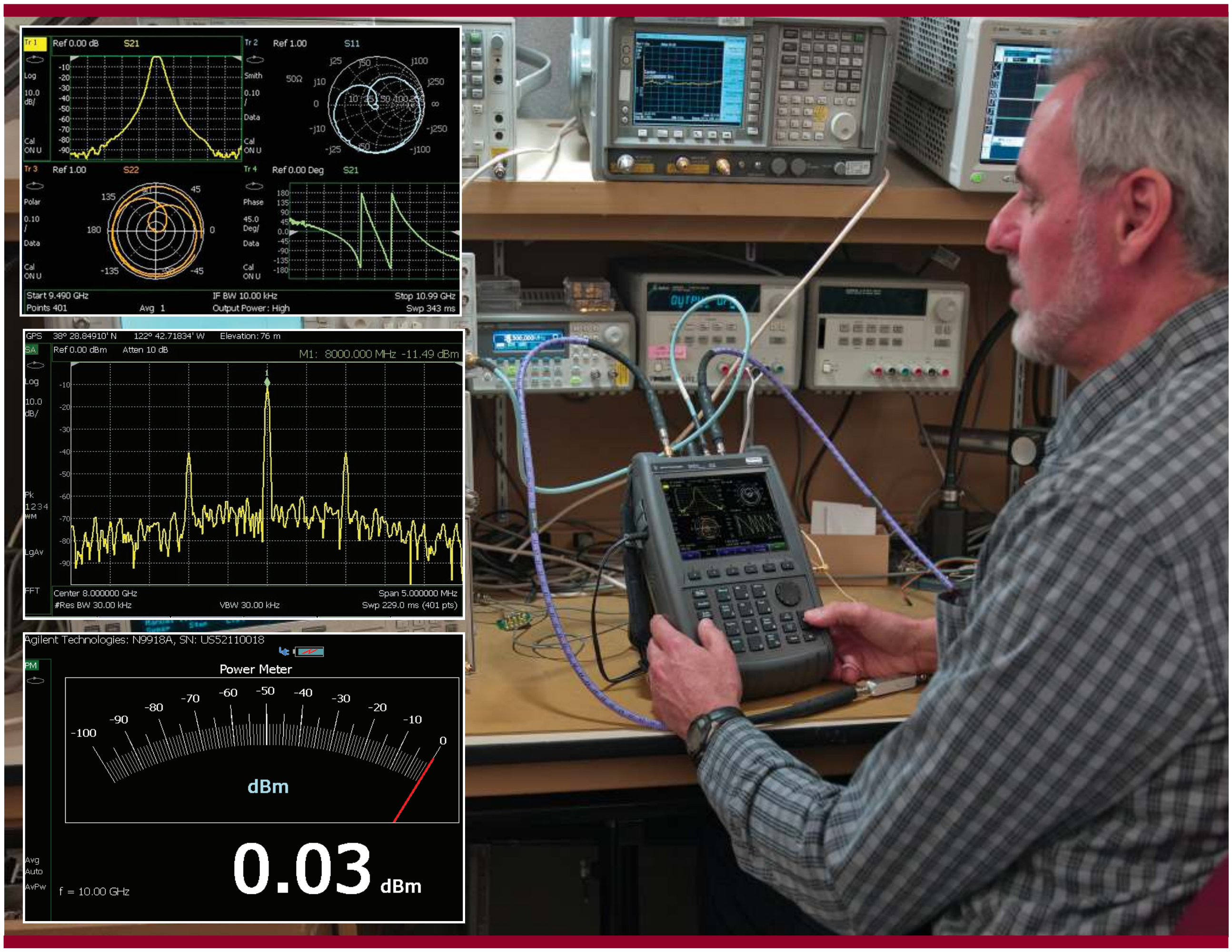
Correlating Microwave Measurements between Handheld and Benchtop Analyzers

Using FieldFox handheld analyzers up to 26.5 GHz

Application Note



For the first time, technology breakthroughs have enabled high-performance measurement capabilities in a handheld analyzer. High-accuracy microwave measurements of network, spectrum, power and frequency can quickly be made using modern all-in-one analyzers with results that correlate to benchtop instruments to within hundreths of a db. This application note discusses the powerful capabilities of modern-day handheld analyzers and includes measurement comparisons between FieldFox handheld analyzers and several benchtop instruments including signal analyzers, power meters and vector network analyzers.

