Agilent
Extended Calibration Using the Agilent 89600 Vector Signal Analyzer

Application Note 1443

Introduction

One of the biggest challenges for any measurement system is accurate and precise calibration. In a general sense, the purpose of any measurement instrument is to verify that a design performs as expected. This type of assurance can only be given if the measuring device is as good or better than the device under test. The only way to assure the measurement capabilities of an instrument is through comprehensive calibration.

In vector signal analysis, the two most important calibration factors are amplitude and phase. In order for the transmitted signal to be effectively analyzed, the vector signal analyzer must only introduce minimal phase or amplitude errors of its own into the measurement. To ensure a good measurement, calibrating the vector signal analyzer or any instrument is essential.

Calibrating an instrument poses many problems, with one central problem being the requirement for a known source in order to calibrate a receiver. Proper calibration requires a source that is stable in phase and amplitude, and as a general rule, the resultant calibration can be no better than the source. This presents a recursive problem, how to create a good receiver without a good source and vice versa.

This document will describe Agilent 89600 vector signal analyzer features that can provide certain types of calibration even when presented with a calibrating source of unknown accuracy.

89611A

Calibration Issues

Any measurement device must have a point of calibration. Anything in the signal path that is after the calibration point can been calibrated for, and thus its affects can be accounted for in the specifications of the measurement device. Characteristics of the signal path before the calibration points are effectively 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.

One of the most common pre-calibration devices in a measurement environment is some sort of frequency changing device, such as a mixer, down-converter, or frequency divider. These devices are often needed when the measurement device used does not have sufficient frequency range to make the measurement needed. However, having these devices in the signal path provides a calibration problem since they inevitably distort and change the signal in unwanted ways.

The solution to this problem is to include these devices in the calibration loop, but 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 Solutions

One way around these calibration problems is to find a source that fits the frequency range of your device and has a calibrated output. Often, especially at microwave frequencies, finding a source that is calibrated adequately is not practical or possible.

The other way around this problem is by implementing a new method of calibration. Because a vector signal analyzer does not need absolute accuracy in order to make modulation measurements, only a relative calibration is needed. One only needs to assure that the amplitude and phase response across the measured channel is flat, not that the phase and amplitude are absolutely accurate. In the 89600 vector signal analyzer this procedure is referred to as extended calibration.

To perform an extended calibration with the 89600 vector signal analyzer, it is only necessary to have a stable source and a stable path. The 89600 accomplishes this by using a vector signal generator to send out a complex signal. This signal traverses the path from the source to the vector signal analyzer and is distorted by the response of that path. Since the Agilent 89611A drives the signal generator and knows what signal was transmitted, it can then mathematically determine the response of that path and apply the inverse response to calibrate that path. In this situation, the absolute accuracy of the source is not relevant, only that the source is stable in generating complex modulated signals.

This solution of using an unknown source to calibrate an unknown receiver is not without some issues. The first issue is that the calibration is relative, not absolute. By using a source that is stable in amplitude and phase over frequency, the vector signal analyzer can determine the amplitude and phase characteristics of the channel and correct for them so that the variance is minimized. This does not imply that the measurement is calibrated to some absolute amplitude standard such as dBm. All it attempts to do is flatten the amplitude response throughout the channel such that a signal of a given amplitude will read the same on the vector signal analyzer no matter where in the measurement band it is located.

Extended Calibration Uses

The main purpose for extended calibration in the 89600 vector signal analyzer is for making modulation accuracy measurements. When performing these measurements, any phase or frequency response error will cause the complex modulated signal to be degraded on the receiver end and may cause the signal to 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 points in the constellation, and a misrepresentative channel response plot are all common problems with an uncalibrated channel.

Because most distortions in the signal path are slow changing over frequency, the extended calibration method is best used for signals 1 MHz and above in bandwidth. Narrower signals will not see the same level of improvement that wide signals exhibit because there is less to correct for over narrower spans. The more bandwidth the signal occupies, the more improvement extended calibration can achieve because there are generally more errors to be accounted for.

