

# Multi-Carrier GSM with State of the Art ADC technology

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Multi-carrier GSM poses significant challenges to both mixers and analog to digital converters. Currently the ADC is the limiting component with the mixer a close second. Above 12 bits, actual ADC bit precision becomes less meaningful and actual performance must be analyzed. ADI currently has a number of 14+ bit converters in the 80 to 250 MSPS range. These offer a variety of performance optimizations from baseband (low IF) to high IF's (up to 225 MHz). The table below shows a number of these converters' noise spectral density and spurious performance. The tables below assume an input termination of 200 ohms differential.

(typicals)	AD9246/AD6655 <sup>1</sup>	AD9445 <sup>2</sup>	AD9446 <sup>3</sup>	AD6645/AD6654 <sup>4</sup>	AD9245 <sup>5</sup>	AD9244
BB SNR	-145.7 dBm/Hz	-147.2 dBm/Hz	-149.1 dBm/Hz	-148.2 dBm/Hz	-143.8 dBm/Hz	-144.8 dBm/Hz
BB SFDR	90 dBc	95 dBc	92 dBc	93 dBc	83 dBc	94.5 dBc
70M SNR	-145.5 dBm/Hz	147.2 dBm/Hz	-148.4 dBm/Hz	-146.7 dBm/Hz	-142.8 dBm/Hz	-143.3 dBm/Hz
70M SFDR	85 dBc	90 dBc	89 dBc	89 dBc	81.6	84.1
225M SNR	-143.7	-145.8 dBm/Hz	na	145.2 dBm/Hz	na	-138.3 dBm/Hz
225M SFDR	80 dBc	88 dBc	na	63.5 dBc	na	60.7

## Sample Rate

A true multi-carrier receiver would need to process a band of up to 75 MHz. Therefore, the sample rate should ideally be at least 180 MSPS and as high as 250 MSPS. These sample rates are likewise good for multi-carrier digital pre-distortion. In geographical regions where this may not be applicable, it may not be unreasonable to sample a band of up to 20 MHz consisting of multiple RF carriers. Here sample rates of 60 MSPS or more are quite realistic. In cases where the input bandwidth is limited, it may be advantageous to use higher sampling rates to improve noise performance. Therefore, many applications may run a much higher sample rate than otherwise required, simply to improve the noise performance.

## Gain based on 900 MHz Blocking

The information above is based on the fullscales listed in the footnotes below. Typically this is between +4 and +7.5 dBm. The goal of the following analysis is to determine the best performance possible with this technology. Based on the ADC fullscale data and given an in-band blocker of -13 dBm, the highest gain possible without clipping would be about 17 dB. Given headroom and margin, this could be closer to 12 dB, a really small number to get a good NF but for this discussion a 3 dB NF will be assumed. While the gain could be increased when input signals are low, this may not be attractive due to the possibility of dropped calls in the event of a sudden large inband blocker. Because up to 5 dB of margin may be allocated to prevent converter clipping, aggressive management of conversion gain could result in better sensitivity. In fact, some converter products, such as the AD6655, are experimenting with fast attack gain control to allow maximized conversion gain with minimized possibility of converter overdrive. However, as a starting point for this discussion, it is assumed that a fixed gain of 12 dB is used. Because the GSM standard is not written to accommodate multi-carrier receivers, some ambiguity does exist in how the receiver should behave while processing multiple carriers. For example, blocking conditions typically allow for a reduced sensitivity of a desired signal.

<sup>1</sup> 117 MSPS

<sup>2</sup> 117 MSPS

<sup>3</sup> 91 MSPS and a fullscale of 3 V<sub>pp</sub> into 200 ohms (+7.5 dBm)

<sup>4</sup> 104 MSPS

<sup>5</sup> 65 MSPS

However, it is conceivable that full sensitivity should be maintained in most if not all blocking conditions. This discussion assumes this to be the case. If a reduction in sensitivity is allowed, then specifications may be degraded appropriately.

