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Selecting High-Linearity Mixers for Wireless Base Stations

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This article discusses the key parameters of mixer performance to assist in the selection of an appropriate device for wireless base station design

Today's communication systems make strong demands on both receiver sensitivity and large-signal performance (dynamic range). When selecting components for a new design, therefore, it behooves the designer to focus on the performance of each one with regard to these requirements. In particular, this article deals with mixers and the basic parameters specified in their data sheets.

The communication standards for wireless base stations—e.g., GSM, UMTS, and (now) LTE, define minimum specifications for various parameters, including receiver sensitivity and performance in the presence of large signals. These key requirements make heavy demands on every functional block of the radio in a wireless base station, and are affected by every single component. In the receive signal path, the mixer performance has a major impact on the receiver's overall sensitivity and large signal performance, so by understanding mixer performance issues and parameters, you can select the best mixer for your receive channel.

To start, we first analyze the block diagram of a typical receiver used in wireless base stations (Figure 1). Such receivers are referred to as *dual-conversion superheterodyne* receivers, because the received signal undergoes two consecutive down-conversions from the operating frequency to lower IF frequencies. As shown, the signal is received by the antenna and then filtered by RF filter #1, which is normally used to reject out-of-band "trash" signals that can cause overload or interference. This filter output is then amplified by a low-noise amplifier (LNA), which normally has a very low noise figure.

The amplified signal is again filtered, this time by RF filter #2, which limits the frequency range while removing any remaining unwanted out-of-band signals that can limit the mixer's performance. The amplified and band-limited signal is then fed to the first mixer, where it is down-converted to an IF frequency by mixing with a local oscillator signal.

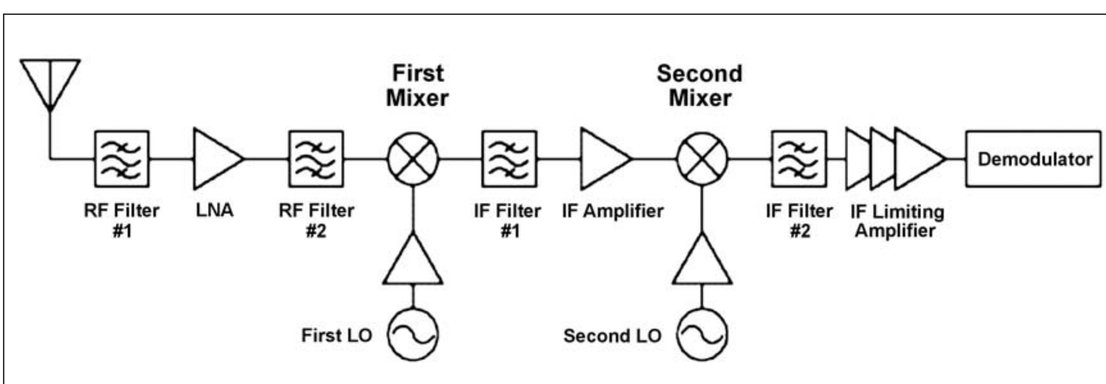

Figure 1 · Block diagram of a typical wireless-basestation receiver.

Depending on the receiver's architecture, this IF signal may be further down-converted to a second, lower IF frequency, and then demodulated to obtain a baseband signal ready for processing.

We now take a closer look at the mixers in this receiver chain. The parameters of the mixers should be investigated, because they have a major effect on the receiver's sensitivity and large-signal performance.

Mixer Performance Parameters

The *noise figure* of a mixer describes the degradation in signal-to-noise ratio from input to output. That ratio is normally expressed in the logarithmic measure of decibels (dB), as shown in equation 1:

$$NF = 10\log\frac{SNR_{RF}}{SNR_{IF}}[dB] \quad (1)$$

A second important parameter is the so-called *conversion gain* (conversion loss, if negative). This parameter gives an important hint as to whether the mixer configuration is active or passive. Passive mixers have insertion loss (conversion loss), because they include no components for amplifying the signal. Active mixers, with their active components, typically provide conversion gain.

An active mixer can be realized either as an integrated mixer based on a balanced design (Gilbert Cell), or as a passive mixer that is combined with a following IF amplifier stage that overcomes the mixer's loss, providing a net gain. Because the integrated mixer has gain, it requires no external IF amplifier stage to make up for insertion loss.

$$\text{Conversion gain/loss} = G = \frac{P_{RF}}{P_{IF}}[dB] \quad (2)$$

Conversion gain (or loss) is a logarithmic measure expressed in decibels. It is frequency dependent, and should be specified over the mixer's entire operating frequency range. To ensure optimal receiver performance, the variation of conversion gain/loss over the user's specified frequency range should be as small as possible.

Because wireless base stations usually operate in a variable temperature environment, the conversion gain/loss should also be specified over the operating temperature range, again with as small a variation as possible. This is important, because under normal conditions a small variation with temperature allows the designer to include a smaller amount of headroom, which is useful in system planning.

