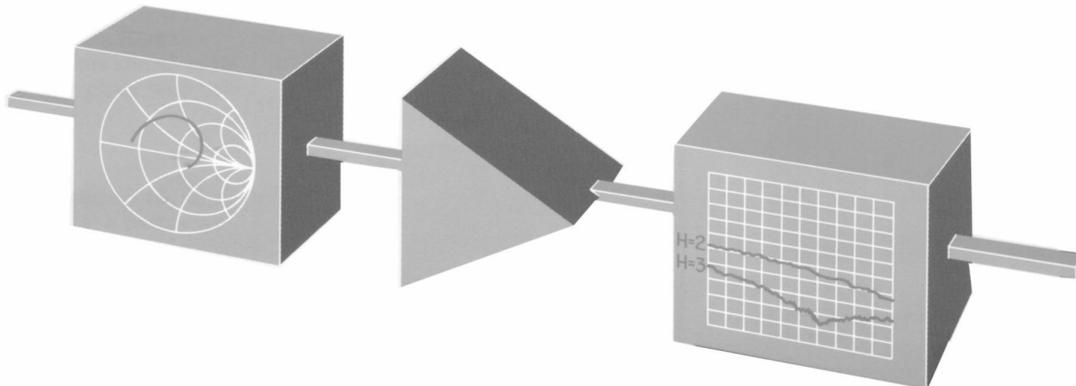


Agilent PN 8753-1

RF Component Measurements: Amplifier Measurements Using the Agilent 8753 Network Analyzer

Product Note



Agilent Technologies
Innovating the HP Way

Introduction

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Network analyzers are traditionally used to measure the transmission and reflection characteristics of components, circuits, and devices. This note describes how the Agilent Technologies 8753 vector network analyzer accurately and efficiently characterizes RF amplifiers.

The 8753 easily measures commonly specified amplifier scalar parameters: gain, gain compression, isolation, return loss (SWR), and gain drift versus time. Built-in phase measurement capability allows characterization of an amplifier's deviation from linear phase, group delay, and complex impedance. Knowledge of both magnitude and phase characteristics is needed for successful higher-level component integration.

Besides phase measurement capability, the 8753 offers other advantages over a scalar system for amplifier characterization. The 8753 employs a tuned receiver that improves dynamic range and sensitivity, and eliminates unwanted spurious responses. The instrument also offers accuracy enhancement, which dramatically reduces systematic errors, for more precise characterization.

Additional capabilities with the Agilent 8753B

Harmonic distortion is often specified to describe amplifier non-linear behavior. The 8753B Network Analyzer with harmonic measurement capability, Option 002, can quickly and easily determine swept amplifier harmonic levels over a broad range.

The 8753B offers several other powerful enhancements to increase amplifier measurement productivity and capability. By employing an Agilent 85047A S-parameter Test Set with 6 GHz receiver, Option 006, complete forward and reverse characteristics of an amplifier can be determined up to 6 GHz. Two-tone third order intermodulation measurements are possible with the instrument by employing two external sources. In fact, the 8753B offers several new instrument modes that allow measurements on frequency translation devices such as mixers. Refer to product note 8753-2, *Mixer Measurements using the Agilent 8753B* (lit. no. 5956-4362), for a discussion on these measurements. Complex tests can be performed automatically with a single key-stroke using the test sequence function. Power meter calibration enables the 8753B's source to be leveled at the input or output of an amplifier.

In this product note, measurements are detailed in easy to follow, step-by-step procedures. Accuracy considerations are covered for each measurement. Finally, an appendix discusses S-parameter test set considerations.

Amplifier definitions

This section contains brief descriptions of the amplifier parameters that can be measured using the 8753 RF vector network analyzer.

Gain

Amplifier gain is defined as the ratio of the amplifier output power delivered to a Z_o load to the input power delivered from a Z_o source, where Z_o is the characteristic impedance in which the amplifier is used (50 ohms in this note). In logarithmic terms, gain is the difference in dB between the output and input power levels.

Since variations in frequency response represent distortion, “gain flatness” is often specified over the frequency range of the amplifier.

Reverse isolation

Reverse isolation is the measure of transmission from output to input. The measurement of isolation is similar to the measurement of small signal gain, except that the stimulus signal is applied to the amplifier’s output.

Gain versus time

Gain versus time is defined as the variation of gain in time, with all other parameters held constant. Stability can be affected by changes in the amplifier’s active devices occurring over time. This parameter is typically specified in maximum variation in gain over a given time interval. Often, gain is investigated with respect to other parameter changes, such as temperature or humidity.

Deviation from linear phase

Ideally, the phase shift through an amplifier is a linear function of frequency. The amount of variation from this theoretical phase shift is known as its deviation from linear phase (also called phase linearity).

Group delay

Group delay is a measure of transit time through an amplifier at a particular frequency. It is defined as the derivative of the phase response with respect to frequency. The 8753 has the ability to derive the group delay from the measured phase response.

Return loss/SWR

A commonly specified parameter is the quality of the match at the input and output of an amplifier relative to the system characteristic impedance. Impedance parameters are defined by the following equations:

$$G = V_{\text{reflected}}/V_{\text{incident}} = r \angle \theta$$

$$\text{Return Loss} = -20 \log_{10} r$$

$$\text{SWR} = \frac{1 + r}{1 - r}$$

Complex impedance

The complex impedance of an amplifier consists of both a resistive and a reactive component. It is derived from the characteristic impedance of a system and the reflection coefficient by the following equation:

$$Z = \frac{1 + G}{1 - G} * Z_o$$

Gain compression

An amplifier has a region of linear gain, where the gain is independent of input power level. This is commonly referred to as “small signal gain.” As the input power is increased to a level that causes the amplifier to saturate, gain decreases, resulting in the “large signal” response. (See Figure 1-a.)

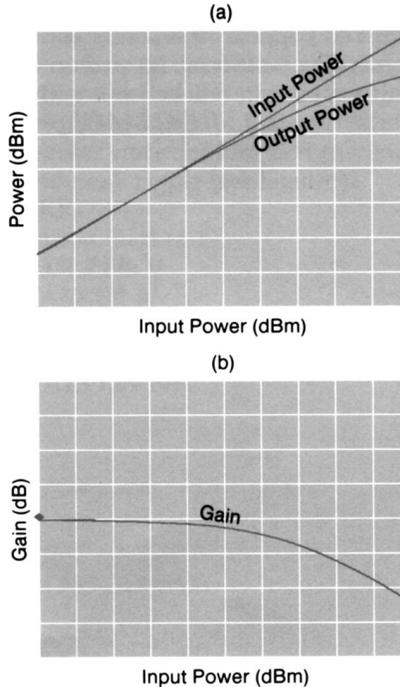


Figure 1. Typical amplifier’s characteristics: (a) output power versus input power and (b) gain versus input power

In this note, gain compression is determined by measuring the amplifier’s 1 dB gain compression point (P_{1dB}). This is the point where the output power drops 1 dB relative to the small signal gain. (See Figure 1-b.) This is a common measure of an amplifier’s power output capability.

Harmonic distortion (Agilent 8753B)

Due to inherent non-linearities, an amplifier generates additional responses at integer multiples of the stimulus frequency. The integer number determines the order of the harmonic. For example, if the harmonic frequency is equal to three times the fundamental frequency, it is known as the third harmonic. Harmonic level is defined as the difference in absolute power between the fundamental and the harmonic, expressed in dBc (dB relative to carrier), for a specified amplifier input or output power.

