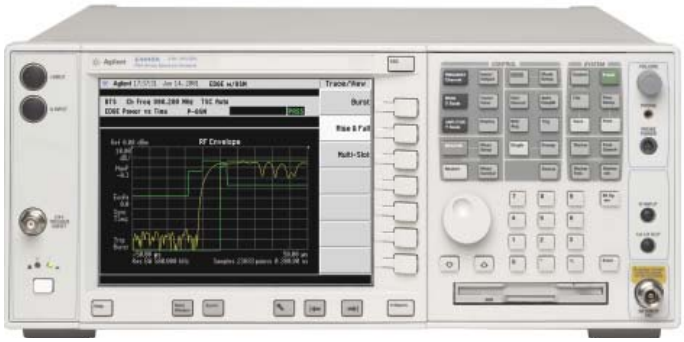
Agilent
Using Extended Calibration Software for Wide Bandwidth Measurements

PSA Spectrum Analyzer Option 122 or Option 140 and 89600 Vector Signal Analyzer

Application Note 1443

Introduction

This application note discusses when extended calibration software is useful for improving phase and amplitude response when making wide bandwidth measurements. The PSA wide bandwidth calibration wizard (Option 235) and the 89600 VSA built-in extended calibration utilities are described in detail so you can use the calibration utilities, understand when a re-calibration is required, and determine what type of calibration is required. The equipment required for extended calibration is also listed in this application note (including the different types of calibration sources). Examples near the end of this document demonstrate the amount of improvement you could expect from an extended calibration.



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Extended Calibration Overview

Extended calibration is a very useful tool to enhance the accuracy of your wide bandwidth measurements. Any phase or frequency response error introduced by the PSA Series (with Option 122 or Option 140), 89600 VSA or user-added devices in the signal path will usually cause the complex modulated signal to be degraded on the receiver end and appear worse than it actually is. This degradation of the signal will show up in virtually every standard modulation measurement. An increase in error vector magnitude (EVM), spreading of the symbol points in the constellation, and a misrepresentative channel response plot are all common problems with a poorly calibrated channel.

Extended calibration is an excellent tool for improving amplitude and phase performance for wide bandwidth measurements using:

- a PSA with Option 122 or Option 140 when tuned above 3.05 GHz (the PSA Series internal calibration provides excellent flatness and phase performance for all other measurements)
- an 89611A/40A/41A VSA with a user-supplied tuner
- either of the above when a user-supplied amplifier or filter is added to the signal path

Extended calibration determines the frequency response of the complete measurement system *at the desired center frequency*. Signal conditioning and frequency-variable preselection filters can be included in the calibration. The analyzer uses the calibration data to correct measurements for the unwanted system frequency response in both amplitude and phase.

Frequency-domain calibration, time-domain correction

Vector signal analyzers typically digitize a band-limited signal, where the bandwidth of the signal is a significant fraction of the digitizer sample rate. The sampled data is then used in various time-domain algorithms such as digital demodulation, or FFT-based frequency-domain algorithms.

The signal is usually passed through a filter in the measurement hardware, to prevent unwanted out-of-band signals from corrupting the measurement through aliasing. Unfortunately, because the perfect filter does not exist, an unwanted frequency response is introduced into the measurement, degrading measurement accuracy.

The solution is to measure the unwanted frequency response (intermediate frequency or IF calibration) and then construct a digital filter that compensates for it. Time-domain correction is needed, rather than frequency-domain correction, because vector signal measurements operate primarily on time data. With proper IF calibration and correction, a flat amplitude response and linear phase response should result.

Absolute calibration versus relative calibration

Many vector signal measurements require relative amplitude or group delay frequency response to be constant across the measured information bandwidth but aren't affected if the absolute amplitude, phase or group delay of the signal are unknown.

For example, an adjacent channel power measurement relates the power in an adjacent channel to the power in the active channel. If the power measurement of the active channel is off by 5 dB, but the power measurement of the adjacent channel is also off by 5 dB, the two errors cancel. The relative measurement accuracy only degrades when the amplitude response of the analyzer is not flat.

Similarly, an error vector magnitude (EVM) measurement of a QAM or PSK signal makes estimates of symbol clock timing and maximum amplitude. The digitized signal is resampled at the estimated symbol points, and an ideal signal of equal amplitude is reconstructed for comparison. *Constant* amplitude or group delay error across the information bandwidth have no affect on the EVM result, because it is a normalized comparison. However, amplitude or group delay *differences* at one frequency relative to another will affect the amplitude and phase trajectory of the measured signal making the signal appear to have a higher EVM.

Other measurements that depend only on relative amplitude and group delay accuracy are code domain power, code domain error, IQ magnitude and phase error, channel frequency response, am-to-pm conversion and CCDF.

The extended calibration utility measures amplitude flatness and phase linearity (group delay flatness) of the measurement system. It does not improve absolute amplitude, phase, or group delay accuracy. Extended calibration is effective in increasing the accuracy of a large number of important vector signal measurements.

Calibration Challenges

Intermediate frequency (IF) calibration challenges

IF calibration of a wide bandwidth measurement system is not a trivial task. It is essentially a 2-port network measurement, where one port is analog (the analyzer RF input) and the other port is digital (after the analog-to-digital converter). The response cannot be measured using matched-receiver measurements typical of vector network analyzers. Conceptually, a continuous-wave signal of known amplitude and phase could be stepped across the information (IF) bandwidth (with the vector signal analyzer at a fixed center frequency) while the amplitude and phase response of the analyzer is obtained. This is impractical at microwave frequencies because it is difficult to measure absolute phase.

Calibration of measurement devices

Anything in the signal path that is after the IF calibration point can be measured and corrected for. Characteristics of the signal path before the calibration points are unknowns. Some of these unknowns are the very characteristics you wish to measure. However, other unknowns are devices necessary to make the measurement that should otherwise be transparent to the measured signal.

A common user-added device in a measurement environment is some sort of frequency changing device, such as a mixer or downconverter. These devices are often needed when the measurement device used does not have a sufficient frequency range to make the measurement needed. However, having these devices in the signal path adds unwanted phase and amplitude errors.

