SmartLEWIS^{TM} RX+

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Sensitivity Improvement by using the Automatic Frequency Control (AFC) for FSK

Application Note

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TDA5240 Enhanced Sensitivity Receiver TDA5240

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Page	**Subjects (major changes since last revision)**
---	Keywords added in document
Page 8	Min values for analog bandwidth added

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1 Introduction

The Automatic Frequency Control (AFC) can be used to decrease the used Channel Filters to the given theoretical occupied bandwidth of the transmitted signal. By doing this, the sensitivity of the receiver system which is defined by the front end noise figure and the used receive channel bandwidth can be increased significantly.

This application note describes the technical background of the AFC and the techniques how to setup the channel filters and AFC loop constants of the receiver. In general it can be stated that the described techniques are only valid for FSK modulation.

In the **Chapter 5** and **Chapter 6** some measurements shows the significant sensitivity improvement by using the AFC in combination with wide possible frequency offsets of the transmitter counterpart.

2 Receiver and FSK Demodulation

The receiver is realized as a superheterodyne architecture with single or double down conversion to the 274kHz IF frequency. The pictures below shows the principle of single and double down conversion:

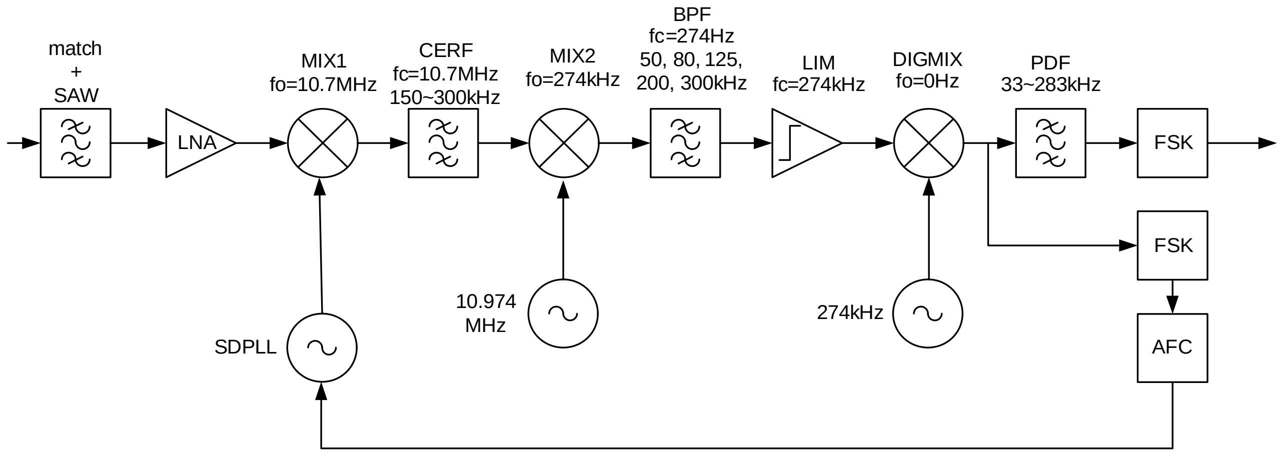

Figure 1 Double down conversion

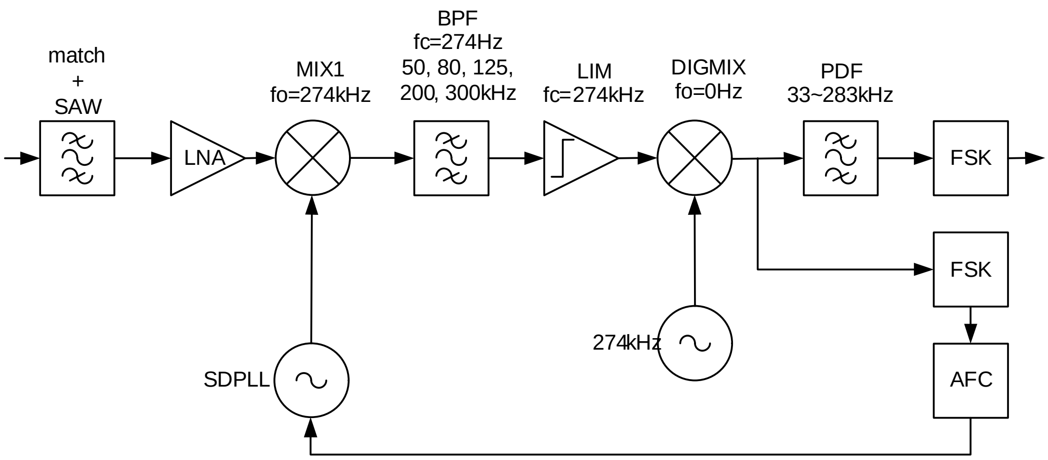

Figure 2 Single down conversion

The local oscillator frequency of the receiver is derived out of the on-chip fully integrated Sigma-Delta Fractional N PLL Synthesizer which enables a high frequency resolution. The functionality of the digital programmable

