

Si446X ETSI CATEGORY 1 RX SETUP GUIDELINES

1. Introduction

The purpose of this document is to give an overview on how to derive the Si446x RFIC family's receiver settings to comply with ETSI EN 300 220-1 category 1 Rx specifications in narrowband (<25 kHz) applications.

2. The Standard

Table 1 lists the specifications a receiver must meet for Category 1 compliance:

Table 1. Receiver Specifications for Category 1 Compliance

Parameter	ETSI limit	Unit	Comment
Sensitivity	-107	dBm	
LBT Threshold	NA	NA	only applications with LBT (Listen Before Talk) protocol
ACS	54	dB	channel spacing \leq 25 kHz
Saturation ACS	44	dB	channel spacing \leq 25 kHz
Blocking	84	dB	At 2 MHz and 10 MHz offset
Spurious Response	60 /35	dB	spec gets relaxed to 35 if spurious is within 0.1 % of the wanted tone, channel spacing \leq 25 kHz
Spurious Radiation	2/20	nW	below and above 1 GHz
Notes: <ol style="list-style-type: none"> All parameters refer to an Rx BW of 16 kHz. If a different BW is used the limits have to be compensated by the following factor $10\log_{10}(\text{RxBW}[\text{kHz}]/16)$. The limits get relaxed by this much when BW is wider than 16 kHz. Specs for channel spacing > 25 kHz are not included in the table. 			

The most popular frequency bands where Category 1 receivers operate at (from ETSI EN 300 220-1).

Table 2. Popular Frequency Bands for Category 1 Receivers

Frequency Bands/Frequencies	Applications	Maximum Radiated Power, E.R.P. / Power Spectral Density	Channel Spacing	Spectrum Access and Mitigation Requirement (e.g. Duty cycle or LBT + AFA)
169.475 MHz to 169.4875 MHz	Social Alarms	10 mW	12.5 kHz	0.10%
169.5875 MHz to 169.6000 MHz	Social Alarms	10 mW	12.5 kHz	0.10%
869.200 MHz to 869.250 MHz	Social Alarms	10 mW	25 kHz	0.10%

3. 868 MHz Solution with SAW Filter

In this section all of the parameters are considered for an ETSI category 1 compliant receiver solution in the 868 MHz frequency band. At this frequency of operation **additional filtering is required** in front of the RFIC's input as on its own the receiver would not comply with the blocking specification. See the details in the following sections.

3.1. Blocking

Modulation format: 2GFSK 3kbps DR with 3 kHz single sided deviation

Receive BW: 12.4 kHz

Center frequency: 869.2125 MHz

Mode of operation: BER testing mode

Table 3. 2 MHz Blocking Results at 869.2125 MHz

2MHz blocking	-40 °C	25 °C	85 °C
Mean [dB]	-77,5	-77,64	-77,82
Stdev [dB]	0,34	0,31	0,36
Mean + 3 stdev [dB]	-76,5	-76,7	-76,7
Mean + 6 stdev [dB]	-75,5	-75,8	-75,7

Notes:

1. The wanted signal power level during the blocking test is defined by ETSI as $-107 \text{ dBm} + 10 \cdot \log_{10} (12.4 \text{ [kHz]} / 16 \text{ [kHz]})$ [dB] + 3 [dB] = -105.1 dBm. At this particular test this level was dropped further by 2.8 dB—the typical insertion loss of a SAW filter in the 868 MHz band—to -107.9 dBm to “simulate” how much power the receiver would see at its input port in a real application.
2. These blocking numbers have been collected with optimized AGC configuration to keep the spread down. For details, refer to section 3.1.2.

The table contains the mean and standard deviation values of the 2 MHz blocking numbers at various temperatures. The values in the last row of the table can be considered as worst case numbers.

It is clearly seen that these numbers fall short of the specification outlined in section 2, therefore additional filtering—practically in the form of a SAW filter—is required in front of the receiver input. After the bandwidth compensation (on the 12.4 kHz filter) the specification is 85.1 dB. Comparing this number with numbers in the last row of the table it can be calculated that **10 dB attenuation at 2 MHz offset** will make all the parts pass the specification.

The following table contains the 10 MHz blocking results from the same characterization run.

Table 4. 10 MHz Blocking Results at 869.2125 MHz

10 MHz blocking	-40 °C	25 °C	85 °C
Mean [dB]	-85,02	-87,08	-87,26
Stdev [dB]	0,82	1,09	0,32
Mean + 3 stdev [dB]	-82,56	-83,81	-86,3
Mean + 6 stdev [dB]	-80,1	-80,54	-85,34

Following the same logic as before a minimum attenuation of 5 dB is required from the selected SAW filter at $\pm 10 \text{ MHz}$ offsets.

3.2. Spurious Response Rejection

ETSI calls for testing selectivity at three particular offset frequencies where spurious responses may occur.

These frequencies are the image frequency of the receiver and the \pm IF/2 (Intermediate Frequency) offset frequencies from the wanted channel. At \pm IF/2 offset there is no spurious response; the selectivity performance is purely limited by phase noise on the receive LO (Local Oscillator). Therefore this sub-section focuses only on image selectivity.

The IF frequency in the recommended mode of operation in the 868 MHz frequency band is 406.25 kHz. The LO is of a low injection type, i.e. it is running one IF frequency below the wanted receive band. The IF frequency is calculated as $1/64^{\text{th}}$ of the reference frequency (XO/TCXO). This calculation yields the IF frequency stated above with the recommended 26 MHz reference source in the 868 MHz frequency band. The image frequency is at **two times** the IF frequency **below** the wanted frequency.

The following table summarizes the image selectivity results taken on Si446x revC2 RFICs over process variation and supply voltage. IQ calibration was activated on the parts.

Table 5. Image Selectivity Distribution at 869.2125 MHz

Image Selectivity	-40 °C	25 °C	85 °C
Mean [dB]	47.16	48.68	50.06
Stdev [dB]	3.23	2.86	4.59
Mean - 3 stdev [dB]	37.5	40.1	36.3

Note that worst case numbers (last row in the table) are estimated with using only three times the standard deviation “guarding” the average. The reason for applying this method is that the distribution of the measurement result is not Gaussian; it is more like a Ryleigh distribution which is much “harder limited” at the lower (i.e worse performance) section than at the higher end. See the distribution of the measurement results on below CCDF (Complementary Cumulative Distribution Function) plot.

