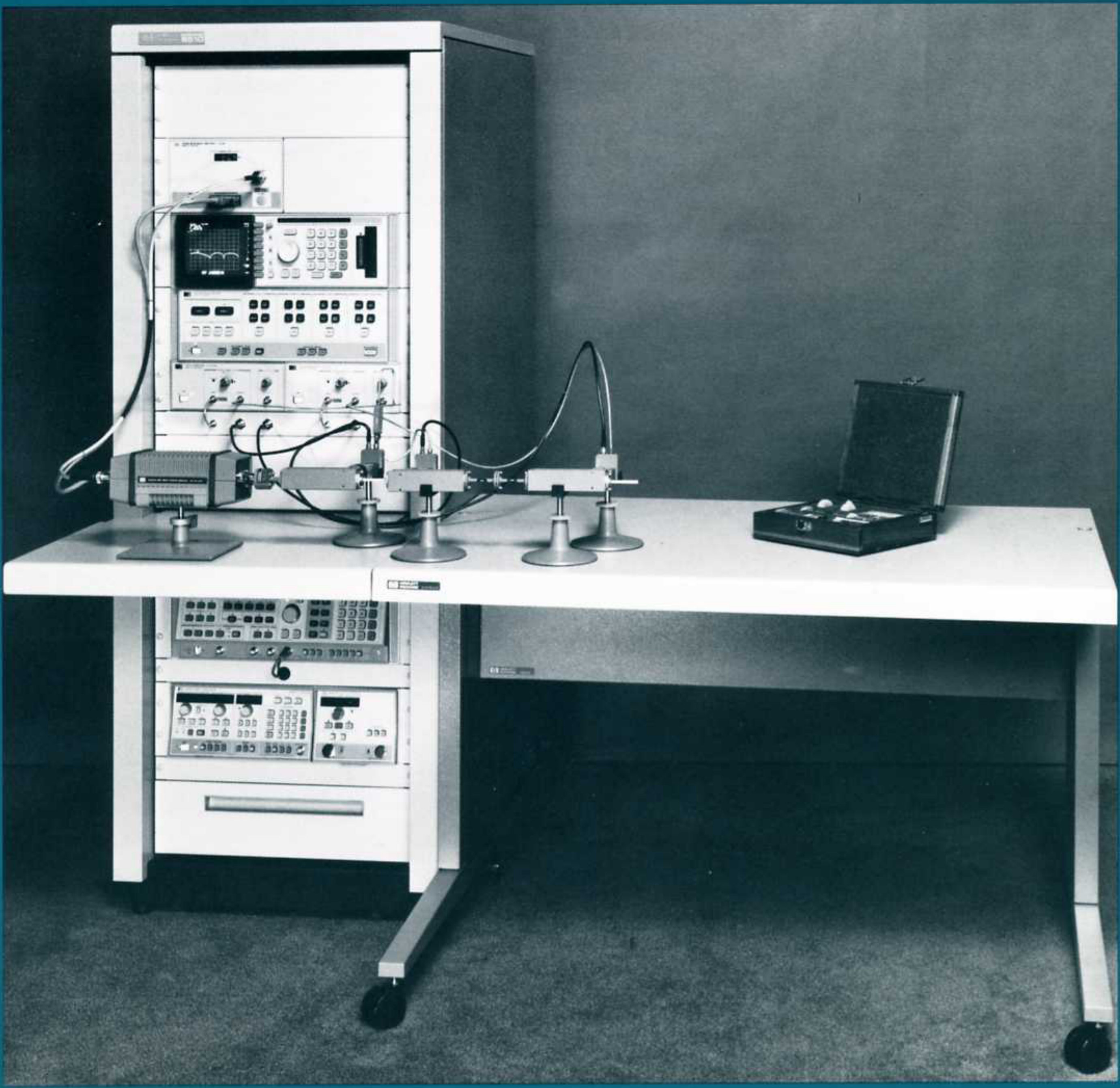
Product Note 8510-12

Millimeter-Wave Measurements
Using the HP 8510B Network Analyzer

HEWLETT PACKARD



Introduction

The HP 8510B network analyzer can be configured for wide dynamic range reflection and transmission measurements of components at millimeter-wave frequencies. This operating note describes the operation of this system, including calibration procedures and some typical measurement examples. This note applies to all HP 8510B millimeter-wave systems* whether they are configured as a benchtop system or a rack-mounted system, such as the HP 85106A. The following other topics are also discussed toward the end of the note:

Appendix A. Common problems and their solutions
Appendix B. Microwave test set operation
Appendix C. Multiple source settings
Appendix D. Upgrading an HP 8510A-based system

The millimeter-wave system uses two sources (one millimeter-wave source and one LO source), a band-independent LO/IF Kit, and one of five band-dependent Test Set Kits to take measurements covering the 26.5 to GHz, 33 to 50 GHz, 40 to 60 GHz, 50 to 75 GHz, and 75 to 100 GHz waveguide bands (R, Q, U, V, and W bands, respectively). Precision calibration standards for all bands permit full use of the built-in HP 8510B accuracy enhancement and data processing features. All of the equipment needed to configure a millimeter-wave measurement system is available from Hewlett-Packard.

In millimeter-wave operation, the HP 8510B uses its multiple source control mode to control both the test signal source and the local oscillator (LO) source over the entire frequency sweep. All system functions, from setting up the measurement frequencies to calibration and measurement, are controlled directly from the HP 8510B front panel. The measurement results are displayed on the HP 8510B CRT in the frequency and/or time domain. With the advent of the HP 8510B multiple source mode, operating an HP 8510B millimeter-wave system is as easy as using an HP 8510B microwave system.

With the addition of a microwave test set and RF switching control hardware, the system may also be configured for coaxial measurements from 45 MHz to 26.5 GHz. A single system can cover the entire frequency range from 45 MHz to 100 GHz with convenient switching between coaxial and waveguide measurements.

*HP 8510B requires firmware revision 3.1 or higher. To upgrade to revision 3.1, order the HP 11575B.

System Description

Shown in Figure 1 is a simplified block diagram of the mm-wave system, applicable to all waveguide bands. The system includes the HP 8510B network analyzer, a test signal source (HP 8340B or 8341B synthesizer and a multiplier), an LO source (HP 8340/41 synthesizer or HP 8350B sweep oscillator), an LO/IF kit (band-independent equipment) and a test set kit (band-dependent equipment).

Stimulus for the device under test is generated using the synthesized source followed by an HP 8349B power amplifier and frequency multiplier. Test set components separate portions of the incident, reflected, and transmitted signals from the main signal path to each of the three millimeter-wave harmonic mixers for the first IF conversion. This setup uses a reflection/transmission test set, so the device must be reversed for the measurement of the reverse parameters.

The second source provides the LO for all of the harmonic mixers. For the first three millimeter-wave bands (R, Q, and U), this LO source may be the more economical HP 8350B/83540A sweep oscillator rather than the HP 8341B synthesized sweeper. This LO source is set such that the millimeter-wave test signal frequency and the appropriate LO harmonic are offset by exactly 20 MHz.