Synthesizer is used by the AFC circuitry to adjust the receiver local oscillator to the transmitted center frequency. In reality all transmitters and receivers have a frequency drift over temperature and supply voltage. Due to this frequency drift of the system, receivers without AFC need to take this frequency drift into account by selecting the appropriate receiver channel filter (occupied bandwidth of Signal + receiver / transmitter frequency inaccuracy).

The architecture of the IFX receiver which uses a analog bandpass filter after the down conversion and a additional digital predemodulation filter where the bandwidth of both filters can be selected independently, enables a wide frequency offset in combination with good jammer behavior and outstanding sensitivity performance.

In parallel to the predemodulation filter (PDF) a second FSK demodulator is used to derive the control signal for the Automatic Frequency Control Unit, which is actually the DC value of the FSK demodulated signal. This makes the AFC loop independent from signal path filtering and allow a wider frequency capture range of the AFC.

Since the digital FSK demodulator determines the exact frequency offset between the received input frequency and the programmed input center frequency of the receiver, this offset can be corrected through the sigma delta control of the PLL. As shown in **Figure 1** and **Figure 2**, for AFC purposes a parallel demodulation path is implemented. This path does not contain the digital low pass filter (PDF). The entire IF bandwidth, filtered by the analog bandpass filter only, is processed by the AFC demodulator.

The maximum frequency offset removed by the AFC can be limited to avoid the tracking of unwanted signal too far away from the selected channel.

3 Bandwidth considerations

The minimal bandwidth for the expected signal is defined by the carson rule:

$$BW_{min} = 2 \times (f_{DRmax} + f_{deviation}) \tag{1}$$

- f_{DRmax} = max frequency in baseband data
- $f_{deviation}$ = deviation of FSK modulation

To achieve the best sensitivity the reception bandwidth of the receiver should be equal or just slightly bigger then the minimal bandwidth. That means that the digital predemodulation filter (PDF) of the receiver should be set to the minimum bandwidth as calculated by the carson rule.

As mentioned before, due to tolerances on the receiver and transmitter side the caption range of the AFC must be large enough to cover those frequency offsets. With the two filter approach the analog bandpass filter (BPF) can be adjusted to cover the frequency tolerances and the PDF can be set to the minimal required occupied carson bandwidth. With such a technique the receiver is setup for highest possible sensitivity in combination with wide frequency tolerances of the transmitter / receiver.

The best way to define the analog system bandwidth is to measure the RSSI voltage by applying a continuous wave (CW) signal at the RF input of the receiver. The measurement shall be done by changing the frequency of the CW and collect at each point a RSSI measurement value. The 3dB reference value should be taken at the center frequency by decreasing the CW signal power by 3dB. In the following picture such a measurement was done and the resulting system bandwidth is calculated.