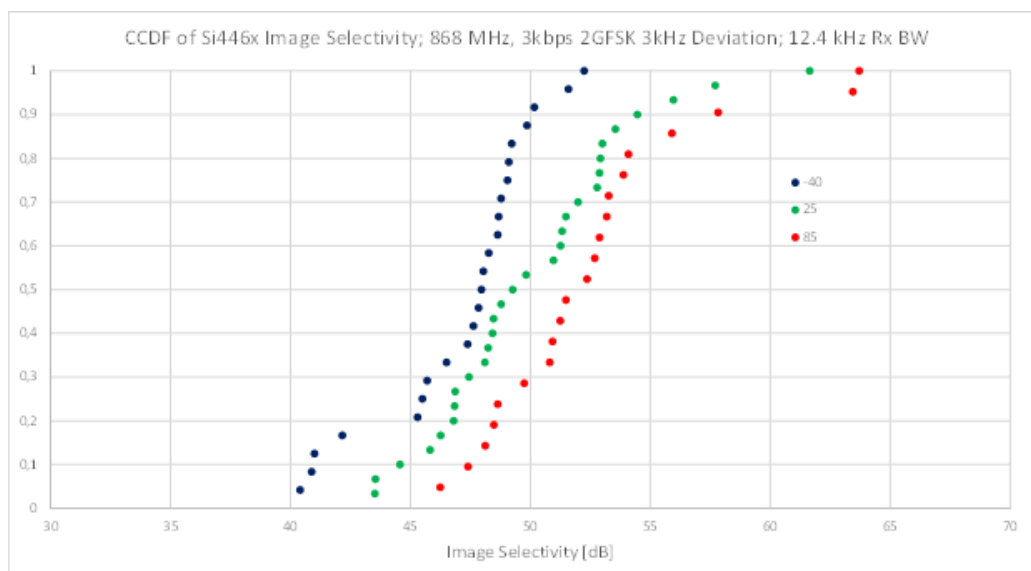


Figure 1. Image Selectivity Distribution at 869.2125 MHz

Even though the spread is relatively high on the data set it is driven by measured points taking on much better values than the average (rather than much worse). In other words the result of the calibration can be arbitrarily good but **cannot be arbitrarily bad**. You can read more on IQ calibration in AN790.

The worst case estimate numbers in the table would fail the 60 dB specification set out in the standard, however as with the recommended configuration (26 MHz TCXO) the image frequency falls within 0.1% of the wanted

frequency a 25 dB relaxation applies to the specification that brings it down to 35 dB which in turn will be met on all parts with the IQ calibration feature enabled. Note also, that most SAW filters will have some attenuation at the image frequency that will also increase the margin on the specification.

3.3. Adjacent Channel Selectivity

Adjacent Channel Selectivity (selectivity at +/- 25 kHz offset) is a rather tough specification. Care must be taken to optimize the receiver for the best performance. ACS depends on a number of factors:

1. Selectivity/attenuation performance of Rx filter
2. PLL phase noise performance at the given offset
3. Demodulator SNR requirement for error-free detection

#1 can be optimized by selecting an Rx filter with the best attenuation at the adjacent channel. #2 can be optimized by selecting a PLL bandwidth resulting in the least integrated phase noise power in the adjacent channel. #3 can be optimized by selecting more robust modulation formats. (This latter one cannot be applied if the modulation format is fixed.) In the following sub-section all above three points are elaborated on.

3.3.1. Rx Filter Selection

The Rx filter has finite attenuation at the adjacent channel (+/-25 kHz), therefore some of the signal energy at this offset will still reach the detector block deteriorating so the receive performance. While phase noise is a much bigger contributor to ACS it is still desirable that a filter be selected that has the best attenuation at +/- 25 kHz offset. The best filters from this aspect are the **12.4 kHz** and the **16.53 kHz** wide ones given that the recommended 26 MHz TCXO is used. They both have approximately the same bandwidth compensated ACS performance. That is to say the 16.53 kHz filter has a 1 dB weaker ACS. The limit, however, is relaxed by 1 dB compared to the 12.4 kHz filter case.

In WDS there are two ways of calculating the receive filter bandwidth. It can **either** be calculated by WDS automatically based on the modulation parameters on the “RF parameters” tab and the crystal tolerance parameters on the “Frequency and power” tab, **or** it can be forced by the user if the checkbox next to the “Rx bandwidth” entry field is ticked. In this latter case WDS will select the closest possible (higher) filter bandwidth regardless of the rest of the input parameters. See below a WDS screenshot on how to force the receive filter bandwidth.

