Errata

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HP References in this Application Note

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Application Note 374-1

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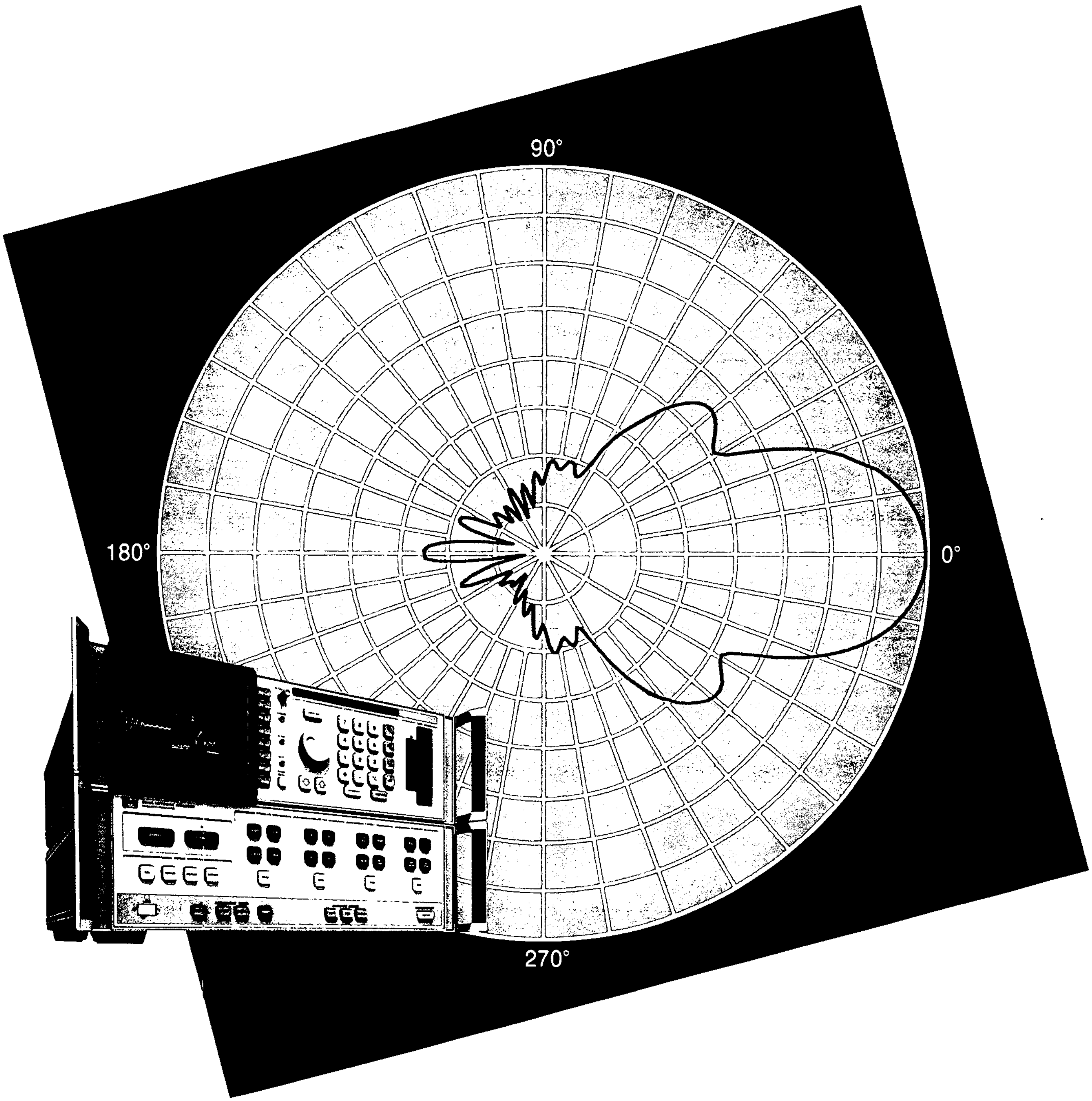
Antenna Measurements
Manual Pattern Measurements Using the HP 8510B



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Introduction

This note describes how to configure and use the Hewlett-Packard Model 8510B Network Analyzer to perform far field antenna pattern measurements. Following a brief overview of the major subsystems in an antenna test system, several HP 8510B receiver configurations are presented with a discussion of performance considerations. Step-by-step procedures for performing manual pattern measurements are included as well as results of measurements made on an indoor range. Several features of the HP 8510B which provide high speed data acquisition and control for high resolution pattern measurements are discussed in an appendix with an example program which illustrates how these features can be used.

General familiarity with the manual operation of the HP 8510B and the fundamental principles of antenna pattern measurements are assumed in this note. For general information on the use of the HP 8510B, please refer to the "**Getting Started**" section of the **HP 8510B Operating and Programming Manual** (P/N 08510-90070) or **Product Note 8510-10, HP 8510B Introductory Users Guide** (Literature P/N 5954-8367). Additional information on antenna pattern measurements and general information on the HP 8510B Network Analyzer is available from the literature referenced in this note.

System Overview

While there are several different kinds of far field antenna ranges, the measurement equipment used on an antenna range does not vary significantly between antenna range configurations. As shown in Figure 1, the measurement and control equipment can be divided into four fundamental subsystems.

Receiver Subsystem

The receiver subsystem is a key element in an antenna measurement system, providing measurements of amplitude and phase of the received signal from the antenna under test (AUT). As the AUT is rotated about an axis, the main lobe, side lobes, and nulls of the AUT will be illuminated by the source antenna. For highly directional antennas, this causes the power level of the received signal from the AUT to vary over a wide range as the antenna is rotated. Accurate characterization of the nulls of an antenna, where the received power is lowest, dictates the need for a receiver with wide dynamic range and excellent sensitivity. The linearity of the receiver is also critical since the power level variation from the first null to the peak of the main lobe can be as much as 60 dB. The receiver subsystem must be capable of accurately testing the highest performance antenna that will be characterized on the range. Phase-locked tuned receivers, such as the HP 8510B, offer the best combination of broadband frequency coverage, sensitivity, linearity, and dynamic range.

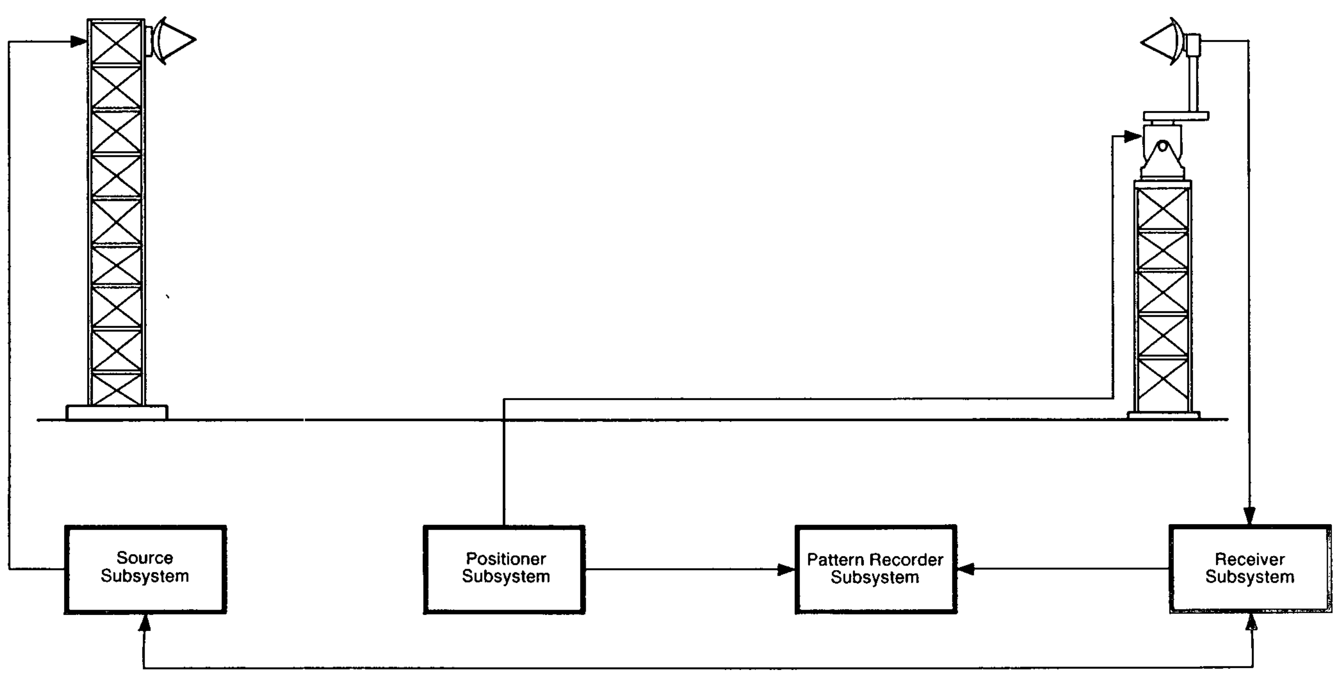


Figure 1. Typical Antenna Test System Block Diagram

Source Subsystem

The source subsystem provides an RF stimulus to the source antenna which illuminates the AUT. As the physical distance between the source antenna and the AUT increases, the spherical wave-front begins to approximate a plane wave. An industry rule of thumb dictates that this distance must be at least $(2D^2)/\lambda$, where D is the largest dimension of the AUT and λ is the wavelength of the test frequency. The RF source must be capable of providing a constant frequency that is stable for the duration of the test in order to ensure measurement accuracy. The source subsystem should also cover a broad frequency range to increase the flexibility and testing capabilities of the range. RF output power is another important parameter since large amounts of propagation loss can potentially limit the overall performance of the antenna range. Additionally, the source subsystem should be capable of being controlled from the receive end of the antenna range where the remainder of the measurement equipment is usually located.

