

Keysight Technologies

High-Power Measurements Using the E5072A ENA Series Network Analyzer

Application Note



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Introduction

High-power test signal levels are often required for network analysis of antennas, power amplifiers, and components used for transmitting data in wireless communications and satellite systems. Testing these RF components with high-power signals can be a challenge as they require output power that may be beyond the measurement capability of a standard network analyzer.

This application note will briefly review the basic measurement fundamentals of characterizing devices with high-power signals using a network analyzer. Unique testing techniques and step-by-step test procedures using the Keysight Technologies, Inc. E5072A ENA series network analyzer will be introduced and described in detail.

Configuration 1: Standard 2-port configuration

The first configuration of a high-power measurement is shown in Figure 1. It uses a network analyzer as a standard test set and simple 2-port measurement is performed using the network analyzer's standard power level.

The E5072A delivers a source power level up to +20 dBm from test ports (port 1 and port 2) in the frequency range from 300 kHz to 1 GHz (SPD¹). The E5072A has a 65 dB power sweep range (i.e. -49 to +16 dBm in 300 kHz to 3 GHz) with specified leveled output power from the test ports that allows measurements of compression characteristics of active devices with a single power sweep^{2,3}. The E5072A provides high output power from the test ports in a wide frequency range from 30 kHz to 8.5 GHz, thus eliminating additional costs associated with extra hardware such as booster amplifiers.

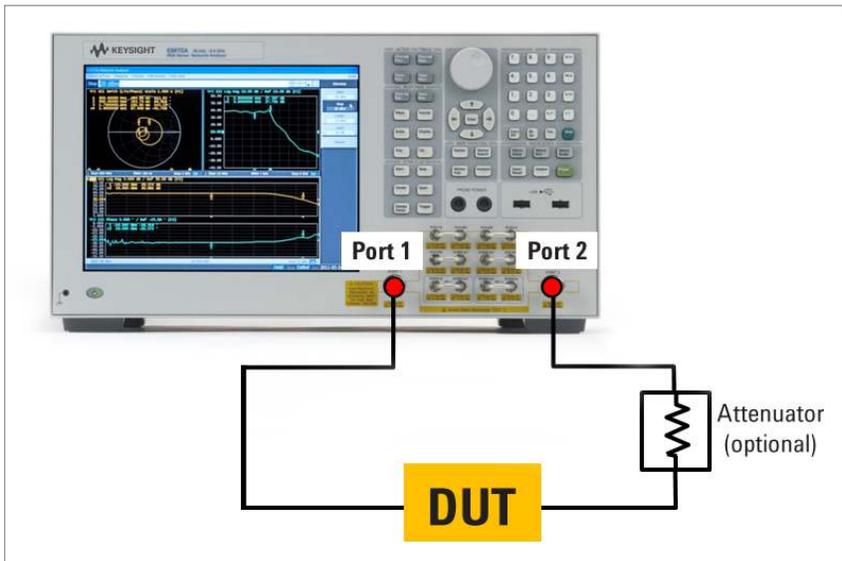


Figure 1. Standard 2-port configuration using test ports 1 and 2

1. SPD or supplemental performance data represents the value that is mostly likely to occur. Not guaranteed by the product warranty.
2. When the E5072A's source power is set to a value greater than the maximum power available, an error message "Power unlevelled" will appear. In this case, lower the output power level to solve this problem.
3. Make sure that the power levels used during calibration do not damage the calibration kit. For Ecal modules, maximum input power and damage level are listed in the data sheet, part number 5963-3743E.

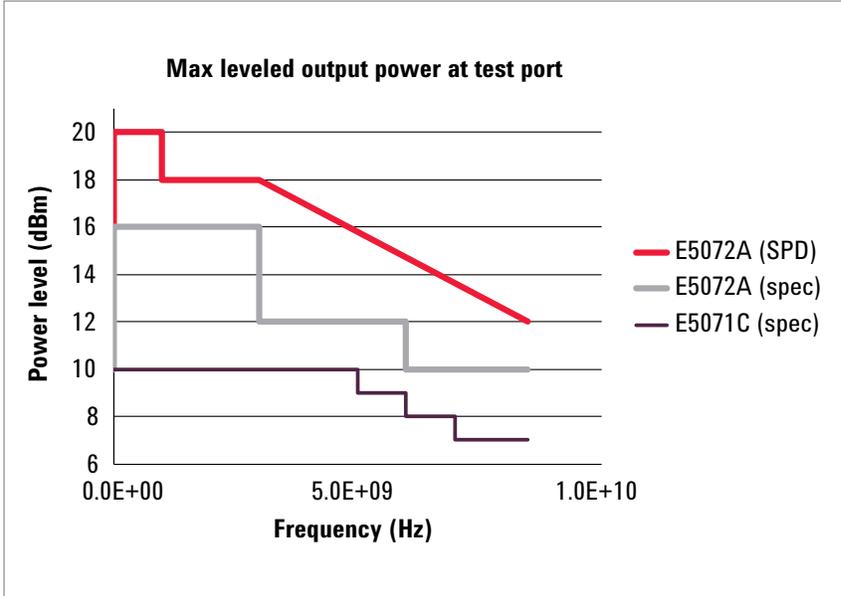


Figure 2. Improved maximum output power level at E5072A's test port

When testing high-power amplifiers, output power of the device under test (DUT) can exceed input compression level and/or cause maximum damage to the internal receivers of the network analyzer. A high-power level can also damage the network analyzer, resulting in costly repairs. It is necessary to reduce down time due to the repairs to lower cost of ownership.