Calibration Considerations

The power of this extended calibration is that a relative calibration works perfectly for a vector signal analyzer. A vector signal analyzer only needs accurate relative amplitude and phase data to make modulation accuracy measurements. This calibration method works well to achieve this goal and will provide accurate modulation measurements even at high frequencies. However, it does not provide an accurate readout of the output power of a device in the same manner as a power meter.

Another caveat of this calibration method is that it is sensitive to path changes that may not be repeatable. The most common occurrence of this is when you have a YIG-tuned filter (YTF) somewhere in your calibrated path. YIG tuned filters display hysteresis and other non-deterministic characteristics when they are tuned away from one frequency and back. Because of this, if a downconverter is used that incorporates a YTF, a calibration must be run any time the YTF is changed, even if it is changed back to its original frequency. One of the main advantages of extended calibration is the ability to calibrate through a YTF, but care must be taken to insure that the path is not changed between the calibration and the measurement.

A general operating procedure of extended calibration is that a calibration should be run any time anything in the signal path is changed or adjusted, including frequency changes. It is also important that thermal effects are considered when making measurements. Many microwave frequency components are highly sensitive to temperature changes and may not act linearly to these changes, necessitating a periodic calibration.

A final consideration is the ability for extended calibration to deal with signal paths that have rapidly changing amplitude and/or phase response versus frequency. Some filters, such as sawtooth filters, can have phase and amplitude ripple that can be periodic on the order of 100 KHz or less. Extended calibration does not have the ability to properly characterize such signal paths. An attempt to calibrate a path with a fast response such as this will result in a calibration that does not match the actual signal path.

Overall, extended calibration is a powerful tool for making modulation accuracy measurements through any extended signal path. As long as the path's characteristics remain constant between calibration and measurement, extended calibration can help provide easy and accurate measurements.

Extended Calibration Setup

Extended calibration requires two pieces of hardware. First, an Agilent 89611A, 89640A or 89641A is required as the digitizing hardware. Second, an Agilent ESG or PSG vector signal generator is required as the calibrating source. The source must have the appropriate option to play back arbitrary complex waveforms. A third device will then be used in the path. This device could be a spectrum analyzer, downconverter, filter, or other device required to make the measurement.

A common requirement for the 89611A is making measurements at high frequencies by utilizing a microwave spectrum analyzer as the front-end downconverter. The microwave signal is input into the spectrum analyzer, converted down to some near-baseband frequency and then digitized by the 89611A's digitizer.

A specific example of this setup is the use of an Agilent 89611A vector spectrum analyzer, an Agilent E4440A PSA spectrum analyzer, and an Agilent E8267C PSG vector signal generator. In this solution, the 89611A has no tuning capability and only accepts a 70 MHz input frequency. The E4440A PSA with Option H70 can tune to 26.5 GHz, and provides the 70 MHz IF output. The E8267C can produce a vector-modulated signal to 20 GHz. This solution gives a 36 MHz digitized bandwidth, an overall tuning range to 26.5 GHz, and a calibration range to 20 GHz.

It is also possible to use the 89640A or 89641A vector signal analyzer, any of the PSA series of spectrum analyzers, or any ESG or PSG with vector modulation capabilities. The calibration range of these setups will be limited to the lowest frequency that either the PSA or ESG/PSG can attain. Currently, the ESG and PSG are the only supported signal generators for calibration, but any device can be used in place of the PSA as long as its output is appropriate for the vector signal analyzer's input.

In this situation, the spectrum analyzer path is uncalibrated and presents serious phase and frequency response errors. On top of this, the spectrum analyzer may incorporate a YIG tuned filter somewhere in it's path, meaning that any change in frequency can cause changes in the calibration for this device.

