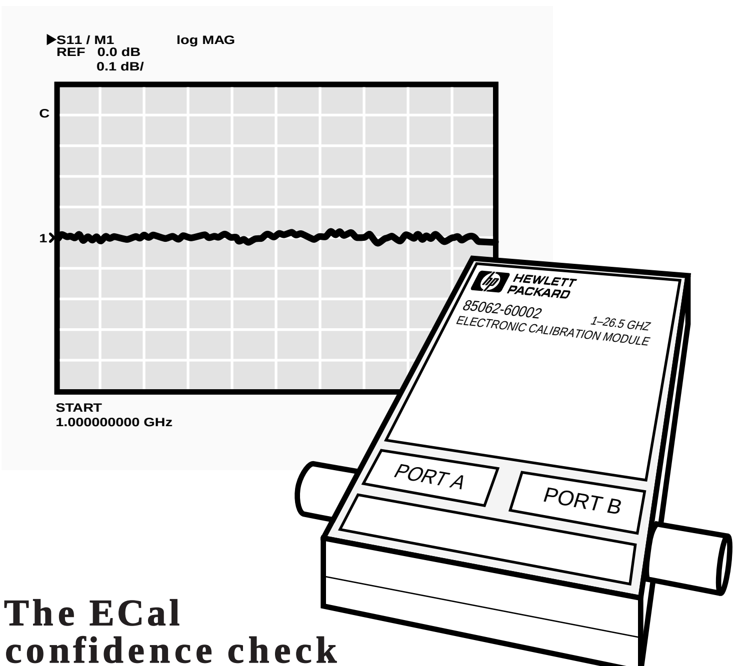
HP 8510 8720 NEWS

June 1997
Volume 8—Number 1

The newsletter for users of HP 8510 and 8720 network analyzers



The ECal confidence check ensures valid calibrations

The accuracy of a vector network analyzer (VNA) measurement is enhanced with calibration. However, the improvement achieved is dependent on the quality of the calibration. After a VNA is calibrated by using either mechanical standards or electronic calibration (ECal), a confidence check should be performed to check the validity of the calibration.

The most significant sources of measurement uncertainty in a VNA are systematic errors, such as directivity, source match, load match, reflection tracking, transmission tracking and crosstalk. Since these errors are repeatable, they can be mathematically removed from the measurement system with calibration. Traditionally, a calibration is performed by connecting a number of well-known passive mechanical standards (i.e., open, short and load circuits) to the ports on the VNA. Using twelve-term error correction algorithms, the VNA can then determine the systematic error coefficients by comparing the previously characterized response of the calibration standards to their measured response. The twelve-term error coefficients can then be used to remove the systematic errors from measurements on the calibrated VNA.

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Also in this issue:

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The validity of the calibration should be checked by measuring a calibration-check standard—a well-known device that is different from any of the calibration standards. If the calibration was performed properly, the measurement of the calibration-check standard should closely match measurements previously obtained; preferably, from a metrology-grade VNA. If the measurements differ significantly, either the calibration was not performed correctly or the VNA is not functioning properly.

Although the ECal calibration and confidence-check procedure is similar to mechanical calibrations, there are some notable differences. ECal uses a calibration transfer standard that can generate a plurality of complex reflection and transmission states at each of its ports. The VNA is calibrated by simply connecting the ECal module to its ports and starting the calibration. As in mechanical calibrations, a twelve-term error model is used to derive the error coefficients which will then be used to remove systematic errors from the VNA measurements. Since only two connections are made during electronic calibration (compared to 7 or more for mechanical calibrations), the accuracy of the calibration is improved considerably by the reduction in connector non-repeatability error.

In addition, each ECal module has a special state—the confidence state—which was measured when the module was characterized by Hewlett-Packard. The confidence state functions as a built-in calibration-check standard, and therefore is not used during the calibration cycle. In order to best check the quality of the calibration, the characteristics of the confidence state are chosen to give a large reflection (small transmission) coefficient, similar to the skirt of a filter. These particular characteristics were selected because most VNA uncertainties are in high-reflection areas.

