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Evaluation of Vector Modulator IC Performance

Application Note—1126

The following brief discussion describes some of the tests used to evaluate the performance of vector modulator ICs.

Power Output

Power output of a vector modulator IC can be specified in different ways. The most common way is the single sideband (SSB) output power level. An alternative way that is easier to test is the peak output power. The SSB output power will be 3 dB lower than the peak power.

Peak power output can be measured by simply applying DC voltages to the I and Q modulation inputs with appropriate reference voltages applied to Iref and Qref. If the normal reference voltage is 2.5 VDC, a 1.2 Vp-p I, Q signal can be simulated by applying 0.6VDC + 2.5VDC = 3.1VDC to both the Imod and Qmod inputs. The resulting output power read on a spectrum analyzer will be about 3 dB above the SSB output power.

The LO leakage section of this discussion describes a method of directly measuring the SSB output power.

LO Leakage

There are two main causes of LO leakage through a QPSK modulator. The first is the basic performance of the IC with no external signals other than required bias voltages and LO signal applied. The second is LO leakage that is due to externally applied signals.

The inherent LO suppression of the IC is the result of the variability of the electrical properties of the transistors and resistors that make up the IC. Random variations IC components can lead to DC offsets at the I and Q inputs. These DC offsets are multiplied by the LO signal and appear at the output as LO leakage. The larger the offset, the greater the LO leakage.

The LO leakage of an IC can be measured by connecting all four I and Q inputs to a bias source (typically Vcc/2 = 2.5 VDC). Apply the LO signal that is standard for the IC (the level used in the data sheet measurements) and observe the output on a spectrum analyzer with the sweep centered on the LO frequency. Subtract the power output indicated from the peak power output (measurement described above) to determine the LO suppression relative to the peak output. The LO suppression relative to a SSB output will be 3 dB lower because the peak power reading is 3 dB higher than the SSB power output.

The most common way of specifying the LO leakage is to specify the LO suppression relative to SSB output power. An SSB test can be performed by applying sine and cosine signals to the I and Q inputs, along with any appropriate DC biases required, and the LO signal. The spectrum analyzer will show a classic SSB output spectrum making it very easy to calculate the LO suppression-simply subtract the LO leakage level from the unsuppressed sideband level.

A third alternative is to use the DSB output obtained by applying in-phase sine wave signals to both I and Q inputs along with appropriate DC biases and the LO signal. The two sidebands will read 3 dB lower in power than the SSB peak output so the LO suppression relative to the sidebands will be 3 dB lower than the value obtained from the SSB

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test (and 6 dB lower than the value obtained from the peak power test).

When performing the SSB and DSB measurements, you must be extremely careful to ensure that the average level of the AC signals applied to the I and Q inputs are exactly equal to the DC bias applied to the Iref and Qref inputs. You should try to match the DC levels within 1 or 2 millivolts.

Modulation Error (Sideband Suppression)

The QPSK modulator's purpose is to modulate the phase of a carrier signal with equal amplitude at each of four or eight possible data points. Real modulators do not shift the phase to the exact theoretical value, and there is always some variation in the amplitude of the output signal.

Modulation error can be expressed in terms of rms or peak levels of amplitude error, phase error, and /or percent error. One common but flawed technique for estimating rms (average) phase error is to use the SSB suppression in the following formula:

SSB suppression (dBc) =

$$10 \log \frac{(1 + \cos f)}{(1 - \cos f)}$$

where ϕ is the average phase error in degrees.

The sideband suppression can be obtained from the above described test for SSB power output/LO suppression. Note that the sideband suppression obtained is critically dependent on matching the peak to peak amplitudes of the I and Q signals.

Though our measured data follows the general shape of the theoretical curve, it rarely meets the curve. The actual data varies by as much as ± 10 dB about the theoretical curve. Also, applications such as GSM telephones have definite limits on the peak phase error, a value that cannot be obtained from the formula. For these reasons, a direct measurement is the best way to evaluate modulator error performance.

