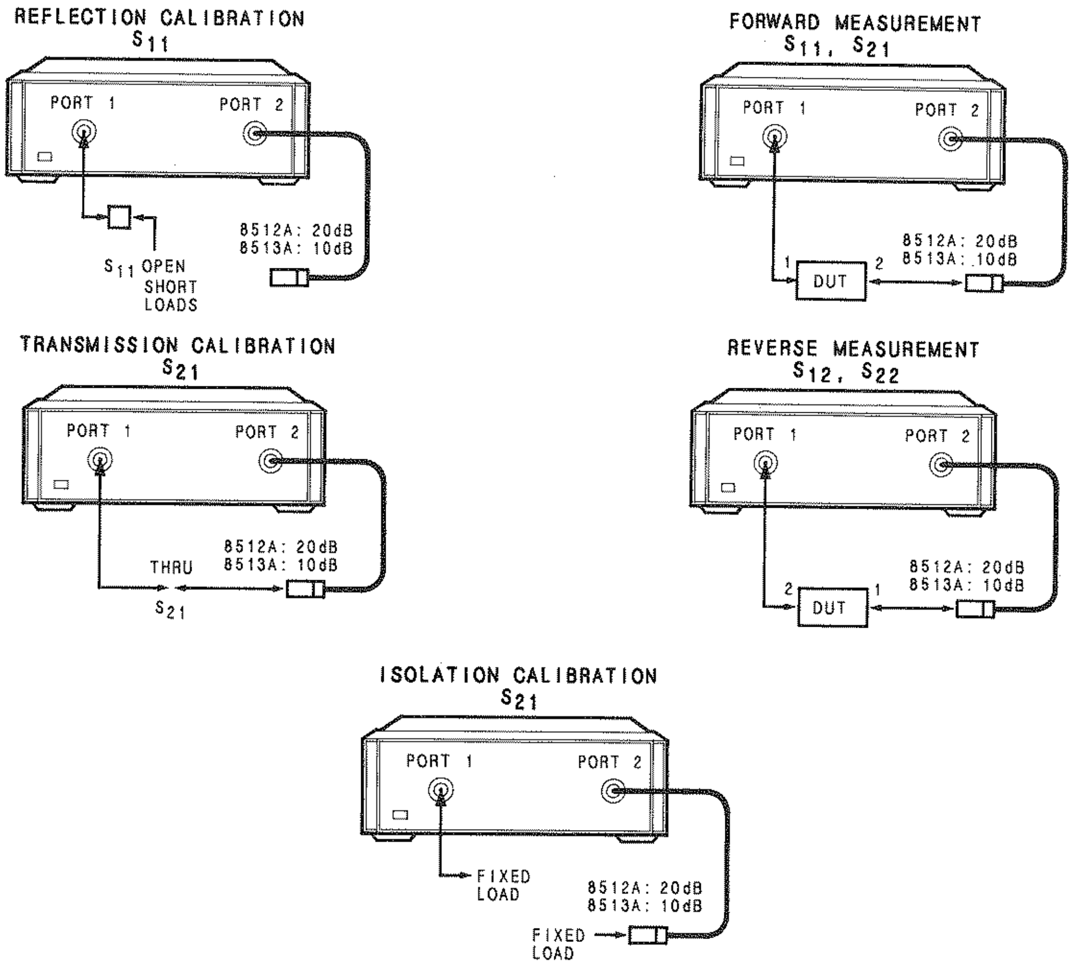


Figure 59. Reflection/Transmission Test Set One-Path 2-Port Calibration

ONE-PATH 2-PORT CALIBRATION SEQUENCE (7 mm)
REFLECTION/TRANSMISSION TEST SET

NOTE - If the test set being used has 3.5mm test port connectors, instead of **CAL 1** use **CAL 2**.

- Press **CAL, CAL 1, ONE-PATH 2-PORT.**
- Press **REFLECT'N**, then proceed as for the S_{11} 1-PORT calibration sequence, already described; use S_{11} **OPEN, SHORT**, and **LOADS**, connect standards at Port 1.
- Press **REFLECT'N DONE.**
  Reflection error coefficients are stored.
- Press **TRANSMISSION.**
- Connect Port 1 to Port 2 using a Thru.
- When the trace is correct, press **FWD. TRANS. THRU.**
  S_{21} frequency response is measured.
- Press **FWD. MATCH THRU.**
  S_{21} load match is measured.
- Press **TRANS. DONE.**
  Transmission error coefficients are stored.
- Press **ISOLATION.**
- Connect a load at Port 1 and a load at Port 2.
- When the trace is correct, press **FWD. ISOL'N ISOL'N STD".**
  S_{21} noise floor is measured.
- Press **ISOLATION DONE.**
  Forward isolation error coefficients are stored.
- Press **SAVE 2-PORT CAL**, then select a **CAL SET 1** through **8.**
  Error coefficients are computed and stored; Cal Menu is displayed with **CORRECTION ON.**)

- Connect test device.

- Select parameter for display by pressing S_{11}, S_{21}, S_{12}, or S_{22}.
- Follow instructions to connect the test device for forward measurement, then **PRESS TO CONTINUE.**
- Follow instructions to connect the test device for reverse measurement, then **PRESS TO CONTINUE.**
- Observe the corrected trace.
- To measure another parameter, press the key for the desired PARAMETER.
- To measure the next test device, connect the test device, then **PRESS TO CONTINUE.**

STORING CALIBRATION DATA

Internal Storage. Error terms are computed and stored in the internal calibration set storage area you specify at the end of the measurement calibration sequence. Up to eight calibration sets can be stored, depending upon the type of calibration performed and the number of points selected for the sweep. That is, if you perform two 401 point Full 2-Port calibrations and store the results in Cal Sets 1 and 2, the internal storage will be full even though cal set numbers 3 through 8 are not designated with the * symbol.

If internal storage is already full, a cal set must be deleted using **DELETE CAL SET** before calibration can proceed. Selecting a cal set to receive error coefficient data automatically replaces the old data with the new data.

Table 12. Calibration Error Coefficient Storage

Cal Type	Number of Points			
	51	**101**	**201**	**401**
Frequency Response	8	8	8	8
1-Port	8	8	8	8
2-Port	8	8	4	2

Tape Storage. Cal data can be stored on tape, recalled, checked for validity, then used if acceptable results are obtained. To store a cal set on tape:

- TAPE, STORE,
  CAL SET 1-8,
  CAL SET n,
  CAL SET FILE n.

To transfer the cal set from tape to internal memory:

- TAPE, LOAD,
  CAL SET 1-8,
  CAL SET n,
  CAL SET FILE n.

Since up to eight tape files of all the cal sets, and up to eight files of a single cal set can be stored on tape, it is convenient to save a cal set and use it at another time rather than recalibrate the system. If an appropriate instrument state is also saved, or the system can be restored to the state during calibration, then the cal set may be used. However, if the test setup has changed, the cal set may no longer apply.

CALIBRATION STANDARDS

For best accuracy and repeatability, use great care in handling and storing the calibration devices. Their performance and accuracy depends on very precise mechanical tolerances, sometimes on the order of a few ten thousandths of an inch. Therefore, the standards must be handled and stored more carefully than ordinary devices. Inspect and clean the connectors as required using the methods recommended in the calibration kit manuals. Use gages on the test port connectors, standards, cables, and the test device to verify that the mating plane dimensions of all connectors are within the allowable tolerances. Always use an appropriate torque wrench when tightening or loosening connections. Detailed information on calibration standards, and on recommended techniques of using them and for making connections, appears in the HP 85050A 7mm and HP 85052A 3.5mm calibration kit manuals.

In simple terms, accuracy enhancement is accomplished by measuring the known standards, comparing the measured response with the predicted response, then computing error terms that are derived from the magnitude and phase difference between the measured response and the predicted response. The predicted response is determined by using a complex mathematical model which predicts its magnitude and phase response of the calibration standard over its entire frequency range. Thus, the accuracy improvement which can be expected is directly related to how well the models predict the response of the standard. The model for each standard is specified in a data file on the tape supplied with the calibration kits.

Examples of "perfect" standards are shown in the assumptions made for the fixed and sliding loads used in reflection calibration. The characteristic impedance, Z_0, is assumed to be exactly 50 ohms.

The standards under the **LOADS** key on the standards selection menu are also specified as to frequency range. For example, if the loads specification is that the sliding load is usable down to 2 GHz, for sweeps that cross this frequency it is necessary to use both the LOWBAND and SLIDING loads, or the BROADBAND load.

The quality of the load used for calibration determines the effective directivity for reflection measurements. A high quality fixed load exhibits the lowest repeatable return loss under 2 GHz. The quality of the sliding load is determined by the return loss of the connector and the transmission line between the connector and the sliding element.

Standard models differ according to connector type. For example, the short circuit in the HP 85050A 7mm calibration kit is modeled as a perfect zero ohm termination, having a reflection coefficient of $1\angle\pm180°$ positioned at the reference plane. The short circuit in the HP 85052A 3.5mm calibration kit is modeled as a perfect short displaced 16.684 ps (mechanically, 0.5 cm) from the reference plane.

Specifications for the shielded open circuits add a reactive phase shift to the modeled response characteristic. In order to model the typical non-linear phase shift, the shielded open circuit is assumed to exhibit a phase shift with frequency that can be approximated using the equation

$$C_{total} = C_0 + C_1{*}F + C_2{*}F^2 + C_3{*}F^3$$

where C_0 is the dc capacitance, $C_1{*}F$ is the capacitance times frequency, $C_2{*}F^2$ is the capacitance times frequency squared, and $C_3{*}F^3$ is the capacitance times frequency cubed. The shielded open circuits in the HP 85052A calibration kit use a center pin extender, so the models for these devices also include a linear phase shift component to account for the offset from the reference plane.

The specifications contained on the calibration kit data cartridge are nominal values based on typical expected responses of the standards. If you wish to substitute your own standards, or change the models for the standards supplied in the calibration kit, you may use the **MODIFY CAL KIT** sequence discussed later in this section of the manual.

Common calibration problems which can be traced to standards are:

- Non-repeatable contact due to wear, dirt, grease, or other contaminants on the contacting surfaces or other accessible parts of the standard. Assure that the standard is properly cleaned and dried.
- Connector damage due to connecting the standard to a connector with mechanical defects or out-of-spec tolerances. Use the connector gage on both the test port and the standard prior to measurement calibration.
- Poor contact due to improper alignment or torquing practice. Use the counter-rotation technique and the proper torque wrench for each connection.
- Using cal standards whose response does not match the constants used in the HP 8510 internal cal kit definitions. Refer to the calibration kit manuals for electrical and mechanical specifications.

EVALUATING CALIBRATION DATA

Immediately following calibration, and at intervals during the measurement process, it is recommended that you measure a standard device with known responses. This is to verify that the system characteristics have not changed thus making the current calibration error coefficients invalid. Measuring a device from the calibration kit used for measurement calibration will allow you to determine that the system is making repeatable measurements. The measured response of a calibration standard will be exactly the modeled response if the connection is repeatable.

To determine measurement accuracy, however, it is necessary to measure an independent standard with known responses, such as the coaxial attenuators or air lines in the HP 8510 verification kit, or a standard you produce that is representative of the devices you are testing. If standards-quality data for the device is available, it can be compared with your measurement results to determine accuracy. If the data is outside acceptable limits and good technique was used during the calibration, then the system characteristics have changed, thus making the current calibration error coefficients invalid.

In any measurement calibration or measurement procedure it is important that the connections be properly tightened. The correct torque wrench settings for various connector types are listed below.

7 mm	12 lb-in	136 N-cm
Type-N	12 lb-in	136 N-cm
3.5 mm	8 lb-in	90 N-cm
SMA to 3.5 mm	5 lb-in	60 N-cm

For details of connection procedures, refer to the calibration kit manuals. Standards class information is supplied with the verification devices.

MODIFY CAL KIT

Begin the process by making certain you have a copy of the cal kit definition you are about to modify. Standard cal kit definitions are on the tape supplied with the calibration kit, and listed in the calibration kit manual. You may copy either the cal kit presently using the **TAPE**, **RECORD**, **CAL KIT 1-2** sequence.

Now fill out a copy of the tables found in the cal kit manuals. Use them as worksheets to specify the characteristics and a label for each standard, to assign each standard to a class, and to spcify a label for the class. Refer to the performance specifications tables in the manuals for the HP 85050A (7mm) and HP 85052A (3.5mm) calibration kits for guidance.

To modify a cal kit, first press **CAL**, **MORE**, then either **MODIFY 1** <cal kit 1 label> or **MODIFY 2** <cal kit 2 label>.

Press **SELECT STANDARD**, then select the device to be modified by entering a Standard Number between 1 and 21 by pressing numeric keys, then **x1**. Assign this standard a type designation by pressing the appropriate *Standard Type Menu* key, then enter the appropriate characteristics using the *Standard Definition Menu* and the *Specify Offset Menu*.

Label the standard using eight or less characters or numbers using **LABEL STD**. This label will appear on the *Standard Selection Menu* during the calibration procedure. When all characteristics of the standard are specified, press **STANDARD DONE (DEFINED)** to return to the *Modify Cal Kit Menu*.

Repeat this sequence for each new or modified standard in the modified cal kit. Standard definitions not changed during this process are included in the modified cal kit with their pre-existing values.

Press **SPECIFY CLASS**. Use the *Specify Class Menu* to assign appropriate standards to each of the classes required for the calibration. Select a class then enter one, or a sequence of, Standard Number followed by **x1** for each standard to be used in the class, then press **CLASS DONE (SPEC'D)**.

Now press **LABEL CLASS** and name each appropriate standard class using 10 or less characters. This label will appear on the *Frequency Response*, *1-Port*, *2-Port Reflection*, *2-Port Transmission*, and *Isolation Calibration Menus*.

Repeat this sequence for each of the standard classes required for the calibration procedure.

Next press **LABEL KIT** and name the modified cal kit using 10 or less characters. This name will appear on the *Cal Menu*. Finally, press **KIT DONE (MODIFIED)** to store the new cal kit in place of the selected kit.

ADJUSTING TRIM SWEEP

The **TRIM SWEEP** function performs a different purpose for HP 834x and HP 835x sources. For HP 8340 sources used in the Ramp Sweep mode, it is used to adjust the end frequency at the band switch points to minimize the frequency difference between the end frequency of one band and the start frequency of the next higher band. **TRIM SWEEP** is not used in the Step Sweep mode.

For HP 835x sources, **TRIM SWEEP** is adjusted to provide the best frequency accuracy. The **TRIM SWEEP** setting is saved as part of the instrument state when you press **SAVE, INSTRUMENT STATE n**, and as part of the limited instrument state saved when you save a cal set. It is set to zero by **PRESET**.

With either HP 834x or HP 835x sources, the **TRIM SWEEP** adjustment is not identical for all frequency ranges. It will have a slightly different value for different sweep widths. As you narrow the sweep, internal HP 8510 logic changes the band switch points in order to, when possible, eliminate band switch points from the frequency range being swept. For best measurement accuracy, perform this sweep trim adjustment for each different frequency range immediately prior to measurement calibration.

