# Optimization of EVM Performance in IQ Modulators

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## Introduction

EVM, or error vector magnitude, is essentially a scalar measurement of digital modulation accuracy, an important figure of merit for any source of digital modulation. This note shows how a vector signal analyzer helps optimize EVM performance of IQ modulators such as the LTC5598, a 5MHz to 1600MHz high linearity direct quadrature modulator.

Low modulator EVM is desired because the EVM degrades farther down the line—transmit up-converters, filters, power amplifiers, the communications channel, and the receiver all impair the received signal.



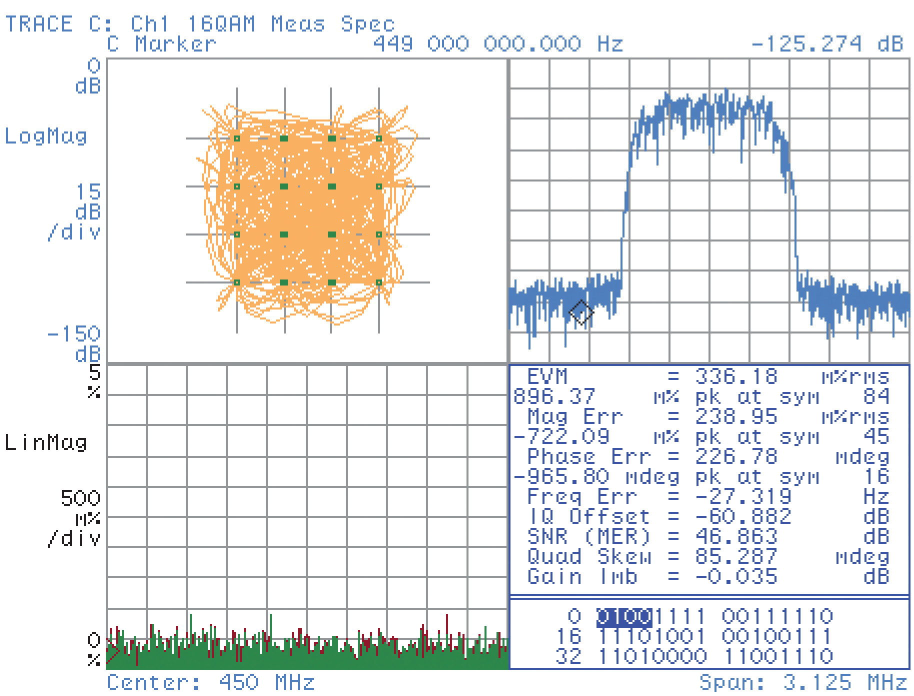
## Test Setup

Unless otherwise noted, the following test conditions apply (See Figure 3):

- LTC5598 IQ modulator on Linear Technology demonstration circuit DC1455A.
- LO: 0dBm, f = 450MHz.
- Baseband Modulation: PN9, root raised cosine (RRC) filtering, $\alpha = 0.35$, symbol rate = 1Msps, 16-QAM (four bits per symbol, peak-to-average ratio 5.4dB).
- Baseband drive: $V_{EMF}$[1] = 0.8V differential ($1.15V_{P-P}$ differential). $V_{BIAS}$ = 0.5V.

**Note 1.** $V_{EMF}$ is the differential IQ baseband amplitude, as indicated on the Rohde & Schwarz AMIQ software. Actual I and Q voltage (peak-to-peak differential) measures as shown.

A. Measured Time | C. Measured Spectrum




B. EVM vs Time | D. Error Summary

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**Figure 1. Typical 450MHz EVM Measurement Result of 0.34% RMS. For Comparison, a High-Grade Lab Signal Generator EVM Measures 0.28% RMS on the Same VSA Setup**

- VSA measurement filter: RRC, $\alpha = 0.35$.

