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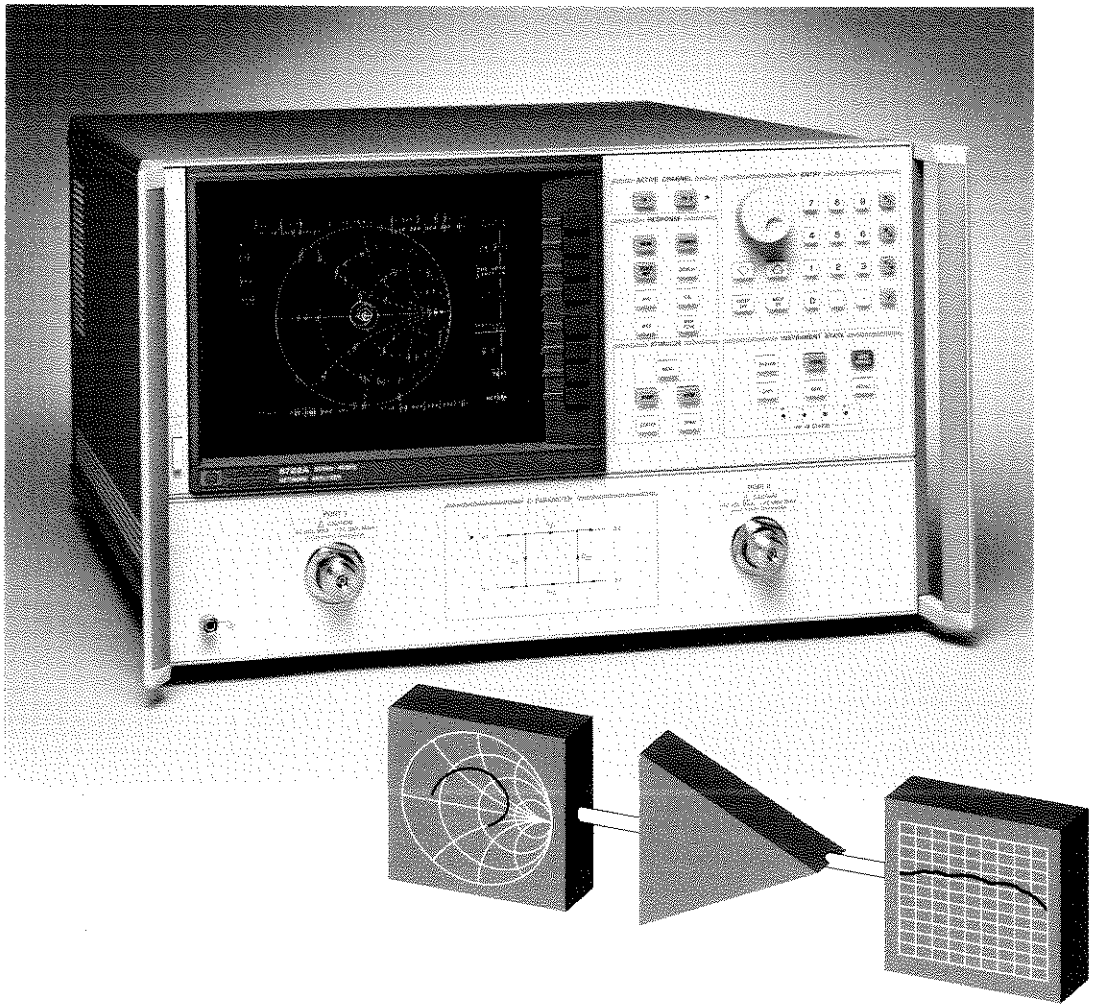
# Testing amplifiers and active devices with the HP 8720 Network Analyzer

## Product Note 8720-1



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# Introduction

The HP 8720C, 8719C and 8722A microwave network analyzers are excellent instruments for measuring the transmission and reflection characteristics of many amplifiers and active devices. Scalar parameters such as gain, gain flatness, gain compression, reverse isolation, return loss (SWR), and gain drift versus time can be measured. Additionally, vector parameters such as deviation from linear phase, group delay, complex impedance and AM-to-PM conversion can also be measured.

A new power meter calibration feature available with the HP 8720C family of network analyzers provides greater accuracy for these measurements and also allows for absolute power and nonlinear measurements such as gain compression. Since the HP 8720 is a tuned receiver, it provides high dynamic range, sensitivity and immunity to unwanted spurious responses. Its accuracy-enhancement capabilities reduce systematic errors for more precise characterization of the amplifier or active device under test (AUT).

## HP 8720C, 8719C and 8722A

**New capabilities for measuring amplifiers and active devices**

- High output power at the test port (+10 dBm for the HP 8720C/8719C, -15 dBm for the HP 8722A) drives high-power devices, eliminating the need for external amplifiers.
- 0.05 dB power resolution provides precise control of the input power to the device.
- Power sweep (20 dB range for the HP 8720C/8719C, 10 dB range for the HP 8722A) allows for convenient gain compression measurements (in dBm or mW).
- Power meter calibration improves measurement accuracy and provides new capabilities such as absolute output power measurements.
- User-defined preset function saves set-up time and protects power-sensitive devices.