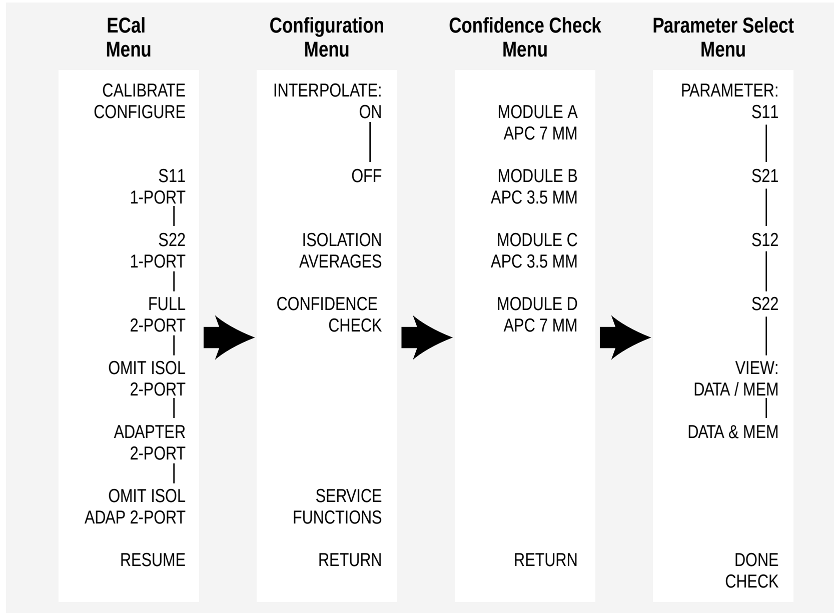


Figure 1. VNA ECal menus for confidence check

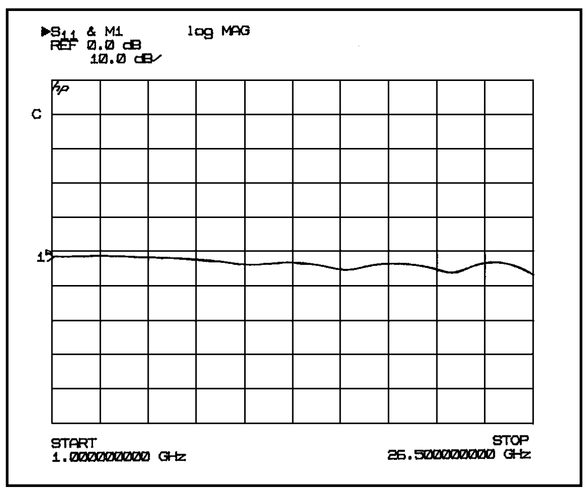


Figure 2. A good calibration (measured and characterization data for S_{11} overlay exactly)

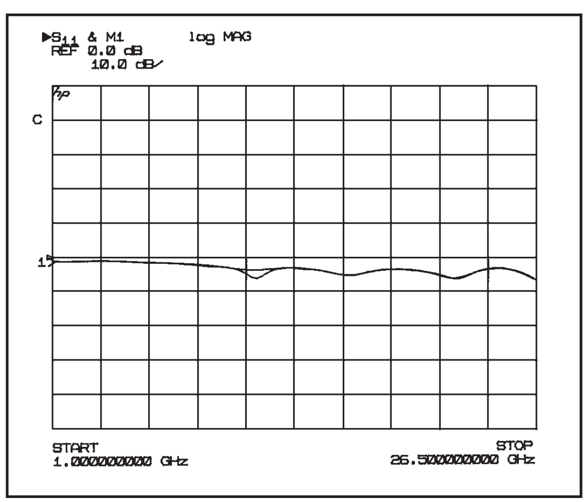


Figure 3. A poor calibration (measured and characterization data for S_{11} do not match)

Since all four S-parameters of the confidence state are measured when the module is characterized, the calibration of the VNA can be validated by looking at any of the S-parameters. After the confidence check is selected and an S-parameter is chosen in the ECaL menu (Figure 1), the characterization data for the selected S-parameter is stored in the trace memory of the VNA. Next, the VNA measures the same S-parameter of the confidence state. Then, the characterization data and the measured data are displayed together graphically on the VNA using the DATA & MEM function. If the calibration was performed correctly, the measured data will match the characterization data very closely (Figure 2). An error in calibration (caused by a dirty or loose connector, for example) would result in a poor match, like that shown in Figure 3. Greater resolution for this comparison can be obtained by selecting DATA/MEM in the ECal menu and viewing any of the S-parameters (Figure 4). For a typical confidence check, there should be less than 0.2 dB difference between the two traces.

For any type of calibration, a confidence check should be performed to check the validity of the calibration. A confidence-check standard is built into Hewlett-Packard's ECal product, so the electronic calibration can be easily verified with a few keystrokes.