To calibrate this path, it must be static. That is, the spectrum analyzer must be in zero span mode so that it is not sweeping. It is also important that the ranges for the attenuators and the spectrum analyzer are set the same as they will be for testing so that none of the gain stages or paths in the analyzer change.

Extended Calibration Use

To use extended calibration on the Agilent 89600 VSA, the system must first be set up so it recognizes the ESG or PSG and so it has the appropriate downconverter information, if a downconverter is used. For the 89600 to find the ESG/PSG, the source must be connected to the GPIB bus or via a LAN connection. When the I/O libraries are set up correctly, the 89600 will find the source upon starting the program and will automatically control it when needed.

For downconverters, the 89600 supports automatically controlling a PSA connected via GPIB or LAN. The 89600 can tune the PSA to the desired frequency and automatically sets up the IF frequencies. If a non-supported downconverter is used, then the 89600 supports manually entering the center frequency, IF frequency and bandwidth of the downconverter. This will then allow the 89600 to properly display and measure the signal. Frequency mirroring is supported if the IF output of your downconverter is mirrored from the input.

Once the hardware is connected one only needs to go to the Utilities menu and choose Extended Cal. The signal source must then be connected to the plane of calibration. The calibration measurement is run under the control of the 89600 software. Once complete, the signal source is disconnected and the DUT reconnected. The 89600 calibration now compensates for the entire signal path including cabling, fixturing, and frequency translation devices.

