Keywords: base station, BTS, receivers, half IF, spurious, RF mixer, IP2, second-order, intercept point, 2x2 spurious rejection

APPLICATION NOTE 5315

Determining the Half-IF Spurious Requirement for an LTE Receiver and Choosing the Appropriate RF Mixer

Sep 18, 2012

Abstract: High-performance base-station (BTS) receivers must meet half-IF spurious requirements, which can be achieved by using the proper RF mixer. To help engineers, this application note illustrates the relationship between a mixer's IP2 and second-order response performance to the half-IF spurious requirement. Examples are given for two mixers that provide superior IP2 performance, making them ideal for wireless design needs.

A similar version of this article appears on *Microwaves and RF*, May 17, 2012.

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

Introduction

This application note explains how to design high-performance base-station (BTS) receivers that meet half-IF spurious requirements. To do this the engineer must understand the relationship between a mixer's IP2 and second-order response performance and then choose the appropriate RF mixer to meet the cascaded requirements. Mixer data sheets will provide second-order response information in terms of either the second-order intercept point (IP2) performance or the 2 x 2 spurious-rejection performance. By showing the relationship between those two parameters, this application note will illustrate their applicability to a receiver design and the determination of the overall half-IF spurious performance. An example demonstrates the IP2 and 2 x 2 relationship for the MAX19997A, an active mixer used in an E-UTRA LTE[1] receiver design.

Mixer Harmonics

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

$$f_{IF} = f_{RF} - f_{LO} = - f_{RF} + f_{LO}$$

Where f_{IF} is the IF at the mixer's output port; f_{RF} is any RF signal applied to the mixer's RF port; and f_{LO} is the LO signal applied to the mixer's LO port.

Ideally, the mixer's output signal amplitude and phase are proportional to its input signal's amplitude and phase; it is independent of the LO signal characteristics. Using this assumption, the amplitude response of the mixer is linear with respect to the RF input signal. It is also independent of the LO signal amplitude.

Mixer nonlinearities, however, produce undesired mixing products called spurious responses. The spurious responses are caused by undesired signals that reach the mixer's RF port and produce a response at the IF frequency. The signals reaching the RF input port need not 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 do not provide sufficient attenuation to keep them from causing additional spurious responses. When these signals interfere with the desired IF frequency, the mixing mechanism is described by:

$$f_{IF} = m\ f_{RF} - n\ f_{LO} = - m\ f_{RF} + n\ f_{LO}$$

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

Knowing the desired RF input-frequency range, frequency planning is used to carefully select the IF and resulting LO frequency. Accurate frequency planning is important because it minimizes mixing products that fall in the desired band which would, in turn, degrade the receiver performance. For wider bandwidth systems, avoiding spurious mixing products becomes significantly more difficult in frequency planning. Filters are used to reject out-of-band (OOB) RF signals that can cause unwanted in-band IF responses. IF filter selectivity following the mixer is specified to pass only the desired frequencies, thereby attenuating the spurious response signals ahead of the final detector that follows the mixer. 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 to minimize LO leakage at the RF and IF ports and provide inherent RF-to-IF isolation. Double-balanced mixer design results in optimum linearity performance and reduces the associated filter attenuation requirements at each of the ports.

Half-IF Spurious Frequency Location

There is a particularly troublesome second-order spurious response called the half-IF (1/2 IF) spurious response, defined for the mixer indices of (m = 2, n = -2) for low-side LO injection and (m = -2, n = 2) for high-side LO injection (**Figure 1**). For high-side injection, the input frequency that creates the half-IF spurious response is located above the desired RF frequency by an amount $f_{IF}/2$ from the desired RF input frequency.

Consider an example where the desired RF frequency is centered at 2510MHz (E-UTRA uplink channel number 39790). When this RF frequency is combined with the LO frequency of 2860MHz, the resulting IF frequency is 350MHz. In this case, an undesired or blocking signal at 2685MHz causes a half-IF spurious product at 350MHz. For low-side injection, the input frequency that creates the half-IF spurious response is located above the desired LO frequency by an amount $f_{IF}/2$.