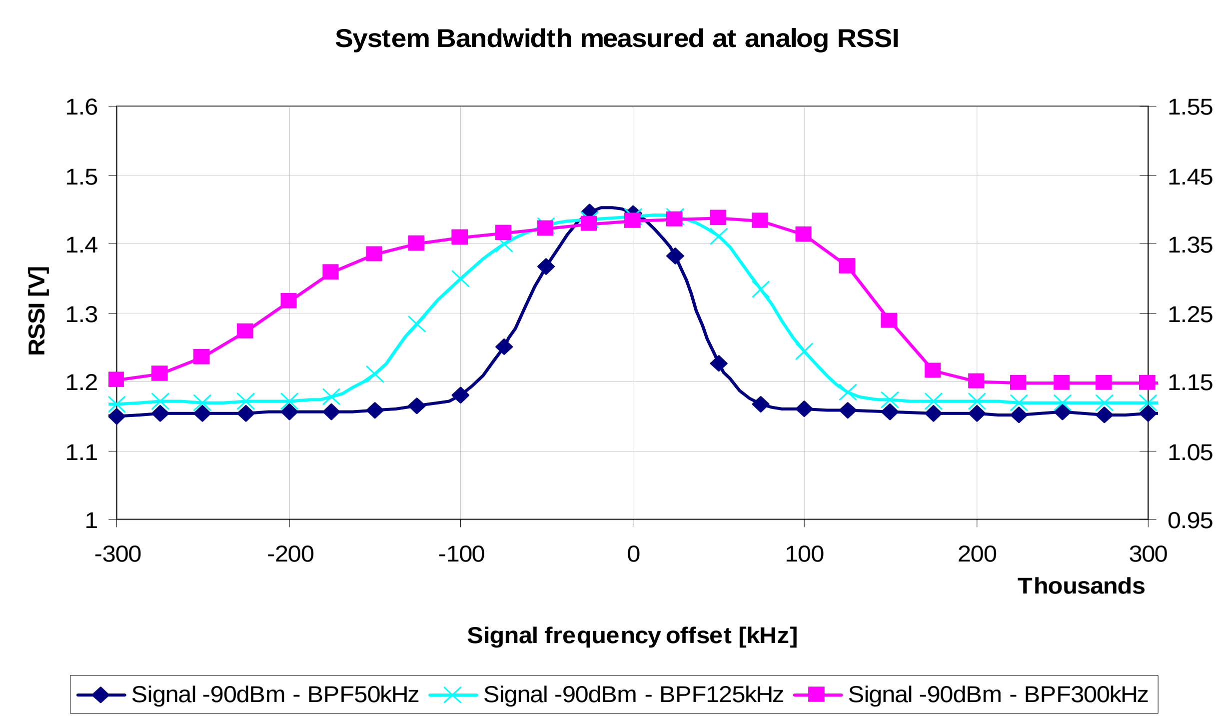

Figure 3 System BW measurement using RSSI voltage

The analog system bandwidth for different bandpass filter settings are shown in the table below:

Table 1 Analog system bandwidth (related to a CW input signal)

BPF setting	BW_{ana} (typ.)	BW_{ana} (min.)
50 kHz	50 kHz (DDC/SDC)	20 kHz (DDC/SDC)
80 kHz	80 kHz (DDC/SDC)	47 kHz (DDC/SDC)
125 kHz	120 kHz (DDC/SDC)	88 kHz (DDC/SDC)
200 kHz	180 kHz (DDC/SDC)	140 kHz (DDC/SDC)
300 kHz	230 kHz (DDC[1])	180 kHz (DDC)
	240 kHz (SDC[2])	200 kHz (SDC)

1) DDC .. Double Down Conversion
2) SDC .. Single Down Conversion

4 AFC configuration

A general rule to setup the right AFC limit for **Run Mode Slave** (always on) is:

(2)

$$f_{AFClimit} \leq \frac{BW_{ana}}{4} + f_{deviation}$$

This rule maintains that the frequency change done by the AFC will never push the center frequency out of the analog frontend system bandwidth.

This has the advantage that the receiver functionality at the presence of a possible interferer which is out of band is not significantly degraded due to the AFC frequency de tuning. (See **Figure 9 “Blocking Comparison” on Page 14**)

The receiver has also the functionality of Self Polling which means autonomous changing from Sleep Mode to Run Mode. If the receiver is configured in self polling mode, the AFC is initialized after each change from Sleep Mode to Run Mode. This means also, that a possible interferer is not able to de tune the AFC which enables a even higher AFC limit.

A general rule to setup the right AFC limit for **Self Polling Mode** is:

$$f_{AFClimit} \leq \frac{BW_{ana}}{2} + f_{deviation} \tag{3}$$

The AFC bandwidth (and thus the settling time) of the AFC loop is programmed by means of the integrator gain coefficients K1 and K2 (x_AFCK1CFG and x_AFCK2CFG register)

K1 mainly determines the AFC bandwidth (AFC_{BW}). K2 influences the dynamics/damping (overshoot) - smaller K2 means smaller overshoot, but slower dynamics.

$$AFC_{BW} = f_{DR} \cdot K1 \cdot 1,3 \tag{4}$$

To avoid residual FM, limiting the AFC_{BW} to 1/20 ~ 1/80 of the data rate is suggested, therefore K1 must be set to approximately 1/25 ~ 1/100 of the data rate.

Table 2 settings available in the Explorer tooling:

AFC tool setting	K1 factor	AFC bandwidth
ultra fast	Data Rate / 10	Data Rate / 7.7
fast	Data Rate / 25	Data Rate / 20
normal	Data Rate / 50	Data Rate / 38.5
slow	Data Rate / 75	Data Rate / 57.7
very slow	Data Rate / 100	Data Rate / 80

4.1 AFC frequency overshoot

The overshoot of the frequency which is mainly influenced by the K2 factor should be reduced as much as possible. Due to the fact that the digital filter is very tight, a overshoot in the frequency domain would result in a extended settling time of the receiver at low input power levels.