### ***Optimistic sensitivity at 900 MHz***

Under these stated conditions, front-end noise (AFE) presented to the ADC will be  $-159$  dBm/Hz ( $-174$  plus  $12$  dB gain plus  $3$  dB NF). This is below the ADC numbers shown in the table above indicating that the ADC will dominate receiver noise, but newer ADCs are quickly approaching the level that is required. The pivotal assumption for MC-GSM is that receiver degradation is not allowed in blocking conditions. Specifically, does reference sensitivity need to be met with a  $-13$  dBm CW blocker? Per the specification it does. This places high requirements on the IF chain including the ADC. Therefore, an AGC provides little or no benefit. Second, all GSM radio manufacturers exceed reference sensitivity by about  $6-8$  dB. Does a MC-GSM radio need to exceed the required reference sensitivity? Again, the assumption is that it must. The challenge to sensitivity at  $900$  MHz is that with the converter limiting input levels, under the  $-13$  dBm blocking condition, only a limited amount of conversion gain is allowed. As noted earlier, conversion gain is limited to about  $12$  dB (more can be used if the ADC input is more heavily terminated, resulting in larger IP3 requirements on the IF signal processing). With a conversion gain this low, it is not only difficult to achieve a reasonable NF but requires that the ADC noise floor either be very low (about  $10$  dB lower than AFE noise or about  $-169$  dBm/Hz) or the ADC noise must be very white. Newer ADCs include calibration, dither and shuffling on-chip which will significantly whiten their noise performance (in addition to improving spurious performance). In this case, newer receiver architectures may be able to significantly reduce or eliminate the  $10$  dB of margin typically used between the AFE noise floor and that of the ADCs. If the ADC is allowed to dominate noise performance without dither, numerous receiver related problems may arise which are documented in “DNL and Some of its Effects on Data Converters”<sup>6</sup>.

If whitening techniques can not be used to reduce the margin, then a higher conversion gain must be used or the ADC noise floor must be lower. Based on the discussion above, the conversion gain should be increased by about  $15$  dB more to  $27$  dB to ensure that front end thermal noise is  $10$  dB greater than ADC noise. This would increase external thermal noise to about  $-144$  dBm/Hz. This would be acceptable for many of the  $14$  bit converters. Because this would pose serious clipping issues with the ADC, this is not an option unless AGC is used and a relaxation of blocking conditions. Therefore, the optimal solution is a lower noise floor from the ADC.