Two-tone intermodulation distortion (Agilent 8753B)

When two or more sinusoidal frequencies are applied to an amplifier, the output contains additional frequency components called intermodulation products. For an amplifier with input signals at frequencies f_1 and f_2 , the output will contain signals at the following frequencies: $nf_1 + mf_2$, where: $n, m = 0, \pm 1, \pm 2, \pm 3, \dots$. The order of the intermodulation distortion product is defined as $i = |n| + |m|$. Third order products ($i = 3$) are a major concern because of their proximity to the fundamental frequencies. (See Figure 2.)

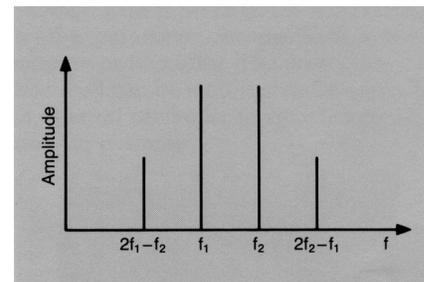


Figure 2. Two-tone third order intermodulation products

Measurements

Equipment required

The following equipment is typically required for the measurements described in this note. Other configurations can also be used:

- Agilent 8753B Network Analyzer/ Opt. 002
- Test Set: Agilent 85044A, 85046A/B, 85047A
- Calibration Kit
- Test Port Cables
- Coaxial Attenuators, as needed
- GPIB Cables
- Bias Supply
- Power Meter and Sensor
- Test Amplifier such as the Agilent 10855A Preamp

The 10855A has the following specifications:

Frequency range: 2 MHz to 1300 MHz
Gain: 24 dB typical
Output power for 1 dB compression: 0 dBm

All measurements described in this note, except for two-tone third order intermodulation, use the 8753B Network Analyzer configured with the 85046A 50 ohm S-parameter test set. Wherever the instrument is referred to as the 8753, either the 8753A or 8753B can be used to make the measurement equally well. Those unfamiliar with the test configuration are advised to read the appendix before continuing. It contains a description of the 85046A and 85047A test sets and shows signal attenuation through each test set and the corresponding power at the ports. Also included are general guidelines for selecting proper attenuation, as well as the 8753 parameters needed for proper test setup design.

The reader should be familiar with general network analyzer operation, including the different calibrations available to enhance measurement accuracy. Refer to the *Agilent 8753B User's Guide* (part no. 08753-90007) or the *Agilent 8753B System Operating and Programming Manual* (part no. 08753-90119) for a complete description of instrument operation and the calibration sequences available.

For power meter calibrations, an Agilent 436A, 437B, or 438A can be used. A power sensor such as the 8482A is also required.

In the following measurement procedures, the 8753 front panel keys such as **[DISPLAY]** appear in brackets with bold type. The "softkeys," labeled on the CRT, also appear in brackets but with bold italic type (e.g., *[LOG MAG]*).

Linear measurements

The following linear measurements can be made with a single connection to the S-parameter test set. (See Figure 3.) A full two-port calibration yields the most accurate results. Before calibration, set the measurement parameters to their desired values. It may be appropriate to step through some of the measurements before performing the calibration to ensure proper stimulus settings. Power levels at the various ports are of primary concern when measuring the linear transmission and reflection characteristics of amplifiers. If external attenuation is needed, calibrate with the attenuator in the system to remove its effects.

Transmission measurements

Transmission measurements can be made using the basic setup shown in Figure 3. An external attenuator at the amplifier output may be necessary to keep the power level at the B receiver input below the maximum level (0 dBm) for gain measurements. The test set attenuator, accessed through the 8753, affects only the source power path.

Both gain and isolation measurements are possible with the same stimulus settings by choosing a source power level for the reverse isolation measurement, then using the test set attenuator to reduce the power at the amplifier input for linear gain measurements.

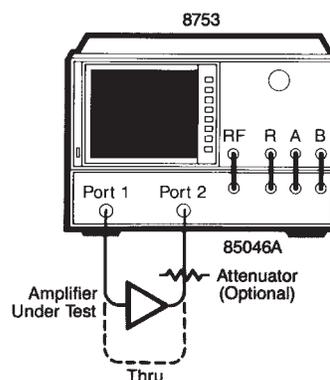


Figure 3. Basic setup for amplifier measurements using the 8753 with an S-parameter test set.

NOTE: When measuring high gain amplifiers, it is possible to overload one of the receiver inputs on the 8753 (> 0 dBm). When this happens, a P_{\downarrow} will appear on the left of the screen and a power trip condition will occur. This forces the source power to be reset to its minimum value (-5 dBm) regardless of the user-specified level. You should then either add more attenuation to the output of the amplifier, or reduce the RF power of the source before repeating the measurement. The following keystroke sequence turns power trip off:

[MENU]
[POWER]
[POWER TRIP on OFF]

Small signal gain

Small signal gain is the gain in the amplifier's linear region of operation. This is typically measured at a constant input power over a swept frequency. Figure 4 shows an example swept frequency gain measurement.

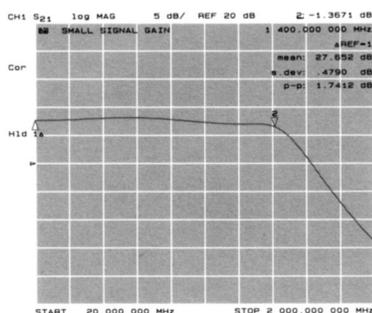


Figure 4. Small signal gain measurement

Measurement procedure

1. Connect the system as shown in Figure 3. Preset the 8753 to return the instrument to a known state of operation.

[PRESET]

CAUTION: At preset, the source power level is set to its default value of 0 dBm and the internal attenuator for port 1 is set to 0 dB. The preset power level available at port 1 is dependent on the test set used. (See Appendix for details.) If the amplifier under test could be damaged by this power level or will be operating in its non-linear region, it should not be connected until these parameters are set to a desirable level.

2. Choose measurement parameters and perform a calibration. When an attenuator is used on the output of the amplifier, calibrate with it in the system. Remember to consider power levels needed for the reverse isolation measurement when setting the source power and test set attenuation.

[START] [20] [M/u]
[STOP] [2] [G/n]
[MENU]
[POWER] [5] [x1]
[ATTENUATOR PORT 1] [30] [x1]
[MEAS]
[S₂₁] [B/R]
[FORMAT]
[LOG MAG]

Perform a measurement calibration. The instrument state can be saved for later measurements.

[SAVE]
[SAVE REG 1]

3. Connect the device and apply bias.
4. Scale the display for optimum viewing of the amplifier's gain. Alternatively, the [AUTOSCALE] softkey can be used to set the scaling parameters automatically, although it may be preferable to control these manually.

[SCALE REF]
[REFERENCE VALUE] [20] [x1]
[SCALE/DIV] [5] [x1]

5. Use a marker to measure the small signal gain at a desired frequency.

[MKR]
Rotate the knob until the marker is set.

6. Measure the gain variation or ripple in the frequency range. Set two markers on the trace to define the start and stop of the frequency range of interest, then use the marker statistics function to view peak-to-peak ripple. (See Figure 4.)

[MKR]
Position marker 1.
[MKR ZERO]
[MARKER 2]
Position marker 2.
[MKR FCTN]
[STATS ON off]

Reverse isolation

Reverse isolation can be measured with the small signal gain setup and procedure, with some modifications.

The RF stimulus signal is applied to the output of the amplifier. When the 85046/7A test set is connected, this can be done from the front panel of the 8753 by simply measuring S_{12} . The external attenuator on the amplifier output is not needed since the signal path now exhibits loss instead of gain.

For amplifiers with very high isolation, measurement sensitivity can be improved by employing averaging or by reducing the IF bandwidth of the 8753.