The problem with this configuration is that measurements are only performed within the output power level capability of the network analyzer. For characterizing nonlinear behavior of high-power devices, higher power levels at the DUT are required.

Special care has to be taken to protect instruments by selecting appropriate attenuating components that can absorb the high power from the DUT. Refer to appendix A "Power-Handling Consideration" for details on the E5072A's power-handling capability.

Configuration 2: Measurements using a booster amplifier

Many test and measurement applications need higher power levels than are typically available from network analyzers. For instance, high-power amplifiers often require high input levels to characterize them under conditions similar to actual operation. When you need an input level higher than the network analyzer's source can provide, preamplifiers are necessary to boost the power level prior to the DUT. An additional advantage of using an external amplifier is that you can place the amplifier physically closer to your DUT, which reduces cable losses to achieve higher power at the DUT. The typical configuration is shown in Figure 3. An optional isolator or attenuator can be added between the booster amplifier and the DUT to improve the source match. Be sure that these components can handle the output power level of the booster amplifier. When the output power of the DUT exceeds the compression level of the analyzer's ports or receivers, attenuation is needed to reduce the DUT's output power.

Frequency response of a booster amplifier is removed or minimized by performing a source power calibration with a power meter/sensor connected to the E5072A. A power meter is connected via GPIB/USB interface (i.e. Keysight 82357B) and a USB power sensor is connected directly to a USB port on the E5072A. After the source power calibration is complete, the output power level of the E5072A is adjusted automatically to achieve the desired power level at the input of the DUT. Source power calibration transfers the accuracy of the power sensor to the network analyzer, and makes the power level at the DUT's input with deviation of less than 1 dB.

The problem with this configuration is temperature drift of a booster amplifier. Since the reference signal is measured before the booster amplifier, the error due to the drift cannot be removed. Moreover, the high reverse isolation of a booster amplifier will prevent accurate reflection measurements on port 1, thus S11 measurements cannot be performed using this configuration.

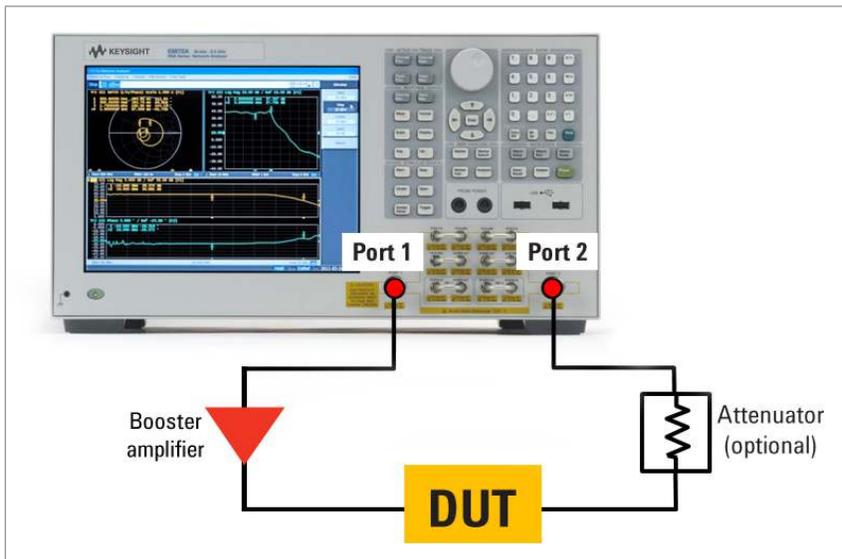


Figure 3. Standard 2-port configuration with a booster amplifier

Configuration 3: Direct receiver access with a booster amplifier

In order to overcome the drift effect of a booster amplifier, the E5072A provides direct access to all source and receiver paths to add external components such as high-power amplifiers, directional couplers, and/or attenuators. The block diagram of the E5072A is shown in Figure 4. It is essential that the network analyzer include direct access to the internal source and receivers so that the test configuration can be modified to handle high-power. A typical test configuration is shown in Figure 5. The internal reference and test bridges are replaced with high-power external couplers since the internal bridges of the E5072A have a damage level of +26 dBm. External components (i.e. couplers or attenuators) should be selected based on their high-power limits or frequency range specifications.

The incident signal can be measured in the reference receiver (i.e. receiver R1 for port 1) of the E5072A after the booster amplifier rather than before, which cancels the effect of temperature drift of the booster amplifier at the test cables and reduces measurement uncertainty. The reflected signal from the DUT is detected at the test receiver A of port 1 for S_{11} ($=A/R_1$) and the transmission signal through the DUT is detected at the test receiver B of port 2 for S_{21} ($=B/R_1$).

External attenuators are inserted in front of the receivers of the E5072A to protect the analyzer from high-power input damage. In order to ensure measurement stability and minimize drift, the cables connected to the attenuators should be kept as short as possible. This can extend the length of time between calibrations but can also minimize the amount of drift between calibrations.

With this configuration, source power calibration is required to remove the effect of the stimulus variation and insertion loss associated with external couplers or RF cables in the source path. Uneveled source power from the E5072A or power fluctuation at the booster amplifier can distort compression measurements of active components under test.

Similar to the standard 2-port configuration with test ports, all calibration techniques are available when using direct receiver access from the E5072A, and high accuracy and long-term stability of measurements are guaranteed. By using direct receiver access and external couplers and attenuators, measurement accuracy is improved as shown in figure 6.