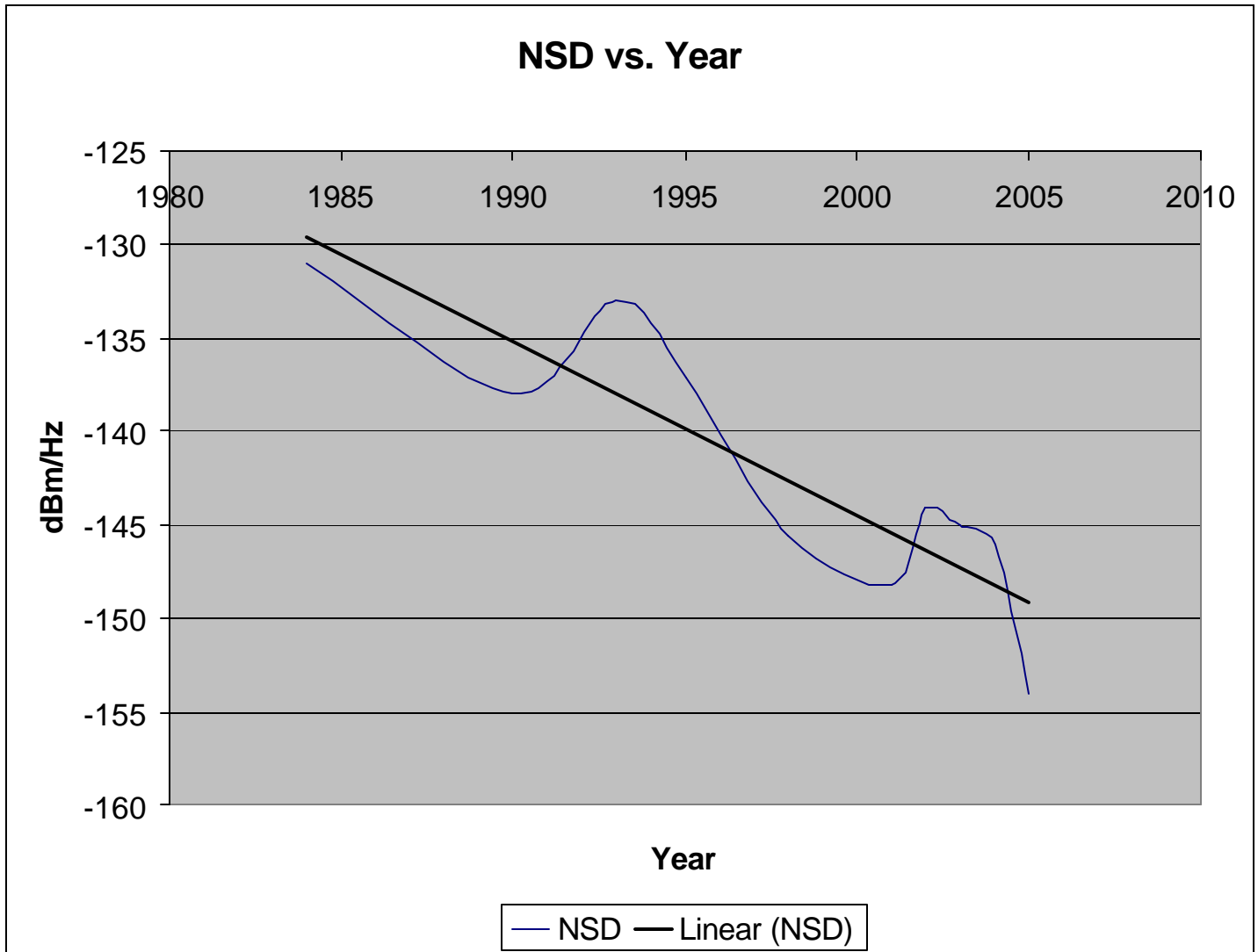
To achieve true multi-carrier performance, the ADC SNR should be improved instead of changing the gain. With a fixed fullscale for the converter, the noise floor should be reduced by  $15$  dB instead of increasing the conversion gain. This would result in ADC SNR requirements of about  $86$  dB with  $104$  MSPS or lower with a higher sample rate. From an SNR perspective, this would enable multi-carrier GSM performance in the  $900$  MHz band. Under this condition, a receiver could simultaneously process a signal at  $-13$  dBm and about  $-110$  dBm<sup>7</sup> which is the typical GSM reference sensitivity. One point of uncertainty for multi-carrier GSM receivers is the necessity of operation in this condition. Since blocking performance is usually rated at  $20$  dB above reference sensitivity, a more realistic range would be  $-13$  dBm to  $-90$  dBm. Under such conditions other optimizations could take place and this should be the subject of many discussions. Another possibility would be to increase the input range of the converter by more heavily terminating the ADC input. This would allow for more conversion gain at the expense of increased IP3 performance. While current ADC performance fails to meet the  $86$  dB requirements for  $900$  MHz band deployment, performance is increasing and should support the

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<sup>6</sup> June 2001, Wireless Design and Development.

<sup>7</sup> Reference sensitivity is estimated by adding the front-end noise to the converter noise (both  $-159$  dBm/Hz) and then integrating over a  $200$  kHz channel. This is a noise power of  $-103$  dBm. It is assumed that a signal  $5$  dB larger than the noise could be processed  $-98$  dBm. Referenced to the antenna this would be  $-110$  dBm.

required noise spectral density in the near future. A final note on SNR is that in applications where performance does not need to meet the 900 MHz levels (1800 MHz & 1900 MHz); existing ADC technology (mid 70's for SNR) exists and can be deployed. See complete discussion below.