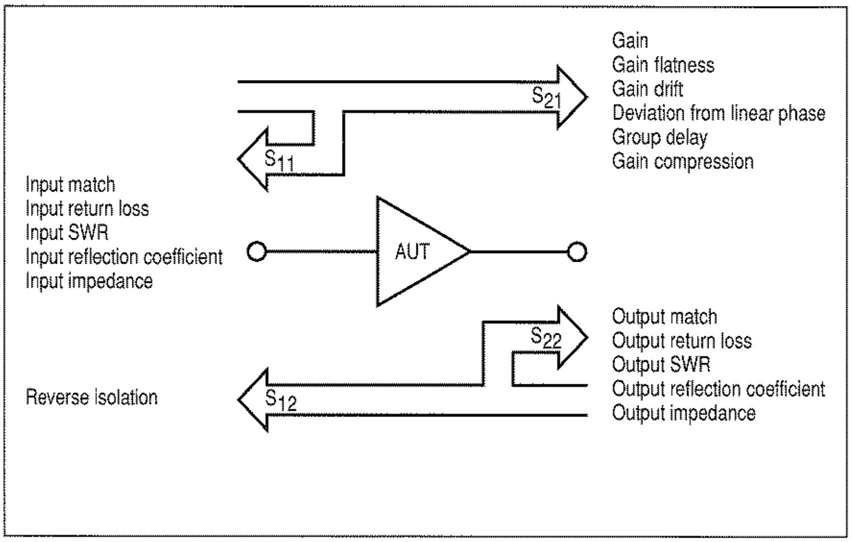


**Figure 1.**
**Amplifier parameters.**

# Amplifier parameters

| Parameter | Equation | Definition |
|---|---|---|
| Gain | $\tau = \frac{V_{trans}}{V_{inc}}$ | The ratio of the amplifier's output power (delivered to a $Z_0$ load) to the input power (delivered from a $Z_0$ source). $Z_0$ is the characteristic impedance, in this case, 50 Ω. |
| | Gain (dB) = $-20\log_{10}\lvert\tau\rvert$ | For small signal levels, the output power of the amplifier is proportional to the input power. Small signal gain is the gain in this linear region. |
| | Gain (dB) = $P_{out}$ (dBm) – $P_{in}$ (dBm) | As the input power level increases and the amplifier approaches saturation, the output power reaches a limit and the gain drops. Large signal gain is the gain in this nonlinear region. |
| Gain flatness | | The variation of the gain over the frequency range of the amplifier. |
| Reverse isolation | | The measure of transmission from output to input. Similar to the gain measurement except the signal stimulus is applied to the output of the amplifier. |
| Gain drift vs. time (temperature, bias, etc.) | | The maximum variation of gain as a function of time, with all other parameters held constant. |
| | | Gain drift is also observed with respect to other parameter changes such as temperature, humidity or bias voltage. |
| Deviation from linear phase | | The amount of variation from a linear phase shift. Ideally, the phase shift through an amplifier is a linear function of frequency. |
| Group delay | $\tau_g \text{ (sec)} = -\frac{\Delta\theta}{\Delta\varpi}$ | The measure of the transit time through the amplifier as a function of frequency. A perfectly linear phase shift would have a constant rate of change with respect to frequency, yielding a constant group delay. |
| | $= -\frac{1}{360} * \frac{\Delta\theta}{\Delta f}$ | |
| Return loss (SWR, ρ) | $\Gamma = \frac{V_{refl}}{V_{inc}} = \rho\angle\theta$ | The measure of the reflection mismatch at the input or output of the amplifier relative to the system $Z_0$ characteristic impedance. |
| | Reflection coefficient = ρ | |
| | Return loss (dB) = $-20\log_{10}\rho$ | |
| | $\text{SWR} = \frac{1+\rho}{1-\rho}$ | |
| Complex impedance | $Z = \frac{1+\Gamma}{1-\Gamma} * Z_0$ | The amount of reflected energy from an amplifier is directly related to its impedance. Complex impedance consists of both a resistive and a reactive component. It is derived from the characteristic impedance of the system and the reflection coefficient. |
| | $= R + jX$ | |
| Gain compression | | An amplifier has a region of linear gain where the gain is independent of input power level (small signal gain). As the power is increased to a level that causes the amplifier to saturate, the gain decreases. |
| | | Gain compression is determined by measuring the amplifier's 1 dB gain compression point ($P_{1dB}$) which is the output power at which the gain drops 1 dB relative to the small signal gain. This is a common measure of an amplifier's power output capability. |
| AM-to-PM conversion coefficient | $\text{AM/PM} = \frac{\Delta\theta}{\Delta P}$ | The amount of phase change generated in the output signal of an amplifier as a result of an amplitude change of the input signal. |
| | | The AM-to-PM conversion coefficient is expressed in units of degrees/dB at a given power level (usually $P_{1dB}$, which is the 1 dB gain compression point). |

# Measurement set-up

Before making an actual measurement it is important to know the input and output power levels of the AUT and the type of calibration required.

## Set-up

### 1. Select input power levels

Selecting the proper stimulus settings at the various ports of the AUT are of primary concern. If the small signal gain and output power at the 1 dB compression point of the amplifier are approximately known, the proper setting for the input power level can be estimated. For linear operation, the input power to the amplifier should be set such that the output power is approximately 3 to 10 dB below the 1 dB compression level.

$$P_{input}\,(dBm) = P_{1dB\ compression}\,(dBm) - Gain_{small\ signal}\,(dB) - 10\ dB$$

For the HP 8720C or 8719C, the power may be varied continuously within a 20 dB range over twelve power range selections (+10 to -10 dBm, +5 to -15 dBm, 0 to -20 dBm, . . . -45 to -65 dBm). For the HP 8722A, the power may be varied within a 10 dB range over nine power range selections (-15 to -25 dBm, -20 to -30 dBm, . . . -55 to -65 dBm). It is advantageous to select a power range that will accommodate the operation of the amplifier in its linear region as well as the nonlinear region.

### 2. Estimate output power

It is also important to know the output power levels from the AUT to avoid overdriving or damaging the test ports of the network analyzer. External attenuation may be necessary after an AUT with high output power to keep the power level below the specified 0.1 dB compression level of the receiver. For more information see Appendix B, *High power measurements*.

When measuring high-gain amplifiers, it is possible to overload the test port. Overload occurs when greater than +20 dBm of power is input into either port. When this happens, "TEST PORT OVERLOAD, REDUCE POWER LEVEL" will be displayed. At this point, either more attenuation should be added to the output of the amplifier, or the input power level should be reduced before continuing the measurement.

### 3. Power meter calibration (optional)

The HP 8720C, 8719C and 8722A network analyzers provide leveled power at the test set port with a specified variation of less than ±2 dB (HP 8720C/8719C) and ±3 dB (HP 8722A). The power meter calibration feature is available to provide more accurate settable power when required and can also serve to remove the frequency response errors of the cables and adapters between the test set and the AUT. If a power meter calibration is performed it should be done prior to a measurement calibration. Power meter calibration with the HP 8720C family of network analyzers is compatible with the HP 437B and 438A power meters.

| | HP 8719C at 13.5 GHz | HP 8720C at 20 GHz | HP 8722A at 40 GHz |
|---|---|---|---|
| **Available output power at test port** (dBm) | +10 to -65 | +10 to -65 | -15 to -65 |
| **Power sweep range** (dB) | 20 | 20 | 10 |

**Table 1.**
**Available output power from network analyzer.**

| | HP 8719C at 13.5 GHz | HP 8720C at 20 GHz | HP 8722A at 40 GHz |
|---|---|---|---|
| **0.1 dB compression level for receiver** (dBm) | +10 | +10 | +4 |
| **Damage power level at test port** (dBm) | +20 | +20 | +20 |

**Table 2.**
**Allowable input power to network analyzer.**

### 4. Measurement calibration

A measurement calibration characterizes and removes the effects of the repeatable variations (or systematic errors) in the test set-up. Systematic errors include frequency response tracking, directivity, mismatch and crosstalk effects. A full 2-port calibration provides the greatest measurement accuracy, but in some situations it may be more practical to use other calibration techniques (i.e., a response calibration for transmission-only measurements or a 1-port calibration for reflection-only measurements). For more information see Appendix A, *Accuracy considerations*.

After a full 2-port calibration has been performed, "C2" appears to the left of the display to indicate that a 2-port measurement calibration is on. For any other type of calibration (i.e. response, 1-port), a "Cor" will appear. After performing a full 2-port calibration and connecting the AUT it is important to press the [MEAS] key to update both the forward and reverse S-parameter data. Any attenuation that is used on the input or output of the AUT should be included in the calibration of the system to remove its effects from the measurement of the AUT.

