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APPLICATION NOTE 3632

Wideband LO Noise in Passive Transmit-Receive Mixer ICs

Sep 23, 2005

Abstract: Passive double-balanced mixers comprised of FET quads and diode-rings can work as up- or down-converters in cellular base-station transceivers. High-linearity (IP3), low-noise, and spurious-response up- and down-converters requiring low-level local-oscillator signals have been realized by integrating buffer amplifiers along with the FET or diode mixer cores. Wideband noise in the buffer amplifier stages impairs the received and transmitted signals. This noise can be characterized and specified by a single parameter. By introducing a noise parameter in dBc/Hz for the passive mixer IC, the user can calculate the system-related impairments when using the IC in base-station transmit and receive applications.

Introduction

Cellular base-station transmitters should, ideally, transmit all their power within their own frequency allocation. This poses a challenge, even without spectral re-growth due to power amplifiers. The wideband residual phase-noise floor present in the upconverted transmit signal produces co-siting difficulties with receivers. This broadband noise is at a significantly lower level than the close-in phase noise, but it can be of sufficiently high level to deafen a co-located receiver. In conventional discrete passive diode or FET mixer cores used in base-station transmitters, the LO ports are matched to 50Ω and it is possible to filter the wideband noise before applying the LO signal into the LO port. In integrated mixer and modulator solutions that provide internal local-oscillator driver stages, the wideband input noise is degraded by the internal circuitry. The upconverted signal takes on the spectral skirt and floor of the local-oscillator buffer output. Specifying and designing for lower wideband noise in LO buffers produces lower out-of-band transmit noise. This will ease the rejection requirements of high-Q transmit filters and diplexer filters in front-end equipment.

Cellular base-station receivers have to deal with high-level blocking interferers when receiving weak in-band signals. The blocking signals reciprocally mix with noise in the local oscillator at the mixer core and increase the noise floor inside the signal band at the IF output. This note reviews base-station mixer ICs and noise in mixers, and specifies one single parameter to address both the single-tone desensitization of the receiver when used as a downconverter and out-of-band wideband transmit noise when used as an upconverter.

Base-Station Mixers

Passive-diode and FET-ring mixers have always been the workhorses of base-station receivers. These devices require large external local-oscillator drives—greater than 17 dBm—to achieve a high IP3. **Figure 1** shows how a passive discrete mixer is used in a base-station receiver. They work with discrete IF amplifiers driving surface acoustic wave (SAW) filters and require drive from discrete LO buffer amplifiers. Though active-IC Gilbert mixers with gain are available, they do not meet the demanding linearity and noise requirements of base stations [2,3]. However, there have recently been a number of new silicon mixer ICs [7] with very high linearity (IP3 = 34dBm) and low noise (NF = 7dB) to meet base-station requirements. These mixers have internal local-oscillator drivers, eliminating the need for large-signal, external driver amplifiers. The passive mixer-based ICs are reciprocal devices unlike the Gilbert-cell counterparts. They can work as up- and downconverters. With cascaded IF amplifiers they yield high IP3 (26dBm), and low NF (<10dB), and have sufficient gain to offset the SAW filter loss in receivers. **Figure 2** shows a functional block diagram of a typical high-dynamic-range (HDR) mixer IC. These devices can work with local-oscillator levels as low as -3dBm. The integrated circuits are available in small-footprint 5mm x 5mm QFN packages with form factors smaller than their discrete counterparts.