The solution to this problem is to include those devices in the calibration loop. However, this often presents a problem because the calibration source in an instrument is often limited to the frequency range of the instrument. This prevents calibrating the device that is needed to make a measurement.

Calibration of systems using a preselector

In measurement systems where most of the frequency response error is due to the last intermediate frequency (IF) stage, calibration is possible by switching in a wide bandwidth source with a known (complex) spectrum into the signal path at the last IF stage. With PSA Option 122 or Option 140, this is done automatically during the PSA Series' system alignments. If this method of calibration is possible, the majority of errors can be removed, independent of the measurement center frequency.

Calibration becomes more difficult when the measurement path includes an RF preselector filter. In this case the calibration source must generate a signal at the measurement center frequency, not at the (lower) intermediate frequency. This type of source is more complex and costly. If an external filter or amplifier is placed in the signal path in front of the analyzer, the same extended calibration techniques are required as in the RF preselector example.

Signal generation for calibration

Extended calibration uses an Agilent ESG or PSG vector signal generator with digital arbitrary IQ modulation to generate a complex wide bandwidth calibration signal. Although the source does not perfectly reproduce the intended signal, extended calibration uses a combination of patented and proprietary algorithms to calculate which part of the overall response is due to the source and which is due to the measurement system.

Extended Calibration Setup

Required hardware

To run extended calibration, you will need an extended calibration utility, measurement system and a calibration source (see Table 1).

Table 1. Agilent measurement systems that support extended calibration

Extended calibration utility	Measurement system	Supported calibration sources
PSA wide bandwidth calibration wizard – Option 235	E4440A/43A/45A/46A/48A PSA with Options 122 or 140, and 235	ESG (E4438C) with one of the following Options: 001, 002, 601, or 602 or PSG (E8267C) with Option 002 or 602
89601A VSA software with built-in calibration utility	89611A and Agilent PSA Series with Option H70 or HY7 or 89611A and Agilent ESA Series with Option H70 or HY7 or 89611A with a non-Agilent downconverter (tuner) or 89640A or 89641A with or without external downconverter	ESG (E4438C) with one of the following Options: 001, 002, 601, or 602 or PSG (E8267C) with Option 002 or 602 or ESG-D (E4433B, E4432B, E4431B or E4430B) with Option UND or ESG-DP (E4437B, E4436B, E4435B or E4434B) with Option UND