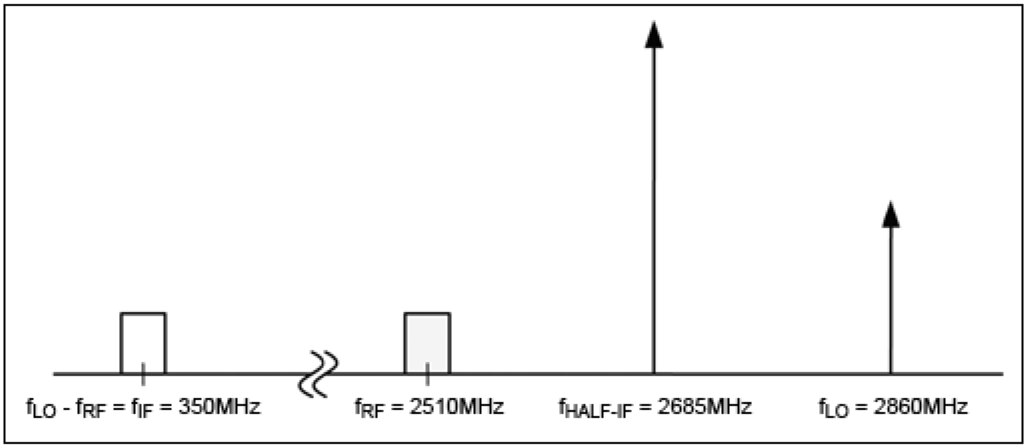

Figure 1. An example of E-UTRA high-side LO injection shows frequency locations for desired f_{RF}, f_{LO}, and f_{IF}, and undesired $f_{HALF-IF}$.

Assume:

- f_{RF} center frequency = 2510MHz
- f_{LO} = 2860MHz
- $f_{IF} = f_{LO} - f_{RF}$ = 2860MHz - 2510MHz = 350MHz

Calculate the blocker frequency that causes undesired spurious response:

$f_{HALF-IF} = f_{RF} + f_{IF}/2$ = 2685MHz

Check the math to verify the half-IF blocker or spurious frequency:

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

This results in the undesired IF spurious signal generated from the half-IF spurious frequency:

2 × 2860MHz - 2 × 2685MHz = 350MHz

Receiver IP2

If not directly specified in a device's data sheet, the amount of rejection, called the 2 x 2 spurious response, can be predicted from the mixer's IP2 performance. Two assumptions are made: only the fundamental RF and LO frequencies are applied to the mixer ports, and the harmonic distortion is created in the mixer alone.

Image-reject filters used in the RF path immediately ahead of the mixer attenuate any undesired RF 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 IP, either at the input or output[2] of the device or system. The input IP represents a hypothetical input amplitude at which the desired signal components and undesired components are equal in amplitude. For the case where the mixer's LO power is held constant, the order of the IP or distortion product is determined only by the RF multiplier and not by the LO multiplier. This is true because variations in the RF signal are the only concern. The order refers to how fast the amplitudes of the distortion products increase with a rise in input level. For example, because of the square-law relationship, the second-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 discussion uses the MAX19997A[3] downconversion mixer as the example. The values are found in the data sheet's AC Electrical Characteristics tables:

- RF spurious power level (at 2685MHz) = -5dBm
- LO level (at 2860MHz) set = 0dBm
- Typical 2LO - 2RF spurious rejection is specified 64dB below the RF carrier level in units of dBc; the 64dBc value is referred to the second-order Intermodulation Ratio (IMR2).
- Calculate P_{SPUR} = -5dBm + (-64dBc) = -69dBm due to mixer performance.