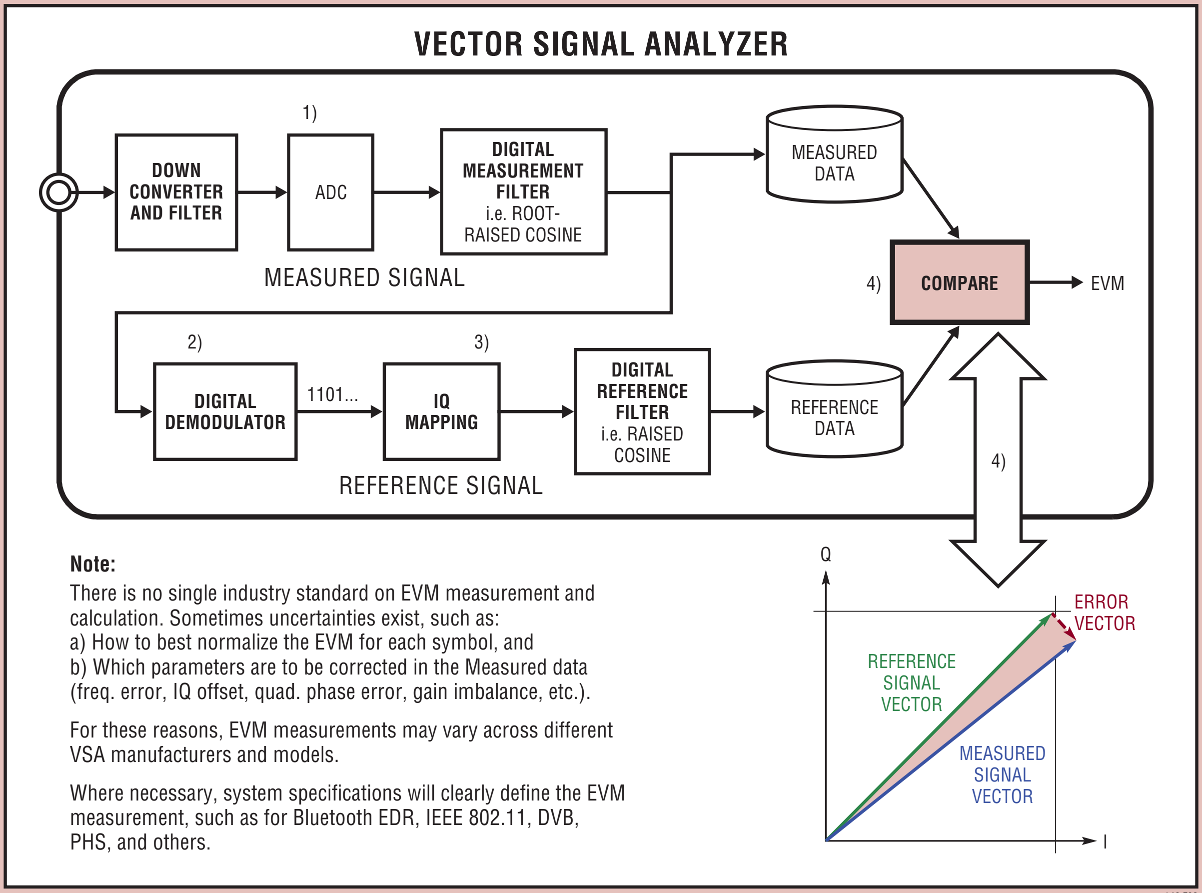
  VSA reference filter: Root Cosine (RC).

16-QAM is a relatively common type of digital modulation, readily demonstrating the modulation accuracy attainable with the LTC5598. It is utilized in many wireless communication standards such as LTE/LTE-Advanced, HSDPA, EDGE Evo, CDMA2000 EV-DO, Cognitive Radio IEEE 802.22 (TV white space), PHS, and TETRA.

### VSA and EVM Basics

Modulation accuracy is often measured with a vector signal analyzer (VSA). In brief, the VSA functions as follows:

1. It downconverts and digitizes the input signal at a specified center frequency over a given bandwidth. The modulation scheme, symbol rate, measurement filter, etc are user selected. This data becomes known as the *measured* signal.
2. It digitally demodulates the measured signal to recover the source digital data stream.
3. Based on the recovered source data, modulation scheme, etc, the VSA mathematically generates an ideal *reference* signal.
4. It calculates error vectors by determining the difference of the measured and reference data vectors, and normalizing to the peak signal level. From the set of error vectors, the rms and peak EVM scalar values are extracted.




**Note:**
There is no single industry standard on EVM measurement and calculation. Sometimes uncertainties exist, such as:
a) How to best normalize the EVM for each symbol, and
b) Which parameters are to be corrected in the Measured data (freq. error, IQ offset, quad. phase error, gain imbalance, etc.).