In the picture below the output of the FSK demodulator (magenta curve) and the corresponding baseband data of the transmitter (blue curve) are shown at -80dBm input level and 40kHz center frequency offset. In addition the digital channel D1 shows the clock recovered data (CHIP_DATA) and the digital channel D0 shows the analog slicer output (DATA).

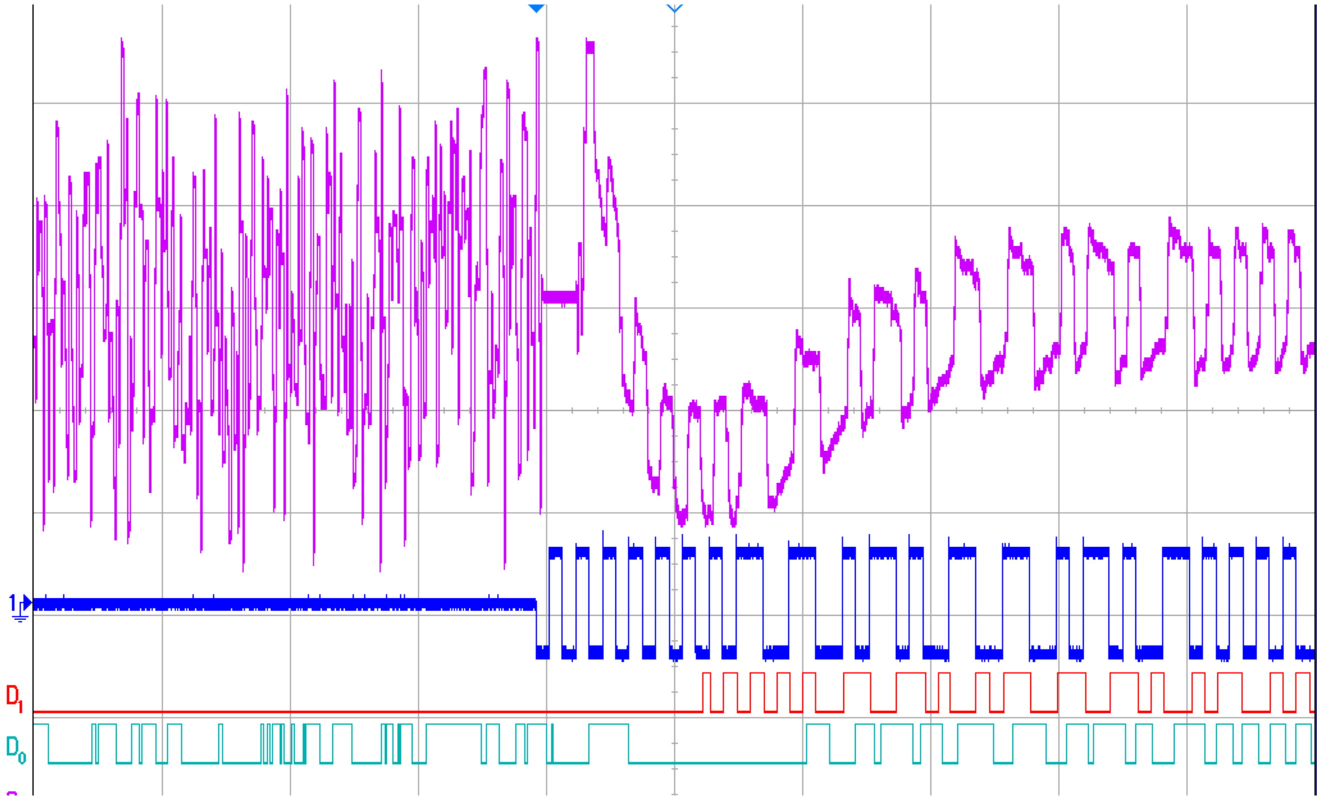