HP 834x Sources

If you are using the **RAMP** sweep mode, set **TRIM SWEEP** to provide minimum frequency difference between the **STEP** and **RAMP** modes as follows:

a. Press **PRESET**. Select S_{21} for display.

b. Connect measurement Port 1 to measurement Port 2 (thru connection).

c. Set the **START/STOP** or **CENTER/SPAN** controls to sweep the frequency range of interest.

d. Select STIMULUS **MENU**, **STEP**. When the sweep is complete, press **DISPLAY DATA → MEMORY, MATH (1)**. When the next sweep is complete, the trace should be a flat line at zero degrees.

e. Press **STIMULUS** MENU, **RAMP**. The displayed trace may exhibit a sharp phase transition at the band switch points. Sharp transitions indicate the need to adjust **TRIM SWEEP**.

f. Press **CAL, MORE, TRIM SWEEP**. Then use the knob to adjust the phase trace for minimum phase change at the band switch points. When the best (flattest) phase trace is achieved, press **SAVE, INSTRUMENT STATE n** to save this setting. Now proceed with the appropriate measurement calibration.

HP 835x Sources

Set **TRIM SWEEP** to provide best frequency accuracy as follows:

a. Press **PRESET**. Select S_{21}, **PHASE** for display.

b. Connect measurement Port 1 to measurement Port 2 (thru connection).

c. Set the **START/STOP** or **CENTER/SPAN** controls to sweep the frequency range of interest.

d. Press **DISPLAY**, **DATA → MEMORY**, **MATH (/)**. The trace should be a flat line at zero degrees.

e. Connect an electrical delay of known length between measurement Port 1 and measurement Port 2. The device should have a low loss and exhibit a precisely known electrical delay, as do the airlines in the 3.5mm and 7mm verification kits.

f. Enter the electrical delay of the airline by pressing **RESPONSE MENU**, **ELECTRICAL DELAY**, and then entering the specified electrical delay of the device. The phase transitions should disappear, leaving a phase trace with some slope. Any residual slope indicates a need to adjust **TRIM SWEEP**.

g. Press **CAL**, **MORE**, **TRIM SWEEP**. Then use the knob to adjust the phase trace for minimum phase change at the band switch points. When the best (flattest) phase trace is achieved, press **SAVE**, **INSTRUMENT STATE n** to save this setting. Now proceed with the appropriate measurement calibration.

TRANSMISSION MEASUREMENTS

ILLUSTRATIONS

INTRODUCTION

This part of the HP 8510 network analyzer system manual explains how to make transmission measurements on a typical two-port device: insertion loss and gain, insertion phase, S-parameters, group delay, electrical delay, and deviation from linear phase. These measurements are described individually, each with separate setup, measurement calibration, and measurement sequences. A brief theoretical review of group delay principles is also included.

TRANSMISSION MEASUREMENTS

When planning a test sequence for a two-port device, there are two important factors to consider: the type of two-port device you are going to measure and the type of test set you are using to measure the device.

DEVICE TYPES

Electrical characteristics notwithstanding, there are basically three types of two-port devices (Figure 60): insertable, reversible, and transitional.

For Insertable devices, port 1 connector type will mate with the port 2 connector type (port 2 is of the same family but is of opposite sex to that of port 1). Reversible devices use the same connector type on both port 1 and port 2 (port 2 is the same family and same sex as port 1). Transitional devices use connectors from different families on port 1 and port 2. Only hermaphroditic (sexless) connectors, like the standard 7 mm, are both insertable and reversible.

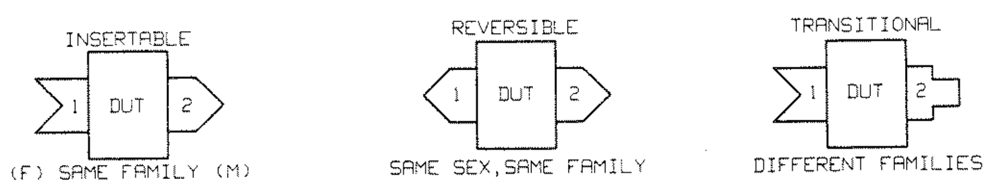


Figure 60. Two-Port Device Types

TEST SETS

There are basically two types of test sets. The S-parameter tests sets are called two-path test sets because the stimulus can be switched to either port 1 or port 2, thus allowing both forward and reverse characteristics of the test device to be measured without manually reversing the test device. The reflection/transmission test sets are called one-path test sets because the stimulus can only be applied to port 1 and the test device must be physically reversed to measure its reverse parameters.

Each combination of device type and test set type calls for a slightly different measurement calibration and measurement sequence. For example, measurement of an insertable device using a two-path test set is the ideal case. Because the test device has connector types which can be mated on its port 1 and port 2, measurement calibration can be performed with the correct adapters in place, and since the test set can switch the stimulus between port 1 and port 2, all parameters can be measured without manually reversing the test device.

TRANSMISSION TEST SETUPS

Figure 61 shows typical transmission test setups for reflection/transmission test sets and S-parameter test sets.

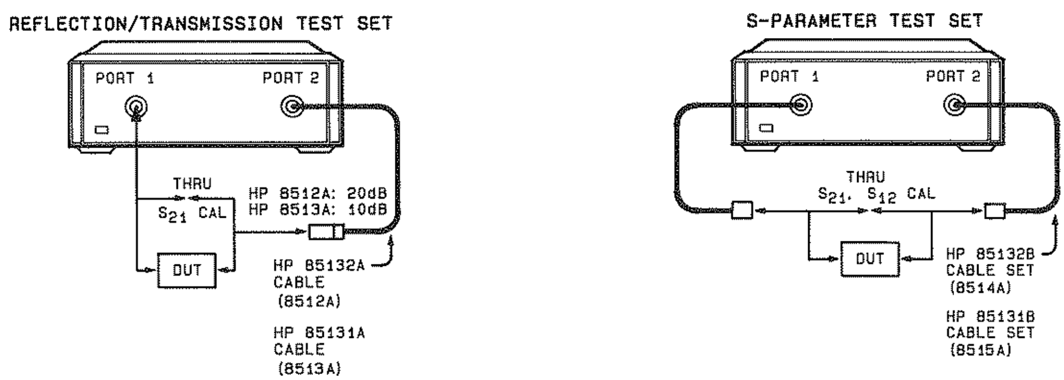


Figure 61. Transmission Test Setups

TRANSMISSION MEASUREMENT CALIBRATION CHOICES

Frequency Response Only Calibrations. The RESPONSE calibration model uses a thru (connect Port 1 and Port 2 together at the point at which the test device will be connected) as the standard device. The RESPONSE model can be used for S_{21} forward transmission calibration and for S_{12} reverse transmission calibration. It can also be used for calibration with all user parameters.

Full 2-Port Calibration. This model provides fully corrected transmission and reflection measurements with an S-parameter test set. It uses a thru, a shielded open circuit, a short circuit, and loads to calibrate at Port 1 and Port 2.

One-Path 2-Port Calibration. This model provides fully corrected transmission and reflection measurements (although not in real time) for a reflection/ transmission test set. It uses a thru, a shielded open circuit, a short circuit, and loads to calibrate at Port 1. The operator follows instructions displayed on the CRT to manually reverse the test device for measurement of the reverse parameters.

INSERTION LOSS/GAIN MEASUREMENT

This sequence lists the steps for a typical insertion loss or gain measurement.

- Perform appropriate S_{21} or S_{12} measurement calibration.
- Select **LOG MAG**.
- Press **MARKER**, and read insertion loss (dB).

Measurement calibration sets the magnitude and phase ratio between the reference and test signal paths to zero with a thru connection. After connecting the test device, a negative measured value indicates insertion loss; a positive measured value indicates gain. Take care to choose signal levels to achieve maximum dynamic range.

Figure 62 shows a display of the magnitude response of a bandpass filter using the **LOG MAG** format. The measurement marker is positioned to the minimum insertion loss point using the sequence **MARKER**, **MORE**, **MARKER TO MAXIMUM**.

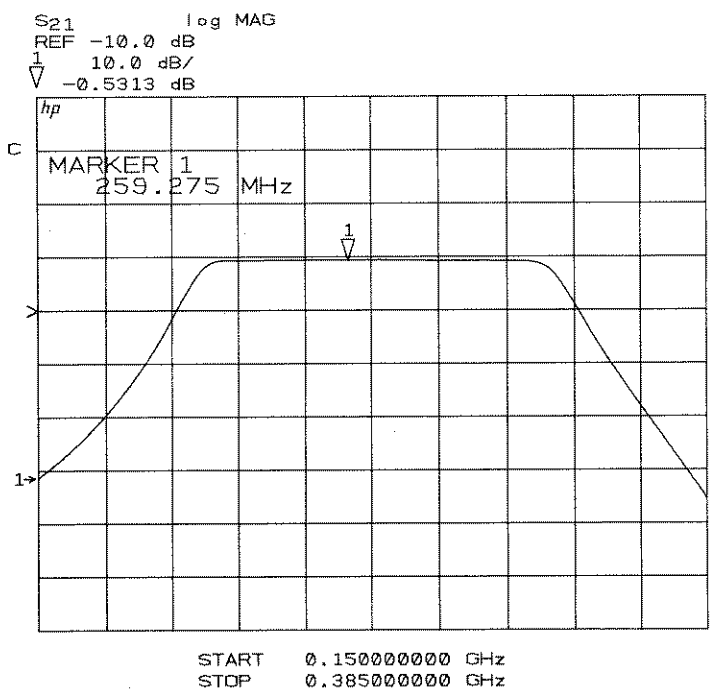


Figure 62. Typical Insertion Loss Display

3 dB FREQUENCIES. The insertion loss and gain measurement procedure can be extended to measure the 3 dB insertion loss points of the filter.

- Press **MARKER, MARKER 1, MORE, MARKER TO MAXIMUM.**
- Press **PRIOR MENU, Δ MODE MENU, Δ REF = 1, MARKER 2.**
- Use the knob to position Marker 2 to read upper frequency -3 dB point.
- Press **MARKER 3.**
- Use the knob to position marker 3 to read lower frequency -3 dB point.

Markers 2 and 3 are now set to the 3 dB points of the filter. To read the entire 3 dB bandwidth frequency span:

- Press **Δ MODE MENU, Δ REF = 3, MARKER 2.**

The frequency span between the 3 dB points will be shown in the Active Entry area.

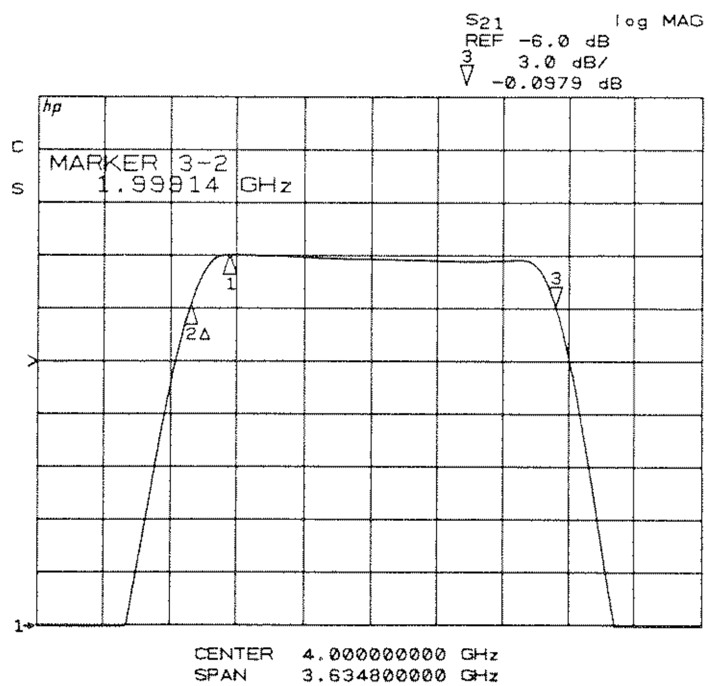


Figure 63. Measuring 3 dB Points

MAXIMUM AND MINIMUM VALUES. Measure the maximum and minimum values of the response using this sequence.

First, find the appropriate start/stop or center/span frequencies over which the maximum and minimum values are to be measured. Then perform appropriate measurement calibration over this frequency range.

- Press **MARKER, MARKER 1, MORE, MARKER TO MINIMUM.**
- Press **PRIOR MENU.**
- Press **MARKER 2, Δ MODE MENU, Δ REF = 1, MORE, MARKER TO MAXIMUM.**

Marker 2 is active, and the Active Entry shows the difference between Marker 1 (at the trace minimum) and Marker 2 (at the trace maximum).

In the example shown below (Figure 64), the test frequencies are chosen so that passband flatness can be measured. Marker 1 is set to the minimum value and marker 2 is set to the maximum value. The sequence provides direct readout of the peak-to-peak difference in the trace.

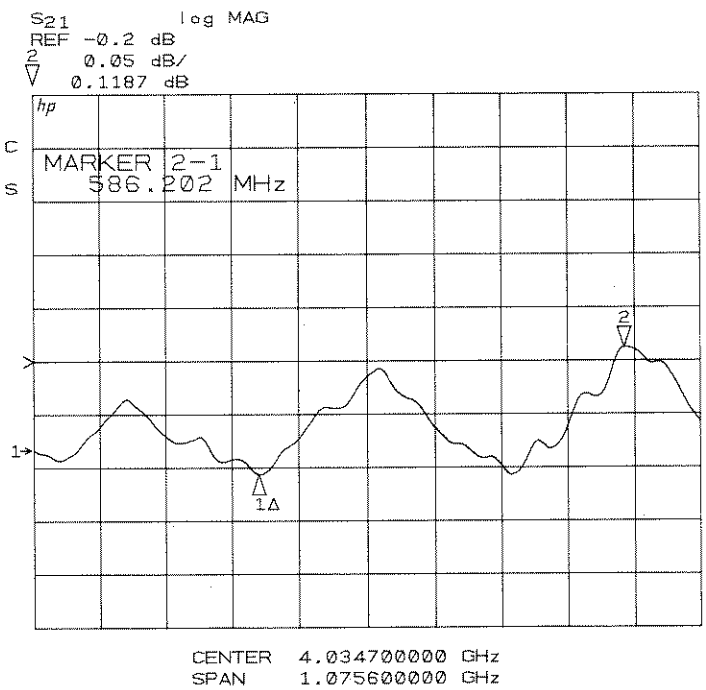


Figure 64. Measuring Minimum and Maximum Insertion Loss

INSERTION PHASE MEASUREMENT

This sequence lists the steps for a typical insertion phase measurement.

- Perform appropriate S_{21} or S_{12} measurement calibration.
- Select **PHASE**.
- Press **MARKER**, and read insertion phase (degrees).

Figure 65 shows a bandpass filter insertion phase display using the **PHASE** format. The measurement range is +180 degrees to -180 degrees, and the vertical line represents the transition between these two values. Thus, the trace between any two of these transitions represents 360 degrees of phase shift.

To illustrate the display format, determine the total phase shift for the selected sweep width as follows: Position the marker as far to the left as possible and note the phase reading. Determine the number of degrees before the first transition. Next, count the second and following transition traces and multiply by 360. Now determine the number of degrees from the last transition trace to the right edge of the screen. The sum of these numbers is the total phase shift over the frequency sweep.

For example, in Figure 65:

$$\text{TOTAL PHASE SHIFT} = 49.313^{o} + 3(360^{o}) + 40^{o} = 1169.3^{o}$$

When the transmitted signal is below the noise floor for insertion phase measurements, the CRT trace usually becomes random.

