The Effect of Out-of-Band Interference on Base Station Receiver Performance

1. Introduction

Standards committees and national regulatory bodies (such as the FCC in the US) provide the system specification framework for interoperability of different air interfaces allocated in different frequencies worldwide. The rules, specifications and acceptance criteria that are the output of these organizations represent a compromise of technology availability, cost, performance, safety and to some extent political considerations. All possible interference scenarios cannot be accounted for, and as more of the global population migrates to mobile wireless networks each user will contribute more to the interference background, bringing to the fore the presence and management of interference. In any wireless network, interference can pose a significant threat to realizing the expected performance.

There are two major classes of out-of band interference:

1. Interference from your own users that are in the same frequency band but are using a different technology. This is generally a part of a technology migration strategy. For example GSM users on a predominantly TDMA network at 850MHz in the US.
2. Interference from other operators in adjacent frequency bands.

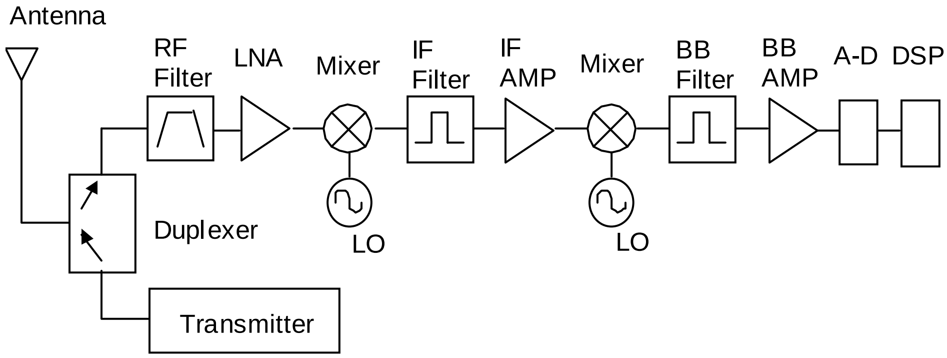
In the first case, since the sites will be typically co-located as the same operator deploys both technologies, any interference can be managed with some frequency allocated to a guard band and by careful optimization of the network design. However, in the latter case, interference is out of the control of an individual operator and thus if an interference problem occurs it is much more difficult to eliminate.

2. Interference Mechanisms

So why is out-of-band interference a problem at all? The very description itself states that it is “out of the band” of interest. Base station and mobile transmitters are required to only transmit within the frequencies they are allocated. Receivers are designed to select particular frequencies, amplify and decode them.

However the root of the problem lies in the compromises reached in the design of the receiver. Every component in a receiver has a non-linear component if the strength of the input signal is high enough. Thus, for any receiver chain, a certain level of input signal will generate harmonics and intermodulation. Because of these non-linearities, the receiver's output spectrum may contain components that are not present in the input signal. If these components fall into the band of interest then they will add additional noise (intermodulation distortion).

In any receiver design, competing with minimizing the generation of IMD (described by the Input Intercept Point, IIP3) is amplification of the in-band signals. Large gain (for increased in-band amplification) early in the receiver chain will enhance the signals of interest but will also cause larger out-of-band signals to be incident on the receiver components generating more IMD and noise in band. The complexity of a typical receiver is shown below.