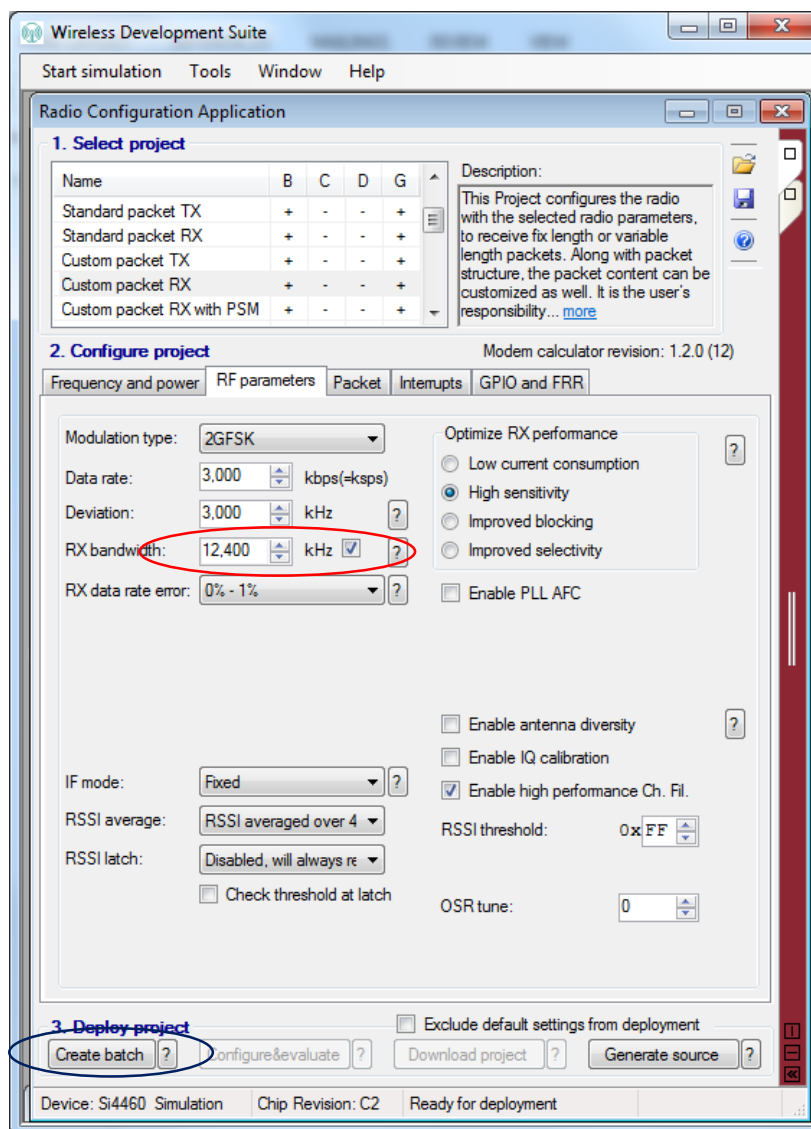


Figure 2. Forcing the Receive Bandwidth in WDS

No matter which method of selecting the filter bandwidth is used the result can be found in the top of the batch file generated by the “Create batch” push button.

```

#BatchName Si4460
#Crys_freq(Hz): 26000000 Crys_tol(ppm): 2 IF_mode: 2 High_perf_Ch_Fil: 1 OSRtune: 0 Ch_Fil_Bw_AFC: 0
ANT_DIV: 0 PM_pattern: 0
#MOD_type: 3 Rsymb(sps): 3000 Fdev(Hz): 3000 RXBW(Hz): 12400 Manchester: 0 AFC_en: 0
Rsymb_error: 0.0 Chip-Version: 2
#RF Freq.(MHz): 869.2125 API_TC: 29 fhst: 250000 inputBW: 1 BERT: 0 RAW_dout: 0 D_source: 0
Hi_pfm_div: 1
#API_ARR_Det_en: 0 Fdev_error: 0 API_ETSI: 0
#
# WB filter 1 (BW = 12.40 kHz); NB-filter 1 (BW = 12.40 kHz)
# Modulation index: 2
RESET
PATCH Si446x_C2_GENERAL.csg (C:\Program Files (x86)\Silabs\WDS3\Patch\Si446x_C2_GENERAL.csg)
'POWER_UP' 81 00 01 8C BA 80
'GPIO_PIN_CFG' 00 00 00 00 00 00 00
'SET_PROPERTY' 'GLOBAL_XO_TUNE' 52
'SET_PROPERTY' 'FRR_CTL_A_MODE' 00
'SET_PROPERTY' 'FRR_CTL_B_MODE' 00
'SET_PROPERTY' 'FRR_CTL_C_MODE' 00
'SET_PROPERTY' 'FRR_CTL_D_MODE' 00
'SET_PROPERTY' 'INT_CTL_PH_ENABLE' 18
'SET_PROPERTY' 'INT_CTL_MODEM_ENABLE' 01
'SET_PROPERTY' 'INT_CTL_CHIP_ENABLE' 08
'SET_PROPERTY' 'INT_CTL_ENABLE' 07
'SET_PROPERTY' 'GLOBAL_CONFIG' 20
'SET_PROPERTY' 'GLOBAL_CLK_CFG' 00
'SET_PROPERTY' 'MODEM_RSSI_CONTROL' 00
'SET_PROPERTY' 'MODEM_RSSI_THRESH' FF
'SET_PROPERTY' 'PREAMBLE_TX_LENGTH' 08
'SET_PROPERTY' 'PREAMBLE_CONFIG_STD_1' 14
'SET_PROPERTY' 'PREAMBLE_CONFIG_NSTD' 00
'SET_PROPERTY' 'PREAMBLE_CONFIG_STD_2' 0F
'SET_PROPERTY' 'PREAMBLE_CONFIG_31'
'SET_PROPERTY' 'PREAMBLE_PATTERN_31_24' 00
'SET_PROPERTY' 'PREAMBLE_PATTERN_23_16' 00
'SET_PROPERTY' 'PREAMBLE_PATTERN_15_8' 00
'SET_PROPERTY' 'PREAMBLE_PATTERN_7_0' 00
'SET_PROPERTY' 'SYNC_CONFIG' 01
'SET_PROPERTY' 'SYNC_BITS_31_24' B4
'SET_PROPERTY' 'SYNC_BITS_23_16' 2B
'SET_PROPERTY' 'SYNC_BITS_15_8' 00
'SET_PROPERTY' 'SYNC_BITS_7_0' 00
'SET_PROPERTY' 'BVT_CFG' 00 00 00 00 00 00 00 00

```

Figure 3. Checking the Selected Filter Bandwidth in WDS

3.3.2. PLL Phase Noise Optimization

Changing the bandwidth (typically opening it up) of the PLL has the effect of re-shaping the noise profile in a way that close-in phase noise gets better at the price of some further-out noise degradation. See below graph on how much improvement can be realized at 25 kHz offset by gradually opening up the bandwidth of the PLL.

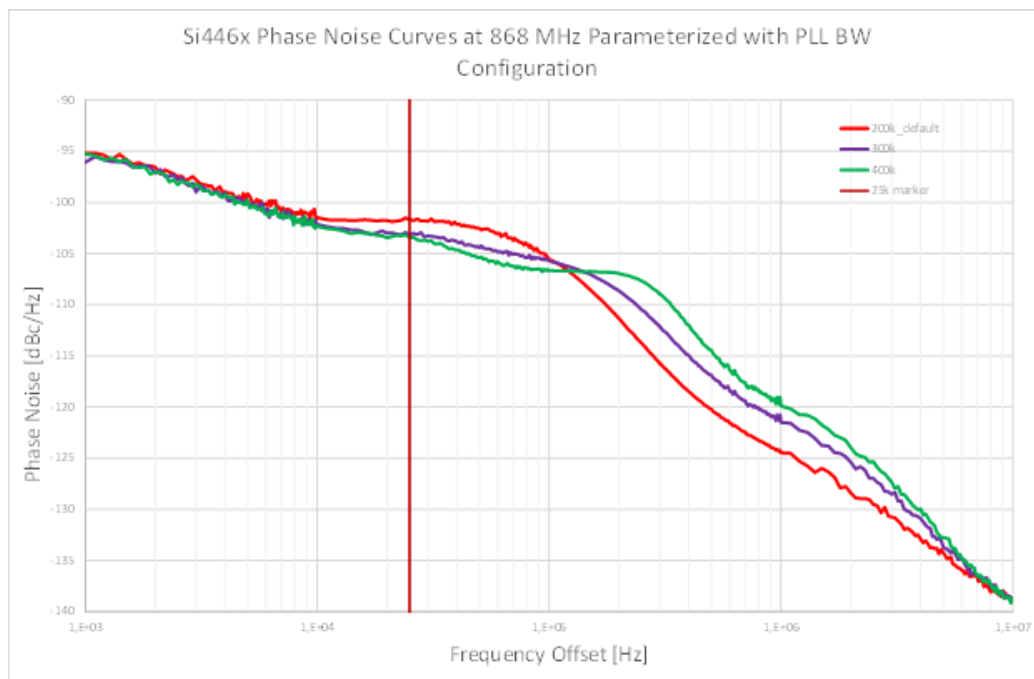


Figure 4. Close-In Phase Noise Improvement with PLL BW Increase

There is approximately 2 dB improvement going from the default 200 kHz to 300 kHz and there is an additional 1 dB gain if the 400 kHz configuration is selected. Note, that simultaneously 2 MHz phase noise degrades by roughly as much too. However, the data in section 3.1 was already taken with the 400 kHz PLL bandwidth configuration so the conclusion on the 2 MHz attenuation of the SAW filter (10 dB) is still valid.

The RCA (Radio Control Application) in WDS does not provide for direct PLL bandwidth adjustment. However if “Improved Selectivity” is chosen from the “Optimize Rx performance” selection control on the “RF parameters tab” the 400 kHz bandwidth PLL configuration will be selected. On how to make the various PLL BW configurations take effect manually refer to section 5. The “improved selectivity” option is primarily devised for 868 MHz band ETSI category 1 applications therefore there are a couple of more “behind the scenes” actions that further optimize the performance.

- Field “ETSI_MODE” in API property MODEM_IF_CONTROL is set to a value of 1. The effect of this value is optimized close-in phase noise performance on the PLL. (On chip revision revB1B this optimization was done through a direct register access POKE command, on chip revision revC2 this is automatically done by the FW.) Note that even though this field resides in an IF related property it has no effect whatsoever on the IF configuration.
- Optimized AGC switching points will be set via API property “MODEM_IFPKD_THRESHOLDS”. This action is needed to keep the variation down on the 2 MHz blocking numbers.

The following WDS screenshot shows how to enable the “Improved selectivity” option.