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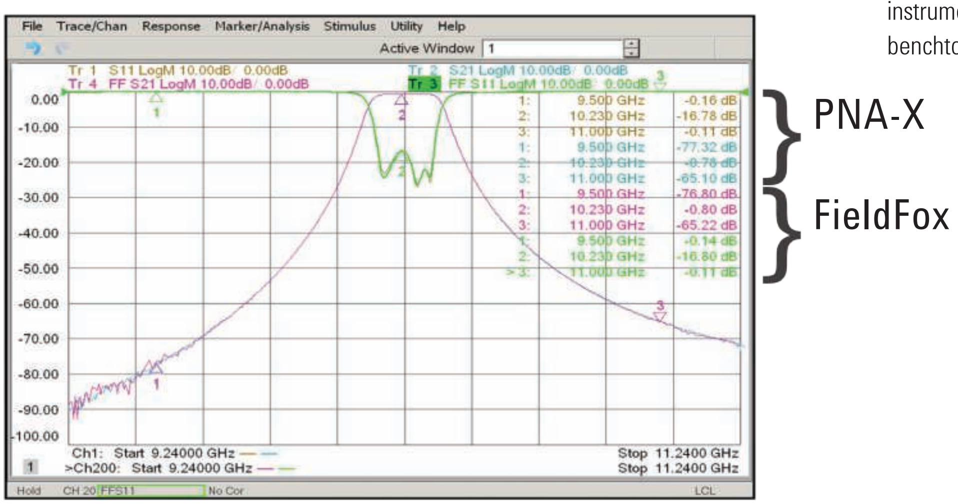
Introduction

For the first time, technology breakthroughs have enabled high-performance measurement capabilities in a handheld analyzer. High-accuracy microwave measurements of network, spectrum, power and frequency can quickly be made using modern all-in-one analyzers with results that correlate to benchtop instruments often to within hundredths of a dB. For example, figure 1 shows the S-parameters of a 10 GHz bandpass filter measured using a benchtop Agilent PNA-X vector network analyzer (VNA) overlaid with measurements using an Agilent FieldFox handheld analyzer. As shown on the figure, the measured parameters are nearly identical between the two instruments. Markers are placed in the passband and rejection portions of the response. The relative difference in the S11 markers between the two instruments is less than 0.02 dB. The relative marker difference in S21 is 0.02 dB in the passband and 0.52 dB in the filter skirt at a level of 78 dB down from the peak. For this example, there is excellent correlation between measurements using the high-performance benchtop instrument and the modern all-in-one handheld.

When working to compare the performance between two instruments, there is no substitution for examining the specifications found on the vendor's datasheets but it may be difficult to directly compare the two as the specifications are often listed under unique operating conditions.

For example, the total amplitude accuracy listed on the datasheet for the Agilent MXA signal analyzer is specified over a temperature range of 20 °C to 30 °C while the accuracy of the FieldFox is specified at 23 °C +/- 5 °C and -10 °C to 55 °C. The specified test parameters are often related to typical operating conditions such as harsh weather conditions for the FieldFox or temperature-stabilized environments for the benchtop instruments. Besides comparing datasheets, there is only a limited amount of technical literature that compares measurements between different instruments [1, 2], and additionally includes examples that compare benchtop instruments to handheld instruments. This application note will bridge this gap by correlating measurements recorded using several bench-top instruments to measurements recorded using a handheld FieldFox. The examples shown in this application note will have the various instruments used in the comparisons configured with the same parameters, such as RBW, VBW, number of points, etc., and measurements will be made using the same environmental conditions and devices under test (DUTs). It will be shown that modern handheld instruments, such as the FieldFox, are highly capable of performing measurements that have excellent correlation to those from benchtop instruments. In some cases these handheld analyzers do not require any warm-up time, and using built-in calibration and automatic alignment techniques will maintain this high level of measurement accuracy across the full frequency range of the instrument. This application note will describe MMIC circuit technology that is the common foundation to both Agilent's high-performance benchtop and handheld instruments. This note will also include a brief discussion of the calibration and alignment techniques found in the FieldFox, namely *CalReady*, *QuickCal* and *InstAlign*.

It should be noted that theoretical concepts of "correlation" analysis typically include statistical methods between two sets of data or random variables. For the purposes of this application note, the term "correlation" will be used to describe the relative agreement between a set of data measured from the same device under test (DUT) but recorded from two different instruments, namely a high-performance benchtop instrument and a FieldFox.



```
Tr 1  S11 LogM 10.00dB/  0.00dB
Tr 4  FF S21 LogM 10.00dB/  0.00dB
Tr 2  S21 LogM 10.00dB/  0.00dB
Tr 3  FF S11 LogM 10.00dB/  0.00dB
  1:    9.500 GHz   -0.16 dB
  2:   10.230 GHz  -16.78 dB
  3:   11.000 GHz   -0.11 dB
  1:    9.500 GHz  -77.32 dB
  2:   10.230 GHz   -0.78 dB
  3:   11.000 GHz  -65.10 dB
  1:    9.500 GHz  -76.80 dB
  2:   10.230 GHz   -0.80 dB
  3:   11.000 GHz  -65.22 dB
  1:    9.500 GHz   -0.14 dB
  2:   10.230 GHz  -16.80 dB
> 3:   11.000 GHz   -0.11 dB
Ch1:    Start 9.24000 GHz    Stop 11.2400 GHz
>Ch200: Start 9.24000 GHz    Stop 11.2400 GHz
```

Figure 1. S11 and S21 for a 10 GHz filter measured using a PNA-X benchtop vector network analyzer (VNA) and a FieldFox VNA

Importance of correlating measurements

So why is it so important to correlate measurements between benchtop and handheld instruments? One of the primary factors driving this requirement is the fact that, along its product lifecycle, a DUT may be measured with a variety of different instruments as the product moves from initial prototype to field installation. It is important that the field test data correlates well to the laboratory data; otherwise it could be possible to fail components that are actually good or pass components that are actually bad. Strong correlation also ensures agreement by all parties involved that the system is performing to design standards.