## Operating considerations

If you perform a factory preset ([RECALL] [RECALL FAC PRESET]) the power is set to the maximum leveled value (in the highest power range) of +10 dBm for the HP 8720C/8719C, and -15 dBm for the HP 8722A. If the AUT could be damaged by this power level or will be operating in its nonlinear region, it should not be connected until the power is set to a desirable level.

A useful feature for the testing of power-sensitive devices is the user preset feature on the HP 8720C/8719C/8722A. This allows the user to specify an instrument setting for a particular measurement and to store it away by pressing [SAVE] [SAVE PRESET5]. Later, when the green [USER PRESET] key is pressed, these same conditions are recalled with the power level and/ or internal step attenuator set to the appropriate level, preventing potential damage to the AUT.

## Measurement examples

The measurement examples described in this note were made on an HP 8720C network analyzer. A full 2-port calibration was performed (except where noted) for the greatest accuracy for both transmission and reflection measurements of the two-port device. The amplifier under test is an HP 8348A amplifier operating over a 2 to 20 GHz frequency range. An HP 8719C or 8722A network analyzer may be used instead of the HP 8720C, but differences in frequency range and available output power will exist.

## Linear measurements

Measurements in the linear operating region of the amplifier can be made with the HP 8720C family of network analyzers by using the basic set-up shown in Figure 2. Care must be taken when setting the input power to the AUT so that it is operating within its linear region.

1. Configure the system as shown in Figure 2. Return the HP 8720C to a known state of operation.

[RECALL]
[RECALL FAC PRESET]

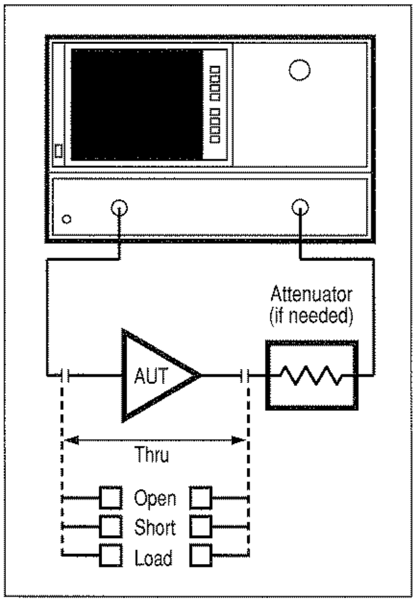


**Figure 2. Basic setup for amplifier measurement using the HP 8720C network analyzer.**

2. Choose the appropriate measurement parameters (start/stop frequency, number of points, IF bandwidth, etc). The power level should be set such that the AUT is operating in its linear region. In this measurement example, an estimated input power level of -15 dBm is derived from:

$$\begin{aligned} P_{in} &= P_{1dB} - \text{Gain} - 10\text{ dB} \\ &= +25\text{ dBm} - 30\text{ dB} - 10\text{ dB} \\ &= -15\text{ dBm} \end{aligned}$$

[START] [2] [G/n]
[STOP] [20] [G/n]
[MENU] [POWER]
[RANGE 2: -15 TO +5] [-15] [x1]

3. Perform a full 2-port calibration. If attenuators are used on the output of the amplifier they should be included in the calibration. In this example, a 20 dB fixed attenuator on port 2 prevents the +25 dBm of output power from overdriving the B input of the HP 8720C. Save the instrument state to one of the internal registers or to an external disk drive.

[SAVE] [SAVE REG1]

4. Connect the AUT and apply bias, if necessary. Be sure to press the [MEAS] key to update all four S-parameters.

### Small signal gain/gain flatness

Small signal gain is typically measured at a constant input power over a swept frequency range.

1. Set up the HP 8720C for an $S_{21}$ log magnitude measurement.

[MEAS] [Trans:FWD S21]
[FORMAT] [LOG MAG]

2. Scale the display for optimum viewing and use a marker to measure the small signal gain at a desired frequency.

3. Measure the gain flatness or variation over a frequency range with the marker statistics feature by first setting two markers (one must be in the Δ-reference mode) on the trace to define the start and stop of the frequency range of interest. Then turn on the marker statistics function to view the peak-to-peak ripple. Statistics are displayed for a portion of the trace between the active marker and Δ-reference marker. If there is no Δ-reference marker activated, the HP 8720C will calculate the statistics for the entire displayed trace.

[MKR] [2] [G/n] [MKR ZERO]
[MARKER 2] [20] [G/n]
[MKR FCTN] [MKR MODE MENU]
[STATISTICS ON off]

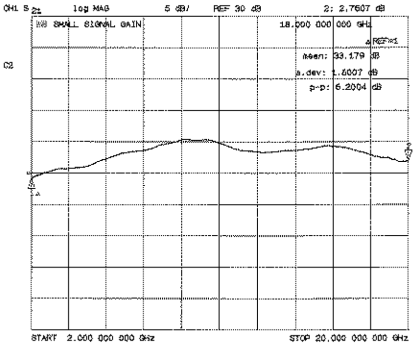


**Figure 3. Small signal gain measurement.**

## Gain versus time

Gain variation or drift versus time can be measured at fixed frequencies over a 100 ms to 24 hour time interval with the HP 8720C network analyzer.

1. Set up the HP 8720C for an $S_{21}$ log magnitude measurement. Turn off the full 2-port calibration. Select the desired fixed (CW) frequency. Change the sweep time from AUTO to MANUAL. Use a single sweep for the calibration and measurement. For this example, a CW frequency of 20 GHz is selected.

[CAL] [CORRECTION on OFF]
[MEAS] [Trans:FWD S21]
[FORMAT] [LOG MAG]
[MENU] [CW FREQ] [20] [G/n]
[SWEEP TIME MANUAL]
[TRIGGER MENU] [SINGLE]

2. If the desired measurement sweep is long, a shorter calibration time may be specified by pressing [STOP] and entering the desired calibration sweep time. A calibration sweep time of four seconds is used in this measurement example. Perform a thru response calibration of the system in the CW time mode. Save the instrument state to one of the internal registers or to an external disk drive.

[STOP] [4] [x1]
[CAL] [CALIBRATE MENU] [RESPONSE]
[THRU]
[DONE: RESPONSE]
[SAVE REG2]

3. Connect the AUT and apply bias, if necessary. Specify the measurement sweep time and begin the measurement. In this example, a measurement time of thirty minutes is selected.

[STOP] [30] [: h:m:s] [0] [x1]
[MEAS] [MEASURE RESTART]

4. Scale the display for optimum viewing. Use marker statistics to measure the maximum peak-to-peak variation in gain over the time interval.

[MKR FCTN] [MKR MODE MENU]
[STATISTICS ON off]

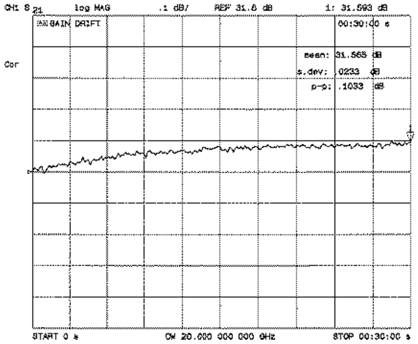


**Figure 4.**
**Gain versus time measurement.**

Gain variation or drift can also be measured with respect to other parameter changes such as temperature, humidity or bias voltage. The procedure described here can be modified by utilizing the external trigger mode of the HP 8720C and adding an external controller to vary these parameters.

