Wide modulation bandwidth measurements

A primer on defining the relationship of a VCO's frequency and amplitude parameters.

By Mikhail Mordkovich and Radha Setty

The frequency of a voltage-controlled oscillator (VCO) is proportional to the amplitude of the tuning voltage. Hence, it can be treated as an FM modulator. Every VCO has a tuning voltage range specified. When the tuning voltage is changed at a slow rate, the VCO responds to the voltage changes faithfully. When the rate-of-change of control port voltage is increased, the VCO frequency may not follow as faithfully. The frequency deviation produced for a given voltage swing reduces as the frequency of the control voltage increases. The frequency at which the frequency deviation reduces to 0.707 (or –3 dB) of the DC or low frequency value is a measure of the frequency response of the control port. As the frequency response of the control port is low pass in nature, it is equal to the 3 dB modulation bandwidth. Measurement of the wide modulation bandwidths is not an easy task, since VCOs can have very wide modulation bandwidths, which are useful in angle modulation communication systems. This tutorial explains the theory and method of measurement of wide modulation bandwidth.

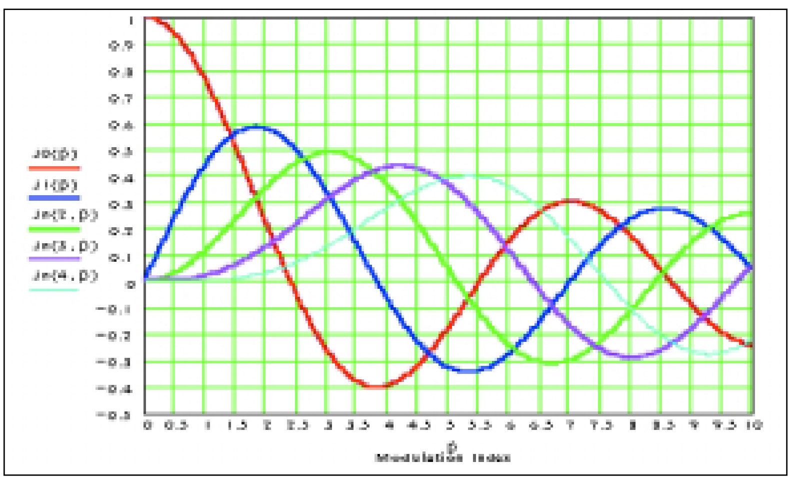

Figure 1. A plot of the Bessel function vs. modulation index.

Theory

Let a DC voltage be applied to the control port of the VCO. This results in a frequency f_0.

Apply a sinusoidal voltage of frequency f_{mod} and amplitude v_{mod} on top of this DC voltage. The result is an FM modulated signal at the output of the VCO and is given by equation 1 (due to string lengths, some of the formulas are at the end of the text).

Where k_v is the tuning sensitivity of the VCO in Hz/V, $\Omega_0 = 2\pi f_0$, and $\Omega_{mod} = 2\pi f_{mod}$

From FM theory, modulation index *b* is defined as:

$$b = \frac{\text{frequency deviation}}{f_{mod}} = \frac{\text{tuning sensitivity} \bullet v_{mod}}{f_{mod}} = \frac{k_v \bullet v_{mod}}{f_{mod}} \qquad (2)$$

Hence, Equation (1) can be rewritten as:

$$V_{out} = V \sin(\Omega_0 t + b \bullet \sin(\Omega_{mod} t)) \qquad (3)$$

Which can be expanded into Equation 4.

As can be seen from Equation 4, the output of the VCO may consist of a carrier signal f_0 and sideband signals spaced at $n \bullet f_{mod}$ on either side of the carrier, where *n* is an integer. The amplitude of the sideband signal is proportional to the n^{th} order Bessel function $J_n(b)$ and is given by:

$$J_n(b) = \sum_{k=1}^{\infty} \left(\frac{(-1)^k}{k!\,(n+k)!} \left(\frac{b}{2}\right)^{(n+2k)} \right) \qquad (5)$$

The carrier amplitude is proportional to the $J_0(b)$, the first sideband amplitude to the $J_1(b)$, etc.

In an ideal VCO of infinite modulation bandwidth, if the amplitude of the modulating signal and f_{mod} are increased proportionally to keep the ratio v_{mod}/f_{mod} constant, the modulation index will remain constant and so will the amplitude of the carrier and sideband signals. In practice, this does not continue indefinitely. As the frequency response of the control port of the VCO starts to become affected, the modulation index starts decreasing or the effective deviation of the modulating signal is decreasing. When it is 0.707 of the initial "slow" deviation value, we have effectively reached the 3 dB response of the control port. Properties of the Bessel functions along with the principle described are used in the modulation bandwidth measurements.

Figure 1 shows a plot of the Bessel function for various values of "*n*" as function of the modulation index. As can be seen in Figure 1, the carrier amplitude is equal to zero when the modulation index is approximately equal to 2.4. This feature is very convenient to use as the specific reference point and it is used in method one of the modulation bandwidth measurements.

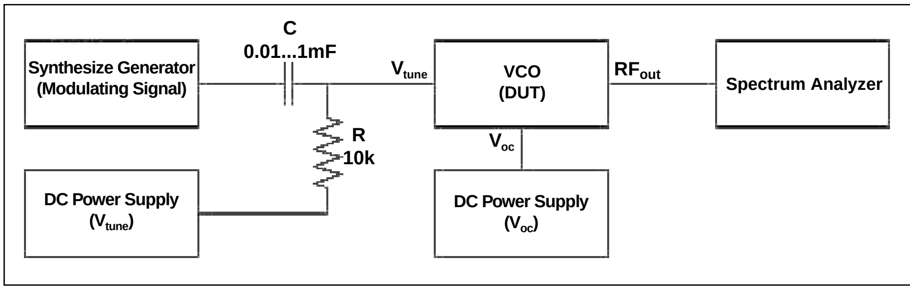

Figure 2. Wide-modulation bandwidth test setup.