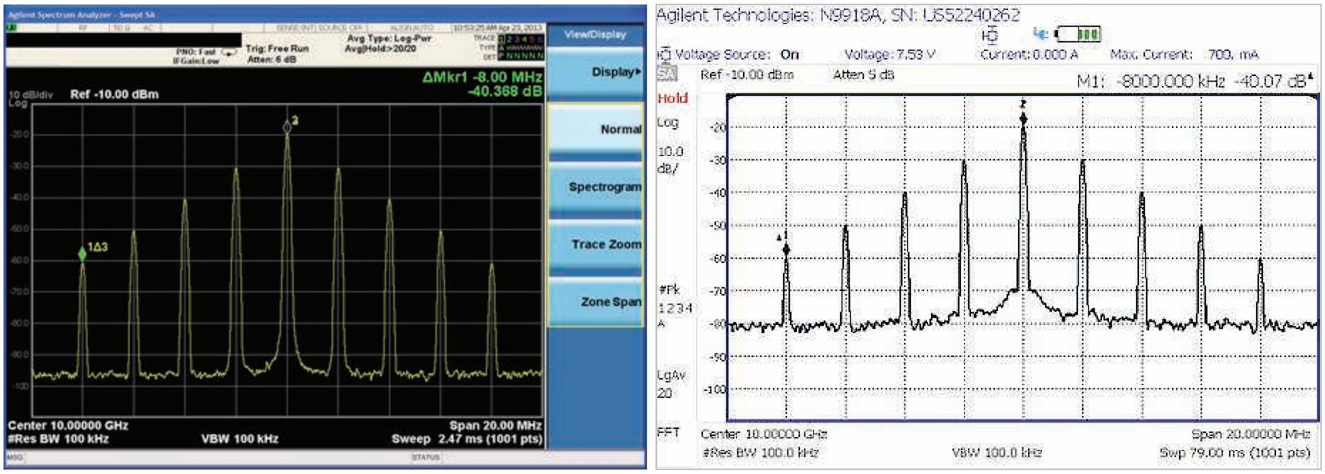
Each stage of the product lifecycle typically requires a unique set of equipment requirements. For example, during the early stages in the product lifecycle which include design validation, product development and manufacturing test, the measurements are usually obtained with benchtop equipment located in controlled laboratory environments.
For research and development testing, benchtop equipment is selected based on its performance, features and dynamic range. For production test, important parameters include high measurement speed and lower instrument cost. Once the new component or system is installed in the field, there is often the requirement to repeat many of the laboratory measurements in order to validate the device performance. Additional field testing may also be required during periodic maintenance and occasional repair operations. These “field” tests are often made with a handheld under the most challenging test conditions including harsh outdoor weather conditions. In all field testing, correlating the data to laboratory measurements is critical to the successful operation of the device and/or system under test. In the next few sections, several examples will be provided showing the excellent correlation between the benchtop and FieldFox measurements.

Correlation of spectrum measurements

Figure 2 shows two spectrum measurements of a 10 GHz multi-tone signal having side tones that are equally spaced in frequency and with amplitudes that are 10 dB lower relative to the adjacent tone. The spectrum measurement (a) on the left was captured using an Agilent MXA benchtop signal analyzer. The spectrum measurement (b) on the right was captured using a FieldFox in spectrum analyzer mode. As a comparison, delta markers are used to measure the difference in amplitude between the center carrier and the 4th side tone. For the benchtop, the delta marker measures -40.37 dB. For the handheld, the marker reading is -40.07 dB resulting in a difference between the two instruments of only 0.3 dB. The marker results for the other tones also show an excellent correlation between the two instruments.

It should be noted that the FieldFox spectrum analyzer uses different receiver architecture than the benchtop MXA, resulting in higher noise floor and slower sweep speed when using the same instrument settings. For this example, comparing the noise floor of these two instruments, the FieldFox has approximately 15 dB higher noise floor for the same instruments' settings in RBW and VBW (the plots in figure 2 have the same scale). It is possible to reduce the noise floor of the FieldFox by reducing the RBW setting but as previously mentioned it is the intention of this application note to make a direct comparison between instruments operating under the same settings. Also, for the measurements shown in figure 2, the FieldFox has a longer sweep time of 79 milliseconds as compared to 2.5 milliseconds for the benchtop MXA.

While the FieldFox is not a direct replacement for a benchtop, it is well suited for field testing and general purpose laboratory testing having measurement capabilities that correlate well with high-performance benchtop instruments.



