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APPLICATION NOTE 1838

Mixer 2x2 Spurious Response and IP2 Relationship

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Abstract: This application note details the definitions for 2nd order intercept point (IP2) and 2x2 spurious response, parameters frequently found in RF-related component datasheets such as mixers. Reading through this application note will enable the user to convert IP2 to its corresponding 2x2 spurious response value and vice versa.

When mixer data sheets provide 2nd-order response information in their AC electrical characteristics table, they will either refer to second order intercept point (IP2) performance or 2x2 spurious rejection performance. The purpose of this application note is to show the relationship between these two parameters and its applicability to a receiver design. An example is provided that demonstrates the IP2 and 2x2 relationship for Maxim's MAX9993 active mixer for use in a UMTS WCDMA system.

Wireless Technology Overview

Click here for an overview of the wireless components used in a typical radio transceiver.

Mixer Harmonics

In receiver circuits, mixers translate a high input radio frequency (RF) to a lower intermediate frequency (IF). This process is known as down-conversion utilizing the difference term between the mixer's RF input and local oscillator input (LO) for low-side injection (LO frequency < RF frequency) or the difference term between the mixer's LO and RF for high-side injection. This downconversion process can be described by the following equation:

$$f_{IF} = \pm f_{RF} \pm f_{LO}$$

where f_{IF} is the intermediate frequency at the mixer's output port, f_{RF} is any RF signal applied to the mixer's RF input port, and f_{LO} is the local oscillator signal applied to the mixer's LO input port.

Ideally, the mixer output signal amplitude and phase are proportional to the input signal's amplitude and phase and independent of the LO signal characteristics. (Note this is in contrast to a multiplier where the input amplitude and phase relationship is not preserved at the device output.) Using this assumption, the amplitude response of the mixer is linear for the RF input and is independent of the LO input.

However, mixer nonlinearities produce undesired mixing products called spurious responses, which are caused by undesired signals reaching the mixer's RF input port and producing a response at the IF frequency. The signals reaching the RF input port do not necessarily have to fall into the desired RF band to be troublesome. Many of these signals are sufficiently high in power level that the RF filters preceding the mixer don't provide enough sensitivity to keep them from causing additional spurious responses. When they interfere with the desired IF frequency, the mixing mechanism can be described by:

$$f_{IF} = \pm m \, f_{RF} \pm n \, f_{LO}$$

Note that m and n are integer harmonics of both the RF and LO frequencies that mix to create numerous combinations of spurious products. In reality, the amplitude of these spurious components decreases as the value of m or n increases.

Knowing the desired RF frequency range, frequency planning is used to carefully select the IF and resulting LO frequency selections to avoid spurious mixing products whenever possible. Filters are used to reject out-of-band RF signals that might cause in-band IF responses. IF filter sensitivity following the mixer is specified to pass only the desired frequencies thereby filtering the spurious response signals ahead of the final detector. Spurious responses that appear within the IF band will not be attenuated by the IF filter.

Many types of balanced mixers reject certain spurious responses where m or n is even. Ideal double balanced mixers reject all responses where m or n (or both) is even. The IF, RF, and LO ports are mutually isolated in all double balanced mixers. Therefore, with properly designed baluns, these mixers can have overlapping RF, IF, and LO bands.

Half-IF Spurious Frequency Location

This application note investigates a particularly troublesome 2nd-order spurious response called the half-IF (1/2 IF) spurious response, which is defined for the mixer indices of (m = 2, n = -2) for low-side injection and (m = -2, n = 2) for high-side injection. For low-side injection, the input frequency that creates the half-IF spurious response is located below the desired RF frequency by an amount $f_{IF}/2$ from the desired RF input frequency (see Figure 1). The desired RF frequency is represented by 1950MHz, and in combination with the LO frequency of 1750MHz, the resulting IF frequency is 200MHz. For this example, the undesired signal at 1850MHz causes a half-IF spurious product at 200MHz. For high-side injection, the input frequency that creates the half-IF spurious response is located above (by $f_{IF}/2$) the desired RF.