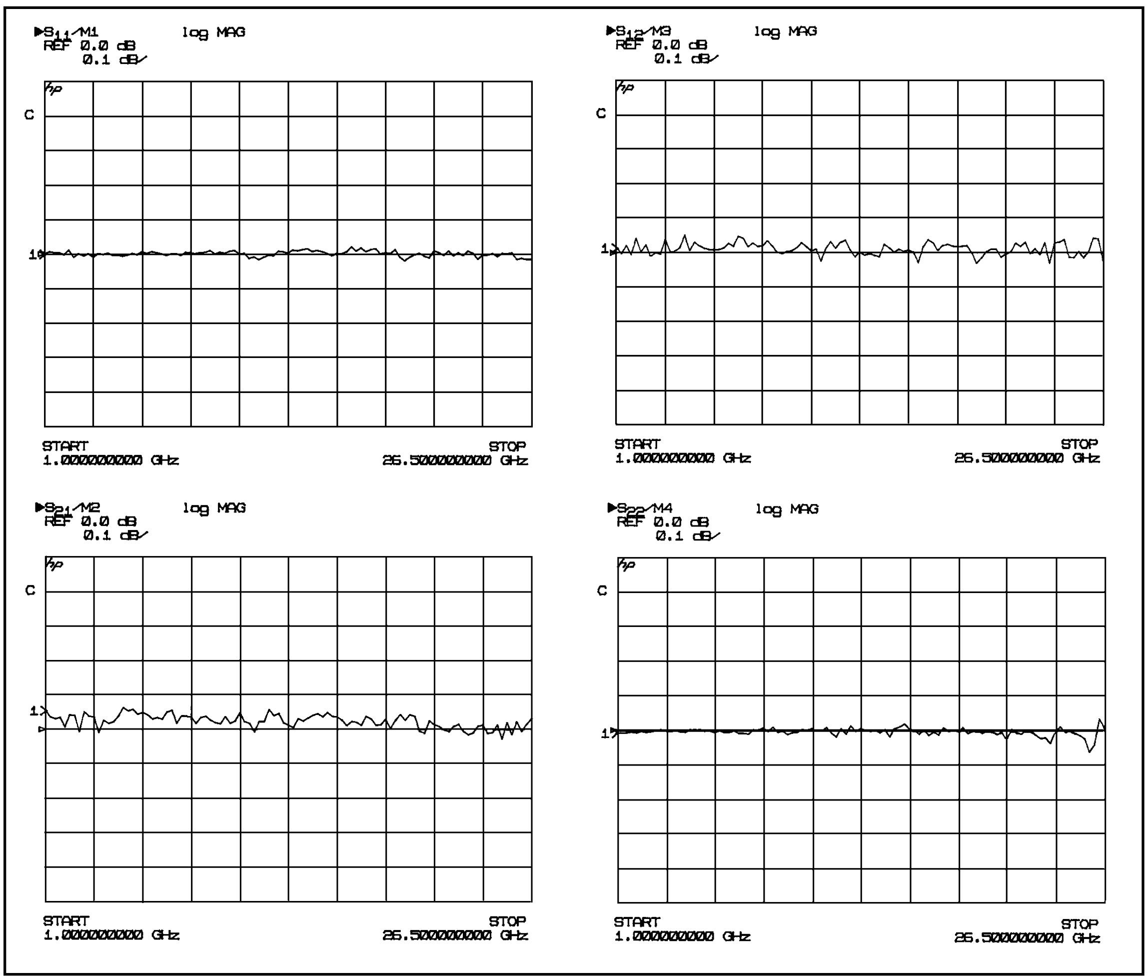


Figure 4. Difference between measured and characterized S-parameters of confidence state (viewed using DATA/MEM feature for high resolution)

Product News

Should I buy an HP 8720D or 8510C?

The HP 8720D family has three VNAs:

- HP 8719D (50 MHz to 13.5 GHz)
- HP 8720D (50 MHz to 20 GHz)
- HP 8722D (50 MHz to 40 GHz).

The HP 8510C has a multitude of test sets and sources that cover the frequency range from 45 MHz to 50 GHz. Millimeter-wave test set modules extend the HP 8510C frequency range to 110 GHz.

Comparison of key features

HP 8510C	HP 8720D
45 MHz to 110 GHz	50 MHz to 40 GHz
Ultimate in accuracy	Lower price
4 S-parameter display	General purpose
Pulsed-RF and DC-bias solutions	Mixer test (Option 089)
TRL (standard)	TRL (Option 400)
Modular design	Smaller
Far-field antenna measurements	Self-contained, completely integrated

Both products are capable of the following*:

- Measuring S-parameters in coax or waveguide, in-fixture and on-wafer
- Medium power handling capability (20 Watts) with the HP 8719/20/22D Option 085. The same capability exist in the HP 8510 family with special HP 8514B/15A/17B sampler-based test sets, and special HP 85110A mixer-based test sets.
- Power flatness calibration to provide level power to the device under test
- Power Sweep to measure the 1dB compression point of amplifiers and for AM-to-PM conversion measurements
- Receiver power calibration to enable the analyzer to accurately measure the non-ratioed power level of the test signal
- Firmware routines for one-port, two-port, TRL, LRM, response and isolation calibrations
- Compatibility with the Electronic Calibration (ECal) product family
- Synthesized sources which can be swept for faster measurements
- 1 Hz frequency resolution
- Extensive markers and limit lines for use in the manufacturing environment

All of Hewlett-Packard's network analyzers are supported with a full line of calibration and verification kits.

*When the HP 8719/20/22D is configured with the appropriate options and the HP 8510C system has the appropriate test set and source.

The HP 8719/20/22D offers the following additional features:

• VGA output on the rear panel for driving an external monitor

• Up to 1601 measurement data points

• Parallel and serial ports for interface to port handler, printer, barcode reader, or keyboard

• Test sequencing for test automation

• A frequency offset mode (Option 089) to allow direct measurement of the conversion loss of a mixer without a reference mixer. Configuration with a reference mixer provides phase measurements and 100 dB of dynamic range.

• Direct access to the samplers. Option 012 allows user access to the A, B, and R samplers, providing 120 dB of dynamic range. This is a useful feature for applications which require high sensitivity, such as near-field antenna measurements.

• High-power tests up to 100W

• New retrace power control for testing AGC amplifiers

• Automated “fast two-port” sweep mode speeds 12-term error correction, allowing real-time tuning with an optional footswitch for quick recall of instrument states.

• New phase-lock algorithm optimized for faster narrowband sweeps

• Prepackaged configuration for non-coaxial device test (waveguide, in-fixture or on-wafer) includes a four-sampler test set for TRL calibration, time-domain analysis for gating, high-stability frequency reference, and direct sampler access for better sensitivity

• Easy upgradability. All options are retrofittable, including frequency.