PNO: Fast
IFGain:Low
Trig: Free Run
Atten: 6 dB
Avg Type: Log-Pwr
Avg|Hold:>20/20
ΔMkr1 -8.00 MHz
-40.368 dB
Ref -10.00 dBm
Center 10.00000 GHz
#Res BW 100 kHz
VBW 100 kHz
Span 20.00 MHz
Sweep 2.47 ms (1001 pts)

Voltage Source: On
Voltage: 7.53 V
Current: 0.000 A
Max. Current: 700. mA
Ref -10.00 dBm
Atten 5 dB
M1: -8000.000 kHz -40.07 dB
Center 10.00000 GHz
#Res BW 100.0 kHz
VBW 100.0 kHz
Span 20.00000 MHz
Swp 79.00 ms (1001 pts)

(a) MXA

(b) FieldFox

Figure 2. Spectrum measurement of a 10 GHz multi-tone signal captured using the (a) MXA signal analyzer and (b) FieldFox spectrum analyzer

Correlations of S-parameter measurements

An S-parameter measurement for the transmission (S21) response of a filter was previously shown in figure 1. In that example, there was excellent correlation between the measurements using a benchtop PNA-X and a FieldFox. Figure 3 shows another example of the measured S-parameters using a 3 to 12 GHz broadband amplifier as the DUT. The amplifier under test has a gain of 23 dB. For this figure, the four S-parameters are measured from three different vector network analyzers, namely the HP 8510C, PNA-X and FieldFox in VNA mode. All three analyzers were configured with a frequency range of 100 MHz to 26.5 GHz, 401 measurement points and an IFBW of 10 kHz. All VNAs were calibrated using a full 2-port mechanical calibration. The three sets of S-parameters were ported into the PNA-X and overlaid for comparison. The 8510C data is shown as the blue trace, the PNA-X is green and the FieldFox is magenta.

The 8510C analyzer system was once considered the gold standard of the microwave industry but the modern PNA-X is currently the world's highest performance benchtop VNA with specifications that far exceed the 8510C in performance, flexibility and speed. When comparing the S-parameters shown in figure 3, the three sets of measurements are virtually identical except for a deviation in the S21 data from the 8510C and only at the high end of the frequency range. There is excellent correlation between the FieldFox and the high-performance PNA-X. Note how the FieldFox receivers track the PNA-X receivers on the S21 measurement from +23 dB all the way to -50 dB. While the PNA-X has the most accurate receivers of any instrument in the world with a dynamic range of 129 dB at 20 GHz, the FieldFox is a highly capable instrument with a dynamic range of 90 dB making it ideally suited for S-parameter measurements in the field as well as for common laboratory applications. Later in this application note, a comparison of different calibration procedures available in FieldFox will be reviewed.

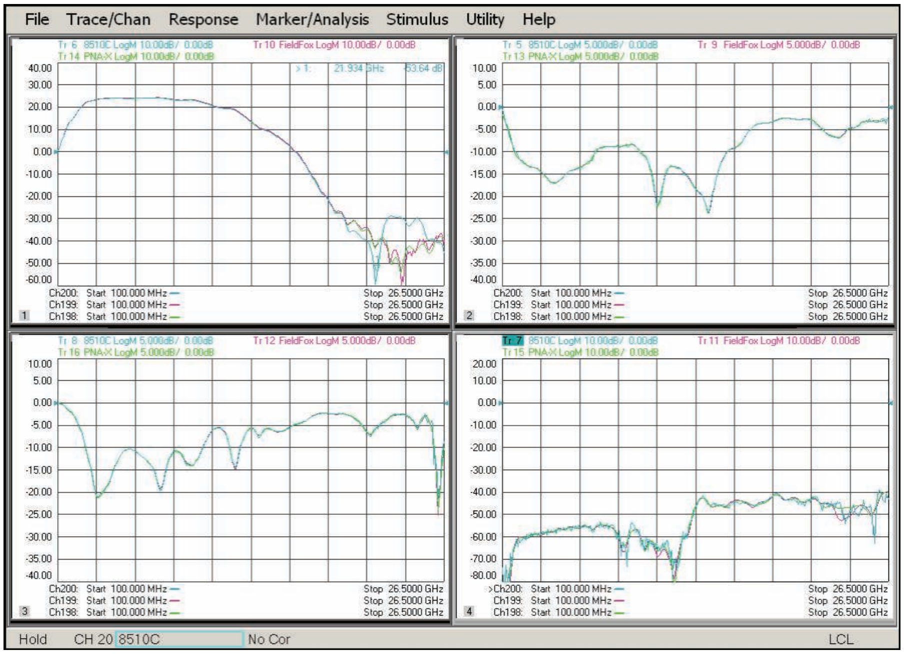


Figure 3. Measured S-parameters of a 3 to 12 GHz broadband amplifier; the plot overlays include measurements from an Agilent 8510C VNA (blue), PNA-X (green) and FieldFox VNA (magenta)

Correlation of RF power measurements

The measurement of RF power for CW pulsed and complex waveforms can be performed using a variety of equipment configurations [3]. The primary measurement component that comes to mind for power measurement is the power sensor. The power sensor can be configured with a separate power meter or connected to a PC or FieldFox through a USB cable. USB power sensors contain all the required signal conditioning, filtering and data processing to accurately convert the incoming RF signal into a measured output for display. In this case, the PC or handheld is used to only display the power measurements. Agilent supplies several types of USB power sensors including the U2000x series diode-based sensor. Figure 4 shows two configurations for measuring RF power using a power sensor. Figure 4a shows the sensor connected to a benchtop power meter. Figure 4b shows the power sensor connected to a FieldFox. If the same power sensor is used in both configurations, the two measurement configurations would yield extremely close results.