Positioner Subsystem

The positioner subsystem provides the capability of rotating the AUT about one or more axes so that many different orientations of the AUT can be illuminated by the source antenna for testing. The positioner subsystem also provides the current angular position through either an analog or digital interface to other subsystems so that the receiver data acquisition can be synchronized to the position of the test antenna.

Pattern Recorder Subsystem

The pattern recorder subsystem provides the means of obtaining a hard copy of the measured pattern in either a polar or rectangular format. Inputs to the pattern recorder subsystem are provided by the positioning and receiver subsystems. The positioning subsystem provides the angular position of the AUT to the pattern recorder in either an analog or BCD format. The receiver subsystem provides an analog voltage proportional to the received amplitude or phase of the AUT.

HP 8510B Receiver Configurations

The HP 8510B provides several configurations with different levels of performance which can be matched to a particular antenna range. The HP 8511A Frequency Converter, when used with the HP 8510B, provides a convenient and economical microwave receiver with excellent measurement performance. The HP 8510B also supports an external mixer configuration for applications which require additional sensitivity and dynamic range or higher frequency coverage. The following sections will examine both of these configurations in detail.

HP 8511A Configuration

The HP 8510B receiver, when used with an HP 8340B Synthesized Sweeper and an HP 8511A Frequency Converter, provides frequency coverage from 45 MHz to 26.5 GHz, with typically over 88 dB of dynamic range and better than −98 dBm sensitivity at the inputs of the test set. As illustrated in Figure 2, the HP 8340B synthesizer provides the RF signal to the source antenna and is controlled by the HP 8510B through its system interface bus. If the distance between the HP 8340B and the HP 8510B is in excess of 20 feet, HP 37204A HP-IB[1] Extenders (or equivalent) should be used. The output of the source is amplified as necessary to provide the largest possible signal incident on the AUT without compressing the front end of the receiver. One possible RF amplifier is the HP 8349B Microwave Amplifier, which typically provides 14 dB of gain and +20 dBm output power from 2 GHz to 20 GHz. Other commercially available amplifiers can be used to provide additional frequency coverage or higher output power. In this configuration, a portion of the RF signal is routed through a coaxial cable to the a_1 input of the HP 8511A to phase-lock the receiver to the test frequency. For ranges where this approach is not practical, the phase-lock reference signal can be obtained by pointing a high gain, fixed position antenna at the source antenna. The received signal from the AUT is routed through an RF cable to the b_2 input of the HP 8511A.

1. HP-IB is Hewlett-Packard's hardware, software, documentation, and support for IEEE-488 and IEC-625, worldwide standards for interfacing instruments.

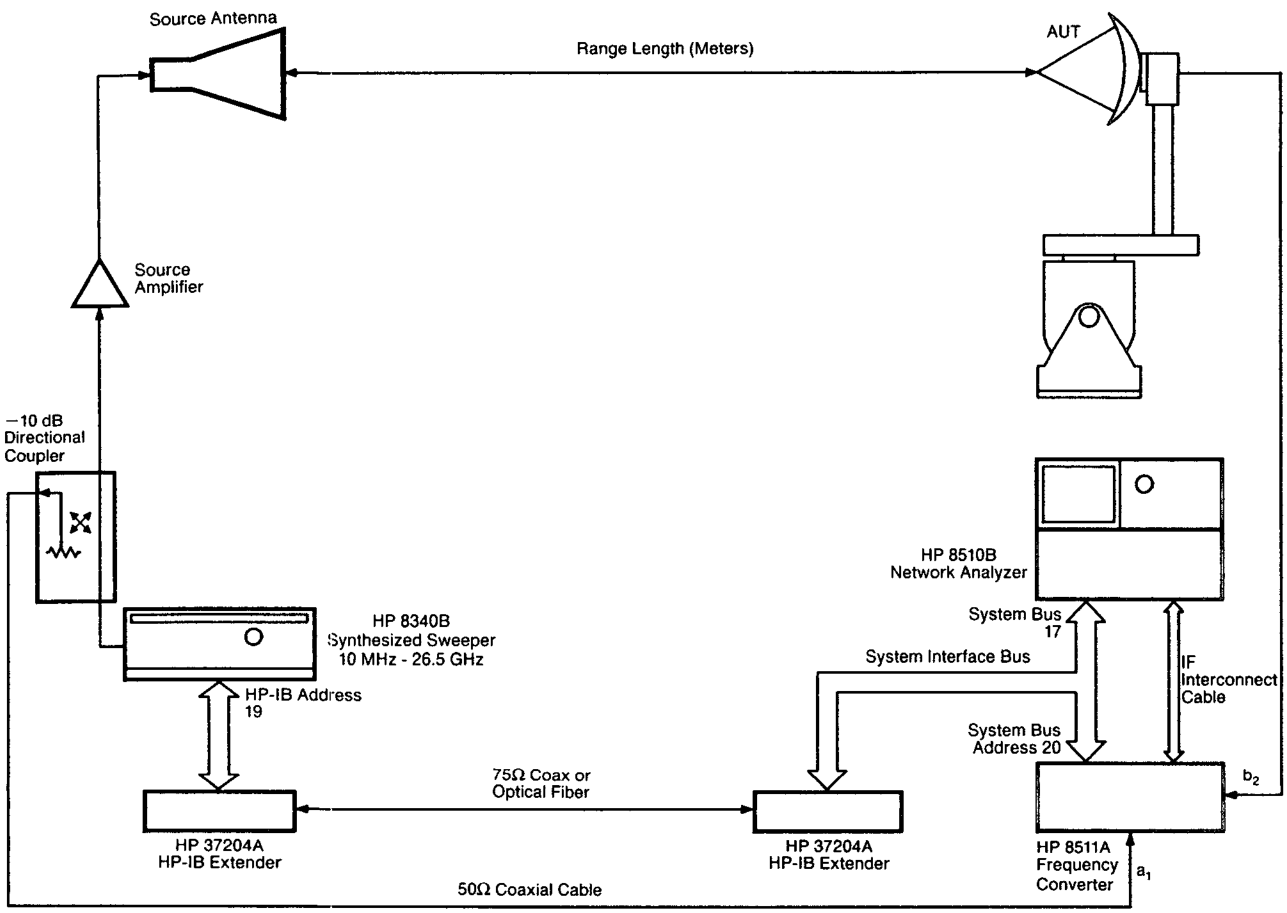


Figure 2. Antenna Test System Using an HP 8511A Frequency Converter

The HP 8511A is a harmonic sampler which uses a built-in 50 MHz to 300 MHz voltage tuned oscillator (VTO) as the local oscillator (LO) for the sampler. A selected harmonic of the VTO mixes with the reference and test signals to produce IF signals that are approximately 20 MHz. The IF reference signal frequency is compared to a 20 MHz frequency reference in the HP 8510B, and a tuning voltage is generated to fine tune the VTO frequency such that an IF frequency of exactly 20 MHz is generated. The reference and test IF signals are routed through the IF interconnect cable from the HP 8511A to the HP 8510B where they are downconverted to 100 kHz, detected, and measured. The HP 8510B displays the ratio of test signal relative to the reference signal (b2/a1) in the format selected by the user. By measuring the ratio of the test signal to the phase-lock reference signal, any variations common to both paths, such as source output power variations or phase shift, are removed from the measurement. When the ANALOG OUTPUT is turned on, the displayed parameter is also converted to an analog voltage which is used as an input to a pattern recorder.

External Mixer Configuration

In many applications, stringent antenna specifications dictate the need for state-of-the-art measurement capability from the antenna range. On long outdoor ranges, where much lower power levels are encountered, additional receiver sensitivity is required to compensate for the added losses. The HP 8510B supports a receiver configuration which allows fundamental or low harmonic external mixers to be used to significantly reduce the conversion loss from the RF frequency to the IF frequency. Additional sensitivity can be obtained by connecting the test mixer directly to the output of the AUT so that the cable losses between the AUT and the HP 8510B occur at the IF frequency instead of the RF frequency.

When using an outdoor range, it can sometimes be impractical to generate a reference signal by routing a sample of the RF source through a cable. Instead, a high gain, fixed position reference antenna (See Figure 3) is used to receive a portion of the radiated test signal and generate a reference signal in this manner.