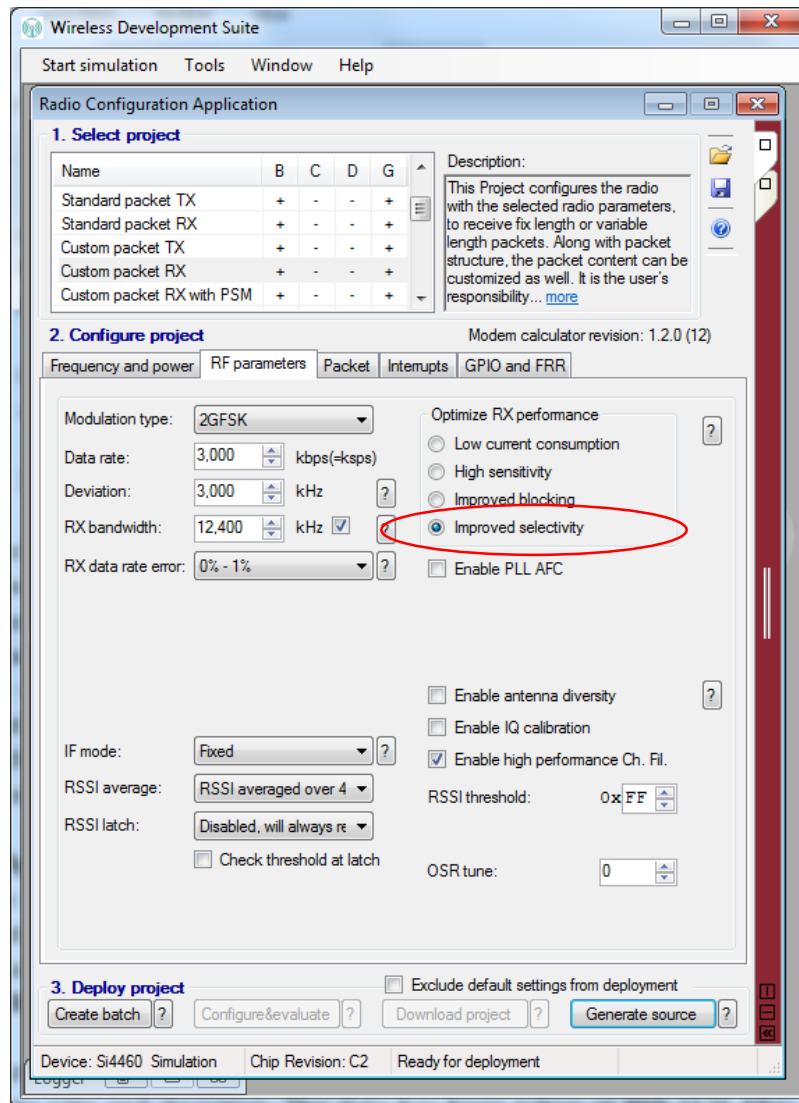


Figure 5. Activating Optimized Rx Performance for 868 MHz Band ETSI Category 1 Applications

As the most limiting factor on ACS performance is phase noise on the receive LO it is important that the selected reference source's (26 MHz TCXO) own phase noise (that directly appears on the LO too) is at least 10 dB better than performance of the synthesizer itself. If this criterion is met then the phase noise of the reference source will not have a degrading effect on ACS. The required phase noise specification on the reference source is -147 dBc/Hz at 25 kHz offset. This number is calculated (see figure below) as the synthesizer's phase noise at 25 kHz offset at 869 MHz (-107 dBc/Hz) "downconverted" to 26 MHz ($20 \cdot \log_{10} (869/26)$) and taking away the 10 dB margin.

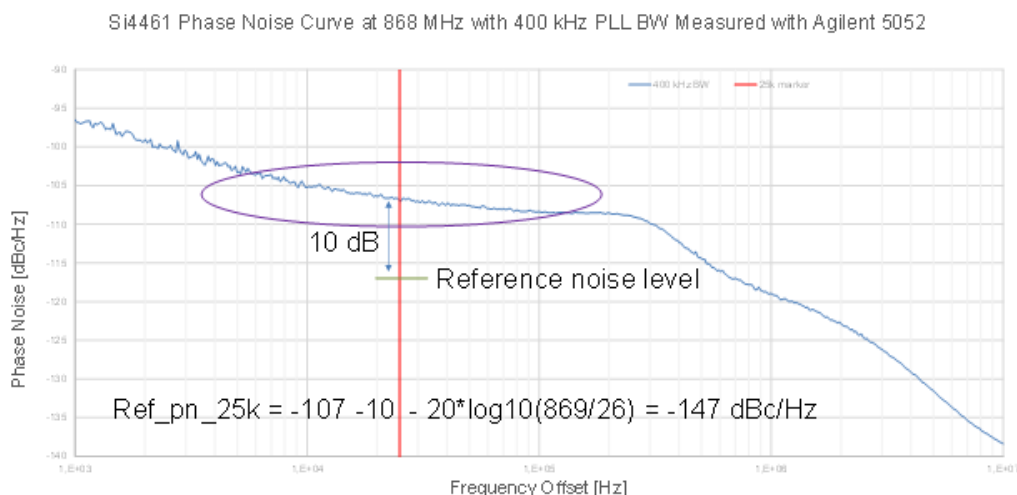


Figure 6. Reference Phase Noise Requirement Calculation

3.3.3. Modem ACS Performance Optimization

The mechanisms described in the previous two sections (finite filter attenuation / mixing on phase noise) have the effect of unwanted signal energy—aka noise—appearing at the demodulator circuitry. Now how much of this noise the demodulator can tolerate before it starts making wrong decisions (in other words what is the least SNR—Signal to Noise Ratio—requirement for successful demodulation) does change with the modulation parameters. Typically the demodulator is more tolerant to noise if the modulation index is higher. The frequency symbols are further apart from one another in this case (in other words the eye opening is bigger) therefore more noise is needed to “smear” the two symbols together. The receiver’s ACS performance thus will be proportional to the demodulator’s least SNR requirement.

Typically the receiver’s ACS will get better if higher modulation indices are used and as long as the modem is running in asynchronous mode, ACS will also get better if the data rate is dropped at a given modulation index. If the modem, however, is operating in synchronous mode, ACS will not change with the data rate at any given modulation index. On modem operation and AFC (Automatic Frequency Control) considerations, please refer to **AN734**.

As a system’s design aid, find below a few sets of curves showing exactly how ACS and sensitivity change with data rate and deviation. The data has been taken at 869.2125 MHz applying all the phase noise enhancement measures detailed in the previous section (“Improved Selectivity” has been ticked in WDS). Data is shown for the two filter settings (12.4 kHz and 16.53 kHz) that yield the best ACS performance. The graphs also show the (bandwidth compensated) specifications as solid red lines. (Beware that sensitivity numbers are referred to the 50 ohm connector of the pico board; they will be degraded by the insertion loss (~3 dB) of the SAW filter.)