For these reasons, EVM measurements may vary across different VSA manufacturers and models.

Where necessary, system specifications will clearly define the EVM measurement, such as for Bluetooth EDR, IEEE 802.11, DVB, PHS, and others.

**Figure 2. Basic Principle of the VSA. It Compares an Input Measured Signal to an Ideally Regenerated Reference Signal**

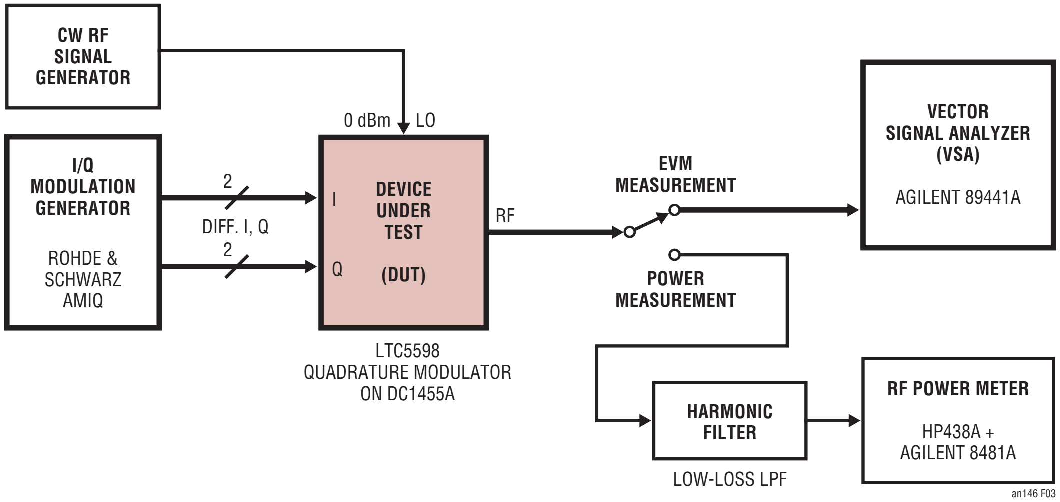



**Figure 3. EVM Test Setup. The Low-Pass Harmonic Filter Removes the Primarily Odd Output Harmonics for Accurate Output Power Measurement**

## LTC5598 EVM Test Results

A typical EVM measurement at LO = 450MHz is shown in Figure 1, demonstrating an LTC5598 EVM of 0.34% rms, and 0.9% peak. After the harmonic filter, output power measures +0.4dBm for the same signal. By comparison, a lab-grade signal generator with the same amplitude, frequency, and digital modulation measures 0.28% rms and 0.8% peak, on the same VSA setup. This indicates that the LTC5598 modulation accuracy is nearly as good as the test equipment being used to measure it.

## EVM vs IQ Drive Level

- 16-QAM, 1Msps, RRC, raised cosine, $\alpha$ = 0.35 (peak-to-average ratio 5.4dB).
- $V_{BIAS}$ = 0.5V DC. LO = 0dBm.

Figure 4 shows EVM increasing rapidly when the baseband inputs drive the modulator output signal peaks into compression. Even without a VSA to measure EVM, this level of maximum rms output power can be estimated by:

| | | |
|---|---|---|
| | +8.4dBm | LTC5598 Output P1dB (Typ. at $f_{RF}$ = 450MHz) |
| – | 5.4dB | Crest Factor of 16-QAM Test Waveform |
| = | +3.0dBm | Average Output Power (Peaks Will Be in 1dB Compression) |

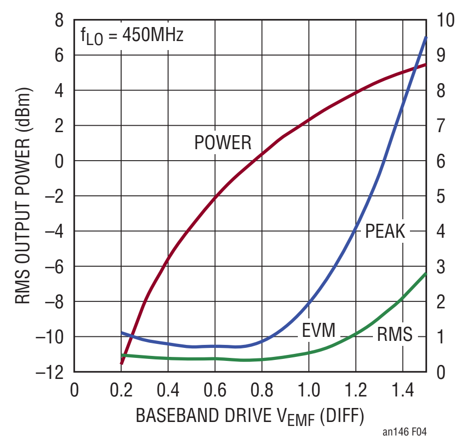



**Figure 4. EVM and RMS Output Power vs IQ Drive Level**

Again, this is just a rough estimate. For more complex modulation schemes, even 1dB compression may be excessive, and at the same time, the crest factor will be higher, thus significantly dropping the average output power that becomes available for highly complex waveforms.