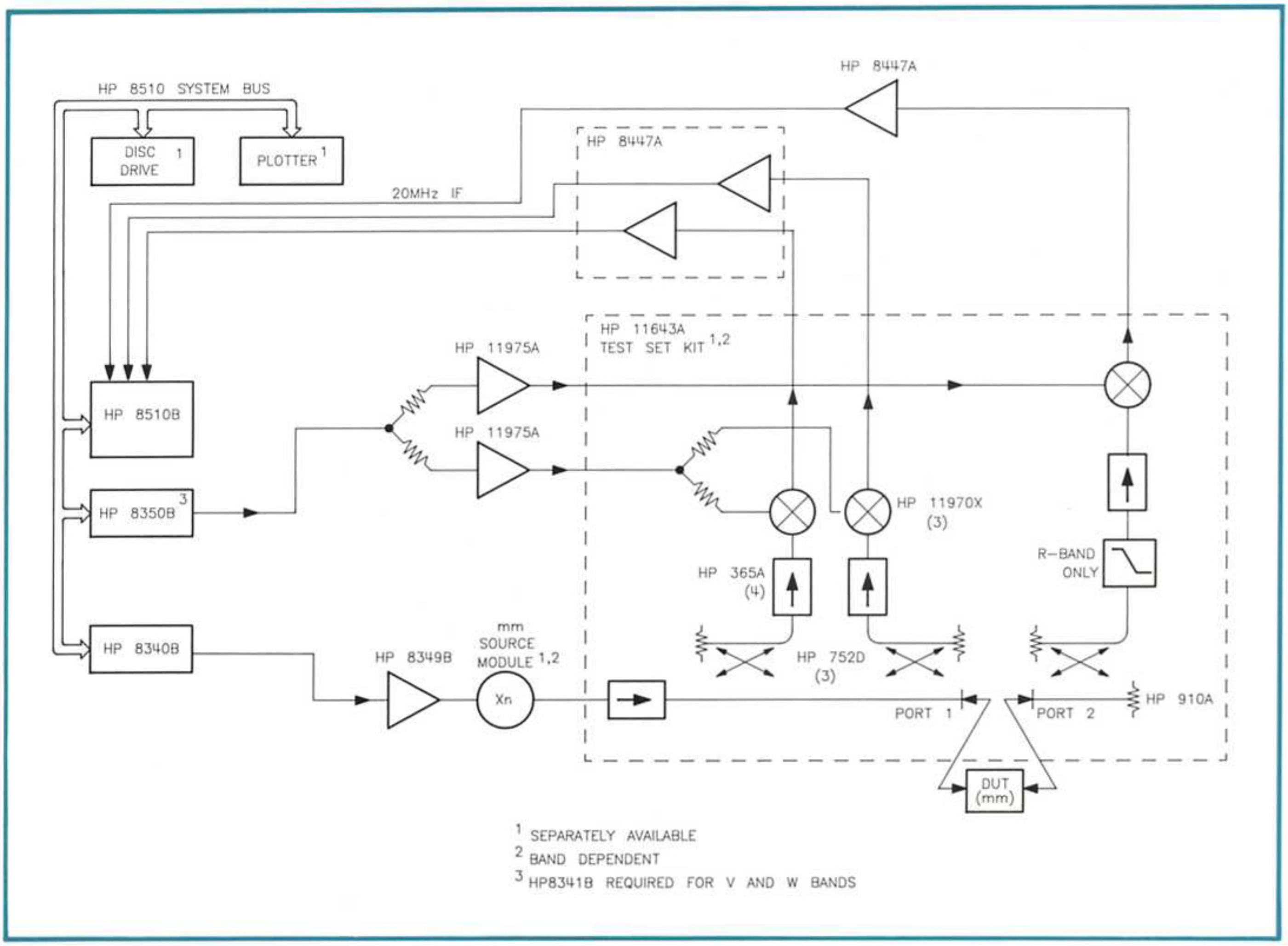


Figure 1. Simplified block diagram of the HP 8510B millimeter-wave system.

As an example of how the multiple source control works, consider a Q band (33-50 GHz) system which is set up to take a measurement from 42 GHz to 48 GHz with 201 points. At the 101st measurement point along the sweep, the test signal frequency at the DUT is 45 GHz. To generate this 45 GHz signal, the test signal source is set to 15 GHz, amplified, and its frequency is tripled by the HP 83555A source module (3x15=45). The incident, reflected, and transmitted portions of this 45 GHz signal are separated by the HP Q11643A test set, and enter the HP Q11970A harmonic mixers. Inside the harmonic mixer the 45 GHz signal is mixed with the tenth harmonic of the LO source to produce an IF signal of 20 MHz. This means that the tenth harmonic of the LO source is at 45.020 GHz, and the LO source fundamental frequency is at 4.502 GHz (10x4.502=45.020). If the LO source is an HP 8350B, the FM input is tuned to ensure the exact frequency.

The resulting 20 MHz IF signals are then processed by the HP 8510B. The same approach may be used to show that for the entire 201 point sweep, the test signal source sweeps from 14 GHz to 16 GHz while the LO source sweeps from 4.202 GHz to 4.802 GHz.

The resulting 20 MHz IF signals are amplified and then applied to the HP 8510B IF/detector section for the second frequency conversion to 100 kHz, detection, post-processing, and display on the HP 8510B CRT. (If the optional microwave test set is installed in the system, the 20 MHz signals first pass through the IF switch inside the microwave test set before entering the HP 8510B IF/detector section.) If an HP 8350B is used as the LO source, it is phase-locked through its FM input to the synthesizer via the external phase-lock feature of the HP 8510B.

The frequency control of the test and LO signal sources is provided by the HP 8510B operating in multiple source mode. The appropriate multiple source frequency definitions for each of the five millimeter-wave bands may be loaded into the HP 8510B directly from a data tape provided with the system manual.

System Operation

This section describes how to operate the millimeter-wave HP 8510B system, including the HP 85106A factory-configured millimeter-wave system. System operation includes setting up the stimulus parameters, calibrating the system, taking measurements, and saving/recalling system hardware and instrument states. To assist the user in troubleshooting the system operation, Appendix A contains a list of possible system problems and their remedies.

The system setup procedure is greatly simplified by loading the configurations from the Millimeter-wave System Tape. This tape, provided with the Millimeter-wave System Manual (HP part no. 85106-90001), contains all the appropriate hardware and instruments states for the millimeter-wave configurations.

The following procedure shows how to get the mm-wave system running.

1. Verify that the hardware is connected as described in the *Getting Started* section of the Millimeter-wave System Manual.

   Turn power on to all the system instruments except the HP 8510B and the two microwave sources. If a microwave coaxial test set is connected, it must also be powered on. Next, turn on the test signal source (source #1) and make sure its address is set to 19 by pressing SHIFT, LOCAL. If the address is not 19, enter 19 and press GHz. Then, turn on the LO source (source #2) and make sure its address is set to 18 by pressing SHIFT, LOCAL. (Press PRESET if necessary to activate the HP 8350B displays.) If the address is not 18, enter 18 and press GHz. Once these addresses are set, they will remain the same, so it is not necessary to set these addresses every time the system is powered up.

   Finally, turn on the HP 8510B. At this point, the HP 8510B may display an error message and a beeper may sound. Do not be alarmed. The HP 8510B will remain in an error condition until the multiple source mode is activated and the HP 8510B receives a signal that it can detect. In the meantime, the beeper may be turned off by pressing SYSTEM and selecting BEEPER OFF.

2. If a microwave coaxial test set is also connected in the system, then proceed with this step. If not, skip this step and proceed to step 3.

   The coaxial test set must be configured with the IF switching option (option 001). On power-up, this switch is not configured correctly for millimeter-wave measurements. The coaxial test set must be temporarily activated, then de-activated.

   Press SYSTEM, HP-IB ADDRESSES, then select TEST SET. Set the test set address to 20 by pressing 20, x1. The test set's ACTIVE light should go on. For mm-wave operation, set the address to 31 by pressing 31, x1. The test set's ACTIVE light should go off. If an RF switch is also used for microwave coaxial measurements (see Appendix B), then the SWITCH 0 light on the HP 11713A switch driver should go on during mm-wave operation.

3. Load the desired HARDWARE STATE from the system tape. Insert the tape cartridge into the HP 8510B tape drive, then press TAPE/DISC and select STORAGE IS TAPE. Select LOAD, MORE, HARDWARE STATE and select the file number for the desired frequency band (see Table 1).

Table 1. Files stored on the Millimeter-wave System Tape.

