 Nov 05, 2003

# Calculating the Sensitivity of an ASK Receiver

*The sensitivity of RFIC Amplitude Shift Keying (ASK) or On-off Keying (OOK) receivers is an important specification for designers of Remote Keyless Entry (RKE) systems, Tire Pressure Monitoring (TPM) systems, Home Automation systems, and other applications. These receivers typically operate at 315 MHz or 433 MHz, but the results apply to almost any carrier frequency. It is important for the users and designers of RFICs to know the theoretical limit of these receivers so that they can determine if their design improvements are fully successful. This application note describes a step-by-step method to predict the sensitivity of an ASK receiver, given a system noise figure, IF bandwidth, and Baseband bandwidth. The results show that the logarithmic amplitude detection in the Received Signal Strength Indicator (RSSI) amplifier decreases the output Signal to Noise Ratio (SNR) for low input SNRs (threshold effect) and that the sensitivity increases as the square root of the IF to Baseband bandwidth ratio.*

Most modern Amplitude Shift Key (ASK) receivers detect data by passing the modulated RF signal to an amplitude detector either directly or after one or more frequency conversions. The amplitude detector is almost always an RF or IF amplifier with an RSSI (Received Signal Strength Indicator) detector whose output is proportional to the logarithm of the input power of the RF or IF signal.

Because the RSSI detector is a nonlinear detector, it changes the Signal to Noise Ratio (SNR) of the signal that goes into it. The key to the ASK sensitivity calculation is the $SNR_{out}$ vs $SNR_{in}$ curve of the RSSI detector.

Once we know the $SNR_{out}$ vs $SNR_{in}$ relationship, the steps to finding the ASK sensitivity for a given Noise Figure, IF Bandwidth, and Data Rate are given below.

1. Determine the Eb/No needed for a target BER (10-3 in this example) then calculate the SNR from the Eb/No by using
   SNR = (Eb/No) * (R/BBW)
   Where R is the data rate and BBW is the Data Filter bandwidth.
2. Reduce the SNR calculated from the previous step by the ratio in dB of the IF (pre-detection) BW to the Data Filter BW. For instance, a 600 kHz IF BW and 6 kHz Data Filter BW means a 20 dB reduction in the SNR. This is the SNR of the signal coming out of the RSSI detector before the Data Filter gets rid of the high frequency noise (assumed to

occupy the IF BW). At sensitivity, this ratio is usually negative in dB.

3. Use the RSSI $SNR_{out}$ vs $SNR_{in}$ curve to find the SNR at the input to the RF or IF Amplifier and RSSI detector. You actually use the curve "backwards" to find $SNR_{in}$ given the $SNR_{out}$ you calculated in Step 2.

4. Use the SNR formula for the front end of a receiver to find the signal level at the receiver input. This is the sensitivity, S.

$$S = (SNR_{in}) * (kTBIFFS)$$

Where kT is the noise spectral density at 290 K (-174 dBm/Hz) BIF is the IF (pre-detection) BW, and FS is the system (not just the front-end) noise figure of the receiver.

Because the RSSI detector is a logarithmic detector, the SNR input-output relationship can be expressed in a closed-form expression, albeit a messy one. An old paper published in the IEEE Transactions on Aerospace and Electronic Systems[1] derived the expression and plotted the $SNR_{out}$ vs $SNR_{in}$ curve. The curve in the article is small and doesn•ft have enough gridlines, but it is possible to evaluate the expression in an Excel spreadsheet and plot it in better detail. The curve appears below, plotted along with a simple $SNR_{out} = SNR_{in}$ curve (linear detection) for comparison. Notice the threshold effect. Below the "crossover point" SNR of 3.7 dB, the SNR gets worse going through the detector. Above this point, it improves.