## Reverse isolation

For the measurement of reverse isolation the RF stimulus signal is applied to the output of the AUT by measuring $S_{12}$. External attenuation placed on the output of the AUT may not be needed for this measurement since the signal path now exhibits loss instead of gain. If it is removed, a new calibration will be required.

1. Recall the full 2-port calibration.

[RECALL] [RECALL REG1]

2. Set up the HP 8720C for an $S_{12}$ log magnitude measurement.

[MEAS] [Trans:FWD S12]
[FORMAT] [LOG MAG]

If the isolation of the AUT is very high (i.e., displayed trace is in the noise floor) it may be necessary to remove the external attenuation at the output of the AUT and re-calibrate (with a response and isolation calibration) at a higher power level and decreased IF bandwidth.

3. Scale the display for optimum viewing and use a marker to measure the reverse isolation at a desired frequency.

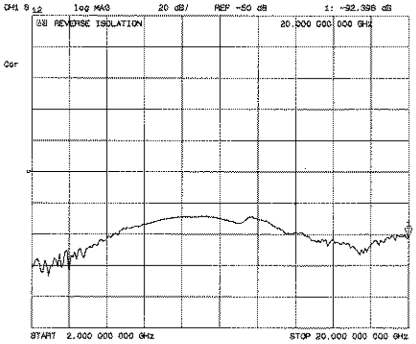


**Figure 5.**
**Reverse isolation measurement.**

## Deviation from linear phase

The measurement of deviation from linear phase of the AUT employs the electrical delay feature of the HP 8720C network analyzer to remove the linear portion of the phase shift from the measurement.

1. Set up the analyzer for an $S_{21}$ phase measurement.

[MEAS] [Trans:FWD S21]
[FORMAT] [PHASE]

2. Place a marker in the center of the band and activate the electrical delay feature.

[MKR] [11] [G/n]
[MKR FCTN] [MARKER→MENU]
[MARKER→DELAY]

3. Expand the scale and use the knob to fine tune the electrical delay for a flat phase response near the center of the passband. The linear phase shift through the AUT is effectively removed and all that remains is the deviation from this linear phase shift.

[SCALE REF] [ELECTRICAL DELAY]

4. Use the marker statistics to measure the maximum peak-to-peak deviation from linear phase.

[MKR FCTN] [STATS ON off]

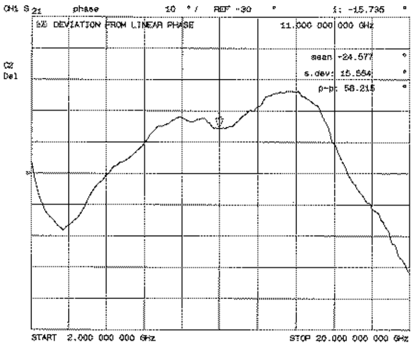


**Figure 6. Deviation from linear phase measurement.**

## Group delay

Group delay is calculated from the phase and frequency information and is displayed in real time by the HP 8720C network analyzer.

1. Set up the HP 8720C for an $S_{21}$ group delay measurement.

[MEAS] [Trans:FWD S21]
[FORMAT] [DELAY]

2. Activate a marker to measure the group delay at a particular frequency.

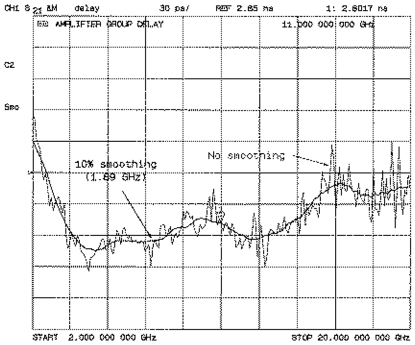


**Figure 7. Group delay measurement with minimum and increased aperture.**

Group delay measurements may require a specific aperture (Δ f) or frequency spacing between measurement points. The phase shift between two adjacent frequency points must be less that $180^{\circ}$, otherwise incorrect group delay information may result.

$$\text{Approximate delay of AUT} < \frac{\text{number of points} - 1}{2 * (\text{frequency span})}$$

The effective group delay aperture can be increased from the minimum by varying the smoothing percentage. Increasing the aperture reduces the resolution demands on the phase detector and permits better group delay resolution by increasing the number of measurement points over which the group delay aperture is calculated. Since increasing the aperture removes fine grain variations from the response, it is critical that group delay aperture be specified when comparing group delay measurements. To adjust the aperture press [AVG] [SMOOTHING ON off] [SMOOTHING APERTURE] and adjust aperture as necessary.

## Return loss, SWR, and reflection coefficient

Return loss (RL), standing wave ratio (SWR) or reflection coefficient (ρ) are commonly specified to quantify the reflection mismatch at the input and output ports of an AUT. Because 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, the noise levels can be reduced by decreasing the IF bandwidth.

1. Set up the HP 8720C for an $S_{11}$ measurement.

[MEAS] [Refl:FWD S11]

2. Display the return loss, SWR, and reflection coefficient of the input port of the AUT.

[FORMAT] [LOG MAG]
[SWR]
[LIN MAG]

3. Similarly, the output match of the AUT can be measured by repeating the procedure for $S_{22}$ (or if a full 2-port calibration was performed simply press [MEAS] [S22]).

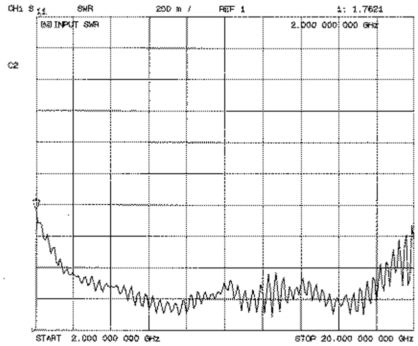


**Figure 8. Input SWR measurement.**

## Complex impedance

When the phase and magnitude characteristics of an AUT are desired, the complex impedance can be easily determined.

1. Set up the analyzer for an $S_{11}$ measurement.

[MEAS] [Refl:FWD S11]

2. Display the input impedance of the AUT.

[FORMAT] [SMITH CHART].

Markers used with this format display R + jX. The reactance is displayed as an equivalent capacitance or inductance at the marker frequency. Marker values are normally based on a system $Z_0$ of 50 Ω. If the measurement environment is not 50 Ω, the network analyzer characteristic impedance must be modified under [CAL] [MORE] [SET SYSTEM ZO] before calibrating. In addition, a minimum loss pad or matching transformer must be inserted between the AUT and the measurement port.

3. Display the complex reflection coefficient (Γ). The linear magnitude and phase will be displayed at the marker frequency.

[FORMAT] [POLAR]

4. Similarly, the output impedance of the AUT can be measured by repeating the process for $S_{22}$ (or if a full 2-port calibration was performed simply press [MEAS] [S22]).