Frequency (GHz)	Band	LO Source	Hardware State File	Instrument State File
26.5-40	R	HP8350B	1	1
		HP 8341B	6	1
33-50	Q	HP 8350B	2	2
		HP 8341B	7	2
40-60	U	HP 8350B	3	3
		HP 8341B	7	3
50-75	V	HP 8341B	4	4
75-100	W	HP 8341B	5	5
.045-26.5	µWave	N/A	8	[PRESET]

When the HARDWARE STATE is loaded, the system parameters are automatically configured as follows:

- HP-IB addresses as follows:
  - Source #1 (test signal) — 19
  - Source #2 — 18
  - Test set — 31 (20 for microwave)
  - RF switch — 28
- Multiple Source Definitions as required for each band (see Appendix C for details). Multiple Source Mode ON.
- SYSTEM PHASELOCK:
  NONE for systems with two synthesizers.
  EXTERNAL for systems with an HP 8350B LO.
  INTERNAL for microwave coaxial setups.
- POWER LEVELING:
  EXTERNAL for source #1,
  INTERNAL for source #2.
  (For R, Q, and U bands, the source power is leveled at the output of the mm-wave source module. For V and W bands, the power is leveled at the output of the HP 8349B amplifier.)

These settings remain active until they are changed or a new file is loaded from tape. PRESET and power-up do not change these settings. Note that these definitions are automatically configured for the selected frequency band, so it is not necessary for the user to set or modify these parameters.

4. Load the desired INSTRUMENT STATE from the system tape. Press TAPE/DISC and select STORAGE IS TAPE. Select LOAD, INSTRUMENT STATE 1-8, and choose an instrument state register (*n*). Then select the file number for the desired frequency band (see Table 1). To activate this instrument state, press RECALL and choose the appropriate instrument state (*n*).

   Note: Instrument state 8 is recalled each time the system is powered up. Since the hardware state is not modified at power-up, the HP 8510 system can be configured to power up in a particular band by loading the instrument state into register number 8.

   The instrument state is then automatically configured for measurements in the desired band. The INSTRUMENT STATE conditions are the same as the PRESET conditions, with these exceptions:

- Start/Stop frequencies set for full band sweep, e.g. 40-60 GHz.
- SYSTEM Z_o =1 (System impedance for waveguide measurements).
- STEP sweep mode. (The millimeter system does not operate in RAMP mode.)
- WAVEGUIDE DELAY, Cutoff frequency (f_{co}) for each band.
- Source #1 POWER set for maximum power from the HP 8349B.

5. Load the desired CAL KIT file from the tape in the appropriate HP 11644A-series calibration kit. Insert the tape cartridge and press TAPE/DISC, LOAD, CAL KIT 1-2, CAL KIT 1, and select CAL KIT FILE 1.

Operational Notes

Once the millimeter-wave system has been configured according to the preceding instructions, the system is ready for normal operation. The HP 8510B front panel behaves the same as for microwave measurements with the following exceptions.

PRESET key not recommended.

When using the millimeter-wave HP 8510B system, it is recommended that the PRESET key not be used. If the PRESET key is pressed, the system hardware state will not be affected, but the instrument state will revert back to the standard microwave system instrument state. The operator must then RECALL the millimeter-wave INSTRUMENT STATE saved in step 4.

Power Control

Changing source output power is accomplished by incrementing or decrementing the output power function value, displayed by the HP 8510B after pressing STIMULUS MENU, POWER MENU, SOURCE 1 POWER. The actual output power is displayed by the HP 8349B amplifier LED display. For R, Q, and U bands, the readout indicates the power at the output of millimeter-wave source module. For V and W bands, the readout indicates the power at the output of the HP 8349B amplifier.

Frequency Control

Start and stop frequencies must be entered using the numeric keypad. The knob and step keys will not function in multiple source mode. Due to source resolution, frequency entries are sometimes modified by the HP 8510. For example, with the U-band system, an entry of 40 GHz may appear as 39.999999996 GHz.

Operational Check

A quick operational check may be performed by observing the power levels of the HP 8510B User parameters a1, b1, and b2. This test gives the user a high level of confidence that the system is operating properly. For complete system verification, see the *Performance Verification* section of the mm-wave system manual.

1. Turn averaging off by pressing RESPONSE MENU, AVERAGING OFF. Connect the test ports together and measure the parameter labeled USER2 (b2). Press PARAMETER MENU, USER2. The approximate power level (Log Mag) displayed on the HP 8510B display should be as indicated in Table 2. Next, measure the parameter labeled USER1 (a1) and verify that its power level is approximately as indicated in Table 2.
2. Disconnect the test ports and connect a flush short to test port 1, and measure USER4 (b1). Check to insure that the b1 power level is approximately as indicated in the table.

   If any of the power levels shown below are not observed, consult the *Service* section of the mm-wave system manual.

Table 2. Typical power levels for operational check of the mm-wave system.

Frequency (GHz)	Band	b2	Power Level a1	b1
26.5-40	R	−29	−29	−29
33-50	Q	−30	−30	−30
40-60	U	−32	−32	−32
50-75	V	−56	−56	−46
75-100	W	−62	−62	−52

Disc Drive Simplifies Setup Procedure

When using the millimeter-wave system tape, the hardware state, instrument state, and cal kit must each be loaded to configure the system for the desired band (steps 3-5). With an external disc drive such as the HP 9122D, all these definitions can be loaded in a single step. This procedure takes advantage of the HP 8510 MACHINE DUMP feature, and simplifies the configuration process considerably.

1. Configure the system for the desired band as described earlier. The hardware state, instrument state, and cal kit must be loaded. You may also wish to define other settings, such as the averaging factor, display format, etc. These will all be saved with the MACHINE DUMP.
2. Connect the disc drive to the 8510 system bus and enter its address into the HP 8510B. Press SYSTEM, HP-IB ADDRESSES, DISC. Enter the disc address, usually 0, then press x1.

   Insert a blank disc into drive 0 and initialize the disc by pressing TAPE/DISC, STORAGE IS DISC, SETUP DISC. Press INITIALIZE DISC, Yes.
3. Store the MACHINE DUMP to disc. Press TAPE/DISC, STORAGE IS DISC, STORE, MORE, MACHINE DUMP. Enter the desired disc file label, for example RBAND or UWAVE, using the knob and the SELECT LETTER key. The prefix MD— indicates a MACHINE DUMP file. Press STORE FILE.
4. To recall this configuration at any time, simply press TAPE/DISC, STORAGE IS DISC, LOAD, MORE, MACHINE DUMP. Select the desired MACHINE DUMP file, and press LOAD FILE.

   Once the MACHINE DUMP is loaded, the hardware state, instrument state, and cal kit are all loaded in a single step.

System Calibration

A perfect vector network analyzer would exhibit flat frequency response, no impedance mismatches, and infinite isolation between channels. In an actual system, all of these characteristics are imperfect, but are generally repeatable and predictable. To correct for these systematic errors, a calibration is performed using known impedance standards connected at the measurement ports. All of the required standards are supplied with the HP 11644A-series calibration kits.

For the millimeter-wave HP 8510B system, four kinds of measurement calibrations are available: Response, Response/Isolation, S_{11} 1-PORT, and ONE-PATH 2-PORT. These different techniques vary in complexity as well as in performance, as described in *Choosing the Right Calibration Technique*. The calibration procedure is described below.

Before Calibration

1. Be sure the CAL KIT definition is loaded in the HP 8510B. This definition is contained on the tape in the HP 11644A-series calibration kits. Press CAL to check the calibration kit label.

2. Set all of the desired STIMULUS characteristics for the device measurement. This includes the frequency range, the number of points, power level, etc. If the DUT must be measured using different STIMULUS settings, then another measurement calibration must be performed.

   It is also advisable to turn on AVERAGING; 64 is a good amount. Press RESPONSE MENU and select AVERAGING ON, then enter 64, x1.

3. Verify that the system Z_o is set to 1. This is used to normalize impedance in waveguide. Press CAL, MORE, SET Z_o. Remember, pressing PRESET will set the system impedance to 50 ohms. If the system Z_o is not 1, RECALL or re-load the instrument state for the desired band.

The following sequences describe how to perform system calibration for the various calibration types.

Response Calibration

1. Select the parameter to be measured. Press CAL and select the appropriate CAL KIT 1 (or 2) WR-xx. Then select CALIBRATE: RESPONSE. (If a Response/Isolation calibration is desired, select RESPONSE & ISOL'N.)

2. Now connect the calibration standard, a thru for transmission or a short for reflection and press the appropriate softkey. After the standard is measured, press DONE RESPONSE.