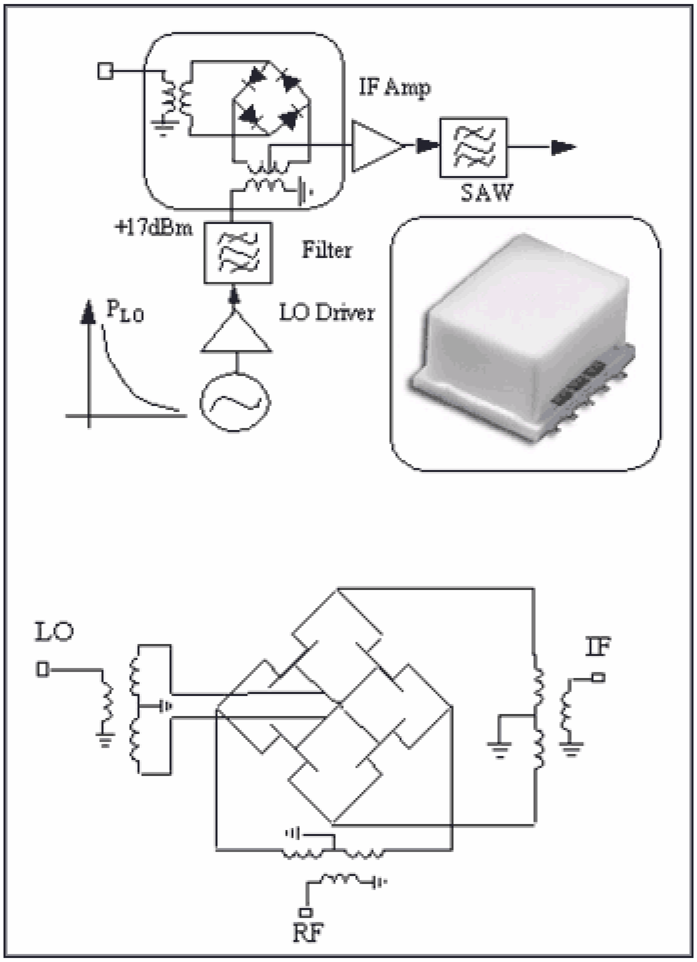

Figure 1. A typical diode-ring or FET passive mixer in a base-station receiver. The package shown in the inset is Mini-Circuits® TTT 167 (12.7mm x 9.5mm surface area).

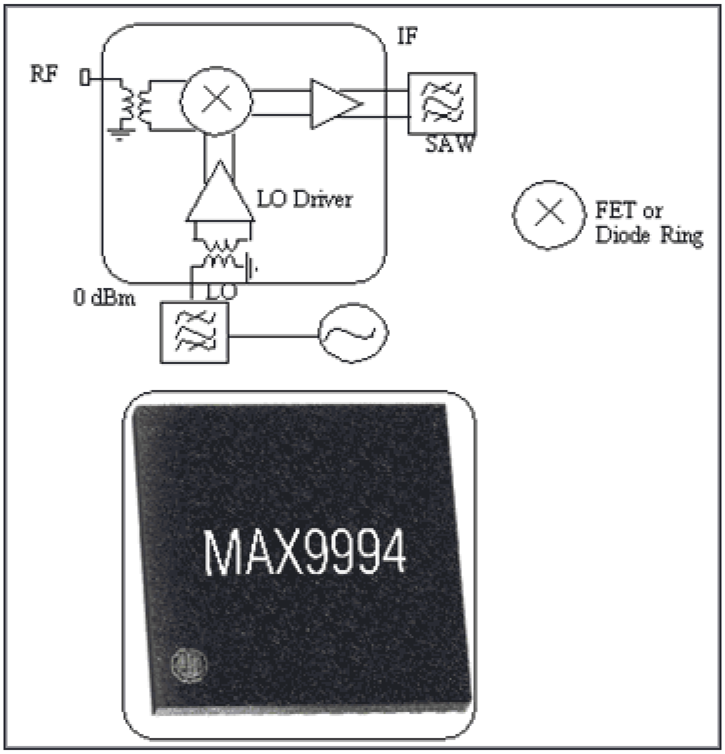

Figure 2. Typical high-dynamic-range silicon base-station receive mixer IC in a 5mm x 5mm package incorporating internal RF and LO baluns, LO buffer, FET or diode ring mixer, and amplifier function at IF. Performance is comparable to discrete mixers have been realized with reduced size and more functionality.