• The HP 8719/20/22D is a compact, self-contained unit that easily fits on a bench top

The HP 8510C systems offer the following additional features:

• RGB output on the rear panel for driving an external monitor

• Up to 801 measurement data points

• Serial I/O port on rear panel (use a serial-to-parallel converter for the newest printers)

• The modularity of the HP 8510C allows the source and test set to be separated from the test system, making the HP 8510C a useful tool when the test set must be physically separated from the display/user, and for far-field antenna measurements.

• Direct access to the samplers. The HP 8511A/B provide access to all four samplers. This is a useful feature for applications which require high sensitivity, such as near-field antenna measurements. High-power applications (which require the use of external high-power couplers, attenuators and isolators) also benefit from this feature.

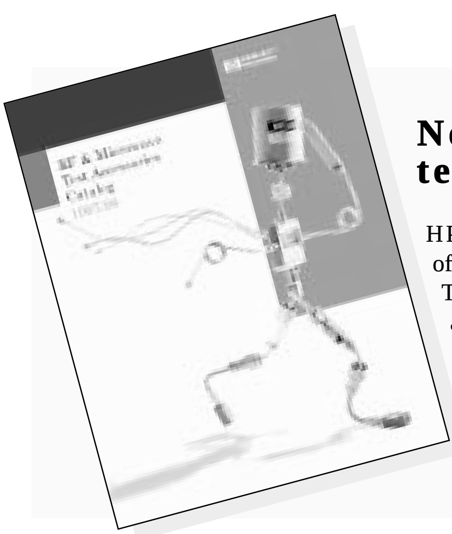
• The multiple test set configuration can control up to four test sets. This is a powerful capability for manufacturing test applications.

• The HP 85106C mm-wave product family provides banded frequency coverage from 45 MHz to 110 GHz

• The HP 85108A/L system is mixer based and has wide-bandwidth detectors for making pulsed-RF and DC-bias measurements

• The HP 85118A custom amplifier test system is designed for measuring high-power base station amplifiers to 400W

• The modular design of the HP 8510 allows for easy hardware upgrades from the HP 8510A or HP 8510B to the HP 8510C. In addition, the source and test set can be changed to provide a different frequency coverage or to add pulse capability. This modular design allows the system configuration to change as measurement needs grow.



New RF & microwave test accessories catalog

HP’s new RF & Microwave Test Accessories Catalog includes descriptions of more than 1,000 accessories for RF and microwave test applications. The products featured in this catalog include step and fixed attenuators, amplifiers, detectors, couplers, switches and switch drivers. Application discussions, detailed specifications, dimensions, photographs and product-family overviews are provided. The 132-page catalog is available free of charge by calling **(800) 452-4844** ext. **5085** or via the Internet at **http://www.tmo.hp.com/tmo/catalogs**.

Total Solutions Partner

Harmonic load pull system helps characterize & optimize power transistors

Power amplifier designers currently face a number of challenges. For mobile applications, battery life and efficiency are critical. Future designs are expected to have 3V and lower voltage rails. Digital modulation formats place unique requirements on linearity and adjacent channel power or spectral re-growth. The efficiency demands of today's applications require amplifiers designed to classes such as AB, B, and F. The efficiency and linearity performance under these bias conditions is a function of the termination presented at the harmonics as well as at the fundamental frequency. To help amplifier designers overcome these challenges, ATN Microwave has introduced the LP2 load pull system. This system, based around the HP 8510/8720/8753 network analyzers, allows characterization and optimization of devices as a function of termination at harmonic as well as fundamental frequencies.

Fundamental versus harmonic termination

Harmonic load pull is new in commercial systems, although many have attempted this either in academic environments or in home-grown applications. A conventional approach has been to put a diplexer at the output of the DUT (Figure 1), allowing the control of one harmonic. Limitations of the diplexer approach are a significant reduction of the tuning radius that a passive tuner can present at the DUT reference (due to the loss in the diplexer), and a significant increase in the cost and complexity of the measurement system. An active load pull approach could eliminate the reflection coefficient magnitude issue, but would greatly reduce the distortion measurement capability, demand expensive high-power amplifiers and necessitate a duplication of the entire active test set. This would be complex and costly, and has not yet been demonstrated in any practical way.

Harmonic termination and the LP2 load pull system

ATN Microwave has developed a solid-state, tuner-based load pull system that overcomes these limitations and performs simple, practical, cost-effective multi-harmonic load pull (Figure 2).

The ATN LP2 harmonic tuning system is based around a new generation of solid-state tuner design. This is the same repeatable tuner technology as in the HP 85060 ECal family of products. The ATN tuners have metrology-level repeatability, 25W distortion-free power capacity, microsecond switching speed and enhancements to allow multi-harmonic tuning with an exponentially increased number of tuner states. Each state is a setting of the tuner that presents a given impedance that varies with frequency. The solid-state harmonic tuner can generate close to half a million different states. The benefit of this number of states lies in redundancy, not quantity.