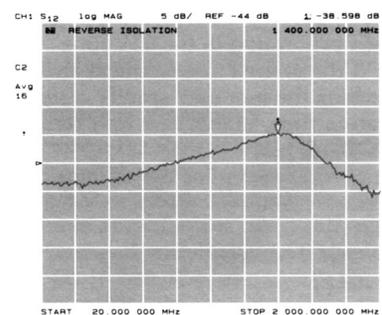


Figure 5. Reverse isolation measurement

Gain versus time

Gain variation in time, with all other parameters held constant, is sometimes referred to as gain drift. The 8753 allows fixed frequency measurements to be made over 100 ms to 24 hour time intervals. This measurement uses the standard setup of Figure 3. An example plot of an amplifier's gain drift over a 10 minute interval is shown in Figure 6.

Often, gain is investigated with respect to other parameter changes, such as temperature or humidity. The procedure described can be modified to be used with an external controller; to vary temperature, for example.

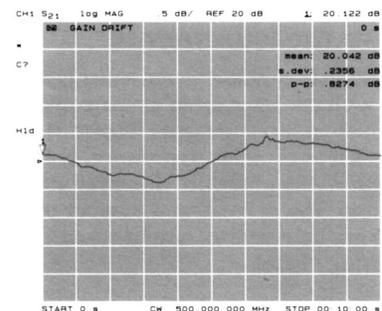


Figure 6. Gain versus time measurement

Measurement procedure

1. Connect the instrument as shown in Figure 3.
2. Preset the instrument and measure S_{21} in log format.
[PRESET]
[MEAS]
[S_{21} [B/R]]
[FORMAT]
[LOG MAG]

3. Enter the desired fixed frequency.
[MENU]
[CW FREQ] [500] [M/u]

4. Modify the parameters such that the amplifier operates in its linear region.
[MENU]
[POWER] [5] [x1]
[ATTENUATOR PORT 1] [30] [x1]

5. When calibrating in the CW time mode, if the desired measurement sweep time is long, the user may specify a shorter calibration time; in this case four seconds.
[STOP] [4] [x1]

6. Use a single sweep for the calibration and measurement.
[MENU]
[TRIGGER MENU]
[SINGLE]

Perform a response calibration.

7. Connect the amplifier under test and apply bias. A 10-minute sweep was used for this measurement. The analyzer will display a $C?$ to indicate that a source parameter has been changed.
[STOP] [10] [:h:m:s] [0] [x1]
[MENU]
[MEASURE RESTART]

8. Scale the display to see the gain variations with time.
[MKR] [0] [x1]
[SCALE REF]
[MARKER → REFERENCE]
[SCALE/DIV] [.2] [x1]

9. Use marker statistics to measure the maximum peak-to-peak variation in gain over the time interval.
[MKR FCTN]
[STATS ON off]

Phase measurements

Transmission phase measurements are made with the same setup as magnitude transmission measurements (Figure 3). For cases such as complex impedance, both magnitude and phase are displayed simultaneously. Power levels and number of points are both considerations when measuring phase.

Deviation from linear phase

The deviation from linear phase measurement employs the electrical delay capability of the Agilent 8753 to add electrical delay to the amplifier to remove the linear portion of the phase shift. (See Figure 7.)

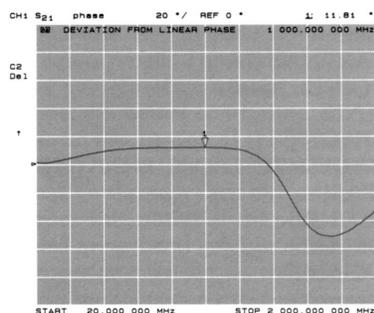


Figure 7. Deviation from linear phase measurement

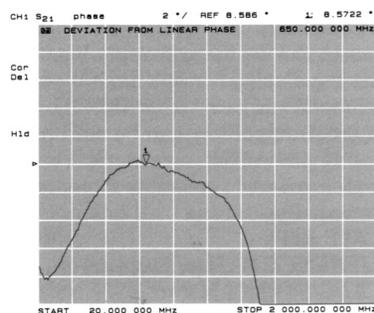


Figure 8. Expanded plot allows fine-tuning of the electrical delay

Measurement procedure

1. Follow the first two steps in the Small Signal Gain Measurement Procedure. Display the phase response of the measurement.
[FORMAT]
[PHASE]
2. Scale the display.
[SCALE REF]
[SCALE/DIV] [20] [x1]
3. Place a marker in the center of the amplifier bandwidth and activate the electrical delay function.
[MKRFCTN]
Position the marker with the knob.
[MARKER → DELAY]

4. Expand the scale and fine-tune the electrical delay to flatten the phase near the center of the passband. (See Figure 8.)
[MARKER → REFERENCE]
[SCALE REF]
[SCALE/DIV] [2] [x1]
[ELECTRICAL DELAY]

Adjust electrical delay to flatten the response. By flattening the phase response we have effectively removed the linear phase shift through the amplifier under test. The deviation from this linear phase shift remains.

Group delay

Group delay, like deviation from linear phase, is a measure of amplifier distortion. The 8753 calculates group delay from the phase and frequency information and displays the results in real time. (See Figure 9.) It is important to keep the phase difference measured between two adjacent frequency points less than 180° . Otherwise, incorrect group delay information may result. The test setup of Figure 3 is again employed.

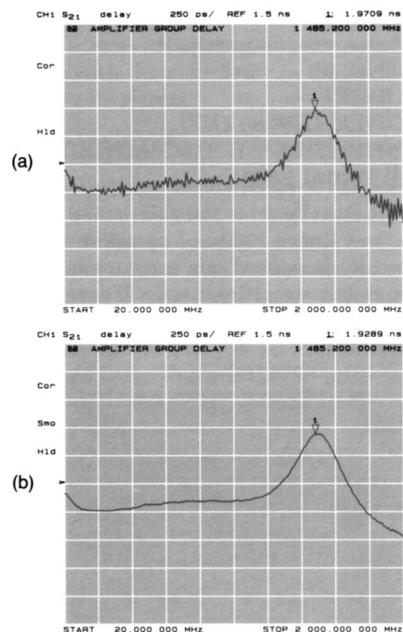


Figure 9. Group delay measurement: (a) with minimum aperture and (b) with increased aperture

Measurement procedure

1. Follow the first two steps in the *Small Signal Gain Measurement Procedure*. If the instrument state was saved, recall it from memory.

[RECALL]
[RECALL REG 1]

2. Display the group delay response of the amplifier under test.

[FORMAT]
[DELAY]
[SCALE REF]
[AUTOSCALE]

3. This measurement may require a specific group delay aperture. The minimum aperture is equal to the frequency span divided by the number of points minus one. (See Figure 9-a.) Aperture can be increased from the minimum by varying the smoothing aperture. Increasing the aperture reduces the resolution demands on the phase detector and permits better group delay resolution. (See Figure 9-b.)

[AVG]
[SMOOTHING ON off]
[SMOOTHING APERTURE]

Adjust aperture as needed.

Reflection measurements

Reflection measurements can be made with the same setup as transmission measurements (Figure 3). If external attenuation is needed for gain measurements, calibrate with the attenuator in the system to remove its effects. Since reflection measurements involve loss instead of gain, power levels are lower at the receiver inputs. Therefore, it may be necessary to increase power levels for reflection measurements.

Alternatively, reduce the noise level by decreasing the IF bandwidth or by employing averaging.

Return loss, SWR, and reflection coefficient

Return loss, standing wave ratio (SWR), and reflection coefficient (ρ) are commonly specified for the amplifier's input and output ports. With the 8753, scalar reflection measurements can be displayed as return loss in dB, SWR, or ρ .

With the internal switching capabilities of the 85046/7A test set, you can switch between displaying the input reflection and output reflection with the touch of a key; no rearrangement of the test setup is required.

Figure 10 shows an example amplifier input return loss measurement.