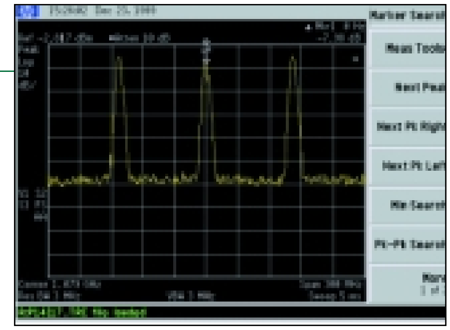

Figure 5. Output RF signal with the modulation index equal to 1.697 applied .

Method one

The block diagram of an experimental set up is shown in Figure 2.

A modulating signal is applied to the device under test (DUT) along with a quiescent DC voltage. DC power supply

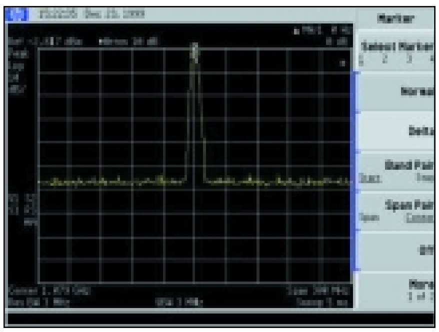

Figure 3. Output RF signal without modulation.

feeds the V_{cc}. The output of the VCO is applied to the spectrum analyzer. The frequency of the modulating signal is set to at least a tenth of the anticipated modulating bandwidth.

Rearranging Equation (2), we get:

$$V_{mod} = \frac{(b \bullet f_{mod})}{k_v} \qquad (6)$$

In the experimental set up in Figure 2, turn off v_{mod} and adjust the spectrum analyzer display to set the carrier to the top of the spectrum display (see Figure 3).

Next, set the f_{mod} to a tenth of the anticipated 3 dB modulation bandwidth. Calculate the amplitude of the v_{mod} required to achieve a modulation index of 2.4 from Equation (6) and set this amplitude. The v_{mod} should be suppressed completely. If required, fine tune the carrier until it is completely suppressed. In practice, a 30 dB suppression is good enough. This should correspond to a modulation index of 2.4. See Figure 4 for a typical spectrum display at this condition.

The task is to find the modulating frequency, which degrades the modulation index to 1.697 (0.707 of 2.4). Slowly

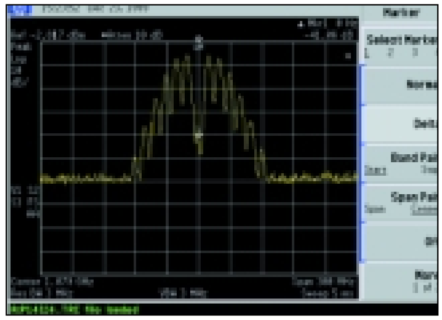

Figure 4. Output RF signal with the modulation index equal to 2.4 applied .

increase the modulating frequency and the amplitude of the modulating signal keeping the ratio of v_{mod}/f_{mod} constant. As the 3 dB modulation bandwidth is approached, the modulation index starts degrading. This results in an increase of the carrier. When the modulation index is equal to 1.697, the carrier level (Equation 3) is 0.4 or it is –8 dBc with the reference to the unmodulated carrier (see Figure 5).

At this time, the modulating frequency is numerically equal to the modulation bandwidth, as the frequency response is assumed to be low pass in nature.

If the selection of the initial frequency is wrong, erroneous results may be achieved. This is true especially if the initial frequency is too close to the 3 dB frequency. To prevent this, repeat the above measurement at half the initial value. If the results are within measurement error, good measurements are made.

Method two

First, set the v_{mod}/f_{mod} to get a modulation index of 2.4, to achieve carrier suppression (as in method one). Again, increase the amplitude of v_{mod} by 1.414 to get a modulation index of 3.4. Increase f_{mod} and v_{mod}, keeping the ratio constant. When the modulation bandwidth is degraded by 0.707, to 2.4, the carrier is fully suppressed and 3 dB bandwidth has been reached.

Method three

Other properties of Bessel functions can be used to do the above measurements as well. For example, begin with a modulation index of 1.44. At this point, the amplitudes of the carrier and the first order sidebands should be equal. Measure the amplitude of the modulating signal and increase it by 1.414 times (inverse of 0.707) of the measured value. This increases the modulation index by 1.414. Increase the amplitude of the modulating signal and the modulating frequency simultaneously, keeping the ratio constant. When the 3 dB frequency has been reached, the carrier and sideband amplitudes are again equal.

Conclusion

Treating VCOs as modulators offers a different perspective on VCO functionality. This process can be effective in helping engineers design and implement VCO designs, both effectively and efficiently.

RF

About the authors

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$$V_{out} = V\sin(\omega_0 t + \int 2\pi k_v)(v_{mod}\cos(\omega_{mod}\, t)dt)) \qquad (1)$$

$$\begin{aligned} V_{out} = V(&J_0(b)\cos(\omega_0 t) - J_1(b)[\cos(\omega_0 t - \omega_{mod}\, t) - \cos(\omega_0 t + \omega_{mod}\, t)] \\ &+ J_2(b)[\cos(\omega_0 t - 2\omega_{mod}\, t) + \cos(\omega_0 t + 2\omega_{mod}\, t)] \\ &- J_3(b)[\cos(\omega_0 t - 3\omega_{mod}\, t) - \cos(\omega_0 t + 3\omega_{mod}\, t)]) \\ &+ \ldots \end{aligned} \qquad (4)$$