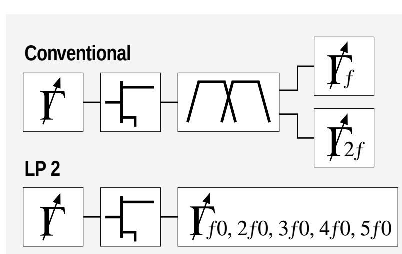


Figure 1. Conceptual approaches of conventional and LP2 harmonic load pull systems

Harmonic tuning

With the large number of settings available to the tuner, there exist many states that have virtually identical impedance at any given frequency. Due to the inherently non-linear way the ATN tuner creates its impedance, states that have the same impedance at a given fundamental disperse their impedance at the harmonic frequencies. The LP2 takes advantage of this phenomenon by presenting a number of different harmonic terminations for any given fundamental or a variety of fundamentals for any given harmonic. This allows multi-harmonic tuning with a single tuner, and without the reflection coefficient limitations of a diplexer.

Harmonic contouring

The LP2 has a harmonic contouring function that takes into consideration harmonic termination when generating contours of all measured or calculated parameters from the LP2 such as constant power, efficiency, ACPr, and IM. Conventional contouring represents the measured or calculated performance parameter as a function of fundamental termination only (Equation 1). The LP2 contouring fits a general equation that represents performance as a function of up to five harmonics (Equation 2). Once this general equation for device performance is established, contours can be created for arbitrary terminations.

Equation 1:
Measured value = $f\,(\Gamma_{f0})$

Equation 2:
Measured value =
$f\,(\Gamma_{f0},\Gamma_{2f0},\Gamma_{3f0},\Gamma_{4f0},\Gamma_{5f0})$

Harmonic load pull characterization of a transistor

In the following example, a FET was conventionally (fundamental) load pulled at 101 states (fundamental control only) for maximum efficiency at 900 MHz. That resulted in maximum efficiency of 51.6% at 0.55 @ 160˚.

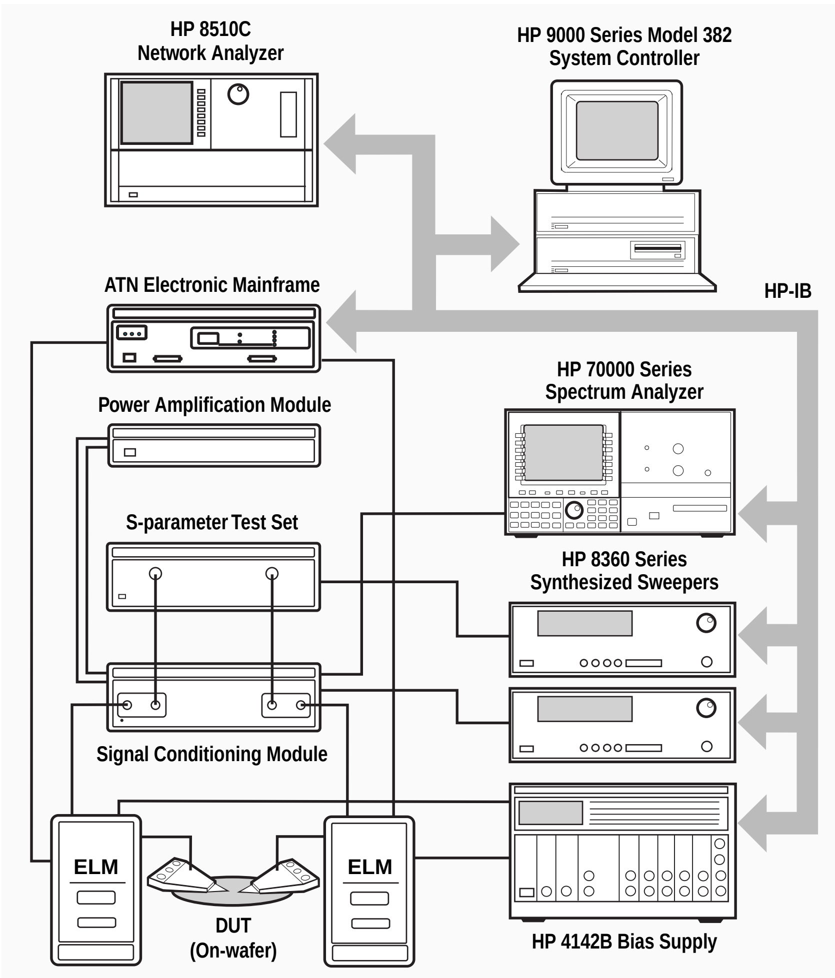


Figure 2. HP 8510-based LP2 load pull system

Then the harmonic tuning was implemented. 0.55 @ 160˚ was selected as a target value, and the tuner chose 61 different settings of the output tuner that had the same target fundamental impedance (plus or minus 0.03 radius). The impedance distribution of these states at the fundamental and second harmonic (0.9 and 1.8 GHz) is illustrated in Figure 3. The efficiency was then measured at each of the harmonic terminations with the fundamental held constant, and a new maximum efficiency value of 70.8% was found at a fundamental of 0.55 @ 160˚and a second harmonic of 0.72 @ –11˚.

The ability to extract an extra 10% PAE (Power-Added Efficiency) or a few dB in TOI is essential to meet the specifications of modern communication systems. The concept of load pull is to provide the data necessary to optimize device or amplifier design and model development. The ATN LP2 with harmonic tuning is the first commercial instrument to demonstrate the potential of this measurement.

