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Application Note

Spurious Free Dynamic Range

The Spurious Free Dynamic Range (SFDR) of a system is the range between the smallest signal that can be detected in a system (i.e., a signal just above the noise level of the system), and the largest signal that can be introduced into a system without creating detectable distortions in the bandwidth of concern. (NOTE: The system parameters used to determine the SFDR of a system may be referred to the input or the output. Care must be taken to be consistent when using these parameters.)

The "low" end of this range is limited by noise. The Output System Noise Level (OSNL) (in units of dBm/Hz) is a straight measurement of the output noise power (with no input signal) in a 1 Hz frequency band. The Input System Noise Level (ISNL) is equal to the Output System Noise Level minus the gain of the system. The Noise Figure (NF) of the system is equal to the ISNL minus the Background Noise Level (BNL), or:

NF = ISNL - BNL

Where BNL is a constant equal to: -174dBm/Hz. @ 25°C

Determining the "high" end of the SFDR is a little more complicated. We need to look at distortion, and something called the "Third Order Intercept".

There are different types of distortions created when a signal is injected into a system.

Harmonic Distortion occurs when a single frequency (f) is injected into a system that is not perfectly linear. Additional output signals (spurs) are created at harmonics of the input frequency (2f, 3f, 4f, etc). The strength of each harmonic is dependent on the linearity (or NON-linearity) of the system.

Intermodulation Distortion occurs when 2 (or more) frequencies interact. Consider 2 signals (f1 and f2) simultaneously injected into a system. The non-linear interaction of the two signals create new output signal products (spurs) at the sum and difference frequencies of the two fundamental frequencies (i.e., at fs=(f2+f1), and fd=(f2-f1) [f2 > f1]). These spurs are called "second order" effects. In the linear portion of a system (well below the 1dB compression point) the amplitude of second order spurs will increase by 2 dB for every 1 dB of increase in the amplitude of the fundamental frequencies.

In addition to these second order effects, interactions occur between the fundamental frequencies and the harmonics. These are higher order effects. Third order effects (between one fundamental frequency and the second harmonics of other frequencies) are considered most troublesome. This is because they usually fall at a frequency near the fundamental frequency, and are in the pass band of the system. (Most higher order effects are either below the noise floor, or outside the frequency band of interest and can be filtered out. But not always. Be careful, especially with wide band or multiple band systems.)

Consider two signals, f1 and f2, where the difference in frequency between them is small. Assume they have the same amplitude. Harmonics at 2f1 and 2f2 are generated. Third order spurs occur at (2f1-f2), and at (2f2-f1), very close to f1 and f2 (see Figure 1). Third order spurs will increase 3 dB for every 1 dB the input signals are increased.

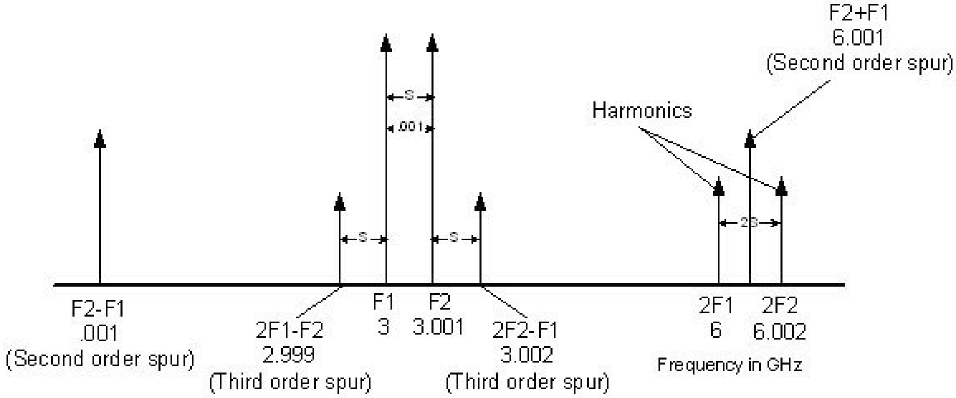

Figure 1: Creating Second and Third Order Products

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Spurious Free Dynamic Range

Third Order Intercept Point (IP3)

Defining the third order Intercept point of a system is a way of characterizing a systems third order distortions and ultimately determining the high end of the system's SFDR.

