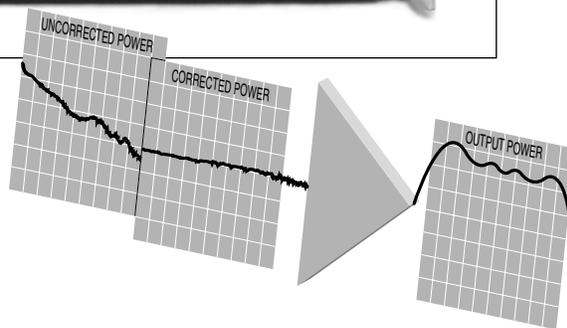


# Agilent PN 8510-16

## Controlling Test Port Output Power Flatness

Product Note



Agilent 8510C Network Analyzer



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## Introduction

Designers and manufacturers of active devices often need to control the power level at the test port<sup>1</sup> of their power-sensitive devices, but find difficulty in overcoming insertion losses. The insertion losses occur as a result of connecting components in the measurement path between the source and the DUT. The Agilent Technologies 8510C is a microwave network analyzer<sup>2</sup> capable of setting and controlling the power level at the test port. This product note reviews the implementation and operational considerations of the 8510C's test port power flatness-correction feature.

The 8510C performs a flatness-correction calibration by measuring the test port power level using an Agilent power meter and creates a table of power corrections versus frequency. The power meter then stores the table into an Agilent 8360 series synthesized sweeper.<sup>3</sup> When the test port flatness correction is enabled, the source will adjust its output power to compensate for path losses at each measurement point in the frequency span.

Power flatness correction is useful for characterizing active devices by allowing measurements of absolute power, gain versus input power, and swept-frequency gain compression. Swept-power gain compression measurements are possible in the power domain with the flatness correction enabled.

The 8510XF measurement system is capable of leveling and controlling the test port power between 45 MHz and 110 GHz without requiring a power calibration for each measurement. When power leveling is enabled, the test port power variation is typically less than  $\pm 1$  dB over the full frequency sweep, with 20 dB of adjustable power. For more information regarding power leveling in the Agilent 8510XF, refer to product note 8510XF-1, literature number 5968-5270E.

1. In this document, "test port" will refer to the point in the system where the test device is connected. This may be port 1 or port 2 of any 8510 coaxial-based test set or the end of a cable or adapter that is attached to the DUT.
2. 8510B network analyzers with revision B.06 or later may also be used to achieve constant test port power levels. To obtain the latest firmware revision order the 11575F upgrade kit.
3. Any 8360 synthesized sweeper with firmware revision of September 25, 1990 or earlier must be upgraded. To upgrade your 8360 to the latest firmware revision, order part number 08360-60167.

### System Configuration

The basic 8510C measurement system configuration needed for test port flatness correction is shown in Figure 1. A single channel power meter such as the Agilent 437B, E4418A, or E4418B is required, along with a compatible sensor, for performing the power flatness calibration. Power meters with the 437B command set must be used for the power level flatness correction.

The Agilent 8511B frequency converter test set may be used with the test port power flatness-correction feature. The range of the test port power is determined by the available power of the 8360 source and the insertion loss of the components added to the measurement system.