   If a Response/Isolation calibration has been selected, then perform the Isolation calibration. Connect a load to the test port, and a short circuit to port 2. Select ISOL'N STD, and when the measurement is complete, press SAVE RESP&ISOL.

   The error coefficients are computed and the Cal Set selection menu is displayed. Press one of the cal set keys to store the error coefficients and turn correction on. The corrected response is automatically displayed.

S_{11} 1-PORT Calibration

1. Press CAL and select the appropriate CAL KIT 1 (or 2) WR-xx. Then select CALIBRATE: S_{11} 1-PORT. S_{11} will automatically be displayed on the screen.

2. Connect the flush short and press SHORT. After the short is measured, insert the quarter-wave offset shim between the test port and the flush short to make a quarter-wave offset short, and press OFFSET SHORT and wait for this measurement to be completed.

3. Press LOADS and notice that you now have several choices for the load. Choose either FIXED, OFFSET, or SLIDING.

   a. FIXED LOAD only. Simply connect the load and select FIXED. When the measurement is complete, press DONE LOADS.

   b. OFFSET LOAD. Select OFFSET, and the two load selections appear, LOAD NO OFFSET, and LOAD OFFSET. Connect the fixed load directly to the test port and press LOAD NO OFFSET. After the measurement, insert the quarter-wave offset shim between the test port and the fixed load. Press LOAD OFFSET, and when the measurement is complete, press OFFSET LOAD DONE, then DONE LOADS.

   c. SLIDING LOAD (not available for V and W bands). Connect the sliding load. Be sure the slide is locked in a fixed position before connecting. Select SLIDING, and then SLIDE IS SET. After the measurement, change the position of the sliding load and press SLIDE IS SET again. Repeat this for at least five positions of the load, covering the full range of positions. Press DONE LOADS.

4. Press SAVE 1-PORT CAL. The error coefficients are computed and the Cal Set selection menu is displayed. Press one of the cal set keys to store the error coefficients and turn on correction. The system is now ready for fully error-corrected reflection measurements of one-ports.

ONE-PATH 2-PORT

1. Press CAL and select the appropriate CAL KIT 1 (or 2) WR-xx. Select CALIBRATE: ONE-PATH 2-PORT.

   Press REFLECT'N, and do an S_{11} 1-PORT calibration as described above. When all three reflection standards have been measured, press REFLECT'N DONE.

2. Next, connect the test ports together and press TRANSMISSION followed by FWD. TRANS. THRU. When the measurement is completed, select FWD. MATCH THRU. Press TRANS. DONE when the measurement is complete.

3. Press ISOLATION. The isolation calibration is recommended for wide dynamic range measurements, but it is not required. To omit the isolation cal, press OMIT ISOLATION. To perform the isolation cal, connect the load to port 1 and press FWD ISOL'N ISOL'N STD. Press ISOLATION DONE.

4. Press SAVE 2-PORT CAL. The error coefficients are computed and the Cal Set selection menu is displayed. Press one of the cal set keys to store the error coefficients and turn correction on.

5. To measure a device, connect it between the test ports, and select a parameter to measure by pressing S_{11}, S_{21}, S_{12}, or S_{22}. Follow the on-screen instructions to connect the test device for forward measurement, then PRESS to CONTINUE. Once the measurement in the forward direction is complete, follow the instructions to connect the device for reverse measurement, then PRESS to CONTINUE. The error-corrected measurement will then appear on the display. Any of the four S-parameters may now be selected for display. To repeat the measurement, press MEASUREMENT RESTART.

Choosing the Right Calibration Technique

The millimeter-wave system allows four kinds of measurement calibrations: Response, Response/Isolation, S_{11} 1-port, and One-path 2-port. Table 3 shows the system errors and which ones are corrected by each calibration type. This section describes the various calibration types and when each is appropriate.

Table 3. Calibration Types and the errors that are corrected.

	Response	Resp/Isol Refl.	Resp/Isol Trans.	S_{11} 1-port	1-path 2-port
Freq. Resp.	x	x	x	x	x
Directivity		x		x	x
Source Match				x	x
Load Match					x
Crosstalk			x		x

The frequency RESPONSE calibration provides for vector normalization of a test (reflected or transmitted) signal with respect to a reference (incident) signal. One standard is required: a flush short for reflection measurements or a zero-length thru for transmission measurements. Frequency response is the only error that is removed with this calibration. The RESPONSE calibration is useful when measuring a well-matched device or when a quick check of device performance is required.

The Response/Isolation calibration accounts for both frequency response and isolation effects. In reflection measurements, both tracking and directivity are removed. In transmission measurements, tracking and crosstalk errors are removed. The isolation standard for either transmission or reflection measurements is the fixed load. The Response/Isolation calibration is useful when measuring well-matched or high loss devices.

An S_{11} 1-port calibration requires three standards to quantify and remove the system frequency response, source match, and directivity. The standards used for this calibration are a flush short, a quarter-wave offset short, and a Z_o termination. Several load standards may be used; see *Choosing the Right Load Standard*. The S_{11} 1-port cal provides best accuracy for one-port devices.

A one path 2-port calibration consists of an S_{11} 1-port calibration followed by a transmission isolation calibration and a transmission frequency response calibration, both using a zero-length thru. This calibration provides best accuracy for 2-port devices using full 12-term error correction, but requires manual reversal of the device under test to measure all four S-parameters.

Another technique for measuring 2-port devices on a reflection/transmission test set like the HP 11643A-series test sets is to combine an S_{11} 1-port calibration and an S21 thru response calibration. With this technique it is not necessary to reverse the device during measurement. This is usually the fastest way to measure a two-port device on a reflection/transmission test set. Since this technique does not account for source and load match effects, it is recommended for measurements of well-matched or high loss devices.

The relative accuracy of the various calibration techniques is shown in Figure 2 for the Q-band system. Notice how the accuracy depends upon the S-parameters of the device under test.