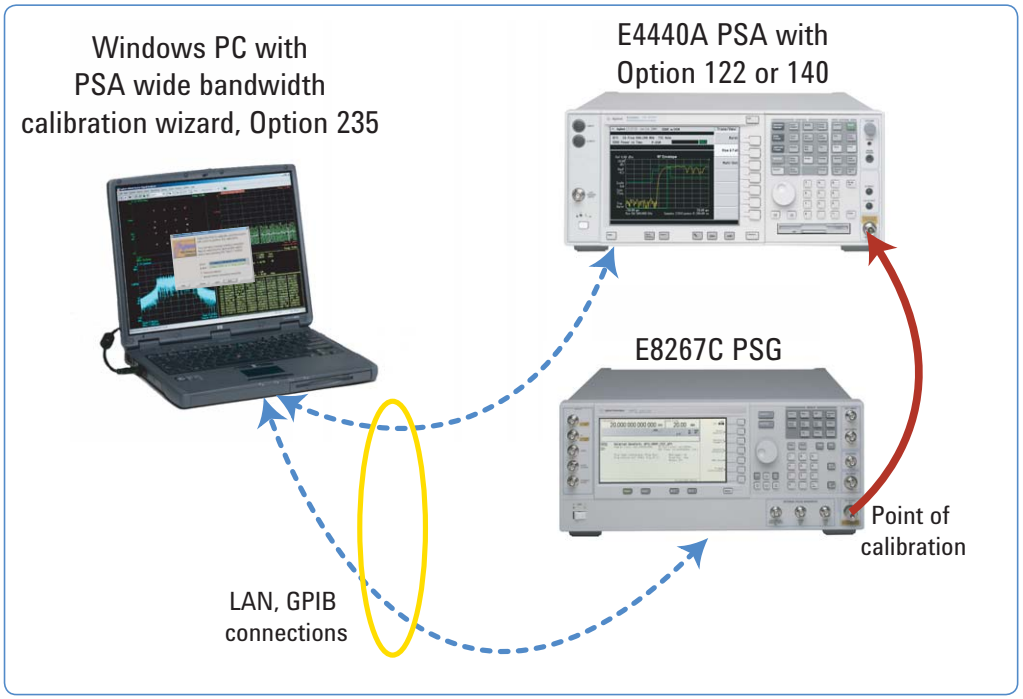

Figure 1. PSA Option 122 or 140 calibration system, equipment setup example

Extended Calibration Setup, *continued*

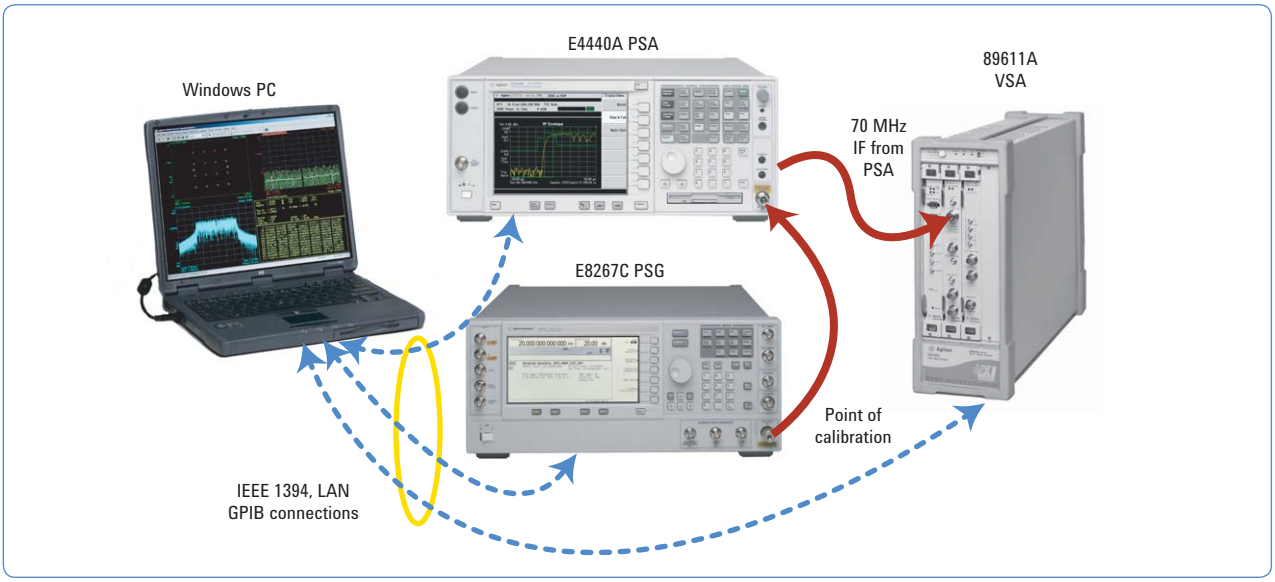

Figure 2. 89611A VSA with PSA (70 MHz IF out) calibration system, equipment setup example

PSA wide bandwidth calibration wizard Option 235

The PSA wide bandwidth calibration wizard is supported on the E4440A/43A/45A/46A/48A PSA with Option 122 (80 MHz bandwidth digitizer) or Option 140 (40 MHz bandwidth digitizer). To enable the wide bandwidth digitizer, the PSA must be in the basic spectrum or basic waveform mode. Once the PSA is in either of these modes the center frequency must be set along with any input conditioning. The extended calibration is performed at these settings and is applicable as long as the center frequency and input signal conditioning remain unchanged. You may need to run extended calibration again if these settings change.

To use the extended calibration software, start the Agilent PSA wide bandwidth calibration wizard (Option 235) on your Windows® PC. The wizard looks for all PSAs and sources that can be controlled via LAN or GPIB using the Agilent IO libraries (the Agilent IO configuration utility must have been previously used to set up the control links – see the *Installation Guide* (literature number 122A-90252) in the directory **\Program Files\Agilent\PSA Calibration\Help)**.

Next, select the PSA and source to be used for the extended calibration, and then let the wizard guide you through the steps of calibration:

Step 1) Connect the source and the measurement hardware
Step 2) Select an appropriate source level
Step 3) Choose a file name for the calibration data

More information is available during each step by clicking the help button. After the calibration routine has finished, the calibration data is stored on the PSA and then loaded into the external time-domain corrections. Calibration data files will remain on the PSA unless they are overwritten or deleted. The wizard also allows you to choose a previously generated calibration file for external time-domain corrections, and to turn external corrections on or off.

89601A VSA software extended calibration utility

An extended calibration utility is built into the 89601A VSA software, and is available whenever the hardware is set to one of the supported configurations (see Table 1).

To run extended calibration on the 89601A VSA software, first set up the center frequency and input range in the software. Then select **Utilities > Extended Cal** to start the calibration wizard to guide you through the extended calibration process. Once the calibration routine has finished, the calibration data is stored on the PC and external IF time corrections are turned on. Select **Utilities > Calibration > Amplitude** to turn external IF corrections on or off and select which calibration file to use.

Recommended Use of Extended Calibration

YIG-tuned preselector systems

Extended calibration is an excellent tool for performing IF calibration on systems that use a YIG-tuned filter (YTFs) as a preselector. YTFs require calibration through the whole signal path every time the center frequency of the analyzer changes. YTF systems include:

- 89611A VSA and PSA Option H70 or HY7 used as a down-converter, when tuned above 3.05 GHz.
- 89611A, 89640A, or 89641A VSAs with any user-supplied tuner using a YTF.
- E4440A/43A/45A/46A/48A PSA with Option 122 (80 MHz bandwidth digitizer) or Option 140 (40 MHz bandwidth digitizer) when the center frequency exceeds 3.05 GHz and Option 123 (switchable preselector bypass) is not enabled.

See the section “Determining When to Recalibrate” for an in-depth discussion of this application.

PSA Option 123 when tuned above 3.05 GHz

Extended calibration improves accuracy on wide bandwidth measurements even when the preselector path is bypassed for frequencies above 3.05 GHz. See Figure 5 for an example of what you can expect from using the PSA wide bandwidth calibration wizard (Option 235).

Devices added in the calibration path

Extended calibration can easily correct for the frequency response of devices (for example, filters and amplifiers) added between the source and analyzer.

Extended Calibration Performance for PSA Option 122 or Option 140

Figures 3 through 7 show nominal plots of the amplitude and phase flatness deviation of an E4440A Option 122 in basic waveform mode showing the inner 64 MHz of an 80 MHz span. The flatness is measured using an E8267C in CW mode with the ALC on. The source is stepped across the information bandwidth and the power measured relative to the center frequency is recorded. The typical level consistency in both the E4438C and the E8267 is better than ±0.05 dB over 80 MHz, eliminating the need for a separate power meter measurement.

Note that for Option 140, the measurements are calibrated to 36 MHz bandwidth. From 36 MHz bandwidth to 40 MHz bandwidth, calibration cannot be used. Figures 3 through 7 are still representative of an E4440A with Option 140, with the aforementioned limitations.