For more information, contact:

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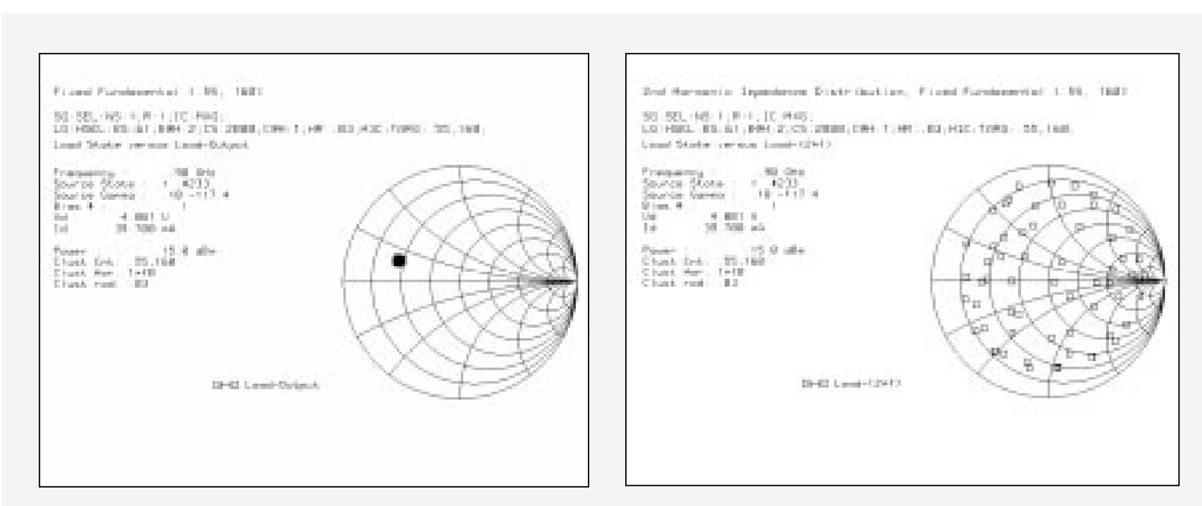
Fax: (508) 667 8548
http:/www.atn-microwave.com

Figure 3. Impedance distribution for fundamental and second harmonic terminations



Tips & Techniques

Q. *How do I configure a high-power measurement with the HP 8720D Option 085 (high-power test set) ?*

A. The configuration will depend on your desired power level. Option 085 allows power measurements of up to 100 watts.

A typical high-power measurement is configured with an external high-power booster amplifier, directional coupler and high-power isolators, as shown in Figure 1.

To determine the best configuration, a good understanding of the network analyzer's internal components is necessary. The following information will provide you with this knowledge as well as give you helpful tips for achieving the most accurate high-power measurements.

For the most accurate measurements, –10 dBm is the recommended power level into the A, B, and R samplers. At this power level, the samplers are operating in their linear region; therefore, compression is not a concern and the best signal-to-noise ratio is achieved. For the R sampler, it is very important to maintain a power level between –34 dBm and 0 dBm within the entire frequency range of operation; otherwise, proper phase-locking will not occur. To configure samplers A and B for their optimum performance, you can set the internal attenuators in 5 dB steps (55 dB maximum). The 16 dB loss through the coupler's coupled arm is separate from the attenuator settings, therefore this loss should also be included in your calculations to achieve the –10 dBm optimum input to the samplers.

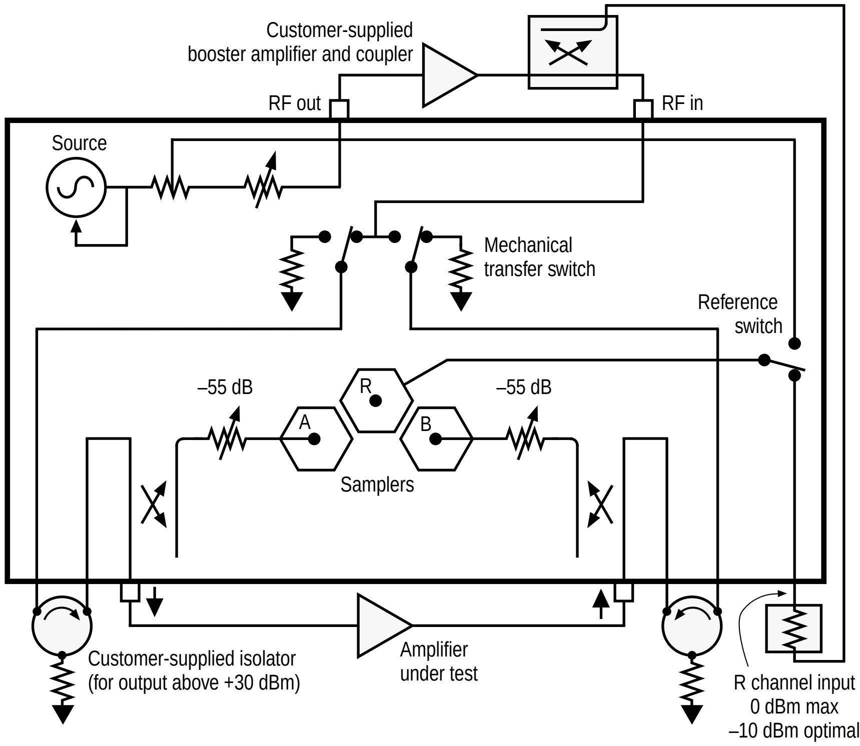


Figure 1. Typical high-power measurement configuration

There are two important considerations for determining the maximum RF input level (at "RF in" in Figure 1). The first is the internal mechanical switch's power-handling capability, and the second is the source's power range. When the internal switch is switching, it can handle 1W (+30 dBm) of incident power. When the switch is at a fixed position (not switching), it can handle 100W (+50 dBm).