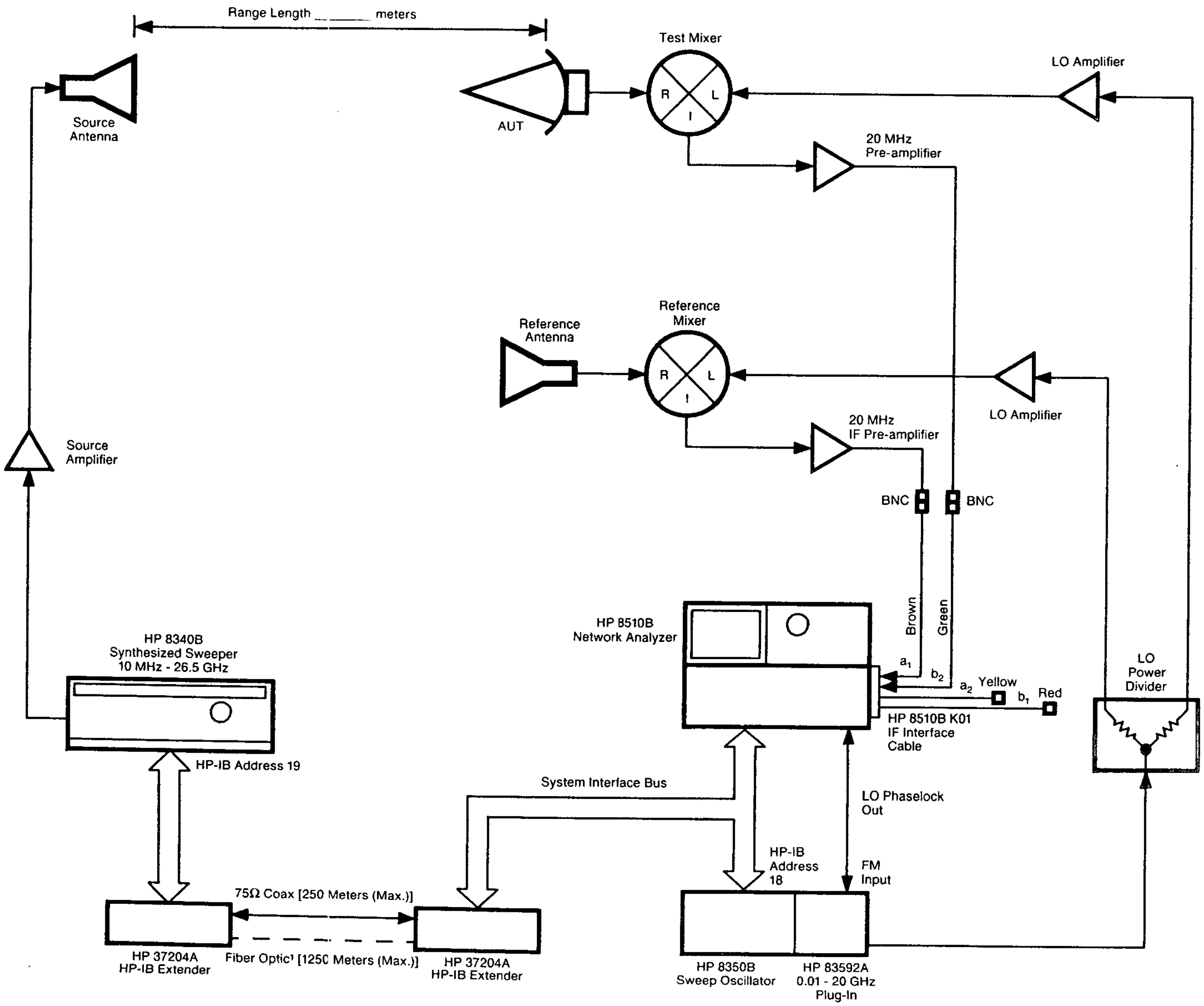


Figure 3. External Mixer Antenna Test System

1. To use optical fiber, include option 002 with the HP 37204A extender.

In the external mixer configuration, an HP 8350B Sweep Oscillator or an HP 8340B-series Synthesized Sweeper can be used to provide the LO drive to external mixers located at the back of the reference and test antennas. The HP 8510B controls both the RF and LO sources through its system interface bus. An LO phase-lock tuning voltage is available through a rear panel BNC connector of the HP 8510B (when external phase-lock is selected) to phase-lock the HP 8350B through its FM input to the incoming RF signal. The frequency relationships of the RF, LO, and IF signals are defined in the HP 8510B Multiple Source menu to allow fundamental or harmonic mixing to be used. Detailed information on how to use the Multiple Source mode is contained in the PERFORMING PATTERN MEASUREMENTS section of this note. The 20 MHz IF signals are amplified and routed directly to the IF input of the HP 8510B where they are downconverted and measured. As in the HP 8511A configuration, the ratio of the test signal relative to the reference signal is displayed on the CRT of the analyzer, and the analog output is directed to the pattern recorder.

The reference mixer may also be located at the reference antenna. However, when external phase-lock is used, the one-way distance between the HP 8510B and the reference mixer must not exceed 50 feet (150 feet with HP 8510B Option H15). This distance limitation occurs because the cable and reference mixer are now part of the HP 8510B's phase-locked loop.

Measurement Performance

Sensitivity

The HP 8511A is a harmonic sampler which uses high harmonic numbers and allows a low frequency VTO to be used to reduce the cost of the system. However, using harmonic downconversion with high harmonic numbers reduces the receiver subsystem's sensitivity and can be subject to measurement errors due to spurious signals. The 0.1 dB input compression level of the HP 8511A test set is −10 dBm and the typical sensitivity with a signal-to-noise (S/N) ratio of 1 is −98 dBm which results in an 88 dB dynamic range for the receiver. Sensitivity can be significantly improved by using IF averaging to reduce uncorrelated noise by 10*log(# of averages) at the expense of added acquisition time. For example, an averaging factor of 64 improves the RF sensitivity by 18 dB and requires an additional 12.8 msec/point.

However, the overall performance of the receiver subsystem is determined by more than just the receiver itself. Sensitivity is directly impacted by the RF and IF losses between the HP 8510B and the test antenna. High quality, low insertion loss cable should also be used to minimize the RF losses between the AUT and the HP 8511A. To reduce RF cable losses, an optional IF interconnect cable is available in either 10, 20, or 40 foot lengths (08510-60107, 08510-60103, or 08510-60104) which allows the HP 8511A test set to be located closer to the AUT. The input power at the reference input port (a_1) of the HP 8511A must be between −10 dBm and −45 dBm to reliably phase-lock the receiver. When a coaxial cable is used to obtain the phase-lock reference signal, excessive insertion loss in the reference RF cable can limit the phase-lock range of the receiver. In this case, a more practical solution may entail the use of a fixed position reference antenna to receive the reference signal.

In the external mixer configuration, fundamental mixing provides the best RF sensitivity by minimizing the conversion loss through the external mixers. This added sensitivity is gained at the expense of using a higher LO source frequency which increases the cable loss between the LO source and the mixers. RF sensitivity can also be improved by using a low noise IF pre-amplifier between the mixer and the HP 8510B to reduce the overall noise figure of the receiver. As an example, an amplifier with a 6 dB noise figure and 20 dB of gain reduces the noise figure of the receiver from approximately 24 dB to 10.1 dB. As mentioned previously, IF averaging can also provide further improvements in sensitivity by reducing uncorrelated noise.

Table 1 summarizes the typical measurement sensitivities which can be obtained from the HP 8511A and external mixer receiver configurations. Measurement sensitivity for the external mixer configuration is shown for fundamental, second, and third harmonic operation using commercially available mixers. Appendix A contains additional information which will be helpful in determining which configuration is best for a particular application.

HP 8510B Measurement Sensitivity (dBm)

Averaging Factor	HP 8511A	External Mixers (N = 1)	External Mixers (N = 2)	External Mixers (N = 3)
1	−98	−119	−113	−109
2	−101	−122	−116	−112
4	−104	−125	−119	−115
8	−107	−128	−122	−118
16	−110	−131	−125	−121
32	−113	−134	−128	−124
64	−116	−137	−131	−127
128	−119	−140	−134	−130
256	−122	−143	−137	−133
512	−125	−146	−140	−136
1024	−128	−149	−143	−139
2048	−131	−152	−147	−142
4096	−134	−155	−150	−145

Table 1. Measurement Sensitivity -vs- Averaging Factor

Port-to-Port Isolation

The phase-lock reference signal for the HP 8510B is obtained through a reference cable or a high gain, fixed position reference antenna. In either case, the reference signal is usually at a higher power level than the test signal received from the AUT. This is especially true when the AUT is oriented so that the source antenna is illuminating a null in the pattern of the AUT. If an RF signal path exists which allows the reference signal to couple into the test signal path, measurement error can result. The magnitude of the error is dependent on the signal levels of both the reference and test signals and the isolation between the reference and test signal paths.

The HP 8511A Frequency Converter has a specified port-to-port isolation to 80 dB and is relatively immune to this source of measurement error. However, in the external mixer configuration, a potentially significant leakage path between the reference and the test mixers does exist through the LO signal path (See Figure 3). To illustrate this situation, consider the case where fundamental mixing is being used. The RF-to-LO isolation of a broadband fundamental mixer, and the port-to-port isolation of a power divider, is typically 20 dB. Without the additional isolation provided by the LO amplifier, this would provide approximately 60 dB of port-to-port isolation between the reference and test mixer, and could cause significant measurement error. The forward gain of the HP 8349B Microwave Amplifier at 10 GHz is specified to be 15 dB, and the reverse isolation is typically 50 dB. This improves the port-to-port isolation to 95 dB and ensures sufficient LO drive level to the mixers.

This source of measurement error can also be reduced by using mixers that operate on the second or third harmonic. Harmonic mixing results in much better RF-to-LO isolation, typically greater than 45 dB. This improves the port-to-port isolation from 95 dB to 145 dB. Using the second or third harmonic increases the conversion loss of the mixers by only 6 dB or 10 dB, respectively, and may prove to be an acceptable performance tradeoff. Since the HP 8510B allows either fundamental or harmonic downconversion, the choice of harmonic number can be made for each test antenna to optimize the system's measurement accuracy. Refer to Appendix A for more detailed information on calculating reference path isolation.

Spurious Susceptibility

A disadvantage of any receiver that uses harmonic downconversion techniques is its susceptibility to measurement errors caused by spurious signals. These errors can occur when the intended test signal is being downconverted by one harmonic, and a spurious signal is being downconverted into the IF passband of the receiver by another harmonic. The degree of susceptibility is directly proportional to the harmonic number being used. When more than one signal is downconverted into the IF passband of the receiver, the vector sum of the two (or more) signals is measured. This can cause a varying signal amplitude if the phase relationship between the desired and spurious signals changes as a function of time. The amount of error will be dependent on the amplitude and phase of the spurious signal. Therefore, the HP 8511A is best utilized on indoor ranges or outdoor ranges where susceptibility to spurious signals is not considered a significant factor. In the external mixer configuration, fundamental mixing provides the best immunity to spurious signals. However, depending on the frequency content of the spurious signal present on a particular range, using the second or third harmonic for the RF to IF downconversion may provide sufficient spurious immunity.

Acquisition Speed

The HP 8510B has several measurement modes which provide a range of acquisition rates. In a manual range, where the analog output is used to provide an input to a pattern recorder, the SINGLE POINT mode provides continuous data at rates of 39 msec/point. For applications which require high resolution pattern data, an automated data acquisition mode, called FASTCW, provides synchronized data acquisition rates of less than 1 msec/point. Appendix B provides more detailed information on the FASTCW mode. When IF averaging is used to increase measurement sensitivity, an additional 0.2 msec/point is required for each averaging factor.