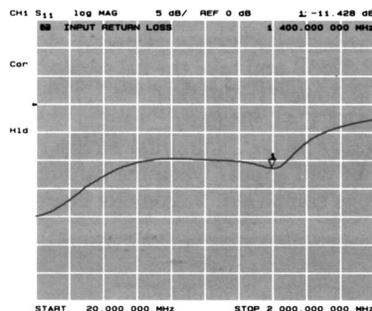


Figure 10. Input return loss measurement.

Measurement procedure

1. Connect the instruments as shown in Figure 3 and preset the network analyzer.

[PRESET]

2. Set source power and attenuation such that the amplifier operates in its linear region, and power levels incident to the receiver inputs are below the maximum level. Also, set all other stimulus parameters.

[MENU]
[POWER] [5] [x1]
[PORT 1 ATTENUATOR] [30] [x1]
[START] [20] [M/u]
[STOP] [2] [G/n]

3. Because reflection measurements are very sensitive to mismatches, a full 2-port calibration is recommended. A full 2-port calibration removes the effects of source and load match, directivity, and frequency response. Perform the calibration.

Alternatively, if a 2-port calibration was performed with suitable stimulus parameters for the small signal measurement, recall that instrument state.

[RECALL]
[RECALL REG 1]

4. If low level signals are being measured, reduce the IF bandwidth.

[AVG]
[IF BW]
[300] [x1]

5. Connect the amplifier under test and apply bias.

6. Display S_{11} on channel 1.

[MEAS]
[S11 [A/R]]

7. View the different reflection formats and scale as necessary. View return loss.

[FORMAT]
[LOG MAG]
View standing wave ratio.
[SWR]
View reflection coefficient, ρ .
[LIN MAG]

8. Now view return loss, SWR, or ρ at the amplifier's output port.

[MEAS]
[S22 [B/R]]
Repeat step 7.

Complex impedance

Because the 8753 measures phase as well as magnitude, complex impedance is easily determined once the instrument is configured to make reflection measurements.

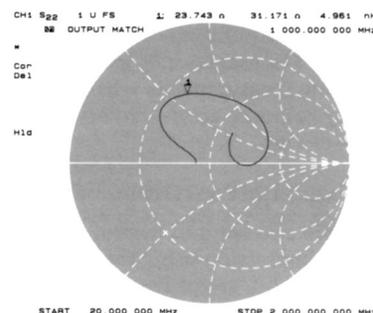


Figure 11. Complex impedance measurement

Measurement procedure

1. Perform the *Return Loss Procedure*.

2. Display the output impedance by measuring S_{22} in Smith chart format. Figure 11 shows amplifier output impedance. Markers used with this format display $R + jX$. In fact, the reactance is displayed as equivalent capacitance or inductance at the marker frequency.

[MEAS]
[S11 [A/R]]
[FORMAT]
[SMITH CHART]

3. View the complex reflection coefficient, Γ . Polar format markers display linear magnitude and phase.

[FORMAT]
[POLAR]

Non-linear measurements

These measurements, with the exception of gain compression, are not usually associated with network analyzers. However, the Agilent 8753 offers some added capabilities that allow some non-linear measurements to be made. Due to the nature of non-linear measurements, measurement calibrations are not applicable. The exception is gain compression measurement where frequency response errors can be removed from the system.

Gain compression

There are two ways to measure amplifier gain compression using the 8753. The first method, swept frequency gain compression, shows how to find the frequency at which 1 dB gain compression first occurs. The second method, swept power gain compression, shows the reduction in gain as a power ramp is applied to the amplifier under test.

Swept frequency gain compression

This measurement allows the user to easily determine the frequency at which 1 dB gain compression first occurs (Figure 12). This is accomplished through normalization to the small signal gain and by observing compression as the drop from the reference line as input power is increased. This frequency can in turn be used as the fixed frequency for a swept power compression measurement, discussed in the next section.

The output power of the amplifier can be displayed on channel 2 to easily determine P_{1dB} . Also, a power meter calibration, available with the 8753B, improves the accuracy of this measurement by setting input power precisely. For a discussion of power meter calibration, see the *Agilent 8753B System Operating and Programming Manual*.

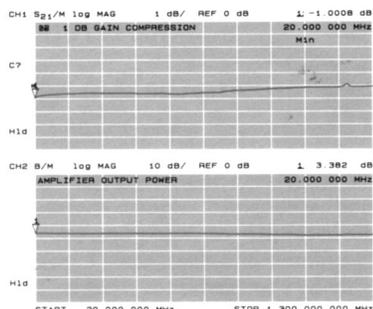


Figure 12. Swept frequency gain compression measurement

Measurement procedure

1. Connect the instrument as shown in Figure 13. Preset the instrument. Channel 1 will display the frequency for which 1 dB gain compression first occurs. Channel 2 will display amplifier output power to allow easy determination of the 1 dB gain compression output power.

[PRESET]

2. Set measurement stimulus parameters.

[MEAS]

[S_{21} [B/R]]

[START] [20] [M/u]

[STOP] [1.3] [G/n]

[MENU]

[POWER]

[ATTENUATOR PORT 1] [20] [x1]

3. Since the output power of an amplifier is important, the loss through the test set between the amplifier output and the receiver input needs to be characterized. To do this, first perform a response calibration on channel 2 as shown in Figure 13.

NOTE: When using the 85044 test set, steps 3 and 4 can be omitted because the amplifier's output is connected directly to the 8753 receiver input.

[CH 2]

[MEAS]

[S_{21} [B/R]]

[CAL]

[CALIBRATE MENU]

[RESPONSE]

[THRU]

[DONE]

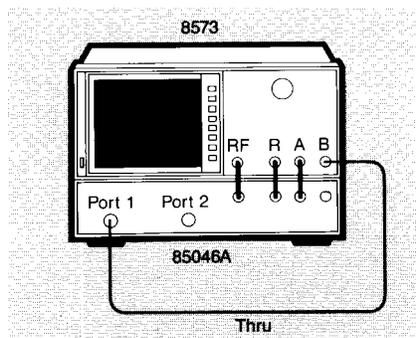


Figure 13. Setup for calibration to input B

4. Connect the standard configuration without the amplifier (see Figure 3) and measure the signal path between port 2 to input B. Use this data to normalize the display to the actual output power of the amplifier, which is the power incident at port 2 of the test set.

[DISPLAY]

[DATA → MEM]

[MEAS]

[INPUT PORTS]

[B]

[DISPLAY]

[DATA/MEM]

5. Calibrate channel 1 for gain measurements.

[CH 1]

[CAL]

[CALIBRATE MENU]

[RESPONSE]

[THRU]

[DONE]

5B. (Optional for the 8753B only) For increased accuracy, also perform a power meter calibration at port 1 to remove source and test set nonlinearities with frequency. Attach the 438A power meter to port 1 of the test set. Also, connect GPIB as shown in Figure 14. Make sure the power meter model and address is known by the 8753. Before proceeding, zero the power meter.

[LOCAL]

[SYSTEM CONTROLLER]

[SET ADDRESSES]

[ADDRESS: P MTR/GPIB] [15] [x1]

[PWR MTR: [438A/437/436A]]

Toggle to select desired power meter.

[CAL]

[PWR METER]

[NUMBER OF READINGS] [1] [x1]

[PWRMTR CAL: ONE SWEEP]

Set the desired power at port 1 of the 8753B and take the cal sweep.

(Cal power) [-20] [x1]

[TAKE CAL SWEEP]

A "Power Meter Calibration Sweep Done" prompt will appear when the calibration sweep is completed. Reconnect Figure 3.