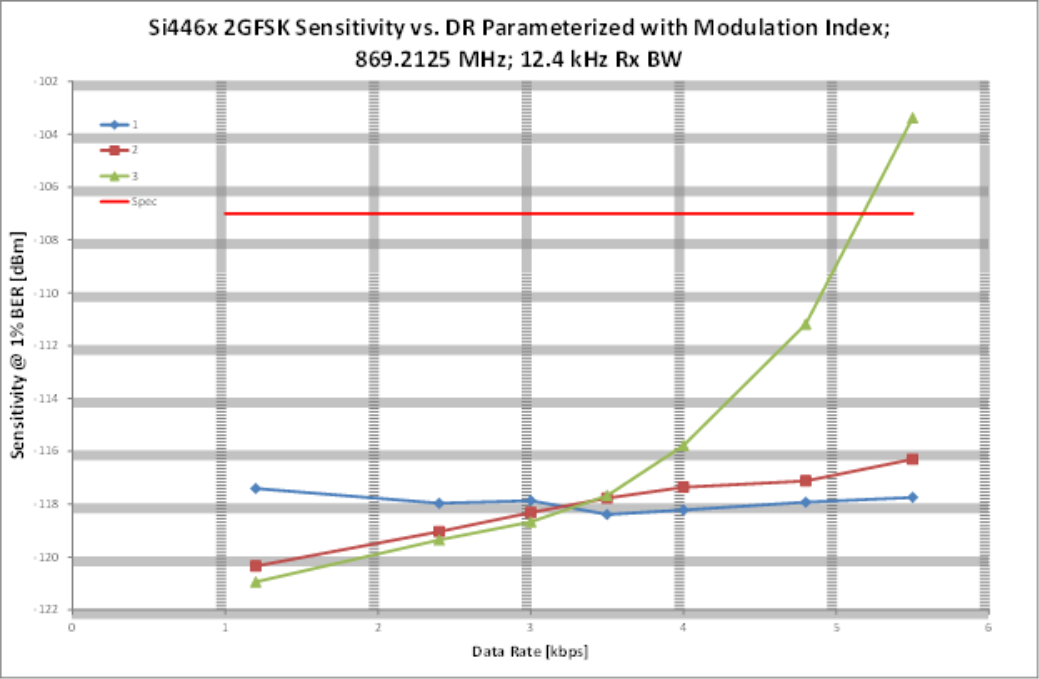


Figure 7. Sensitivity vs Data Rate 12.4 kHz Rx Filter

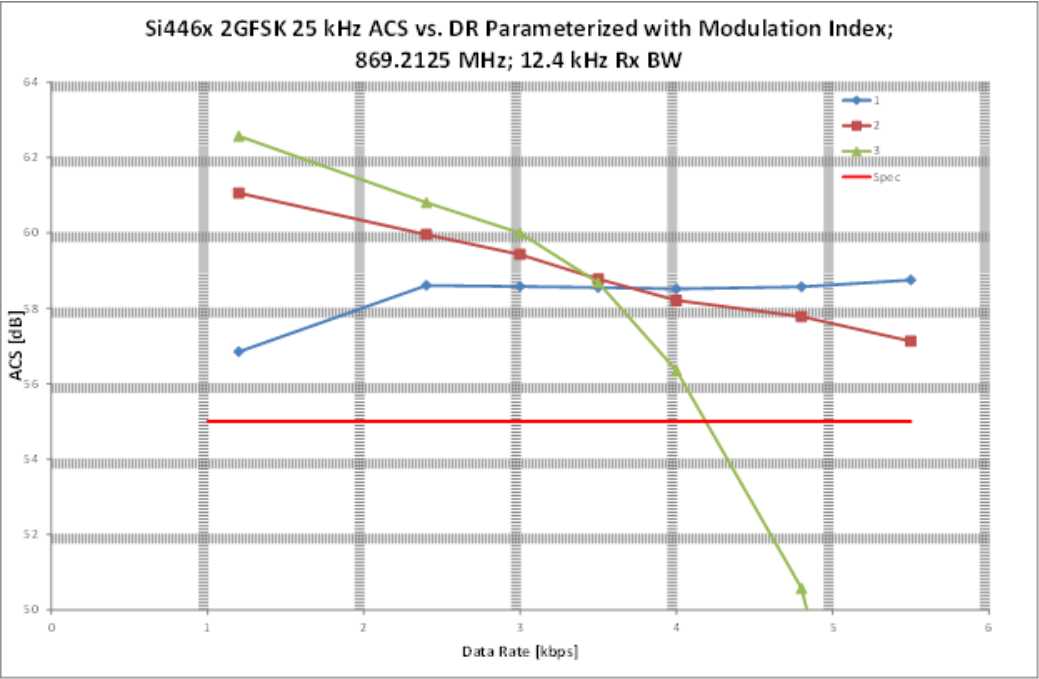


Figure 8. ACS vs Data Rate 12.4 kHz Rx Filter

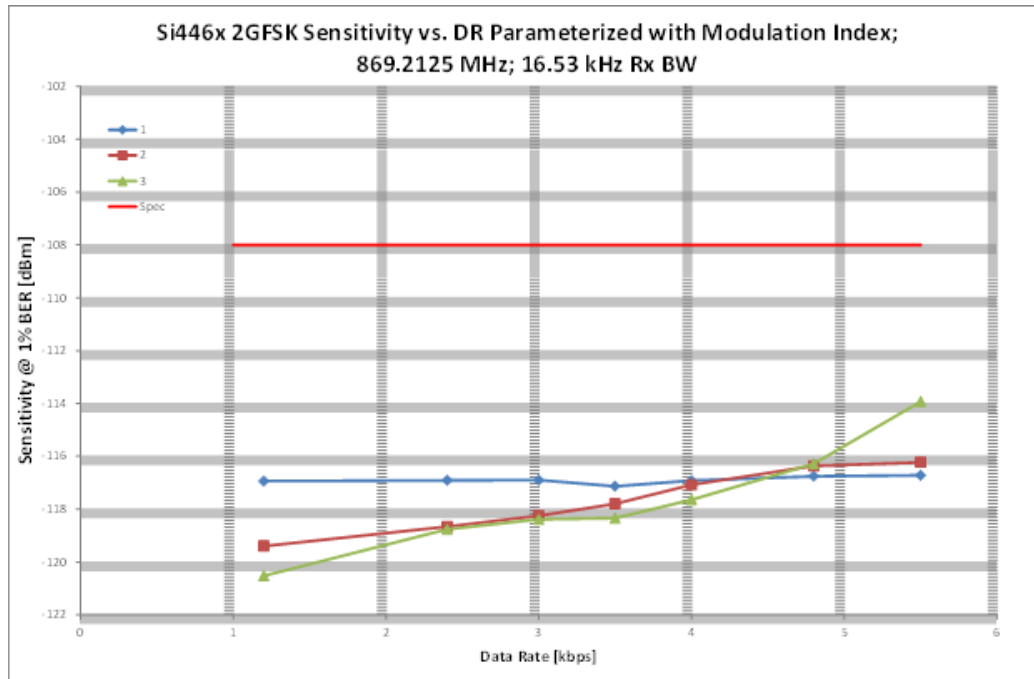


Figure 9. Sensitivity vs Data Rate 16.53 kHz Rx Filter

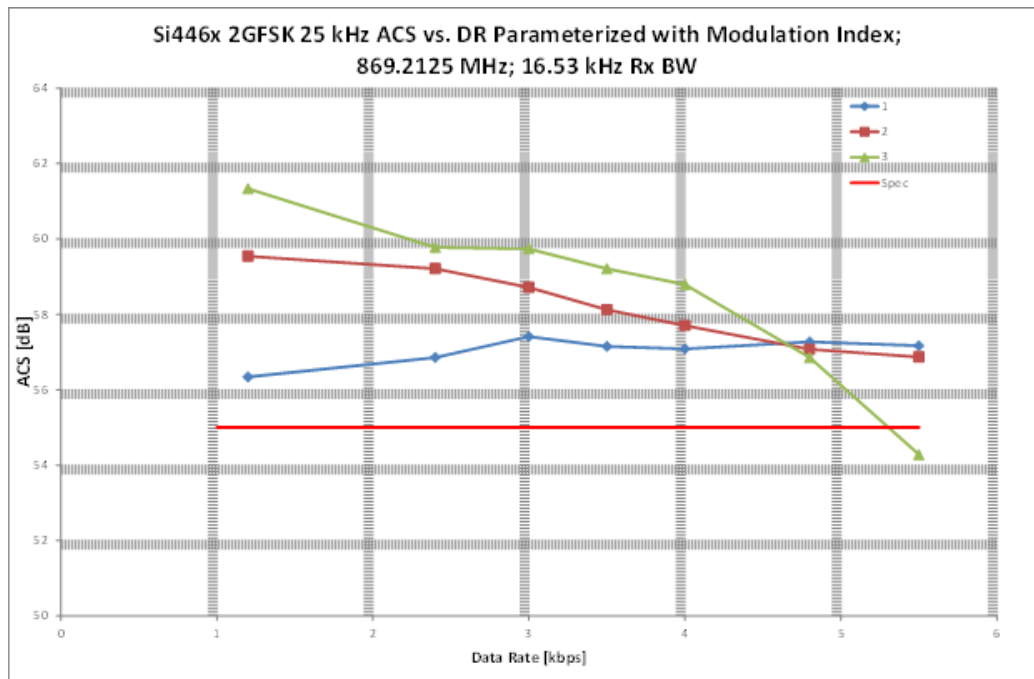


Figure 10. ACS vs Data Rate 16.53 kHz Rx Filter

3.3.4. ACS Statistical Analysis

The following table summarizes ACS results in the 868 MHz frequency band on 20 pieces of Si446x revC2 RFIC over process variation and supply voltage at room temperature. The parts were configured the following way:

Modulation format:	2GFSK 3kbps DR with 3 kHz single sided deviation
Receive BW:	12.4 kHz
Center frequency:	869.2125 MHz
Mode of operation:	BER testing mode with “Improved selectivity” option

Table 6. ACS Results at 869.2125 MHz

ACS at +/- 25 kHz	25 °C
Mean [dB]	-59,82
Stdev [dB]	0,73
Mean + 3 stdev [dB]	-57,63
Mean + 6 stdev [dB]	-55,44

At this particular modulation format the worst case ACS result (modeled by the last row of the table) still meets the -55 dB specification. Note that the part the detailed sweeps were taken on in the previous sub-section well represents the average of the population. The data point on figure Figure 8, “ACS vs Data Rate 12.4 kHz Rx Filter,” on page 10 at 3kbps DR and a modulation index of 2 matches well with the average result in this table. So if other modulation formats are chosen simply shift the results in this table by as much as the measurement results differ on the detailed graphs.

With increasing data rates and lower modulation indices the population of parts may not meet the specification statistically. **If the 12.4 kHz wide filter is selected try to stay below 3 kbps DR with a modulation index of greater than or equal to 2. If the 16.53 kHz wide filter is selected try to stay below 4 kbps DR with a modulation index of greater than or equal to 2.**

3.4. Summary

There are a few restrictions that must be adhered to for building an ETSI category1 compliant receive application in the 868 MHz band with the Si446x RFIC family.

- Keep the DR below 4 kbps and maximize the modulation index
- Enable the “Improved Selectivity” Rx operation mode in WDS