Block diagram of Base Station Receiver

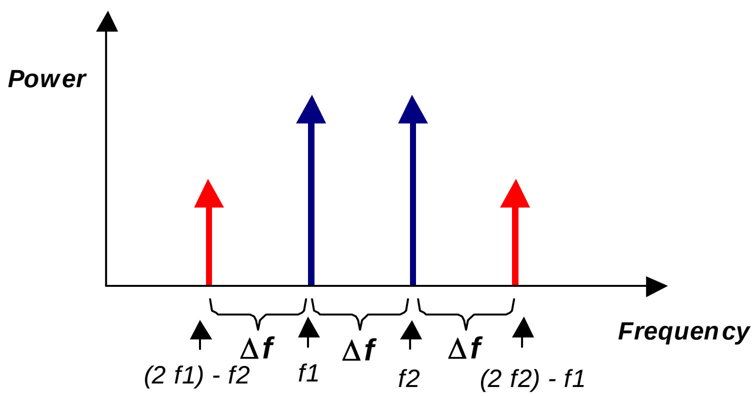
As out-of-band interference increases, the first deleterious effect on a receiver caused by large out-of-band signals is intermodulation distortion. This will degrade the performance of the particular channel where the IMD product happens to land. If very large signals are incident on a particularly non-linear receiver component then de-sense can occur. This will affect all of the channels used by that receiver. This will be described in the later sections

2.1 Intermodulation distortion (IMD)

Non-linearity takes place in every component of the receiver if the signal level is high enough. When two or more high power signals are added together in the non-linear element then, in addition to the signals, at the input frequencies other components will be generated. The third order intermodulation is particularly troublesome because of its strength and of the proximity to the band of interest. Higher order IMD products are also generated but these are not as strong. For two similar strength out-of-band signals the power generated in the third order product is given by:

$$P_{IMD}^{in} = 3.P_i - 2.IIP_3 \qquad (1)$$

where P_{IMD}^{in} (in dBm) is the power of the IMD signal generated by two signals of equal power, P_i (in dBm), in a receiver with a third order input intercept point of IIP3 (dBm). The frequency at which the signal is generated is also important and is shown below.



Third order IMD products falling in adjacent frequency bands to the band of operation.

IMD generation is particularly insidious because it is a probabilistic phenomena requiring large, simultaneous signals at the right frequency to land in the band of interest and these unwanted signals are then seen as noise by the receiver and degrade the signal to noise ratio (SNR) of the desired signal. Note that this increases the *noise* of a single channel. However, this effect is most prevalent when you want it least – at the busy hour. It is not only the busy hour for you, but it is also the busy hour for your near-band neighbors and hence the busy hour for interfering signals.

2.2 Blocking, Saturation, De-Sensitization

As the power of the interfering signals increase, a point is reached when one of the receiver components saturates. At this point the gain expected is no longer added to the wanted signals. That is, the signal itself is degraded, as are all signals passing through that component. Hence, the SNR is degraded for all wanted signals and as the interfering signal increases in power then so does the degradation on all of those in-band signals. This effect is called blocking, saturation or de-sensitization.

Blocking involves “over-filling” of the receiver’s capacity to process any more signals, and will have a substantial impact on the performance of the receiver on all of the in-band signals. For example, for a typical CDMA receiver with –8dBm IIP3, a +5dBm signal going into the receiver will cause a 15 to 20 dB reduction in the desired signal strength, which when combined with the IMD generation results in a massive degradation in SNR.

2.3 In Summary

As out-of-band signals incident upon a receiver increase in power, the first measurable effect on in-band performance is the generation of in-band IMD. This requires two signals suitably spaced in frequency in order to land in the band of interest. This will be more and more likely as more users are using the network and power increases. A receiver has multiple components, all of which must be selected for their linearity under high RF power, however, as the out-of-band power increases ultimately one of these components will saturate and thus cause a significant degradation in the signal to noise ratio for all of the in-band signals for that receiver. The exact signal strength where these different, but related phenomena have a measurable effect on the receiver performance depends upon the linearity of the receiver (characterized principally by IIP3) and the noise floor above which the wanted signals are measured. These vary by technology and to a lesser extent by infrastructure vendor. Approximate values are shown in the table below where the IIP3 was implied from the appropriate specifications.

