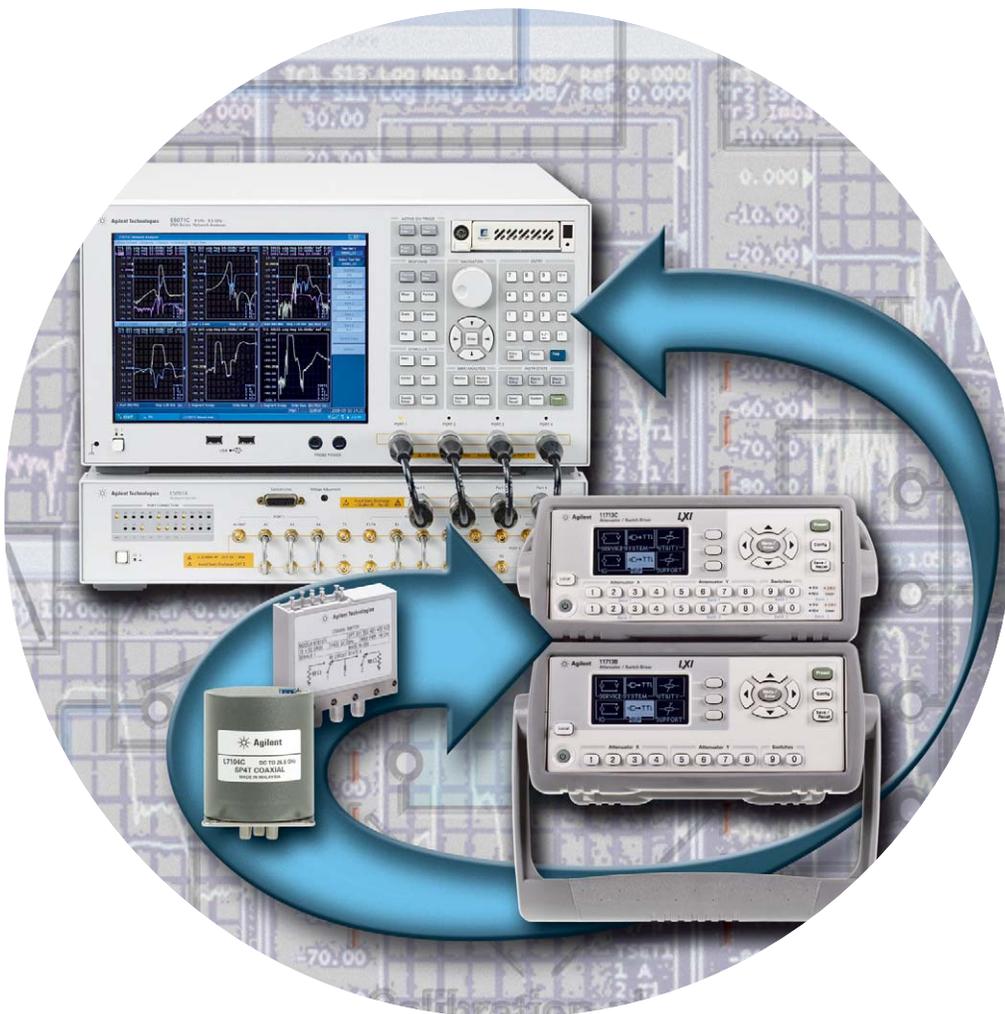# Multiport Solutions for E5071C ENA RF Network Analyzers Using External Switches

Application Note

Agilent Technologies

Introduction

The evolution of components and modules is unstoppable because of increasing requirements from the market. In the wireless communication industry, designers and manufacturers of cellular handsets desire smaller and less expensive components with multi-band capability in order to meet the increasing demands from their end users. More and more functionalities are integrated onto a single component, which introduces multiport devices with combined features and thus, overall multiport characterization becomes increasingly important than in the past. While there are an increasing number of measurement parameters for multiport devices, total testing time is aimed to be minimized by high volume manufacturers. For network analysis, multiport test sets designed to work with the network analyzers are beneficial especially for reducing test times, as one way to boost production throughput is to reduce the time required for connecting devices under test (DUTs).

For devices connected to power amplifiers in a cellular handset, non-linearity characterization such as harmonic distortion measurements with a high-power signal applied to the DUT is required, as well as S-parameter measurements that are typically performed under small signal conditions. Because of the power handling capability, it is recommended to combine a multiport test set with external electro-mechanical (EM) switches in order to achieve faster test times in a cost-effective manner.

This application note will briefly explain how to expand the capability of multiport solutions on the E5071C network analyzer, and provide insights for handling high-power and low-power signal measurements with a single connection.