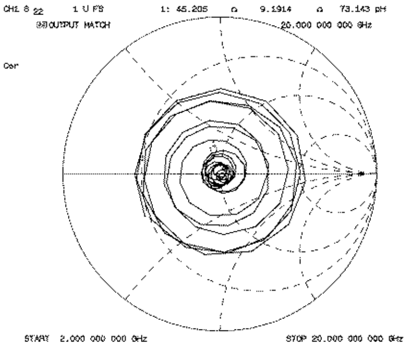


**Figure 9. Complex output impedance measurement.**

# Power meter calibration

The power meter calibration feature of the HP 8720C, 8719C and 8722A network analyzers provides a more precise power level to the AUT. An HP 437B or 438A power meter and an appropriate power sensor such as the HP 8481A, 8485A or 8487A are required.

The power sensor is attached to the desired test port, after any cables or adapters leading up to the point where the AUT will be connected, and a single power calibration sweep is performed. The power meter monitors the source power at each measurement point across the frequency band of interest, and correction data is derived to achieve a constant power level at the desired test port. When the power meter is disconnected and power correction turned on, the correction data is recalled for subsequent sweeps with no degradation in measurement speed.

A power meter calibration is typically performed at a fixed power level over a swept frequency range. A power calibration can also be performed for a swept power measurement at a fixed frequency. This references the swept power to a power meter standard.

1. Configure the system as shown in Figure 10. Connect the HP 437B power meter to the HP-IB port of the HP 8720C. Zero and calibrate the power meter.

Verify the address of the power meter matches the setting in the network analyzer. The default address for the HP 437B is 13.

[LOCAL] [SYSTEM CONTROLLER]
[SET ADDRESS]
[ADDRESS: POWER MTR] [13] [x1]

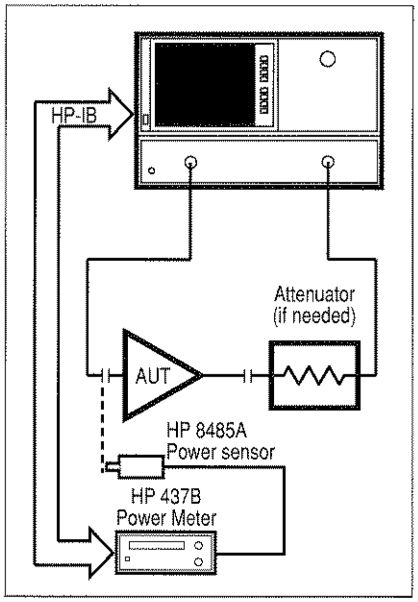


**Figure 10. Power meter calibration set-up.**

2. Enter the power sensor calibration factor data at each desired frequency segment. Specify the number of power measurements to be made at each point. The number of readings should be increased for greater accuracy.

[CAL] [PWR METER CAL]
[SET CAL FACTOR]
Enter calibration factors.
[DONE]
[NUMBER of READINGS] [1] [x1]

3. Choose the appropriate measurement parameters. The test port power level must be set so that it is approximately correct at the desired measurement port.

[START] [2] [G/n]
[STOP] [20] [G/n]
[MEAS] [Trans:FWD S21]
[MENU] [POWER] [RANGE 2:-15 TO +5]
[-15] [x1]

4. Connect the power sensor to the active test port (normally port 1 where the input of the AUT is connected).

5. Set the calibrated power for the desired value. Initiate the power meter calibration. The measurement will sweep very slowly, especially when the number of points is high or when the measured power is small.

[CAL] [PWR METER CAL]
[CAL POWER] [-15] [x1]
[TAKE CAL SWEEP]

6. Activate the power meter calibration. A "PC" will appear to the left of the display to indicate that the power meter calibration is on.

[PWRMTR CAL ON off]

7. Verify the constant power level at the test port by slowing the sweep time down and using the HP 437B to measure the power.

8. Save the power meter calibration to an instrument state register or to an external disk drive.

[SAVE] [SAVE REG3]

9. Remove the power sensor. Connect AUT and apply bias if necessary.

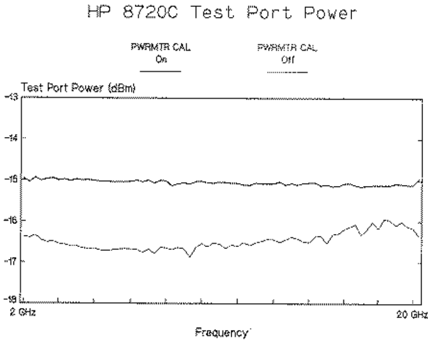


**Figure 11. Test port power before and after a power meter calibration.**

The correction data may be stored to an internal instrument state register or an external disk drive by using the [SAVE] key. If the start or stop frequency is changed after a power meter calibration has been activated, the data will be interpolated for the new range. If the calibration power is changed, the correction data array is offset to reflect the new power level. This results in some loss in accuracy and is reflected by a “PC?” which appears to the left of the display.

## Absolute output power

After port 1 has been calibrated for a constant input power, the HP 8720C can be used to display absolute power (in dBm or mW) versus frequency.

1. Perform a power meter calibration over the desired frequency range and power level (as previously described).

2. Set up channel 1 for an output power measurement using the B input.

[CH 1] [MEAS] [INPUT PORTS] [B]
[FORMAT] [LOG MAG]

3. Set the reference value at the expected power level (CAL POWER), in this case -15 dBm. This step is necessary to get a correct reading of absolute power. Connect a thru and perform a receiver calibration to remove the frequency response errors of the port 2 path in the measurement. Be sure to include any attenuators or adapters which are part of the measurement.

[CAL] [RECEIVER CAL]
[-15] [x1]
[TAKE RCVR CAL SWEEP]
[SAVE REG4]

A flat line should be displayed at the correct power level.

4. Connect the AUT and apply bias, if necessary.

5. Measure the absolute output power (in dBm) at any frequency by placing a marker on the trace.

The absolute power may also be measured in mW.

[FORMAT] [LIN MAG]

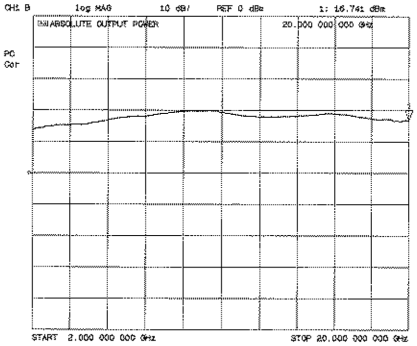


**Figure 12. Absolute output power measurement.**

# Nonlinear measurements

The HP 8720C has the capability to make measurements of amplifiers operating in their nonlinear region. A swept-frequency gain compression measurement locates the frequency at which the 1 dB gain compression first occurs. A swept-power gain compression measurement shows the reduction in gain at a single frequency as a power ramp is applied to the AUT. An AM-to-PM conversion coefficient measurement shows the change in phase as the input power to the AUT is increased to produce some degree of gain compression.