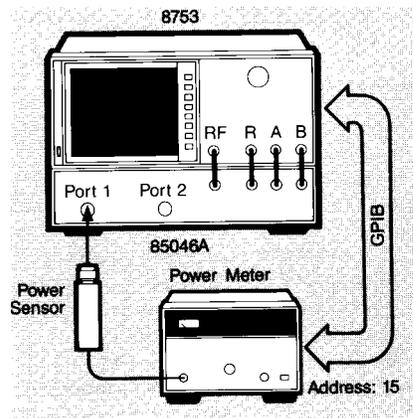


Figure 14. Setup for power meter calibration at amplifier input

6. Connect the amplifier, apply bias, and turn on dual channel split display.

[DISPLAY]
[DUAL CHAN ON off]

7. Normalize the trace to the small signal gain. The new trace should be a flat line at 0 dB.

[DISPLAY]
[DATA → MEMORY]
[DATA/MEMORY]

8. Scale the display to allow easy observation of a 1 dB drop from the small signal gain.

[SCALE REF]
[SCALE/DIV] [1] [x1]
[REFERENCE VALUE] [0] [x1]

9. Use the rotary knob to increase the source power level until the trace drops by 1 dB at some point. A marker can then be used to track the exact frequency where 1 dB compression first occurs. Care should be taken when increasing the source power so that the input power limitation of the amplifier under test is not exceeded. Channel 2 displays the actual output power of the amplifier because the test set loss has been removed.

[MKRFCTN]
[MARKER SEARCH]
[TRACKING ON off]
[SEARCH: MIN]
[MENU]
[POWER]

Adjust power for 1 dB compression.

Swept power gain compression

By applying a fixed frequency power ramp to the input of an amplifier and investigating gain, gain compression is observed as a 1 dB drop from small signal gain. The fixed frequency chosen could be, for example, the frequency for which 1 dB compression first occurs in a swept frequency gain compression measurement. As with the swept gain compression measurement of the previous section, channel 2 displays the output power of the amplifier in order to easily determine P_{1dB} .

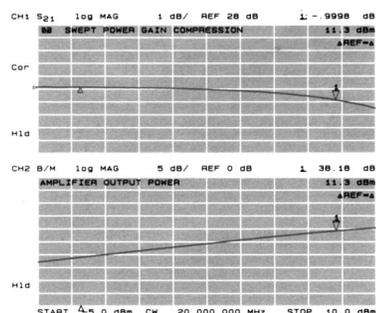


Figure 15. Swept power gain compression measurement

Measurement procedure

1. Connect the instrument as shown in Figure 14 and preset the instrument. Channel 1 will display the amplifier's response to a power ramp. Channel 2 will display amplifier output power to allow easy determination of the 1 dB gain compression output power.

[PRESET]

2. Select a power sweep at the fixed frequency of interest. This could be the frequency at which 1 dB gain compression first occurs for a swept frequency gain compression measurement.

[MENU]
[SWEEP TYPE MENU]
[POWER SWEEP]
[RETURN]
[CWFREQ] [20] [M/u]

3. Set the stimulus parameters. Power levels must be set so that the amplifier is forced into compression. The range of the 8753's source is from -5 dBm to +20 dBm. An external output attenuator may be required to prevent overdriving input B.

[MEAS]
[S₂₁ [B/R]]
[START] [-5] [x1]
[STOP] [10] [x1]
[MENU]
[POWER]
[ATTENUATOR PORT 1] [20] [x1]

4. Since the output power of the amplifier is important, the loss through the test set between the amplifier output and the receiver input needs to be characterized. To do this, first perform a response calibration on channel 2 as shown in Figure 13.

NOTE: When using the 85044 test set, steps 4 and 5 can be omitted since the amplifier's output is connected directly to the 8753 receiver input.

[CH 2]
[MEAS]
[S₂₁ [B/R]]
[CAL]
[CALIBRATE MENU]
[RESPONSE]
[THRU]
[DONE]

5. Connect the standard configuration without the amplifier (see Figure 3) and measure the port 2 to input B path. Use this data to normalize the display to the actual output power of the amplifier, which is the power incident at port 2 of the test set.

[DISPLAY]
[DATA → MEM]
[MEAS]
[INPUT PORTS]
[B]
[DISPLAY]
[DATA/MEM]

6. Calibrate channel 1 for gain measurements.

[CH 1]
[CAL]
[CALIBRATE MENU]
[RESPONSE]
[THRU]
[DONE]

7. Reconnect the amplifier, apply bias, and turn on dual channel split display. Gain versus input power will be displayed on channel 1, and absolute output power will be displayed on channel 2.

[DISPLAY]
[DUAL CHAN ON off]

8. Move a marker to the flat portion of the trace. (If there is no flat portion, the amplifier is in compression throughout the sweep, and power levels must be decreased.) Use the marker search to find the power for which a 1 dB drop in gain occurs.

[MKR]
Position the marker in the flat gain portion of the trace.

[SCALE REF]
[MARKER → REFERENCE]
[SCALE/DIV] [1] [x1]
[MKR]
[MKR ZERO]
[MKR FCTN]
[MKRSEARCH]
[TARGET] [-1] [x1]
[MKR]
[Δ MODE MENU]
[Δ MODE OFF]

The 1 dB gain compression output power should be displayed on channel 2.

Non-linear measurements with the Agilent 8753B

Swept harmonic levels (Option 002)

Traditionally, harmonic measurements are made with a spectrum analyzer at several CW frequencies. Many frequencies must be tested for complete characterization, which can dramatically increase test time. With the 8753B, however, you can make swept frequency (and power) second and third harmonic response measurements. This capability provides “real-time” update of the measured harmonic response versus frequency.

Harmonic response measurements on the 8753B are made using the channel trace math functions to normalize the harmonic response to the fundamental response. In this manner, the harmonic response of the device under test can be displayed directly in dBc. (See Figure 16.)

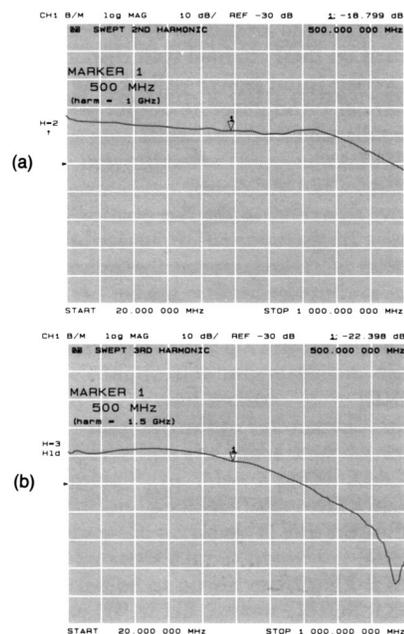


Figure 16. Swept harmonic response measurement: (a) 2nd harmonic dBc and (b) 3rd harmonic dBc

The 8753B can measure the second harmonic response of a fundamental signal up to 1.5 GHz, and third harmonic response of a 1 GHz fundamental. The 8753B with 6 GHz capability, Option 006, allows measurements of frequencies up to 6 GHz. So, for second harmonic measurements, the fundamental frequency can be up to 3 GHz, while for third harmonic measurements, the fundamental frequency can be up to 2 GHz. The test setup for measuring the harmonic response of an amplifier can be made with the same connections that were employed for all the linear measurements. (See Figure 3.)

Measurement procedure

1. Set up the instrument as shown in Figure 3. Notice that a 20 dB external attenuator at the amplifier’s output serves to reduce the power level incident on the receiver. This protects against overloading and reduces the harmonics generated by the receiver.

2. Preset the instrument.

[PRESET]

3. Measure input port B.

[MEAS]

[INPUT PORTS]

[B]

[FORMAT]

[LOG MAG]

4. Set the source power level and port 1 attenuation such that the amplifier operates in its linear region. Remember that the source output power level affects the uncertainty of harmonic measurements.