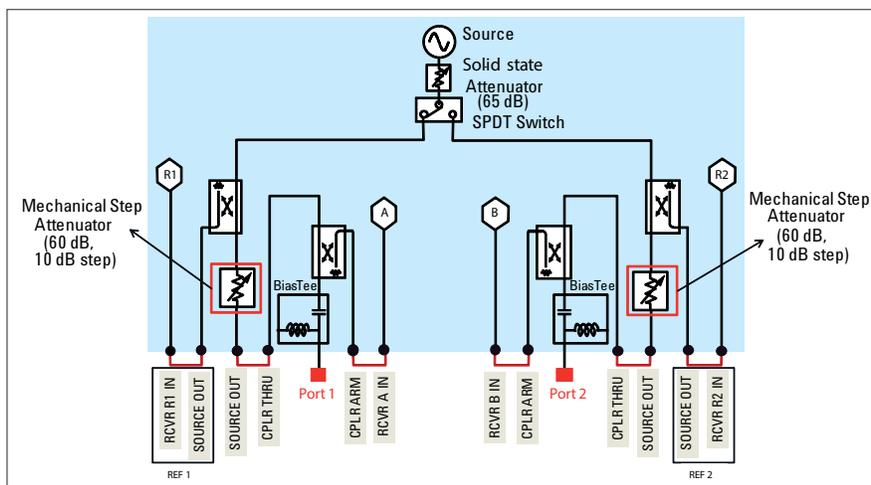


Figure 4. Block diagram of the E5072A

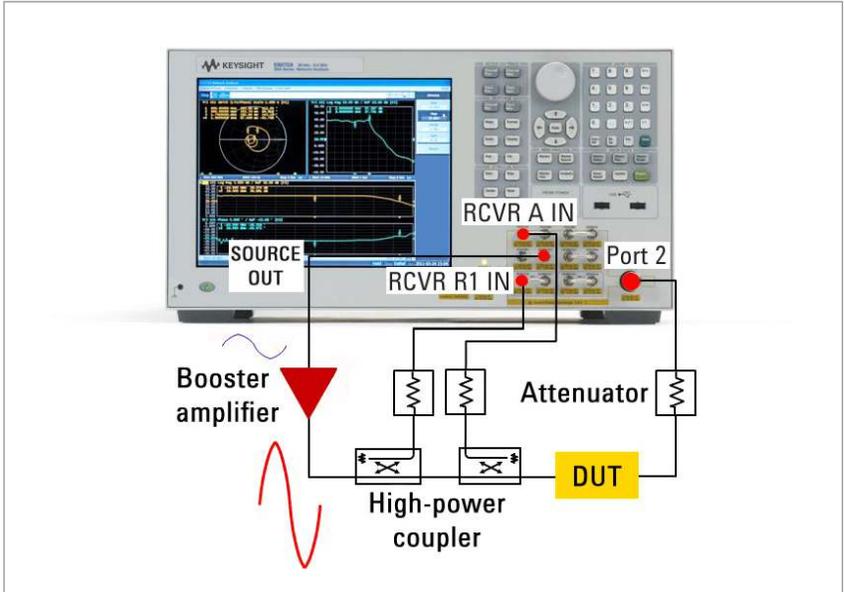
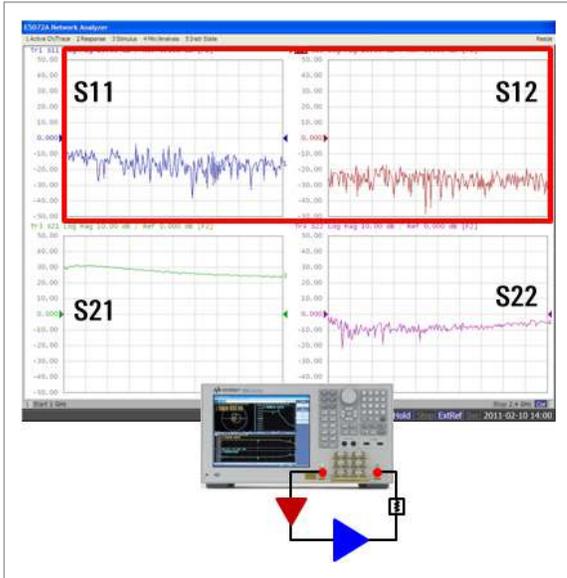
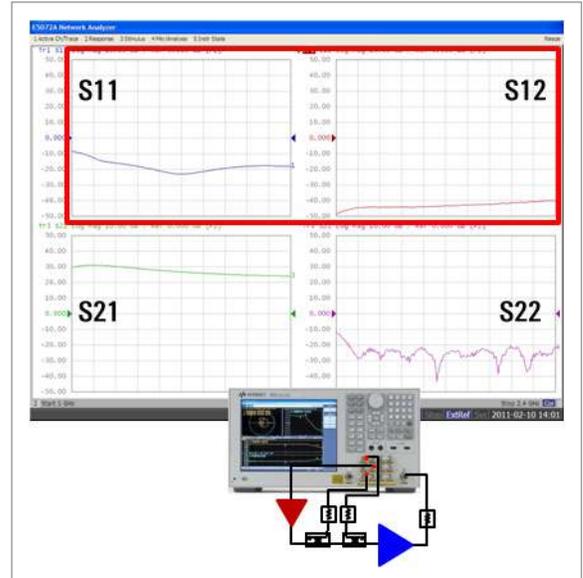


Figure 5. Configuration using direct receiver access with a booster amplifier



Standard 2-port configuration



Configuration with direct receiver access

Figure 6. Improved measurement accuracy with configuration using direct receiver access

Receiver Leveling

Some active components need to be specified with a certain power level at the input or output port. When doing high-power measurements with an external booster amplifier, temperature drift of the amplifier causes variation of the input power level to the DUT giving unexpected errors in measurement results. It is desirable to know the power levels accurately and sweep the power over a desired range. If you want to measure non-linear behavior of your devices such as 1 dB compression point or AM to AM/AM to PM conversion, it is necessary to know power levels more accurately.