Mixer Noise Model

Thermal noise is the most commonly specified and measured noise in receive mixers. It describes the noise performance of a mixer with a 50Ω matched RF input port and a noise power density of -174dBm/Hz (kTo). The input-referred thermal noise is extracted from the noise figure (10log10F) specification of a mixer,

$$N_{th}^{\;i} = kT_O(F-1) \qquad \text{(Eq: 1)}$$

where

k = Boltzman's constant (1.381 x 10-23 J/K)
T_o = absolute temperature (290 K),

and

F = the noise factor of the passive mixer, given by

$$F = 1 + \frac{(L_C - 1)T_P}{T_O} \qquad \text{(Eq: 2)}$$

where

L_c is the conversion loss of the mixer at a given temperature, T_p (K).

Reciprocal mixing happens in the presence of a strong RF signal at the RF port. This is an additional noise not accounted for during noise-figure measurements. Reciprocally mixed noise $N_{rm}i$ referred to the input can be evaluated at a specific blocker level S_{bl}. Given an LO noise floor *L* into the mixer and a bandwidth *B*, the reciprocally mixed noise at IF is

$$N_{rm}^{\ i} = S_{bl}LB \qquad \text{(Eq: 3)}$$

The phase noise is assumed flat if the interferer frequency offset is a sufficiently large offset from the desired signal. These two noise sources are independent [4] and can be summed as shown in **Figure 3**. The signal-to-noise ratio degradation from input to output in the presence of blockers can be expressed as

$$\frac{SNR_{in}}{SNR_{out}} = F + \frac{N_{rm}^{\ i}}{kT_{o}B} \qquad \text{(Eq: 4)}$$

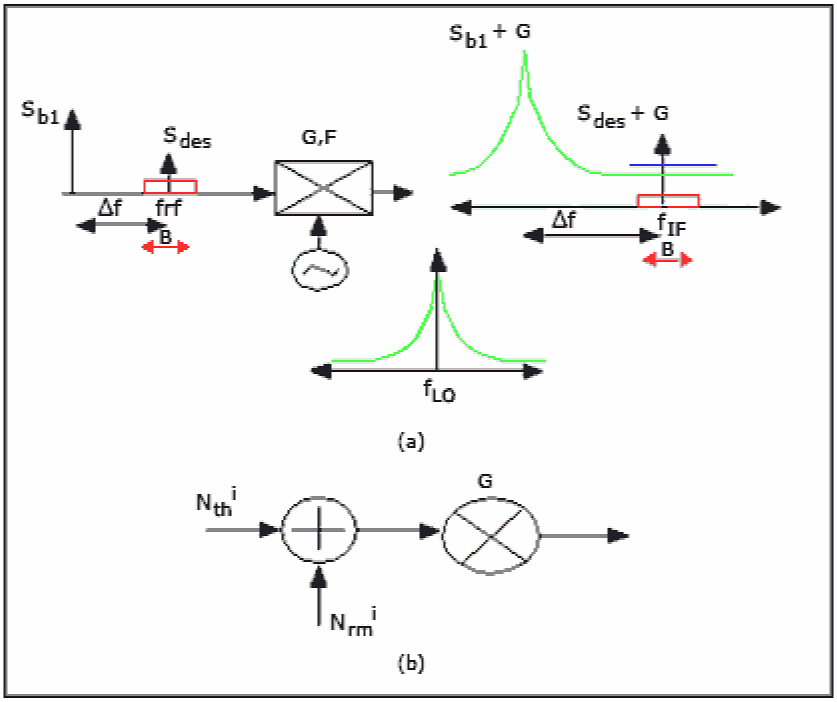

Figure 3. (a) Reciprocal mixing of the RF blocker at power level (S_{bl}) with the wideband LO noise from the LO port. (b) Representation as two independent noise sources, $N_{th}i$ and $N_{rm}i$.

Base-Station System Requirements for Wideband LO Noise

Receivers are primarily specified for sensitivity and allowable impairments to reception due to their non-ideal behavior. For example, in a GSM system, the base station should be able to receive a -104dBm signal with a specified maximum allowable error rate. With the presence of interfering tones, the GSM base-station receiver sensitivity can degrade only by 3dB. These interfering tone levels and their offset from the carrier are pictorially represented in **Figure 4**. For a GSM system with bandwidth *B* = 200kHz, with a blocker level of -13dBm (S_{bl}), and a desired signal level of -101dBm, the wideband LO noise, *L* = 151dBc/Hz, can be computed [4].