The large-signal behavior of a mixer is described by a mixer parameter called the 1 dB signal compression point, also simply called *compression point* (P_{1dB}), and the *second-* and *third-order intercept points* (IP_2 and IP_3). The P_{1dB} compression point predicts the level of input power at which mixer gain is reduced by 1 dB, with respect to the linear expression in equation (3):

$$P_{out} = G \cdot P_{in} \quad (3)$$

Thus, P_{1dB} is a figure of merit representing the point above which the mixer is subject to an overload condition and no longer maintains its specified conversion gain.

A mixer should also have the ability to convert a weak signal when large signals of nearly the same frequency are applied to the mixer's input. This behavior is normally described by the third-order intercept point (IP_3), which together with the noise figure describes the dynamic range of the mixer. IP_3 is is the signal level at which third-order distortion products would be equal to the desired signal. In reality, it cannot be reached because an overload condition would occur at a much lower signal level, but it is a valuable figure of merit, derived from measurements made using signal levels below P_{1dB}. A large IP_3 is the indicator for a high-linearity mixer.

The mixer data sheet should also specify intercept points for the mixer's input and output. Using equation (4), you can calculate the output intercept point from the input intercept point, and vice versa:

$$OIP_3 = IIP_3 + G \quad (4)$$

where OIP_3 is the intercept point at the mixer output, IIP_3 at the input, and G is the conversion gain, or loss, if negative. The OIP_3 for a passive mixer is therefore reduced by the mixer's conversion loss. This insertion loss requires compensation in either the RF or IF gain stages, to establish the receiver's desired overall noise figure (an additional parameter that must be accounted for in the receiver design).

Passive vs. Active Mixers

A big advantage of passive mixers is that they can also be used as frequency up-converters—i.e., their input signals can be converted to a higher frequency. That capability is normally employed in a transmitter chain, to convert an IF signal to the final transmit frequency. Because a passive mixer can be used in the transmit chain as well as the receiver chain, you need to order and stock only one component.

Some receivers employ a *direct down-conversion* architecture that directly down-converts input signals to the baseband, without recourse to an IF signal. For such receivers, the mixer data sheet should specify another important parameter called *port-to-port isolation*. This parameter specifies the amount of isolation between the local oscillator (LO) signal and the mixer input signal. If port-to-port isolation is not large enough, the LO can mix with itself, producing a DC offset at the mixer output that affects the interface to following stages and degrades the receiver performance.

Because a mixer converts frequencies, it generates "new" frequencies called mixer *spurs,* which are unwanted spurious signals. Spurs should be investigated thoroughly, especially those at (2*RF – 2*LO), (3*RF – 3*LO), and higher orders that affect the receiver by creating spurious signals that are near its IF frequency, where they cannot be effectively filtered. This behavior is usually described in a mixer data sheet by the "2 × 2" and "3 × 3" parameters.

Besides these various parameters, you must also consider the level of integration. Some applications can benefit by integrating the mixer core with an LO amplifier, baluns, and LO switch. Nowadays, however, the effort in development projects can be reduced by using one layout for differ-

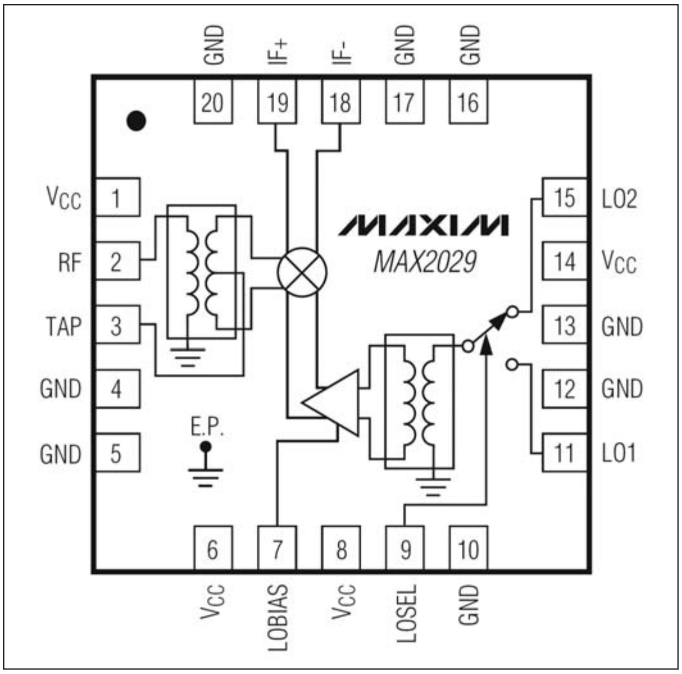

Figure 2 · Block diagram of the MAX2029 passive mixer, showing the major RF functions.