Multiport Solution For Network Analysis

One example of a multiport solution for the network analysis is shown in the Figure 1. Figure 1 describes the internal block diagram of the Agilent E5091A test set, a switching multiport test set that is designed to work with the ENA network analyzer. Signals from the 4-port ENA are diverted via internal switches in the test set for characterization of multiport devices. This test set can be controlled with the firmware on the ENA, and high-speed measurements are achievable with communication via a USB interface between the two instruments. The E5091A offers two different options: option 009 (9-port configuration in left) and option 016 (13- or 16-port configuration in right).
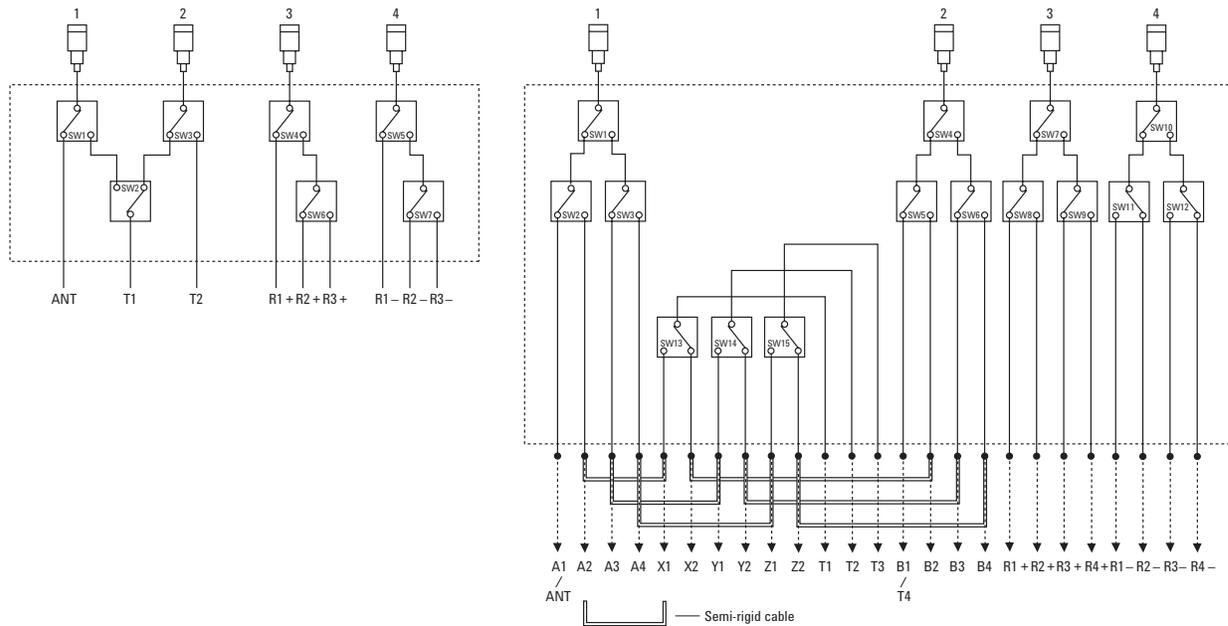

Figure 1. Block diagram of the E5091A multiport test set (Option 009 left, Option 016 right)

The E5091A utilizes an architecture based on multiple SPDT (Single-Pole-Double-Throw; one input and two outputs) switches. By turning on and off these internal SPDT switches with the softkey of the ENA, the RF signal from the ENA can be routed to each port on multiport devices under test (DUT).

Since the solid state switches are installed inside the test set, switching time is minimized for fast measurements compared to switches with different technologies. Also the timing of switching in the test set is highly optimized by considering the wait time of frequency sweep of the ENA. As a result, the additional time in the total measurement sequence is dramatically reduced. This is definitely valuable for high-volume manufacturers with automated test equipment (ATE) systems, because measurement speed is the most significant parameter and high throughput in measurements has a huge impact on the total cost of test.

Though the measurement speed is highly optimized with the E5091A, there are trade-offs for some applications with the test set. For example, the solid state switching solution cannot handle high-power measurements because of its specification on the damage level. The internal solid state switches limit the maximum damage level of the test set at approximately +20 dBm, which is not sufficient for characterization of components in GSM handsets. Amplifiers for this application are usually operated in the non-linear region for efficiency and high-power measurements with more than +30 dBm (= 1 Watt) are required in some cases.

To avoid the electrical stress from outside conditions and hardware failure on internal components in the test set, engineers today can use external EM switches to extend the capability of the E5091A. The application example is discussed in detail in the following section, highlighting the key benefits of this flexible configuration, as well as providing details of selection criteria. EM switches can be used to expand the functionality of the E5091A because these switches have superior distortion characteristics than solid-state switches. Agilent offers high-performance coaxial switches for a wide range of required applications, providing the long life cycle, guaranteed 0.03 dB insertion loss repeatability, and reliability required for achieving higher performance in the majority of switching applications.