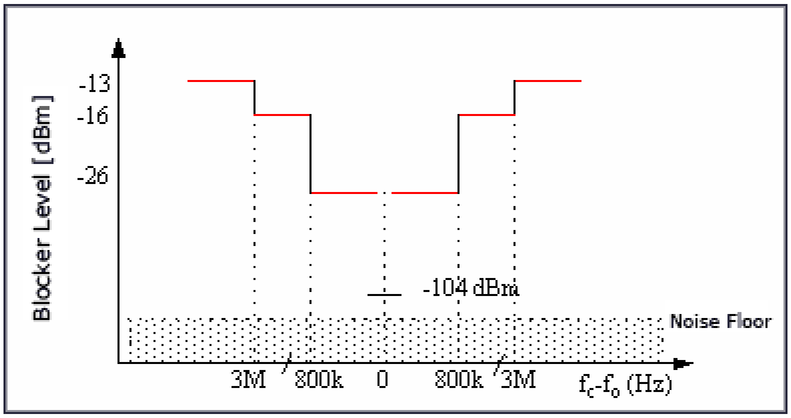

Figure 4. Interferer levels in a GSM system as a function of offset frequency.

Base-station transmitters are allowed to send signals that comply with a spectral mask for in-band and out-of-band signals. GSM also specifies -98dBm as the maximum allowed transmit energy in the receive band [8]. If the base station transmits, say, 43dBm (20W) with a wideband noise of 160dBc/Hz, -117dBm/Hz (43 -160) spills into the co-located receiver. The integrated noise level into a GSM receive band (*B*) of 200kHz is -64dBm. This noise results in an unwanted interference in the receive band and is 4dB above the minimum receivable signal level of -104dBm. Diplexers that connect both the transmitter and receiver to one antenna have to provide sufficient knocking of transmit noise from -60dBm to well below -98dBm. The more wideband noise that is generated in the transmit mixer IC, the more filtering in receive band will be required in the diplexer.

Characteristic Parameter L for Wideband Noise in Base-Station Mixer ICs

Receiver Case

Local-oscillator buffer amplifiers in high-linearity, passive mixer ICs are designed to provide constant higher level drive into the mixer cores, with a varying range of input signal levels. The outputs of these buffers are high-level signals that directly drive the mixer cores so as to achieve high linearity (IP3). The saturated local-oscillator buffers used in passive mixer ICs degrade the wideband signal-to-noise-ratio of the filtered, low-level input. The wideband noise floor can be filtered to -174dBm/Hz. With a 0dBm signal level, the wideband signal-to-noise ratio is 174dBc at the input of the IC's LO port. Practical IC local-oscillator, large-signal buffers cannot degrade this ratio to below 155dBc/Hz to meet system requirements. These buffers are inside the chip in a non-50Ω system, and we do not have access to the LO-buffer outputs, but we can still measure the signal-to-noise degradation of these buffer amplifiers. This degradation in a receive mixer has been characterized by using a blocking signal and measuring the noise output at the 50Ω IF port. The characteristic parameter, L in dBc/Hz, described in Equation 4 can be deduced from the noise measurement [4].

The plot in **Figure 5** shows the RF-to-IF SNR degradation of a PCS/DCS/UMTS-band, passive mixer-based downconverter (MAX9994) as a function of the blocking level. This is a representation of Equation 4 as a function of local-oscillator noise *L* in dBc/Hz. The four different regions of noise are identified in the graph. At low RF-blocker levels, the SNR degradation is mostly thermal, *F*. Thermal noise is the "noise figure" that is commonly referred to for mixers. As the blocker level increases, we see a region 2 where thermal noise and reciprocally mixed local-oscillator noise contribute equally to the SNR degradation. Region 3 is a straight-line portion of the characteristic where the SNR degradation is mostly determined by local-oscillator noise. A base-station receive mixer is designed to handle blocker levels in region 3. The data points indicate a good match between simulation and measurement vs. the model described by Equations 3 and 4. In region 4, a deviation between measurement data and the characteristic curve is noticeable. This is due to compression effects not accounted for in the simple model.