[MENU]

[POWER] [-5] [x1]

[ATTENUATOR PORT 1] [10] [x1]

5. Set the desired start and stop fundamental frequencies. Frequencies greater than 16 MHz must be used.

[START] [20] [M/u]

[STOP] [1] [G/n]

6. Apply bias to the amplifier.

7. Configure channel 2 like channel 1.

[CH 2]

Repeat step 3.

8. Display the fundamental response of the amplifier for optimum viewing.

[SCALE REF]

[REFERENCE POSITION] [10] [x1]

9. Uncouple the channels to allow second or third harmonic responses in dBc.

[MENU]

[COUPLED CH on OFF]

10. Normalize the trace to the fundamental response.

[DISPLAY]

[DUAL CHAN ON off]

[MORE]

[SPLIT DISP on OFF]

[MORE]

[D2/D1 to D2 ON off]

A flat line should now be displayed at 0 dB.

11. Use the harmonic mode menu to view the second and third harmonic responses in dBc.

[SYSTEM]

[HARMONIC MEAS]

View the second harmonic response. (See Figure 16-a.)

[SECOND]

Now view the third harmonic response. (See Figure 16-b.)

[THIRD]

An “H=2” or “H=3”, respectively, will appear to the left of the display. Markers display both the fundamental and corresponding harmonic frequencies. Return to the fundamental response.

[HARMONIC OFF]

If the trace appears noisy, you are near the noise floor of the 8753B. This noise floor can be lowered by narrowing the IF bandwidth.

[AVG]

[IF BW]

Enter a lower value for the IF bandwidth.

Often, when making harmonic response measurements, it is important to accurately know the power level entering the device under test. The 8753B power meter calibration procedure can be used to level the source power at the amplifier input.

Two-tone third order intermodulation

Intermodulation distortion (IMD), like harmonic distortion, describes nonlinearities of an amplifier. Two-tone intermodulation products are generated when two incoming signals enter the amplifier and interact to produce IMD products.

Corresponding to each IMD product is a theoretical *Intercept Point* of order i . This term is often used to specify the IMD performance of an amplifier. Because of the proximity of the third order ($i = 3$) products to the fundamental frequencies, these are of greatest concern. Assuming the two input signals are of equal magnitude, the third order intercept point, TOI, is then calculated from:

$$TOI = P_0 + (P_0 - P_3)/2$$

(all quantities in dBm), where:

P_0 = output power of the individual test frequencies

P_3 = output power of the third order IMD product

This measurement must be performed in the linear operating region of the amplifier to ensure a correct intercept point calculation. (See Figure 17.)

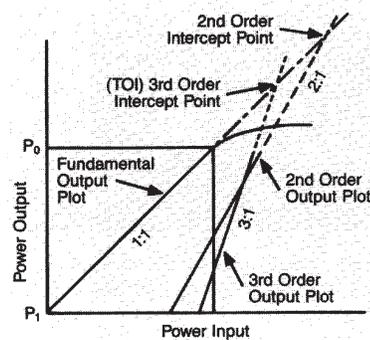


Figure 17. Plot for intercept point calculation

In the tuned receiver instrument mode, the 8753B displays IMD in a similar fashion to a spectrum analyzer. (See Figure 18.) Because the 8753B's receiver tunes to a frequency without phaselocking, it is necessary to use synthesizers to ensure precisely known CW input signals.

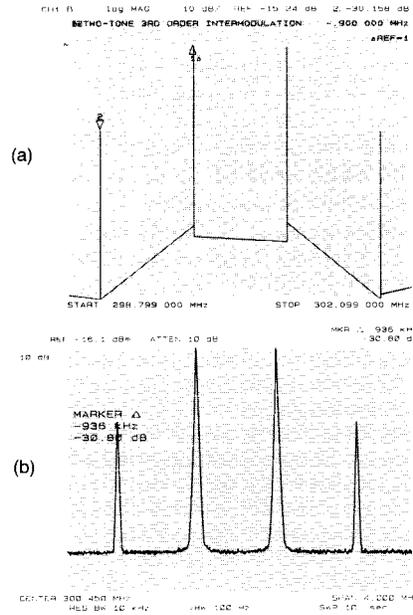


Figure 18. Two-tone IMD measurement (a) using the 8753B and (b) using a spectrum analyzer.

The measurement setup is shown in Figure 19. The two synthesizers used were 8656Bs. Attenuators are used to ensure the individual fundamental power levels at the receiver input are below -20 dBm.

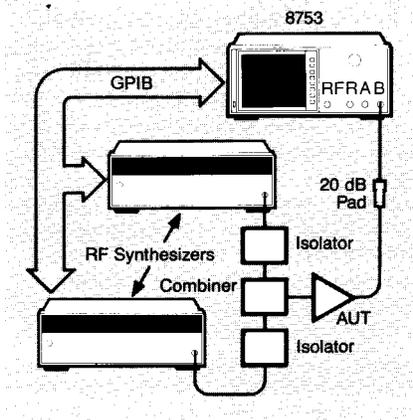


Figure 19. Two-tone third order intermodulation measurement setup

Measurement procedure

1. Connect the instruments as shown in Figure 19. Connect the external frequency references together to synchronize the measurement frequencies. Preset the 8753B.

[PRESET]

2. Preset the synthesizers and then select CW frequencies, f_1 and f_2 . In the example, $f_1 = 300$ MHz and $f_2 = 300.9$ MHz.

Also, set the power on both instruments to the same level.

3. Reduce the IF bandwidth of the 8753B receiver to lower the noise floor of the trace.

[AVG]
[IF BW]
[100] [x1]

4. Set up a frequency list for the four frequencies of interest: f_1 , f_2 , $2f_1 - f_2$, and $2f_2 - f_1$. Five points are chosen to ensure detection of the desired signals at the four frequencies.

[MENU]
[SWEEP TYPE MENU]
[EDIT LIST]
[ADD]
[CENTER] [#] [M/u]
[SPAN] [2] [k/m]
[NUMBER OF POINTS] [5] [x1]
[DONE]

where: # refers to the four frequencies of interest. The example frequencies are 299.1 MHz, 300 MHz, 300.9 MHz, and 301.8 MHz. Step 4 must be repeated for each frequency.

NOTE: If the third order products are unequal in magnitude or any of the signals appear unstable, vary the frequencies used slightly. The *Agilent 8753B Operating and Programming Manual* gives a listing of frequencies that should be avoided.

5. Enter two other frequency segments to allow better viewing of the frequencies of interest on the display.

[ADD]
[CENTER] [#] [M/u]
[SPAN] [2] [k/m]
[NUMBER OF POINTS] [1] [x1]
[DONE]
[DONE]
[LIST FREQ]

where: # refers to 298.9 and 302 MHz.

6. Place the instrument in tuned receiver mode.

[SYSTEM]
[INSTRUMENT MODE]
[TUNED RECEIVER]

7. Third order IMD should now be displayed on the 8753B's display. To calculate the third order intercept point, TOI, use the equation:
 $TOI = P_0 + (P_0 - P_3)/2$

Remember to account for any padding between the amplifier's output and the 8753B. For the example measurement shown in Figure 18, since P_0 is about $+4.8$ dBm and $(P_0 - P_3)$ is 30.2 dB, TOI is calculated as 19.9 dBm.

Enhanced manufacturing techniques

Limit lines

The limit line feature of the Agilent 8753 network analyzer allows arbitrary limit values to be entered on the screen for direct comparison with the measured data. (See Figure 20.) Up to fifteen limit segments can be added per channel as single points, flat lines, or sloped lines. Each segment contains an upper and lower limit and a starting stimulus value. Results are displayed with a *PASS/FAIL* message, and an optional beep upon failure. For example, gain over a certain frequency range can be tested by using a flat limit line with a lower limit set to the minimum gain allowable and an upper limit set to the upper gain value. This allows testing of both minimum gain and gain ripple simultaneously. The following procedure describes how to use limit lines to perform this test.