The E5072A has a powerful function that adjusts the source power level across a frequency or power sweep using its receiver measurements. Before each measurement sweep, a variable number of background sweeps are performed to repeatedly measure power at the receiver for each stimulus point. Those power measurements are then used to adjust the source power level of the E5072A. With this receiver leveling function, you can achieve greater source power level accuracy with faster throughput compared to conventional methods using a power meter and power sensor.

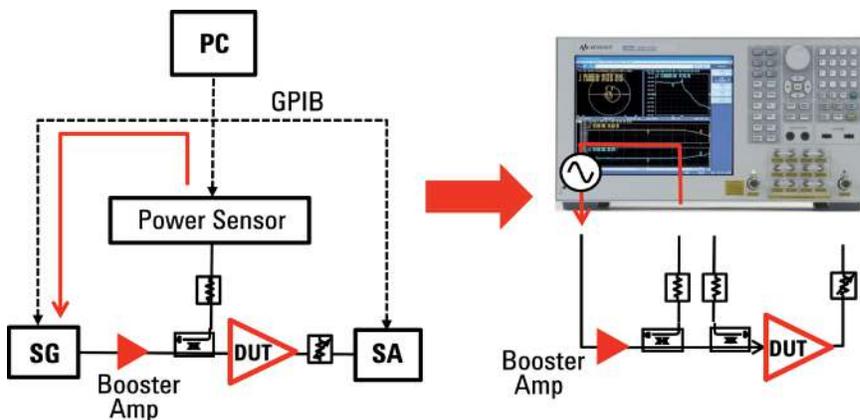


Figure 7. Receiver leveling with the E5072A replaces conventional power-adjustment method

Step-by-step guide for measuring a power amplifier

This section describes necessary steps to measure a high-power amplifier (15 dB gain) using the E5072A. Measurement of gain compression at 1 GHz is needed under a power sweep condition to provide 0 to +43 dBm from the DUT's output. The gain compression test requires that the DUT be driven with high-power levels beyond the E5072A's capability, thus an external booster amplifier is needed to complete the test system. This measurement process is described in the following steps:

- Step 1 Setup of test configuration
- Step 2 Setup of stimulus parameters
- Step 3 Power calibration
- Step 4 Receiver calibration and receiver leveling
- Step 5 Calibration
- Step 6 Measurement

Step 1 Setup of test configuration

Since the DUT needs to be operating with high-power input ($> +20$ dBm), the test setup requires a booster amplifier, external couplers, and attenuators as shown in Figure 8. See appendix A "Power Handling Consideration" to examine the power handling capability of the E5072A's hardware and determine necessary external components.

A booster amplifier is added on the source path to provide maximum +28 dBm at the DUT input. Since the internal directional bridges inside the E5072A have a damage level of +26 dBm, two external high-power couplers are used instead and are connected to the output of the booster amplifier to handle the high-power. Assuming that the couplers have 1 dB insertion loss and 20 dB coupling factor, additional attenuators are inserted in front of the E5072A's receivers to avoid compression.

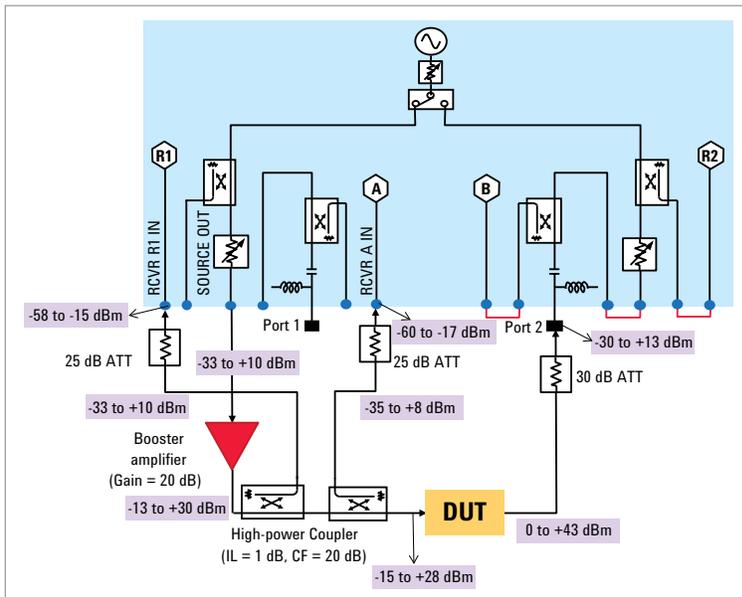


Figure 8. Test configuration for power amplifier measurement

Step 2 Setup of stimulus parameters

Stimulus parameters should be entered before calibration and measurement.

- (1) Configure stimulus parameters
(IF Bandwidth, NOP, sweep type, CW Frequency etc.)

[Trigger] > [Hold]
[Average] > [IF Bandwidth] (1 kHz)
[Sweep Setup] > [Points] (101)
[Sweep Setup] > [Sweep Type] > [Power Sweep]
[Sweep Setup] > [Power] > [CW Freq] (1 GHz)

Step 3 Power calibration

Power calibration with a connected power sensor is performed to get accurate power level at the DUT's input. If the power sensor cannot handle high-power input, a high-power attenuator or a directional coupler should be inserted to protect the power sensor. The effect of this attenuation is mathematically removed by a compensation table in the E5072A firmware and the power level at the DUT's input is adjusted to the target value.