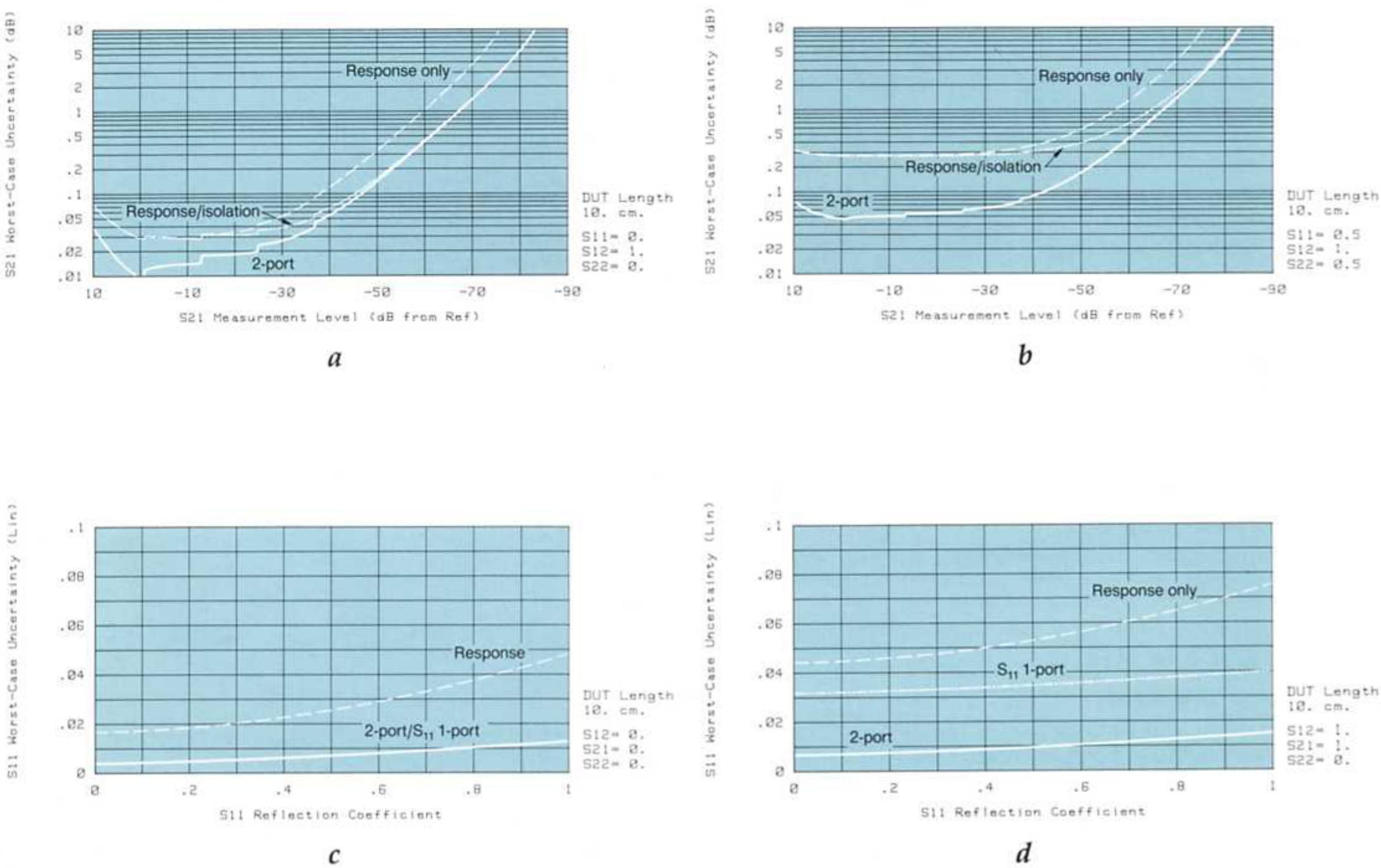


Figure 2. Plots of the accuracy for various calibration types with 1024 averages. a) S_{21} uncertainty for well-matched device ($S_{11}=S_{22}=0$), b) S_{21} uncertainty for a poorly matched device ($S_{11}=S_{22}=0.5$), c) S_{11} uncertainty for a high loss device ($S_{21}=S_{12}=0$), and d) S_{11} uncertainty for a low loss device ($S_{21}=S_{12}=1$).

Choosing the right load standard

A load termination is used to determine the system directivity — the error signal that appears in the reflected signal path that did not reach the test port. This section describes the various load standards that can be used by the HP 8510B.

The fixed load is the simplest load standard and provides adequate performance for many applications. During a fixed load cal, the measured directivity is the combination of the actual system directivity and the reflection coefficient of the load. The effective system directivity is therefore dependent on the reflection coefficient of the load element (see Figure 3a).

Combining a fixed load with an offset load offers significantly better system directivity. This "offset load" technique (also called "short line" technique) is a two-step process. First, the fixed load is connected to the test port and measured. Then the same fixed load is offset by a precisely known distance and measured again. Using these two measurements and the angle, the HP 8510B can determine the exact directivity. With the offset load, the dimensions (and the impedance) of the offset determine the effective system directivity. The performance is significantly improved to over 50 dB effective directivity (46 dB in W-band). The accuracy of the offset load technique depends on how precisely the offset length is known (see *Entering the exact offset delay*).

A sliding load may also be used to determine directivity. The load element is moved to five (or more) positions, determining corresponding points of the circle of Figure 3c. The HP 8510B then uses a circle-fitting routine to determine the center of the circle which is the actual directivity. Again, the effective directivity is determined by the dimensions of the line. Effective directivity with the sliding load is 50 dB in R, Q, and U bands.

An important concern with the sliding load is the mechanical stability of the load element. This restriction has made the sliding load technique impractical in V and W bands, due to the small dimensions.

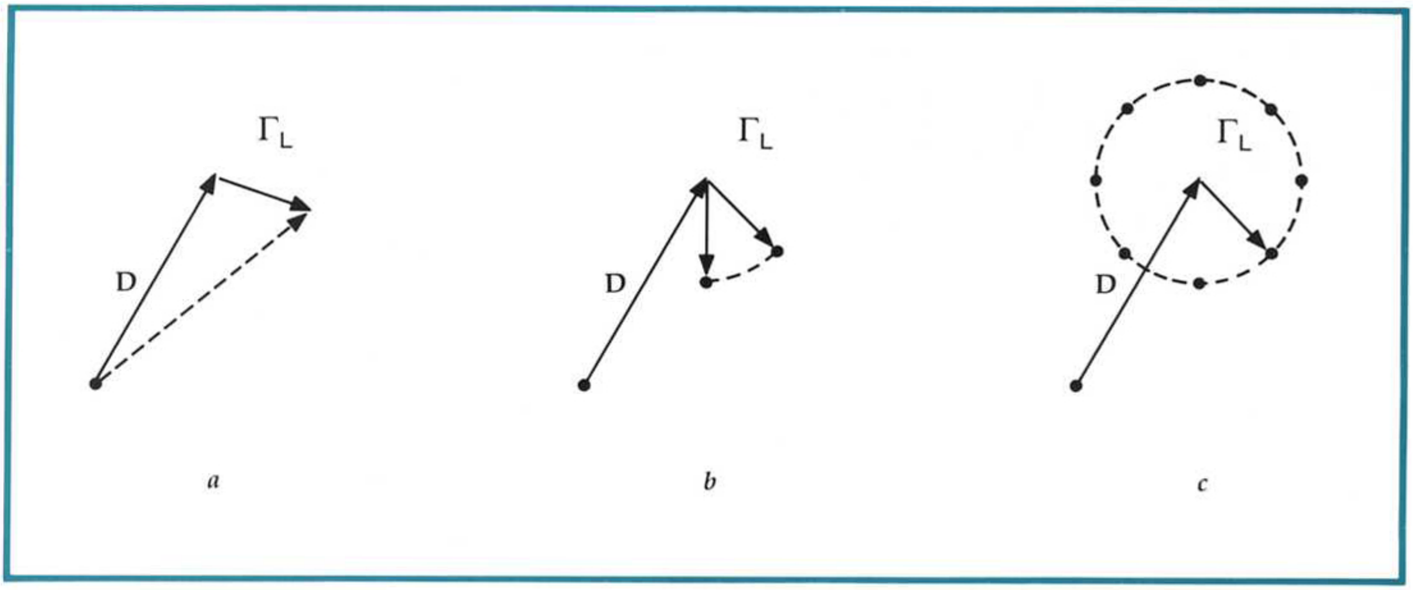


Figure 3. Phasor diagram during directivity measurement using a) fixed load, b) offset load, and c) sliding load.

Modifying the CAL KIT definitions

The "cal kits" loaded from tape contain definitions of the various waveguide standards in the 11644-series calibration kits. For each of the waveguide bands, the file contains the "nominal" length of the waveguide section used to make the quarter-wave offset short and the quarter-wave offset load (see Table 4).

Table 4. Calibration Kit Nominal Offset Delay

Freq (GHz)	Band	Waveguide Designation	Nominal $\lambda g/4$	Cutoff f_{co} (GHz)
26.5-40	R	WR-28	10.0702ps	21.069
33-50	Q	WR-22	8.084	26.340
40-60	U	WR-19	6.646	31.382
50-75	V	WR-15	5.378	39.864
75-100	W	WR-10	3.620	58.995

Defining the Offset Load Standard

Calibration kits with revision 2.0 or higher (check tape for revision no.) contain the definition for the offset load standard. If you have a previous revision, you can add the offset load using the following procedure.

1. Press CAL, MORE, MODIFY 1 WR-xx. This initiates the process of modifying the calibration kit.

2. Define the offset load standard. Press DEFINE STANDARD, 20, x1. Select LOAD, OFFSET. Press SPECIFY OFFSET, and define the parameters in the SPECIFY OFFSETS menu as follows:
   - OFFSET DELAY: Nominal delay for the desired band (see table)
   - OFFSET LOSS: 0
   - OFFSET Z_0: 1
   - MINIMUM FREQUENCY: Enter f_{co} for the desired band (see table)
   - MAXIMUM FREQUENCY: Enter 2 times f_{co}

   Select WAVEGUIDE, then STD OFFSET DONE. Press LABEL STD and use the knob and SELECT LETTER key to enter label "OFFSET", then press TITLE DONE. Press STD DONE (DEFINED).