The firmware of the HP 8720D helps to keep the power low while switching occurs. The internal synthesized source operates over power ranges. The HP 8719D and 8720D have a 20 dB range per power range; the HP 8722D has 15 dB. In order to protect the internal switch, the source actually lowers its power level to the lowest setting within a given power range before the switch is switched. The source's lowest setting is limited by its power range.

With an understanding of these two considerations, we can calculate the maximum allowable RF input. For the HP 8719D and 8720D, the maximum RF input is +50 dBm because, within a given range, the source can decrease its power by 20 dB before switching the switch; as a result, only +30 dBm is incident upon the switch as it switches. Similarly, the HP 8722D can have a maximum RF input of +45 dBm. (Note that the internal switch terminations cannot handle that much power. If the power into the switch terminations exceeds +30 dBm, then high-power isolators are required to absorb the RF power, as shown in Figure 1.)

The maximum RF input levels above are calculated with the assumption that the RF output level is set to the highest setting within a given power range so that the source can utilize the entire range as it lowers its power. If the RF output is not set to the highest

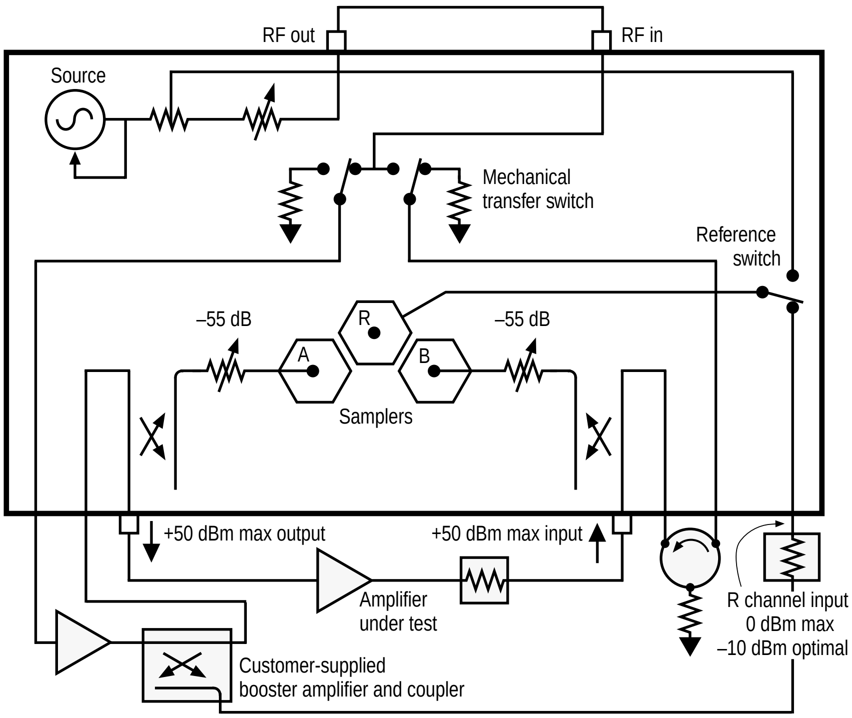


Figure 2. 100W power measurement configuration

setting within a given range, then the maximum RF input power level will need to be lowered accordingly.

The maximum RF level into the test port is limited to +50 dBm. The internal attenuators are conservatively specified at +30 dBm (1W) maximum, but at room temperature they can handle up to +34 dBm (2.5W). The coupler's power rating is +50 dBm (100W). These specifications plus the 16 dB coupling loss of the internal coupler indicate the input power at the test port should not exceed +50 dBm.

These maximum RF levels are different from those found in the HP 8720D Technical Specifications. Typically, HP is quite conservative with published specifications. This article provides more accurate values and, armed with this knowledge, you can push the HP 8720D to its limit for high-power testing.

If you are interested in 100W (+50 dBm) of test power into your DUT, we recommend the configuration in Figure 2. With the configuration in Figure 1, the test power will not be equal to the maximum RF input of 100W because, as the signal transmits through the test set, it experiences some loss before it reaches the test port of the network analyzer. The 100W configuration shown in Figure 2 is useful for high-power forward measurements (S_{11}, S_{21}) only. As is commonly done with power amplifiers, reverse high-power measurements (S_{22}, S_{12}) can be accurately obtained with other measurement techniques such as the load pull method.

Notice in Figure 2 that only one isolator is used, since we are only measuring in one direction and the reverse isolation of the booster amplifier should be sufficient to protect the switch termination. Attenuation is placed in the R and B paths to protect the samplers and to achieve the optimum sampler power level of –10 dBm. As shown in Figure 2, the maximum power into the test port should not exceed +50 dBm.

Calibration is always an important consideration in making accurate network analyzer measurements. In general, a calibration is made under the same stimulus and response conditions as required for the actual measurement. Amplifiers present a challenge, since their gain means that for a fixed RF power level from the analyzer's source, the power level during the calibration will be different than the measurement. However, the dynamic linearity of the HP 8720D is quite good, so this issue is relatively minor.