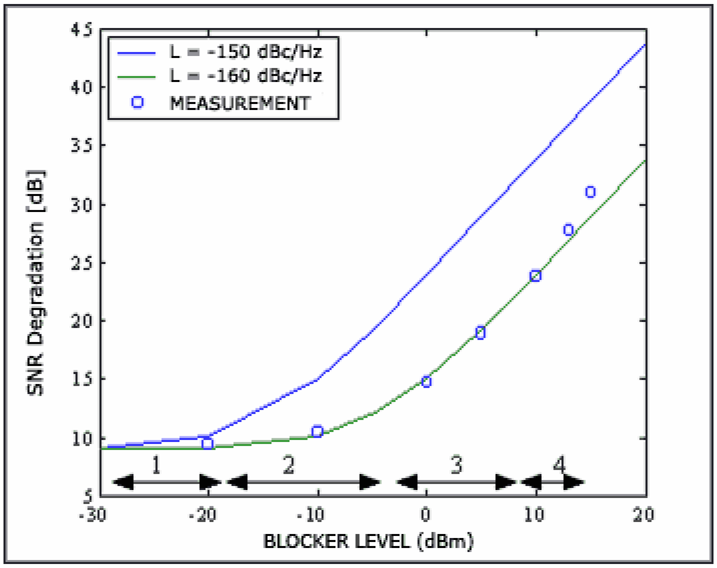

Figure 5. The characteristic curve of MAX9994 HDR mixer IC noise as a function of RF level. The various regions of the curve and the dominant contributors are highlighted. The receive mixer is designed for blocker levels in the straight-line portion of the curve.

The MAX9994 downconverter has a passive mixer in cascade with an IF amplifier. The downconverter is designed to have nominal gain of 8.5 dB, NF = 9.5dB, P1-dB = 13-dBm and requires 220mA DC current. The input intercept point (IP3) is 26dBm to 27dBm, nominally. The SNR degradation under blocking conditions can be measured using the setup described in our *Microwave Journal* article [4]. The SNR_{in}/SNR_{out} with a blocker level of 5dBm is 19-dB. This is noted by measuring the output noise floor of the downconverted signal under blocking conditions. This point lies right on the L = -160dBc/Hz curve in Figure 5. This region is ideal for characterizing LO noise (L) because the buffer-amplifier noise is the dominant contributor for the cumulative SNR degradation, and thermal noise can be ignored as a first-order approximation. We can crosscheck the LO noise from the SNR degradation of 19 dB. Referring the noise to the input, we have Ni = -174 + 19 = -155dBm/Hz. Because the blocker level used is 5dBm (Si), the signal-to-noise ratio, L = -160dBc/Hz.

Transmitter Case

The MAX2039 uses a passive-FET mixer with the same LO buffer as the MAX9994. The MAX9994's IF amplifier is bypassed internally. The IC can be used as an up- or downconverter. The conversion loss (L_C) is 7.0dB in both cases. The IP3 is 34.5dBm as a downconverter and 33.5dBm as an upconverter. When used as an upconverter, the same LO-noise parameter determined by receiver measurements in the "receiver section" should also determine the wideband output noise floor at the RF port. For this to be true, the reciprocal mixing of local-oscillator buffer-amplifier noise (L) with an input RF-blocker in the downconverter should be the same as reciprocal mixing of the IF signal with noise (L) that ends up at the RF transmit port. If L can be measured in the MAX9994 that uses the same passive mixer and buffer amplifier as the MAX2039, then we should be able to use the same L to deduce the wideband transmit noise of the MAX2039. Our objective is to use L as determined by the receive measurement to deduce the transmit noise and verify the transmit noise by measurement.

In the presence of a blocker in region 3 of the characteristic, say, P_{rf} = 5dBm, the IF amplifier is not compressed. The noise floor at the output of the passive mixer in the MAX9994 is high ($P_{in} - L_C + L = 5$

- 7 + 160 = -158-dBm/Hz), compared to the input referred noise of the IF amplifier (2.5 - 174dBm/Hz). This noise simply gets amplified by the IF amplifier and ends up at the output of the MAX9994. Thus, the LO-noise measurement of the passive-mixer portion of the MAX9994 is not disturbed by the IF amplifier.