It is important to ensure that the acquisition rate of the receiver is fast enough to allow the AUT to be rotated as quickly as possible to minimize test time and provide sufficient data resolution. Most antenna positioners have a maximum rotational velocity of approximately 12 degrees per second (2 RPM). If the AUT is large, the rotational velocity may need to be reduced to avoid damaging the antenna. Figure 4 illustrates the relationship between positioner velocity, angular measurement resolution, and the data acquisition rate of the measurement system. For example, in the SINGLE POINT mode, the data acquisition rate of the HP 8510B is 39 msec/point. If the required angular measurement resolution is 0.5 degrees, then the positioner velocity must not exceed 12.8 degrees/second.

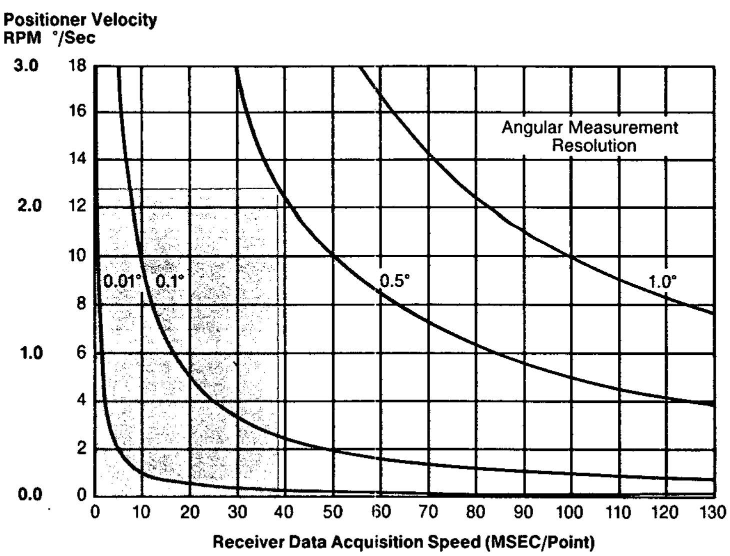


Figure 4. Positioner Velocity -vs- Acquisition Rate and Angular Resolution

However, care must also be taken that the data acquisition rate does not exceed the input bandwidth of the pattern recorder which could result in a smearing of the antenna pattern. Many older analog X-Y recorders have an input bandwidth of 25 Hz which results in a time constant of 40 milliseconds. It is necessary to allow two to three time constants for the recorder to fully respond to the input signal. In the example HP 8511A and the external mixer configurations, the HP 7090A Measurement Plotting System has been used as the pattern recorder. The HP 7090A plotter provides a 3 kHz input bandwidth with each of its three input channels. This results in a time constant of 333 microseconds which allows the plotter to fully respond to the input signal within 1 msec. Table 2 contrasts the acquisition rates of the HP 8511A and external mixer configurations as a function of measurement sensitivity for manual pattern measurements.

HP 8510B CW Data Acquisition Time (mS)

Sensitivity dBm	Manual	
	HP 8511A	External Mixers (N = 1)
−95	39	39
−105	41	39
−115	52	39
−125	141	39
−135	—	41
−145	—	65

Table 2. Acquisition Rate -vs- Measurement Sensitivity

Performing Pattern Measurements

The following section describes a suggested procedure to generate antenna patterns with an HP 8510B. In the example range shown here, ORBIT[1] positioning equipment, a Flam & Russell[2] Model 911 Pattern Recorder interface, and an HP 7090A Measurement Plotting System have been used to provide the positioning and pattern recorder subsystems. While this procedure applies to the hardware configuration shown in Figure 5, it can be easily adapted for use with the HP 8511A configuration.

Once the system has been configured as detailed in Figure 5, the following procedure may be used to set up the system and perform pattern measurements.

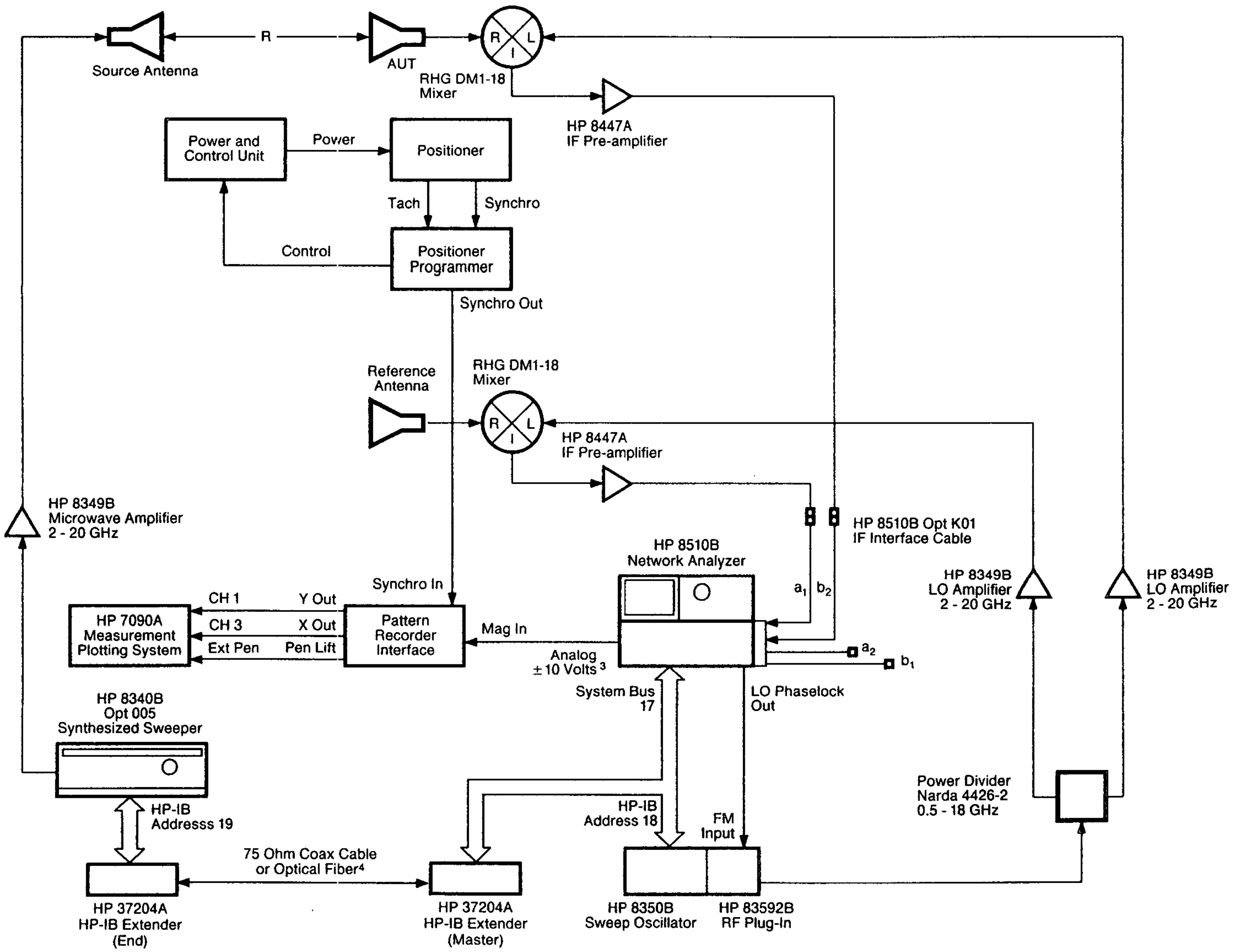


Figure 5. Detailed Hookup Diagram of External Phase-lock Configuration

1. ORBIT is a trademark of ORBIT Advanced Technologies Limited.
2. Flam & Russell is a trademark of Flam & Russell Inc.
3. A 1.837K Ohm pull down resistor was used to scale the output to ±5 volt.
4. To use optical fiber, include option 002 with the HP 37204A extender.

Power Up

	Turn on the line power to all of the instrumentation except the HP 8510B. Verify that the HP-IB address on the HP 8340B and the HP 8350B are set to 19 and 18, respectively.
SHIFT,LOCAL,1,9,HZ	Set the address on the HP 8340B.
SHIFT,LOCAL,1,8,HZ	Set the address on the HP 8350B.
	Now turn on the line power to the HP 8510B.

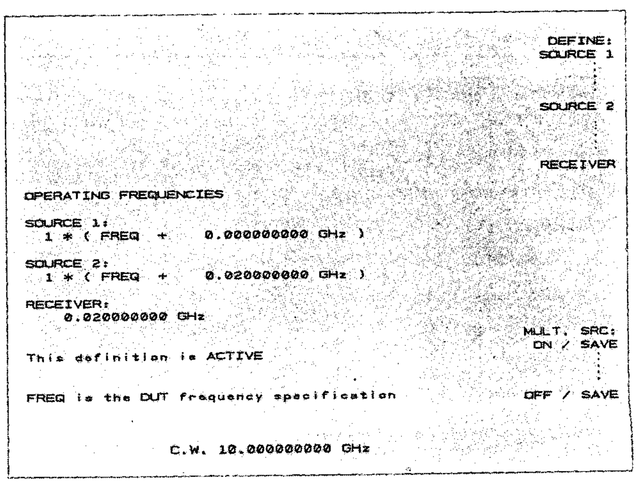
Defining the HP 8510B Hardware State

PRESET,LOCAL, TEST SET,3,0,X1, SOURCE 1,1,9,X1, SOURCE 2,1,8,X1	Preset the HP 8510B and verify that the RF and LO source addresses are set correctly.
SYSTEM,MORE, ANALOG OUT ON	Turn Analog Out on.
SYSTEM PHASELOCK, EXTERNAL	Set the system phaselock to external.
SYSTEM,MORE, EDIT MULT. SRC	Set up the Multiple Source Menu for fundamental mixing with the external mixer configuration.
RECEIVER, CONSTANT FREQUENCY, 2,0,MZ,DONE	Set the receiver frequency to a constant IF frequency of 20 MHz.
SOURCE 1, MULTIPLIER NUMER., 1,OFFSET FREQUENCY,0,HZ, DONE	Set the RF source to equal the center frequency.
SOURCE 2, MULTIPLIER NUMER.,1, OFFSET FREQUENCY, 2,0,MZ,DONE	Set the LO source to equal the center frequency plus a 20 MHz offset. This sets up SOURCE 2 for fundamental mixing with SOURCE 1. If harmonic mixing is desired, simply enter the harmonic number to be used into the MULTIPLIER DENOM. of SOURCE 2.
ON / SAVE	Turn on the Multiple Source definition and save the definition in non-volatile memory.
	NOTE: This "hardware state" can be saved to either a disc or tape file using the built-in tape drive or an external disc drive connected to the system interface bus.