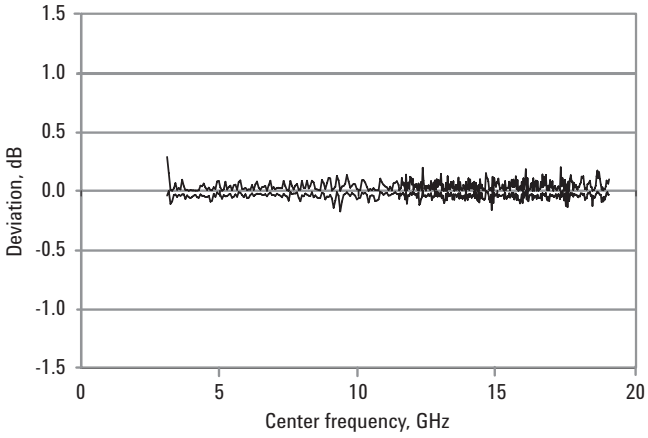

Figure 3. Nominal peak positive and negative amplitude deviation after calibration (using preselector, 64 MHz bandwidth)

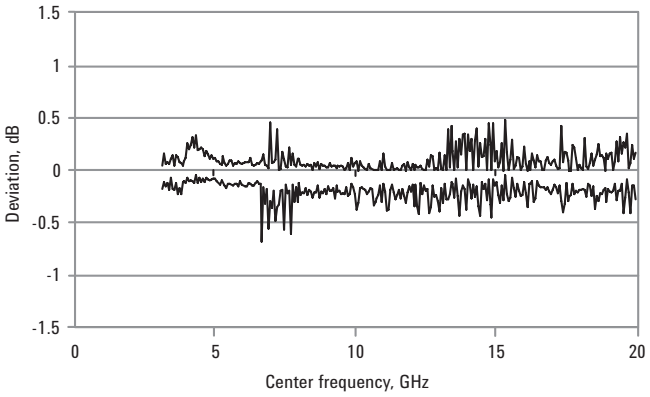

Figure 4. Nominal peak positive and negative amplitude deviation before calibration (preselector bypassed, 64 MHz bandwidth)

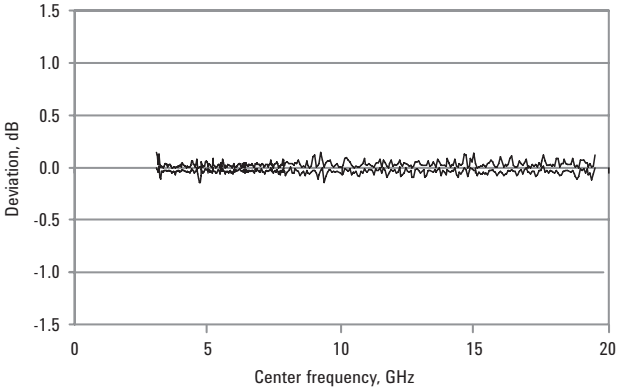

Figure 5. Nominal peak positive and negative amplitude deviation after calibration (preselector bypassed, 64 MHz bandwidth)

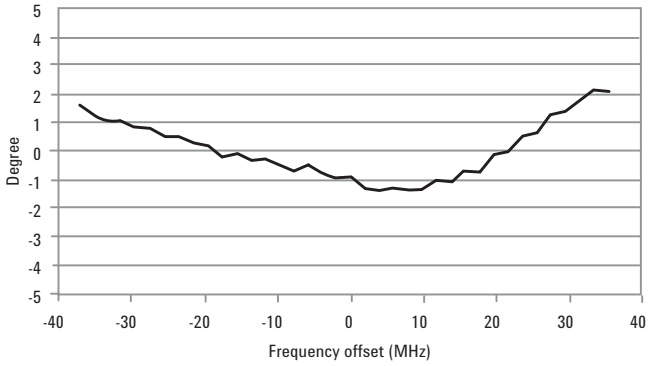

Figure 6. Phase deviation before calibration, 72 MHz span at 18.1 GHz (preselector bypassed)

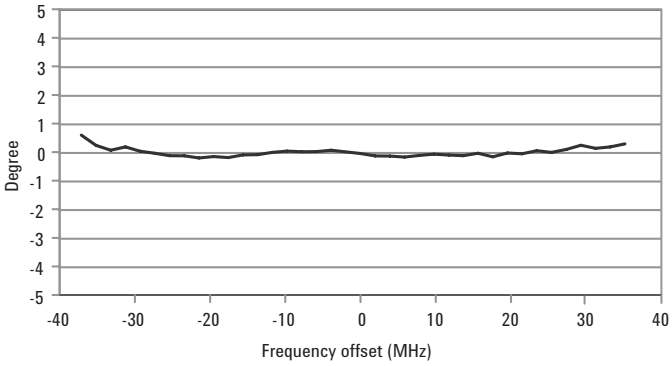

Figure 7. Phase deviation after calibration, 72 MHz span at 18.1 GHz (preselector bypassed)

Verifying Calibration Accuracy

It is easy to check amplitude flatness before and after calibration, using the same source used for calibration. In CW mode, the sources use a leveling loop that holds the output power constant within ±0.05 dB for frequency changes of up to 80 MHz. Set the PSA to show the spectrum, and press **Meas Setup > Average > Avg Type > Maximum**, or in the 89601A VSA software select **MeasSetup > Average > Average Type > Continuous Peak Hold**. This displays the peak magnitude at each frequency of successive spectrum measurements. Next, tune the source through the span, and watch its peak trace out the flatness of the IF.

The 89601A software includes an example macro that is useful for doing this. From the **Utility > Macros** dialog choose Recall **C:\Program Files\Agilent\89600VSA\Examples\Macros\flatness.vbs** and then run the macro.

With the 89601A VSA software, you can also view the correction spectrum. The correction spectrum is the composite frequency response of all internal and external corrections. Click on a trace to select it, double click on its title and select **Correction** from the list of available measurement data. You can click on the format annotation to change it from log magnitude to phase, real or imaginary. Then choose **Utilities > Calibration > Amplitude** and toggle **External IF calibration** on and off to see the effect of the extended calibration data on the correction spectrum.

Determining When to Recalibrate

Extended calibration is made with respect to a specific system setup. The system must be recalibrated if any part of the setup changes that could substantially affect the frequency response of the system.

An exception to this requirement is span changes. Extended calibration measures the response at the maximum measurement span. For spans less than the maximum, the appropriate subset of the calibration data is used for correction. Therefore, spans may be changed without recalibration.

Recalibration may be required when center frequency or input attenuation is modified on the analyzer. In addition, measurement system frequency response drifts with ambient temperature, and to some extent, time. You must use your knowledge of the specific test conditions and required accuracy to determine how often to calibrate. Measuring the amplitude flatness provides a convenient check to determine if recalibration is required.