Since it is desirable to calibrate with the full test-port power for maximum accuracy, another problem can occur when testing high-power amplifiers: precision high-power loads are not readily available. However, there is a work-around. When the power level is changed within a given power range, the source's hardware settings remain essentially unchanged. Therefore, the calibration can be performed at the lowest power setting within the power range, while the measurement can be performed at the highest power setting within the power range. As long as the source remains in the same power range, you can maintain very close to full accuracy.

If the configurations discussed here do not meet your specific high-power needs, contact us; we have various other configurations created by our Special Handling Department. Call your local HP sales office for further details. HP DIRECT Call Centers are another source of information. Within the U.S., the telephone number is 1-800-452-4844.

For Your Files

HP 8510 Documentation

HP 8510C Manual Set	08510-90275
Operating/Programming	08510-90281
Quick Reference Guide	08510-90292
Keyword Dictionary	08510-90280
Test and Accessories Binder	08510-90283
On-Site Service	08510-90282
HP 85107B 50 GHz Vector Network Analyzer System	
HP 85107B System Manual	85107-90069
HP 8510C Manual Set	08510-90275
HP 83651B Synthesized Source Manual Set	08360-90138
HP 85106C Millimeter Wave System	
HP 85106C System Manual	85106-90039
HP 8510C Manual Set	08510-90275
HP 83621B Synthesized Source Manual Set	08360-90138
HP 8350B Operating and Service Manual	08350-90092
HP 83540A Operating and Service Manual	08354-90050
HP 85108A RF Pulse System (2 to 20 GHz)	
HP 85108A Pulsed System Manual	85108-90023
HP 8510C Manual Set	08510-90275
HP 83621B Synthesized Source Manual Set	08360-90138
HP 85110A Operating and Service Manual	85110-90001
HP 85108L Pulse System (0.05 to 2 GHz)	
HP 85108L Pulsed System manual	85108-90036
HP 8510C Manual Set	08510-90275
HP 83621B Synthesized Source Manual Set	08360-90138
HP 85110L Test Set, Operating and Service Manual	85110-90048
HP 85109C On-Wafer Vector Network System	
HP 85109C On-Wafer System Manual	85109-90023
HP 8510C Manual Set	08510-90275
HP 83621B Synthesized Source Manual Set	08360-90138
HP 8350B Operating and Service Manual	08350-90092
HP 83540A Operating and Service Manual	08354-90050
HP 8511A Test Set, Operating and Service Manual	08511-90017
HP 8511B Test Set, Operating and Service Manual	08511-90046
HP 8514B & 8512A Test Set, Operating and Service Manual	08514-90014
HP 8515A & 8513A Test Set, Operating and Service Manual	08515-90015
HP 8516A Test Set, Operating and Service Manual	08516-90001
HP 8517B Test Set, Operating and Service Manual	08517-90041
HP 85110A Test Set, Operating and Service Manual	85110-90001
HP 85110L Test Set, Operating and Service Manual	85110-90048
HP 8510B Installation Manual	11575-90014
Performance Upgrade Pkg. HP 11575C	11575-90007
HP 83621/31/51B Manual Set	08360-90138
HP 83621/31/51B Troubleshooting	08360-90136
HP 83621/31/51B Service Manual	08360-90137

HP 8719/8720/8722 Documentation

HP 8719D, 8720D & 8722D	
Operating and Programming Manual Set	08720-90282
User's Guide	08720-90288
Quick Reference Guide	08720-90289
Installation & Quick Start Guide	08720-90291
Programming Guide	08720-90293
Service Guide	08720-90292
Component Level Information Package	08720-90296
HP 8719C & 8720C	
Manual Set	08720-90157
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User's Guide	08720-90136
Quick Reference Guide	08720-90137
Programming Manual	08720-90161
Service Manual	08720-90138
Manual Supplement, Option 011	08720-90226
HP 8722A/C	
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User's Guide	08720-90109
Quick Reference Guide	08720-90110
Service Manual	08720-90110

[1]per·spec·tive

\pər-'spek-tiv\ *n*

: the capacity to view things in their true relations or relative importances

Over my many years of service at Hewlett-Packard, I have participated in the design, manufacture and testing of network analyzers and the precision calibration accessories required to calibrate a network analyzer. Today, I am heavily involved with the manufacture of Hewlett-Packard's precision calibration accessories, in particular the ECal modules. In our environment, we achieve the highest-performance calibrations possible through our "golden" calibration kits, used to calibrate our network analyzer systems. It is essential these calibrations remain stable and repeatable. This is accomplished through process-check standards.

Process-check standards are required to continuously characterize and monitor processes. For network analyzer systems, check standards "watch" the performance of the network analyzer system with time. These standards are sensitized to changes in the calibration kit, calibration, network analyzer and environment. For example, after performing a calibration, the check standard is connected and measured. The check standard results will show if the calibration is valid or not. After some time, the check standard can be reconnected and re-measured, and measured results can determine if the calibration is valid.

ECal confidence states are process-check standards. Using an ECal module, you have the ability to calibrate your network analyzer and, through its confidence states, "watch" your system performance.

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Production Engineering
Project Manager

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