Using Multiple Source Mode

In the external mixer configuration, SOURCE 1 is the HP 8340A/B which is used as the RF source in the source subsystem. SOURCE 2 is an HP 8350B Sweep Oscillator which is used to provide the LO signal to the external mixers. The RECEIVER frequency is the 20 MHz IF frequency that is routed to the HP 8510B. The HP 8510B has the ability to control both the RF and the LO sources through its system interface bus. The frequency relationship between the RF and LO sources and the receiver are defined in the Multiple Source menu using either linear equations or constant (CW) frequencies. In the external mixer configuration, the RF reference and test signals are downconverted to a constant IF frequency of 20 MHz and routed to the HP 8510B.

The variable FREQ in the Multiple Source menu equations represents the frequencies that are defined with the STIMULUS keys on the HP 8510B. For CW pattern measurements, the analyzer is operated in the SINGLE POINT (CW) mode, and the pattern test frequency is adjusted using the CENTER frequency key on the front panel of the analyzer. In the example shown below, the frequency of the RF source (SOURCE 1) is equal to the center frequency, since its equation has a multiplier of 1 and a 0 Hz offset frequency. For fundamental mixing, the LO source (SOURCE 2) uses a multiplier of 1 and an offset frequency of 20 MHz. This definition will always program the LO source to a frequency 20 MHz higher than the RF source no matter how often the center frequency is changed. To use the third harmonic of the LO source to downconvert the RF source to 20 MHz, a multiplier of 1/3 would be used.



Multiple Source Menu of HP 8510B

Setting Up the Pattern Recorder

From power-up, perform the following steps for either a rectangular or polar pattern to set up the HP 7090A Recorder.

Rectangular Patterns

RANGE 1,7 VOLTS, OFFSET 3,5.0 VOLTS, GRID DIVISIONS X-AXIS,18, GRID DIVISIONS Y-AXIS,16, CHANNEL 1 VS CHANNEL 3,	Change the settings on the HP 7090A so that they correspond to the voltage outputs of the pattern recorder interface.
INSERT PLOTTER PAPER, **GRID**	Plot the graticule for a rectangular pattern.
SHIFT,SAVE SETUP	**NOTE:** The settings on the HP 7090A may be saved in non-volatile memory.
RECALL SETUP	Once saved, it may be recalled for use at any time.
RECORD DIRECT	Enable the analog inputs to the plotter.

Polar Patterns

It is only necessary to change one of the settings on the HP 7090A plotter to configure the plotter for polar plots instead of rectangular plots. It is also necessary to use preprinted polar chart forms since the HP 7090A does not have the ability to generate graticules in a polar format.

OFFSET 1,3.5 VOLTS	Change the offset voltage on Channel 1 from 0 Volts to 3.5 Volts.

Setting Up Pattern Test Parameters on the HP 8510B

STIMULUS,SINGLE POINT, ENTRY OFF	Put the HP 8510B into the SINGLE POINT mode.
NUMBER OF POINTS,51	Set the number of points to 51. This minimizes the number of points displayed on the CRT of the analyzer and, therefore, keeps data acquisition time to a minimum.
PRIOR MENU,POWER MENU, SOURCE 1,*value,* **SOURCE 2,***value*	Set the RF and LO power levels appropriately. The exact power level will depend on cable losses and the required LO drive level for the mixer.
CENTER,*value*	Set the center frequency to the desired test frequency. Use either the numerical keypad, knob, or up/down step keys to enter the frequency.
S21	Select S21 as the test parameter. This displays the received signal of the AUT relative to the reference signal (b2/a1).

NOTE: The previous procedure may be saved in non-volatile memory by pressing the **SAVE** key in the INSTRUMENT STATE section of the front panel and selecting one of the instrument state registers from the softkey menu. Once saved, it may be recalled by simply pressing the **RECALL** key and re-selecting the appropriate instrument state. The instrument state may also be stored on an external disc or on magnetic tape for convenience.

Boresiting the Antenna

	Using the positioner controller, position the antenna approximately at boresite.
REF VALUE, =MARKER	Position the measured response of the AUT on the reference line of the HP 8510B located at the center of the CRT.
SCALE,5,X1	Set the vertical scale to 5dB/division.
	Fine tune the boresite position of the AUT to locate the maximum received signal of the CRT. If preferred, the marker readout may also be used (located in the upper left corner of the CRT display). Depending on the AUT's main lobe response, a higher resolution scale setting may be desired to pinpoint the peak of the main beam.

Normalizing the Pattern Response

CAL,CAL 1, CALIBRATE: RESPONSE, THRU, DONE RESPONSE,CAL SET 1	Perform a response calibration on the HP 8510B to normalize the boresite response of the AUT to 0 dB.
SCALE,1,0,X1, REF VALUE,0,X1, REF POS,1,0,X1, ENTRY OFF	Adjust the display settings on the HP 8510B in preparation for making pattern measurements.
MARKER,ALL OFF	Turn off the markers to optimize the data acquisition rate of the HP 8510B.

Setting Up the Pattern Recorder Interface

180, or **90,** or **45,** or **9**	Choose the angular extent of the pattern measurement to be performed by selecting one of the horizontal scale settings.
GAIN/PHASE to **OPERATE, ANGLE** to **OPERATE**	Enable the outputs of the Pattern Recorder Interface.
ZERO	Calibrate the boresite position at zero degrees on the Pattern Recorder Interface.
RECTANGULAR	Select the rectangular format on the Pattern Recorder Interface.
or	
POLAR	Select the polar format on the Pattern Recorder Interface.
	Adjust the **OFFSET** potentiometer on the Pattern Recorder Interface until the pen is located at 0 dB on the vertical axis. *(The pen should already be at zero degrees on the horizontal axis.)*

Making Measurements

	Position the AUT at the start angle for the test and adjust the Positioner velocity to the desired value.
	Select the desired pen on the HP 7090A plotter.
PEN WRITE	Using the Pattern Recorder Interface controls, lower the plotter pen.
FORWARD	Begin the test by setting the direction switch on the positioner controller to FORWARD. When the AUT has rotated through the angular extent chosen for the test, the pen will lift automatically.
	Stop the positioner and remove the finished pattern from the plotter.

Measurement Results

The following measurements were performed on an indoor tapered range where the distance between the source antenna and the test antenna was approximately 50 feet. The test antennas used were an X-band standard gain horn and a broadband conical horn antenna. Both the HP 8511A test set and external mixer configurations were used as he RF to IF downconverters for the receiver. In Figure 6, a pattern measurement was performed on an X-band standard gain horn in an H-plane orientation at 10 GHz using the HP 8511A configuration. The pattern measurement was performed in 50 seconds over an angular extent of ±180 degrees. Figure 7 is a polar pattern plot of a broadband, linearly-polarized conical horn measured at 8.5 GHz in an E-plane orientation. The pattern in Figure 8 is a rotating source polarization measurement of an X-band standard gain horn in an E-plane orientation. This measurement is made by rotating a linearly-polarized source antenna about its centerline axis while making a pattern measurement of the AUT. The envelope of the resultant pattern consists of the in-line and cross-polarized responses of the AUT. This type of measurement allows the axial polarization ratio of the AUT to be easily determined. The AUT was rotated at 0.5 degrees per second over an angular extent of ±45 degrees,while the source antenna rotated at 30 RPM. Although the external mixer configuration was used in this pattern measurement, the multi-path responses from the absorber on the walls of the chamber limited the usable dynamic range of the measurement system to approximately 60 dB.