At microwave and mmWave frequencies, many Agilent spectrum analyzers employ a YIG-tuned filter (YTF) as a preselector, whose frequency response changes with respect to center frequency, tuning history, temperature and time. Understanding the effect of each of these factors on the YTF will help you determine when to recalibrate an analyzer using a YTF preselector.

If you are using the preselected path on the spectrum analyzer and you have just changed the center frequency or input attenuation, wait at least 10 minutes (see Figures 10 an 11), and then calibrate just before making the measurement to obtain the best accuracy possible.

Why Recalibration is Necessary for Measurements Made with a YIG-Tuned Filter

Changing spectrum analyzer center frequency

A YTF is a band-pass filter whose center frequency is tuned by means of a DC magnetic field. As the center frequency increases, so does the bandwidth (see Figures 8 and 9). Therefore, if you perform an extended calibration at one center frequency, then change to another, the calibration will no longer accurately match the system frequency response. It may be close enough if the center frequency change is small. You must determine that by experiment, considering the accuracy you want.

Hysteresis

YIG (yttrium-iron-garnet) is a ferromagnetic material, and its magnetization is determined mainly by its magnetic field, and partially by its past history of magnetization. If you tune a settled YTF away from its present center frequency and back, and allow it to settle again, you may end up with a different frequency response than before. This memory effect, known as hysteresis, may be mitigated by always tuning to a particular center frequency in a set sequence. But in general, past calibrations at a particular center frequency will give less accurate results than a new calibration each time you tune to a different frequency.

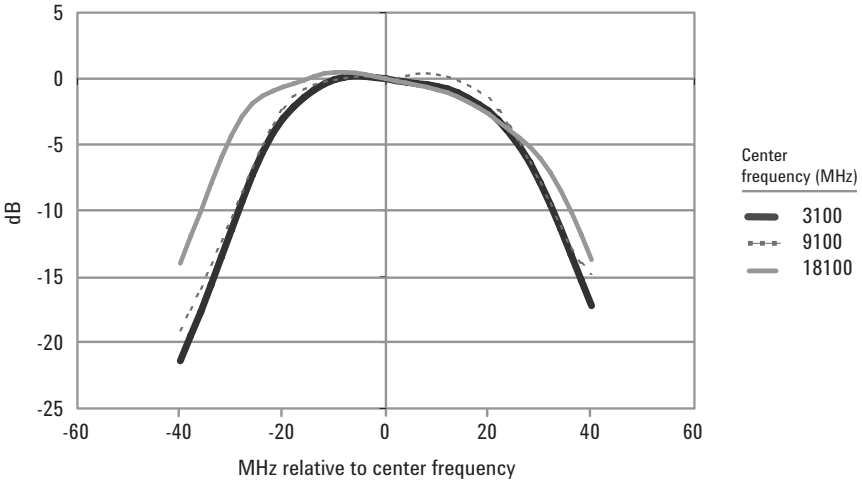

Figure 8. PSA Option 122 – 80 MHz IF response plotted by center frequency, without Option 123. For Option 140, the IF response is identical over –18 MHz to +18 MHz.

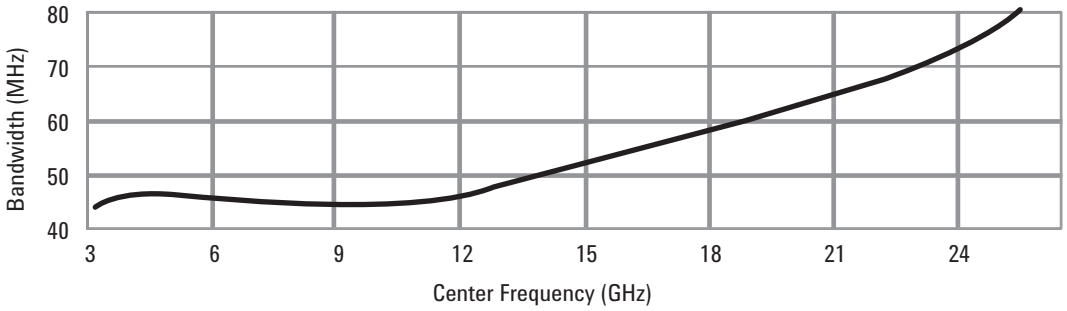

Figure 9. PSA Option 122 nominal IF bandwidth (–4 dB) versus center frequency, CF > 3.05 GHz, without Option 123. For Option 140, the IF response is identical over –18 MHz to +18 MHz.

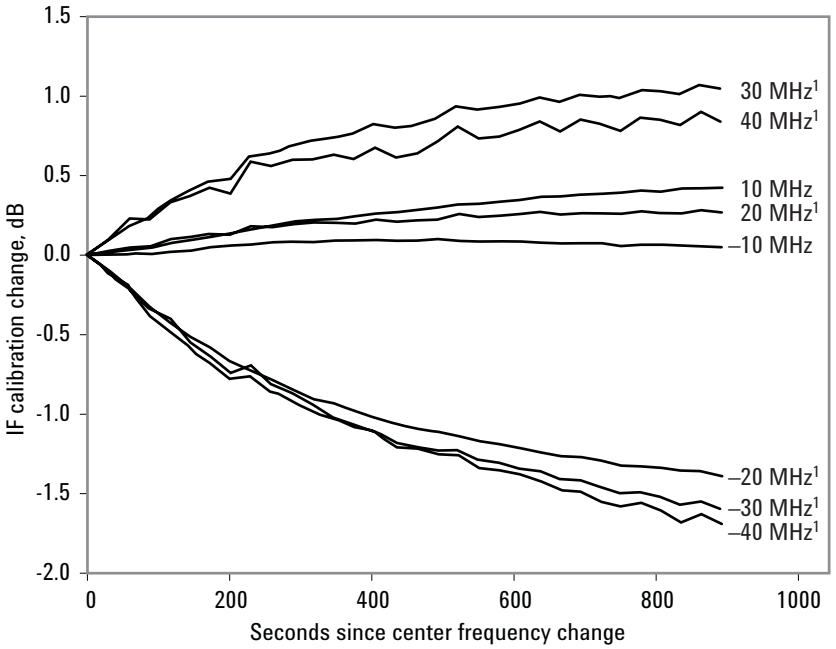

Figure 10. IF calibration change following a 19 GHz to 3.1 GHz center frequency change, for various offsets from center frequency (PSA Option 122)