As noted before, the third order spurs increase by 3 dB for every 1 dB increase in the fundamental frequency. A plot of the fundamental frequency's output power vs. input power would show a slope of 1:1, until you started to reach the systems non-linear region. A plot of the third order frequencies would show a slope of 3:1 in the linear region of the system. If you extend the linear portions of these two plots on the same graph, they would eventually intersect. This point where they intersect is called the Third Order Intercept point (IP3). The IP3 can be referenced to the input or the output. The input IP3 (IIP3) is the input power at the intercept point. The output IP3 (OIP3) is the output power at the intercept point. The IIP3 equals the OIP3, minus the system gain.

We can use the IP3 to predict the third order distortion that will appear in a system.

Since the difference between the slope of the third order response curve and the slope of the fundamental response curve is 2:1, for any output signal, the third order products (spurs) will be twice the distance down from the fundamental as the fundamental is down from the OIP3. This is true as long as the signal is in the linear portion of the system (See Figure 2.)

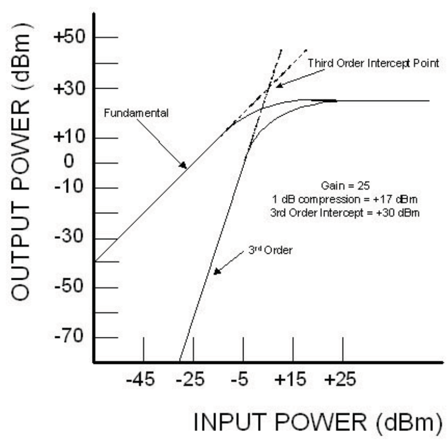

Figure 2: Third Order Intercept Point (Log-Log Scale)

In this example, the OIP3 is +30 dBm. Note that at any fundamental signal level in the linear region of the system, the difference between the fundamental output and the generated output third order spurs is twice as many dB as the difference between the fundamental output and the OIP3. These signal amplitudes can be referenced back to the input by subtracting the system gain from each signal level.

In this example, the Gain is 25, so IIP3=+5 dBm. If the fundamental signal's input level was -25dBm, the fundamental signal's output level is 0dBm. This is 30dB down from the OIP3, so the generated third order spurs at the output would be 60dB down from the fundamental, or -60dBm.

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Spurious Free Dynamic Range (SFDR)

Once the IP3 is known, SFDR is calculated using the following equation:

SFDR = 2/3(IIP3-BNL-10Log (BW) -NF)

Where:

IIP3 = Input Third Order Intercept = Output IP3 - Gain
BNL = Background Noise Level at the input = -174dBm/Hz
BW = System Bandwidth in Hz. (Controlled by filtering or system response)
NF = Noise Figure of the system, in dB

The “high” end of the SFDR is calculated by:

The Maximum Distortion Free Signal, MDFS = BNL + NF + SFDR

Be aware that “distortion free” is a misnomer. In actuality, the MDFS is the largest signal that can be input without generating third order spurs which rise above the noise floor. The distortion is present, just below the noise. As stated before, other distortions may be present.

Putting it all together: an example

Assume the Noise Figure of a system is 37, the OIP3 is +27 dBm, the system bandwidth is 100KHz, and the gain (G) is 0 dB.

1. What is the Input Noise Floor of the system?
2. What is the SFDR of the system?
3. What is the largest signal input level that will not generate detectable third order distortion?
4. What happens if the signal bandwidth was reduced to 1Hz?

1. NF = ISNL - BNL
   ISNL = NF + BNL = 37 + (-174 dBm/Hz) = -137 dBm/Hz

2. SFDR = 2/3(IIP3-BNL-10Log (BW) -NF)
   IIP3 = OIP3 - G = 27 dBm - 0 dB = +27 dBm
   SFDR = 2/3 (27 dBm- (-174dBm/Hz) - 10log105 - 37)

   *SFDR = 2/3 (114) = 76 dBm/Hz2/3

3. MDFS = BNL + NF + SFDR = ISNL + SFDR = -134 + 78 = -56 dBm

4. *Decreasing the bandwidth by a factor of 105 would increase the SFDR by 33.3 dB
   (2/3x (10log105)) to 109.3 dBm/Hz2/3, and the MDFS would increase to -89.3dBm

*NOTE: It is common practice, when comparing the characteristics of two or more systems, to refer the system bandwidth to “unity bandwidth”, or 1 Hz.

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