- (1) Connect the power meter/sensor to the E5072A. Add an attenuator or coupler if necessary¹. (Figure 9)
- (2) Configure setup of power sensor. (In this case, instructions are given for calibration with a USB power sensor)

[System] > [Misc Setup] > [Power Meter Setup] > [Select Type] (USB)
[System] > [Misc Setup] > [Power Meter Setup] > [USB]
(i.e. Keysight U2000 Series with its serial number)

- (3) Set power offset and power level at calibration plane
Power offset allows you to specify a gain or loss to account for components connected between the E5072A's test port and calibration plane. Set 18 dB in power offset, as a 20 dB booster amplifier and two couplers with 1 dB insertion loss are inserted. After entering power offset, you can setup high-power level at the calibration plane (in this case, -15 to 28 dBm).

[Calibration] > [Power Calibration] > [Power Offset] (18 dB)
[Stimulus] > [Start] (-15 dBm)
[Stimulus] > [Stop] (28 dBm)

- (4) Loss compensation
If you have cable loss between the analyzer and the test port, then the source power is adjusted upward to compensate for the loss². Loss compensation table eliminates loss of the attenuator or coupler before a power sensor. Edit the compensation table by adding a frequency point and related loss of the attenuator and cables.
(Example: Frequency = 1 GHz, Loss = 20 dB)
When performing frequency sweep, frequency response of the attenuation should be entered in the table.
[Calibration] > [Power Calibration] > [Loss Comp]
(To edit the compensation table)

1. Every power sensor has a maximum power level that it is able to sense. Do not exceed the values indicated on your power sensor or listed in the data sheet.

2. If the loss is too great and the source power level can not be reached at the required level, the source level will become unleveled and an error message, "Power unleveled" is displayed.

- (5) Set tolerance and maximum iteration for power calibration
 Measurement sweep of power calibration is continued until the power level at the calibration plane is adjusted within the accuracy tolerance. Maximum iteration allows you to set the maximum number of sweeps for power calibration until the required accuracy is obtained.

[Calibration] > [Power Calibration] > [Tolerance] (0.1 dB)
 [Calibration] > [Power Calibration] > [Max Iteration] (10)

- (6) Perform power calibration

[Calibration] > [Power Calibration] > [Take Cal Sweep]

The calibration indicator ("PC") in blue will be displayed bottom-right of the channel display.

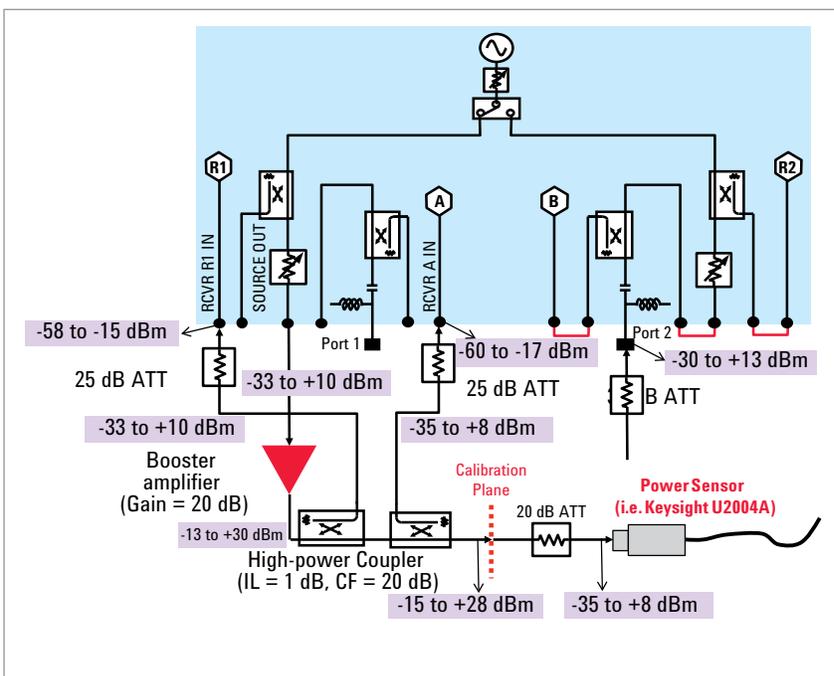


Figure 9. Connecting a power sensor for power calibration

Step 4 Receiver calibration and receiver leveling

To avoid short-term temperature drift of a booster amplifier, use receiver leveling to adjust the power level at the DUT's input. Receiver calibration should be performed prior to receiver leveling. Receiver calibration mathematically removes frequency response in the receiver path, and adjusts the E5072A's readings to the same as the power level in dBm at the calibration plane.

Receiver leveling is performed to adjust the E5072A's source power to obtain the target power level at the calibration plane. Leveling sweeps are performed at each stimulus data point and the deviation from the target power level is applied to the source power level until the desired target power level is achieved.

Receiver calibration:

- (1) Select source and receiver port to be calibrated.

[Calibration] > [Receiver Calibration] > [Select Receiver] (R1)
[Calibration] > [Receiver Calibration] > [Source Port] (1)
[Calibration] > [Receiver Calibration] > [Power Offset] (0 dB)

- (2) Perform receiver calibration

[Calibration] > [Receiver Calibration] > [Calibrate]

If the "R1(1)" (the absolute value at receiver R1 when port 1 is selected for the source) is selected as a measurement trace, the power level in dBm at the calibration plane is displayed. When receiver calibration is completed, softkey [Correction] under [Receiver Calibration] is turned on.