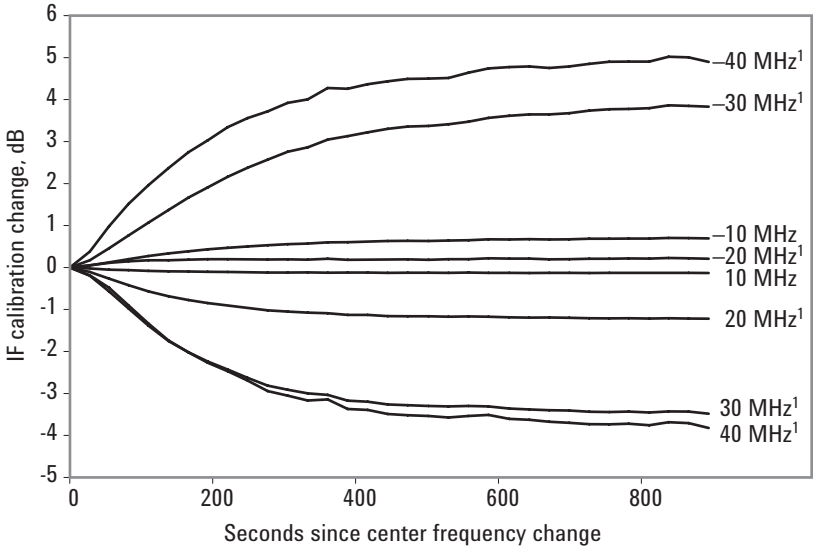

Figure 11. IF calibration change following a 3.1 GHz to 19 GHz center frequency change, for various offsets from center frequency (PSA Option 122)

Temperature changes

Temperature changes can affect the frequency response of the YTF. A typical YTF has a large coil to create the variable magnetic field that tunes it. This coil carries higher current for higher center frequencies and lower current for lower center frequencies. The difference in Joule heating when you change center frequencies causes a thermal transient in the YTF frequency response that can have a time constant of 2 to 3 minutes (see Figures 10 and 11). The magnitude of the thermal transient is proportional to the difference in the squares of the starting and ending frequencies. For example an 18 GHz to 20 GHz change [Δ (frequency^2) = 76 (GHz)^2] would cause a bigger transient than a 3 GHz to 9 GHz change [72 (GHz)^2]. Ambient temperature change can also affect frequency response. For best accuracy the temperature should be kept within a few degrees Celsius after calibrating.

1. Trace applies to PSA Option 122 only

Using Calibration Data Libraries

If the frequency response of the measurement system changes with center frequency, but is stable at any given center frequency, it is possible to create a library of calibration files.

If you are not using a YTF in your calibration path, the following example may be useful for recalling calibration files (for inherently band-limited signals):

Suppose you needed to make three measurements repeatedly at 4, 5, and 6 GHz. You could tune to 4 GHz, perform extended calibration, and save the data in a file called “4gh.cal”. You could repeat this at 5 and 6 GHz, and name the files “5gh.cal” and “6gh.cal”, respectively. Then whenever you tune to each of these frequencies, you would then simply recall the appropriate calibration file for use in external corrections.

Extended Calibration Best Practices

Source setup

To obtain the greatest accuracy, perform the extended calibration with the source set close to the maximum level for your measurement range. You want to maximize the signal-to-noise ratio for the calibration measurements but avoid distortion. The extended calibration wizard suggests a source level and allows you to change it.

Effect on noise floor of wide-band YTF correction

The YTF in the E4440A was designed for narrower bandwidths, and has considerable loss at the edges of wide spans. Because of this design, correction for its roll-off will exaggerate noise at the edges, and gives the system noise floor a bowl shape. However, the amplitude response is flat for the real signal. The noise degradation in the outer portions of the band may affect EVM results. It is better to use the narrowest span possible for your measurement when using the YTF preselector.

Low frequency calibration

At center frequencies below 3 GHz, extended calibration does not consistently improve measurement performance over what is provided by internal IF calibration. For example, if you use it at these frequencies to correct for an external filter, you should check the flatness of the system both before and after calibration. See “Verifying Calibration Accuracy” for a suggested technique.

Example Applications

OFDM channel response

OFDM (orthogonal frequency division multiplexing) measurements are largely immune to frequency response errors, however extended calibration can improve OFDM channel response measurements. Standards that use OFDM such as IEEE 802.11a require an equalization filter within the receiver, so much of the error within a distorted signal path is automatically removed. Because OFDM uses many narrow bandwidth carriers, each is exposed to very little variation in the path and thus the EVM of the OFDM signal stays low even if there are significant differences over the channel as a whole.

The one measurement that is affected by signal path distortion is channel response. Channel response is a composite of the transmitter and channel response and analyzer response. Extended calibration can be used to remove the analyzer response to observe the composite transmitter and channel response.