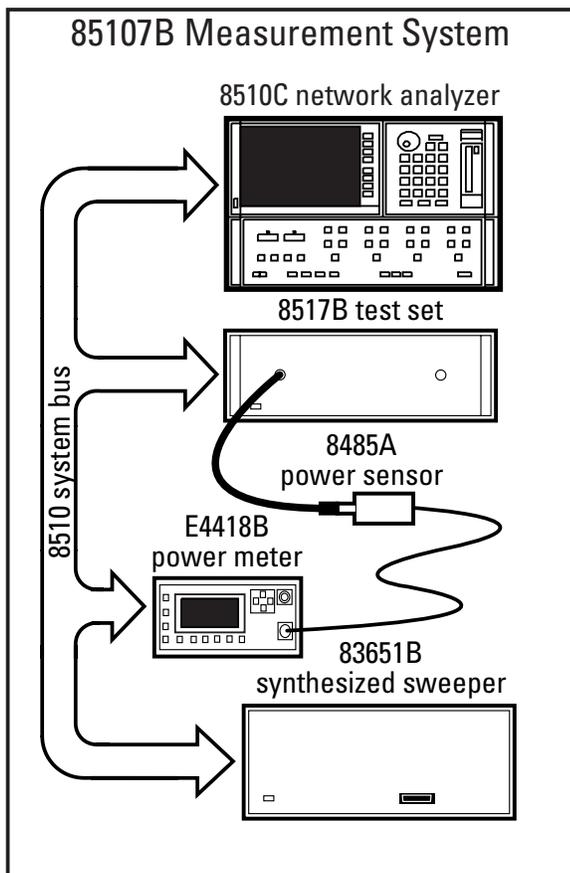


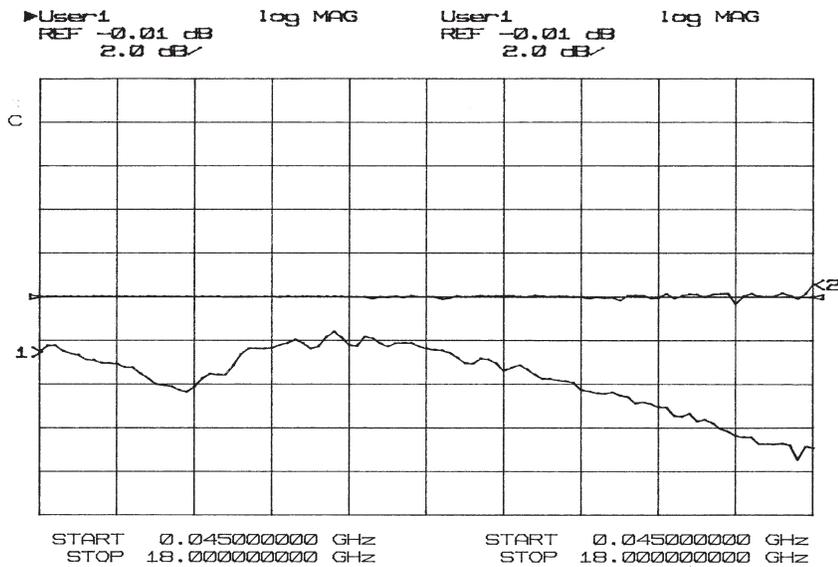
Figure 1. Basic Agilent 85107B measurement system configuration for test port flatness correction

### Flatness-Correction Operation

The basic setup procedure to obtain flat test port output power is illustrated in Table 1. To simplify the execution of the procedure, the front panel hardkeys are enclosed in [brackets]. The softkeys are enclosed in {braces}. Table 2 provides the procedure for setting up the power meter. The network analyzer should be reset before performing any procedures. The flatness-correction calibration can be performed in step, ramp, or frequency list sweep mode. Figure 2 illustrates test port power versus frequency with and without flatness correction using an 85107B measurement system.

When the flatness correction is enabled in an 8510C measurement system the analyzer's *Power Source 1* softkey controls the test port power level. The source and test set used will determine the available test port power range.

The maximum leveled power the source can output at different frequency spans is indicated in Table 3. Once the flatness correction is enabled, the test port power level must be set within the power range presented in Table 4 for common source/test set combinations.



**Figure 2. Comparison of test port power without flatness correction (channel 1) and with flatness correction (channel 2)**