The amplitude and phase error can easily be measured by using a vector network analyzer to perform an S21 measurement. The LO signal for the modulator is provided by port 1 of the analyzer (set the output to an appropriate value) with the output of the modulator connected to port 2 of the analyzer (an attenuator at the output of the IC may be needed. The Iref and Qref pins should be biased normally (≈2.5 VDC) and the Imod and Qmod pins connect to precise DC sources such as HP-6626A system power supply. The Imod and Qmod voltages are set to values that should give predictable phase shifts (at 15° intervals, for example) and an S21 reading is performed at each point as the voltages are changed, until a full 360° phase rotation has been achieved. Table 1 shows a sequence of voltages to apply to a vector modulator for 15° steps around the I, Q circle.

Table 1.

Voltage at Imod (VDC)	Voltage at Qmod (VDC)	Relative Vector Angle (degrees)
3.750	2.500	0
3.707	2.824	15
3.583	3.125	30
3.384	3.384	45
3.125	3.583	60
2.824	3.707	75
2.500	3.750	90
2.176	3.707	105
1.875	3.583	120
1.616	3.384	135
1.417	3.125	150
1.293	2.824	165
1.250	2.500	180
1.293	2.176	195
1.417	1.875	210
1.616	1.616	225
1.875	1.417	240
2.176	1.293	255
2.500	1.250	270
2.824	1.293	285
3.125	1.417	300
3.384	1.616	315
3.583	1.875	330
3.707	2.176	345

Notes to Table 1:

1. voltages applied to Imod and Qmod inputs always fit the following formula: $\sqrt{(V_{Imod} - 2.5)^2 + (V_{Qmod} - 2.5)^2} = 1.25$ which is simply the equation of the I, Q circle in the V_{Imod}, V_{Qmod} coordinate axes shown in Figure 1.
2. $V_{Imod} = 2.5 + 1.25 \cos\theta$ where θ is the vector angle from the I axis.
3. $V_{Imod} = 2.5 + 1.25 \sin\theta$ where θ is the vector angle from the I axis.

The average value of the magnitude of the S21 readings will be the reference for amplitude error calculations. Since the phase value read will depend upon the analysis frequency, the cables used and the fixture or test board, the phase readings will be relative. The first phase measurement is normally chosen as the reference to which all the other phase readings will be compared. The average amplitude error is just the numerical average of the difference between each amplitude reading and the reference value (the average value of all the readings). The average phase error is the average of the differences between each phase value and the reference value. The peak phase error is the highest magnitude value of difference between the input phase (corrected to the reference) value and each measured value.

Modulation error can be expressed as a percentage by using the instantaneous amplitude error and phase error values. The modulation error percentage is 100 times the ratio of the error vector (the line between the actual modulation point and the average modulation point) and average vector magnitudes (the average value of magnitude at all points measured). The magnitude of the error vector is determined by following the formulas presented below.

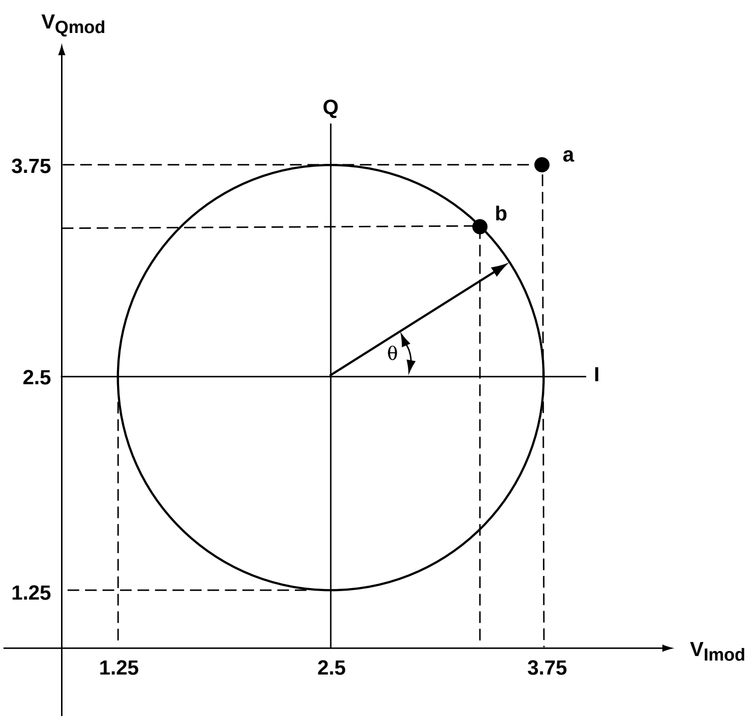

Figure 1. I and Q coordinate axes. "a" is the point where peak output power is measured. "b" is the point where the SSB output power is measured.