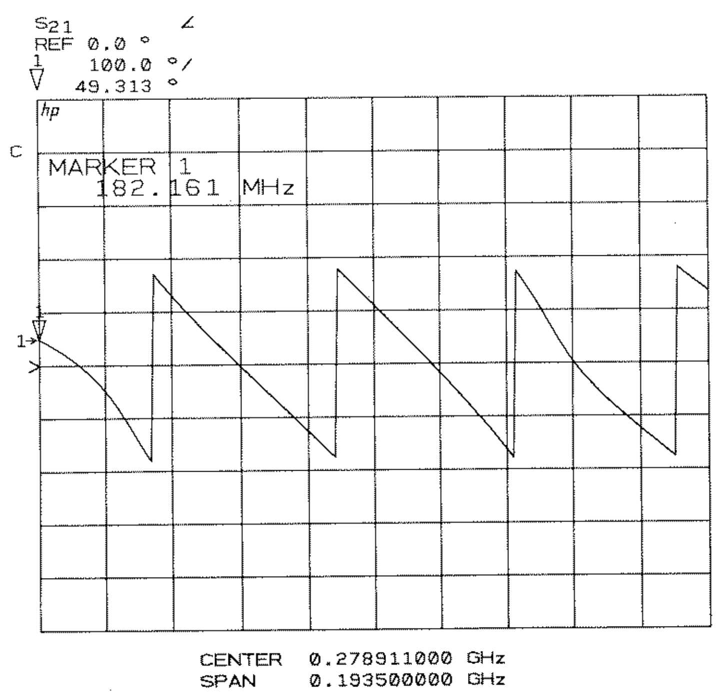


Figure 65. Typical Insertion Phase Display

S-PARAMETERS

The procedure for measurement of transmission S-parameters is identical to measurement of insertion loss and insertion phase described earlier except that the response is viewed using the **LIN mkr on POLAR** display on the **FORMAT** menu.

The magnitude is given in linear terms (τ) and an angle $\angle\theta$, in degrees. A magnitude value greater than one indicates gain; less than one indicates loss. The conversion from dB to linear units is given by the equation

$$dB = 20 (\log \tau).$$

Note that the **LOG mkr on POLAR** format presents the same data with magnitude given in dB.

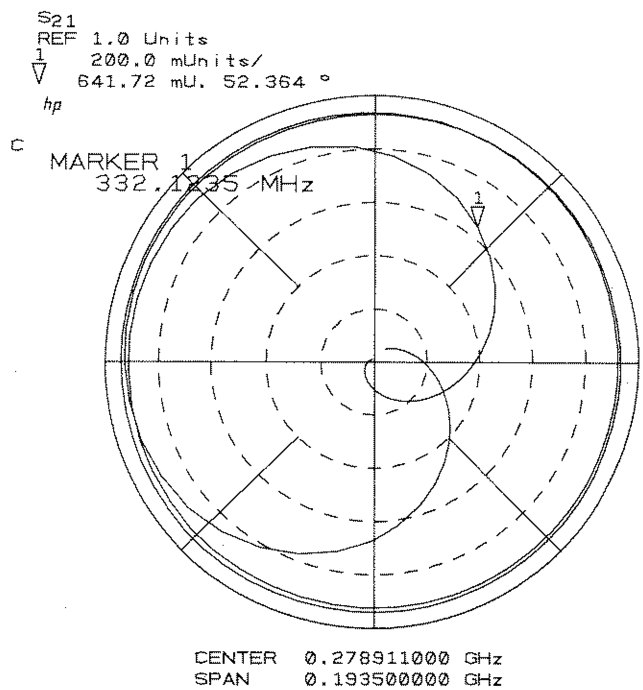


Figure 66. Typical S-Parameter Display

GROUP DELAY MEASUREMENT

This sequence lists the steps for a typical group delay measurement.

- Perform appropriate S_{21} or S_{12} measurement calibration.
- Select **DELAY**.
- Press **MARKER**, and read group delay (seconds).

Measurement calibration sets the group delay to zero seconds with a zero-length thru connection. After connecting the test device, a positive measured value indicates transit time through the test device.

- Press **RESPONSE MENU, SMOOTHING ON.**

With smoothing selected, the displayed smoothing aperture represents the percent of span (and the actual frequency range) over which the point-to-point group delay values are averaged. Discontinuities in the group delay trace may appear if there are more than 180 degrees of phase shift that occur from one frequency point to the next. With smoothing off, the minimum aperture for a given sweep width depends on the number of points selected.

$$\text{Measurement Aperture} = \frac{(\text{stop frequency - start frequency})}{(\text{number of points - 1})}$$

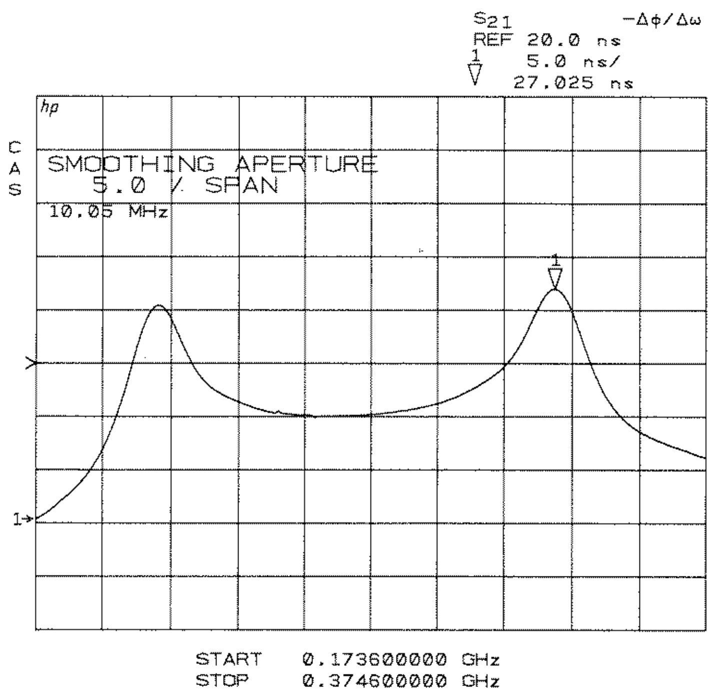
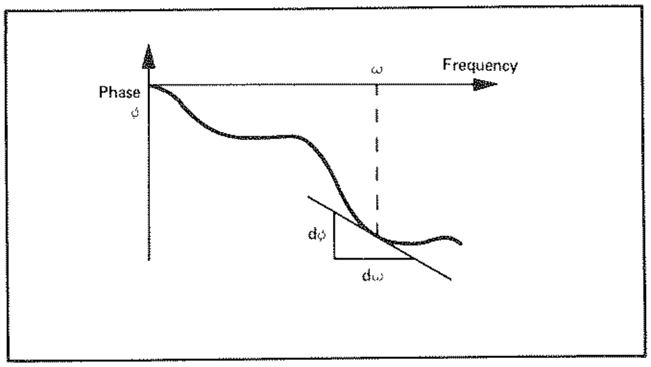


Figure 67. Typical Group Delay Display

GROUP DELAY PRINCIPLES

Reduced phase measurement uncertainty due to error correction provides very meaningful and flexible group delay measurements. This implementation makes it quite simple to make accurate, very high resolution group delay measurements at microwave frequencies.

Group delay is the measurement of signal transit time through a test device. It is defined as the derivative of the phase characteristic with respect to frequency:

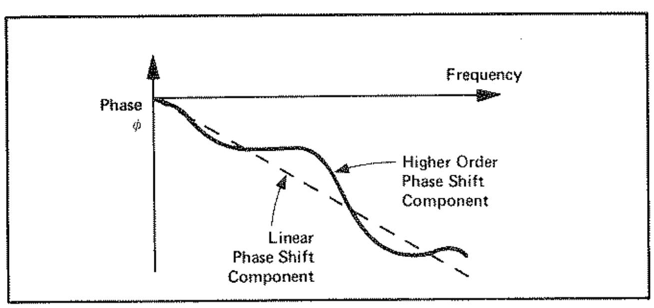


$$\text{GROUP DELAY} = \tau_g = \frac{-d\phi}{d\omega} \qquad \phi \text{ in Radians}, \ \omega \text{ in Radians}$$

$$= \frac{-1}{360^{\circ}} \cdot \frac{d\phi}{df} \qquad \phi \text{ in Degrees}, \ f \text{ in Hz } (\omega = 2\pi f)$$

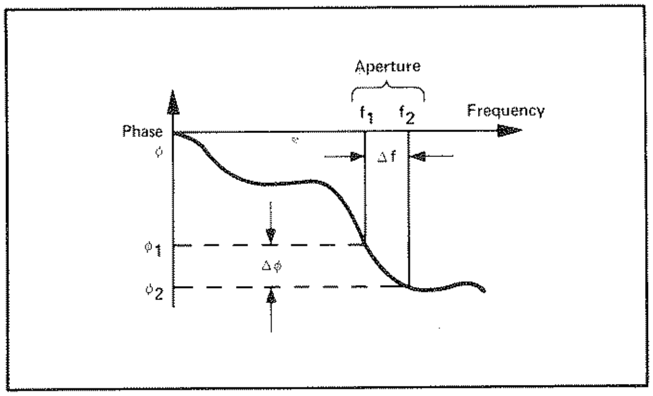
Since the derivative is basically the instantaneous slope (or rate of change of phase with frequency), a perfectly linear phase shift will result in a constant slope and, therefore, a constant group delay.

Note, however, that the phase characteristic will typically consist of both linear and higher order (deviations from linear) components:



The linear component can be attributed to the electrical length of the test device and represents the average signal transit time. The higher order components are interpreted as variations in transit time for different frequencies, and represent a source of signal distortion.

The HP 8510 network analyzer computes group delay from the phase slope. Phase data for the selected parameter is used to find the phase change, $\Delta\phi$, over a specified frequency aperture, Δf, to obtain a linear approximation for the rate of change of phase with frequency:

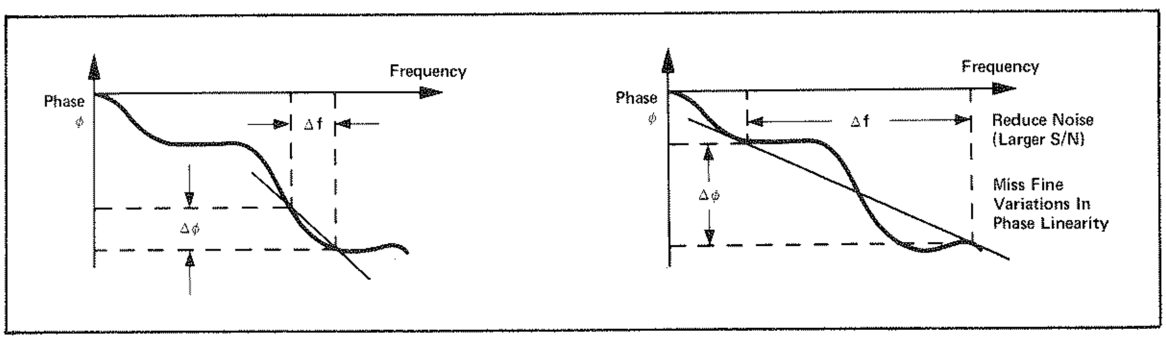


$$\text{GROUP DELAY} = \tau_g = \frac{-d\phi}{d\omega} \qquad \phi \text{ in Radians},\ \omega \text{ in Radians}$$

$$= \frac{-1}{360^\circ} \cdot \frac{d\phi}{df} \qquad \phi \text{ in Degrees},\ f \text{ in Hz } (\omega = 2\pi f)$$

This value, τ_g, represents the group delay in seconds assuming linear phase change over the frequency aperture Δf.

When deviations from linear phase are present, changing the frequency aperture can result in different values for group delay:



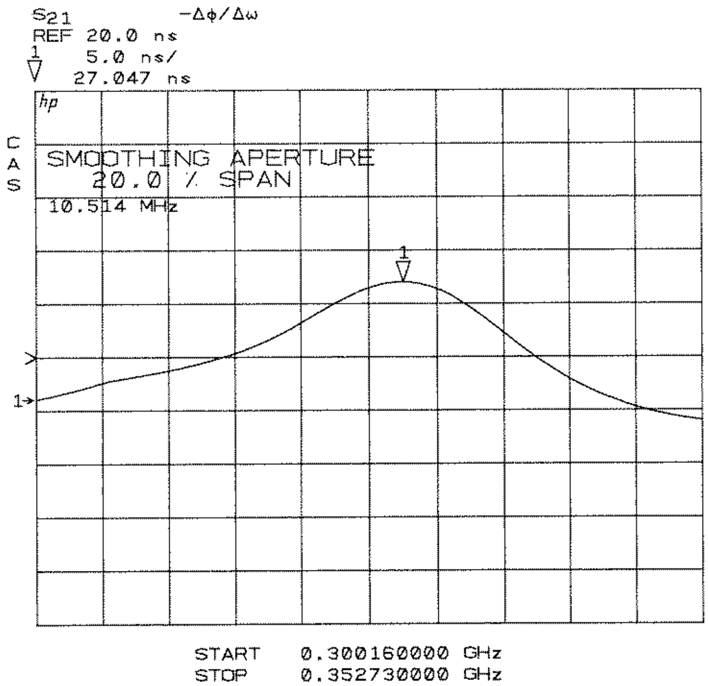
Note that in this case the computed slope varies as the aperture is increased. A wider aperture results in loss of the fine grain variations in group delay. This loss of detail is the reason that in any comparison of group delay data you must know the aperture used to make the measurement.

In using aperture, there is a tradeoff between resolution of fine detail and the effects of noise. The effects of noise can be reduced by increasing the aperture; however, this will tend to smooth out the fine detail. In decreasing the aperture, more fine detail will become visible but the noise will also increase, possibly to the point of obscuring the detail.

For a specific measurement, the average electrical length, or phase slope characteristic of the test device must be considered. To maintain phase resolution uncertainty below 1 percent, use an aperture which results in a phase change of at least 1 degree.

Smoothing is used to change the aperture during the measurement. For example, with smoothing off, group delay is computed using the phase change between each frequency step. With smoothing on, the phase change over the selected percent of sweep is used to compute group delay. Errors in the computation will result if more than 180 degrees of phase shift occurs from one frequency point to the next.

The two CRT display plots in Figure 68 show the effect of increasing the aperture. You may find it to be good practice to use a smaller aperture to assure that fine grain variations are not missed, then increase the aperture to smooth the trace.



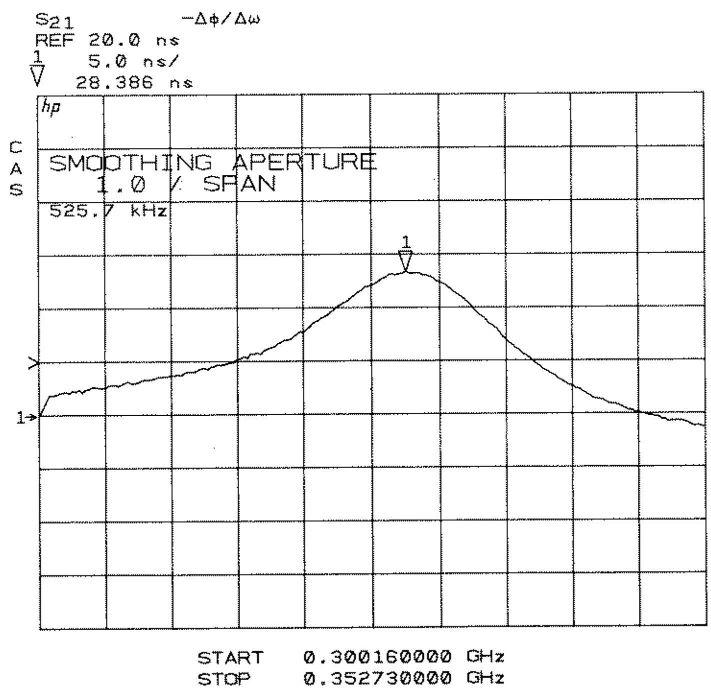


Figure 68. Group Delay Plots with Different Aperture Selections

DEVIATION FROM LINEAR PHASE MEASUREMENT

Measuring deviation from linear phase is an alternative to measuring group delay made possible by the range of the Electrical Delay capability. Insertion phase consists of two components, linear and non-linear. Deviation from linear phase is a measure of the non-linear component of the insertion phase. By compensating the linear insertion phase component using the Electrical Delay controls, the deviation from linear phase over the frequency sweep can be measured directly.