Measurement system performance can be optimized by using various switches for specific applications. In the following measurement application example, we are recommending a combination of SPDT and single-pole-four-throw (SP4T) multiport EM switches. Agilent provides a broad selection of switches which provides configuration flexibility for various application and needs. The Agilent N1810TL is recommended for the SPDT switch, which routes signals from one input to two output paths. It provides superior insertion loss of 0.03 dB, as well as an exceptional isolation of >60 dB. As for a SP4T, which allows a single input and four output paths, users may opt for the Agilent 87104A or L7104A. For high-volume manufacturing, the 87104A is preferred due to its guaranteed 0.03 dB repeatability, which ensures accuracy and reduces calibration cycles for the entire 5 million cycle operating life (10 million cycles typical). For economic considerations, Agilent offers the L7104A, which is a high-performance SP4T at an affordable price. It has guaranteed 0.03 dB repeatability, which ensures accuracy and reduces calibration cycles for the entire 2 million cycles operating life (5 million cycles typical).

In the following section, a procedure of setting up the measurement will be discussed. The details of each component in the setup will then be explained to enhance your understanding of how to expand the potential of the Agilent E5071C ENA RF Network Analyzer.

Driving The Electro-Mechanical Switches

Agilent 11713 series attenuator/switch driver

In order to drive the electromechanical switches, a switch driver is needed to supply the necessary DC voltage. The switching set up should be completed in advance of a measurement sweep by the network analyzer so that accurate and stable measurement results can be achieved.

The Agilent 11713C attenuator/switch driver is capable of driving as many as 20 SPDT switches. The supported switches can range from SPDT to single-pole-six-throw (SP6T) multiport switches. The 11713C comes with a tri-voltage selection of 5V, 15V and 24V and also allows for a user-defined voltage supply.

The configuration of the ENA with the 11713B/C is described in Figure 2. The USB/GPIB interface (i.e. Agilent 82357B) is connected between the two instruments for remote control operation from the ENA. The interface is connected to the USB connector on the ENA and the GPIB connector on the 11713B/C. With this setup, the ENA can be utilized as a system controller, and is able to control external switches via the 11713B/C. The 11713B/C provides the ease of point-to-point connection from the driver to the switches by providing nine cable options, enabling easy connection between the instrument and the switches. For the Agilent N1810TL SPDT, which is recommended in this solution, cable option 201 (Viking connector to 12-pin bare wire conductor cables) and option 501 (Viking connector to 4 9-pin DSUB connectors) can be used. On the other hand, the 87104A or L7104A can be connected to the driver by using cable option 201 and option 601 (Viking connector to 16-pin DIP connector). More information can be obtained from the 11713B/C Configuration Guide, Agilent literature number 5989-7277EN.

USB Interface

USB/GPIB Interface (82357B)

Cable for SPDT:
11713B-201 (bare wire) or
11713B-501 (DSUB)

Cable for SP4T:
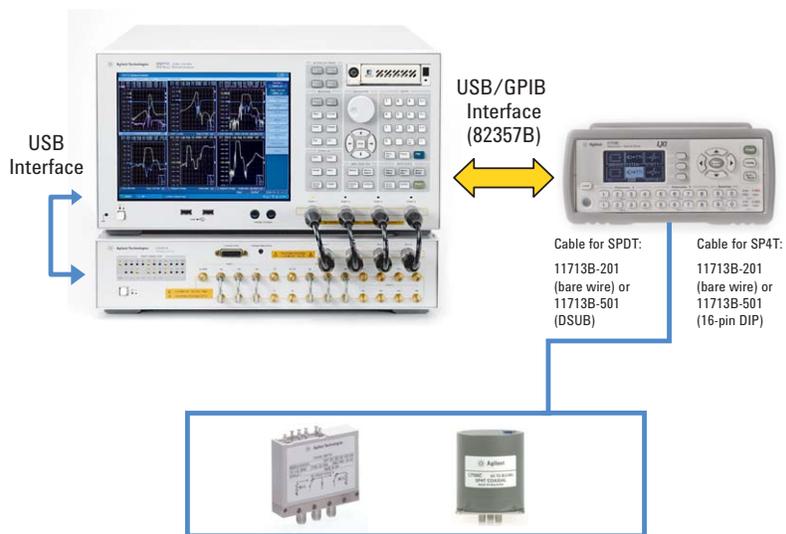11713B-201 (bare wire) or
11713B-501 (16-pin DIP)

Figure 2. Connection of the ENA and the 11713B/C

Note that the E5091A multiport test set has its own internal driving circuit which can supply the DC voltage through the D-sub 15-pin connector on the front panel (Figure 3). This circuit was originally designed for enabling control bits of DUTs such as antenna switch modules in cellular handsets, but it is possible to drive other devices within the hardware specification of the test set. The output DC voltage can range from 0 to +5 V for positive signals and –5 V to 0 V for negative signals. The maximum supply current is limited below 50 mA.