The half-IF spurious response scenario illustrated in **Figure 1** assumes low-side injection (m = 2, n = -2) is used in a UMTS WCDMA receiver. Though the WCDMA RF and IF carrier occupies a 3.84MHz bandwidth, it's illustrated as a single frequency indicating the center carrier frequency.
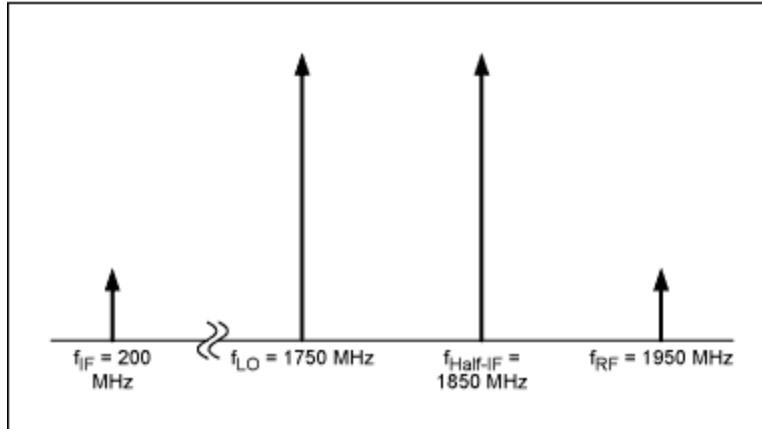
Figure 1. Frequency locations for desired f_{RF}, f_{LO}, f_{IF}, and undesired $f_{Half-IF}$.

Assumptions:

- f_{RF} = 1950MHz
- f_{LO} = 1750MHz
- f_{IF} = 200MHz
- Calculate $f_{Half-IF}$ = $f_{RF} - f_{IF}/2$ = 1850

Check:

$2 \times f_{Half-IF} - 2 \times f_{LO} =$
$2 \times (f_{RF} - f_{IF}/2) - 2 \times (f_{RF} - f_{IF}) =$
$2 \times f_{RF} - 2 \times f_{IF}/2 - 2 \times f_{RF} + 2 \times f_{IF} = f_{IF}$

Results in:

$2 \times 1850MHz - 2 \times 1750MHz = 200MHz$

Receiver IP2

The amount of rejection, called the 2x2 spurious response, can be predicted from the mixer's IP2. When specifying the mixer's IP2 or 2x2 performance, it is assumed that only the fundamental RF and LO frequencies are applied to the mixer ports and that the harmonic distortion is created in the mixer alone. Image-reject filters used in the RF path immediately ahead of the mixer attenuate any amplifier harmonics. The noise filter in the LO path attenuates harmonics caused by the LO injection source. High-level input signals create distortion or intermodulation products and can be quantified by calculating the intercept point, either at the input or output[1] of the device or system. The input intercept point represents a hypothetical input amplitude at which the desired signal components and undesired components are equal in amplitude. For the case where the mixer LO power is held constant, the order of the intercept point or distortion product is determined only by the RF multiplier and not by the LO multiplier because variations in the RF signal are only of concern. The order refers to how fast the amplitudes of the distortion products increase with a rise in input level. For example, the 2nd-order intermodulation (IM) products will increase in amplitude by 2dB when the input signal is raised by 1dB.

Half-IF Spurious Power Levels

The following values are found in the AC Electrical Characteristics Table of the MAX9993 data sheet:

- RF spur level at 1850MHz set equal to –5dBm.
- LO level at 1750MHz set equal to +6dBm.
- Measure typical 2RF – 2LO spurious response equal to 70dB below the RF carrier level, thereby in units of dBc.
- The 70dBc value is referred to the Intermodulation Ratio (IMR).

Note the signal levels in **Figure 2** are referred to the input of the mixer in which the input IP2 or IIP2 performance is calculated.
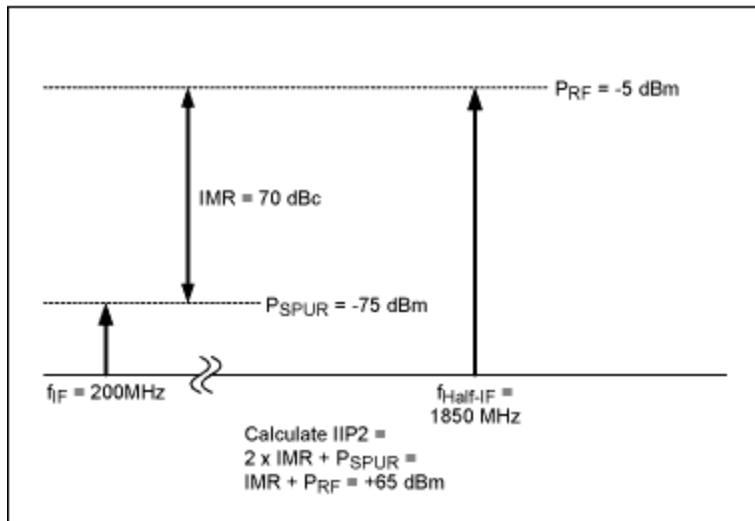

Figure 2. Second-order intercept calculation for signals referred to mixer input, IIP2.