Receiver leveling:

- (1) Select a receiver to be used for receiver leveling.

[Sweep Setup] > [Power] > [Receiver Leveling] > [Port 1] > [Receiver R1]

- (2) Set power offset for receiver leveling

Power offset value for power calibration is normally used for power offset for receiver leveling.

[Sweep Setup] > [Power] > [Receiver Leveling] > [Port 1] > [Power Offset] (18 dB)

- (3) Set tolerance and maximum iteration

Receiver leveling continues until the target power level at the calibration plane for each stimulus data point is adjusted within the specified tolerance value, or until the specific number of leveling sweeps has been reached.

[Sweep Setup] > [Power] > [Receiver Leveling] > [Port 1] > [Tolerance] (0.1 dB)
[Sweep Setup] > [Power] > [Receiver Leveling] > [Port 1] > [Max Iteration] (5)

- (4) Turn on receiver leveling for port 1.

[Sweep Setup] > [Power] > [Receiver Leveling] > [Port 1] > [Leveling] (On)

Step 5 Calibration

In transmission measurements, enhanced response calibration improves accuracy compared to a typical response calibration. Although this calibration technique is not as accurate as a full 2-port calibration, it provides a fast measurement with a single frequency sweep.

You must make sure that the power levels of the calibration measurements do not damage the calibration standards. When using an electrical calibration unit (ECal), the power levels of calibration should not exceed the compression level of the standard. Compression level and damage level is listed in the data sheet for the ECal modules, part number 5963-3743E.

- (1) Select calibration method

**[Calibration] > [Calibrate] > [Enhanced Response] > [Select Ports]
> [2-1 (S21 S11)]**

- (2) Perform reflection measurement for full 1-port calibration using connected calibration standards (Figure 10)

**[Calibration] > [Calibrate] > [Enhanced Response] > [Open]
[Calibration] > [Calibrate] > [Enhanced Response] > [Short]
[Calibration] > [Calibrate] > [Enhanced Response] > [Load]**

- (3) Connect thru standard and perform calibration measurement (Figure 11)

[Calibration] > [Calibrate] > [Enhanced Response] > [Thru]

- (4) Enable error correction

[Calibration] > [Calibrate] > [Enhanced Response] > [Done]

When calibration measurements are completed, the calibration indicator ("Cor") in blue will be displayed at bottom-right of the channel display.

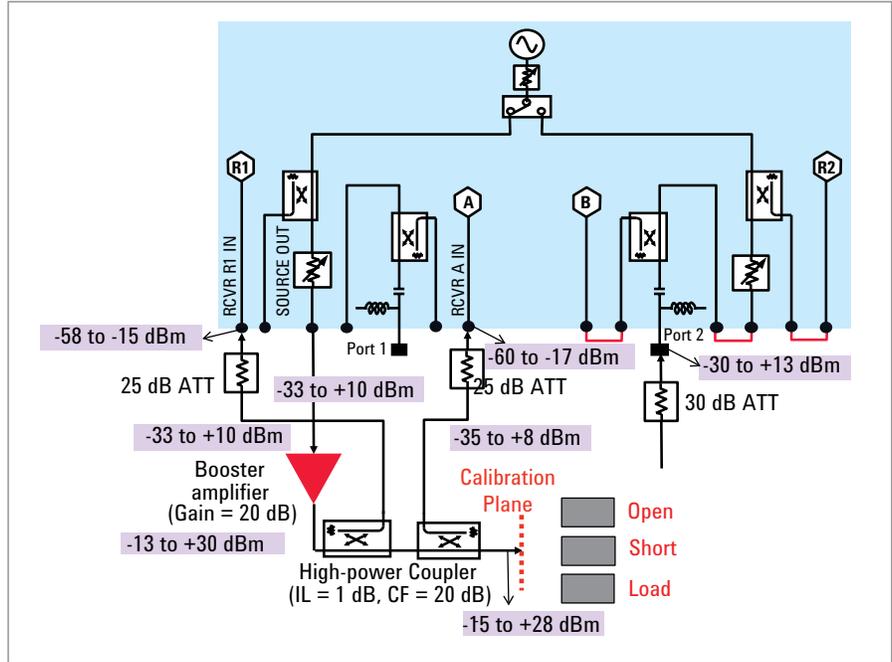


Figure 10. Connecting calibration standards (Open/Short/Load) for full 1-port calibration