3. Add the offset load standard to the appropriate classes ($S_{11}C$ and $S_{22}C$). Press SPECIFY CLASS, SPECIFY $S_{11}C$. Enter the three load standards by pressing 9, x1, 10, x1, and 20, x1. Repeat for $S_{22}C$ and press CLASS DONE (SPEC'D). Save the kit by pressing KIT DONE (MODIFIED).

   Note that the "*" in the cal kit label indicates that the cal kit has been modified. (The label can be modified using LABEL KIT.) This new definition will remain in the HP 8510B memory until a new kit is loaded.

4. Save this definition onto the CAL KIT tape, but do not write over the original CAL KIT file. Press TAPE/DISC, STORAGE IS TAPE, STORE, CAL KIT 1-2, CAL KIT 1, then FILE 2.

Entering the Exact Offset Delay

Calibration accuracy can be improved by entering the actual measured length of the quarter-wave waveguide section instead of the nominal value as defined on the Cal Kit tape. The actual value of the waveguide section is engraved on the waveguide section itself and may be entered into the Cal Kit standard definitions using the following procedure.

1. Read the engraved number on the quarter-wave waveguide section (in mm). Calculate the offset delay using the following formula:

   $$\text{Offset delay (ns)} = \frac{L(\text{mm})}{299.6953\ \text{mm/ns}}$$

   where L is the length in mm and 299.6953mm/ns is the velocity of propagation in air (23 degrees C, 50% humidity, 760mm of pressure).

   This is the length of the section in millimeters. Press CAL, MORE, MODIFY 1 WR-xx. This initiates the process of modifying the calibration kit.

2. Define the offset delay of the offset short circuit. Press DEFINE STANDARD, 3, x1. Standard 3 is the offset short.

   Select SHORT, SPECIFY OFFSET, OFFSET DELAY. The offset delay is then displayed, both in picoseconds of delay and in millimeters of length. Enter the exact offset delay in ns from step 1. Press STD OFFSET DONE, STD DONE (DEFINED).

3. Define the offset delay of the offset load standard (if any). Press DEFINE STANDARD, 20, x1. Standard 20 is the offset load.

   Select LOAD, SPECIFY OFFSET, OFFSET DELAY. The offset delay is displayed. Enter the exact offset delay from step 1.

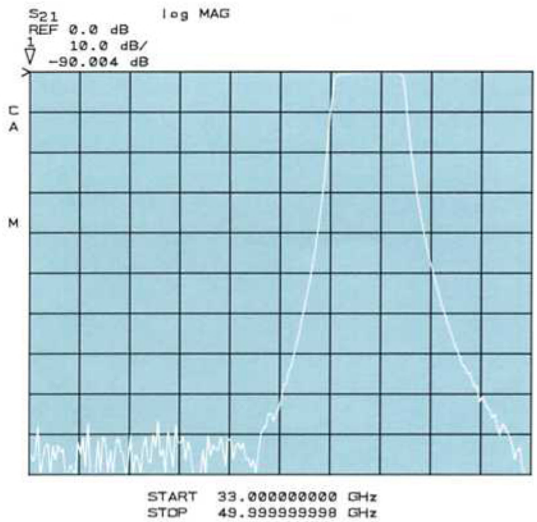
   Press STD OFFSET DONE, STD DONE (DEFINED), then KIT DONE (MODIFIED). The "*" in the cal kit label indicates that the cal kit has been modified. (The label can be modified using LABEL KIT.) This new definition will remain in the HP 8510B memory until a new kit is loaded. You may also want to store this definition onto tape or disc for future reference.

For further information on modifying the cal kit definition see Product Note 8510-5A (HP lit. no. 5954-1559).

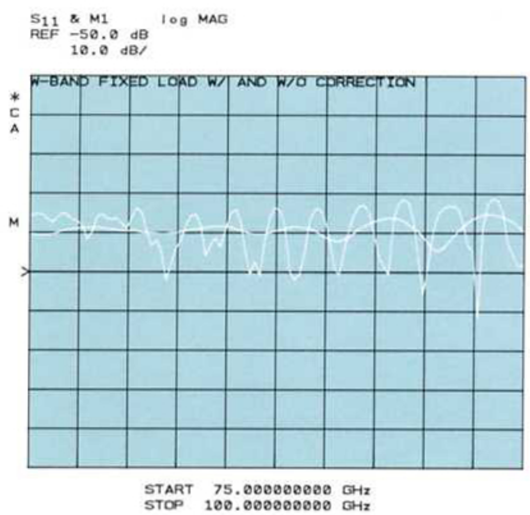
Example Measurements

The millimeter-wave HP 8510B system, with its multiple source mode, waveguide line stretcher, frequency list mode, and other new features, is capable of making measurements with unprecedented speed, accuracy, and convenience.

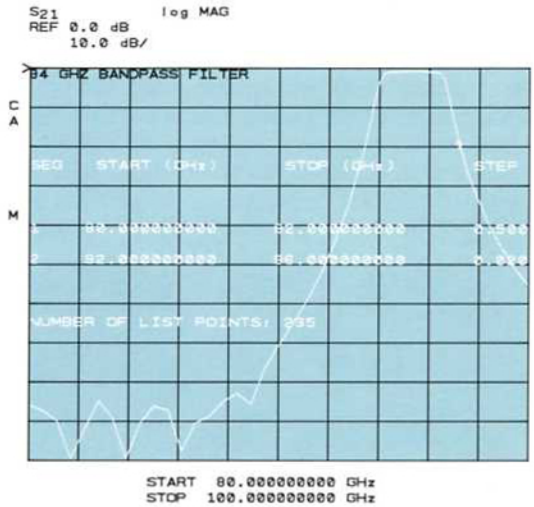
The frequency conversion technique used by the HP 11643A-series test set kits allows high dynamic range measurements of millimeter-wave components. This measurement shows the transmission response of a 44 GHz bandpass filter measured from 33 GHz to 50 GHz. This kind of high dynamic range is achieved in every band.



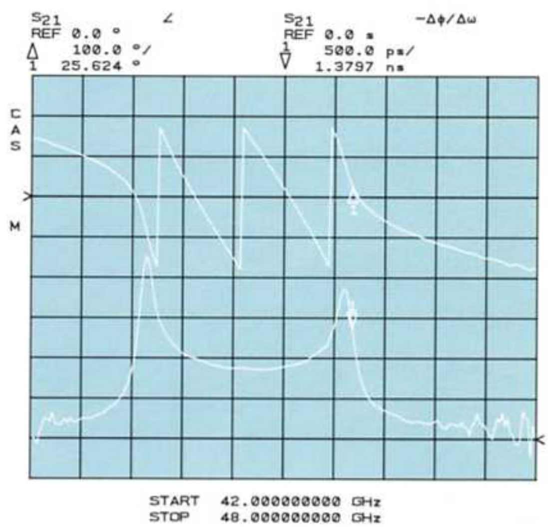
Built-in error-correction provides a powerful measurement capability at millimeter-wave frequencies. Systematic errors can be mathematically removed from the measurement system by measuring calibration standards with precisely known characteristics. The measurement shown here compares the uncorrected and corrected impedance measurements of a W-band fixed load. The slowly varying trace shows the result using an S_{11} 1-port calibration.



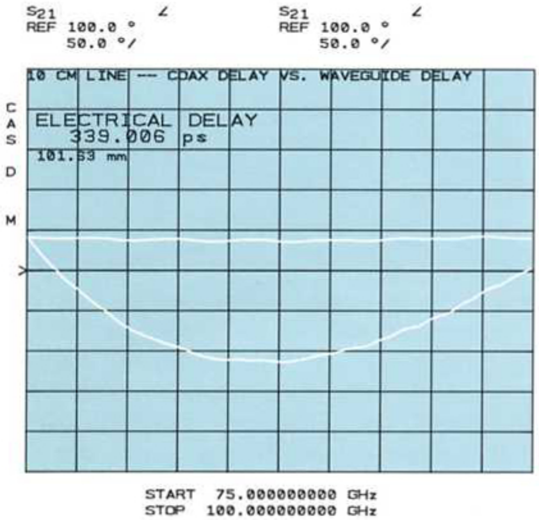
The HP 8510B frequency list mode allows the measurement of devices at specific user-defined frequency points. In this measurement of a 94 GHz bandpass filter, frequency list mode is used to measure the filter transmission response from 80 GHz to 100 GHz in 500 MHz steps, with an increased resolution of 20 MHz from 92 GHz to 96 GHz.