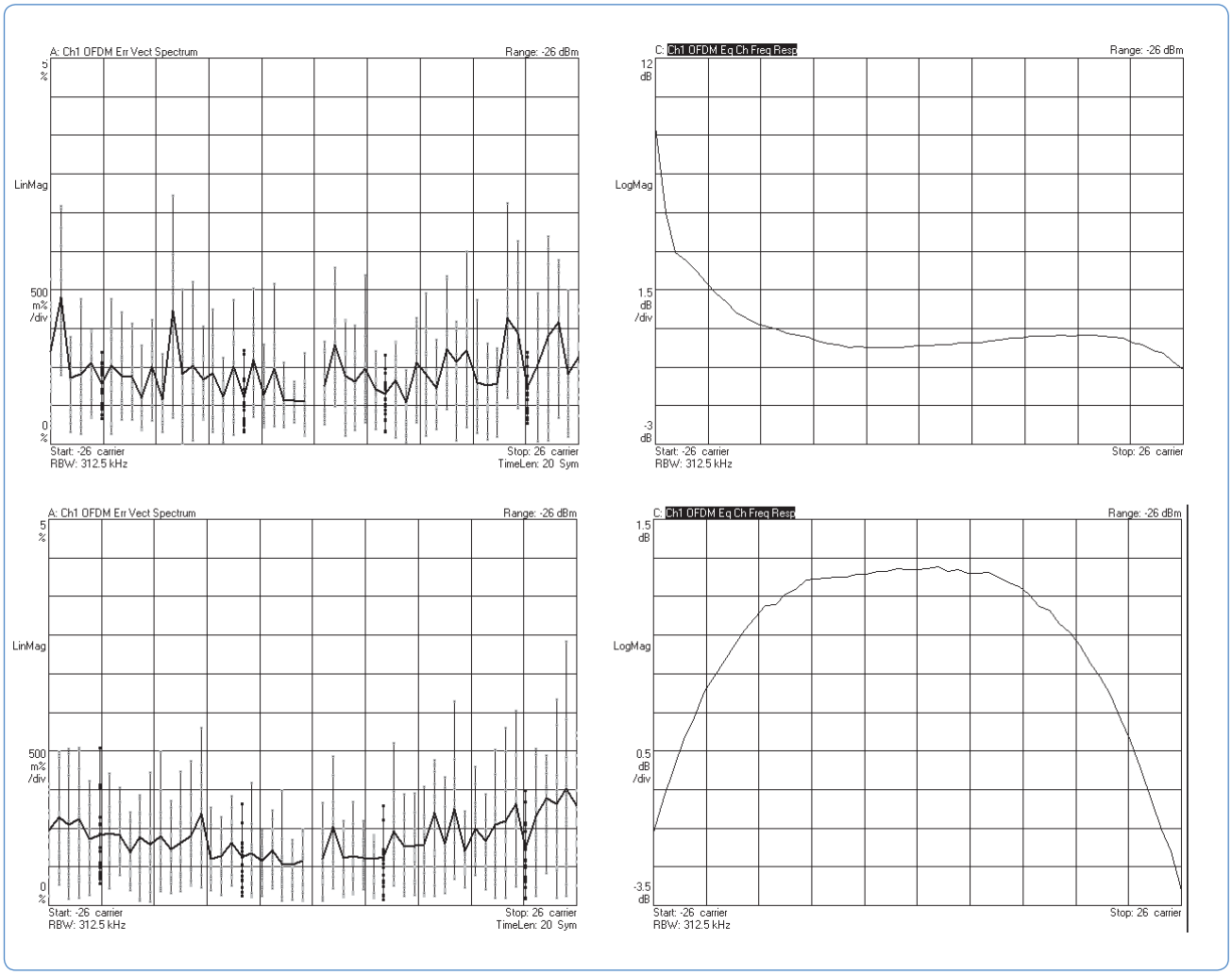

Figure 12. OFDM error vector spectrum and channel response before (top) and after (bottom) extended calibration[1]

1. Figure 12 shows an example of the extended calibration built-in utility in the 89601A VSA software using a PSA with Option H70 and an 89611A VSA at 5 GHz. Similar or better results are possible with Option HY7.

Example Applications, *continued*

IEEE 802.11b wireless LAN

Extended calibration provides the best increase in instrument performance when applied to wide bandwidth, synchronous modulation formats such as IEEE 802.11b. Because 802.11b uses a single carrier with a single modulator, any distortion within the path will affect the signal adversely. The 22 MHz bandwidth of 802.11b provides a perfect example of the power of extended calibration.

As you can see from the measurement example, the error vector frequency measurement shows significant improvement after calibration, indicating the flattening of frequency response. The constellation points are also much tighter, demonstrating the decrease in residual EVM through this calibration.