Measuring deviation from linear phase typically produces greater detail than measuring group delay when the phase response of the device under test changes rapidly over a small frequency range. This is because group delay is a derived measurement (the derivative of the phase change with frequency) and is averaged over the specified aperture.

- Perform appropriate measurement calibration.
- Select **PHASE**.
- Press RESPONSE **MENU**, **ELECTRICAL DELAY**.
- Use the knob (femtosecond resolution), **STEP** keys (1, 2, 5 sequence), or numeric and units (x1=seconds) to enter Electrical Delay.

This measurement determines the linear insertion phase required to equalize the electrical length of the reference and test signal paths, and thus achieve a flat phase trace, with the test device installed. Adding positive Electrical Delay tends to flatten the trace. When the phase response in the area of interest is flat, read the Electrical Delay value in seconds (and the corresponding free space distance in metres).

As an alternate way to enter the Electrical Delay value necessary to flatten the trace, use the Group Delay measurement results as follows:

- Press RESPONSE **MENU**, **ELECTRICAL DELAY**, **0**, **x1** to zero the Electrical Delay value.
- Press **DELAY**.
- Position the Marker to the center of the area of interest.
- Press **ELECTRICAL DELAY**, **=MARKER**.
- Press **PHASE**.
- Use the knob for fine adjustment of the Electrical Delay required to flatten the trace in the area of interest.

Note that adding Electrical Delay changes the phase slope and thus changes the group delay measurement. Since Electrical Delay is independent for Channel 1 and Channel 2, you can measure Deviation from Linear Phase and Group Delay simultaneously, as shown in in Figure 69. In Figure 69, Group Delay is the top trace, Deviation From Linear Phase the bottom trace. Press **DISPLAY**, **DUAL CHANNEL**, then **OVERLAY**. Present the deviation from linear phase display on Channel 1, then select Channel 2, **DELAY**, and zero seconds.

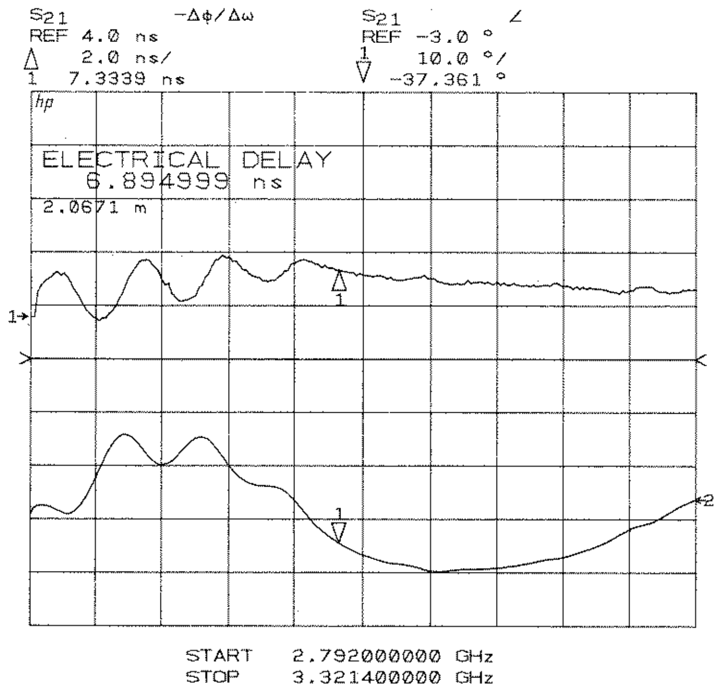


Figure 69. Typical Group Delay and Deviation From Linear Phase Displays

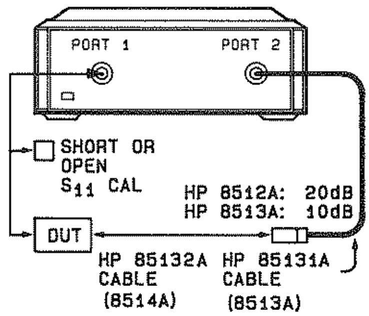
REFLECTION MEASUREMENTS

ILLUSTRATIONS

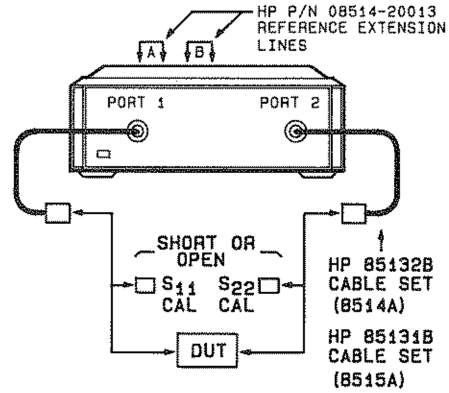
INTRODUCTION

This part of the HP 8510 network analyzer system manual explains how to make reflection return loss, SWR, S-parameter, impedance, and admittance measurements on a typical one-port or two-port device.

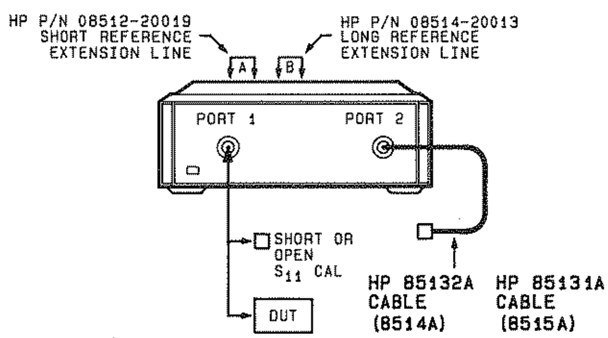
To make reflection measurements on multiport devices all ports except the test port are assumed to be terminated with Z_0.



Reflection-Transmission Test Set
(Standard Configuration)



S-Parameter Test Set
(Standard Configuration)



S-Parameter Test Set
(Device Under Test Connected Directly to Port 1)

Figure 70. Test Setup for Measuring One-Port Device

REFLECTION MEASUREMENTS

REFLECTION TEST SETUPS

One Port Devices. To measure 1-Port devices, connect the appropriate adapter (if necessary) at Port 1, perform the appropriate measurement calibration, then connect the device under test.

Two-Port Devices. When measuring reflection of a two-port device the device output port must be terminated in Z_0. This is accomplished either by actually terminating the device output with Z_0 or by using 2-Port error correction to compensate the measurement for the actual terminating impedance.

REFLECTION MEASUREMENT CALIBRATION CHOICES

Frequency Response Only Calibration. A Short Circuit or a Shielded Open Circuit is used as the standard.

1-Port Calibration. Use this for fully error-corrected Reflection Measurements for one-port devices. A Load, a Short Circuit, and a Shielded Open Circuit are used as the standards.

Full 2-Port Calibration. This model provides fully corrected transmission and reflection measurements with an S-parameter test set. It uses a thru, a shielded open circuit, a short circuit, and loads to calibrate at Port 1 and Port 2.

One-Path 2-Port Calibration. This model provides fully corrected transmission and reflection measurements (although not in real time) for a reflection/transmission test set. It uses a thru, a shielded open circuit, a short circuit, and loads to calibrate at Port 1. The operator follows instructions displayed on the CRT to manually reverse the test device for measurement of the reverse parameters.

RETURN LOSS MEASUREMENT

This sequence lists the steps for a typical Return Loss measurement.

- Perform appropriate S_{11} or S_{22} measurement calibration.
- Select **LOG MAG**.
- Press **MARKER**, read return loss (dB).

Measurement calibration sets the magnitude and phase ratio between the reference and test signal paths to zero dB at ±180 degrees with a short circuit at the reference plane. Figure 71 shows the return loss of a bandpass filter. The measurement marker is positioned to the minimum return loss in the passband.

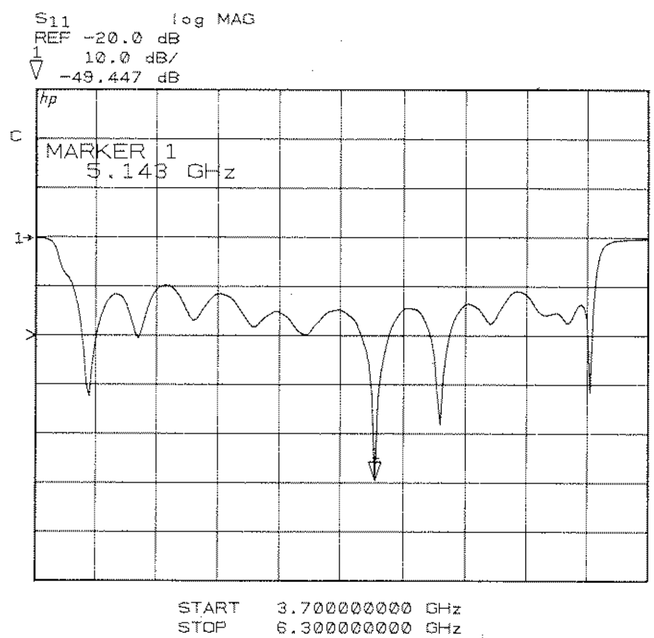


Figure 71. Typical Return Loss Display

SWR MEASUREMENT

The measurement sequence for Standing Wave Ratio, SWR, is the same as that for return loss.

Select the SWR display by pressing FORMAT MENU, then **SWR**.

SWR is calculated from the return loss value using these equations:

$$\rho = 10^{D} \quad \text{where } D = \text{measured value (dB)}/20$$

$$SWR = (1 + \rho) \,/\, (1 - \rho)$$

For example, if the measured magnitude ratio is -30 dB, then ρ is 0.032 and the SWR is 1.07.

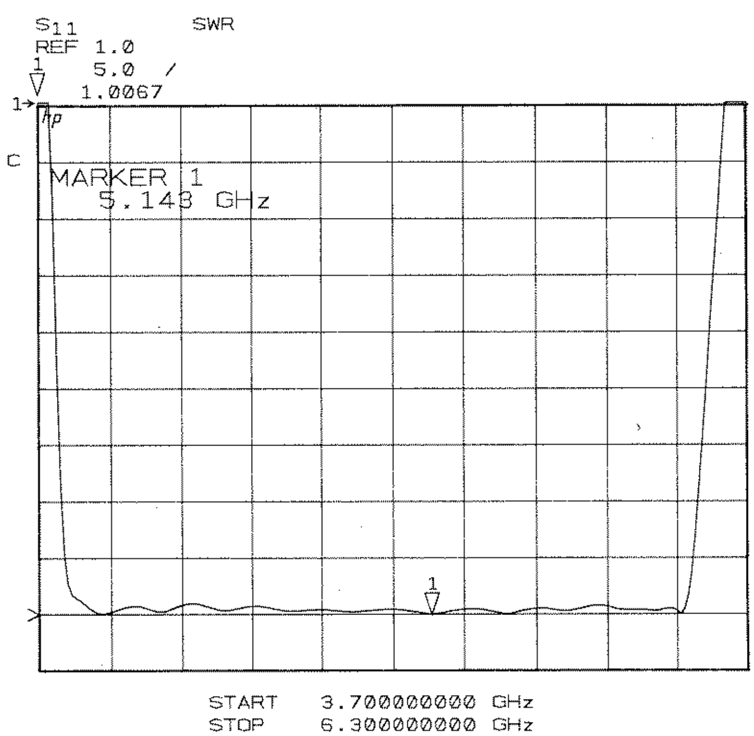


Figure 72. Typical SWR Display

S-PARAMETER MEASUREMENT

The procedure for measurement of reflection S-parameters is identical to measurement of return loss and reflection phase discussed earlier except that the response is viewed using the **LIN mkr on POLAR** display on the **FORMAT** menu.

The magnitude is given in linear terms (ρ) and an angle ∠θ, in degrees. A magnitude value greater than one indicates greater than unity reflection; less than one indicates lower than unity reflection. The conversion from dB to linear units is given by the equation

$$dB = 20 (\log \rho).$$

Note that the **LOG mkr on POLAR** format (Figure 73) presents the same data with magnitude given in dB.

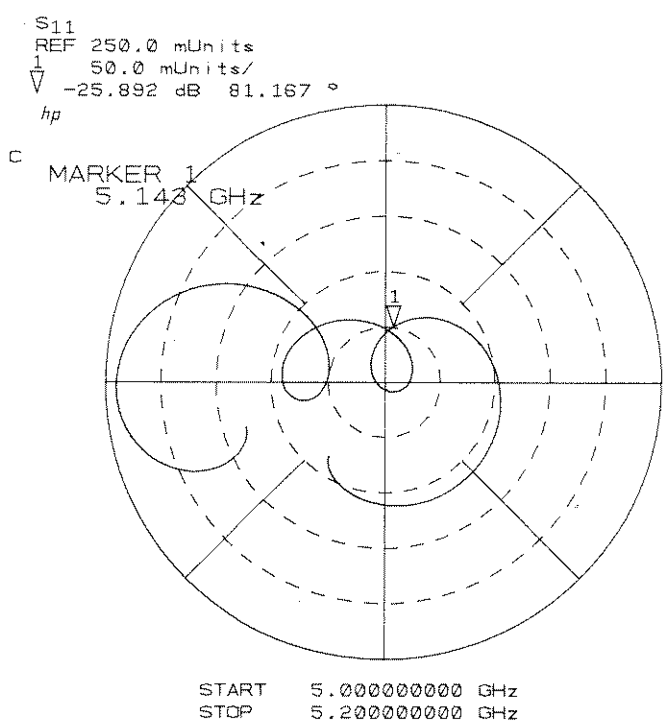


Figure 73. Typical S-Parameter Display

IMPEDANCE MEASUREMENT

Pressing the softkey labeled **SMITH CHART** on the Format Menu presents the reflection measurement using the Smith Chart, providing readout in units of resistance and reactance (R ± jx). The measurement calibration and measurement procedure are the same as for Return Loss described above. The impedance base for the marker readout is set by the system Z_0.

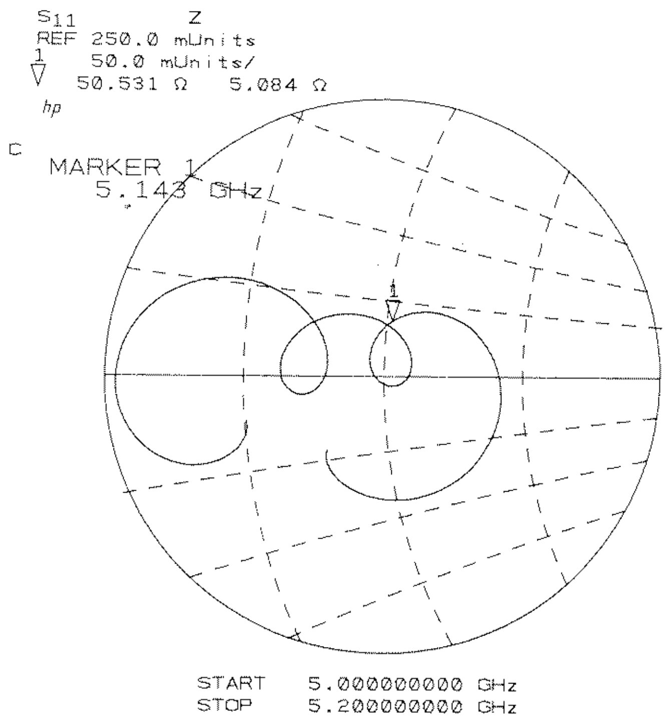


Figure 74. Typical Impedance Display

ADMITTANCE MEASUREMENT

Pressing the softkey labeled **INVERTED SMITH** on the Format Menu presents the reflection measurement using an inverted Smith, or Admittance, chart. The readout is in terms of susceptance and conductance (G ± jB). The measurement calibration and measurement procedure are the same as for the Return Loss measurement described above.