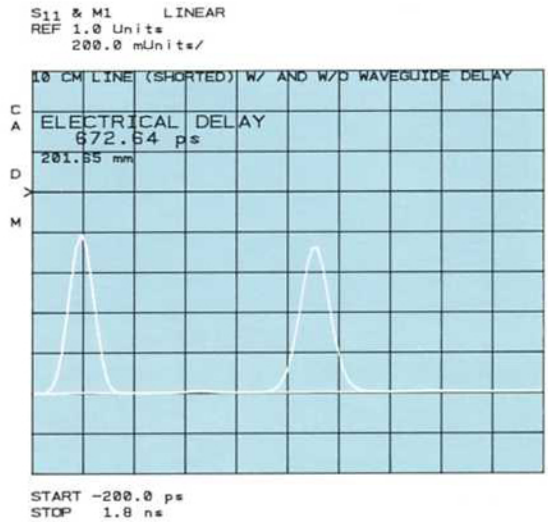
Phase and group delay measurements are easily made by selecting PHASE and DELAY in the PARAMETER MENU of the HP 8510B. It should be remembered that the propagation constant in waveguide and other non-TEM transmission lines is frequency dependent and that phase and group delay will therefore also exhibit this frequency dependence. This measurement shows the phase and group delay of the 44 GHz bandpass filter.



The HP 8510B waveguide delay may be used to compensate for the frequency dependent propagation constant of rectangular waveguide (dispersion). First, input the waveguide cutoff frequency (f_{co}) by pressing RESPONSE MENU, MORE, WAVEGUIDE DELAY, and entering the appropriate f_{co} for the waveguide band in use. The electrical delay then applied will vary as a function of frequency to account for dispersion. This measurement shows the phase response of the 10 cm line with electrical delay applied. Note that coaxial delay (linear) cannot flatten the phase response. With waveguide delay, the phase response can be flattened, so the actual device length can be measured.



When the HP 8510B is equipped with Option 010, Time Domain, use TIME BAND PASS to locate impedance changes within the device under test. Here, the S_{11} time band pass response of a shorted 10 cm waveguide section is shown, with and without waveguide delay applied. With no delay applied, the reflection of the short is displayed at about 900 ps. Both the magnitude and location of this time domain response are affected by the dispersive nature of the waveguide. To get a more exact measurement of the shorted line, waveguide delay is added to move the response to time t=0. The delay required is 672 ps, or 201.65 mm, which is the actual electrical length of the waveguide section (round trip). Notice also the change in magnitude, due to the dispersion. The corrected response now displays the actual effects of the loss in the line and is unaffected by dispersion.



Appendix A
Common problems and their solutions

While setting up for millimeter-wave measurements, you may encounter some of the following operational problems. Shown below are some recommended things to check for when these problems are encountered.

Problem:
CAUTION: NO IF FOUND displayed
(or very low detected signal levels)
Possible Causes and Solutions:
If a microwave test set is also connected, verify that the test set ACTIVE light is off. If it is on, then toggle the test set address. Press SYSTEM, HP-IB ADDRESSES, TEST SET. Enter 20, x1, then 31, x1. If an RF SWITCH is also used, the SWITCH 0 light should be on during mm-wave operation, off during microwave operation.

Problem:
CAUTION: PHASE LOCK LOST displayed
Possible Causes and Solutions:
PRESET was pressed, so the sweep mode was set to ramp. the mm-wave system does not operate in RAMP. Recall the mm-wave instrument state.

Problem:
CAUTION: SYSTEM BUS ADDRESS ERROR
Possible Causes and Solutions:
RF SWITCH DRIVER not connected or at incorrect address. Check address. If no switch driver is used, press ENTRY OFF and ignore this error.

Problem:
No Sweep, inactive trace; START/STOP frequencies set to 0 GHz.
Possible Causes and Solutions:
System source addresses set incorrectly. Power off the HP 8510B and set the correct addresses on the sources (SHIFT LOCAL).

Problem:
Data is grossly incorrect after calibration.
Possible Causes and Solutions:
PRESET was pressed and the system Z_o was reset to 50 ohms. RECALL the correct mm-wave instrument state (Z_o=1).

Appendix B

Microwave test set operation

The HP 8510B millimeter-wave system may also be configured for coaxial microwave measurements from .045 to 26.5 GHz. This requires a coaxial test set (e.g. HP 8515A) with option 001 (IF switching) recommended.

Also recommended is an RF switch to switch the RF test signal source from the synthesizer to the input of the HP 8515A test set. Using this configuration (see Figure 4), the system may be easily switched from millimeter-wave to microwave test set operation without changing rear panel connections. This configuration is used in the HP 85106A option 001.

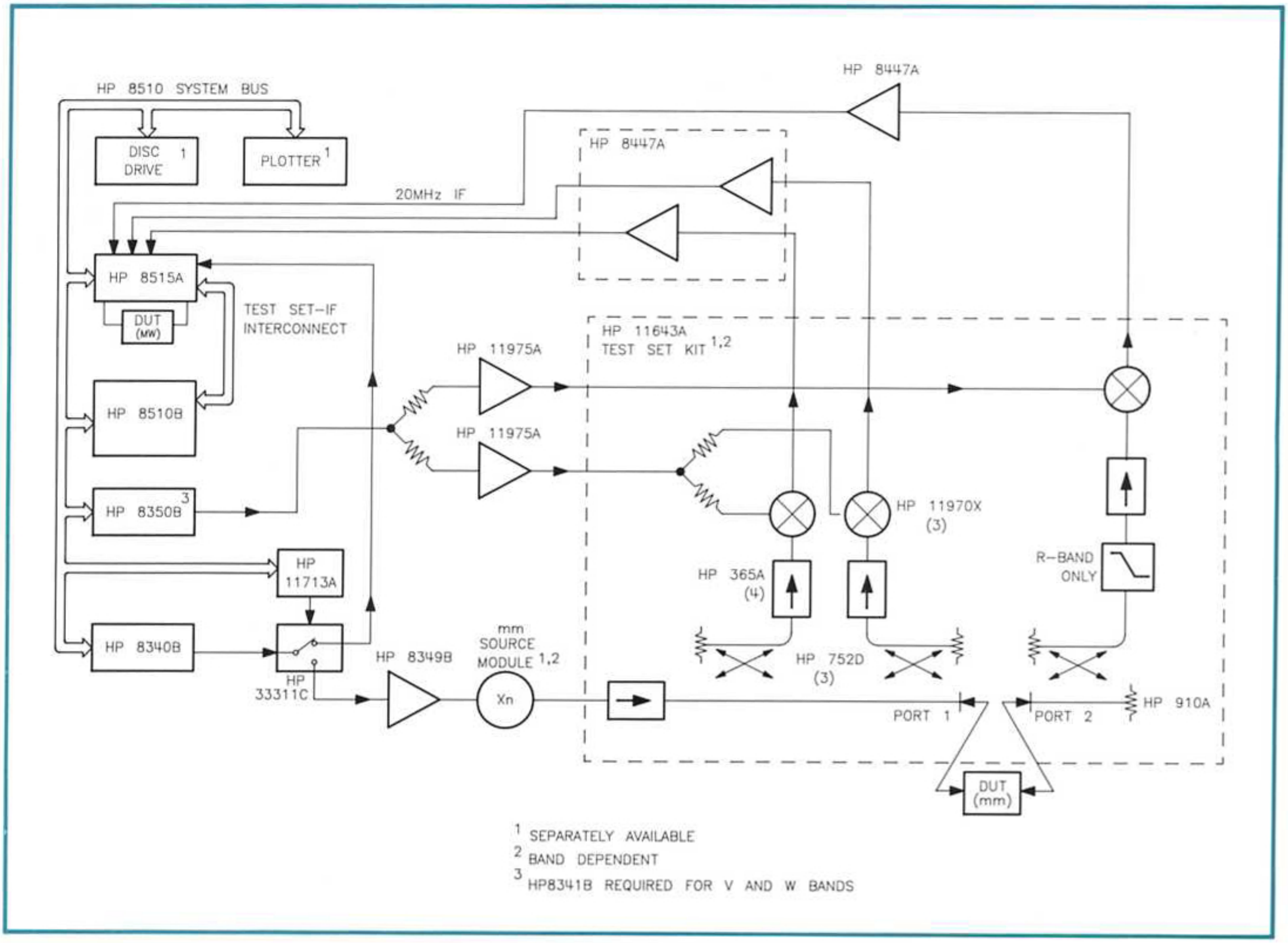


Figure 4. Block diagram of millimeter-wave/ microwave HP 8510B system.