Using the LO noise, *L* = 160dBc/Hz determined by working the passive mixer in receive mode, and conversion loss, L_C of the mixer, the following can be derived for the transmitter. For an input IF signal level of 10dBm, we have 3.0dBm RF signal at the output with a noise-floor of 3 - 160 = -157dBm/Hz. The noise floor, when amplified by 22.0-dB of external RF gain in the setup, should yield, N_{out} = -135dBm/Hz. The measurement setup in **Figure 6** confirms this. Therefore, we can use one parameter, L (dBc/Hz), deduced in the blocking noise measurement described in [4], to determine the transmit noise floor.

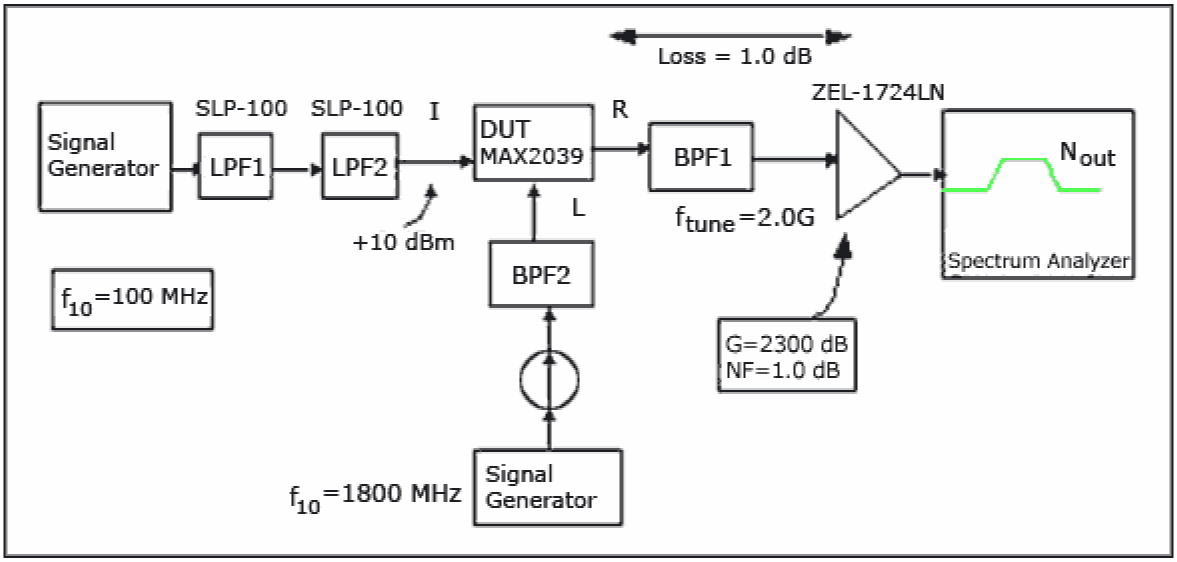

Figure 6. Experimental setup to measure the RF output noise of the upconverter.

Conclusion

We have reviewed LO-noise impacts on base-station receive and transmit mixers. Specifically, local-oscillator SNR measurement on reciprocal FET and diode-core mixers driven by stages of buffer amplifiers yields

1. SNR degradation (desensitization) of the downconversion receiver under blocking conditions, and
2. Determines the noise floor at the RF output when working as an upconverter.

We have shown that one LO-noise specification, *L* (dBc/Hz), for a base-station passive-mixer-based IC, enables evaluation of system impairments in transmit and receive applications.

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Related Parts		
MAX2039	High-Linearity, 1700MHz to 2200MHz Upconversion/Downconversion Mixer with LO Buffer/Switch	Free Samples
MAX9994	SiGe High-Linearity, 1400MHz to 2200MHz Downconversion Mixer with LO Buffer/Switch	Free Samples

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