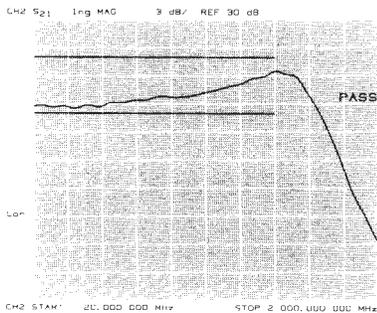


Figure 20. Limit lines example

Measurement procedure

1. Perform the small signal gain measurement.
2. Enter the limit line menu.
[SYSTEM]
[LIMIT MENU]
[EDIT LIMIT LINE]
3. Enter the stimulus value as well as the upper and lower amplitude limits for your limit line.
[ADD]
[STIMULUS VALUE]
[20][M/u]
[LOWER LIMIT]
[20][x1]
[UPPER LIMIT]
[26][x1]
[DONE]

4. Define the type of limit line to be used.

[LIMIT TYPE]
[FLAT LINE]
[RETURN]

5. The flat line segment is valid from its stimulus value to the end of the frequency sweep range. To shorten its range, terminate the segment with a corresponding single point.

[ADD]
[STIMULUS VALUE]
[1.4][G/n]
[DONE]
[LIMIT TYPE]
[SINGLE POINT]
[RETURN]
[DONE]

6. Repeat steps 3 to 5 until all desired limit lines are entered.

7. Turn on limit lines.
[LIMIT LINES ON off]

8. Activate PASS/FAIL limit testing.
[LIMIT TEST ON off]

Test sequence function (Agilent 8753B)

The amplifier measurements covered in this note are typical of those made in manufacturing environments. The 8753B test sequence function increases throughput by automating the test procedure. This is accomplished by simply performing the measurement manually from the front panel while in the test sequence mode. Figure 21 shows a sample sequence for the swept harmonic levels measurement.

In addition to throughput, the chances of operator error are reduced when using sequencing. Also, since no external controllers are required, no time is wasted learning instrument control commands, and in some cases, a new programming language.

Each sequence can be up to 2000 bytes, or about 200 lines in length. With the ability to call other sequences, complex tasks can be easily handled. Limited decision making is possible, such as: *IF LIMIT TEST PASS THEN DO SEQUENCE*. The test sequence function can also control other GPIB programmable instruments. For example, optimize harmonic levels with respect to bias by using a sequence to automatically control a power supply. Refer to the *Agilent 8753B System Operating and Programming Manual* for a complete discussion of the test sequence function.

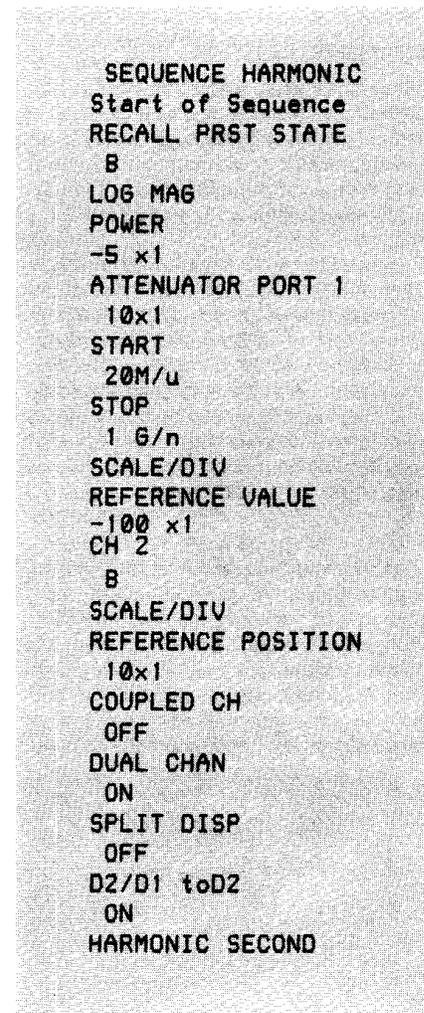


Figure 21. Swept harmonic levels sequence

Accuracy Considerations

Linear measurements

This section summarizes key accuracy considerations for the measurements described in this note. Vector accuracy enhancement can be applied to the linear measurements discussed to greatly reduce measurement uncertainty. This is accomplished by removing systematic errors through measurement calibration with standards such as a short, an open, and a thru.

To illustrate the differences between the various accuracy enhancement techniques, the following amplifier characteristics were assumed.

- Gain: 22 dB
- Reverse isolation: 45 dB
- Input SWR: 3.0
- Output SWR: 2.2

An 85046A test set and 3.5 mm calibration accessories are used in these examples. For a complete table of uncertainty improvements resulting from various calibration procedures, see the *Agilent 8753 System Operating and Programming Manual*.

Gain

The major sources of error in a gain measurement with the 8753 network analyzer are the frequency response of the test setup, the source and load mismatch during measurement, and the system dynamic accuracy. The frequency response of the test setup is the dominant error in a transmission measurement. A simple response calibration significantly reduces this error. For greater accuracy, a full 2-port calibration can be used.

Mismatch uncertainties are a function of effective source and load mismatches. A full 2-port calibration not only reduces the effects of frequency response, it also improves the effective source and load match. An example illustrates the accuracy improvements of a full 2-port calibration over a response calibration.

Total measurement uncertainty of gain (worst case):

Response calibration: ± 1.4 dB
Full 2-port calibration: ± 0.3 dB

Dynamic accuracy, a measure of the tuned receiver's performance as a function of incident power level, also influences the uncertainty of gain measurements. This is because a receiver usually sees a different power level between calibration and measurement. The dynamic accuracy of the 8753 is typically ± 0.02 dB over a 50 dB range (-10 dBm to -60 dBm).

Reverse isolation

Isolation is subject to the same error considerations as gain. In addition, if the isolation of the amplifier under test is very large, the transmitted signal level may be near the noise floor and/or crosstalk level. To lower the noise floor, employ averaging or reduce the IF bandwidth of the 8753. When crosstalk levels affect the measurement accuracy, a response and isolation calibration or a full 2-port calibration removes the crosstalk error term.

Gain versus time

Since the gain drift measurement described in this note is a fixed frequency gain measurement over time, it is subject to the error considerations discussed for gain. Another factor that could be significant in this type of measurement is the transmission tracking drift of the test setup. This is primarily caused by a change in the test setup temperature between calibration and measurement. If the instrument is allowed to stabilize to the ambient temperature before calibration and measurement, this error term should be small.

Deviation from linear phase

Transmission phase uncertainty is calculated from a comparison of the magnitude uncertainty, previously discussed for gain measurements, with the test signal magnitude. The typical size of this uncertainty is best illustrated with an example.

Total measurement uncertainty of phase (worst case):

Response only calibration: $\pm 9.4^\circ$
Full 2-port calibration: $\pm 2.2^\circ$

Reflection measurements

The uncertainty of reflection measurements is affected by directivity, source match, load match, and the reflection tracking of the test system. With a full 2-port calibration, the effects of these factors are minimized. A 1-port calibration provides the same accuracy if the output of the amplifier is well terminated. An example using the amplifier described earlier best illustrates this improvement.

Total measurement uncertainty of input return loss (worst case):

Response only calibration: $+3.0$ dB
Full 2-port calibration: ± 0.6 dB

Since the magnitude of the mismatch uncertainty depends on the input and output match of an amplifier, a measurement of a better matched amplifier will contain less uncertainty.