Figure 4 Input power = -80 dBm; K1 = K2; 25% overshoot

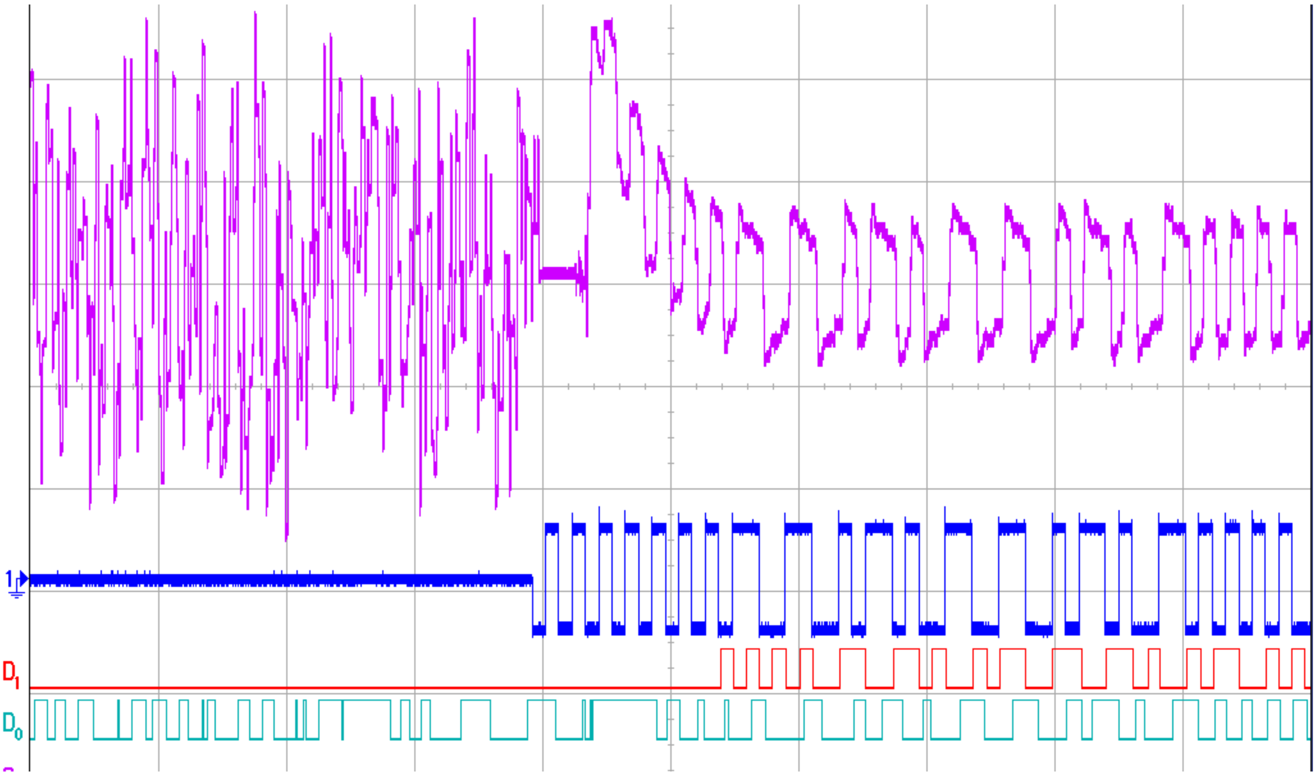

Figure 5 Input power = -80 dBm; K2 = K1/10; no overshoot

It can be seen that at high input level the overshoot effect has no influence on the settling time.

The next pictures were taken with input power levels at the sensitivity boarder and 40kHz center frequency offset.