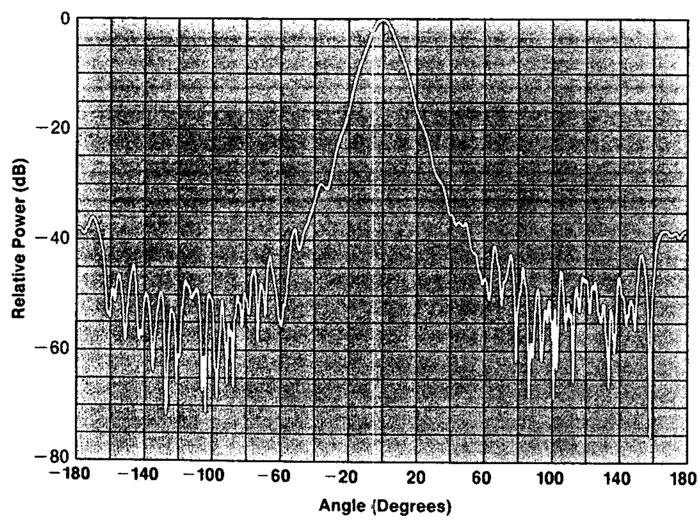


Figure 6. H-plane 80 dB Rectilinear Plot of a Standard Gain Horn at 10 GHz

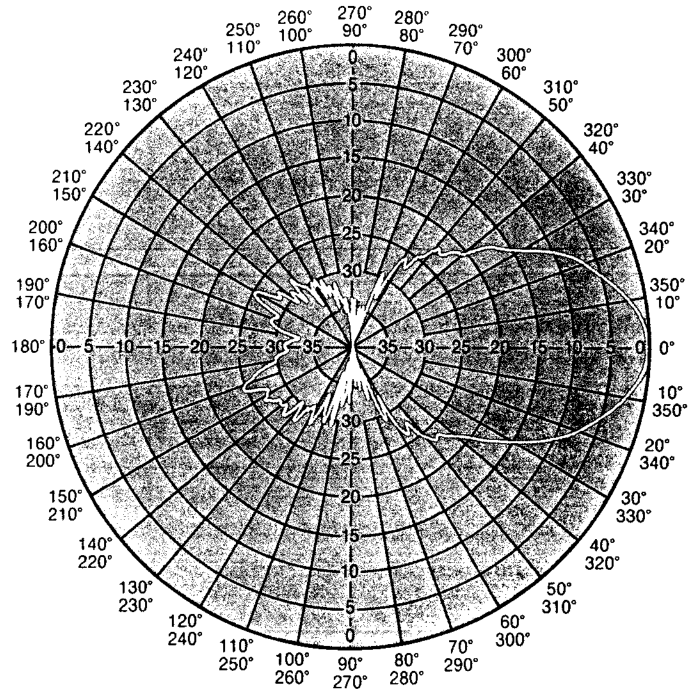


Figure 7. E-plane 40 dB Polar Plot of a Conical Broadband Horn at 8.5 GHz

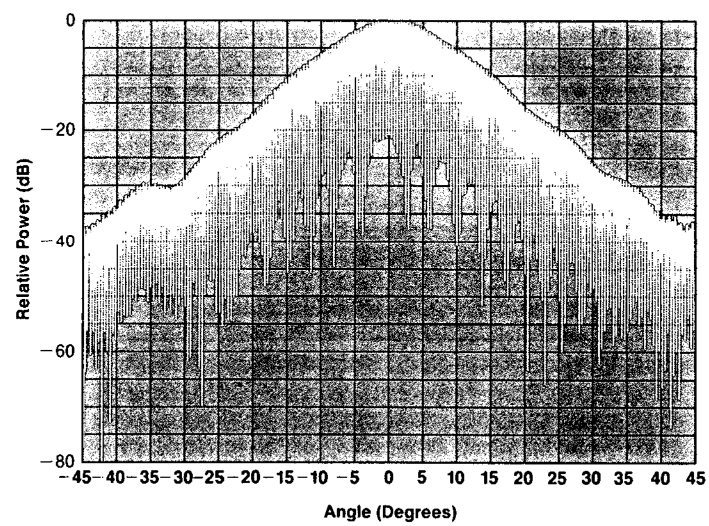


Figure 8. Rotating Source Polarization 80 dB Plot of X-band Standard Gain Horn at 10 GHz

Summary

The HP 8510B system can be easily configured to make accurate manual antenna pattern measurements. Used with the HP 8511A, the analyzer provides a broadband, economical receiver used primarily for indoor antenna range applications, with measurement sensitivities ranging from −98 dBm to over −120 dBm. For longer outdoor range applications, an external mixer configuration provides up to 20 dB additional measurement sensitivity by using low harmonic or fundamental mixing and low noise IF preamplifiers to reduce the conversion loss of the system. By using low harmonic downconversion, the external mixer configuration provides excellent immunity to spurious signals.

The speed of the measurement system can be limited by the maximum rotational velocity of the positioner or the AUT, the response time of the pattern recorder, or the receiver's data acquisition rate. Data acquisition rates for a range of measurement sensitivities available with the HP 8510B were presented for manual pattern measurements. High-speed, semi-automatic pattern measurements, using the FASTCW mode, can provide data acquisition rates of less than 1 msec/point (See Appendix B for details). A suggested procedure for performing manual pattern measurements was presented as well as representative measurements performed on an indoor tapered range.

Appendix A: Antenna Range Evaluation Worksheets

To determine the applicability of either an HP 8511A or an external mixer configuration, it is essential to understand the power budget of the antenna range in which the measurement system will be installed. Figures A-1 and A-2 provide worksheets for collecting all of the gain and loss stages of an antenna test system using an HP 8510B with either the HP 8511A or external mixer configurations. Equations are presented for calculating important signal levels as an aid in determining which type of receiver configuration is required for a particular application.

NOTE: All gain and loss stages should be expressed as positive values.

HP 8511A Configuration

The HP 8511A configuration offers a low cost solution for indoor or outdoor antenna ranges where a tradeoff in sensitivity and susceptibility to spurious signals is acceptable. Figure A-1 is a worksheet that can be used to collect information about the loss and gain stages of an antenna system using the HP 8511A configuration. The equations that follow the worksheet can be used to calculate important signal levels in the system.

Effective Radiated Power

To determine the effective radiated power (ERP) of the source antenna, simply calculate the result from the following equation using the information from the worksheet:

ERP (dBm) = RF Output Power − Directional Coupler loss − Source Cable 1 loss + Source Amplifier Gain − Source Cable 2 loss + Source Antenna Gain

Power Dispersion

The power dispersion of the transmitted test signal increases as a function of distance between the source and test antennas, and the test frequency. The power dispersion between the source antenna and the receive antenna can be approximated from the following formula:

Power Dispersion (dB) $= 10 * \log[(4*\pi*R/\lambda)^2]$ $\quad R >> \lambda$

$= 32.45 + 20*\log(\text{Frequency}) + 20*\log(R)$

where R is the length of the antenna range in meters and Frequency is expressed in GHz.

Receiver Phase-lock Power

The RF power level at the a_1 input of the HP 8511A must remain between −10 dBm and −45 dBm to reliably phase-lock the receiver. The power level at the input to the HP 8511A can be calculated from the following formula:

Receiver Phase-lock Power = RF Output Power − Directional Coupler Coupling − Reference Cable loss

RF Sensitivity

The RF sensitivity, or noise floor, at the inputs to the HP 8511A is typically greater than −98 dBm with a S/N = 1. Averaging provides an additional reduction in uncorrelated thermal noise as a function of 10*log(N) where N is the number of averages. For example, 64 averages improves the sensitivity of the system by 18 dB, resulting in an RF sensitivity of −116 dBm.

The sensitivity at the output of the AUT can be calculated as follows:

RF Sensitivity at AUT output = Test Cable loss − RF sensitivity

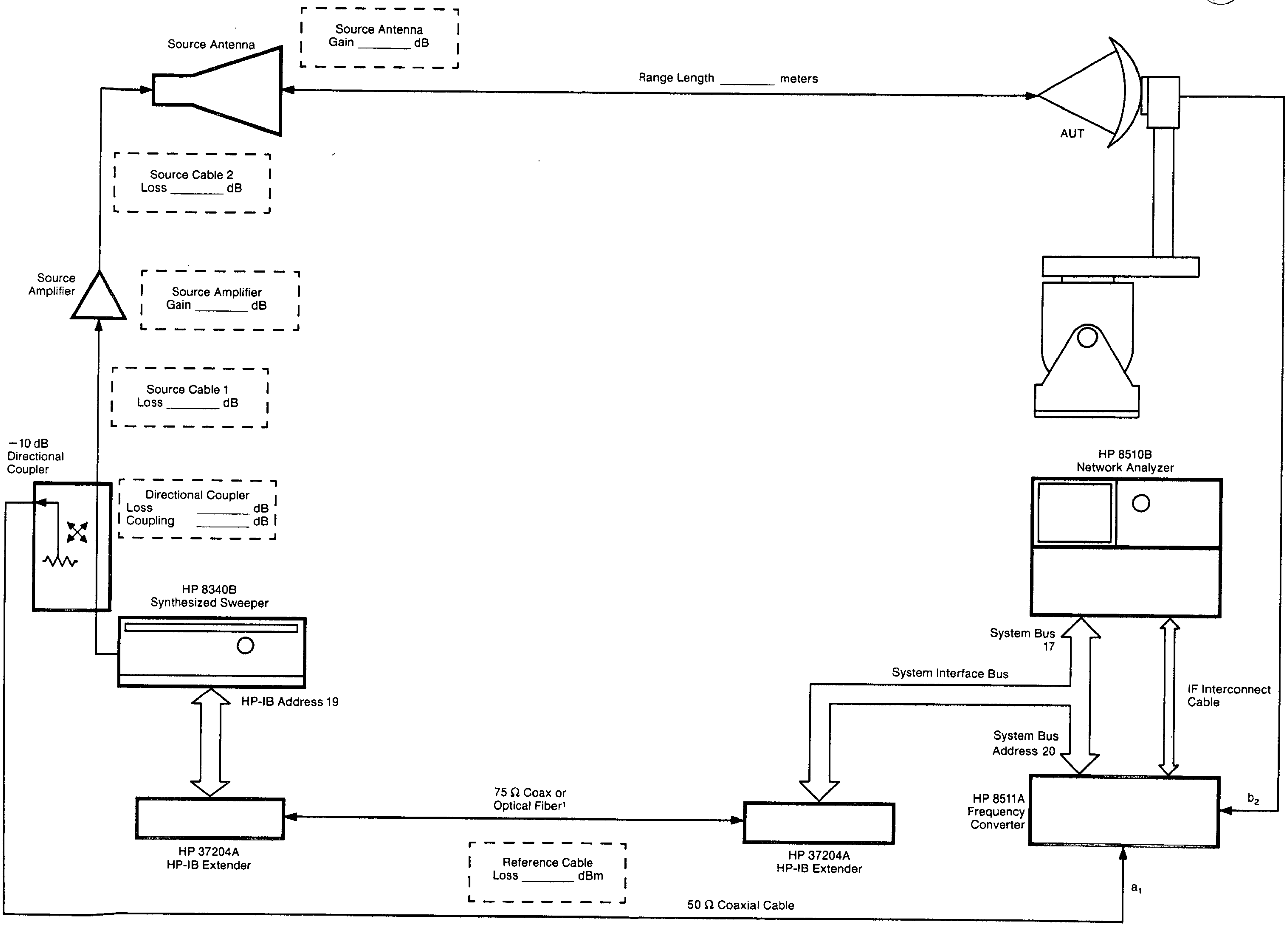


Figure A-1 Power Budget Worksheet for HP 8511A Configuration

1. To use optical fiber, include option 002 with the HP 37204A extender.

External Mixer Configuration

The external mixer configuration offers the highest performance and the greatest flexibility in the choice of LO frequency range and harmonic numbers. Figure A-2 is a worksheet that can be used to collect information about the loss and gain stages of an external mixer configuration. The equations that follow the worksheet can be used to calculate important signal levels in the system.