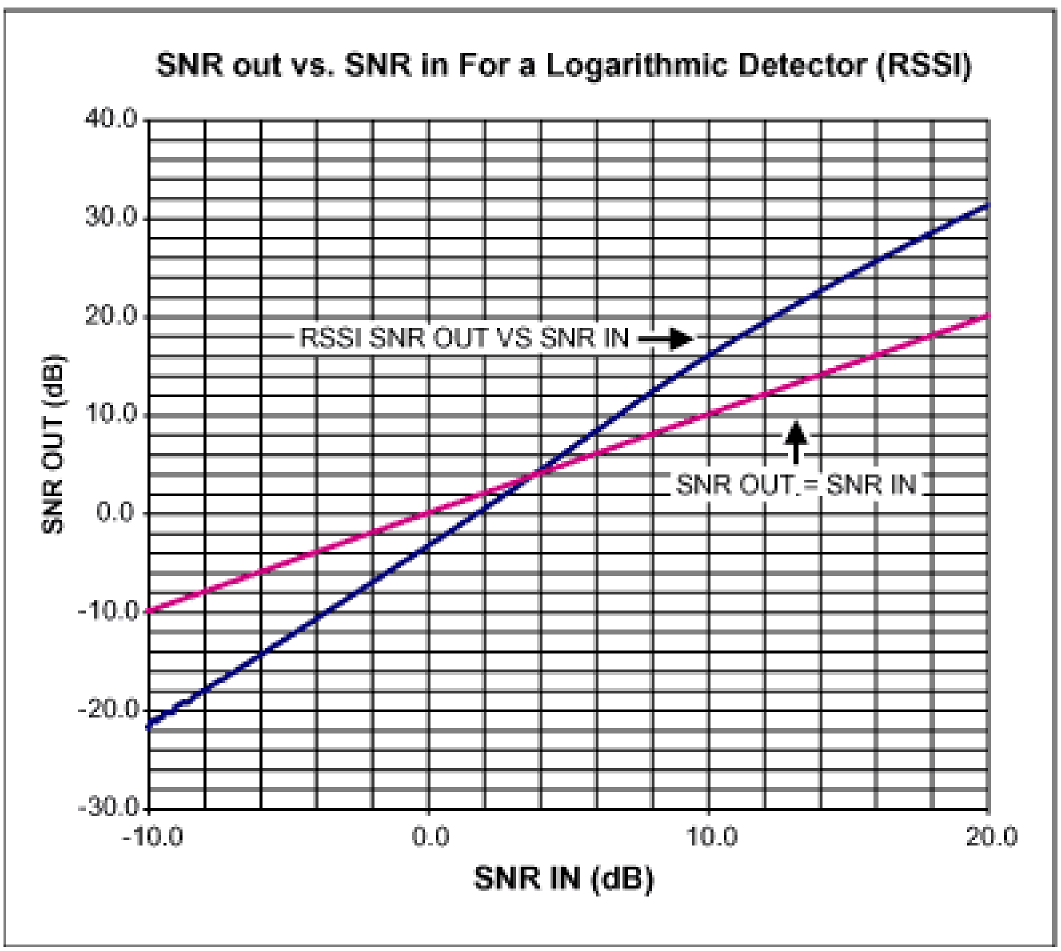


*Figure 1.*

Another Excel spreadsheet incorporates Steps 1 through 4 above with the $SNR_{out}$ vs $SNR_{in}$ curve to produce the sensitivity calculations shown in the next graph. They are plotted as Sensitivity vs. Data Rate for three IF bandwidths, using 7 dB for a Noise Figure. Notice that sensitivity improves roughly as the SQUARE ROOT of either the IF BW or the Data Rate. This is because at sensitivity we are working in the range of the RSSI SNR curve where the slope of $SNR_{out}$ to $SNR_{in}$ is roughly 2 (a square-law relationship) in log scale.

The curves are consistent with practical experience for carefully designed ASK receivers. For instance, at a 3 kbps data rate and 280 kHz IF BW, the sensitivity is -114 dBm. An 11 dB Eb/No, corresponding to a $10^{-3}$ BER for ASK, is used in this calculation, which leads to about 12 dB SNR for a steady CW signal ("peak" Eb/No is 14 dB because data is 50% duty cycle on average, less about 2 dB for the ratio of 1.5:1 of BBW to Data Rate).