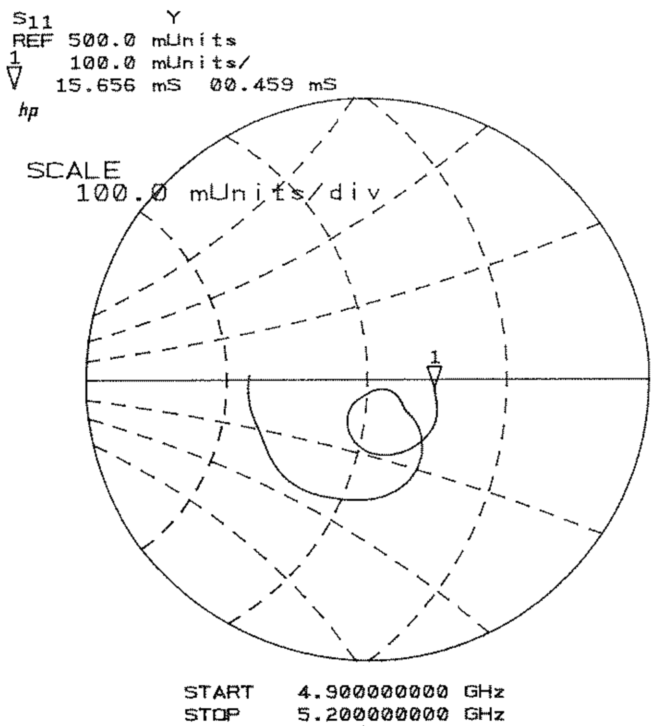


Figure 75. Typical Admittance Display

TIME DOMAIN MEASUREMENTS

ILLUSTRATIONS

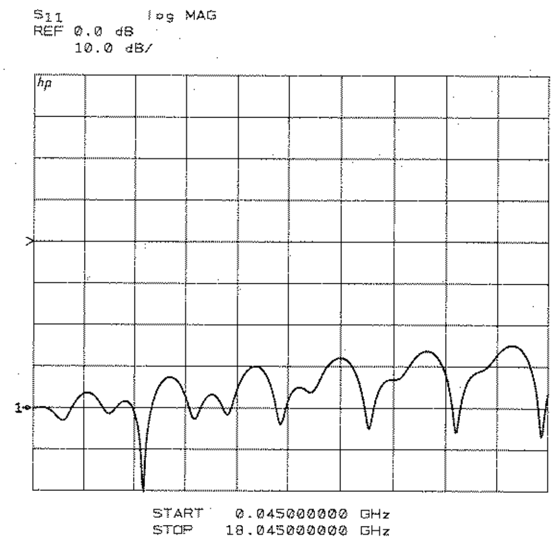
TABLES

INTRODUCTION

This part of the HP 8510 network analyzer system manual explains how to make reflection and transmission measurements in the time domain. Measurements actually made in the frequency domain are transformed mathematically into the time domain using the internal high-speed computer in the HP 8510, and this requires that the system be equipped with Time Domain Option 010, either at the time of original shipment or by means of the HP 85012A Time Domain Software Package.

The time domain band pass mode is especially useful for measuring band-limited devices and in making fault location measurements. The time domain low pass mode simulates the traditional TDR measurement and makes it possible to determine the type of discontinuity present in a device. Both modes are explained here, as are special time domain features such as masking, windowing, and gating.

FREQUENCY DOMAIN



TIME DOMAIN

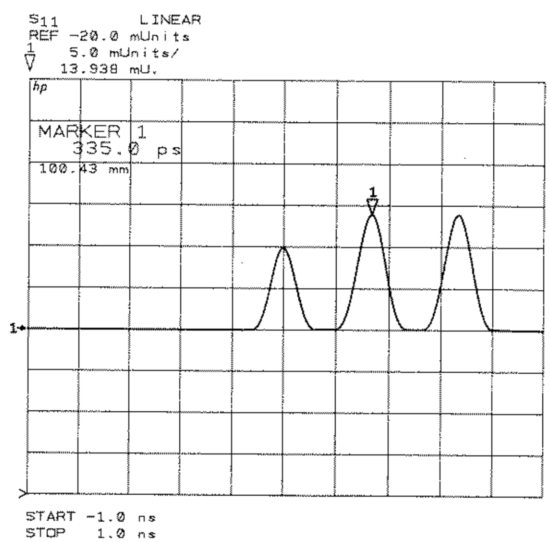


Figure 76. Frequency Domain and Time Domain Measurements

GENERAL THEORY

The relationship between the Frequency Domain response and the Time Domain response of a network is described by the Fourier Transform:

FREQUENCY DOMAIN		TIME DOMAIN
H(f)	---------------->	h(t)

It is therefore possible to measure the response of a device under test (DUT) in the Frequency Domain and then mathematically calculate the inverse Fourier Transform of the data to give the Time Domain response. The internal high-speed computer in the HP 8510 does this calculation using Chirp-Z Fast Fourier Transform computation techniques. The resulting measurement is the fully error-corrected Time Domain reflection or transmission response of the device displayed in near real time.

In Figure 76, the Frequency and Time Domain responses of the same device are displayed. The Frequency Domain reflection measurement is a composite response of all of the discontinuities present in the device under test.

The Time Domain measurement shows the effect of each individual discontinuity as a function of time (or distance). The time domain response shows that the device response consists of three separate impedance changes, with the second discontinuity having a relfection coefficient magnitude of 0.013. This discontinuity is located 167.5 picoseconds from the reference plane relative to the speed of light in a vacuum. (In the time domain trace shown in Figure 76, the display and the marker show the round-trip time to the reflection and back: 335 ps.)

TIME DOMAIN MODES

The HP 8510 network analyzer system has two different modes of operation for Time Domain measurements, Band Pass and Low Pass.

The Band Pass mode, the most general purpose mode of operation, gives the Impulse response of the device. Band Pass will work with any device and over any frequency range and is the least complicated mode to use.

The Low Pass mode is used to simulate the traditional Time Domain Reflectometer (TDR) measurement. The response gives the user information to determine the type of discontinuity present (R, L, or C). The Low Pass mode will also provide either the impulse or step response of the device.

TIME DOMAIN BAND PASS

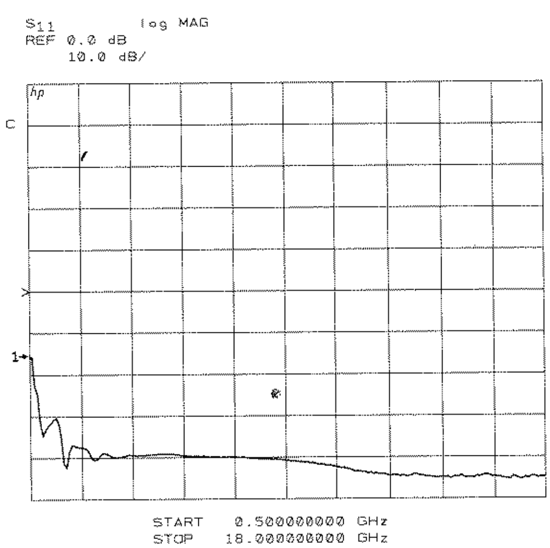
The Band Pass mode is so named because it will work with band-limited devices. This is a distinct advantage over traditional TDR, which requires that the DUT be able to operate down to dc. With Band Pass there are no restrictions on the frequency range of the measurement.

Reflection Measurements Using Band Pass

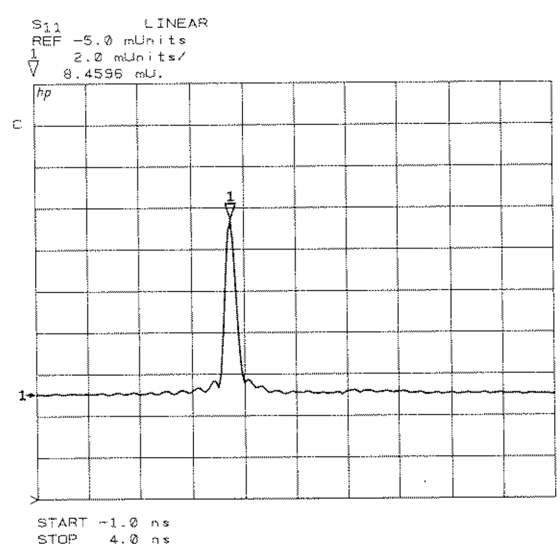
Before making Time Domain reflection measurements, it is necessary to perform the appropriate measurement calibration.

- Press **PRESET**.
- Perform an S_{11} **1-PORT** calibration.
  Leave the sliding load connected and observe the Frequency Domain response as the sliding element is moved.
- Press **DOMAIN**, **TIME BAND PASS**.
- Press **AUTO** to display the trace and observe the Time Domain response as the sliding element is moved.

The typical Frequency Domain and Time Domain responses of a sliding load are shown in Figure 77.



Frequency Domain



Time Domain Band Pass

Figure 77. Measurement of a Sliding Load

Move the sliding element and observe the response in both the Frequency Domain and the Band Pass Time Domain. The Frequency Domain measurement of the sliding load should change very little when the slide is moved (unless the calibration is bad). However, the Time Domain measurement shows the individual response of the load element, and it moves along the horizontal axis as the slide is moved.

Interpreting the Band Pass Response Horizontal Axis. In Band Pass reflection measurements, the horizontal axis represents the amount of time that it takes for an impulse, launched at the test port, to reach the discontinuity and return. Thus, this is the two-way travel time to the discontinuity, which in Figure 77 is the load element of the sliding load.

The Marker reads out both the time (x2) and the electrical length (x2) to the discontinuity. The electrical length is obtained by multiplying the time by the velocity of light in a vacuum (2.997925E8 m/sec). To get the physical length, multiply the electrical length by the relative velocity of light in the transmission medium.

In the Time Domain, the **STIMULUS** keys (**START**, **STOP**, **CENTER**, and **SPAN**) refer to time, and they can be used to change the horizontal (time) axis of the display independent of the frequency range chosen. This can be done using the knob, step keys, or the keypad. The keypad terminators also refer to time in seconds (with the lowercase prefixes).

Interpreting the Band Pass Response Vertical Axis. The quantity displayed on the vertical axis depends on the format selected. Band Pass is **PRESET** to the Linear Magnitude format which displays the response in reflection coefficient (ρ) units. This can be thought of as an average reflection coefficient of the discontinuity over the frequency range of the measurement.

Other useful formats are listed in Table 13. The Band Pass response gives the magnitude of the reflection only and has no impedance information (R, L, or C). This information is available, however, in the Low Pass response.

Table 13. Useful Time Domain Band Pass Formats

FORMAT	PARAMETER
LINEAR MAG	REFLECTION COEFFICIENT UNITS
LOG MAG	RETURN LOSS (dB)
SWR	SWR UNITS

Fault Location Measurements Using Band Pass

The Band Pass mode is very useful in making fault location measurements. Figure 78 shows the Band Pass Time Domain measurement of a length of coaxial cable having multiple discontinuities and terminated in 50 ohms. Note the responses of each discontinuity and of the terminating element.

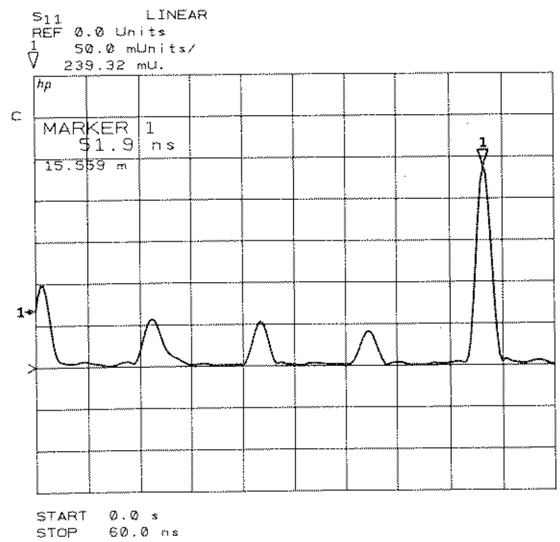


Figure 78. Cable Fault Location Measurement Using Band Pass

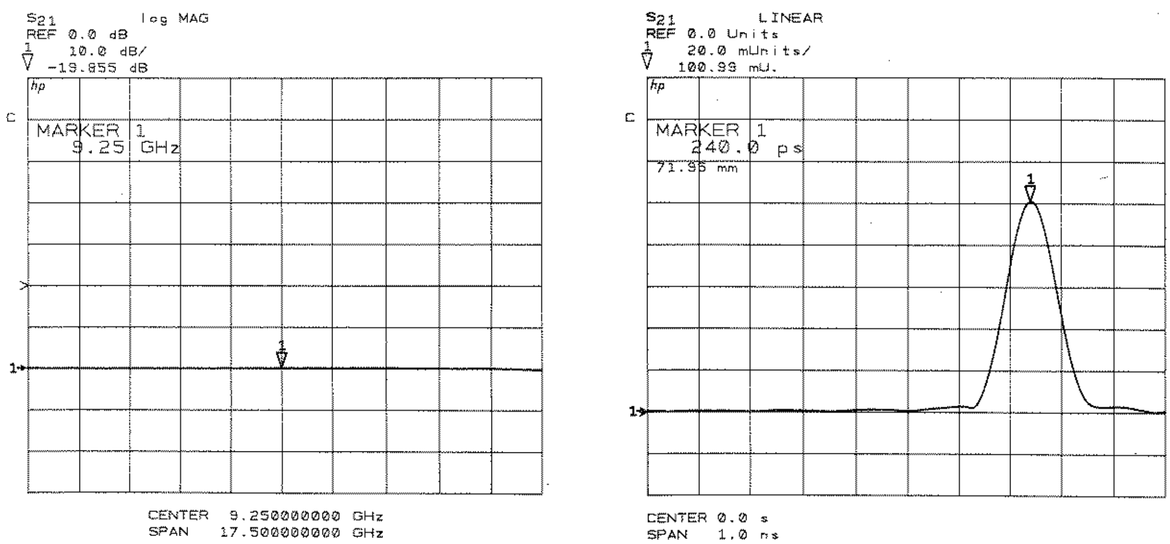
Also, because the Band Pass mode will work over any frequency range, it can be used to do fault location in band-limited transmission media, such as waveguide.

Transmission Measurements in Band Pass

The Band Pass mode is also useful in making transmission measurements. Before making Time Domain transmission measurements, it is necessary to perform the appropriate measurement calibration.