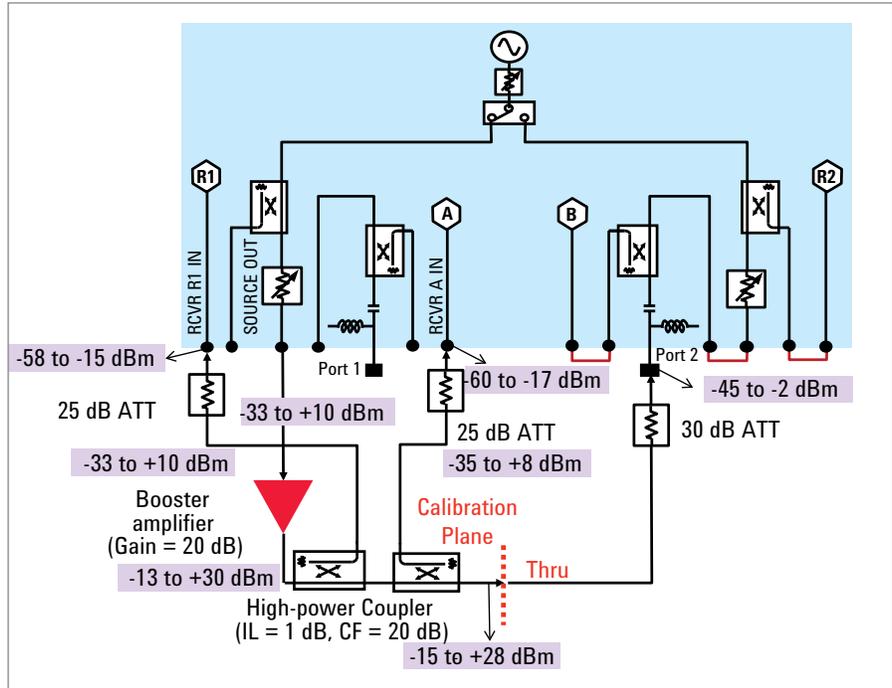


Figure 11. Connecting thru standard for calibration measurement

Step 6 Measurement

The gain compression (S21) of the amplifier under test is measured with a single trigger.

[Meas] > [S21]

[Trigger] > [Single]

Summary

This application note reviewed the basic techniques for high-power measurements using network analyzers with a configurable test set and a step-by-step measurement procedure using a power amplifier and the E5072A ENA series network analyzer. The cost-effective E5072A is an ideal solution for characterization of your devices with high-power levels.

Appendix A. Power Handling Consideration

One of the main factors to consider in a high-power network analyzer measurement is the power handling capability of the internal components of the network analyzer. High power levels can damage the network analyzer, and it is costly to repair the internal components of the analyzer. It is important to understand how the analyzer works and the power handling capability of each component in the signal path.

Each test port of the E5072A is associated with six SMA connectors and three jumper cables for direct receiver access on the front panel (Figure 12). The damage level and compression level are listed in Table 1. Be sure not to exceed these levels and add external attenuating components such as attenuators or couplers to the test system if necessary. The input power level should be at least 3 dB below the damage level of the connectors on the E5072A (ideally at least 6 dB lower).

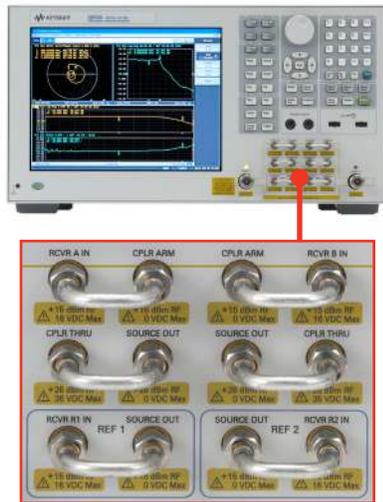


Figure 12. Test port jumpers on front panel

Table 1. Damage level and compression level of test ports

Connector	RF Damage Level (Typ.)	DC Damage Level (Typ.)	0.1 dB Compression Level (SPD)
Test port 1 & 2	+26 dBm	± 35 VDC	+6 dBm (30 to 300 kHz) +16 dBm (300 k to 2 GHz) +14 dBm (2 G to 6 GHz) +10 dBm (6 G to 8.5 GHz)
CPLR ARM	+15 dBm	0 VDC	—
RCVR A IN, RCVR B IN	+15 dBm	± 16 VDC	-15 dBm (30 to 300 kHz) -10 dBm (300 k to 8.5 GHz)
SOURCE OUT (Port 1 & 2)	+26 dBm	0 VDC	—
CPLR THRU (Port 1 & 2)	+26 dBm	± 35 VDC	—
REF 1/2 SOURCE OUT	+15 dBm	0 VDC	—
RCVR R1 IN, RCVR R2 IN	+15 dBm	± 16 VDC	-15 dBm (30 to 300 kHz) -10 dBm (300 k to 8.5 GHz)

It is important to know the loss of path associated with internal components of the E5072A, in order to determine the power level applied to the individual components. The loss of internal directional bridges on the E5072A is listed in data sheet, part number 5990-8002EN. Typical coupling factor and insertion loss of internal directional bridges are shown in Figure 13 and Figure 14.

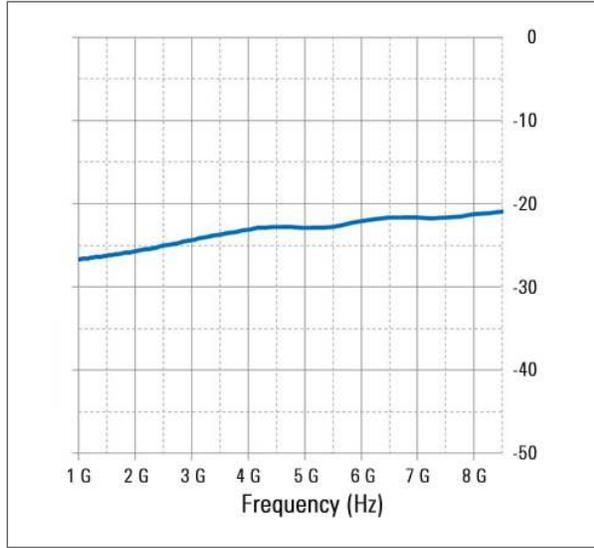
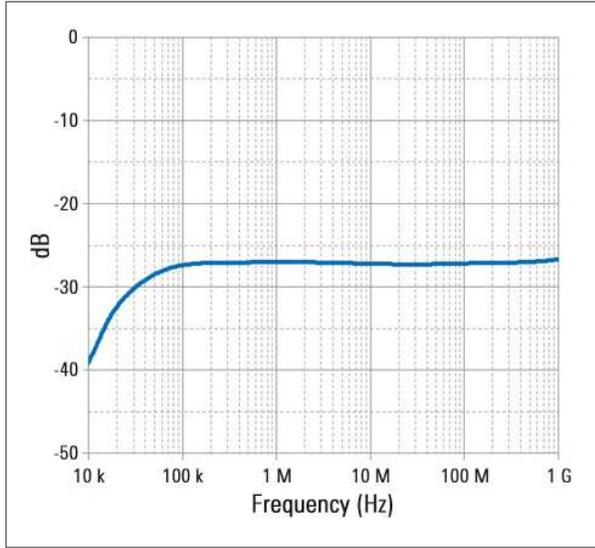