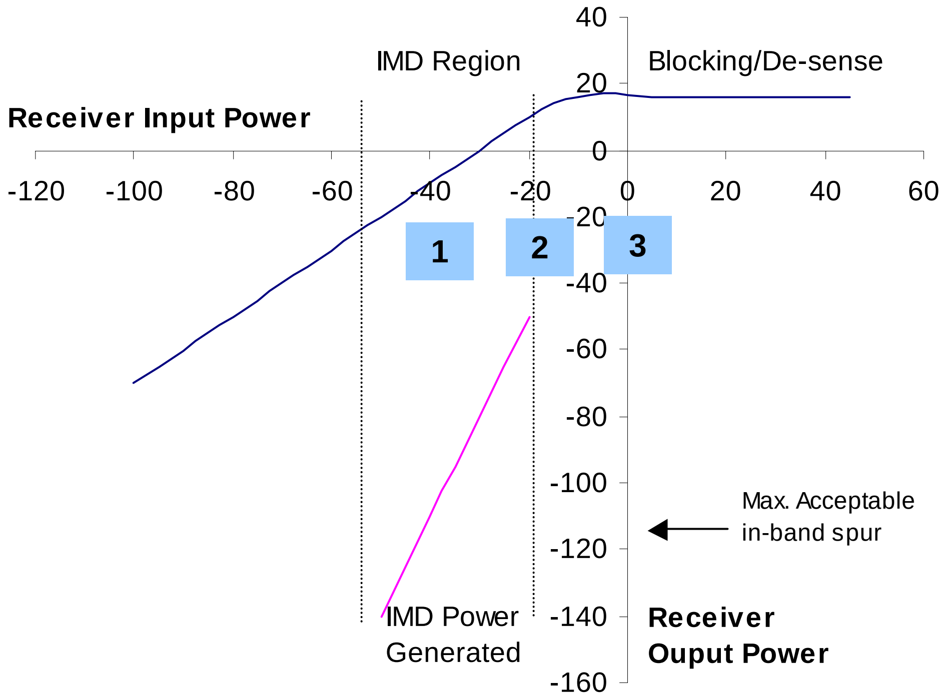
Table : Key technology characteristics and non-linear performance metrics derived from the standards. In the case of CDMA the IIP3 may be higher in an actual BTS.

	TDMA IS-136	*GSM*	*CDMA IS-95*	*W CDMA*
Bandwidth (kHz)	**30**	**200***	**1250**	**5000**
Receiver IIP3 (dB)	**-4**	**-8**	**-18**	**-23**
Minimum signal to produce in-band IMD (dBm)	**-48**	**-45**	**-47**	**-50**
Minimum signal to produce Blocking (dBm)	**-15**	**-19**	**-29**	**-34**

*with frequency hopping enabled the effective bandwidth may be greater than 1MHz depending upon the number of frequencies used in the hop pattern

The transitions from linear to non-linear to blocking/de-sense is best shown by investigating the output to input power curves for a typical receiver (figure below). This illustrates the performance of a typical CDMA receiver with 30dB of gain. As the input power increases so does the output power on a dB for dB basis. This is true until the input power exceeds the ability of the receiver to process.

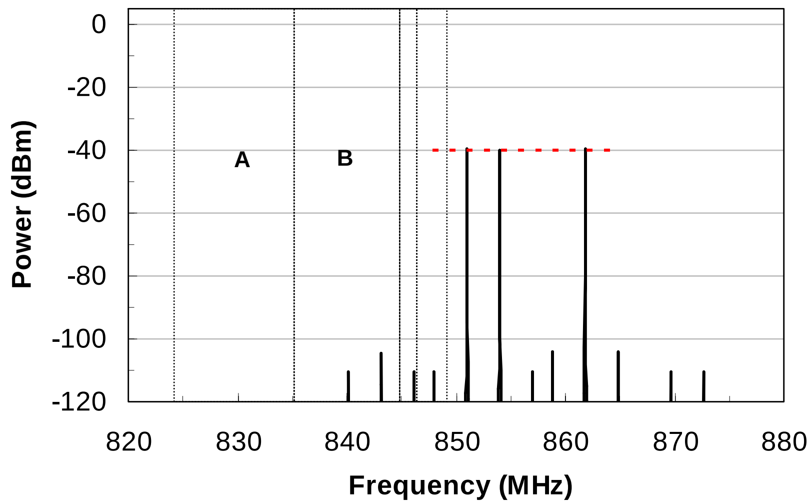
This is show as the "blocking/de-sense" region. When the receiver is in this regime, a dB of input power does not result in any change of output power.