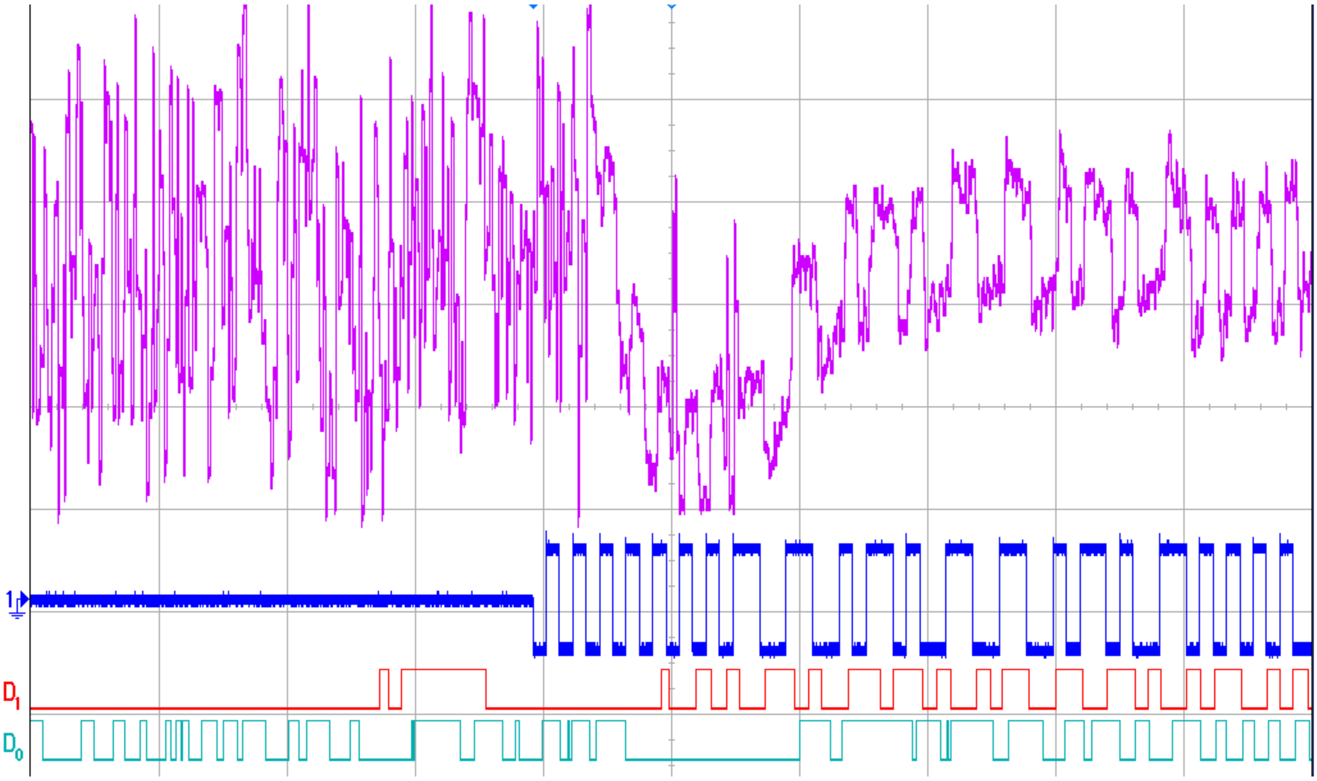

Figure 6 Input power at sensitivity level; K1 = K2; 25% overshoot

This figure shows that the overshoot results in a degradation of the FSK output signal and corresponding to that also a degradation of the sensitivity by a given constant settling time of the receiver.

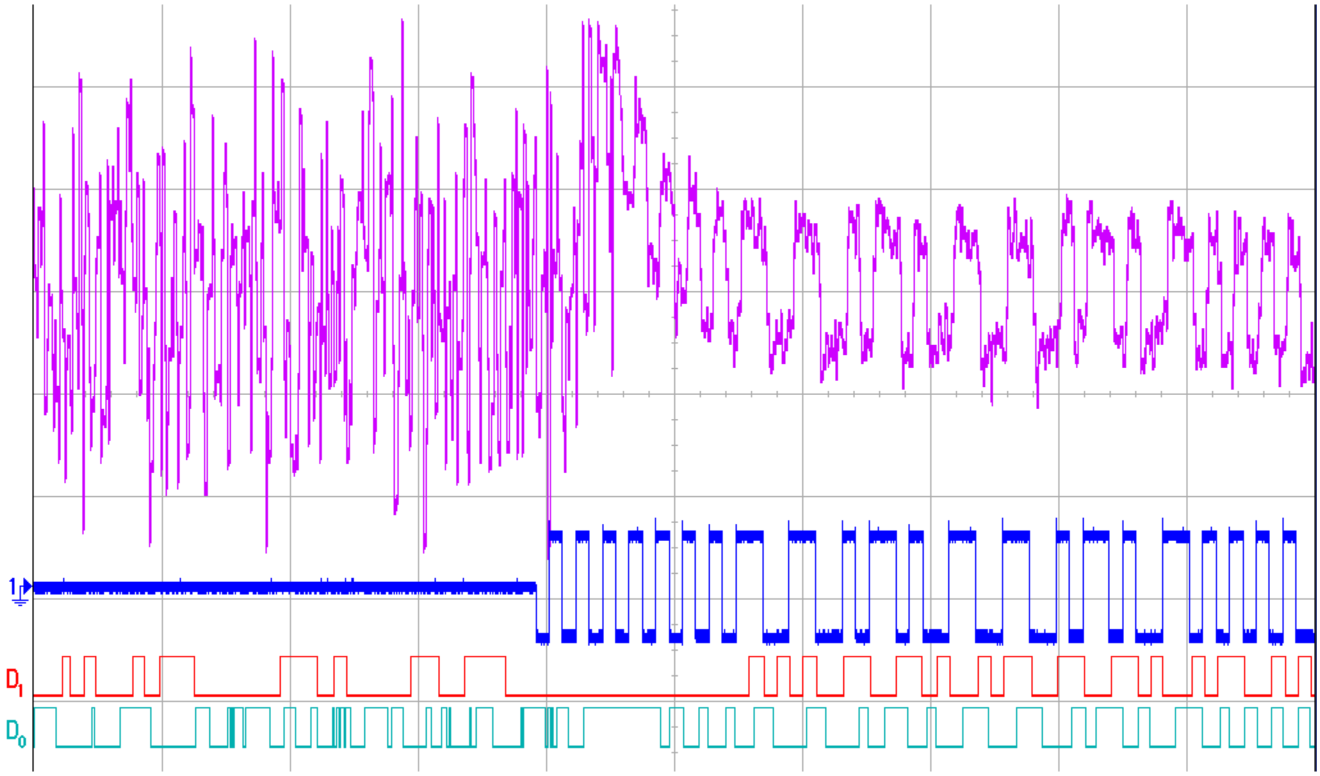

Figure 7 Input power at sensitivity level; K2 = K1/10; no overshoot

By avoiding the overshoot the signal stays always within the digital PDF filter and therefore no degradation of the sensitivity is expected.