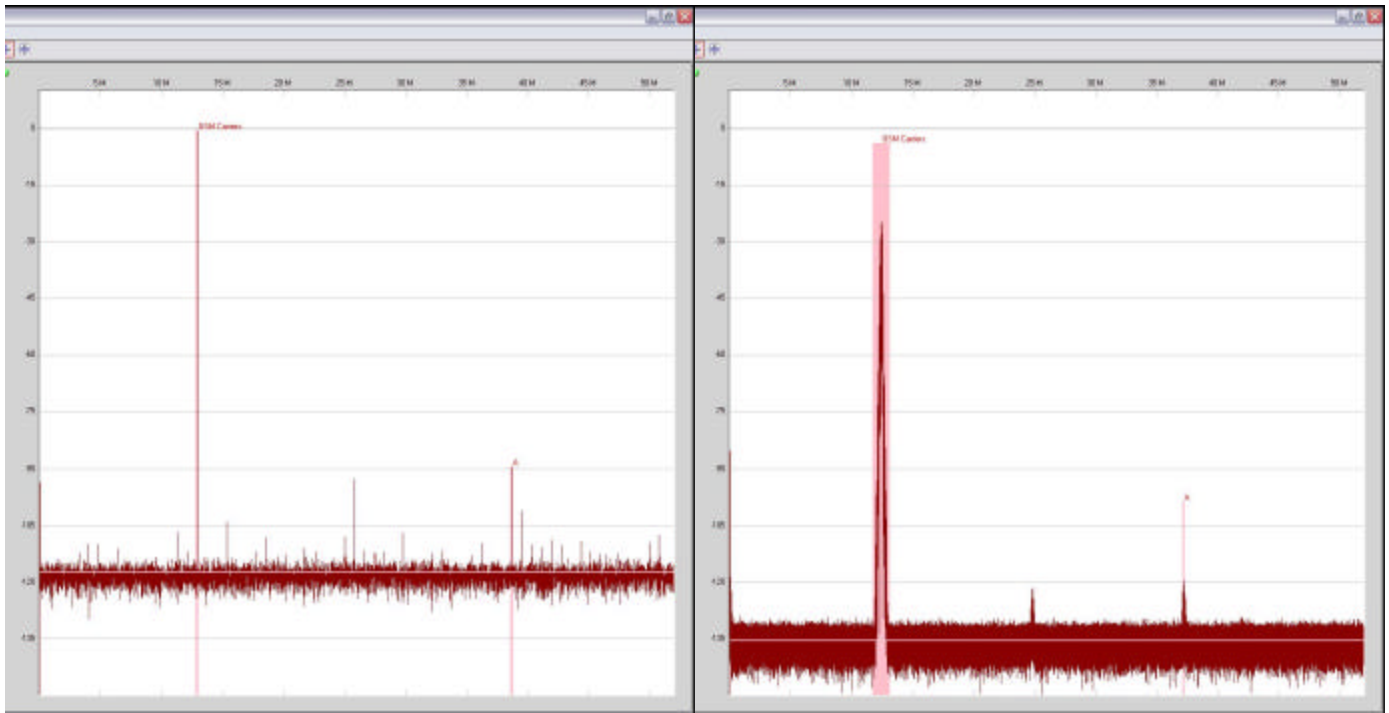
ADC Noise Spectral Density over the last few decades

### ***Optimistic blocking at 900 MHz***

A signal at -13 dBm could produce a spurious in the ADC that behaves as a co-channel interferer. In this case, the spurious should be 9 dB lower than the desired sensitivity to prevent co-channel blocking. As mentioned above, a subject for discussion would be the necessity for meeting both -13 dBm tolerance in the presence of a signal at or near the reference sensitivity, either the required level of -104 dBm or the typical of about -110 dBm. However, assuming the required level of -104 dBm, the spurious that could be tolerated must be 9 dB lower or -113 dBm. Therefore, the spurious requirements of the receiver should be 100 dB total. In order for the ADC not to take the entire budget, a more realistic number should be about -106 dB. Additionally, if the reference sensitivity of -110 dBm is used, another 6 dB would be required to achieve this. Clearly ADC technology is not at this level of performance yet.

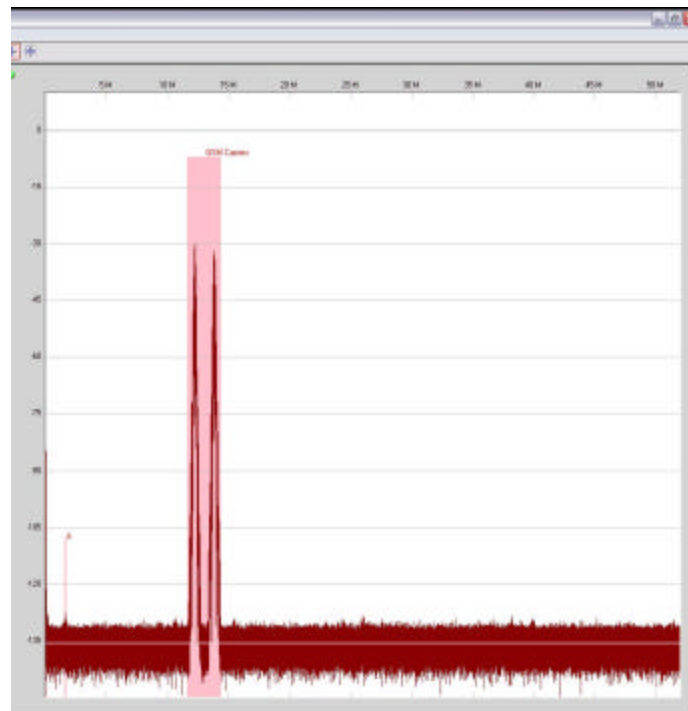
An interesting side note is that while converter performance with un-modulated tones (CW) does limit converter performance, converter performance with modulated signals is significantly better. The figure below shows performance with single and multi-carrier EDGE application. For deployment in bands where CW tones do not