Such superb level of 2x2 performance results in the following:

$$IIP2 = 2 \times IMR + P_{SPUR} = IMR + P_{RF}$$
$$IIP2 = 2 \times 70dBc + (-75dBm) = 70dBc + (-5dBm)$$
$$IIP2 = +65dBm$$

Similarly, Maxim's MAX9982 900MHz active mixer provides typical 2RF – 2LO spurious response equal to 65dBc under similar conditions which results in:

$$IIP2 = 2 \times IMR + P_{SPUR} = IMR + P_{RF}$$
$$IIP2 = 2 \times 65dBc + (-70dBm) = 65dBc + (-5dBm)$$
$$IIP2 = +60dBm$$

UMTS WCDMA Example

Using the 2x2 values from the MAX9993 data sheet for a UMTS WCDMA 3G design, the equivalent IIP2 performance is calculated to be + 65dBm (in Figure 2 above). Given that a UMTS WCDMA cellular system was co-located with a DCS1800 cellular system, the resulting out-of-band CW blocker level is +16dBm (as described in the 3GPP2 standards). For the UMTS WCDMA receiver, an approximate IIP2 value calculated at the antenna terminal is +128dBm. Refer to **Figure 3** for a simplified receiver front-end block diagram depicting stage gains, 2nd-order intercept point, and half-IF sensitivity for each stage through the 1st mixer.
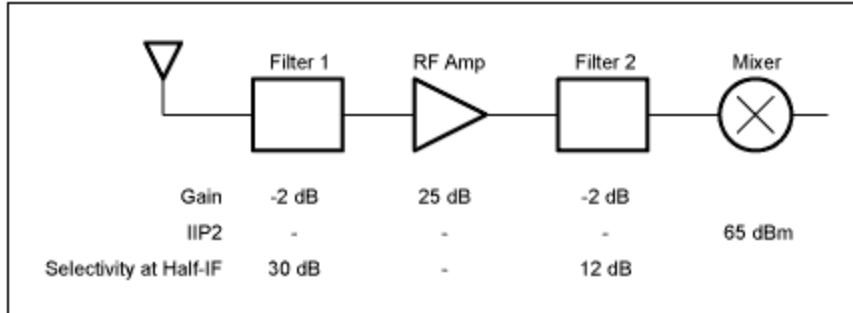
Figure 3. Simplified block diagram for IIP2 example.

The overall cascaded IIP2 performance is determined by a combination of stage gain, filter sensitivity at the half-IF frequency, and mixer 2x2 or IIP2 performance. The cascaded IIP2 is degraded (dB for dB) by the value of the power gain preceding it in the line-up. RF sensitivity can be added in front of the mixer to provide additional spurious rejection. The equivalent intercept point calculated at the antenna improves by twice the amount of the half-IF sensitivity in dB because the amplitude of the second harmonic distortion component increases at a rate two times that of the desired on-channel signal. The IIP2 calculated at the antenna is:

$$IIP2_{Cascade} = IIP2_{Mixer} - Gain + 2 \times Sensitivity = +128dBm$$
$$IIP2_{Cascade} = 65 - (-2 + 25 - 2) + 2 \times (30 + 12) = +128dBm$$

It becomes obvious that the high IIP2 performance of the MAX9993 eases the filter sensitivity requirements to meet the half-IF spurious response. For instance, if the mixer IIP2 were reduced from +65dBm to +45dBm, the cascaded filter sensitivity would have to increase by 10dB.

Conclusion

After reading through this application note, one should be able to convert the 2x2 spurious response value of a mixer to its corresponding IIP2 value, and vice versa. This level of understanding for this 2nd-order relationship allows an RF engineer to determine the proper mixer performance level for the desired application. The MAX9993 2GHz mixer and the MAX9982 900MHz mixer provide superior 2x2 (IP2) performance thereby easing filter requirements making it ideal for high performance wireless systems.

References

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Notes

1. The output intercept point is merely the input intercept point plus the gain (in dB) of the circuit or system under measurement.

Related Parts

MAX9993	High-Linearity 1700MHz to 2200MHz Down-Conversion Mixer with LO Buffer/Switch	Free Samples

More Information

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