Another power measurement option available in the FieldFox does not require a power sensor. In this configuration, the high-performance receiver within the FieldFox will directly measure the signal power. All that is required is a short coaxial cable to connect the analyzer to the test point. This option on the FieldFox is called the Channel Power Meter (CPM) and requires the user to specify a bandwidth to measure the channel power. While this configuration may not be as accurate as those using a power sensor, the convenience of a single instrument for measuring power may be well suited for challenging environments and test conditions.

As an example, table 1 shows the measured power of a CW test signal as a function of frequency. This table compares the measured power using a power sensor and meter combination to that of a FieldFox CPM configuration. For this example, the test source frequency is varied over the range from 100 MHz to 26.5 GHz. The test signal was supplied by an Agilent PSG microwave signal generator. The power sensor was the E4413A E-series CW sensor and the power meter was the N1914A. At 100 MHz the power sensor measured -0.07 dBm. The FieldFox CPM measured -0.10 dBm. Assuming the power meter is the gold standard there is a difference of only 0.03 dB when using the handheld. At 18 GHz, the power meter measured -2.90 dBm and the handheld measured -2.84 dBm a difference of 0.06 dB. At 26.5 GHz, the power meter measured -3.75 dBm and the handheld measured -3.71 dBm, again a very small difference between the two instruments showing that there is excellent correlation between the two instrument types. As a note for table 1, the decrease in the power level as the test frequency was increased was the result of the loss of a short coaxial cable connected between the source and the instrument.

Table 1. Measured RF power of a CW test signal as a function of frequency

Freq (GHz)	Power meter and power sensor (dBm)	FieldFox CPM (dBm)
0.1	-0.07	-0.10
18	-2.90	-2.84
26.5	-3.75	-3.71


(a)

(b)

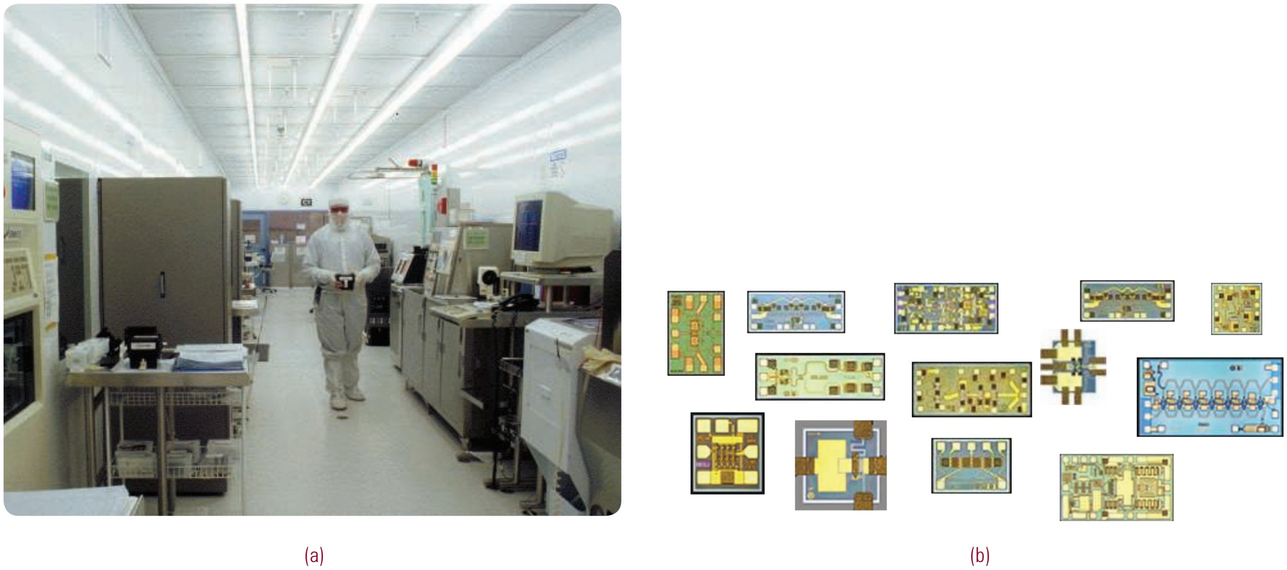
Figure 4. Equipment configurations for measuring RF power using a power sensor with the (a) power meter and (b) FieldFox

MMIC technology enables performance

It has been shown that FieldFox has excellent measurement correlation to high-performance benchtop instruments. To achieve these characteristics, FieldFox shares the same measurement science as Agilent's high-performance benchtop instruments. Those high-performance RF and microwave instruments rely on custom Monolithic Microwave Integrated Circuits, or MMICs, which are designed at Agilent's High Frequency Technology Center (HFTC) in Northern California. The HFTC is a complete MMIC design and fabrication facility which includes a 13K square foot clean room and is capable of producing 250,000 chips per month. Figure 5a shows a photo of the HFTC clean room where MMIC chip designs are fabricated onto semiconductor wafers. Figure 5b shows several MMIC chip designs used in several of Agilent's benchtop and handheld instruments including the PXA, PNA-X, and FieldFox.