- Press **PRESET**.
- Perform an S_{21} **RESPONSE**, **FULL 2-PORT**, or **ONE PATH 2-PORT** calibration.
- Connect a 20 dB coaxial attenuator and observe the Frequency Domain response.
- Press **DOMAIN**, **TIME BAND PASS**.
- Press **AUTO** to display the trace.

The Frequency Domain and Time Domain responses of a 20 dB attenuator are shown in Figure 79.



Frequency Domain Response *Time Domain Response*

Figure 79. Transmission Measurement in Time Domain Band Pass

Interpreting the Band Pass Transmission Response Horizontal Axis. In Time Domain transmission measurements, the horizontal axis is displayed in units of time. The response of the thru connection used in the calibration is an impulse at t = 0 and with unit height, indicating that the impulse made it through in zero time and with no loss. When a device is inserted, the time axis indicates the propagation delay or electrical length of the device. Note that in Time Domain transmission measurements, the value displayed is the actual electrical length (not x2). The Marker reads out the electrical length in both time and distance. You must multiply the distance number by the relative velocity of the transmission medium to get the actual physical length.

Interpreting the Band Pass Transmission Response Vertical Axis. The vertical axis displays the transmission response in transmission coefficient units (τ) in the Linear Magnitude format and the transmission loss or gain in dB in the Log Magnitude format. This can be thought of as an average of the transmission response over the frequency range of the measurement. For the 20 dB attenuator example, the Band Pass response has a magnitude of 0.10 transmission coefficient units (-20 dB insertion loss).

TIME DOMAIN LOW PASS

The Low Pass mode of Time Domain is used to simulate the traditional TDR measurement. This mode gives the user information to determine the type of discontinuity (R, L, or C) that is present. Low Pass provides the best resolution (fastest rise time), and it may be used to give either the Step or Impulse response of a device.

The Low Pass mode is less general purpose than Band Pass in that it places strict limitations on the frequency range of the measurement. It requires that the Frequency Domain data points be harmonically related from dc to STOP frequency (STOP = N x START, where N = NUMBER of POINTS). The dc frequency response is extrapolated from the low frequency data. The requirement to pass dc is the same limitation that exists for traditional TDR measurements.

Setting Frequency Range for Time Domain Low Pass

Before making measurements in the Low Pass mode, the frequency range of the measurement must be set so that STOP = *n* x START, where *n* is the number of points. This can be done directly by the user, or else it will be done automatically when the **SET FREQ. (LOW PASS)** softkey is pressed. This key is included in the **CAL** Menu and also after the **TIME LOW PASS** softkey. Because the HP 8510 will not convert to the Low Pass mode until the **SET FREQ. (LOW PASS)** key is pressed at least once, it is very important that this be done before calibrating. Otherwise, going to Low Pass will change the measurement frequencies which will turn off error correction.

Pressing **SET FREQ. (LOW PASS)** will set the STOP frequency as close as possible to the value entered by the user, and it will set the START frequency equal to STOP/ N. As an example, if the user selects 101 points, with START = 100 MHz, and STOP = 5.05 GHz, then pressing **SET FREQ. (LOW PASS)** will change START to 50.0 MHz (= STOP/ 101).

Because the lowest measurement frequency for the HP 8510 is 45 MHz, for each value of N there is a minimum allowable STOP frequency that can be used, and this is given by N x 45 MHz. Table 14 describes the minimum frequency range that can be used for each value of N when making Low Pass Time Domain measurements.

Table 14. Minimum Frequency Ranges For Time Domain Low Pass

NUMBER of POINTS (N)	MINIMUM FREQUENCY RANGE
51	45 MHz to 2.295 GHz
101	45 MHz to 4.545 GHz
201	45 MHz to 9.045 GHz
401	45 MHz to 18.045 GHz
NOTE: If the source cannot operate over the required frequency range, the HP 8510 will nevertheless attempt the operation.	

If the STOP frequency entered is lower than the minimum that is available for the value of N selected, then pressing the **SET FREQ. (LOW PASS)** softkey will change the STOP frequency to that minimum value. For example, if Number of Points = 201, START = 100 MHz, and STOP = 6.00 GHz, then pressing **SET FREQ. (LOW PASS)** will change START to 45 MHz and STOP to 9.045 GHz (= START x 201). Because of these restrictions on the frequency range of the measurement, the Low Pass mode is most useful for measuring lowpass broad band devices.

Analyzing Low Pass Reflections

As mentioned, the Low Pass mode gives the TDR response of the device under test. This response contains information that is useful in determining the type of discontinuity present. Before making actual measurements in the Low Pass mode, it is helpful to review the Low Pass responses of known discontinuities. Each circuit element of Figure 80 was simulated to show the corresponding Low Pass Time Domain S_{11} response waveform. The Low Pass mode will give the response of the device to either a Step or an Impulse stimulus. (Mathematically, the Low Pass Impulse stimulus is the derivative of the Step stimulus.)

These Time Domain responses were generated using the Circuit Modeling Program which is supplied with the Time Domain option (described at the end of the Time Domain section).

LOW PASS REFLECTIONS
(REAL FORMAT)

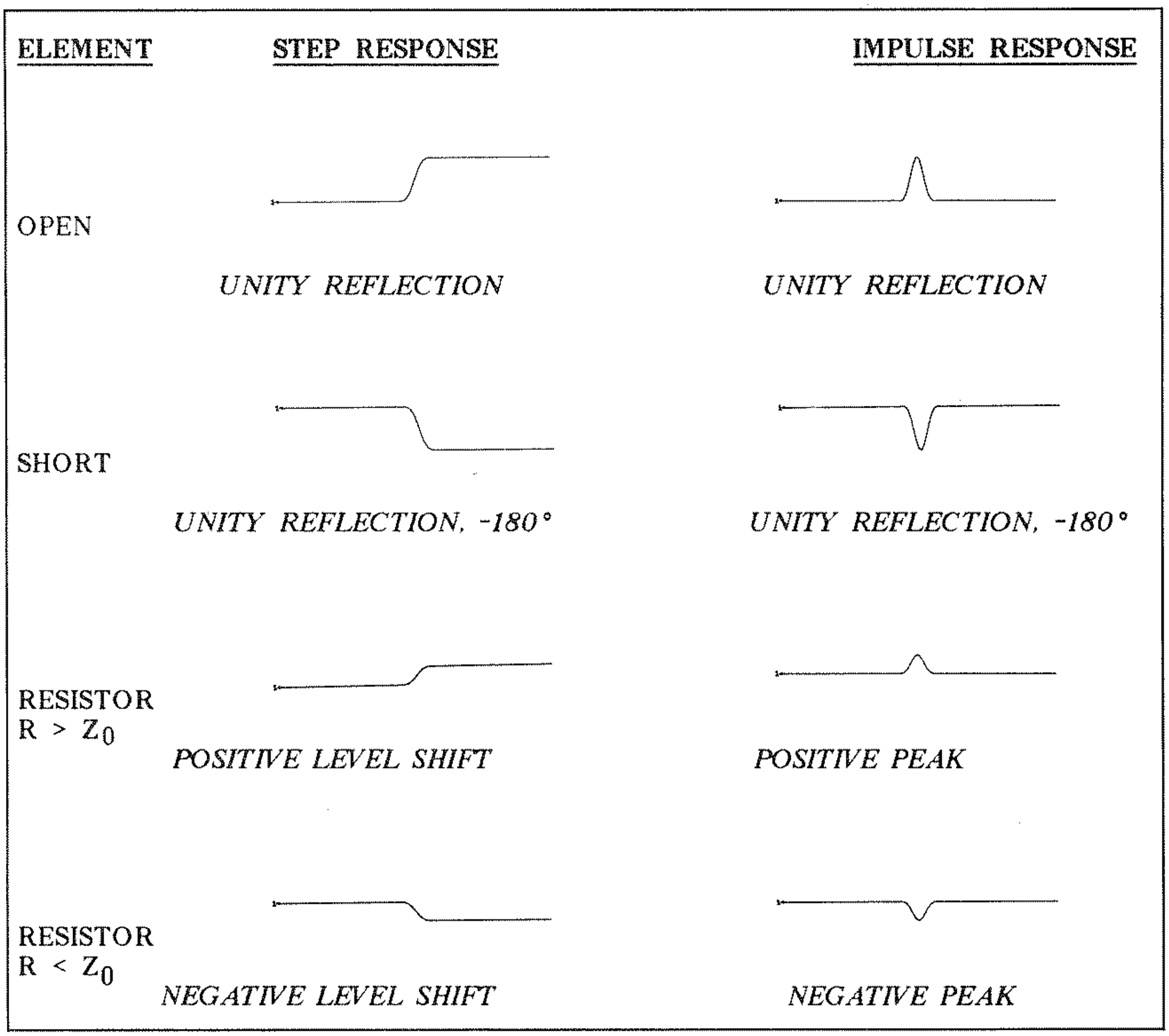


Figure 80. Low Pass Step and Impulse Response Waveforms (1 of 2)

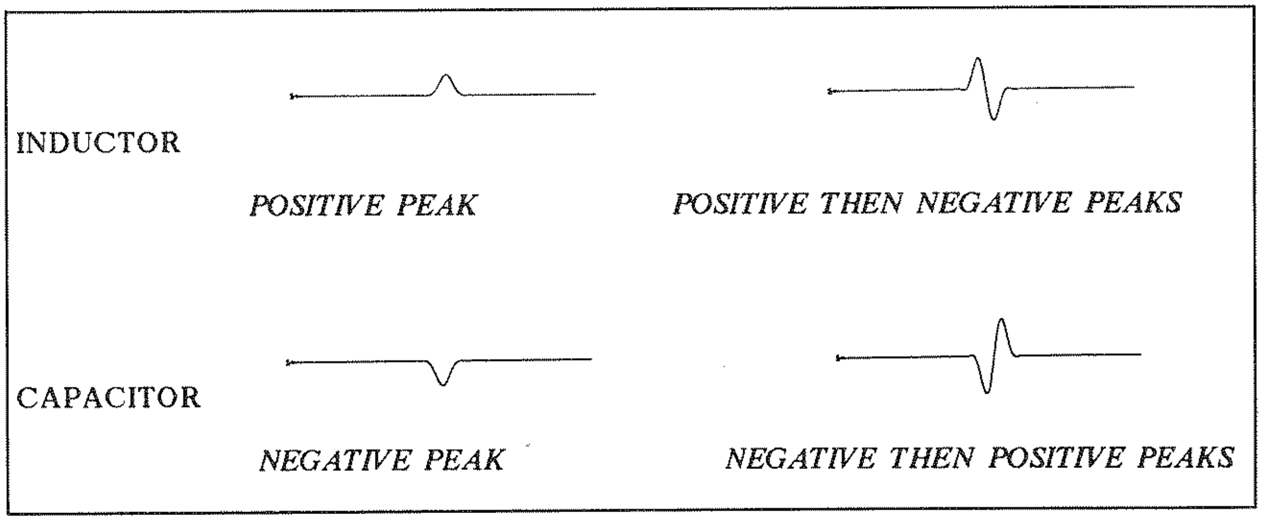


Figure 80. Low Pass Step and Impulse Response Waveforms (2 of 2)

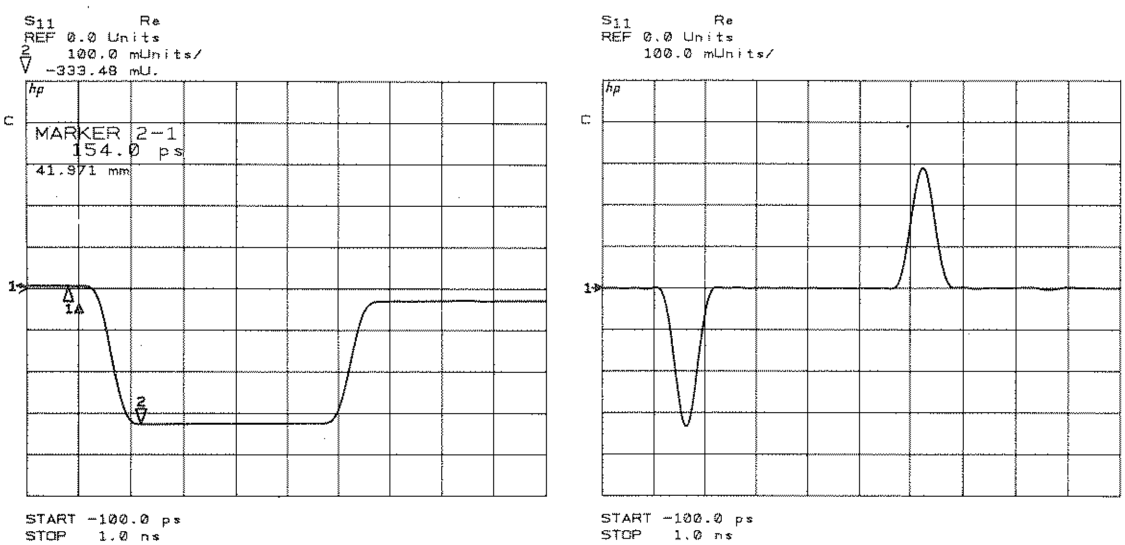
Reflection Measurements in Time Domain Low Pass

To make measurements in the Low Pass mode, use the following procedure:

- Press **PRESET.**
- **CAL, CAL 1 (7 mm)** or **CAL 2 (3.5 mm).**

The Cal Type menu (Figure 51, p. 183) will be displayed.

- Press **SET FREQ. (LOW PASS).**
- Perform an S_{11} **1-PORT** calibration.
- Connect a 25 Ω airline and broadband load.
- Press **DOMAIN, TIME LOW PASS, SET FREQ. (LOW PASS).**
- Press **AUTO** to view the STEP response, Figure 81.
- To view the Low Pass Impulse response of the device, press **DOMAIN, SPECIFY TIME, IMPULSE (LOW PASS).**



STEP Response *IMPULSE Response*

Figure 81. Low Pass Step Response of a 25 Ω Airline and Fixed Load

Interpreting the Low Pass Response Horizontal Axis. The horizontal axis for the Low Pass measurement is the 2-way travel time to the discontinuity, the same as for the Band Pass mode. Also, the Marker function displays both the time (x2) and electrical length (x2), obtained by multiplying the time by the velocity of light in a vacuum (2.997925E8 m/sec). To get the actual physical length, multiply by the relative velocity of light in the propagation medium.

Interpreting the Low Pass Response Vertical Axis. The vertical axis depends upon the format chosen. In the Low Pass mode, the most useful format is **REAL**, which displays the TDR response in reflection coefficient units.

This points out a key difference between the Band Pass and Low Pass modes. The Band Pass measurement is actually the response of the device to an RF pulse with an impulse shaped envelope. For Band Pass, the Inverse Fourier Transform of the (complex) Frequency Domain data gives a complex (real and imaginary parts) Time Domain response, and it is the magnitude of this response that is displayed.

In the Low Pass mode, because the Frequency Domain data is taken at harmonically related frequencies down to dc, the Inverse Fourier Transform has only a real part (the imaginary part is zero). Therefore, the most useful format for the Low Pass mode is the REAL format, which displays the response in reflection coefficient units. Other useful formats are listed in Table 15.

Table 15. Useful Time Domain Low Pass Formats

FORMAT	PARAMETER
REAL	REFLECTION COEFFICIENT UNITS
LOG MAG	RETURN LOSS (dB)
SWR	SWR UNITS

Trace Bounce. Depending on the magnitude of the response and on the test set used, the Low Pass Step response of the device may exhibit a phenomenon called display trace bounce. This is normal, and it can be improved by turning on AVERAGING (under the Response MENU). This trace bounce is caused by a loss of measurement dynamic range at low frequencies because of the roll off of the coupler-based test sets (HP 8512A and HP 8514A) below 500 MHz (down -30 dB at 45 MHz). The trace bounce is a factor of 30 times less in the bridge-based test sets (HP 8513A and HP 8515A), which have flat magnitude frequency responses down to 45 MHz.