Such superb 2 x 2 performance for the MAX19997A results in the following equivalent IP2 performance at its input (IIP2):

$$\begin{aligned} IIP2 &= 2 \times IMR2 + P_{SPUR} = IMR2 + P_{RF} \\ &= 2 \times 64dBc + (-69dBm) = 64dBc + (-5dBm) \\ &= +59dBm \end{aligned}$$

Similarly, the MAX19985A[4] 900MHz active mixer provides typical 2RF - 2LO spurious response equal to 71dBc under similar conditions:

$$\begin{aligned} IIP2 &= 2 \times IMR2 + P_{SPUR} = IMR2 + P_{RF} \\ &= 2 \times 71dBc + (-76dBm) = 71dBc + (-5dBm) \\ &= +66dBm \end{aligned}$$

E-UTRA LTE Numeric Example

Assuming that an E-UTRA LTE cellular system is colocated with a BTS of the same class, the resulting OOB continuous wave (CW) blocker level is specified as +16dBm (described in the 3GPP TS 36.104 V10.2.0 standards and illustrated in **Figure 2**). For the LTE receiver, the equivalent IIP2 value required at the antenna terminal is +131dBm due to the half-IF spurious signal. The following steps are used for this calculation:

- Desired signal level = sensitivity power level ($P_{SENSITIVITY}$) + 6dB = -95.5dBm
- For LTE 5MHz carrier, use SNR = -1.1dB which corresponds to the highest level of combined noise and spurious product, -96.6dBm.

- Determine the maximum allowable spurious product level = -98.9dBm by subtracting thermal noise + noise figure in the desired bandwidth (in this example, subtract KTBF = -100.4dBm).
- Calculate second-order intermodulation ratio, IMR2 = 115dB.
- Finally, calculate IIP2 = +131dBm as shown in Figure 2.

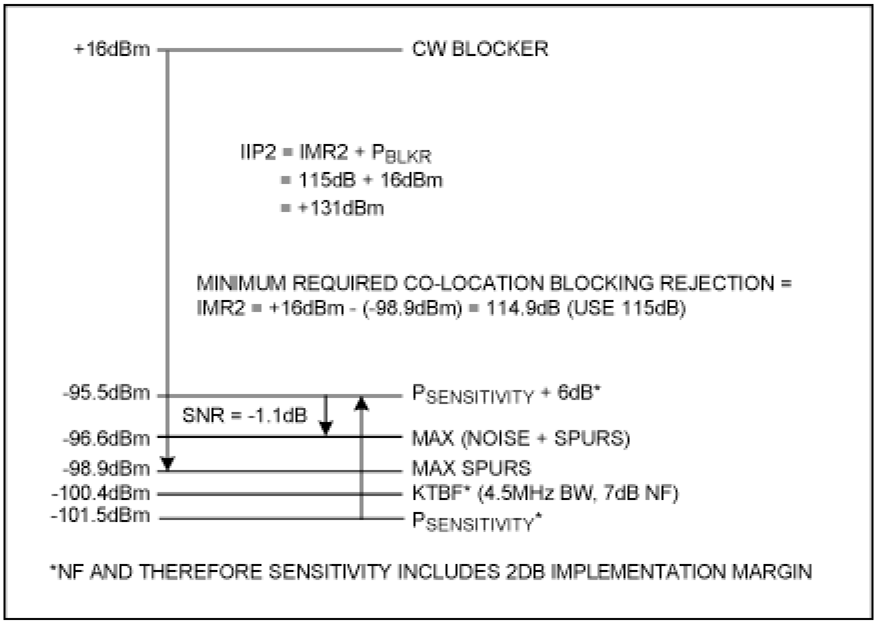

Figure 2. OOB +16dBm CW blocker requires minimum IIP2 performance of +131dBm for LTE wide-area BTS receiver; 5MHz spacing using QPSK, R = 1/3 modulation.

Refer to **Figure 3** for a simplified receiver front-end block diagram depicting stage gain, second-order IP, and half-IF selectivity for each stage through the first mixer.

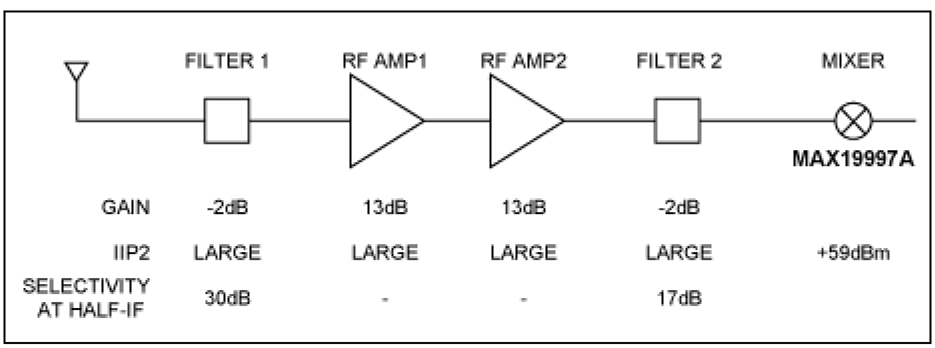

Figure 3. Simplified block diagram for IIP2 LTE example illustrates the MAX19997A's IIP2 performance and related filter selectivity.