Unique to the industry, the FieldFox handheld is designed with custom MMICs that integrate multi-functions into compact high-performance chipsets. These highly integrated circuits improve the instrument performance and reliability as well as greatly reducing the total power consumption of the FieldFox to approximately 15 watts. This high level of integration allows FieldFox to be configured with ten different instruments in one 6.6 pound (3 kg) handheld. The instrument functions include a spectrum analyzer, VNA, power meter, cable and antenna test analyzer, vector voltmeter, RF source, DC source, and DC multimeter. The low power consumption provides 3.5 hours of battery life and allows FieldFox to operate without cooling fans and vents resulting in a highly reliable instrument that is completely sealed and successfully tested to IP53 requirements for ingress of dust and water.

FieldFox also includes several unique features not found in benchtop instruments. These features improve instrument accuracy as a function of temperature and simplify the VNA calibration process. These features will be discussed in the next two sections of this application note.


(a)

(b)

Figure 5. (a) Photo of the clean room at Agilent's High Frequency Technology Center and (b) MMIC chip designs for FieldFox and benchtop analyzers

FieldFox automatic temperature compensation - *InstAlign*

An important feature unique to FieldFox is an automatic internal alignment function which compensates for temperature changes over a range of -10 °C to +55 °C. With this feature, named *InstAlign*, the spectrum analyzer is ready to make high-accuracy measurements immediately at turn on and through any temperature changes over the specified range. In comparison, benchtop spectrum analyzers and other handhelds typically require a minimum of 30 minutes for the temperature to stabilize. The InstAlign feature is based on an internal and very stable CW amplitude reference which is characterized over the entire frequency range of the instrument. Any discrepancies between the measured amplitude of this reference and its characterized values are applied as corrections during measurements of the test signal. When the FieldFox's internal sensors detect that the instrument's temperature has changed by approximately 2 °C, an amplitude alignment is executed as a background process resulting in high-accuracy measurements across the full temperature range of -10 °C to +55 °C.

FieldFox VNA calibration options – *CalReady* and *QuickCal*

Operators familiar with VNA calibration will most likely be familiar with the numerous steps required to calibrate the analyzer using a mechanical calibration kit. This Mechanical cal type is available on FieldFox and uses the same calibration engine as the PNA-X. The Mechanical calibration process requires the use of high-quality calibration standards that must be protected against damage, dirt and moisture which may be difficult in some challenging field test environments. Fortunately, FieldFox also includes two unique calibration options that eliminate the requirement for a mechanical calibration kit. These options, named *CalReady* and *QuickCal*, may be used in place of the traditional SOLT calibration when a calibration kit is not available or when test time and convenience is most important.

CalReady is one of the two calibration options available on FieldFox that does not require a cal kit. *CalReady* provides a "full two-port calibration" available immediately at instrument turn on, that requires no intervention by the operator and uses factory stored calibration coefficients. It is important to note that the *CalReady* calibration plane is located at the instrument's test port connectors and therefore does not remove the effects of any external test cables and adapters.

QuickCal is the second calibration option available on FieldFox that does not require a calibration kit. *QuickCal* is a rapid two-step cal process that removes the effects of test cables and adapters attached to the analyzer. During the first step in the simplified calibration process, the two test ports are left unconnected and measured by the instrument. The second step requires a direct connection (thru) between the two test ports. At this point, FieldFox is calibrated for full two-port S-parameter measurements with the calibration plane located at the ends of the test cables/adapters. As a comparison between a mechanical calibration and *QuickCal*, figure 6 shows the measured insertion loss (S21) of a short coaxial cable using both cal types as measured on FieldFox. The yellow trace is the cable measurement using *QuickCal* and the blue trace is the measurement using a traditional SOLT mechanical calibration. As shown in the figure, the two traces have excellent correlation as there is very little difference between the two measurements yet *QuickCal* has a fairly simple calibration process that is very convenient for most field operations. Note that the vertical axis is .2 dB per graticule.

Another feature in FieldFox to aid the operator through the calibration process is a guided "Cal Wizard" which provides a graphical step by step guide for *QuickCal* and Mechanical calibrations. Additional information regarding the FieldFox VNA calibration options can be found in the FieldFox User Guide and the Agilent Application Note Techniques for Precise Calibrations in the Field Using FieldFox Handheld Analyzers [4].