1. For the complete uncertainty equations, see the *General Information and Specifications* section of the *Agilent 8753B System Operating and Programming Manual*.

Non-linear measurements

The non-linear measurements discussed in this note make use of the Agilent 8753's receiver to measure absolute power. Vector accuracy enhancement is not applicable to power measurements. Uncertainties for these measurements are affected by the previously mentioned sources of error. Thus, care should be taken to reduce mismatch effects because mismatch errors contribute to total measurement uncertainty. For absolute power measurements, additional uncertainty is introduced by the receiver power accuracy. The tuned receiver of the 8753 is accurate to ± 1 dB in absolute amplitude measurements over the 300 kHz to 3 GHz frequency range (typically $< \pm 0.5$ dB). From 3 to 6 GHz with the 8753B, the receiver is accurate to ± 3 dB (typically ± 1 dB). One method of increasing the accuracy of absolute power measurements is to reference the receiver inputs with a power meter. In this manner, the receiver can be characterized and the measured data improved.

Remember, when using the 85046/7A test sets, there is uncertainty in the amount of insertion loss from the output of the amplifier under test to the receiver input on the 8753. For maximum accuracy in absolute power level measurements, this loss must also be characterized and removed from the measurement. See the *Swept Frequency Gain Compression Measurement Procedure* for a discussion on how to remove this loss from the system.

Gain compression

Gain compression measurements employ response calibrations to reduce uncertainties. Be aware, however, that to determine swept frequency gain compression, the source power level must be changed. The 8753's source linearity is ± 0.2 dB from -5 to $+15$ dBm. Therefore, the validity of the response calibration is reduced when varying source power for swept frequency measurements. Source linearity uncertainty can be reduced for swept power gain compression measurements by performing a power meter calibration at the input of the amplifier. This precisely sets the power level incident to the amplifier under test by compensating the source power for any nonlinearities in the source or test setup.

Swept harmonic levels (Agilent 8753B)

For harmonic distortion measurements, it is important to note that the source and the receiver of the 8753B generate their own harmonics. The level of these additional harmonics affects the range and uncertainty of harmonic measurements. The 8753B is capable of making up to 40 dBc harmonic measurements with a source power level of 0 dBm, and a power level of -20 dBm or lower, incident on the receiver. Increasing the source power level and/or the power level incident on the receiver reduces the range of harmonic levels that can be measured. Performance for different source and receiver levels is specified in the *Agilent 8753B Data Sheet* (lit no. 5956-4335) and in the *Agilent 8753B System Operating and Programming Manual*.

With harmonic measurements, measurement calibration is not used, since the harmonic and fundamental frequencies are different. Instead, the absolute values of the amplifier's fundamental and harmonic levels are compared using the $D2/D1$ to $D2$ trace math function.

Two-tone third order intermodulation (Agilent 8753B)

A power combiner should be used for two-tone IMD measurements to sufficiently isolate the sources. In some situations, it may be necessary to further isolate the sources with amplifiers. Attenuators can be used to reduce mismatch errors. In cases where source harmonics affect the intermodulation response, low pass filtering can be inserted between the amplifier and the signal sources to reduce their harmonics.

Appendix: S-parameter test set considerations

When configuring a test setup for amplifier measurements, knowledge of power levels through the various signal paths is vital. This appendix describes the 85046A (300 kHz to 3 GHz) and 85047A (300 kHz to 6 GHz) 50-ohm S-parameter test set, and explicitly shows the signal paths and power levels through them. The actual power levels available at the test ports of the 8753/S-parameter test set system are listed in Table 1. Finally, an example is presented to clarify attenuator and power level requirements for a particular amplifier. Figure 22 shows a schematic representation of the 85046A S-parameter test set and lists the attenuation from the RF input (0 dB reference point) to the other ports. The same is done in Figure 23 for the 85047A.

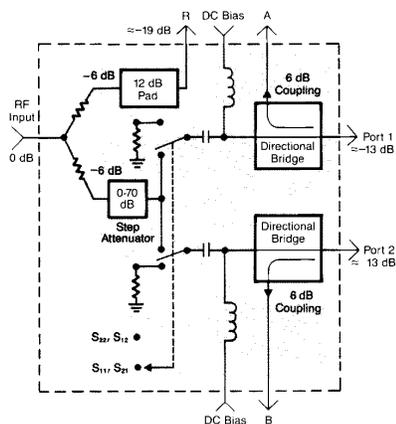


Figure 22. Schematic of the 85046A S-Parameter Test Set

NOTE: This appendix describes the 85046A and the 85047A only. The 85046B 75-ohm S-parameter test set and other signal separation devices, such as the 85044A/B transmission/reflection test set, have different insertion losses and should be considered separately.

Some important parameters of the 8753 test system:

- Source power range = +20 dBm to -5 dBm
- Receiver input ranges:
(best accuracy when signal levels are kept below -10 dBm)
R channel = 0 dBm to -35 dBm
A, B channel = 0 dBm to -100 dBm

The following example illustrates the general procedure for choosing attenuator levels and source power.

Example: Measuring the small signal gain of an amplifier, using the 8753/85046A test system.

Given: The general test setup of Figure 3. Amplifier under test has the following parameters:

- gain of approx. 40 dB
- desired input power of -30 dBm

Required: To design a test setup and set operating parameters such that the amplifier operates in its linear region (*i.e.*, input power < -30 dBm).

Procedure: Start with the amplifier's maximum input, -30 dBm. The input power must be less than this so that the amplifier is operating in its linear region. With the source power at its default value of 0 dBm, and a nominal loss through the test set to port 1 of 13 dB, the default power at port 1 is about -13 dBm. The step attenuator must therefore be used to decrease this power below -30 dBm. The step attenuator can be set in increments of 10 dB up to 70 dB, by setting

[**ATTENUATOR PORT 1**] or [**ATTENUATOR PORT 2**] (depending on the direction of the measurement) in the 8753 power menu. Increasing the port 1 attenuation to 20 dB, changes the power level at port 1 (the amplifier input) to -33 dBm, which is about the required power limit.

Now consider the amplifier output. Since the output power is approximately 7 dBm (-33 dBm + 40 dB of gain) and the loss in the test set from port 2 to channel B is only about 6 dB, an external attenuator must be inserted before port 2 in order to keep input B below its maximum power level (0 dBm). A 20 dB pad at the amplifier output will keep the maximum power at B ≤ 19 dBm, which allows the receiver to operate in its most accurate range.

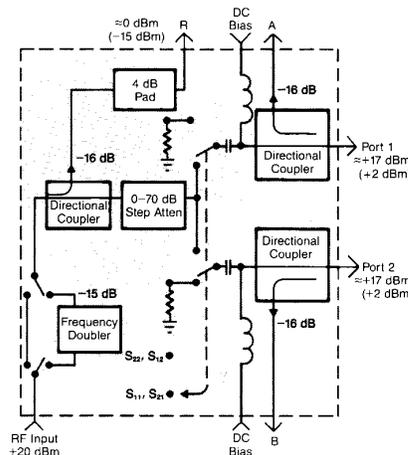


Figure 23. Schematic of the 85047A S-Parameter Test Set

Table 1. Power available at the test ports with the 85046/7A S-Parameter Test Sets

	85047A Test Set		
	85046A Test Set	3 GHz	6 GHz
Maximum attenuation from RF input to port 1, 2	83 dB	73 dB	88 dB
Minimum attenuation from RF input to port 1, 2	13 dB	3 dB	18 dB
Maximum power level at port 1, 2	+7 dBm	+ 17 dBm	+2 dBm
Minimum power level at port 1, 2	-88 dBm	-78 dBm	-93 dBm
Nominal attenuation from port 2 to channel B	6 dB	16 dB	16 dB

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