Figure 3. D-sub 15-pin connector for control voltage on the E5091A

Software Connectivity

For multiport measurements, there are many measurement parameters that need to be input into the test instruments. It can be very time consuming and sometimes the preparation of testing, as well as the calibration procedure, takes longer than the actual measurement time. Thus, the setup software becomes critical for reducing the time on multiport measurements.

The ENA has a Measurement Wizard Assistant (MWA) software option (E5071C-790) that is definitely beneficial to all operators of multiport measurements. Figure 4 indicates the overall concept of the MWA. The software consists of two main applications -- front-end and back-end. The front-end application running on Microsoft Excel generates a setup file that includes all parameters for network analysis such as power level, frequency range, IFBW or number of points.

Once the necessary parameters of the front-end application have been input with the Excel-based user interface, they no longer have to input by softkey on the ENA. That minimizes fatigue in operation time, and testing productivity is greatly improved.
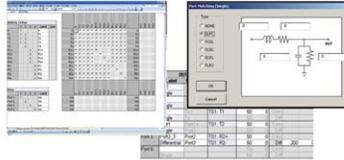
The generated setup file (.mwa) is recalled by the back-end application of the Microsoft VBA software on the ENA, and all the included parameters are set up automatically within the ENA. The back-end application also has the calibration wizard function that offers the calibration procedure when using the multiport test set. This wizard minimizes the number of connections required for the calibration procedure, and eliminates the possibility of connecting wrong ports during calibration.

Front-End Application

Operation environment
- Software based on the Microsoft Excel
- Can be operated on any PC with Microsoft Office 2000 installed
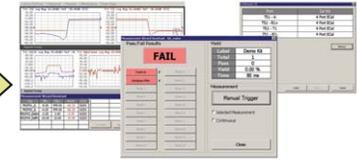

Features and benefits
- Easy and fast setup of multiport measurements for the ENA
- Generates one setup file (.mwa) including all the measurement parameters
- "Step-by-step" setup wizard with Excel-based user interface

Back-End Application

Operation environment
- Software based on the Microsoft VBA Macro working in the ENA
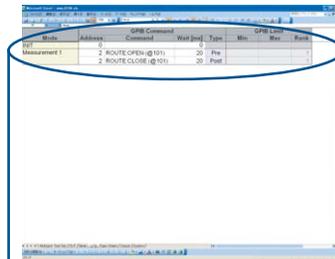- Option E5071C-790 for the ENA is required for full capability operation

Features and benefits
- Recall the .mwa setup file and set all the parameters on the ENA automatically
- Calibration wizard for minimum operation time
- Automatic test procedure with go/no go limit test

Setup file (.mwa)

Figure 4. MWA concept

Figure 5 shows an example of the "GPIB" sheet in the front-end application, which can be utilized for a remote control between the ENA and external instruments in multiport measurements.

Mode	GPIB Command			
	Address	Command	Wait [ms]	Type
INIT	0		0	
Measurement 1	2	ROUTE:OPEN (@101)	20	Pre
	2	ROUTE:CLOSE (@101)	20	Post

Figure 5. "GPIB" sheet of the MWA for controlling switches via driver

As previously mentioned, when the ENA is connected to peripherals via the USB/GPIB interface, the ENA can be operated as a system controller in the test system and it is possible to transmit GPIB commands to peripherals with a selected GPIB address. By sending commands to turn on or off the switches, a desired switch port is selected via the 11713C switch driver within the test procedure that is defined by the front-end application of the MWA.

Measurement Example

In this section, an example of a multiport measurement is introduced. The DUT is an RF multiport switch typically used in a cellular handset, and it is required to perform both S-parameter measurements on all paths and a harmonic distortion measurement on the transmission path of the DUT. To perform both of these measurements with a single connection, it is beneficial to use external EM switches.