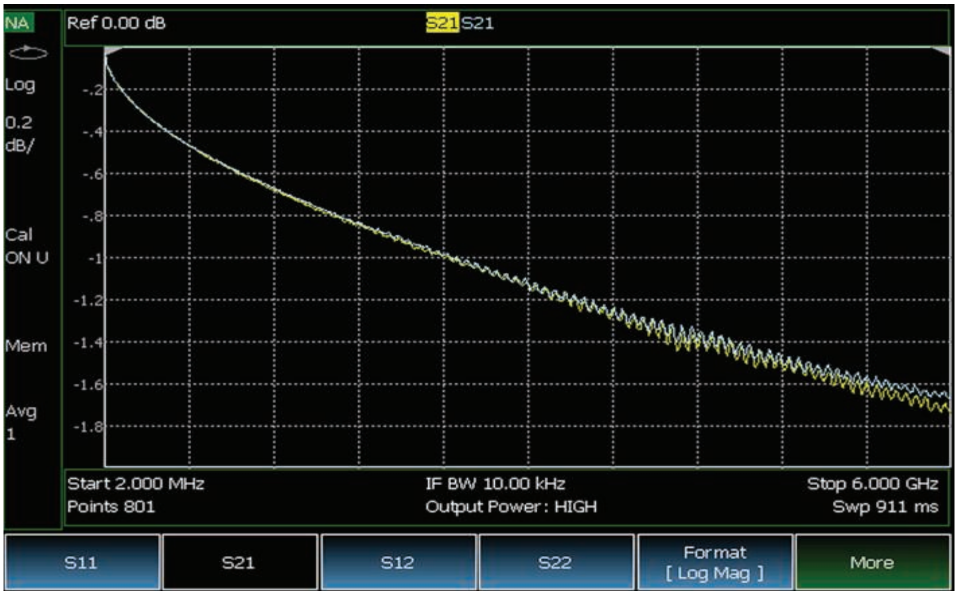

Ref 0.00 dB
Log 0.2 dB/
Cal ON U
Avg 1
Start 2.000 MHz
Points 801
IF BW 10.00 kHz
Output Power: HIGH
Stop 6.000 GHz
Swp 911 ms

Figure 6. Measurement comparison of a coaxial cable using a Mechanical calibration (blue) and the rapid QuickCal (yellow) available on a FieldFox VNA

Application example: prototype amplifier testing in the laboratory

Now that it has been shown that measurements using FieldFox have excellent correlation to those measurements using benchtop equipment, this section of the application note will discuss two options for creating a test bench when measuring the performance of a prototype amplifier. Table 2 lists a set of typical test parameters required to characterize the RF and DC performance of a low-power high-gain amplifier. The table also lists the different types of benchtop equipment required to perform each test. For this example, a total of six different instruments are required for the test bench.

When creating the prototyping test bench, one option would be to stack the six pieces of equipment onto a single laboratory bench as shown in figure 7a. Another option is to replace the entire rack of equipment with a single handheld such as the N9918A 26.5 GHz FieldFox combination analyzer. Figure 7b shows the equivalent test bench with FieldFox connected to the amplifier under test. FieldFox is an ideal solution for rapid prototype testing especially when a quick verification of the operation of an amplifier, filter, or any other microwave device is required.

Table 2. Test parameters and equipment requirements for characterizing a microwave amplifier

Test Parameter	Benchtop Equipment
Output RF power	RF source / RF power meter
Harmonics	Spectrum analyzer
Spurs	Spectrum analyzer
Gain	Vector network analyzer
Bandwidth	Vector network analyzer
VSWR	Vector network analyzer
Reverse isolation	Vector network analyzer
DC Power	DC supply / multimeter

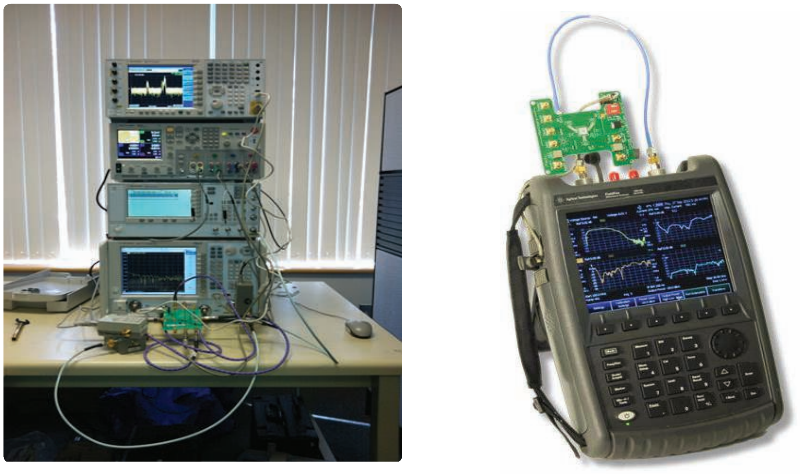

(a) (b)

Figure 7. (a) Amplifier test bench using benchtop equipment and (b) the equivalent test bench using a handheld FieldFox combination analyzer

Application example: microwave backhaul testing in the field

In this section of the application note, the measurement requirements for the installation and verification of a microwave backhaul communications system will be discussed. The backhaul is the critical component in a wireless communications network which provides the transport layer between a cell site and the mobile switching center. Demand for backhaul services has been driven by 3G and 4G networks requiring increased capacity for video and data usage. These microwave systems utilize tower mounted 2 to 6 ft diameter antennas which can deliver data rates of 200 Mb/s to over 1 Gb/s.