## Swept-frequency gain compression

A measurement of swept-frequency gain compression locates the frequency at which the 1 dB gain compression first occurs. The swept-frequency gain compression is determined by normalizing to the small signal gain and by observing compression as the 1 dB drop from the reference line as input power is increased. The swept-frequency gain compression and corresponding output power ($P_{1dB}$) can be displayed simultaneously on the HP 8720C network analyzer.

1. Perform an absolute output power calibration and measurement (as previously described).

2. Channel 1 should already be set up for an absolute power measurement (with correction on). Set up channel 2 for an $S_{21}$ gain measurement. Turn on a dual channel split display.

[CH 2] [MEAS] [Trans:FWD S21]
[FORMAT] [LOG MAG]
[DISPLAY] [DUAL CHAN ON off]
[MORE] [SPLIT DISP ON off]

3. Connect the AUT and apply bias, if necessary.

4. Normalize the display to the small signal gain.

[DISPLAY] [DATA→MEMORY]
[DATA/MEM]

A flat line at 0 dB should now be displayed on channel 2.

5. Set a scale of 0.5 dB/division and a reference value of 0 dB to allow easy viewing of a 1 dB drop from the small signal gain.

6. Increase the source power level until the trace drops by 1 dB at some frequency. A marker can then be used to track the exact frequency where the 1 dB compression first occurs. Care should be taken when increasing the source power so that the input power limitation of the AUT is not exceeded.

[MKR FCTN] [TRACKING ON off]
[SEARCH: MIN]
[CAL] [PWR METER CAL]
[CAL POWER]
Use knob to increase power.

7. The channel 1 marker displays the actual output power of the amplifier (in dBm) at the 1 dB gain compression point. In this example, the 1 dB gain compression first occurs at 16.5 GHz at an output power level of 27.246 dBm.

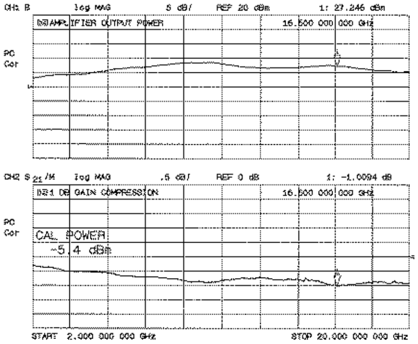


**Figure 13.**
**Swept-frequency gain compression measurement.**

## Swept-power gain compression

By applying a fixed-frequency power sweep to the input of an amplifier, the gain compression can be observed as a 1 dB drop from small signal gain. The power sweep should be selected such that the AUT is forced into compression.

The $S_{21}$ gain will decrease as the input power is increased into the nonlinear operating region of the amplifier. The HP 8720C network analyzer has a power sweep range of 20 dB. The fixed frequency chosen could be the frequency for which the 1 dB drop first occurs in a swept-frequency gain compression measurement. The swept-power gain compression and corresponding output power ($P_{1dB}$) can be displayed simultaneously on the HP 8720C network analyzer. A power meter calibration over a power sweep range (at a fixed frequency) may be performed first if very accurate power is required at the input to the AUT.

1. Configure the system as shown in Figure 2.

2. Select a power range and power sweep at the CW frequency of interest. The beginning and end points of the power sweep are adjusted with the START/STOP stimulus keys. Power levels must be set so that the AUT is forced into compression. External attenuation may be necessary at the output of the amplifier to prevent overdriving of input B. In this measurement example, a 10 dB power sweep from -15 to -5 dBm compresses the amplifier.

[MENU] [CW FREQ] [16.5] [G/n]
[POWER] [RANGE 2: -15 TO +5]
[RETURN]
[SWEEP TYPE MENU]
[POWER SWEEP] [RETURN]
[START] [-15] [x1]
[STOP] [-5] [x1]

3. Perform a power meter calibration, if necessary.

4. Set up channel 1 for an absolute power measurement and channel 2 for an $S_{21}$ gain measurement. Turn on a dual channel split display.

[CH 1] [MEAS] [INPUT PORTS] [B]
[FORMAT] [LOG MAG]
[CH 2] [MEAS] [Trans:FWD S21]
[FORMAT] [LOG MAG]
[DISPLAY] [DUAL CHANNEL ON off]
[MORE] [SPLIT DISP ON off]

5. Temporarily change the stop power to be the same as the start power. Connect a thru and perform a receiver calibration on channel 1 to get a correct reading of absolute power.

[CH 1]
[STOP] [-15] [x1]
[CAL] [RECEIVER CAL]
[-15] [X1]
[TAKE RCVR CAL SWEEP]

6. Change the stop power back to the original value. Connect a thru and perform a thru response calibration on channel 2.

[STOP] [-5] [x1]
[CH 2]
[CAL] [CALIBRATE MENU]
[RESPONSE] [THRU]
[DONE: RESPONSE]

7. Connect the AUT and apply bias, if necessary.

8. Move a marker to the flat portion of the trace. If there is no flat portion the AUT 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. On channel 1 read out the input power and corresponding output power where the 1 dB gain compression occurs.

[MKR] [MKR ZERO]
[MKR FCTN] [TARGET] [-1] [x1]
[RETURN]
[MKR] [Δ MODE MENU] [Δ MODE OFF]

In this example, the 1 dB gain compression at 16.5 GHz occurs at an output power level of 27.135 dBm and an input power level of -5.7 dBm.

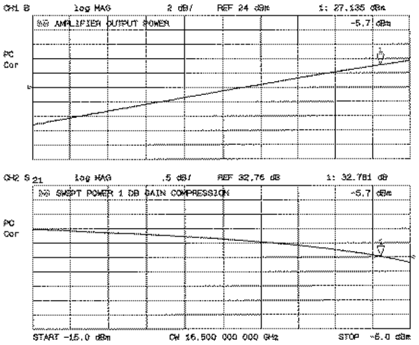


**Figure 14.
Swept power
gain compression
measurement.**

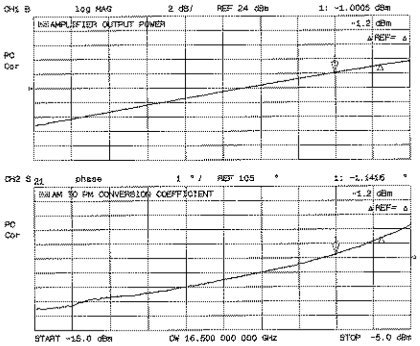


**Figure 15.
AM-to-PM
conversion
coefficient
measurement.**

## AM-to-PM conversion

The HP 8720C can be used to determine the AM-to-PM conversion coefficient at the 1 dB gain compression point by using the procedure described for the swept-power gain compression measurement.

1. Perform a swept-power gain compression measurement at a chosen frequency and locate the 1 dB gain compression point with a marker (as previously described).

2. Change the $S_{21}$ measurement on channel 2 from a log magnitude format to a phase format (no new calibration is required).