**Table 1. Flatness-correction calibration procedure**

8510C Keystrokes	Description
<b>Set up the power meter (see Table 2)</b>	
	For proper operation, the E4418B must be set up before initiating the flatness-correction routine. See Table 2 for specific instructions.
<b>Verify the power meter's address on the 8510 system</b>	
[LOCAL] {POWERMETER}	When shipped from the factory, the address of the power meter is 13. If this conflicts with another instrument on the system bus, change the address of the conflicting instrument. The power meter must be set to address 13 in order for the firmware to function properly. Press [SYSTEM/INPUTS], {REMOTE INTERFACE} and {INTERFACE OVERVIEW} on the E4418B to ensure the power meter's address is set to 13. Verify that the power meter is connected to the system bus.
<b>Set up the analyzer and measurement</b>	
	Set up the start/stop frequencies and the measurement type (for example, S <sub>11</sub> , S <sub>12</sub> ).
<b>Adjust the number of analyzer trace points (if needed)</b>	
STIMULUS [MENU] {NUMBER OF POINTS} {POINTS}	When the flatness calibration is initiated, the analyzer sends the source a list of flatness-correction frequencies equal to the number of trace points set on the analyzer.
<b>Set the source to the maximum leveled power</b>	
STIMULUS [MENU] {POWER MENU} {POWER SOURCE 1} P <sub>1</sub> [x1]	Set the 8360 for maximum specified power (P <sub>1</sub> ) at the highest frequency in the span; see Table 3. At higher power levels, the power meter will take less time to settle between measurement points during the calibration process.
<b>Connect the power sensor to the active test port and begin the flatness calibration</b>	
<b>Initiate flatness calibration</b>	
{POWER FLATNESS} {CALIBRATE FLATNESS}	Do not cycle the power on the analyzer or the source during the calibration process. The calibration may be aborted at any time by pressing any key on the analyzer's front panel. Aborting the calibration is not recommended, since the command may cause the system to freeze. By pressing {CALIBRATE FLATNESS} the analyzer will remind the user to zero the power meter and connect the power sensor to the source. Press {CALIBRATE FLATNESS} again on the analyzer to initiate the calibration. Once initiated, the analyzer retrieves the power meter measurement data and transfers it to the 8360 where it is processed and stored with the appropriate correction frequency. During the flatness-correction calibration, the analyzer will display <i>MEASURING DATA, xx% DONE, PRESS ANY KEY TO ABORT</i> . The <i>xx% DONE</i> indicates the percentage of the total number of correction points that have been measured; it is not an indication of elapsed measurement time. When the flatness-correction calibration is completed, the analyzer will automatically store the correction table into register 1 of the source. Any new calibration of the source will overwrite the flatness-correction table.
<b>Activate the flatness-correction</b>	
{FLATNESS ON}	The source output power will now be unleveled as it attempts to output the test port power level (Power Source 1) plus the flatness correction for each measurement point in the frequency span. <i>IF Overload or Source 1 Warning—RF Unleveled</i> may be displayed on the analyzer until the test power level is reduced.
<b>Set the test port power level</b>	
STIMULUS [MENU] {POWER MENU} {POWER SOURCE 1} P <sub>2</sub> [x1]	Set the test port power level (P <sub>2</sub> ) equal to or below the maximum allowed test port power (see Table 3) for the highest frequency in the measurement span. A constant power level equivalent to P <sub>2</sub> will now be available at the test port. The flatness-correction calibration can be verified using the E4418B to measure the power at certain CW frequencies in the frequency range.
<b>Perform the measurement calibration</b>	
	Compensate for systematic errors by performing a measurement calibration (if desired). Although a measurement calibration can be performed before or after the flatness-correction calibration with or without correction enabled, it is recommended that the calibration be performed after the flatness correction is enabled. The calibration is no longer valid if the source power is changed after performing the calibration.
<b>Connect the DUT to the test port</b>	

**Table 2. Agilent E4418B power meter setup**

E4418B Keystrokes	Description
<b>Preset and zero the power meter</b>	
[PRESET/LOCAL] {CONFIRM} [ZERO/CAL] {ZERO}	Return the power meter to a known state.
<b>Set up the 437B emulation on the power meter</b>	
[SYSTEM/INPUTS] {REMOTE INTERFACE} {COMMAND SET} {437B}	The 437B command set must be activated in order to perform the power flatness calibration. Power meters that can be used in place of the E4418B are the E4418A and 437B. The E4419B dual channel power meter does not have the 437B command set and cannot be used to perform the calibration.
<b>Connect the sensor to the power reference output on the power meter and calibrate the power sensor</b>	
[ZERO/CAL] POWER REF {ON} {CAL} POWER REF {OFF}	Choose a power sensor that can perform within the desired frequency span. To determine which power sensors are compatible with the E4418B, consult the user's guide. Agilent E-Series power sensors cannot be used for calibration because they are incompatible with the 437B command set. Additional configuration may be needed to connect the sensor to the power reference; this information can also be found in the E4418B user's guide, part number E4418-90032. After calibrating the sensor, the power meter should display a reading of 0.0 dBm (or 1 mW) when the sensor is connected to the reference and the power reference is activated.
<b>Select or create the calibration factor table that applies to the power sensor in use (if needed)</b>	
[SYSTEM/INPUTS] {TABLES} {SENSOR CAL TABLES} HIGHLIGHT TABLE TABLE {ON} {DONE}	The factory enters nine tables of typical calibration factors for nine different sensors in the E4418B. Use the up and down arrows on the display to highlight the desired table. If tables 2 through 9 are cleared, the data previously stored in those tables cannot be restored. See the E4418B user's guide, part number E4418-90032, for information on entering custom calibration factor tables.