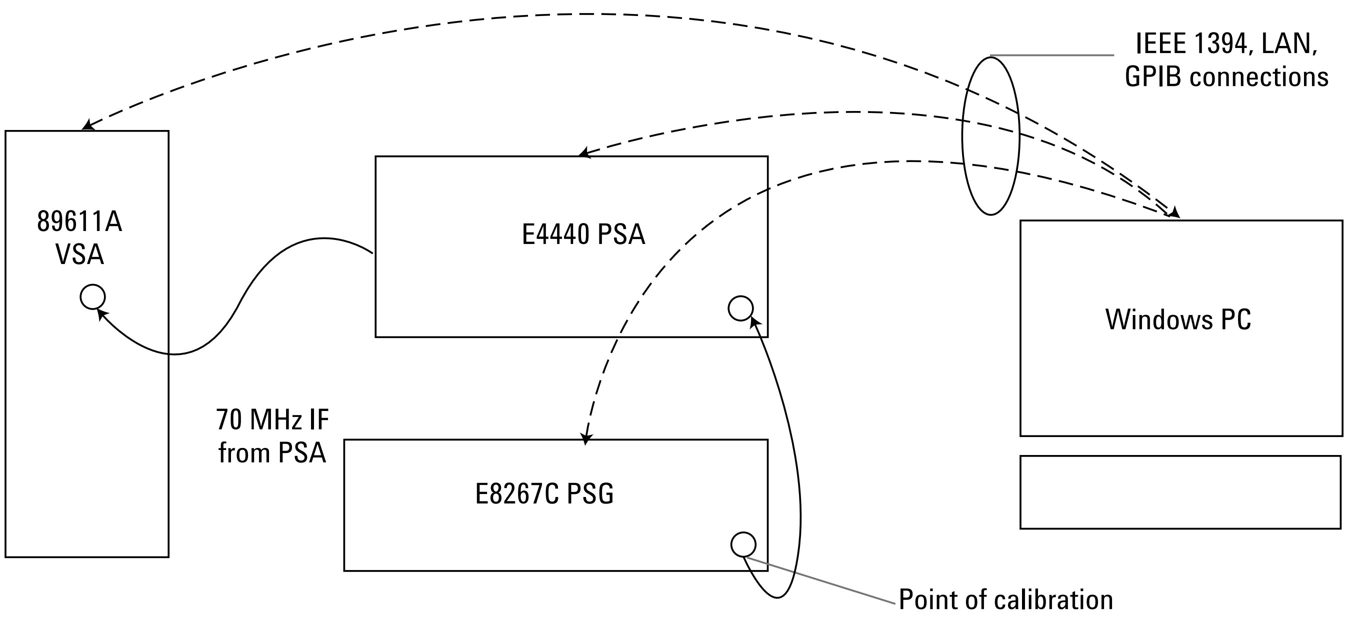

Figure 1. Example 89611A/PSA setup

Example Applications

OFDM channel response

OFDM is a unique case when it comes to calibration. Standards that use OFDM such as 802.11a require an equalization filter within the receiver; much of the error within a distorted signal path is automatically removed. Since 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.

The one measurement that is affected by signal path distortion is channel response. This measurement shows you the theoretical frequency response of your transmitter. Of course, any other frequency response characteristics of the signal path are also combined into this measurement result. By calibrating the entire signal path, the resultant channel response measurement will show only the output of the transmitter.