The following procedure describes how to configure the millimeter-wave system for microwave coaxial measurements.

1. Disconnect the millimeter-wave test set and connect the coaxial test port cables. Configure the test set and switching hardware as shown in Figure 4. Notice that the HP 8515A test set must be configured with option 001 (IF switching). The HP 85106A system with option 001 includes the test set already configured this way.

   When powering up the system, it is only necessary to power on the instruments that will be used in the microwave measurements. It is not necessary to power on the LO source or other hardware used only for mm-wave measurements. The HP 11713A switch driver must be on for microwave or mm-wave measurements.

2. Load the microwave HARDWARE STATE from the mm-wave system tape. Press TAPE/DISC, STORAGE IS TAPE, LOAD, HARDWARE STATE, and select file 8. Press PRESET (it is not necessary to load an instrument state from tape. The key differences between the mm-wave state and the microwave state are shown in Figure 5.

   The test set's ACTIVE light should go on.

	Millimeter-wave	Microwave
Test Set Address	31	20
System Phase Lock	None or External	Internal
Mlt. Src.	On	Off
Leveling Source #1	External	Internal
Sweep Mode	Step	Ramp
System Z_0	1	50

Figure 5. Millimeter-wave vs. microwave settings

3. Verify that the address of the RF switch driver (HP 11713A) is set correctly in the HP 8510B. Press SYSTEM, HP-IB ADRESSES, MORE, RF SWITCH, 28, x1.

4. Load the CAL KIT definition from the tape in the desired coaxial calibration kit. Insert the tape, and press TAPE/DISC, STORAGE IS TAPE, LOAD, CAL KIT 1-2, etc. You may wish to store a coaxial calibration kit in CAL KIT 2 and a mm-wave cal kit in CAL KIT 1.

Appendix C
Multiple source settings

The multiple source settings are shown below for all the mm-wave bands. These definitions are loaded automatically when the hardware state is loaded. It is also possible to set and modify these parameters from the front panel of the HP 8510B under SYSTEM, MORE, EDIT MLT. SRC.

```
R-BAND

OPERATING FREQUENCIES

SOURCE 1:
   1/2 * ( FREQ  +     0.000000000 GHz )

SOURCE 2:
   1/8 * ( FREQ  +     0.020000000 GHz )

RECEIVER:
      0.020000000 GHz

This definition is ACTIVE

FREQ is the DUT frequency specification

                  START  26.500000000 GHz
                  STOP   40.000000000 GHz
```

```
Q-BAND

OPERATING FREQUENCIES

SOURCE 1:
   1/3 * ( FREQ  +     0.000000000 GHz )

SOURCE 2:
   1/10 * ( FREQ  +     0.020000000 GHz )

RECEIVER:
      0.020000000 GHz

This definition is ACTIVE

FREQ is the DUT frequency specification

                  START  33.000000000 GHz
                  STOP   49.999999998 GHz
```

```
U-BAND

OPERATING FREQUENCIES

SOURCE 1:
   1/3 * ( FREQ  +     0.000000000 GHz )

SOURCE 2:
   1/10 * ( FREQ  +     0.020000000 GHz )

RECEIVER:
      0.020000000 GHz

This definition is ACTIVE

FREQ is the DUT frequency specification

                  START  39.999999996 GHz
                  STOP   60.000000000 GHz
```

```
V-BAND

OPERATING FREQUENCIES

SOURCE 1:
   1/5 * ( FREQ  +     0.000000000 GHz )

SOURCE 2:
   1/14 * ( FREQ  +     0.020000000 GHz )

RECEIVER:
      0.020000000 GHz

This definition is ACTIVE

FREQ is the DUT frequency specification

                  START  50.000000000 GHz
                  STOP   75.000000000 GHz
```

```
W-BAND

OPERATING FREQUENCIES

SOURCE 1:
   1/5 * ( FREQ  +     0.000000000 GHz )

SOURCE 2:
   1/18 * ( FREQ  +     0.020000000 GHz )

RECEIVER:
      0.020000000 GHz

This definition is ACTIVE

FREQ is the DUT frequency specification

                  START  75.000000000 GHz
                  STOP  100.000000000 GHz
```

Appendix D
Upgrading a HP 8510A-based system

Upgrading a millimeter-wave HP 8510A system to a millimeter-wave HP 8510B system provides some significant benefits. No computer is required to run the system, and a sweep oscillator may be used as the system LO. These enhancements are described below in more detail.

To upgrade an HP 8510A to an HP 8510B system, order the HP 85103A Performance Upgrade Package. To aid in the installation and service of the millimeter-wave HP 8510B system, users must order the *HP 8510 Millimeter-wave Network Analyzer Systems Installation and Service Manual* (HP part no. 85106-90001).

No Computer Required.

Once the upgrade is performed, the HP 85129A software and the external computer used to run it are no longer required (all system instruments are connected directly to the HP 8510B system bus). The external computer may now be used for other purposes such as storing and/or evaluating measurement data. All system functions from calibration to verification are controlled directly from the front panel of the HP 8510B with the same ease as a standard microwave system.

Sweep Oscillator LO for R, Q, and U bands

When upgrading a millimeter-wave HP 8510A system to a millimeter-wave HP 8510B system, it may be cost effective to replace the LO synthesizer with an HP 8350B/83540B sweep oscillator (only applicable to R,Q, and U bands). This change requires only a minor investment in the sweep oscillator, and does not affect the performance of the system. The synthesizer could then be used in another measurement system.

System Speed Improvement

Because the computer is no longer used in the system, the system speed is improved dramatically, as shown in the following times for a typical sweep:

Computer-based system: 125ms per pt.
HP 8510B system
  w/ HP 8350B as LO: 80ms per pt.
  w/ HP 8341B as LO: 50ms per pt.

For more information, call your local HP sales office listed in your telephone directory or an HP regional office listed below for the location of your nearest sales office.

United States:
Hewlett-Packard Company
4 Choke Cherry Road
Rockville, MD 20850
(301) 670-4300

Hewlett-Packard Company
5201 Tollview Dr.
Rolling Meadows, IL 60008
(312) 255-9800

Hewlett-Packard Company
5161 Lankershim Blvd.
No. Hollywood, CA 91601
(818) 505-5600

Hewlett-Packard Company
2000 South Park Place
Atlanta, GA 30339
(404) 955-1500

Canada:
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6877 Goreway Drive
Mississauga, Ontario L4V1M8
(416) 678-9430

Japan:
Yokogawa-Hewlett-Packard Ltd.
29-21, Takaido-Higashi 3-chome
Suginami-ku, Tokyo 168
(03) 331-6111

Latin America:
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Sp.A. de C.V.
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Lomas de Chapultepec
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(905) 596-7933

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Blackburn, Victoria 3130
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(03) 895-2895

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26 Harbour Road, Hong Kong
(5) 833-0833

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Hewlett-Packard-Strasse
6380 Bad Homburg
West Germany
(49) 6172/400-0

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2, avenue du Lac
91040 Evry Cedex, France
(33) 1/60778383

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(4) 344/424898

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Via G. di Vittorio, 9
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(39) 2/923691

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1180 AZ Amstelveen,
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(31) 0/437771

Southeast Europe/Africa/ Middle East:
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1217 Meyrin 1, Geneva
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