The basic configuration examples of the measurements are shown in Figures 6 and 7. Because both configurations are focused on 2-port measurements out of multiple ports on the device, additional EM switches may be required for a complete measurement setup. Figure 6 is for the S-parameter measurement with a low-power signal applied to the DUT, while Figure 7 is for the harmonic distortion measurement with a high-power signal to the DUT. Both measurements can be selected by changing the EM switch ports.
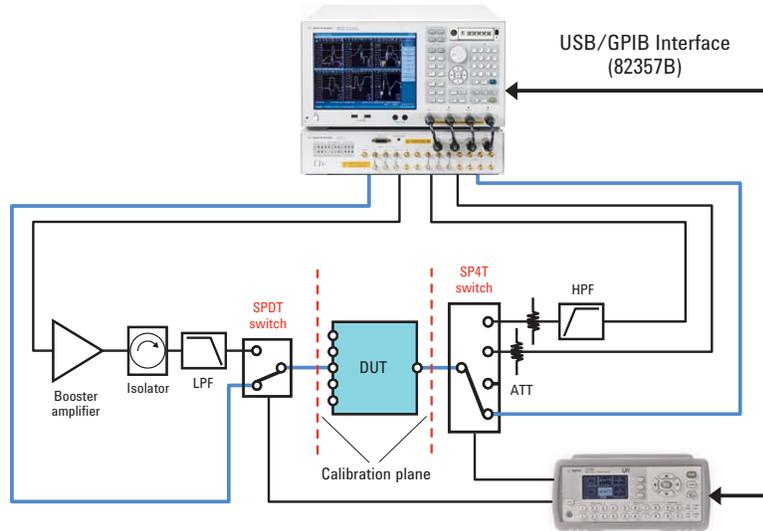

Figure 6. Configuration example of low-power measurement (S-parameter measurement)
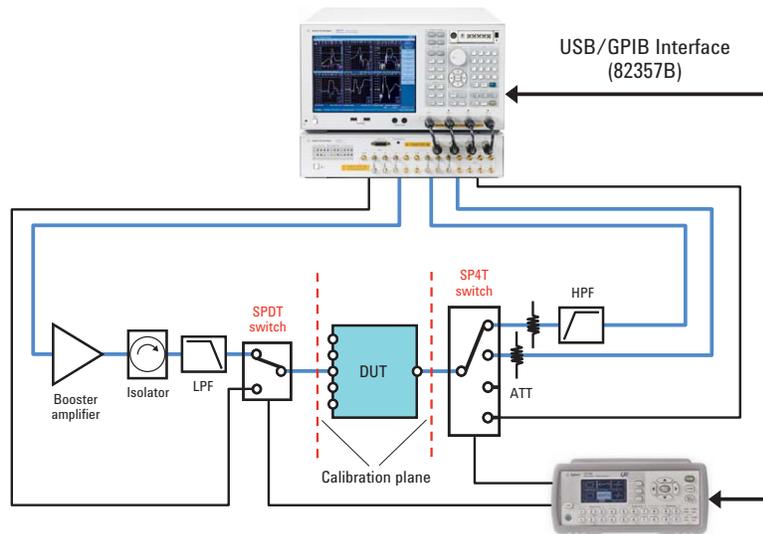

Figure 7. Configuration example of high-power measurement (harmonics measurement)

Because the DUT is normally connected to power amplifiers for transmission operation within a cellular handset, distortion measurements of the device are normally performed under the condition of high input power level. An external booster amplifier is necessary to obtain the high power level that is well beyond the maximum output power level of the network analyzer. An isolator is inserted after the booster amplifier to improve mismatch due to poor S22 characteristics of the amplifier. For harmonic performance measurements, a low pass filter (LPF) needs to be placed to remove unwanted harmonic products generated by the amplifier or the signal source of the network analyzer. Also a high pass filter (HPF) is necessary for suppression of the fundamental frequency on the receiver path in order to maximize the Signal-to-Noise (S/N) ratio of absolute measurements using the receivers of the network analyzer. Agilent EM switches are suitable for this application as they provide guaranteed 0.03 dB insertion loss repeatability, which ensures accuracy and reduces calibration cycles. The exceptional isolation performance of > 60 dB is also a key contributor that maximizes measurement accuracy and improves system dynamic range.

Harmonic Measurement Procedure

In this section, the harmonic distortion measurement procedure with the ENA will be described in detail. The signal from port 1 of the ENA is applied to the 2-port DUT, and the output of the DUT is routed to port 2 of the ENA for an absolute measurement at the fundamental frequency, and to port 3 for the measurement at harmonic frequencies. The E5091A multiport test set can be useful when ports on the DUT are increased.

The necessary steps consist of the following:

(1) Parameters setup
(2) Receiver calibration
(3) Source power calibration
(4) Measurement

(1) Parameters setup

(1-1) Measurement parameters setup
All the necessary measurement parameters such as frequency, number of points, and IFBW should be selected appropriately. For this measurement example, measurement frequency ranges from 800 MHz to 1 GHz for a fundamental signal from the source port of the ENA. The absolute measurement at the fundamental frequency is performed on channel 1 of the ENA, while measurement of the 2nd harmonic stimulus is done on channel 2.