- Use a 26 MHz TCXO with at least as good an accuracy as +/- 2.5 ppm and as good a phase noise as -147 dBc/Hz at 25 kHz offset
- Enable IQ calibration on the chip
- Use one of the recommended Rx filters from section 3.1.1
- Use a SAW filter in front of the receiver’s input with the following specification

Table 7. 868 MHz Band SAW Filter Specification

868M SAW spec	+/- 2MHz	+/- 10MHz
Attenuation [dB]	10	5

As far as the reference accuracy is concerned if one assumes an Rx BW of 12.53 kHz the best AFC range the part can provide is +/- 4.38 kHz (see AN734 for details) which split between Rx and Tx equally (+/- 2.19 kHz) yields a reference accuracy requirement of $2190 \text{ [Hz]} / 869 \text{ [MHz]} = 2.52 \text{ [ppm]}$. This sort of accuracy requirement can only

be met with TCXOs.

For development purposes and radio performance evaluation order the following radio pico board: 4463CPCE20C869SE. This picoboard comes with an EPCOS B3749 SAW filter and a TX0341E +/- 2.5 ppm 26 MHz TCXO from Tai-Saw Technology (TST).

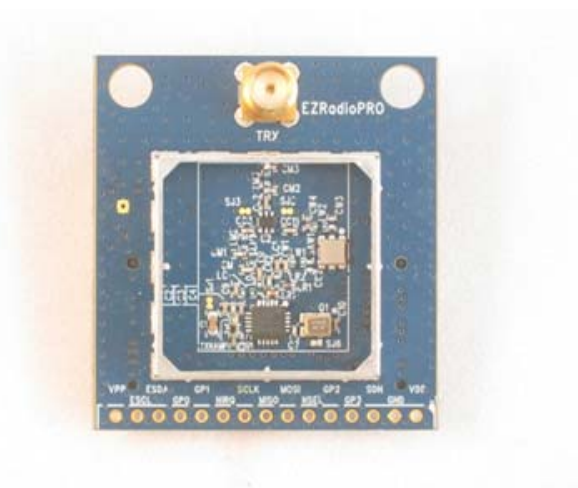


Figure 11. 4463CPCE20C869SE

4. 169 MHz Solution without a SAW Filter

In this section all of the parameters are considered for an ETSI category1 compliant receiver solution in the 169 MHz frequency band. At this frequency of operation no additional filtering is required in front of the receiver input.

4.1. Blocking

The following table summarizes narrowband blocking results in the 169 MHz frequency band both at 2 MHz and 10 MHz offsets. The data were taken on 10 pieces of Si446x revC2 RFIC at room temperature and nominal 3.3 V supply voltage. The parts were configured the following way:

Modulation format:	2GFSK 3kbps DR with 3 kHz single sided deviation
Receive BW:	10.65 kHz
Center frequency:	169 MHz
Mode of operation:	BER testing mode with "Improved selectivity" option

Table 8. Blocking Results at 169 MHz

Blocking	25 °C	
	2 MHz	10 MHz
Mean [dB]	-87,32	-87,92
Stdev [dB]	0,13	0,21
Mean + 3 stdev [dB]	-86,9	-87,3
Mean + 6 stdev [dB]	-86,5	-86,7

The table contains the mean and standard deviation values of the 2 MHz and 10 MHz blocking numbers. The values in the last row of the table can be considered as worst case numbers at room temperature.