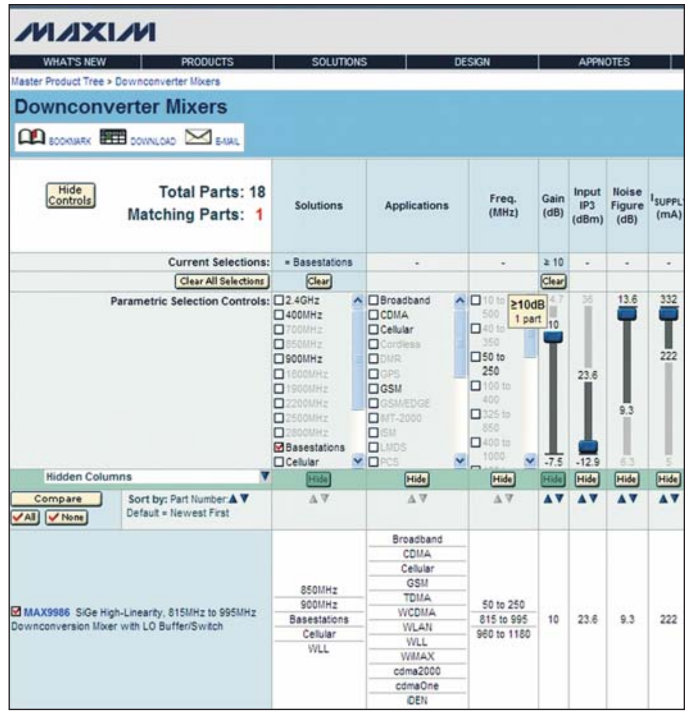

Figure 3 · This new Web tool provides a parametric search that reveals the number of products matching the data filter settings, updating immediately as the user makes selections.

ent frequency ranges. A receiver designed for a 900 MHz GSM system can then be used for an 1800 MHz GSM system, just by changing some key components.

A family of pin-compatible mixers covering the different bands, therefore, would be ideally suited for applications in which a common PC-board layout accommodates multiple frequency bands used for the wireless infrastructure. The ultimate goal is development of a single layout for a multi-standard wireless base station that handles the current set of transmission formats: GSM, UMTS, WiMAX, and LTE.

For example, a passive mixer (MAX2029) in the receiver chain can down-convert the receiver signal, and another identical mixer in the transmitter can up-convert the IF signal to the final transmit frequency. As shown in the block diagram for this chip (Figure 2), it integrates all the typical external components: LO buffer amplifier, baluns, and LO switch.

When used as a down converter, the MAX2029 has an IIP_3 of +36.5 dBm, with P_{1dB} of +27 dBm, 6.5 dB of conversion loss, and a 6.7 dB noise figure. It is well suited for base-station applications in which high linearity and a low noise figure are critical, because its SiGe process technology enables impressive performance.

The 2RF–2LO rejection performance (72 dBc with a –10 dBm RF input signal), enables simpler and more cost-effective filters by easing the requirements for filtering the close-in harmonics. The MAX2029, which is pin-compatible with MAX2039 and MAX2041 mixers, expands the frequency range at the lower end from 815 MHz to 1000 MHz. As one member of a family of pin-compatible mixers, it allows the creation of a single p.c. board layout for receivers that handle different frequency ranges and different communication standards.

As noted before, active mixers can take the form of either a balanced Gilbert Cell design or a passive mixer combined with an IF-amplifier stage. The MAX9986, for instance, represents the second configuration. Its noise figure performance requires less RF gain ahead of the mixer stage, which in turn makes possible a better overall linearity for the receiver. Otherwise, if more gain is required in front of the mixer to minimize the cascaded noise figure, the mixer's linearity must be higher to maintain overall receiver linearity.

Choose the Right Mixer

When searching the Internet for a mixer, the challenge is to sift through all the specifications listed for the various mixers available from a manufacturer and make an optimum choice. Fortunately, a Web-based "parametric search tool" has recently been introduced by Maxim to do just that. It enables design engineers to quickly find the right IC for an application. A single page shows all the criteria available for filtering information from the web, and the corresponding parts. Changing any of these criteria updates the parts list immediately. Features include single-click filtering, sliding filter controls, multilevel sorting, and abundant “tool tips.” There is no easier way to find the right part for an application.

Figure 3 shows the search results for an active mixer with 10 dB gain, designed especially for base stations. The part proposed is a MAX9986. An additional click on that component leads the user directly to the component’s homepage, where the associated data sheet, application notes, and other information can be found.

A parametric search by this new Web tool from Maxim reveals the number of products matching a particular combination of filter settings—before the user makes the first click. The “smart” search algorithm shows only valid criteria. The user cannot make selections that eliminate all parts. Built using the latest Web 2.0 technologies, the tool requires no plug-ins on the user’s system. It is available now at para.maxim-ic.com.

Author Information

Stephanie Overhoff joined Maxim in 2006 as a field applications engineer. She studied Electrical Engineering at Stuttgart University (Germany) and received a master’s degree in 1995. She then worked for one year at Bosch Telecom, in the development department for DECT telephones (the Digital European Cordless Telephone standard). In 1996 she joined Siemens AG and worked in the RF development department, responsible for developing crystal oscillators, synthesizers, and PLLs for mobile phones based on the GSM standard. She also worked on Siemens projects that were integrating GPS receivers with mobile phones for GSM and UMTS.