As with any tower or remote application, the initial installation and continued maintenance of these systems includes some of the most challenging test environments for the operators. A single backhaul installation requires numerous measurements including antenna alignment, cable and transmission line sweeping, spectrum, transmit power level, frequency verification, component tuning and path loss verification. If individual benchtop instruments are shipped to the installation site, there could be a lengthy delay of several weeks or more which includes properly packing and shipping the valuable test equipment to the installation site. On the other hand, combination handhelds, such as FieldFox, provide a complete suite of measurement applications resulting in reduced system downtime and excellent data correlation between the field data and the baseline factory data.

For those challenging test environments, FieldFox can be remotely controlled using an iOS device such as an iPad or iPhone. For example, the FieldFox analyzer can be positioned in areas which may be uncomfortable or hazardous for an operator to remain for extended periods of time. With an iOS device, having a wireless LAN or cellular broadband data connection, the FieldFox is controlled using the Remote Viewer iOS app. The iOS app interface displays the same instrument panel as the FieldFox allowing the instrument to be configured using the iOS device. Additionally, if one technician or engineer has trouble making a measurement or determining the source of a problem, another operator can step in remotely to troubleshoot and resolve any issues. In the configuration shown in figure 8, the FieldFox is connected to a coaxial cable transmission line located high up on the tower of a microwave communication system (a) and the FieldFox is controlled using an iPad by the operator located in an automobile (b).

The iOS Remote Viewer app can also be used to access FieldFox demo videos and technical literature such as user guides, application notes and datasheets. This enables engineers and technicians in the field to quickly measure and resolve component network issues as they arise.

(a)

(b)

Figure 8. (a) FieldFox connected to a microwave communications system and (b) using an iPad to control FieldFox through Agilent's iOS Remote Viewer application

Conclusion

It has been shown in this application note that FieldFox measurement data correlates well with data measured using high-performance benchtop instruments. It was discussed that instrument accuracy and correlation was related to custom circuit designs based on a shared MMIC technology developed by Agilent's HFTC facility in northern California. Several important features concerning FieldFox automatic alignment and calibration were also discussed.

For additional technical literature regarding FieldFox, Agilent provides a set of application notes [3, 4, 5, 6, 7] available for download from the Agilent website. Each application note has a companion webcast available for on-demand viewing. The webcasts can be found at Agilent's website under *FieldFox Handheld Analyzers Education Series*.

References

[1] Toh Chee Leng, "***Measurement corrections for phase noise characterization with different baseband analyzer***," Asia-Pacific Conference on Applied Electromagnetics, APACE 2007, December 4-6, 2007.

[2] Agilent Webcast, "Correlating Microwave Measurements between Handheld and Benchtop Analyzers," Original broadcast July 24, 2013. Available on Agilent website under ***FieldFox Handheld Analyzers Education Series***.

[3] Agilent Application Note, ***Techniques for Precise Power Measurements in the Field Using FieldFox handheld analyzers***, Literature Number 5991-0423EN.

[4] Agilent Application Note, *Techniques for Precise Calibrations in the Field Using FieldFox handheld analyzers*, Literature Number 5991-0421EN.

[5] Agilent Application Note, *Techniques for Precise Interference Measurements in the Field Using FieldFox handheld analyzers*, Literature Number 5991-0418EN.

[6] Agilent Application Note, *Techniques for Precise Cable and Antenna Measurements in the Field Using FieldFox handheld analyzers*, Literature Number 5991-0419EN.

[7] Agilent Application Note, *Techniques for Time Domain Measurements Using FieldFox handheld analyzers*, Literature Number 5991-0420EN.

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Every piece of gear in your field kit had to prove its worth. Measuring up and earning a spot is the driving idea behind Agilent's FieldFox analyzers. They're equipped to handle routine maintenance, in-depth troubleshooting and anything in between. Better yet, FieldFox delivers Agilent-quality measurements - wherever you need to go. Add FieldFox to your kit and carry precision with you.

Related literature	Number
FieldFox Combination Analyzers, Technical Overview	5990-9780EN
FieldFox Spectrum Analyzers, Technical Overview	5990-9782EN
FieldFox Vector Network Analyzers, Technical Overview	5990-9781EN
FieldFox Handheld Analyzers, Data Sheet	5990-9783EN
FieldFox Handheld Analyzer, Configuration Guide	5990-9836EN
FieldFox N9912A RF Analyzer, Technical Overview	5989-8618EN
FieldFox N9912A RF Analyzer, Data Sheet	N9912-90006
FieldFox N9923A RF Vector Network Analyzer, Technical Overview	5990-5087EN
FieldFox N9923A RF Vector Network Analyzer, Data Sheet	5990-5363EN

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Published in USA, November 17, 2013
5991-0422EN

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