## EVM vs LO Frequency

The same test conditions are used:

16-QAM, 1Msps, RRC, raised cosine, $\alpha$ = 0.35 (peak-to-average ratio 5.4dB). $V_{EMF}$ = 0.8V differential (1.15$V_{P-P}$ differential), $V_{BIAS}$ = 0.5V.

Figure 5 illustrates how the LTC5598 modulation accuracy is affected near the ends of the IQ Modulator frequency

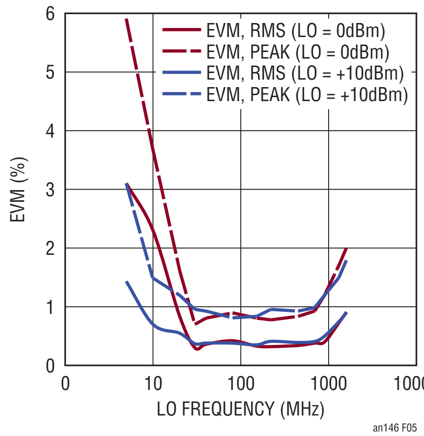



**Figure 5. LTC5598 EVM vs LO Frequency. At Low LO Frequencies, EVM Can Be Improved with Higher LO Drive Power and/or Quadrature Phase Error Correction within the Baseband**

range specification. EVM is lowest at midband frequencies from 30MHz to 700MHz. At LO frequency below 30MHz, EVM is reduced with stronger LO drive (consult the LTC5598 data sheet).

At both LO frequency extremes, the main contributor to LTC5598 EVM is quadrature phase error, as shown in Table 1. Some IQ gain imbalance is also present, but generally not much of a contributor to overall EVM. Where necessary, either or both of these error terms can be corrected open-loop in baseband, or in some transmit chains as part of an existing closed-loop PA pre-distortion correction system[2].

Slightly higher EVM may be perfectly acceptable in some systems, for example when simple, low-order digital modulation schemes are used.

**Table 1. LTC5598 Quadrature Phase and Gain Imbalance Errors (LO Drive = 0dBm). Sideband Suppression is the Aggregate Effect Of Both**

| LO FREQUENCY (MHz) | QUADRATURE PHASE ERROR (DEG.) | IQ GAIN IMBALANCE (dB) | SIDEBAND SUPPRESSION (dB) |
|---|---|---|---|
| 5 | 4.3 | 0.14 | 28 |
| 10 | 3.6 | 0.01 | 30 |
| 20 | 1.2 | 0.02 | 40 |
| 40 | –0.3 | 0.03 | 50 |
| 1600 | –1.2 | 0.05 | 39 |

### Tips for Lowest IQ Modulator EVM

- Use "clean" IQ baseband source:
  - IQ DAC clock should be low phase noise and jitter.
  - Be sure DAC reconstruction filter does not encroach upon the baseband bandwidth.
  - Be sure the baseband IQ signal paths have sufficiently flat frequency response.
- Use a "clean" LO signal source:
  - LO phase noise adds random phase error, increasing EVM. This type of error cannot be later removed.
  - LO harmonics will give rise to quadrature phase error. For best results, adhere to the modulator datasheet recommendation regarding LO harmonic content.

## Conclusion

The LTC5598 provides excellent digital modulation accuracy across many popular VHF and UHF communications bands. In some cases, EVM is comparable to that of a lab-grade signal generator. Where desired or necessary, baseband correction of quadrature phase and/or gain may be implemented for enhanced accuracy.

## REFERENCES

1 "Digital Modulation in Communications Systems – An Introduction", Application Note 1298, Agilent Technologies

2 "Using Vector Modulation Analysis in the Integration, Troubleshooting, and Design of Digital RF Communications Systems", Product Note 89400-8, Agilent Technologies

**Note 2.** While the subject of pre-distortion correction (Pre-D) is beyond the scope of this document, suffice it to say that the Pre-D will have its own receiver that can effectively measure transmit EVM and make adaptive corrections to the baseband waveforms to minimize error. The Pre-D does not know or care where the error originates (modulator, PA, or both).





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