Set the start and stop frequency
    [Start] > [Start] (800 MHz)
    [Stop] > [Stop] (1 GHz)

Allocate two channels in the display for absolute measurements
    [Display] > [Allocate Channels] > [x2]
    [Meas] > [Absolute] > [B (1)] (for channel 1)
    [Meas] > [Absolute] > [C (1)] (for channel 2)

(1-2) Turn on Frequency Offset Mode (FOM)
By turning on the FOM, the source and receiver of the ENA can be tuned at different frequencies; harmonic stimulus generated in the DUT can be obtained at the receivers of the ENA. Option E5071C-008 for the ENA or upgrade product E5003A is required for enabling this functionality.

Turn on the FOM for channels 1 and 2
    [Sweep Setup] > [Frequency Offset] > [Frequency Offset] (On)

Tune at the harmonic frequency on the source (port 1) and receiver (port 3) for channel 2
    [Sweep Setup] > [Frequency Offset] > [Port 1] > [Multiplier] (2)
      > [Port 3] > [Multiplier] (2)

The frequency range of channel 1 is set at 800 MHz to 1 GHz for the source (port 1) and receiver port (port 2), and the range for channel 2 is from 1.6 GHz to 2 GHz for the both ports (port 1 and port 3). An integer of the multiplier should be selected depending on the harmonic stimulus of interest.

(2) Receiver calibration

The absolute power level at the receiver ports on the ENA can be calibrated with the receiver calibration. The effect of insertion loss on the receiver path is eliminated with the calibration, and values of absolute power level at the calibration plane are displayed on the screen of the ENA.

Receiver calibration is done at the frequency range of a selected source port. Thus, for the harmonic measurement, the frequency range of the source port should be the same range as the receiver port.

It is recommended to perform the power calibration in advance of the receiver calibration in order to achieve a more accurate power level on the input signal.

(2-1) Power calibration
   Set the power level of the ENA on channels 1 and 2.
      [Sweep Setup] > [Power] > [Power] (dBm)

Note: The input power level for the receiver calibration is limited under the maximum output power level of the ENA.

Perform the power calibration for channels 1 and 2. The ENA and power meter are connected via USB/GPIB interfaces such as the Agilent 82357B. (Figure 8)
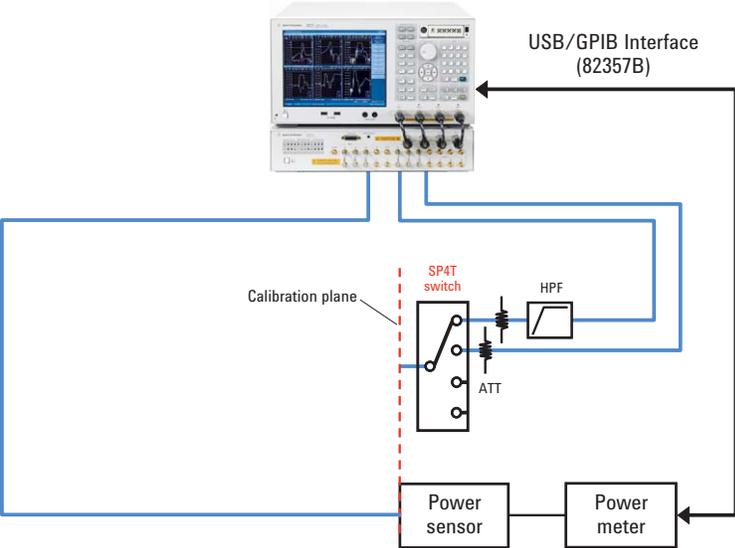   [Cal] > [Power Calibration] > [Take Cal Sweep]

USB/GPIB Interface
(82357B)

SP4T switch

HPF

Calibration plane

ATT

Power sensor

Power meter

Figure 8. Power calibration (for receiver calibration)

(2-2) Receiver calibration

Perform receiver calibration after connecting the source and receiver paths. (Figure 9)

For channel 1:

    [Cal] > [Receiver Calibration] > [Select Port] (2)

      > [Source Port] (1)

      > [Take Cal Sweep]

For channel 2:

    [Cal] > [Receiver Calibration] > [Select Port] (3)

      > [Source Port] (1)