[CH 2] [FORMAT] [PHASE]

3. Use the Δ marker mode menu to target a 1 dB decrease in output power from the $P_{1dB}$ point.

[CH 1] [MKR] [MKR ZERO]
[MKR FCTN] [TARGET] [-1] [x1]
[RETURN]

The displayed marker value on channel 2 is the phase change over a 1 dB change in output power, or the AM-to-PM conversion coefficient at the 1 dB gain compression point.

In this example, the AM-to-PM conversion coefficient is $1.1416^{o}$/dB for an output power level of 27.135 dBm at the 1 dB gain compression point.

# Appendix A
# Accuracy considerations

Error correction can be applied to the measurements discussed in this note to reduce the measurement uncertainty. A full 2-port calibration was used for the measurement examples (except where noted) to provide the best measurement accuracy of both transmission and reflection measurements of 2-port devices. When a full 2-port calibration is applied, the dynamic range and accuracy of the measurement is limited only by the system noise and stability, connector repeatability and the accuracy to which the characteristics of the calibration standards are known.

It some instances it may be more convenient to perform a response calibration to remove the frequency response errors of the test set-up for transmission only measurements when extreme accuracy is not a critical factor. Likewise, an $S_{11}$ 1-port or $S_{22}$ 1-port calibration to remove directivity, source match and frequency response errors may be more convenient for reflection only measurements when the AUT is well-terminated.

## Transmission measurements

For a gain measurement, the three major sources of error are the frequency response error of the test set-up, the source and load mismatch error during the measurement, and the dynamic accuracy. A simple response calibration using a thru connection significantly reduces the frequency response error which is usually the dominant error in a transmission measurement. For the greatest accuracy, a full 2-port calibration can be used which also reduces the uncertainty in the measurement caused by the source and load match.

Dynamic accuracy is a measure of the receiver's performance as a function of the incident power level and has an effect on the uncertainty of a gain measurement. This is because the receiver detects a different power level between calibration and measurement. The effects of dynamic accuracy on a gain measurement are negligible (less than 0.5 dB) as long as the network analyzer is operating below the specified 0.1 dB compression level.

A gain drift measurement is subject to the same errors as a gain measurement. Another factor that could be significant is the transmission tracking drift of the system. This drift is primarily caused by the change in the temperature of the test set-up between calibration and measurement. To minimize this effect, allow the instrument to stabilize to the ambient temperature before calibration and measurement.

A reverse isolation measurement is subject to the same errors as a gain measurement. In addition, if the isolation of the AUT is very large, the transmitted signal level may be near the noise floor or crosstalk level of the receiver. To lower the noise floor, a decreased IF bandwidth may be necessary. When crosstalk levels begin to affect the measurement accuracy, a response and isolation calibration or a full 2-port calibration (including the isolation part of the calibration) removes the crosstalk error term. When performing the isolation part of the calibration it is important to use the same averaging factor and IF bandwidth during the calibration and measurement.

For deviation from linear phase measurements, the phase uncertainty is calculated from a comparison of the magnitude uncertainty (already discussed for gain measurements) with the test signal magnitude.

## Reflection measurements

The uncertainty of a reflection measurement such as return loss, SWR, reflection coefficient and impedance is affected by directivity, source match, load match and reflection tracking of the test system. With a full 2-port calibration, the effects of these factors are minimized. A 1-port calibration can provide equivalent results if the amplifier has sufficient isolation to reduce the effects of the load match.

## Nonlinear measurements

For absolute power measurements, a frequency response calibration is used. Because the power calibration is made relative to 50 Ω, inaccuracies due to mismatch will occur when a device is attached that is not exactly 50 Ω. Since the power meter calibration feature is not a true leveling feature, it cannot correct for mismatches that occur between the test port and the AUT. Mismatch can be reduced by using attenuators at the input or output of the AUT.

For a gain compression measurement a response calibration reduces the frequency response errors. A gain compression measurement requires the power level to be changed after a calibration. The HP 8720C is specified to have a source linearity of ± 0.5 dB within a power range selection (± 0.2 dB for a power sweep less than 5 dB). Source linearity uncertainty can be reduced by performing a power meter calibration at the input of the AUT. This precisely sets the power level incident to the AUT by compensating the source power for any nonlinearities in the source or test set-up.

# Appendix B
# High-power measurements

When power levels from the AUT are such that external attenuation is not practical or when the source cannot deliver enough power to properly drive the AUT, it may be necessary to construct a custom test set.

## Custom test set configurations

Option 011 (available on the HP 8720C, 8719C and 8722A) provides the greatest flexibility for the testing of high-power amplifiers which often require custom test set configurations. Option 011 allows direct access to the R, A and B samplers and receivers. The transfer switch, couplers and bias tees are eliminated. External test set components (amplifiers, couplers, isolators, attenuators, etc) can be specially selected to provide the necessary power handling capability.

For example, if the required input power for the AUT is greater than the +10 dBm that the HP 8720C network analyzer can provide, the Option 011 three-sampler direct access test set allows the addition of a high-power source to properly drive the AUT. A sample of the source output must be provided to the R input for phase-locking. High-power couplers and attenuators are required to prevent over-driving the reference and test samplers.