As a second example of Low Pass reflection measurements, consider the Low Pass Step response of a 30 cm airline and fixed load, shown in Figure 82.

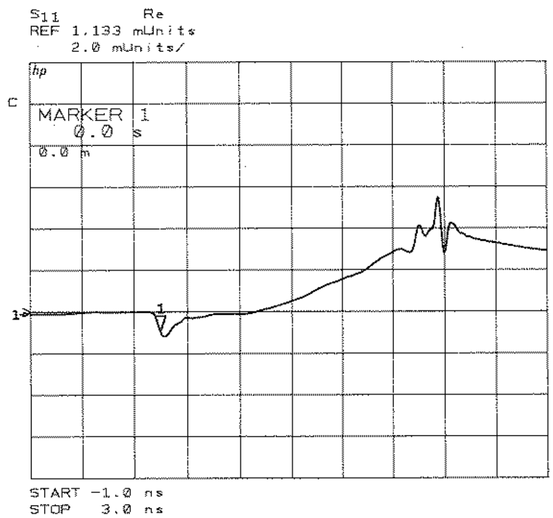


Figure 82. Step Response of a 30 cm Airline and Fixed Load

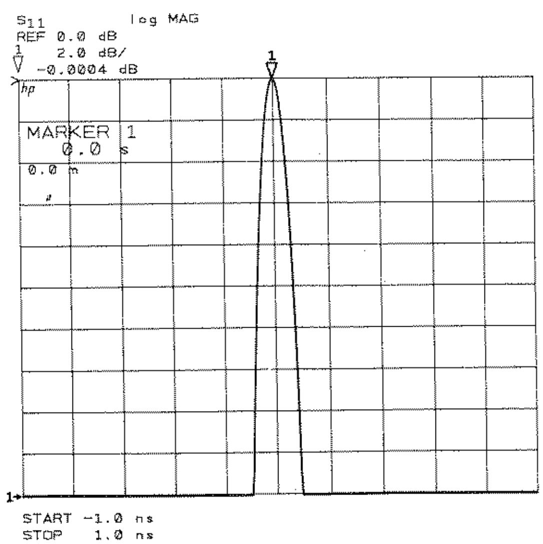
The Low Pass response at t = 0 is that of the airline connection. By comparing this response with the theoretical Low Pass responses, one can determine whether the mismatch present is capacitive or inductive. The discontinuity at the first connection of the airline is capacitive. The upward slope of the center section of the response is caused by the loss in the airline. The second major response is that of the fixed load.

TIME DOMAIN CONCEPTS

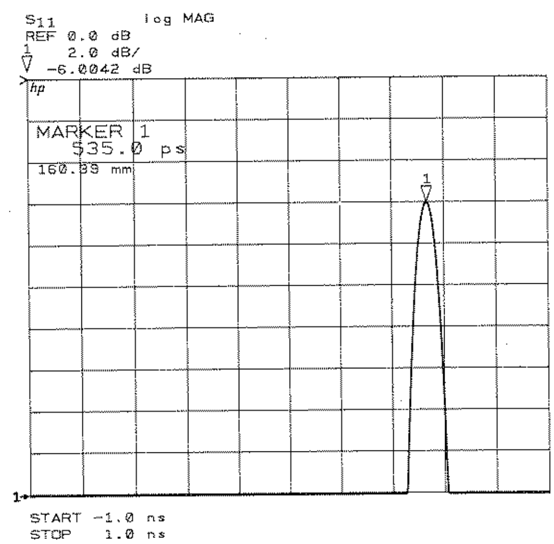
MASKING

Masking is a physical phenomenon in which the Impulse or Step response of one discontinuity affects the response of each subsequent discontinuity in the circuit. This occurs because the energy reflected from or absorbed in the first discontinuity never reaches the second. In the 25 Ω airline example (Figure 81), the Low Pass step response shows the reflection coefficient at the first discontinuity of -0.33, which is correct for an impedance of 25 Ω. However, at the end of the 25 Ω section the response does not return to zero reflection coefficient, which it should at a 50 Ω impedance. The reason is that the step incident on the second response is of less than unity amplitude because of the energy reflected in the first mismatch.

As a second example of masking, consider the Time Domain response of a 3 dB attenuator and a short circuit. The Impulse response of the short circuit alone, Figure 83, shows a return loss of 0 dB. However, the response of the short circuit placed at the end of the 3 dB attenuator displays a return loss of -6 dB. This value actually represents the forward and return path loss through the attenuator, and it illustrates how a lossy network can affect the responses that follow it.



Short Circuit



Short at End of 3dB Pad

Figure 83. Masking Example: 3 dB Pad and Short Circuit

WINDOWING

The HP 8510 has a feature called WINDOWING that is designed to enhance Time Domain measurements. The need for Windowing is due to the abrupt transitions in the Frequency Domain measurement at the START and STOP frequencies. This band limiting of the Frequency Domain response causes overshoot and ringing in the Time Domain response. It causes the (un-Windowed) Impulse stimulus to have a sin(kt)/kt shape ($k = \pi$/frequency span), which has two effects that limit the usefulness of the Time Domain measurement:

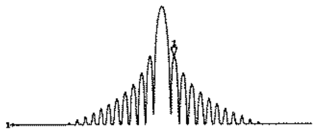
(1) Finite Impulse Width. This limits the ability to resolve between two closely spaced responses. The effects of the finite impulse width cannot be improved without increasing the frequency span of the measurement. See Table 16.

(2) Sidelobes. The Impulse sidelobes limit the dynamic range of the Time Domain measurement by hiding low level responses within the sidelobes of the higher level responses. The effects of sidelobes can be improved by Windowing. See Table 17.

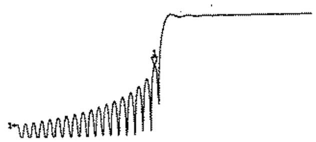
Windowing improves the dynamic range of the Time Domain measurement by modifying (filtering) the Frequency Domain data prior to conversion to the Time Domain to produce an impulse stimulus with lower sidelobes. This greatly enhances the effectiveness in viewing Time Domain responses that are very different in magnitude. The sidelobe reduction is achieved, however, as the tradeoff with increased impulse width. The effect of Windowing on the STEP stimulus (integral of the impulse stimulus, Low Pass mode only) is a reduction of overshoot and ringing at the tradeoff with increased rise time.

Three Windows are available: **MINIMUM**, **NORMAL**, and **MAXIMUM**. The Window may be selected by pressing **DOMAIN**, **SPECIFY TIME**. The sidelobe levels of the Time Domain stimulus depend only on the Window that is selected (see Table 17). MINIMUM is essentially no window and therefore gives the highest sidelobes; NORMAL (selected by **PRESET**) gives reduced sidelobes and is normally the most useful; MAXIMUM gives the minimum sidelobes and thus provides the greatest dynamic range.

Table 16. Time Domain Window Characteristics



Impulse Sidelobe Level



Step Sidelobe Level

WINDOW TYPE	IMPULSE SIDELOBE LEVEL	STEP SIDELOBE LEVEL
MINIMUM	-13 dB	-21 dB
NORMAL	-44 dB	-60 dB
MAXIMUM	< -90 dB	< -90 dB

The sidelobe reduction due to Windowing is achieved at a tradeoff with an increase in the Step (10% - 90%) Rise Time and the Impulse (50%) width. These parameters also depend upon the frequency span of the measurement, and they can be calculated using the approximate formulas given in Table 17.

Table 17. Approximate Formulas For Step Rise Time and Impulse Width

LOW PASS

$$\text{STEP RISE TIME (10\% - 90\%)} = \frac{0.45}{\text{FREQ SPAN}} \times \begin{cases} 1.0 & \text{MINIMUM WINDOW} \\ 2.2 & \text{NORMAL WINDOW} \\ 3.3 & \text{MAXIMUM WINDOW} \end{cases}$$

$$\text{IMPULSE WIDTH (50\%)} = \frac{0.60}{\text{FREQ SPAN}} \times \begin{cases} 1.0 & \text{MINIMUM WINDOW} \\ 1.6 & \text{NORMAL WINDOW} \\ 2.4 & \text{MAXIMUM WINDOW} \end{cases}$$

BAND PASS

$$\text{IMPULSE WIDTH (50\%)} = \frac{1.20}{\text{FREQ SPAN}} \times \begin{cases} 1.0 & \text{MINIMUM WINDOW} \\ 1.6 & \text{NORMAL WINDOW} \\ 2.4 & \text{MAXIMUM WINDOW} \end{cases}$$

Multiply by the velocity of light in a vacuum (2.997925E8 m/sec) to get electrical length, and then by the relative velocity of light in the the propagation medium to get physical length.

The purpose of windowing is to make the Time Domain response more useful in isolating and identifying individual responses. The window does not affect the displayed Frequency Domain response. It is turned on only when the Time Domain response is viewed. Figure 84 shows typical effects of windowing on the Time Domain response of the reflection measurement of a short circuit.

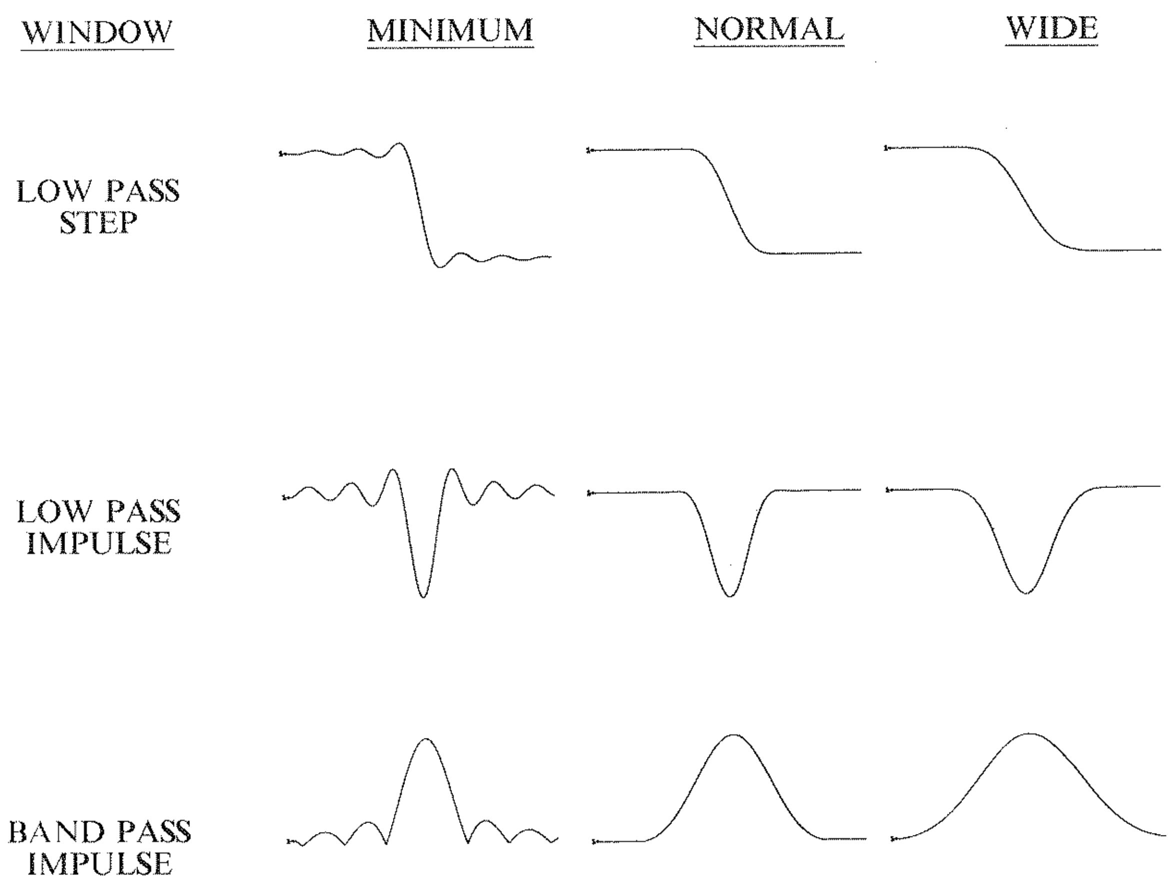


Figure 84. Effect of Windowing on Time Domain Responses of a Short Circuit

RANGE

In the Time Domain, the RANGE is defined as the length in time that a measurement can be made without encountering a repetition of the response (see Figure 85). The repetition of the Time Domain response occurs at regular intervals of time and is a consequence of the Frequency Domain data being taken at discrete frequency points rather than being continuous.

The Range of a measurement is equal to $1/\Delta F$, the spacing between frequency data points. It is therefore directly proportional to the number of points and inversely proportional to the Frequency Span (STOP - START frequency) and can be calculated using the following formula.

$$\text{RANGE} = 1/\Delta F = (\text{Number of Points} - 1)/\text{Frequency Span}$$

As a sample calculation, for a 201 point measurement from 50 MHz to 18 GHz (SPAN = 17.95 GHz), the Range is (201 - 1) / 17.95 GHz = 11.1 nsec (3.34 m). Thus the device under test has to be 3.34 m or less in electrical length for a transmission measurement (1.67 m for a reflection measurement) or else an overlapping of the Time Domain responses (aliasing) will occur. (Remember to multiply by the relative velocity of light in the medium to get actual physical length.)

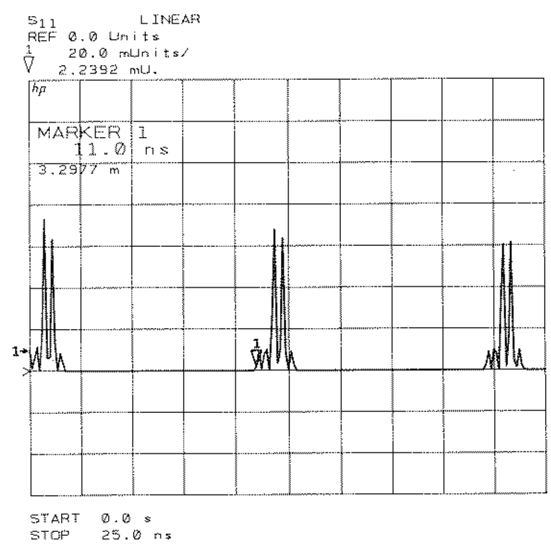


Figure 85. Time Domain Measurement Showing Response Repetitions

To increase the Time Domain measurement Range, it is usually better to first increase the number of points, because decreasing the frequency span will reduce the resolution.

