

Computing the LO Phase Noise Requirements in a GSM Receiver

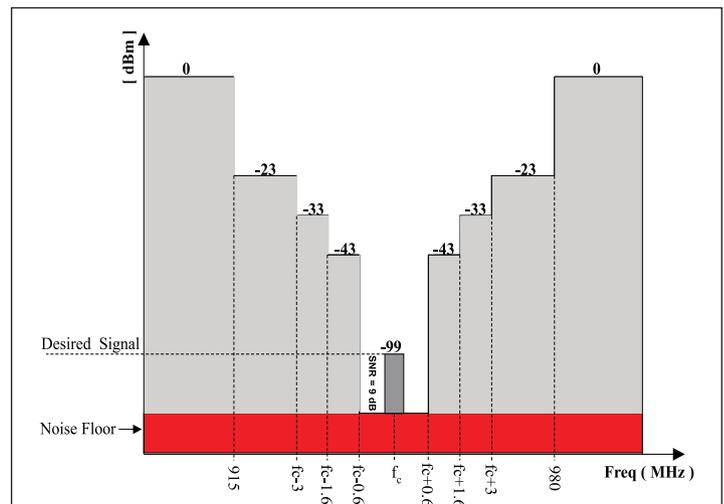
Specify the proper level of performance by considering the effects of blocking signals and increased noise due to reciprocal mixing

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This article presents a formula for computing the local oscillator (LO) phase noise requirements for a GSM receiver. The formula not only takes into account the effects of reciprocal mixing of a blocking signal with the phase noise of the LO, it also includes the effects of gain compression in the receiver front-end due to the blocking signal as well as the white noise added to the desired signal band.

In a typical heterodyne wireless receiver, the LO, usually implemented in a frequency synthesizer, provides the carrier signal necessary for the mixing process. The single-sideband (SSB) phase noise of the LO is a critical performance parameter for the receiver. In phase-modulated digital communications systems such as the Global System for Mobile Communications (GSM) handsets, the integrated phase noise of the synthesizer contributes to the RMS phase error of the transceiver. In a GSM receiver, when the Gaussian minimum-shift-keying (GMSK) signal is demodulated, the phase error will generate deviations in the location points within the demodulation's scheme constellation diagram. These deviations in the constellation points, which can be directly correlated to the LO phase noise, contribute to an increase in the system's bit-error-rate (BER).

Given the impact of the LO phase noise in the receiver, it is critical to find out what level of this noise will meet the required receiver performance. We will derive a formula that can be used to compute the LO phase noise require-



▲ Figure 1. GSM blocking signal level requirements (at the antenna input).

ments for a GSM receiver. This formula includes the effects from the reciprocal mixing, receiver gain compression and receiver thermal noise.

Reciprocal mixing effects

The simplest method for calculating the phase noise performance required for the LO is to assume that the receiver channel is noiseless. In this case, the only interference produced within the signal bandwidth as it moves through the receiver chain is due to the phase noise reciprocal mixing with a strong interferer (also called the blocking signal or blocker) [1]. The GSM standard imposes stringent constraints on the close-in and far-out receiver interference levels. As depicted in Figure 1, the blocker at the antenna input can be as high as 76 dB above the desired signal at a frequency

only 3 MHz away from the carrier. The receiver must still meet a specified BER for a useful signal at the desired frequency that is 3 dB above the reference sensitivity in the presence of a larger continuous blocking signal. The reference sensitivity is specified as -102 dBm minimum, which would give the desired signal a level of -99 dBm.

As shown in Figure 2, when the desired signal is accompanied by a strong interferer, the two signals mixing with the UHF LO produces a downconverted signal. This signal consists of two overlapping spectra and will suffer from significant noise due to the “tail” (noise sidebands) of the LO.