**Table 3. Agilent 8360 series synthesized sweeper maximum leveled power (in dBm)**

Maximum Frequency	83620B	83621B	83623B	83623L	83631B	83651B
20 GHz	13	10	17	15	10	10
26.5 GHz	N/A	N/A	N/A	N/A	4	4
40 GHz	N/A	N/A	N/A	N/A	N/A	3
50 GHz	N/A	N/A	N/A	N/A	N/A	0

**Table 4. Settable test port power ranges (assuming no test set step attenuation)**

RF Source	83620B/83621B		83631B	83651B	
8510 Test Set	with 8514B	with 8515A	with 8515A	with 8517B	with 8517B, Option 007
Frequency	Test Port Power Levels [ $P_{max}$ to $P_{min}$ ] (in dBm)				
0.05 GHz	2.5 to -20.5	-3.5 to -26	-3.5 to -26	-1.5 to -21.5	5 to -21
2 GHz	1 to -22	-6 to -29	-6 to -29	0.5 to -23.5	5 to -21
20 GHz	-7.5 to -27	-13.5 to -30	-13.5 to -30	-7.5 to -30	2 to -23
26.5 GHz	N/A	N/A	25 to -30	13.5 to -30	1 to -24
40 GHz	N/A	N/A	N/A	-20 to -30	-3 to -21.5
50 GHz	N/A	N/A	N/A	-27 to -30	-13 to -29

## Operational Considerations

### Calibration time

The user may choose to speed up the calibration process by reducing the number of trace points on the analyzer. Table 5 provides some typical calibration times for flatness correction over the full frequency span of the source for different source/test set combinations. Calibration times may be slightly reduced by increasing the stepped measurement speed with the quick step feature on the Agilent 8510C.

**Table 5. Typical calibration times (in minutes) versus number of calibration points with maximum leveled source power**

Number of Points	83620B/83621B		83631B	83651B
	with 8514B	with 8515A	with 8515A	with 8517B
801	30	32	40	60
401	15	16	20	30
201	8	8	10	15
101	4	4	5	8
51	2	2	2	4

The following error messages may occur while attempting to enable the flatness correction and/or reducing the test port power level:

- If flatness correction is enabled before reducing the test port power level, *IF Overload* or *Source 1 Warning—RF Unleveled* may be displayed on the analyzer as the source becomes unleveled. Unleveling occurs when the source attempts to output its maximum specified power plus the flatness correction.
- If the output power is reduced to a suitable test port power level before turning flatness correction on, *No IF Found* may be displayed. There may not be sufficient output power from the source for the 8510C to phase lock to the signal.

These error messages should disappear when flatness correction is enabled with the appropriate test port power level setting. If the test port power level is not correctly reduced, the source will become unleveled and try to output maximum power. Although flatness correction will be applied to the unleveled signal, the measurement for the unleveled portion of the frequency span will not be valid because the flatness-correction feature cannot compensate for the inconsistent power variations that occur.

### Power control with flatness correction

The ability to compensate for power variations across the entire measurement span of the source will depend on the highest leveled output power the source can produce and the amount of power compensation required. The test port power may be adjusted over the entire  $P_{\max}$  to  $P_{\min}$  range without degrading the flatness-correction calibration.

Table 4 shows test port power ranges for various source/test set combinations. To determine the test port power levels for a particular frequency span, choose a power level between  $P_{\max}$  of the highest frequency in the measurement span and  $P_{\min}$  of the lowest frequency in the measurement span. For example, the power range for a 50 MHz to 20 GHz span with an 83621B/8515A system is  $-13.5$  dBm to  $-26$  dBm. A high-power Agilent 83623B adds 7 dBm to  $P_{\max}$  of the 83621B. If a user sets up a 50 MHz to 20 GHz measurement with an 83623B and an 8515A, the test port power range is  $-6.5$  dBm to  $-26$  dBm.

### **Verifying a flatness-correction calibration**

To verify the flatness-correction calibration, the power sensor should be reconnected to the test port to measure the test port power at individual frequencies. Since the measurement system is calibrated in 50W, inaccuracies will occur when a device is not well matched. Since the flatness-correction calibration is not a real-time power leveling feature, it cannot correct for mismatches that occur between the test port and the DUT.

### **Adjusting the frequency span after calibration**

Once a flatness-correction calibration with the maximum number of points (801 points) has been completed, adjustments can be made to reduce the number of trace points on the analyzer. The user may also change the measurement frequency span to a subset of the original calibration span without invalidating the calibration. The source will output corrected power at the appropriate measurement points.