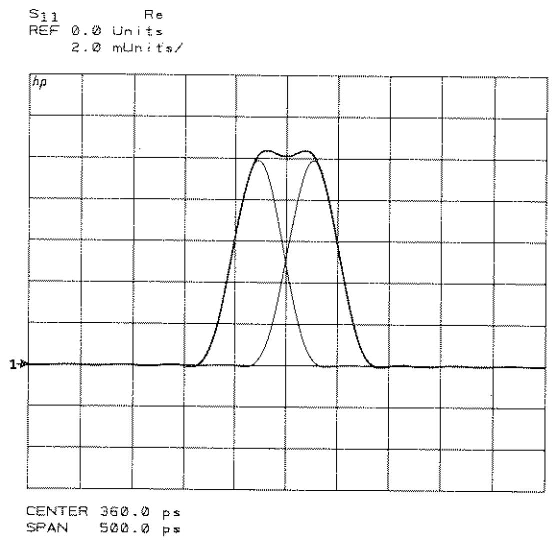
RESOLUTION

There are two different terms involving resolution in Time Domain: RESPONSE-RESOLUTION and RANGE-RESOLUTION. The Time Domain Response-Resolution is defined as the ability to resolve two closely spaced responses. In other words, if two responses are present, this is how closely they can be spaced and still be distinguished from one another. For responses of equal amplitude, the Response-Resolution is equal to the 50% (-6 dB) impulse width. It therefore is inversely proportional to the frequency span of the measurement and is also a function of the window that is used. Approximate formulas for calculating the 50% Impulse width are given in Table 17. For responses that are of different amplitudes, the Response-Resolution will be wider.

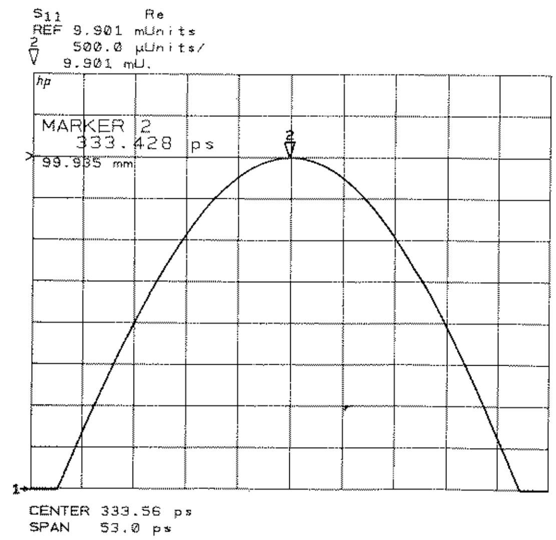
Range-Resolution is defined as the ability to locate a single response in time. In other words, if only one response is there, this is how closely you can pinpoint the peak of that response. The Range-Resolution is equal to the digital resolution of the CRT display which is the time span displayed divided by the number of points. Maximum Range-Resolution is achieved by centering the response on the display and then reducing the time span. Therefore, the Range-Resolution is always much finer than the Response-Resolution.

To illustrate the difference between these two resolution terms, consider a measurement with a frequency span of 18 GHz. For Low Pass, with a Normal Window, the Response-Resolution (Impulse width) is 53 psec (0.6 x (1/18 GHz) x 1.6) or 16 mm in electrical length (53 psec x 2.997925E8 m/sec). As illustrated in Figure 86, two Time Domain responses of equal amplitude separated by 16 mm could be resolved in this Time Domain measurement. (This indicates an actual discontinuity separation of 8 mm for reflection measurements.)

Now consider the case where only one response is present. By centering that response on the display and adjusting the time SPAN to equal the 50% Impulse width (53 psec, 16 mm), Figure 86, the Range-Resolution is reduced to 40 µm (16 mm/401 points). The Range-Resolution can be further reduced by narrowing the time span.



Response-Resolution



Range-Resolution

Figure 86. Resolution in Time Domain

GATING

The HP 8510 gating feature gives the user the flexibility to selectively remove reflection or transmission Time Domain responses. In converting back to the Frequency Domain, the effects of the responses outside the Gate are removed. In a reflection measurement, you can remove the effects of unwanted mismatches or else isolate and view the response of an individual mismatch. In a transmission measurement you can remove the responses of multiple transmission paths.

Setting the Gate. A Gate is a temporal band pass filter used to filter out unwanted Time Domain responses. Responses outside the selected gate are not included in the trace. There are three Gate indicators: START, CENTER, and STOP. The Gate has a bandpass filter shape, as shown in Figure 87. The GATE CENTER indicates the center time (not frequency) of this filter, and the Gate START and STOP indicate the -6 dB cutoff times. Gate SPAN = STOP - START.

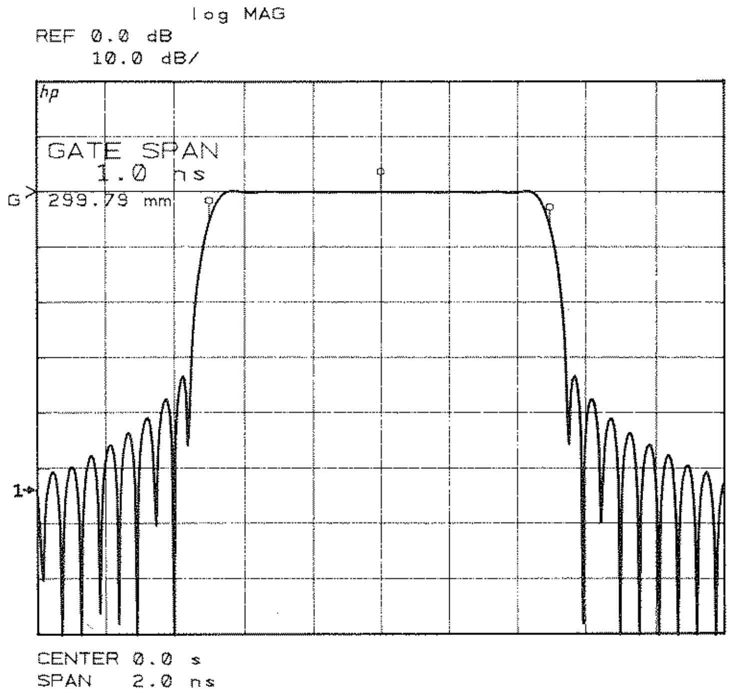
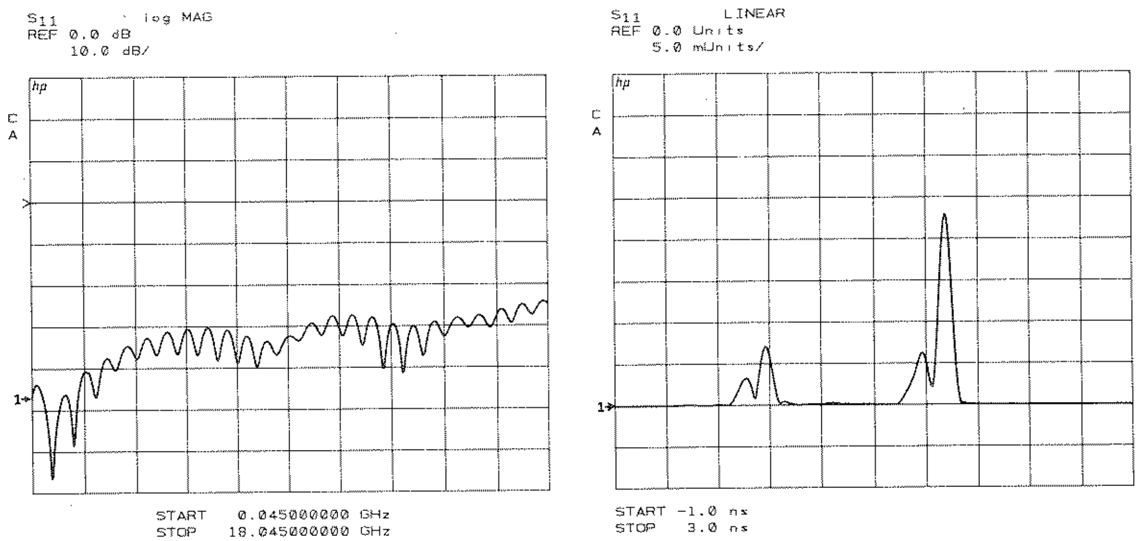


Figure 87. Gate Shape

Consider using gating to analyze the response of a 7mm-to-3.5mm adapter connected to a 3.5mm airline and a fixed load. The Frequency Domain and the Band Pass Time Domain responses of such a setup are shown in Figure 88.

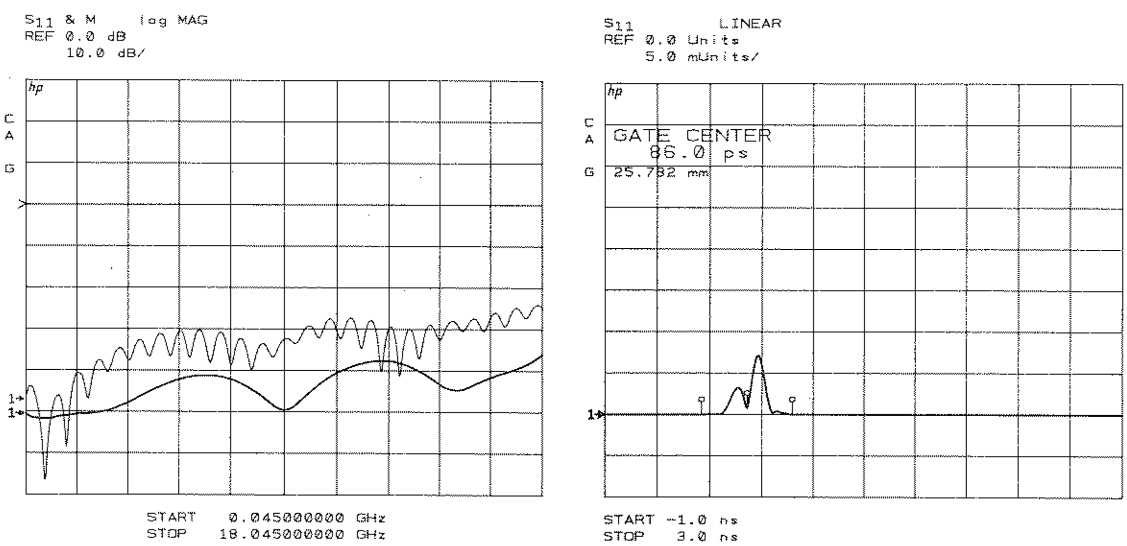


Frequency Domain Response *Time Domain Response*

Figure 88. Reflection Measurement of 7mm-to-3.5mm Adapter, Airline, and Load

We will now use gating to analyze the response of the adapter only.

- Press **DOMAIN, TIME BAND PASS, SPECIFY GATE.**
- The three Gate indicators will now appear on the screen. Press **GATE CENTER**, and use the knob or keypad to move the center indicator to t = 0.
  In Figure 89, the time domain display shows the gate center, 86 ps, as the Active Function.
- Press **GATE SPAN** and use the knob or keypad to adjust the Gate Span to 0.70 ns.
- Press **GATE ON** to turn on the Gate.
  The responses outside the Gate will be removed. See Figure 89.
- Press **DOMAIN, FREQUENCY.**
  View the gated Frequency Domain response of the adapter. See Figure 89.



Frequency Domain Response *Time Domain Response*

Figure 89. Gated Responses of the 7mm-to-3.5mm Adapter

The darker shaded trace in the Frequency Domain plot of Figure 89 shows the Gated Frequency Domain response, which is that of the adapter only. The effects of the fixed load on the measurement are removed.

Select Gate Shape. Four different Gate shapes are available: **MINIMUM, NORMAL, WIDE,** and **MAXIMUM.** Each of the Gates have different pass-band flatness, cutoff rate, and sidelobe levels. T1 indicates the Gate span which is the time between the Gate start and stop indicators. T2 is the time between the edge of the Gate passband and the -6 dB Gate stop time. T3, equal to T2, is the time between the Gate stop time and the point where the filter first reaches the level of the highest Gate sidelobe. The Gate characteristics for each Gate shape are listed in Table 18.

Table 18. Gate Characteristics

GATE SHAPE	PASSBAND RIPPLE	SIDELOBE LEVELS	CUTOFF TIME T2 = T3	MINIMUM GATE SPAN
MINIMUM	± 0.40 dB	-24 dB	0.6/ FSPAN	1.2/ FSPAN
NORMAL	± 0.04 dB	-45 dB	1.4/ FSPAN	2.8/ FSPAN
WIDE	± 0.02 dB	-52 dB	4.0/ FSPAN	8.0/ FSPAN
MAXIMUM	± 0.01 dB	-80 dB	11.2/ FSPAN	22.4/ FSPAN

The Passband Ripple and Sidelobe Levels are descriptive of the gate (filter) shape. The Cutoff Time, T2 = T3 (see Table 18), indicates how fast the gate filter rolls off. For each gate shape, there is also a Minimum Gate Span ($T1_{min}$ = 2 x T2) which gives a filter passband of zero. To enter a Gate span smaller than minimum will produce a distorted filter shape that will have no passband, will not have a narrower shape, may have higher sidelobe levels, and will give an incorrect indication of gate START and STOP times. Therefore, it is important to always select a Gate span that is higher than the minimum value. The Cutoff time and the Minimum Gate Span are inversely proportional to the frequency span of the measurement as indicated in Table 18.

For best results using Gating, it is important to always center the Gate around the response(s) that you want to retain in the measurement and to make the Gate span wide enough to include all of those responses. It is also recommended to use the widest Gate shape possible.

MEASUREMENT RECOMMENDATIONS

When making Time Domain measurements, it is generally a good practice to measure the device within the frequency range that it is designed to operate. There are two reasons for this. First, the noise floor of the Time Domain response is directly related to the noise in the Frequency Domain data. Therefore, if many of the Frequency Domain data points are taken at or below the noise floor of the measurement, then the noise floor of the Time Domain measurement will be increased. A second reason to measure the device within its operating frequency range is because the in band response is normally of interest. The Time Domain measurement is an average of the response over the frequency range of the measurement, and if the Frequency Domain data is measured out of band, then the Time Domain measurement will also be the out of band response. However, since the Time Domain Response-Resolution is inversely proportional to the frequency span, it may at times be desirable (with these limitations in mind) to use a frequency span that is slightly wider than the device bandwidth to give better resolution.

Source Considerations

Although either source will work well in making Time Domain measurements, the HP 8340A synthesized sweeper has the advantage that it provides greater dynamic range than the HP 8350B sweeper. The main reason for this is the frequency stability of a synthesized source. The small nonlinearities and phase discontinuities that occur in the ramp sweep mode cause low level noise sidebands on the Time Domain Impulse or Step stimulus. These interfere in measurements requiring large dynamic range. Perform a TRIM SWEEP adjustment before calibrating to help minimize these noise sidebands. Adjusting trim sweep is explained at the end of the section of this manual titled Measurement Calibration.

In the HP 8340A (synthesized) step sweep mode, the improvement in source stability eliminates these noise sidebands and improves the Time Domain measurement dynamic range by as much as 30 dB. A second improvement is that the HP 8340A stepped sweep mode allows the use of many averages per point without greatly affecting the sweep time, and this lowers the noise floor of the Time Domain measurement. It is recommended to perform a Trim Sweep adjustment prior to calibrating when making measurements in the ramp sweep mode to minimize phase discontinuities.

Test Set Considerations

The bridge-based test sets (HP 8513A and HP 8515A) have two advantages over the coupler-based test sets (HP 8512A and HP 8514A) when making Time Domain measurements. First, the bridge-based test sets extend in frequency to 26.5 GHz, versus 18 GHz for the coupler-based test sets. When measuring broadband devices, this extra bandwidth provides better Time Domain Response-Resolution.

The second advantage is that the bridge-based test sets have a flat response down to 45 MHz, whereas the coupler-based test sets begin to roll off (but are still usable) below 500 MHz. This coupler roll off reduces the dynamic range available at the low frequencies (-30 dB at 45 MHz) and therefore increases the Time Domain noise floor when measurements are made at those frequencies (this causes the trace bounce in the Low Pass Step response).