Here, the phase noise is assumed to be flat across the band of interest at a certain offset frequency (Δf_c) from the carrier. The interference component that is then produced when the blocker mixes with the phase noise sidebands is then compared to the desired signal which mixes with the carrier energy. Based on the required carrier-to-interference (C/I) ratio at the output of the mixer, and on the blocker level along with its frequency relative to the desired signal, the required phase noise performance in dBc/Hz may be estimated using the following equation:

$$L(\Delta f_c) = S_{des} - S_{bl}(\Delta f_c) - C/I_{req} - 10\text{Log}(BW) \quad \left(\frac{\text{dBc}}{\text{Hz}} \right) \quad (1)$$

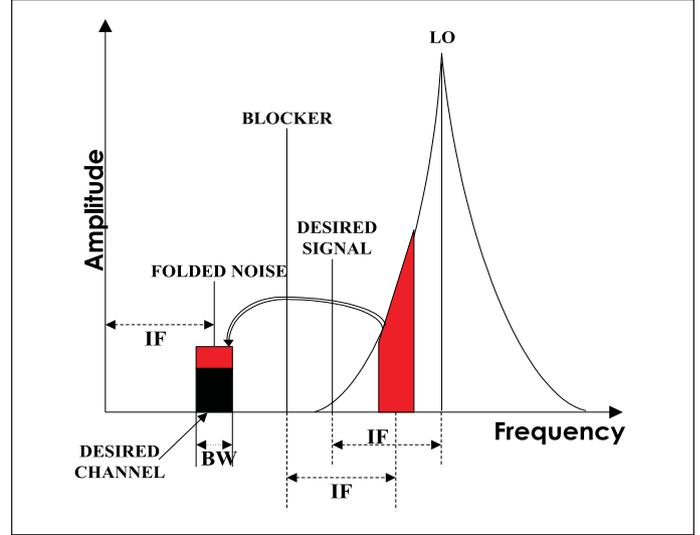
where,

- $L(\Delta f_c)$ = phase noise in dBc/Hz at Δf_c away from the carrier
- $S_{bl}(\Delta f_c)$ = magnitude of the blocker in dBm (or dBV)
- C/I_{req} = minimum magnitude of the required carrier-to-interference ratio at the baseband processor input in dB
- S_{des} = desired signal level in dBm (or dBV)
- BW = receiver noise bandwidth

Using the previous formula and considering the blocking signal levels in Figure 1 with 200 kHz of channel bandwidth and 9 dB of signal-to-interference ratio, we will obtain the phase noise requirements shown in Table 1.

Δf_c	S_{bl}	$L(\Delta f_c)$
3 MHz	-23 dBm	-138 dBc/Hz
1.6 MHz	-33 dBm	-128 dBc/Hz
600 kHz	-43 dBm	-118 dBc/Hz

▲ **Table 1. LO phase noise requirements at various frequency offsets based on equation (1).**



▲ **Figure 2. Reciprocal mixing effects.**

Gain compression effects

The previous formula did not take into account the fact that the presence of the small desired signal and a strong interfering signal at the receiver input will create a reduction in the small signal gain of the receiver. Known as “blocking,” this process is created by the non-linearity in the receiver front-end since it contains compressive circuits (LNA, mixer). As a result, the small signal gain of the receiver front-end (all the receiver stages up to the first downconverter) will be reduced and therefore, the desired signal will see an “apparent gain” G' [2] which is given by the expression:

$$G' = G_1 \left[1 + 3 \frac{G_3 (S_{bl})^2}{2G_1} \right] \quad (2)$$

where S_{bl} is the blocking signal level as previously defined, G_1 and G_3 respectively are the gain shown by the small desired signal and the blocking signal, and their ratio $\alpha = G_1/G_3$ is related to 1 dB compression point of the receiver front-end by the following equation [1]:

$$\alpha = - \frac{(A_{1-dB})^2}{0.145} \quad (3)$$

where A_{1-dB} is the receiver 1 dB compression point.