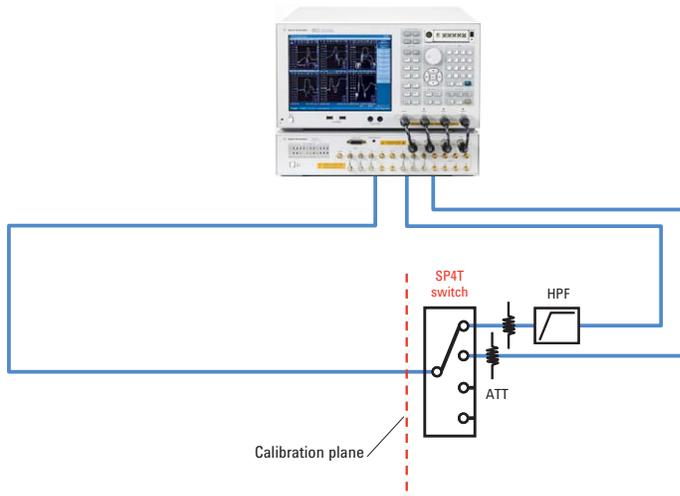   > [Take Cal Sweep]

Figure 9. Receiver calibration

(3) Source power calibration

(3-1) Lower the power level of the ENA

For high-power measurements with a booster amplifier, the output power level from the source port on the ENA must be set to a proper value so that the input signal to the receiver ports will not cause a hardware failure in the ENA. Note that maximum damage level of the test ports on the ENA is typically +26 dBm, and +20 dBm for the ports on the E5091A.

For channels 1 and 2:

    [Sweep Setup] > [Power] > [Power] (dBm)

(3-2) Set the frequency of the source port

Set the source port (port 1) of channel 2 at the fundamental frequency range.

For channel 2:

    [Sweep Setup] > [Frequency Offset] > [Port 1] > [Multiplier] (1)

Now the frequency of the source port (port 1) in both channels ranges from 800 MHz to 1 GHz for fundamental signals. The frequency at port 2 is tuned for the fundamental measurement (800 MHz to 1 GHz), while the frequency at port 3 is tuned for the harmonic measurement (1.6 GHz to 2 GHz).

(3-3) Power calibration at high-power level

The configuration for high-power calibration with an external amplifier is illustrated in Figure 10. The power level of the input of the DUT is adjusted to a desired value by the power meter and sensor connected to the ENA.
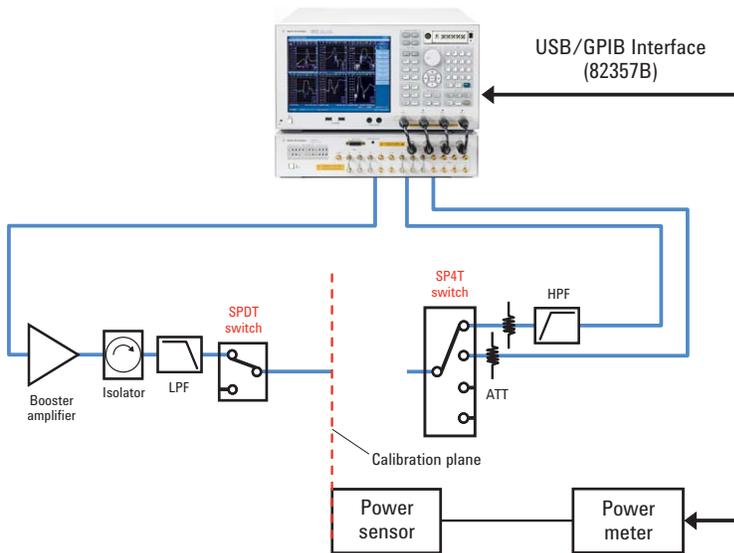

Figure 10. Power calibration with high-power signal

Insertion loss or gain on the source path can be compensated by inputting appropriate values in the loss compensation table (Figure 11). At high-power measurements, for example, when the output power level of the ENA is set at 0 dBm and a negative value such as –32 dB is added in the compensation table, the power level at the calibration plane of the power sensor is adjusted to +32 dBm for the entire frequency range.
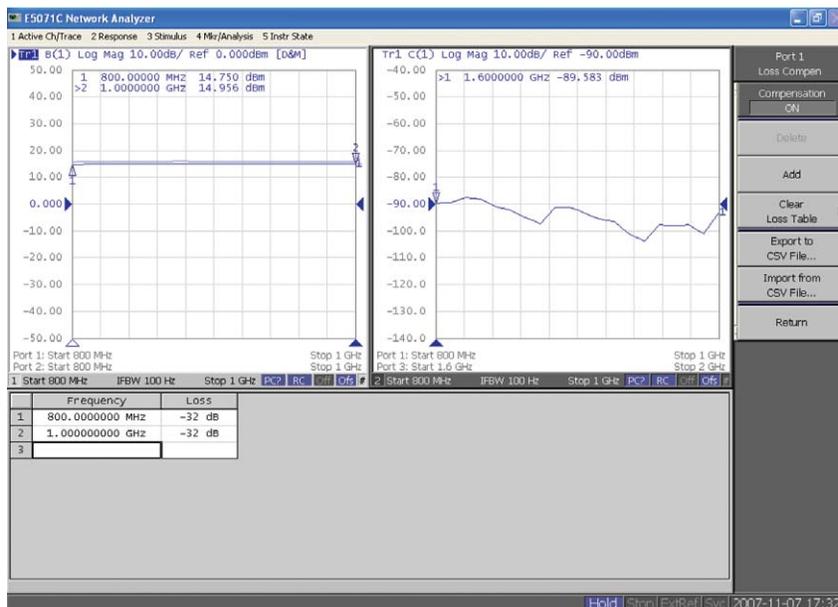