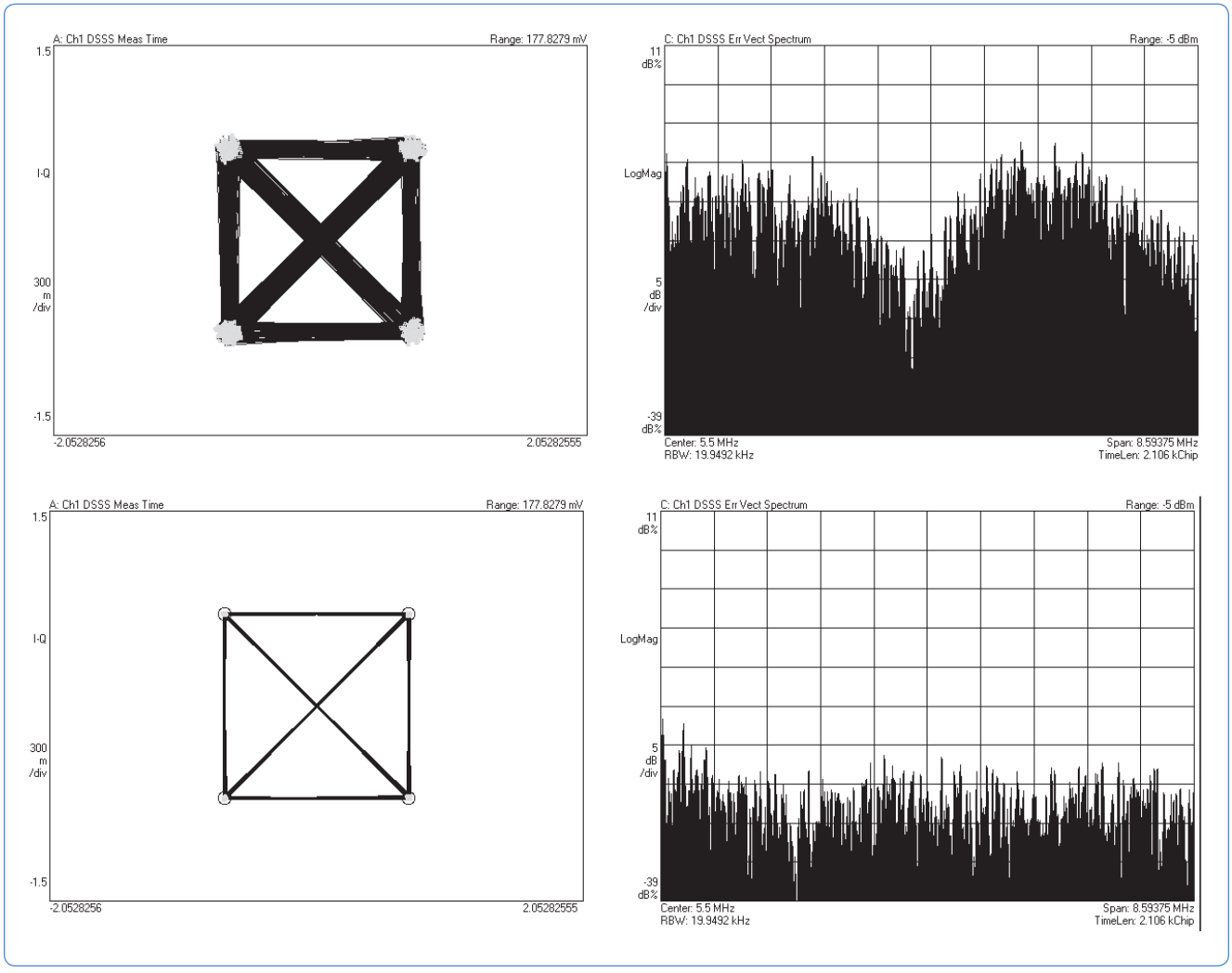

Figure 13. 802.11b error vector spectrum and constellation before (top) and after (bottom) extended calibration[1]

1. Figure 13 shows an example of the extended calibration built-in utility in the 89601A software using an 89640A at 2.4 GHz.

Example Applications, *continued*

QPSK 50 Msps modulation at 18.5 GHz

Extended calibration with the PSA and 89600 VSA can easily be used with any of the flexible modulation analysis capabilities of the 89601A VSA software. In this example, a 50 Msps QPSK signal is modulated onto an 18.5 GHz carrier, as you might see being used for satellite communications. The signal is run through an E444xA PSA spectrum analyzer with Option 122 and is then analyzed by the 89601A VSA software. As shown in Figure 14, a significant improvement in EVM can be achieved by calibrating the signal path through the PSA before making a measurement. This calibration insures that the measurement that is made focuses on the actual transmitted signal instead of the distortion in the signal path.

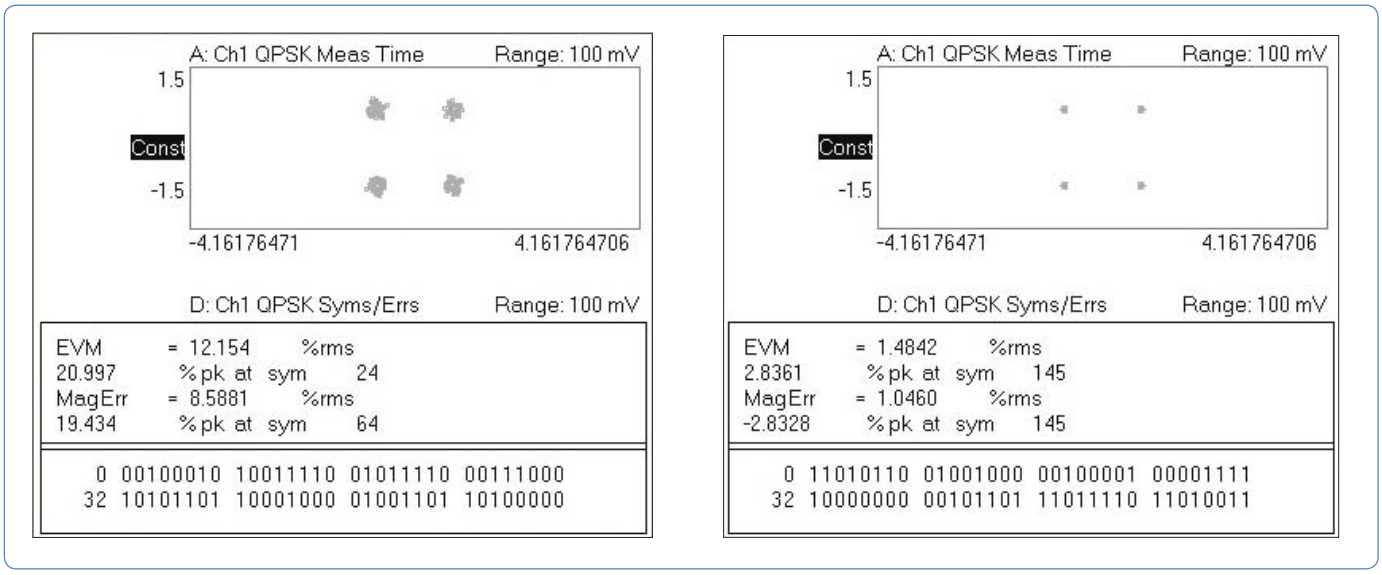

Figure 14. QPSK constellation and EVM summary table before (left image) and after (right image) extended calibration

Related Literature

Agilent PSA Series Spectrum Analyzers brochure, literature number 5980-1283E

Agilent PSA Series Spectrum Analyzers data sheet, literature number 5980-1284E

Agilent 89600 Series Vector Signal Analyzers brochure, literature number 5980-0723E

Agilent 89600 Series Vector Signal Analyzers data sheet, literature number 5988-7811EN

Agilent 89600 Series Vector Signal Analyzers VXI configuration guide, literature number 5968-9350E

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Denmark	45 70 13 15 15
Finland	358 (0) 10 855 2100
France	0825 010 700*
	*0.125 €/minute
Germany	01805 24 6333**
	**0.14 €/minute
Ireland	1890 924 204
Israel	972-3-9288-504/544
Italy	39 02 92 60 8484
Netherlands	31 (0) 20 547 2111
Spain	34 (91) 631 3300
Sweden	0200-88 22 55
Switzerland	0800 80 53 53
United Kingdom	44 (0) 118 9276201

Other European Countries:
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