As the spread is very little on the data room temperature worst case numbers are only slightly worse than the average and still **meet the bandwidth compensated specification of 85.8 dB**.

In order to achieve the blocking numbers above that make the use of a SAW filter unnecessary the “Improved blocking” checkbox must be selected at “Optimize RX performance” control on the “RF parameters” tab in WDS. See the control on the below WDS screenshot.

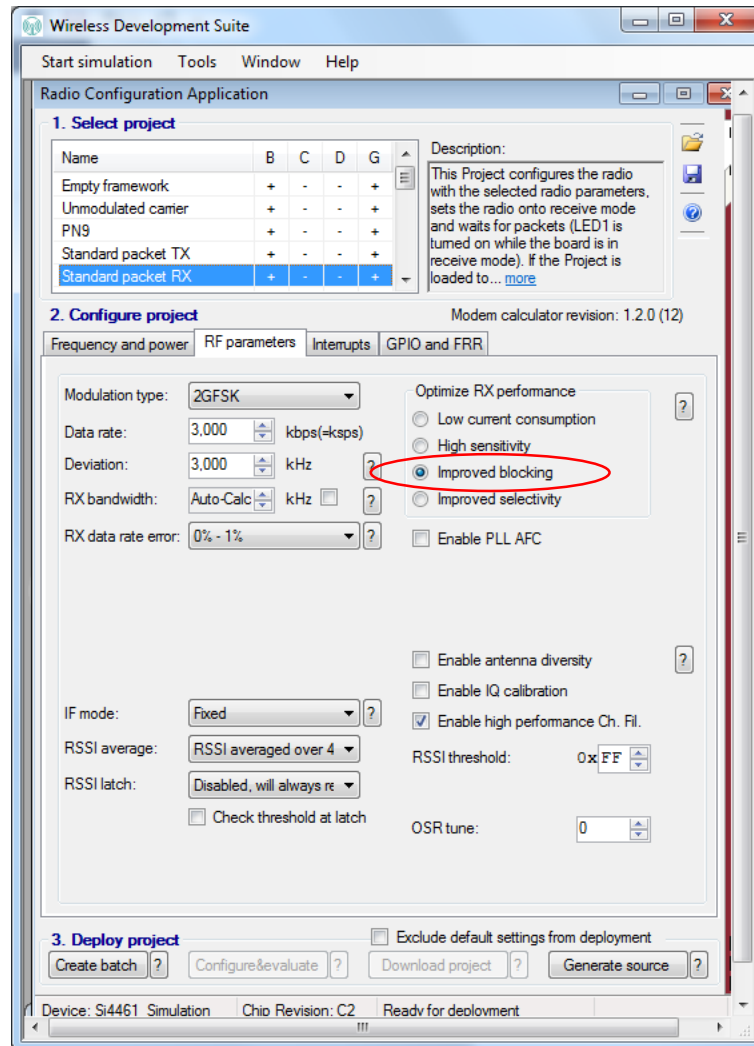


Figure 12. Enabling the “Improved Blocking” Operation Mode in WDS

There are several actions taken if the “Improved Blocking” mode of Rx operation is selected. Field “ETSI_MODE” in API property MODEM_IF_CONTROL is set to a value of 2 that has the following implications on the part.

- The AGC (Automatic Gain Control) algorithm is optimized to always withstand -20 dBm blocker power level while maintaining enough gain in the system to still meet the ETSI defined sensitivity specification.
- The mixer is placed in “high linearity” mode. Note that this mode of mixer operation will increase overall receive current consumption by ~ 300 uA.
- The bandwidth of the analog baseband will be set to its minimum value of 375 kHz to provide more attenuation at the blocker frequencies. Note that this mode of operation makes the use of SIF (Scaled IF) mode recommended. If FIF (Fixed IF) mode were used the IF frequency (at 468.75 kHz assuming a 30 MHz reference

source) would already be attenuated by the baseband filter. This mechanism would lead to a few dB sensitivity loss. (Another requirement that makes the **SIF mode operation** not only recommended but **mandatory** is the spurious response specification. See section 4.2 for details.)

4.2. Spurious Response Rejection

Calibrated image selectivity numbers at 169 MHz are the same as at 868 MHz. From section 3.2 it is clearly seen that the specification is only met if the 25 dB relaxation is applied to the 60 dB limit. For the relaxation to take effect a sufficiently low IF frequency (<84.5 kHz) is required to keep the image frequency within 0.1% of the wanted frequency itself. It follows that SIF (Scaled IF) mode has to be utilized on the part as in FIF (Fixed IF) mode the IF frequency would be way higher than the maximum allowed for the specification relaxation. Note, that ZIF (Zero IF) mode would get rid of the image frequency entirely, it would come, however at a price of a few (~3) dB sensitivity degradation and more susceptibility to low frequency noise. So while the specification would still be met in ZIF mode, SIF is the recommended mode of operation for better overall performance.

In scaled IF mode of Rx operation by default the image frequency falls onto the (lower) adjacent channel (from the channel filter's bandwidth point of view). There is a way of scaling the IF frequency upwards by stepping the sampling clock frequency higher in the demodulator. This scaling can be achieved by increasing the OSRtune (Over Sampling Ratio tune) value on the "RF parameters" tab in WDS. While the exact oversampling ratio cannot be set it can be stepped up (as well as down) with regards to the nominal value by changing the OSRtune control. The resulting IF frequency is shown in the batch and radio configuration header files right below the Rx BW value. Now, as the default IF frequency places the image frequency on the lower adjacent channel (from the channel filter's bandwidth point of view) it will obviously degrade the ACS performance therefore a higher IF frequency is recommended to be used. Increasing the IF frequency, however has a degrading effect on Rx filter selectivity. (The reason for this is that increasing the IF frequency is achieved by upscaling the sampling clock in the digital demodulator, which in turn makes it necessary that a different digital filter be selected whose relative bandwidth will be lower which fundamentally results in less sharper a roll off at the filter's edges.) Experiments have shown that the best compromise between above two factors is an OSRtune value selection of 3. The WDS screenshot below shows how to configure Scaled IF mode with the aforementioned OSRtune value of 3.