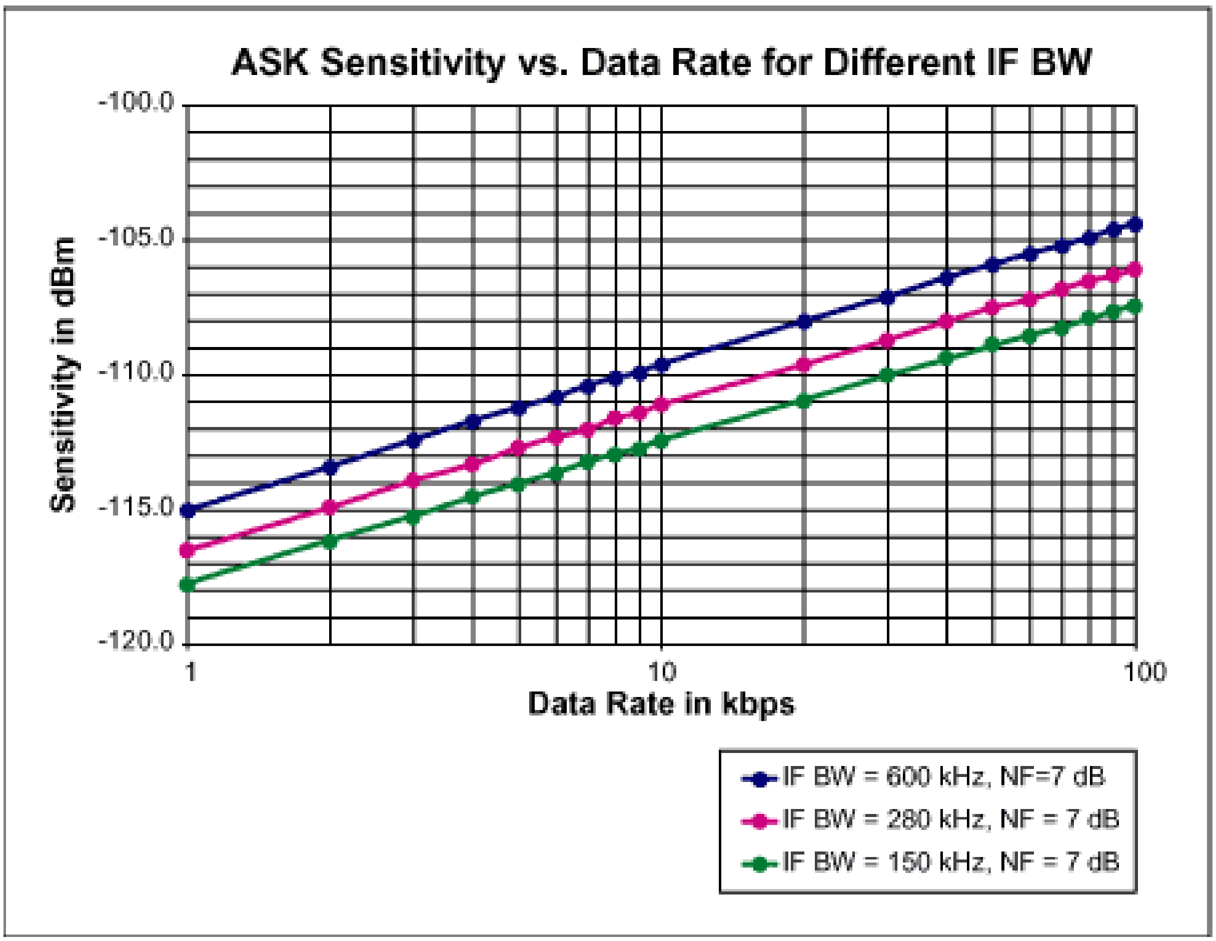


*Figure 2.*

It is important to point out two assumptions made here: (1) That the noise bandwidth at the output of the RSSI detector is the same as the IF bandwidth, and (2) that the noise distribution at the output of the RSSI detector is Gaussian. In fact, the noise bandwidth of the RSSI detector might be much larger than the IF bandwidth. This can be taken into account by increasing the effective system noise figure. The output noise distribution is not Gaussian, so a complete analysis would require calculating probabilities of error for the exact noise distribution at the RSSI output. We believe that the difference in Eb/No for a given BER is small, and that it will not change the fundamental results of this paper listed below.

1. The $SNR_{out}$ vs $SNR_{in}$ relationship of the RSSI detector has been characterized.
2. There is a threshold effect, in which the output SNR improves for input SNRs above 3.7 dB and degrades for input SNRs below 3.7 dB
3. ASK sensitivity improves as the square root of the ratio of IF bandwidth to Baseband bandwidth instead of linearly.

**Reference**

[1] Bales, C. W., "A Comparison of Logarithmic and K-th Law Detectors", IEEE Trans. AES, July 1978, pp. 693-696

**More Information**

MAX1470: QuickView -- Full (PDF) Data Sheet -- Free Samples

MAX1471: QuickView -- Full (PDF) Data Sheet -- Free Samples

MAX1473: QuickView -- Full (PDF) Data Sheet -- Free Samples