Figure 13. Typical coupling factor of internal directional bridges for test receivers A or B (CPLR THRU to CPLR ARM)

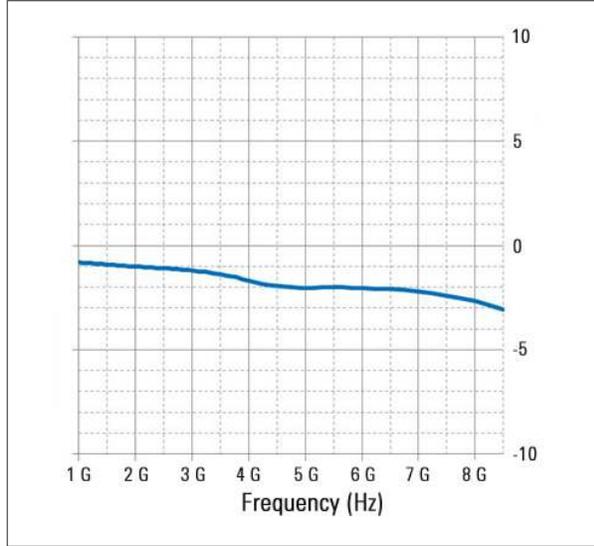
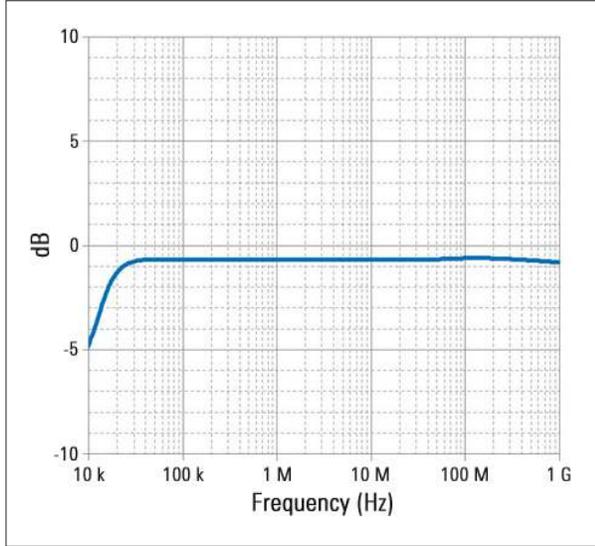


Figure 14. Typical insertion loss of internal directional bridges (Test port (port 1 or port 2) to CPLR THRU)

Appendix B. Robust Design of the E5072A

The E5072A have adopted a robust design for its internal architecture, both hardware and software. Protection circuits inside the instrument protect the E5072A from electronic stress thus dramatically reducing downtime and repair costs.

Power trip

The E5072A has implemented a useful function called power trip that monitors input signal levels at the internal receivers (R1, R2, A or B) of the E5072A. If the excessive signal levels are detected, output power from the E5072A's source is turned off automatically. This function protects the E5072A's internal circuits from the unexpected damage, especially when making high-power measurements with an external booster amplifier. Since the monitored frequency range is not limited to tuned frequency at the receivers but the whole operation frequency of the E5072A (that is 30 k to 4.5 GHz for option 245, 30 k to 8.5 GHz for option 285), this function is beneficial when measuring devices with frequency-offset mode turned on.

Power limit

Maximum power limit sets a maximum power level from the E5072A's source for each port of the E5072A. Once the maximum power limit is set, the power level can only be set below the defined maximum power limit. This prevents an unexpected high-power input to the DUT or the booster amplifier and potential damage of the receivers of the E5072A.

[System] > [Misc Setup] > [Power Limit Setup] > [Port 1 (2)] > [Max Power] (i.e. -10 dBm)
[System] > [Misc Setup] > [Power Limit Setup] > [Port 1 (2)] > [Enable] (On)

User preset

As a default, presetting the E5072A will preset the output power level to 0 dBm, which may result in damaging the booster amplifier of the DUT in the test system or the E5072A itself with high-power input. In this case, setup user preset to recall a pre-defined state file with the power level lower than factory preset condition.

[Save/Recall] > [Save State] > [UserPres]
[System] > [Misc Setup] > [Preset Setup] > [State] > [User]

References

E5072A Configuration Guide, part number 5990-8001EN

E5072A Data Sheet, part number 5990-8002EN

E5072A Quick Fact Sheet, part number 5990-8003EN

E5072A Technical Overview, part number 5990-8004EN

7 Reasons to update from the 8753 to the ENA, part number 5989-0206EN

Network Analyzer Selection Guide, part number 5968-5260E

ENA series web page: <http://www.keysight.com/find/ena>

E5072A web page: <http://www.keysight.com/find/e5072a>

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