This capability is particularly useful for users who are testing a number of devices with different frequency spans at the same test station. In this case, the user may choose to perform the flatness-correction calibration with the maximum number of calibration points across the full frequency range. Subsets of the original calibration frequency range can then be used to meet the specific testing requirements of the individual devices.

### **When to recalibrate**

The flatness-correction calibration does not need to be repeated unless: (1) the user wants to calibrate over a wider frequency range, (2) the measurement path between the source and the test device changes, (3) the RF source power changes, (4) the user wants to increase the number of measurement points, or (5) the environmental conditions under which the original calibration was performed changes dramatically.

Keep in mind that the flatness-correction table is automatically saved into register 1 of the RF source. Any new calibration of the source will overwrite the flatness-correction table. If multiple flatness-correction calibrations are performed, only the most recent calibration will be saved for the DUT.

### **Using test set step attenuators with flatness correction**

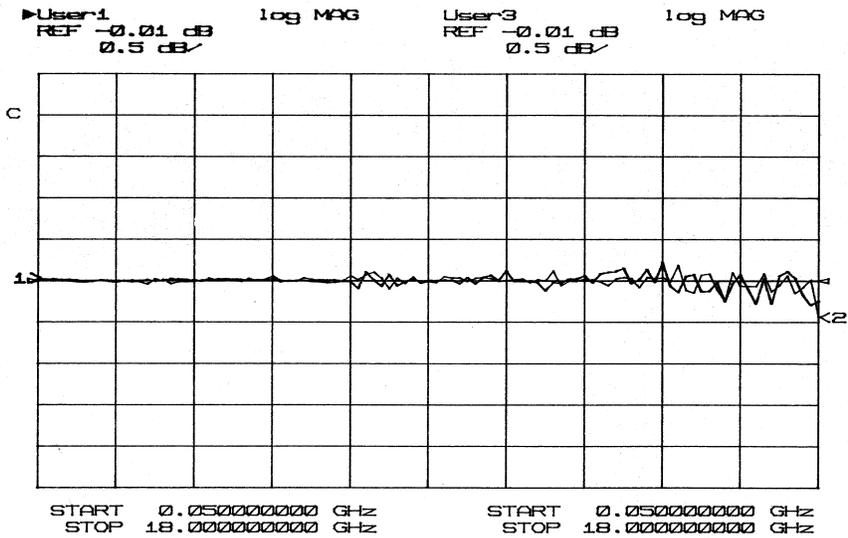
If lower test port power levels are desired, test set step attenuators may be used. The frequency response of the step attenuators can be eliminated from the measurement by performing the flatness-correction calibration with the appropriate attenuation enabled. High sensitivity power sensors (8485D to 26.5 GHz and 8487D to 50 GHz) are available for power measurements from -20 dBm to -70 dBm. The limitation of making power meter measurements at these low power levels is that the actual calibration process takes considerably more time since the power meter takes much longer to settle at each correction frequency.

**Using test port 1 calibrations on test port 2**

In most cases, port 1 will be the input port of the DUT. When port 2 must be used as the input port to the device, the user may choose to use a port 1 flatness-correction calibration on port 2 since the port 1 and port 2 signal paths are symmetrical.<sup>1</sup> Figure 3 illustrates the use of port 1 flatness correction on both ports 1 and 2. The port 2 measurement with port 1 flatness-correction calibration is optimized for measurements below 30 GHz.

**Flatness corrections in fixture or wafer-probing environments**

Test port flatness correction may be applied with any other power function. Power slope may be used to compensate for the path loss in non-coaxial environments such as microstrip and coplanar waveguide measurement systems. The maximum test port power for any particular frequency span cannot exceed the maximum test port power level for the highest frequency in the span (see Table 3) minus the maximum power slope compensation required.



**Figure 3. Corrected test port power using port 1 flatness correction on port 1 (channel 1) and port 2 (channel 2)**

1. Test sets with option 003 (high forward dynamic range) cannot be used because the reverse transmission dynamic range is degraded.

## Practical Application Examples

### Absolute output power measurements with flatness correction

One benefit of the flatness-correction capability is the ability to measure the absolute output power of active devices. Since the input power level to the DUT is kept constant, the magnitude offset feature of the Agilent 8510 can be used to display absolute output power across the entire frequency span of the device. Table 6 shows the procedure for absolute output power versus frequency measurements with test port flatness correction.