Effective Radiated Power

ERP (dBm) = RF Output Power −
Source Cable 1 loss +
Source Amplifier Gain −
Source Cable 2 loss +
Source Antenna Gain

Power Dispersion

Identical to the HP 8511A configuration

Receiver Phase-lock Power

To reliably phase-lock the HP 8510B receiver, the IF power level at the input to the analyzer must be between −10 dBm and −50 dBm. The following calculation determines the available phase-lock power at the IF input to the HP 8510B.

Power available at Reference antenna input = ERP − Power Dispersion

Receiver Phase-lock Power = Power available at Reference antenna input +
Reference Antenna Gain −
Reference Mixer Conversion loss +
IF Pre-amplifier 1 Gain −
20 MHz IF cable 1 loss

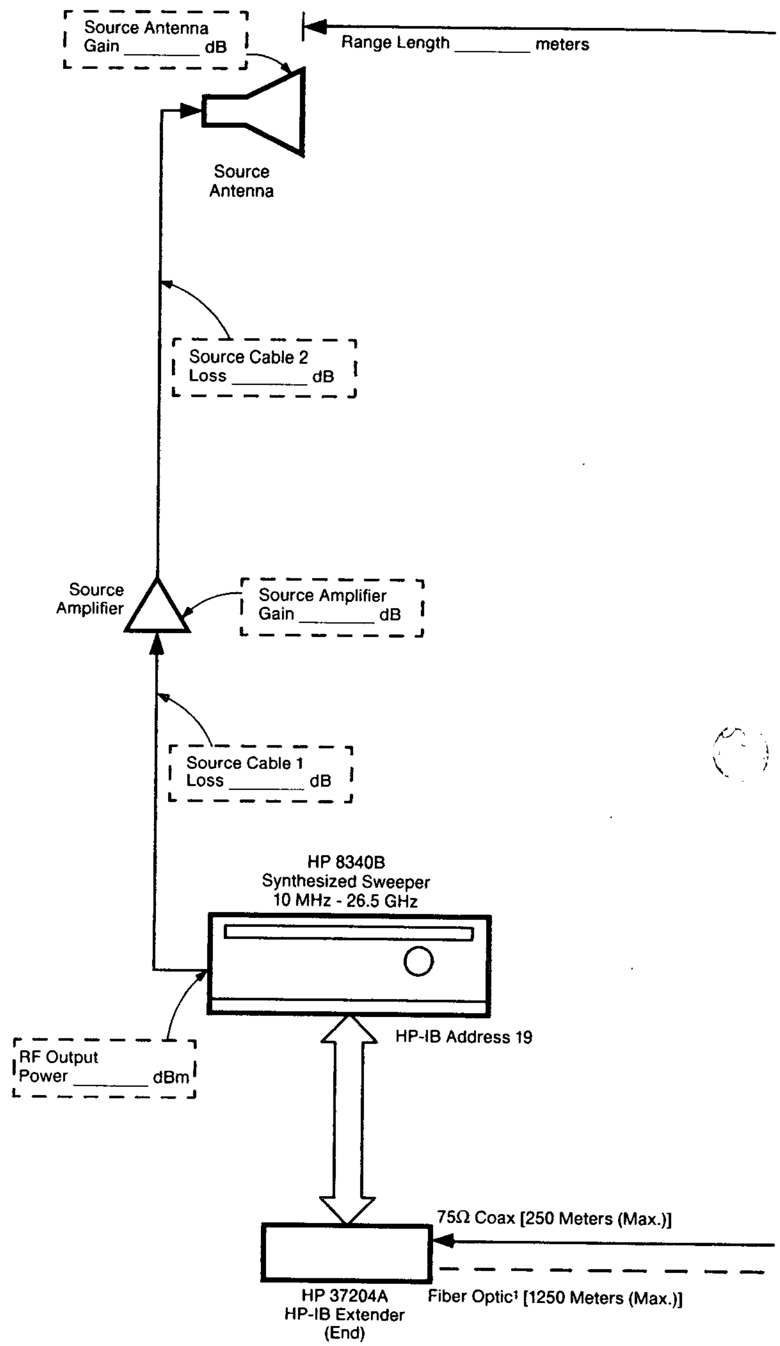
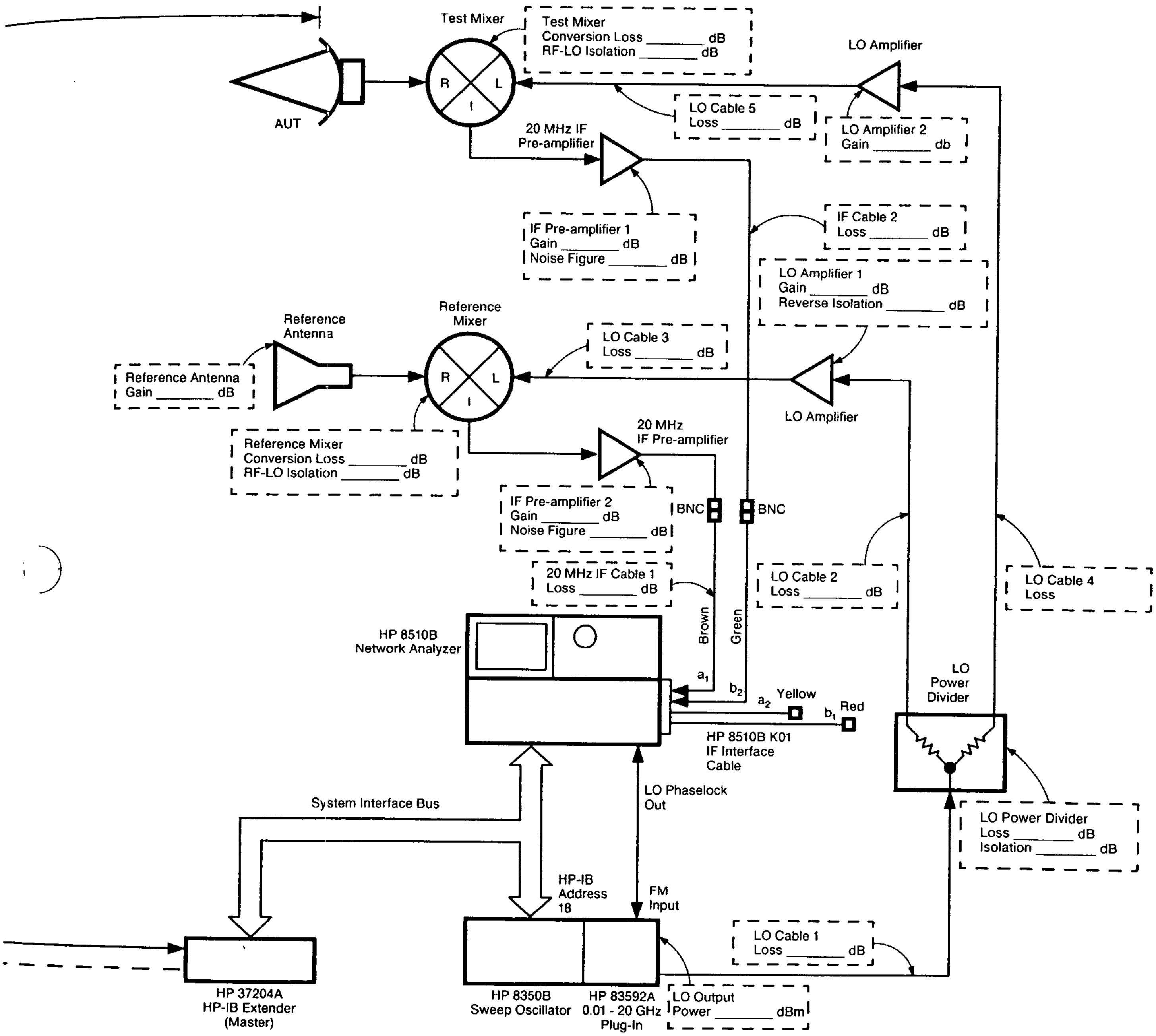


Figure A-2. Power Budget Worksheet for External Mixer Configuration



1. To use optical fiber, include option 002 with the HP 37204A extender.

Receiver Noise Figure Analysis

The noise figure of the HP 8510B at its IF inputs is approximately 24 dB. The addition of a high gain, low noise IF pre-amplifier to the IF output of the reference and test mixers can significantly improve the overall system noise figure. The receiver noise figure can be calculated using the formula shown below.

Receiver Noise Figure = NF[IF amp] + (NF[Rcvr] − 1)/Gain[IF amp]

where NF [IF amp], NF [Rcvr], and Gain [IF amp] are linear quantities.

Example IF Noise Figure Calculation:

Gain [IF Pre-amp 1]	20.0 dB
Noise Figure [IF Pre-amp 1]	6.0 dB
20 MHz IF Cable 1 Loss (50′)	4.0 dB
Typical IF Noise Figure [Receiver]	24.0 dB

Including the effects of the IF cable, the overall receiver noise figure is 28 dB (631 linear). The gain and noise figure of the IF amplifier, expressed in linear terms, are 100 and 3.98, respectively. Substituting these values into the equation results in the following:

Overall IF Noise Figure at IF Preamp Input = 3.98 + (631 − 1)/100
= 10.28
= 10.12 dB

This represents a 17.9 dB improvement in the sensitivity of the measurement system. To determine the RF noise figure, add the conversion loss of the mixers to the IF noise figure of the receiver.