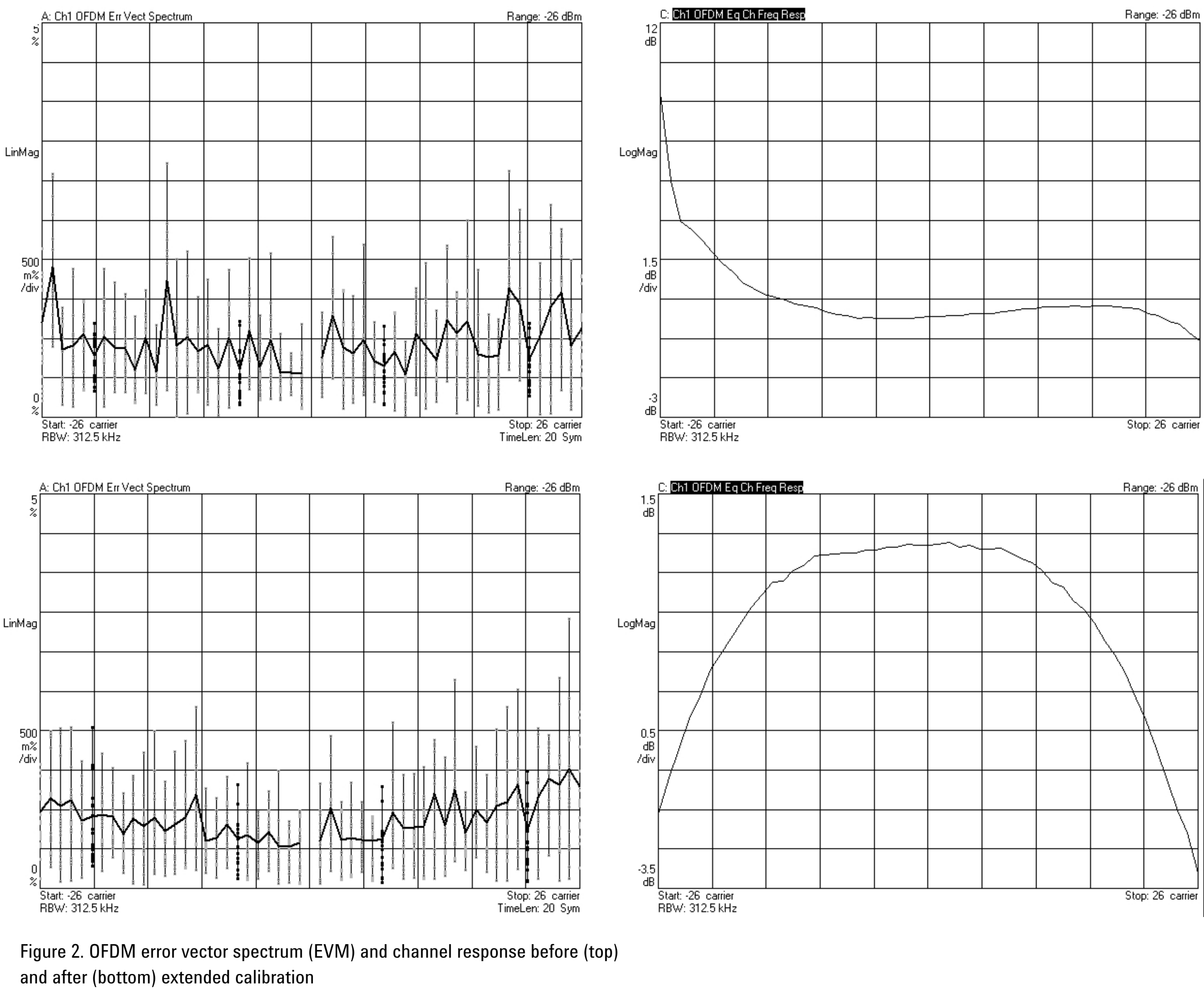

Figure 2. OFDM error vector spectrum (EVM) and channel response before (top) and after (bottom) extended calibration

802.11b

Extended calibration provides the best increase in instrument performance when applied to wide bandwidth, synchronous modulation formats such as 802.11b. Since 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 can be seen from the above measurement example, the EVM 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.