The overall cascaded IIP2 performance is determined by a combination of stage gain, filter selectivity at the half-IF frequency, and mixer IIP2 (or 2 x 2) performance. Because the mixer dominates the cascaded IIP2 performance of the entire lineup, IIP2 values for the remaining stages are neglected in the following calculations. IIP2 is degraded (dB for dB) by the value of the power gain preceding the mixer in the lineup. In practice, RF selectivity at the half-IF frequency is added in front of the mixer to provide additional spurious rejection. The equivalent IP calculated at the antenna improves by twice the amount of the half-IF selectivity at the undesired blocking frequency in dB. This improvement occurs because the amplitude of the second-harmonic distortion component increases at a rate two times that of the desired on-channel signal. Using the calculated +59dBm IIP2 value for the MAX19997A in an E-UTRA LTE 3GPP receiver design example, the cascaded IIP2 calculated at the antenna is:

$IIP2_{Cascade} = IIP2_{Mixer}$ - Gain + 2 × Selectivity = +131dBm
$IIP2_{Cascade}$ = +59dBm - (-2 + 13 + 13 -2)dB + 2 × (30 +17)dB = +131dBm

The superb 2LO - 2RF spurious performance of the MAX19997A is of significant value in a design. It can ease the filter selectivity requirements to meet the receiver's half-IF spurious response (as shown in this example) or can provide margin-to-specification when using additional filter selectivity.

Conclusion

This application note has shown how to determine the required receiver's half-IF spurious performance and convert the mixer's 2 x 2 spurious response value (IMR2) to its corresponding IIP2 value, and vice versa. Understanding this second-order relationship allows an RF engineer to determine the proper mixer performance level for the desired application. The MAX19997A 2.5GHz mixer and the MAX19985A 900MHz mixer both provide superior 2 x 2 (IP2) performance which eases filter requirements for the receiver's half-IF spurious performance. This makes these mixers ideal for high-performance wireless designs.

References

1. 3GPP TS 25.104 V10.4.0 (2011-12): 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Base Station (BS) radio transmission and reception (FDD) (Release 10).
2. The output intercept point is merely the input intercept point plus the gain (in dB) of the circuit or system under measurement.
3. MAX19997A Dual, SiGe High-Linearity, 1800MHz to 2900MHz Downconversion Mixer with LO Buffer data sheet.
4. MAX19985A Dual, SiGe, High-Linearity, 700MHz to 1000MHz Downconversion Mixer with LO Buffer/Switch data sheet.

Reference Bibliography

Larson, Lawrence E. ed., *RF and Microwave Circuit Design for Wireless Communications*, Artech House, Inc., 1997.

Loy, Matt ed., "Understanding and Enhancing Sensitivity in Receivers for Wireless Applications," Texas Instruments® Technical Brief SWRA030, May 1999.

Vizmuller, Peter, *RF Design Guide Systems, Circuits and Equations*, Artech House, Inc., 1995.

Related Parts		
MAX19985A	Dual, SiGe, High-Linearity, High-Gain, 700MHz to 1000MHz Downconversion Mixer with LO Buffer/Switch	Free Samples
MAX19997A	Dual, SiGe High-Linearity, High-Gain, 1800MHz to 2900MHz Downconversion Mixer with LO Buffer/Switch	Free Samples

More Information
For Technical Support: http://www.maximintegrated.com/support
For Samples: http://www.maximintegrated.com/samples
Other Questions and Comments: http://www.maximintegrated.com/contact

Application Note 5315: http://www.maximintegrated.com/an5315
APPLICATION NOTE 5315, AN5315, AN 5315, APP5315, Appnote5315, Appnote 5315