**Table 6. Absolute output power measurements with flatness correction**

8510C Keystrokes	Description
<b>Set up the source and power meter as illustrated in Figure 2</b>	
<b>Set up the measurement</b>	
PARAMETER [MENU] {USER 2 b <sub>2</sub> }	Set up the analyzer for a b <sub>2</sub> measurement.
<b>Activate the test port power flatness-correction</b>	
	Perform the flatness correction calibration. Set the test port power level and enable the flatness correction as explained in Table 1.
<b>Connect a thru</b>	
<b>Perform a thru calibration with the flatness correction enabled</b>	
[CAL] {CAL#...} {CALIBRATE:RESPONSE} {THRU} {DONE RESPONSE} {CAL SET #}	Perform a thru calibration to eliminate the frequency response errors of the port 2 path in the measurement. Be sure to include any attenuators and/or adapters which are part of the measurement in the thru calibration. It may be necessary to swap adapters for the thru connection. Any cal set may be selected to access the response calibration in the calibration menu structure
<b>Connect the DUT</b>	
<b>Measure the absolute output power</b>	
RESPONSE [MENU] {MORE} {MAGNITUDE OFFSET} P <sub>2</sub> [x1]	When the device is reconnected, the gain will be displayed. Enter a magnitude offset equivalent to the test port power level (P <sub>2</sub> ). Measure the absolute output power at any point in the measurement span.

### Amplifier measurement example

Step-by-step instructions for setting up and applying flatness corrections for the measurement of an amplifier are shown in Table 7. Gain, absolute

output power, and gain compression measurements procedures are covered. For more information on measuring amplifiers, refer to Agilent product note 8510-18, literature number 5963-2352E.

**Table 7. Absolute output power and 1 dB compression measurements of an amplifier**

8510C Keystrokes	Description
<b>Perform the flatness-correction calibration as presented in Table 1</b>	
<b>Set up the test port power level</b>	
STIMULUS [MENU] {POWER MENU} {POWER SOURCE 1} $P_A$ [x1]	Set the test port power below the amplifier's compression level ( $P_A$ ) and within the settable power range presented in Table 4.
<b>Set up a <math>b_2</math> measurement and connect a thru</b>	
PARAMETER [MENU] {USER 2 $b_2$ }	Set up the analyzer for a $b_2$ measurement.
<b>Perform a thru calibration</b>	
[CAL] {CAL#...} {CALIBRATE:RESPONSE} {THRU} {DONE RESPONSE} {CAL SET #}	Perform a thru calibration to eliminate the frequency response errors of the port 2 path in the measurement. Be sure to include any attenuators and/or adapters which are part of the measurement in the thru calibration. It may be necessary to swap adapters for the thru calibration. Any cal set may be selected to access the response calibration in the calibration menu structure.
<b>Connect the amplifier and measure the absolute output power</b>	
RESPONSE [MENU] {MORE} {MAGNITUDE OFFSET} $P_A$ [x1] [AUTO]	Display the absolute power by entering a magnitude offset ( $P_A$ ) equivalent to the test port power level during the thru calibration. Gain can be calculated for any measurement point by subtracting $P_{in}$ from $P_{out}$ (or $P_{measured}/P_A$ ). The gain can also be measured by performing an $S_{21}$ measurement.
<b>Set up a 1 dB compression measurement and normalize the trace</b>	
[DISPLAY] {DATA AND MEMORIES} {DISPLAY→ MEMORY 1} {MATH(/)}	By normalizing the measurement, the first frequency point to drop by 1 dB will be easy to identify.
<b>Adjust the display</b>	
[REF VALUE] 1 [x1] [REF POSN] USE DOWN ARROW [SCALE] 1 [x1]	Move the reference line near the bottom of the grid to allow full use of the display.
<b>Increase power to find the 1 dB gain compression point</b>	
STIMULUS [MENU] {POWER MENU} {POWER SOURCE 1} USE UP ARROW [MARKER]	Increase the test port power 1 dB at a time until the trace visibly drops. Then use the knob to adjust the power until a 1 dB drop in the trace occurs. Note the test port power and use a marker to measure the frequency.
<b>Measure the absolute output power at the 1 dB compression point</b>	
[REF POSN] [DISPLAY] {DATA AND MEMORIES} {DISPLAY:DATA} [AUTO]	Move the reference level back to the center of the screen and display the absolute output power versus frequency. The marker will indicate the amplifier's absolute output power for the 1 dB compression point.

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