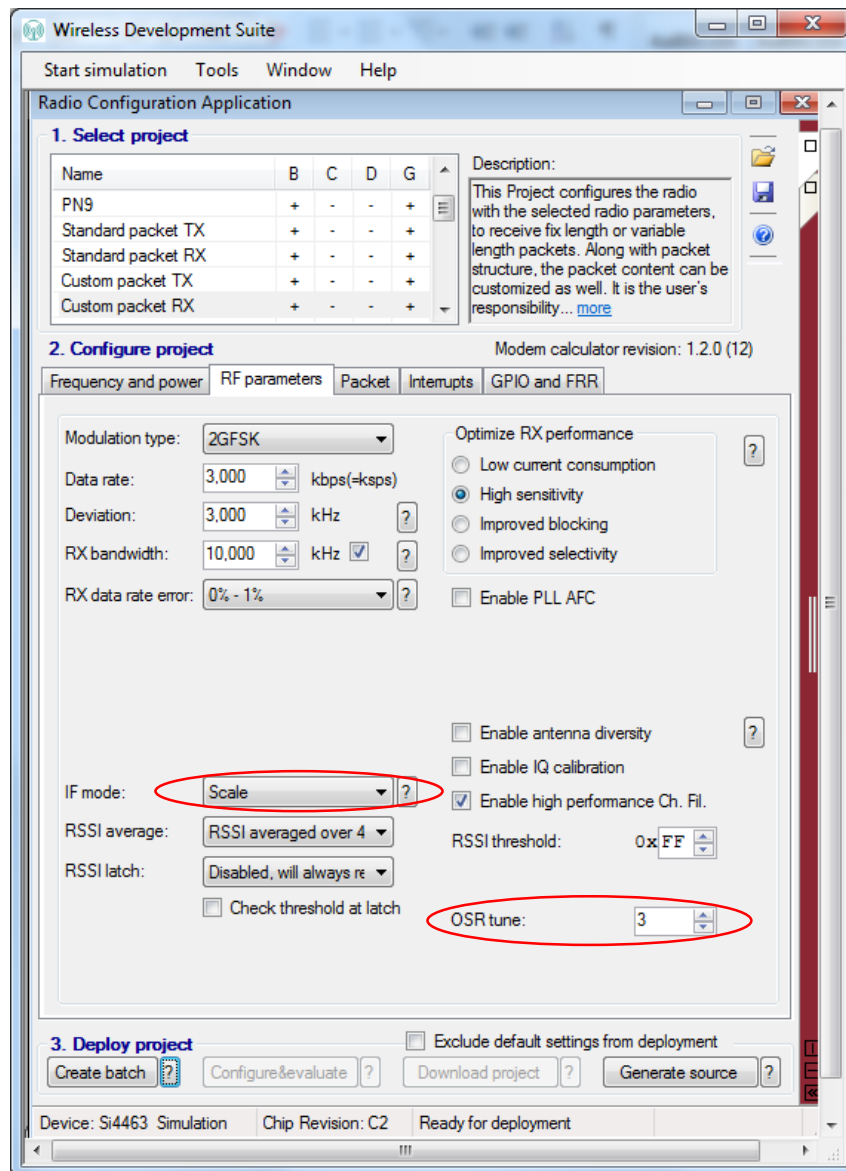


Figure 13. Configuring Scaled IF (SIF) Mode From WDS

This particular configuration with a forced RX bandwidth of 10 kHz and an OSRtune value of 3 the IF frequency is 19.531 kHz. The image frequency therefore is 39.062 kHz below the wanted frequency. For information find below how the IF frequency changes with OSRtune value at this particular configuration.

Table 9. IF Frequency vs OSRtune Value

OSRtune	IF [Hz]
-2	3662
-1	4883
0	7324
1	9766
2	14648
3	19531
4	29297
Note: Access to OSR tune is locked by license in WDS (3.2.7.0 onwards) for advanced users. Contact Silicon Labs should you need this feature to be activated.	

4.3. Adjacent Channel Selectivity

Adjacent channel selectivity in the 169 MHz is not as critical as in the 868 MHz band. The main limiting factor on ACS is phase noise on the receive LO at a frequency offset equal to the channel spacing. Phase noise is fundamentally better at 169 MHz by a factor of $20 \times \log_{10}(868\text{M}/169\text{M}) = 14.2$ [dB] at any given offset frequency. Therefore there is no need for configuration optimization for meeting the ACS specification in the 169 MHz frequency band.

4.4. Summary

There are a few restrictions that must be adhered to for building an ETSI category1 compliant narrowband receive application in the 169 MHz band with the Si446x RFIC family.

- Enable the “Improved Blocking” Rx operation mode in WDS
- Configure Scaled IF Rx operation with an OSRtune value of 3
- Enable IQ calibration on the chip
- Use the recommended 30 MHz XO/TCXO

Note that while in the 868 MHz band a TCXO is always recommended in the 169 MHz band a conventional XO may as well be used as long as its accuracy is at least as good as ± 10 ppm. If one assumes a 10 kHz Rx BW (that is typical in the 169 MHz band) the best AFC range the part can offer is ± 3.5 kHz (see AN734 for details) which split equally between Rx and Tx (± 1.75 kHz) yields an accuracy requirement of $1750 \text{ [Hz]} / 169 \text{ [MHz]} = 10.35$ ppm.

For development purposes and RF performance evaluation order any of the following pico boards:

- 4463CPSQ20D169TRx board
- 4362CPRXB169Rx only board

4.5. PLL BW configurations

There are multiple API properties involved in modifying the bandwidth of the PLL. For the sake of completeness find here the settings for all mentioned (200 kHz - default, 300 kHz and 400 kHz) cases.

Synth control group = **200 kHz** Loop BW

```
'SET_PROPERTY' 'SYNTH_PFDPCP_CPFF' 2C  
'SET_PROPERTY' 'SYNTH_PFDPCP_CPINT' 0E  
'SET_PROPERTY' 'SYNTH_VCO_KV' 0B  
'SET_PROPERTY' 'SYNTH_LPFILT3' 04  
'SET_PROPERTY' 'SYNTH_LPFILT2' 0C  
'SET_PROPERTY' 'SYNTH_LPFILT1' 73  
'SET_PROPERTY' 'SYNTH_LPFILT0' 03
```

Synth control group = **300 kHz** Loop BW

```
'SET_PROPERTY' 'SYNTH_PFDPCP_CPFF' 34  
'SET_PROPERTY' 'SYNTH_PFDPCP_CPINT' 04  
'SET_PROPERTY' 'SYNTH_VCO_KV' 0B  
'SET_PROPERTY' 'SYNTH_LPFILT3' 04  
'SET_PROPERTY' 'SYNTH_LPFILT2' 07  
'SET_PROPERTY' 'SYNTH_LPFILT1' 70  
'SET_PROPERTY' 'SYNTH_LPFILT0' 03
```

Synth control group = **400 kHz** Loop BW

```
'SET_PROPERTY' 'SYNTH_PFDPCP_CPFF' 14  
'SET_PROPERTY' 'SYNTH_PFDPCP_CPINT' 07  
'SET_PROPERTY' 'SYNTH_VCO_KV' 0B  
'SET_PROPERTY' 'SYNTH_LPFILT3' 02  
'SET_PROPERTY' 'SYNTH_LPFILT2' 10  
'SET_PROPERTY' 'SYNTH_LPFILT1' 73  
'SET_PROPERTY' 'SYNTH_LPFILT0' 03
```

Any of these settings can be made to take effect if the corresponding property values are manually overwritten to these values in the radio configuration header file.

4.6. Recommended External Components for ETSI Category 1 Compliance

This section contains recommended external components for ETSI Category 1 compliance.

Table 10. Recommended Reference Source Parts

Manufacturer	Part number	Operating Frequency [MHz]	Temperature range [°C]
TST	TX0338A	30	-30 - 75
TST	TXO341E	26	-40 - 85

Table 11. Recommended SAW Filters at 869 MHz

Manufacturer	Part number	Center Frequency [MHz]	Operating band [MHz]	Temperature range [°C]
EPCOS	B3749	869,3	868,6-870	–10 to 55
TST	TA0275A	869,6	869,12-870,26	–45 to 90
RFM	SF2280E	869.2125	868.6125-869.8125	–10 to 55
EPCOS	B3941	868,95	868,7-869,2	–45 to 85
EPCOS	B3746	868,6	868-869,2	–45 to 95

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