LO Power Analysis

The conversion loss of the RF mixers is specified for a specific LO drive power level. The following equation computes the available LO power at the reference and test mixers.

Reference Mixer LO Power (dBm) = LO Output Power − LO Cable 1 loss −
LO Power Divider loss −
LO Cable 2 loss +
LO Amplifier 1 Gain − LO Cable 3 loss

Test Mixer LO Power (dBm) = LO Output Power − LO Cable 1 loss −
LO Power Divider loss −
LO Cable 4 loss +
LO Amplifier 2 Gain − LO Cable 5 loss

Test Mixer RF Sensitivity

The IF sensitivity, or noise floor, of the receiver, referred to the input of IF Pre-amplifier 2, can be calculated as follows:

IF Sensitivity = kT*B*(F − 1)

where
k is Boltzmann's constant (1.379×10^{-20} mW/°K-Hz)
T is room temperature in degrees Kelvin (290 deg K)
B is the receiver bandwidth in Hertz (10,000 Hz)
F is the linear noise figure (10.12 [with IF Preamp])

or expressed in logarithmic terms

IF Sensitivity = −174 dBm +10*log(B) +10*log(F-1)
= −174 dBm +40 dB +10.1 dB
= −123.9 dBm

IF averaging provides an additional reduction in uncorrelated thermal noise as a function of 10*log(N) where N is the number of averages. For example, 64 averages improves the sensitivity of the system by 18 dB, resulting in an IF sensitivity of −141.9 dBm.

NOTE: RF feedthrough from the reference mixer to the test mixer through the LO path can limit the usable sensitivity of the system. Refer to the following section for more detailed information.

The sensitivity at the RF test mixer can be calculated as follows:

Test Mixer RF Sensitivity = IF Sensitivity +
Test Mixer Conversion Loss

LO Feedthrough Analysis

Since the reference antenna will be a fixed position, high gain antenna, the received power level at the RF port of the reference antenna will remain constant at a fairly high level. When measurements of the AUT's pattern are made at a null position of the antenna, the received power level in the test channel can be much lower than the reference channel. This measurement condition can cause errors due to a leakage path through the LO cabling from the reference channel RF signal to the test channel RF signal. The isolation between the reference and test ports can be calculated from the following equation:

Reference Mixer to Test Mixer Isolation = Reference Mixer RF-LO Isolation +
LO Cable 3 loss +
LO Amplifier 1 Reverse Isolation +
LO Cable 2 loss +
LO Power Divider Isolation +
LO Cable 4 loss −
LO Amplifier 2 Gain +
LO Cable 5 loss +
Test Mixer RF-LO Isolation

NOTE: Be sure to use insertion loss and gain values for the *RF frequency* and not the LO frequency since they can be very different if harmonic mixing is used.

Appendix B: FASTCW Data Acquisition Mode

If the pattern measurement requires a faster data acquisition rate than the SINGLE POINT mode can provide, an automated data acquisition mode, called FASTCW, can be used to perform semi-automated pattern measurements. FASTCW mode provides synchronized data acquisition at rates of less than 1 msec/point which includes the time required to acquire the measurement data and transfer the data over the HP-IB bus to the controller. A rear panel hardware trigger input is used to precisely control when data acquisition occurs.

Some of the newer positioner programmers available today have a raster scan mode. This mode allows the positioner to be scanned over a settable angular range in one or two axes. Each time the positioner passes through a settable increment angle, the positioner programmer issues either a TTL trigger output or issues an SRQ over the IEEE-488 interface bus.

To perform a pattern measurement, the positioner is first moved to the desired start angle for the selected axis. Next, the user defines the RASTER SCAN by specifying the start and stop angles, increment angle, direction of rotation, and the rotational velocity for the test. After selecting the test frequency and the desired measurement parameter, the HP 8510B is commanded by the controller to the FASTCW mode, triggered, and an ENTER statement is executed to begin the process of transferring the measured data (when it is available) into an array in the controller. The scan is then started from the front panel of the positioner programmer. A rear panel RECORD INCREMENT output from the positioner programmer provides a TTL trigger to the trigger input of the HP 8510B each time the positioner travels through the increment angle. Once the scan is completed, the transferred pattern data can be formatted for display on the CRT of the controller or output to a hardcopy device. An example program written in BASIC for Hewlett-Packard Series 200 or Series 300 desktop controllers is listed below to illustrate how the FASTCW mode can be used.

FASTCW Example Program

```
10   OPTION BASE 0
20   ASSIGN @Nwa1 to 716;FORMAT ON                        !Assign IO paths
30   ASSIGN @Nwa2 to 716;FORMAT OFF
40   INTEGER Fast_data(3600,0:2)                          !Dimension Arrays for 3600
50   REAL Data_16bit(3600,0:1),Magnitude(3600)            !measurement points
60   REAL Exp_tbl(0:255)
70   Num_of_points=3600
80   ON ERROR GOSUB Handle_error
90   ABORT 7
100  CLEAR 7
110  GOSUB Init_nwa
120  GOSUB Setup_nwa
130  GOSUB Trigger_nwa
140  GOSUB Enter_data
150  GOSUB Stop_data_acq
160  GOSUB Convert_data
170  GOSUB Compute_mag
180  STOP
190 Init_nwa: !
200  OUTPUT @Nwa1;"PRES;"                                 !Preset the HP 8510B
210  RETURN
```

```
220 Setup_nwa: !
230   OUTPUT @Nwa1;"POIN51;"                    !Set up buffer size,
240   OUTPUT @Nwa1;"S21; CENT 12 GHZ;"          !parameter, frequency,
250   OUTPUT @Nwa1;"POWE 10;"                   !and RF power
260   OUTPUT @Nwa1;"FASC;"                      !Put HP 8510B in FASTCW mode
270   RETURN
280 Trigger_nwa:!
290   REPEAT
300     WAIT .01                                !Loop until HP 8510 is ready
310   UNTIL BIT(SPOLL(716),2)                   !for HP-IB trigger
320   TRIGGER @Nwa1                             !Trigger analyzer
330   RETURN
340 Enter_data: !
350   ENTER @Nwa2;Fast_data(*)                  !Enter FORM1 data
360   RETURN
370 Convert_data:!                              !Convert FORM1 data to FORM3
380   GOSUB Build_table
390   INTEGER I
400   REAL Exp
410   FOR I=0 to Num_of_points
420     Exp=Exp_tbl(BINAND(Fast_data(I,2),255))
430     Data_16bit(I,1)=Fast_data(I,1)*Exp
440     Data_16bit(I,0)=Fast_data(I,0)*Exp
450   NEXT I
460   RETURN
470 Build_table:!
480   Exp_tbl(0)=2^(-15)
490   FOR I=0 TO 126
500     Exp_tbl(I+1) =Exp_tbl(I)+Exp_tbl(I)
510   NEXT I
520   Exp_tbl(128)=2^(-143)
530   FOR I=128 TO 254
540     Exp_tbl(I+1)=Exp_tbl(I)+Exp_tbl(I)
550   NEXT I
560   RETURN
570 Stop_data_acq:!                             Put HP 8510B in hold when
580   OUTPUT @Nwa1;"SINP;FRER;HOLD;"            !data acquisition is complete
590   RETURN
600 Compute_mag:!                               Convert from Real and
610 !                                           Imaginary to Log Magnitude
620   FOR I=1 TO Num_of_points
630     Magnitude(I)=20*LGT(SQR((Data_16bit(I,0))^2+(Data_16bit(I,1))^2))
640     PRINT Magnitude(I)                      !Print Log Magnitude data
650   NEXT I
660   RETURN
670 Handle_error:!
680   PRINT "Error occurred"                    !Error handling routines
690   RETURN                                    !go here
700   END
```

FASTCW Theory of Operation

When the HP 8510B is commanded to the FASTCW mode, the analyzer phase-locks the receiver to the current CENTER frequency and waits for an HP-IB trigger from the controller. Once the HP-IB trigger has been received, the analyzer will acquire a data point each time a TTL level trigger (falling edge) is received through a rear panel trigger input. The measured data is then placed into a first-in, first-out (FIFO) buffer. If the controller has executed an ENTER or TRANSFER statement, the data is transferred immediately to the controller in an internal binary format (FORM 1). If the controller removes data from the buffer as fast as it is being acquired, data acquisition can continue indefinitely with no limitations on the number of measured points. If the controller is not ready to accept data, pattern data accumulates in the FIFO buffer until an ENTER or TRANSFER statement is executed by the controller or the buffer overflows. If the buffer overflows, bit 0 is set true in the primary status byte, an End On Interrupt (EOI) is sent to the controller, and a CAUTION: SWEEP TOO FAST message will be displayed on the CRT of the analyzer. The EOI is sent to the controller to terminate any ongoing ENTER statement so that the controller can restart the test or branch to an error routine. Other system errors are handled in a similar manner. The analyzer is still in the FASTCW mode, but another HP-IB trigger is required to re-enable the external trigger input. The size of the FIFO buffer is determined by the NUMBER OF POINTS that has been selected in the analyzer up to a maximum of 801 points.

IF averaging may also be used with the FASTCW mode to improve measurement sensitivity by reducing the effective noise present in the receiver. Each average adds 200 microseconds to the acquisition time of the analyzer. If an averaging factor of N points has been specified, the analyzer will acquire N points while computing a linear average and then place the data in the FIFO buffer each time a hardware trigger is received.

References

IEEE Std 149-1979; IEEE Standard Test Procedures for Antennas; Published by The Institute of Electrical and Electronics Engineers, Inc.

Operating and Programming Manual; HP 8510B Network Analyzer; Hewlett-Packard Company; Part Number 08510-90070.

Keyword Dictionary; HP 8510B Network Analyzer; Hewlett-Packard Company; Part Number 08510-90072.

Product Note 8510-10, HP 8510B Introductory Users Guide; HP 8510B Network Analyzer; Hewlett-Packard Company; Part Number 5954-8367.

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