5 Sensitivity Comparison

In this section of the application note we will show, how the sensitivity of the system can be improved by using the AFC and the tight predemodulation filter.

The measurement was packet based using the on chip FIFO and the message error rate limit was set to 10%.

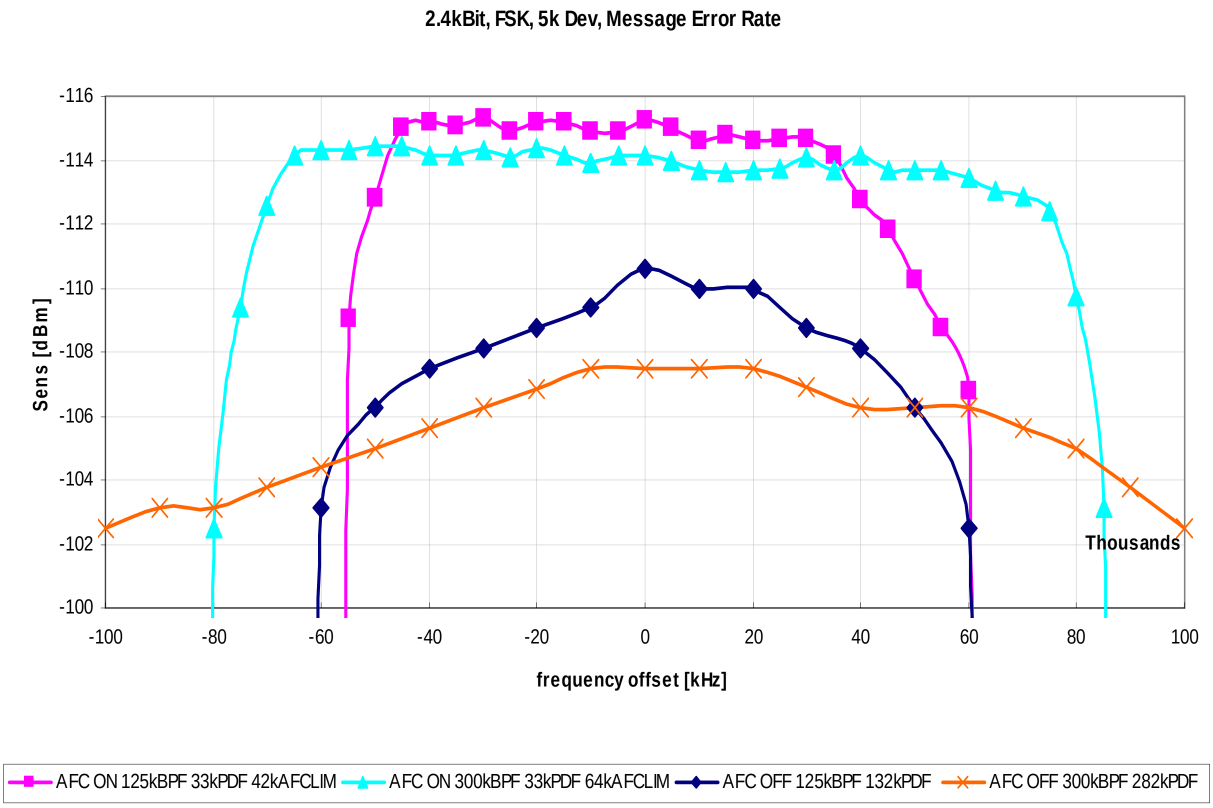

Figure 8 Sensitivity Comparison

It can be seen by using the AFC a sensitivity improvement of ~5dB can be achieved with 125kHz BPF and ~7dB improvement by using the 300kHz BPF setting.

The following formula shows the theoretical sensitivity improvement by reducing the PDF filter bandwidth.

$$\mathrm{Sens_{diff}} = 10 \times \log(\mathrm{BW_{diff}}) \tag{5}$$

Example:

$$\mathrm{Sens_{diff}} = 10 \times \log(\mathrm{BW_{diff}}) = 10 \times \log\left(\frac{120\mathrm{kHz}}{33\mathrm{kHz}}\right) = 5,6\mathrm{dB} \tag{6}$$

$$\mathrm{Sens_{diff}} = 10 \times \log(\mathrm{BW_{diff}}) = 10 \times \log\left(\frac{230\mathrm{kHz}}{33\mathrm{kHz}}\right) = 8,4\mathrm{dB} \tag{7}$$

As can be seen the calculation follows roughly the measurements.