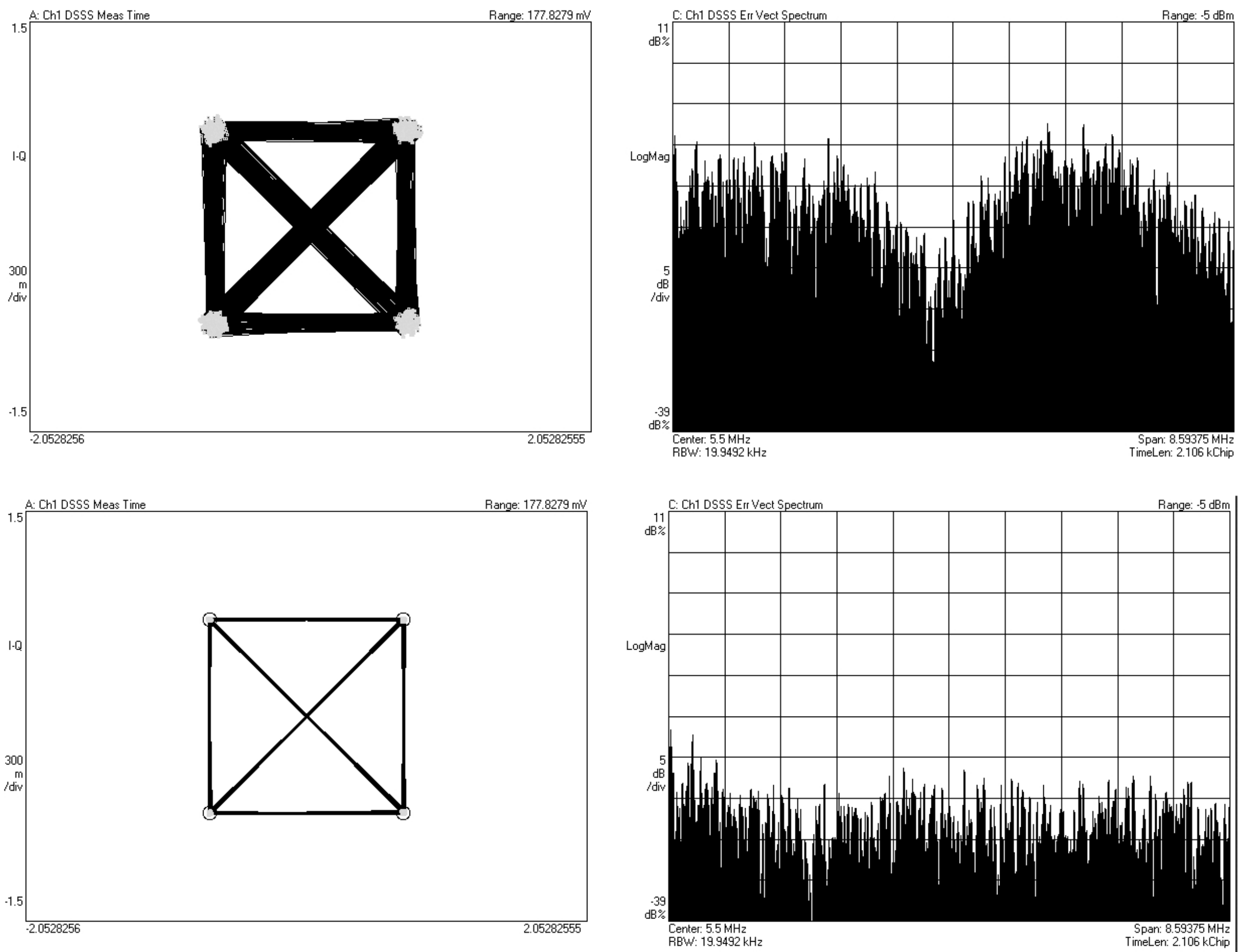

Figure 3. 802.11b Error Vector Spectrum (EVM) and constellation before (top) and after (bottom)

16 QAM, 15 Msps modulation

Extended calibration can easily be used by any of the flexible modulation analysis capabilities of the 89600 VSA. In this example, a 15 Msps, 16 QAM signal is modulated onto an 18 GHz carrier, as might be used for satellite communications. The signal is run through an E4440A PSA spectrum analyzer and downconverted to 321 MHz before being digitized by the 89641A VSA.

As can be seen from the results below, a significant improvement in EVM can be achieved by calibrating the signal path through the PSA before making a measurement. This insures that the measurement that is made focuses on the actual transmitted signal instead of the distortion in the signal path.

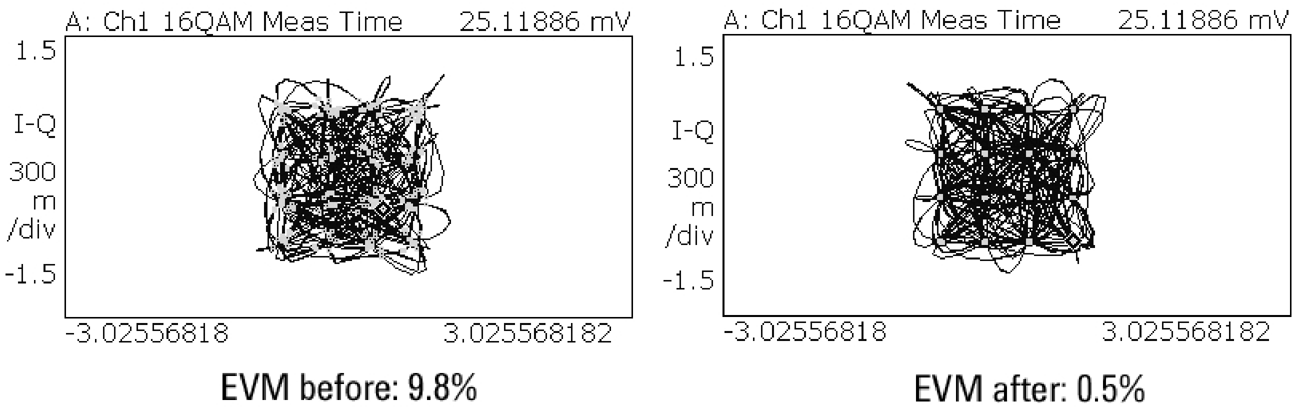

Figure 4. 16 QAM constellation and EVM before and after calibration

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Other Asia Pacific Countries:
(tel) (65) 6375 8100
(fax) (65) 6836 0252
Email: tm_asia@agilent.com

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