Additionally, the blocker will also see an apparent gain G'' given by the equation:

$$G'' = G_1 \left[1 + 3 \frac{G_3 (S_{bl})^2}{4G_1} \right] \quad (4)$$

So the resulting desired signal at the output of the mixer will be $S_o = S_{des} \times G'$ and the blocker level will be $S_I = S_{bl} \times G''$. Therefore, substituting these new variables in (1), we obtain a new expression for the phase noise of the LO using the gain compression effects:

$$L(\Delta f_c) = S_{des} + G' - S_{bl}(\Delta f_c) - G'' - \frac{C}{I_{req}} - 10 \log(BW) \quad \left(\frac{\text{dBc}}{\text{Hz}} \right) \quad (5)$$

Let us consider a typical GSM receiver with the following parameters: $G_1 = 22$ dB, $A_{1-\text{dB}} = 0.014$ V (−24 dBm in 50 ohms). For 9 dB of minimum signal-to-interference-ratio at the receiver front-end output, equation (5) will produce the results in Table 2.

As the table shows, by considering the gain compression effects on the receiver front-end and the presence of a strong blocker near the desired signal, the LO phase noise requirement is 1.5 dB lower at 3 MHz away. At 1.6 MHz and 600 kHz offset frequencies, the effects of gain compression are less pronounced because at these offsets, the interferer levels are lower, resulting in smaller differences between the apparent gains of the desired signals (G') and the interferers (G''). Because the receiver is desensitized by a smaller amount at these offset frequencies, the reciprocal mixing effects are not as important as with the 3 MHz offset.

Thermal noise effects

Equation (5) can be used to approximate the required phase noise performance of the local oscillators in the receiver, assuming there is no contribution from thermal noise at the receiver output. Practically speaking, this is far from the true situation; the receiver noise contribution will further degrade the overall carrier-to-interference ratio at the output. Therefore, a better picture of the true C/I ratio at the receiver front-end output should include the white noise added to the desired signal band. At the receiver front-end output, the total SNR will have a contribution from the thermal noise (C/N_{th}) and a contribution from the reciprocal mixing effects as derived in the previous section (C/N_{rm}).

Combining these two effects, the total SNR at the receiver output will then be given as follows:

$$\frac{C}{N} = \left[\left(\frac{S_o}{N_{th}} \right)^{-1} + \left(\frac{S_o}{S_I} \right)^{-1} \right]^{-1} \quad (6)$$

As previously explained, $S_o = S_{des} \times G'$, $S_I = S_{bl} \times G''$ and the thermal noise is given by:

$$N_{th} = k \cdot T \cdot BW \cdot F \cdot G'$$

where F is the receiver front-end noise factor in the presence of a blocking signal.

Δf_c	S_{bl}	$L(\Delta f_c)$
3 MHz	−23 dBm	−139.5 dBc/Hz
1.6 MHz	−33 dBm	−128.3 dBc/Hz
600 KHz	−43 dBm	−118.1 dBc/Hz

▲ **Table 2. LO phase noise requirements based on equation (5). The same results are obtained using equation (7).**

Combining equations (5) and (6), the overall phase noise requirement on the LO should now be given by equation (7):

$$L(\Delta f_c) = 10 \log \left[\left[\left(\frac{S_o}{kT \cdot BW \cdot F} \right)^{-1} + \left(\frac{S_o}{S_I \cdot BW} \right)^{-1} \right]^{-1} \right] - \frac{C}{I_{req}}$$

The phase noise requirements for the receiver LO obtained using equation (7) are the same as in Table 2. The LO phase noise requirements are identical to the ones obtained previously using equation (5) because, in the GSM receiver, the thermal noise is much lower than the noise from the reciprocal mixing effects. The limiting factors are thus the reciprocal mixing and the gain compression, not the thermal noise.

Conclusion

In this article, we have considered the effects of reciprocal mixing, receiver front-end gain compression due to the presence of blocking signals and thermal noise on the LO phase noise requirements for a heterodyne receiver. Using the GSM receiver as an example, we found that the reciprocal mixing effects are the limiting factor for the LO phase noise. ■

References

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