6 Blocking Comparison

The setup for the blocking measurement: Two Signal Generators where used and combined to the RF input of the receiver. The wanted signal was set to 3 dB above the sensitivity limit at the center of the channel and the jammer power level was increased as long the message error rate of 10% was reached again. The difference between jammer level and wanted signal power level for different BPF bandwidth settings and AFC configurations are plotted in the figure below.

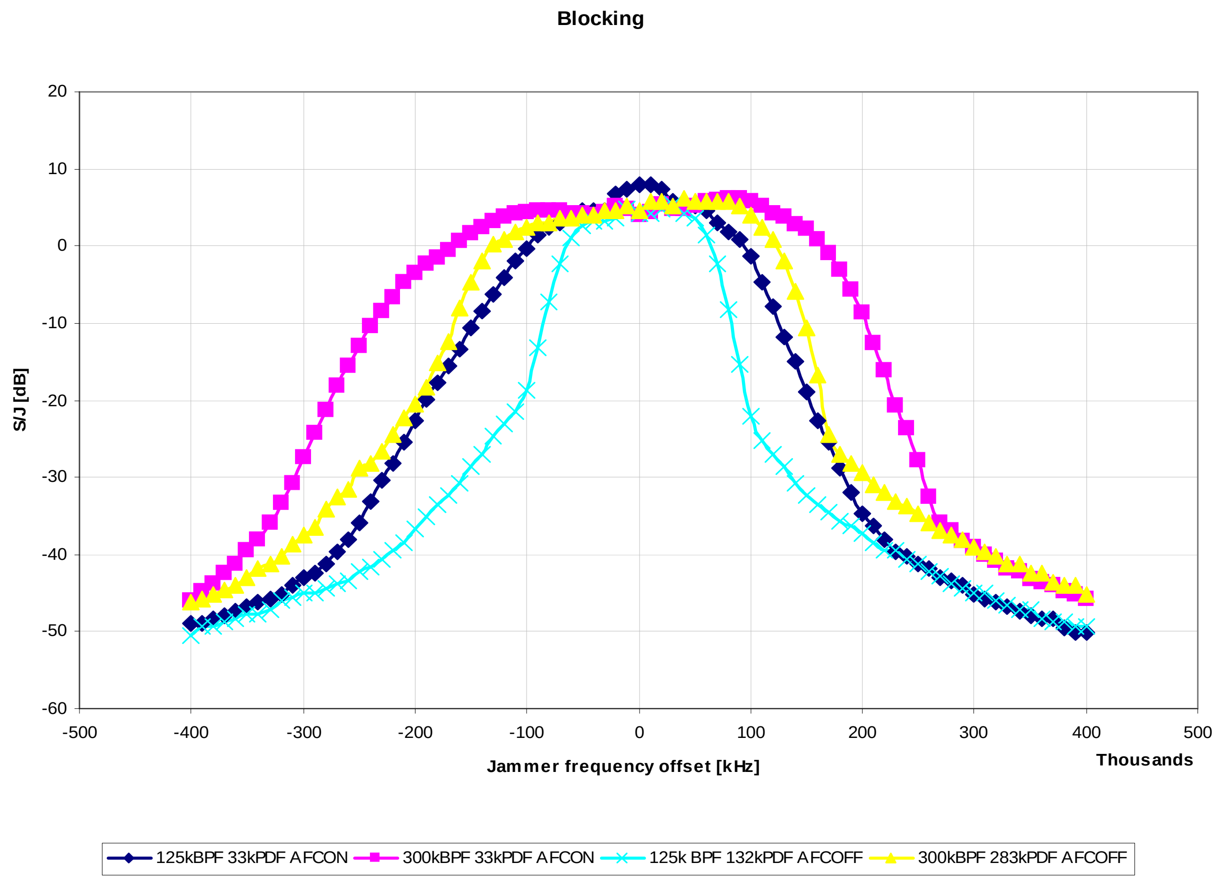

Figure 9 Blocking Comparison

7 Conclusion

It can be seen that usage of the AFC has a slight impact on the blocking performance. The curves using the AFC are wider according to the used AFC limit. A trade off between the wider blocking curve and the enhanced sensitivity needs to be done.

In general it can be seen, by using the AFC a significant sensitivity improvement can be achieved which approximately doubles the range of the system.

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