Figure 11. Loss compensation table for power calibration

For channels 1 and 2:
[Cal] > [Power Calibration] > [Compen] > [Compensation] (On)
   > [Take Cal Sweep]
      ("Take Cal Sweep" key is located under "Power Calibration")

(4) Measurement

The measurement result is shown in Figure 12. The frequency dependency of the fundamental signal of the output of the DUT is displayed on channel 1, and the 2nd harmonic stimulus of the DUT is displayed on the channel 2.
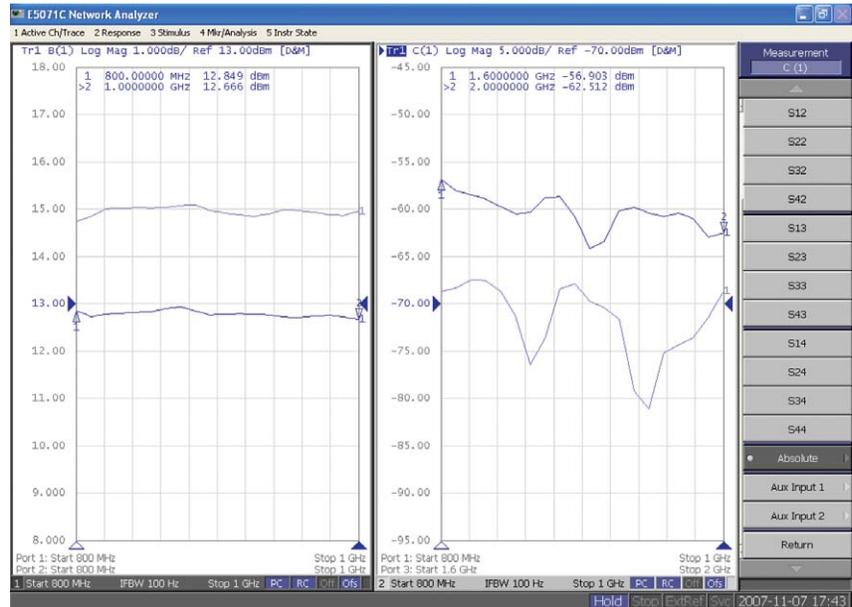

Figure 12. Results of harmonic distortion measurement

Summary

This application note explains how the potential of a multiport solution for network analysis can be expanded using the E5071C ENA network analyzer with external electro-mechanical switches for handling high-power and low-power signal measurements. Appropriate switches should be selected depending on the system individual performance needs, given the wide portfolio of switching solutions from Agilent switches with the 11713B/C switch driver.

In today's manufacturing environment, reducing cost of test and optimzing manufacturing yields are of primary importance. Agilent has the combined portfolio of test instruments and premium grade RF and microwave test accessories to address the critical demands of today's test and measurement world.

Recommended Instruments and Accessories

E5071C ENA RF Network Analyzer, 9 kHz to 8.5 GHz
E5091A Multiport Test Set
87104A/B Multiport Coaxial Switch, DC to 4/20 GHz, SP4T
L7104A/B Multiport Coaxial Switch, DC to 4/20 GHz, SP4T
N1810TL Coaxial Switch, DC to 2/4/20/26.5 GHz, SPDT

References

ENA series web page: **www.agilent.com/find/ena**
Multiport Test Sets: **www.agilent.com/find/multiport**
Switch Drivers: **www.agilent.com/find/switchdrivers**
RF & Microwave switches: **www.agilent.com/find/switches**

Related Literature

E5071C ENA RF Network Analyzers, Data Sheet
  (5989-5479EN)
Agilent RF & Microwave Switches, Performance you can count on, Brochure
  (5989-6947EN)
Agilent 11713B/C Attenuator/Switch Drivers, Configuration Guide
  (5989-7277EN)
Agilent L Series Multiport Electromechanical Coaxial Switches, Technical Overview
  (5989-6030EN)
87104/87106A,B,C Multiport Coaxial Switches, Product Overview
  (5091-3366E)
N1810/1/2 Coaxial Switch, Product Overview
  (5968-9653E)

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