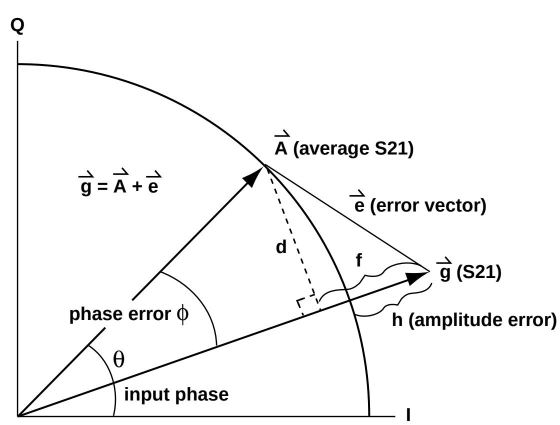

Figure 2. Illustration of error vector magnitude for calculating percent modulation error.

Amplitude error, $h = |\vec{A}| - |\vec{g}|$ where $|\vec{A}|$ is the average S21 magnitude and $|\vec{g}|$ is the magnitude of the S21 reading at the specific point where we want to calculate the modulation error percentage. Note: S21 magnitude readings must be in linear terms, not decibels. Phase readings should be in degrees.

$$\text{percent modulation error} = 100 \frac{|\vec{e}|}{|\vec{A}|}$$

$$|e| = \sqrt{d^2 + f^2}$$

$$d = |\vec{A}| \sin\left(\phi \frac{\pi}{80}\right) \approx |\vec{A}|\, \phi \frac{\pi}{180} \quad \text{for small values of phase error, } \phi$$

$$f = |\vec{g}| - |\vec{A}| \cos\left(\phi \frac{\pi}{180}\right) \approx h \quad \text{for small values of phase error, } \phi$$

$$\therefore |e| = \sqrt{\left(|A| \phi \frac{\pi}{180}\right)^2 + h^2}$$

$$\text{percent modulation error} \approx 100 \frac{\sqrt{\left(|\vec{A}| \phi \frac{\pi}{180}\right)^2 + h^2}}{|\vec{A}|}$$

Summary

The old computer adage about GIGO (garbage-in, garbage-out) is especially applicable to IC modulator tests. Measuring the performance of a vector modulator IC requires a thorough understanding and careful control of all the input signals. The table below summarizes the common problems and their causes.

Symptom	Probable Cause/Solution
Power output below spec	Test conditions (SSB, DSB, peak) should match data sheet conditions-any of the following conditions may lead to low output power: 1) insufficient LO power 2) I and Q signal levels too low or the wrong type 3) Vcc too low 4) LO frequency too high 5) blocking caps at LO input or RF output too small at low frequencies 6) quality of solder connections—especially at RFout pin
LO leakage above spec (poor carrier suppression)	DC offset between Imod and Iref and/or Qmod and Qref. Check for offsets with DMM, make adjustments to average Imod, Qmod signal levels, or adjust bias voltages at Iref and/or Qref for 0 offset. Use **sine wave** LO drive! Using signals with harmonics above about -20 dBc will degrade performance of the modulator.
Sideband suppression above spec	Amplitude imbalance between Imod and Qmod. Adjust for equal amplitude with an oscilloscope or a true-rms voltmeter. This problem can also be the result of a non 90° phase shift between the I and Q signals or an improperly functioning LO phase shifter. Use **sine wave** LO drive! Using signals with harmonics above about -20 dBc will degrade performance of the modulator.
Harmonics of I, Q signals in output spectrum	Probably using too high an I, Q level—check peak-to-peak levels using an oscilloscope or wide bandwidth true-RMS voltmeter. This problem can also be the result of using a distorted sine-wave signals (GIGO)- check I and Q signals for harmonic content with a low frequency spectrum analyzer or distortion analyzer.
Other poor performance	Be sure you are using a "clean" LO signal. You should be using a sine-wave source with harmonics at least 20 dB below the fundamental frequency. Square wave sources will not work!