exist, spurious performance may well be achieved. The figures below show the same 14 bit converter with a CW tone, a single EDGE carrier and 2 EDGE carriers. In all 3 cases, the peak input drive level was about .5 dB below fullscale. In the case of the CW tone, the SFDR is about -90 dBc. In the single EDGE case, performance is now about -120 dBc remembering that the EDGE power is still fullscale even though it has been distributed across about 200 kHz. Finally for the 2 EDGE case, spurious performance is even better, limited almost entirely by the noise floor of the converter. Multi-carrier EDGE has been demonstrated to be even better. Similar performance can be achieved with WCDMA, CDMA2000 and WiMAX waveforms however, it should at all times be remembered that in the presence of CW blockers performance will be limited by those waveforms.



14 bit ADC driven with CW tone

14 bit ADC driven with 1 EDGE Carrier



14 bit ADC driven with 2 EDGE Carriers

As shown here, spurious performance with modulated waveforms is significantly better than with CW tones. As stated earlier, in applications that can avoid CW tones, performance is coming into line with the required performance. However, as with SNR, SFDR requirements for non-900 MHz applications are relaxed by 10 or more dB. Therefore, current technology exists, even for CW tone tolerance in these bands.

### ***Gain based on 1800 MHz Blocking***

For operation in this band, the largest in-band blocker is  $-23$  dBm. The highest gain possible is now increased to 27.8 dB. Given headroom and margin, a good number to use for gain would be 22 dB and the noise figure of 3 dB could be used.

### ***Optimistic sensitivity at 1800 MHz***

Front-end noise presented to the ADC will be  $-149$  dBm/Hz. This is comparable to the ADCs and therefore is acceptable. If the ADC noise is white in nature, this may perhaps be tolerable especially if techniques such as dithering are used. Given that nearly 6 dB of headroom has been allocated, some of this may carefully be traded off to achieve a slightly higher conversion gain and even better performance. Therefore, it may be possible to manage receiver gain in such a way that the converter neither clips and non-blocking sensitivity is maximized while not allowing the ADC noise floor to over contribute to the noise floor. For this case, assume a gain of as much as 28 dB. In this case, the AFE noise will be about  $-90$  dBm in a 200 kHz bandwidth. If an SNR of 5 dB is required then total signal power at the ADC would need to be about  $-85$  dBm or referenced to the antenna about  $-113$  dBm. Therefore, for the 1800 MHz band, it is possible to meet the requirements given current ADC SNR performance.

### ***Optimistic blocking at 1800 MHz***

With an in-band signal of  $-23$  dBm and a reference sensitivity of  $-104$  dBm, the required spurious performance for the receiver would be  $-90$  dB. Again allowing a split between AFE and the ADC, this would require the ADC to be  $-96$  dBFS. This again is achievable with current technology, especially in light of the discussion above on performance of the ADC with modulated inputs. However, if the lower reference sensitivity is required in the presence of the larger blocker, this requirement becomes slightly more difficult to achieve and should be a point of discussion.

### ***Conclusion***

Based on this overview, 900 MHz is still not feasible from an ADC perspective for both SNR and SFDR but is seen to change in the near future. Performance at 1800/1900 MHz is possible based on the discussion above. This includes a balanced view of premium sensitivity ( $-110$  dBm) and blocker tolerance as long as conversion gain and NF are appropriately balanced. In order to achieve 900 MHz operation, an SNR in the mid-80's is required and a spurious of between 100 and 110 dBFS are required.