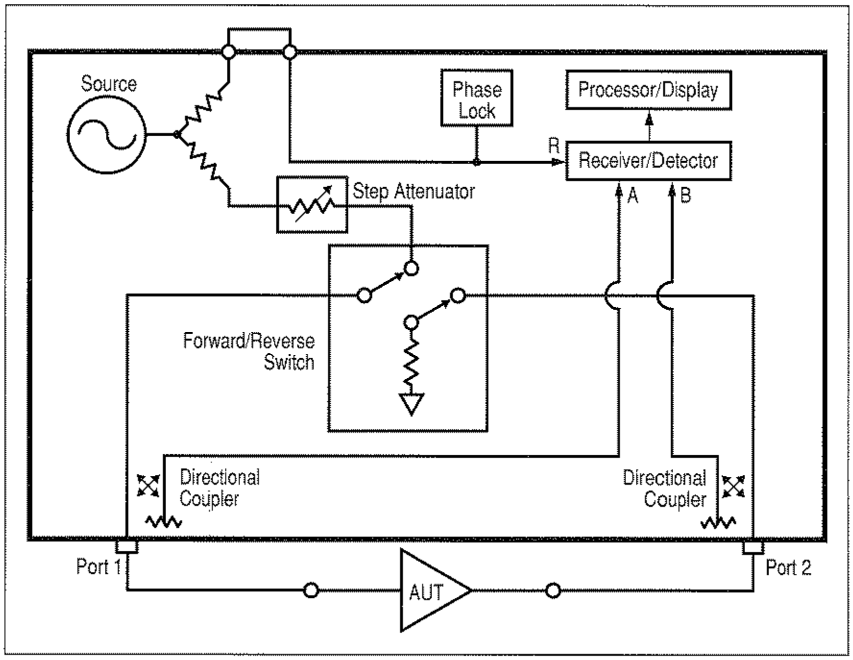


**Figure 16. HP 8720C simplified block diagram.**

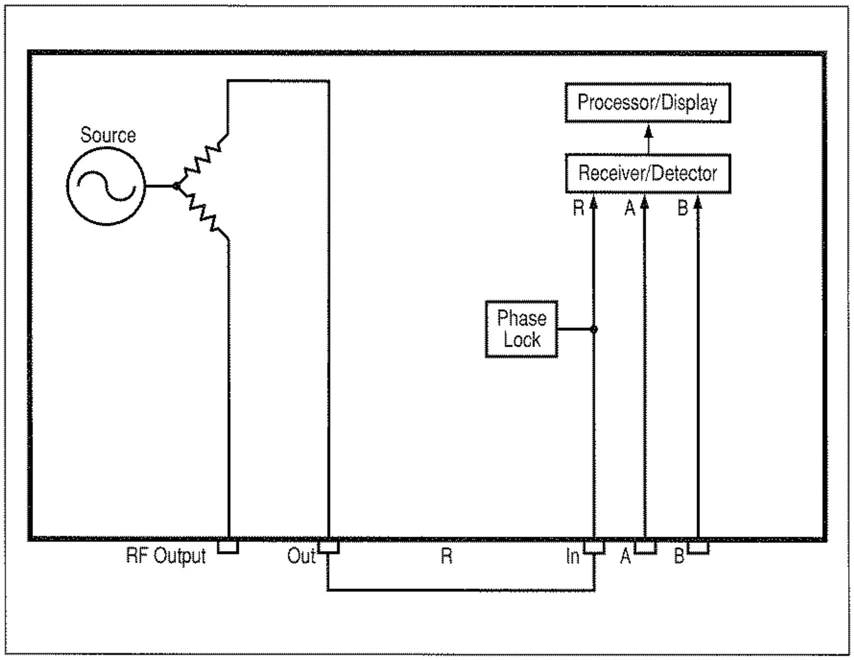


**Figure 17. Option 011 block diagram.**

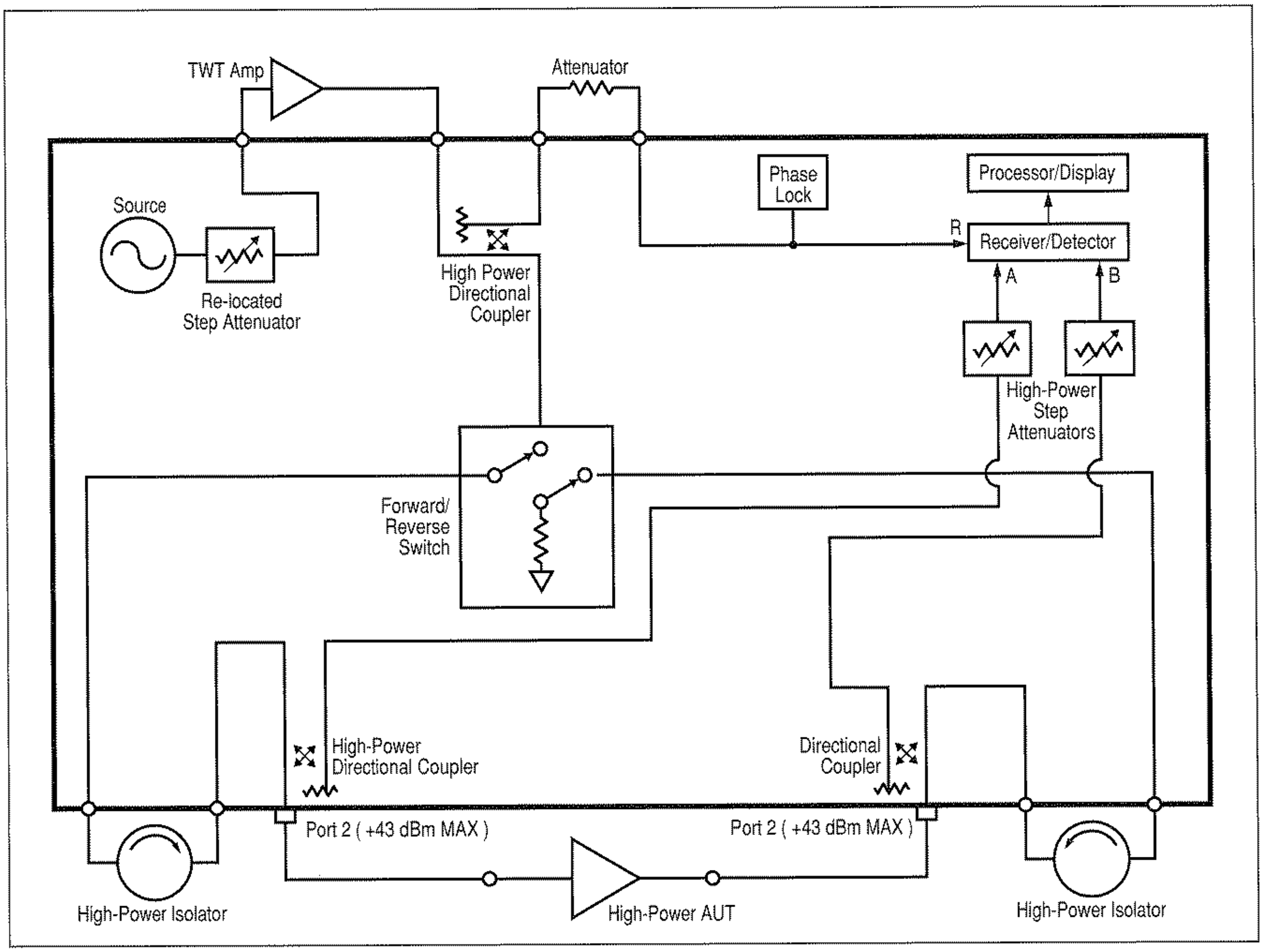
## Special test set configurations

Special HP 8720 family network analyzer test set configurations for high-power testing are available on a request basis. An example of a special HP 8720C configuration is shown in Figure 18. This modified RF block diagram allows up to 20 Watts of high-power handling capability and also provides the ability to connect additional test equipment to the AUT via a single RF connection.

High-power directional couplers replace the standard directional couplers and power splitter in the HP 8720C. The internal step attenuator which usually follows the power splitter, is repositioned to follow the source because of its limited power handling capability. A new rear panel jumper allows the insertion of a high-power amplifier to increase the drive power to the AUT. Two new front panel jumpers allow the insertion of high-power attenuators (and/or isolators) to control the power into the AUT. A pair of high-power step attenuators are added before the test samplers (A and B) to prevent them from being overdriven by the AUT.

For some amplifier measurements, throughput is a major concern due to the multiplicity of tests that are required. It is desirable to make as many measurements as possible at one test station with a single connection to the device to reduce lengthy set-up time. The front panel port 1 and port 2 jumpers also allow the addition of other test equipment (power meter, spectrum analyzer, noise figure meter, etc.) for a single connection multiple measurement solution.

**Figure 18. Block diagram for special high-power test set configuration for the HP 8720C.**



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