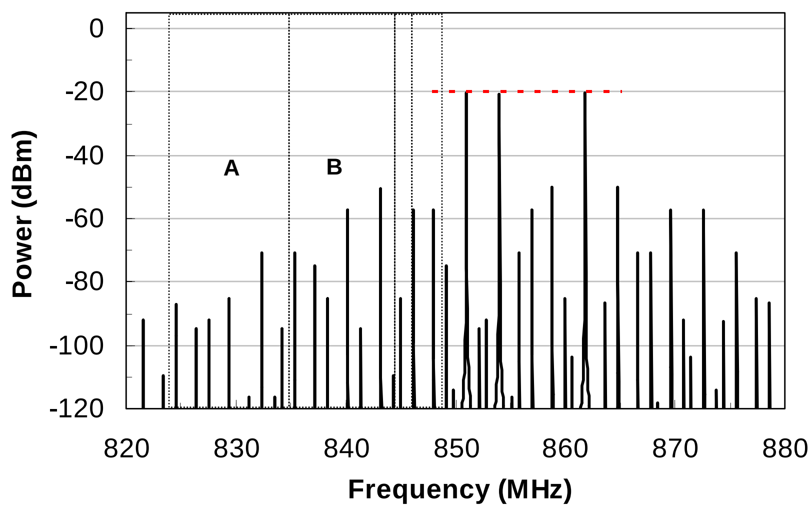
Power In vs Out for a typical CDMA receive (Blue curve). The IMD generated are shown as the pink curve. For an input signal greater than –20dBm blocking will occur on all CDMA carriers.

For input powers in the range designated "IMD region", third order "spurs" are produced in the receiver. These "spurs" are sufficient to cause degradation of in-band performance. As can be seen from the chart the increase in power of these unwanted in-band "spurs" increases much faster than the input power of the signals causing them. As the signal levels increase, higher order IMD products (greater than 3^{rd}) are generated. The following simulations show the in-band IMD products from three signals of equal power distributed in the SMR band.

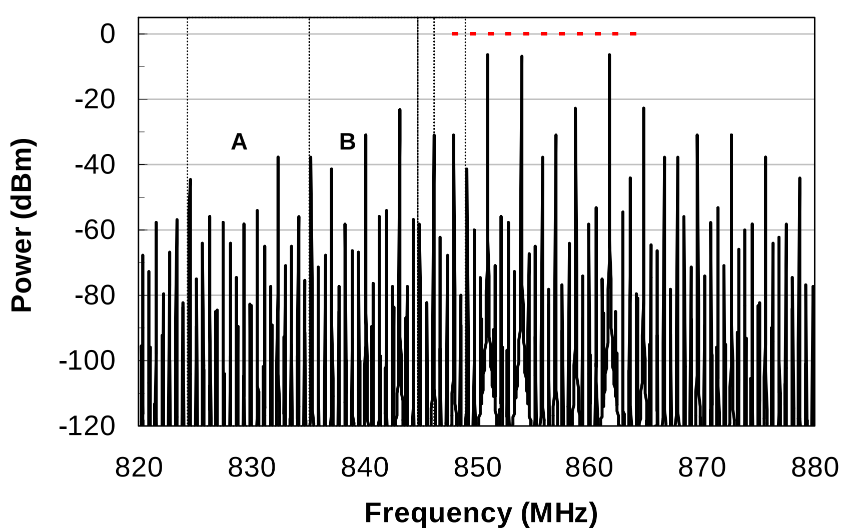
1



2



3

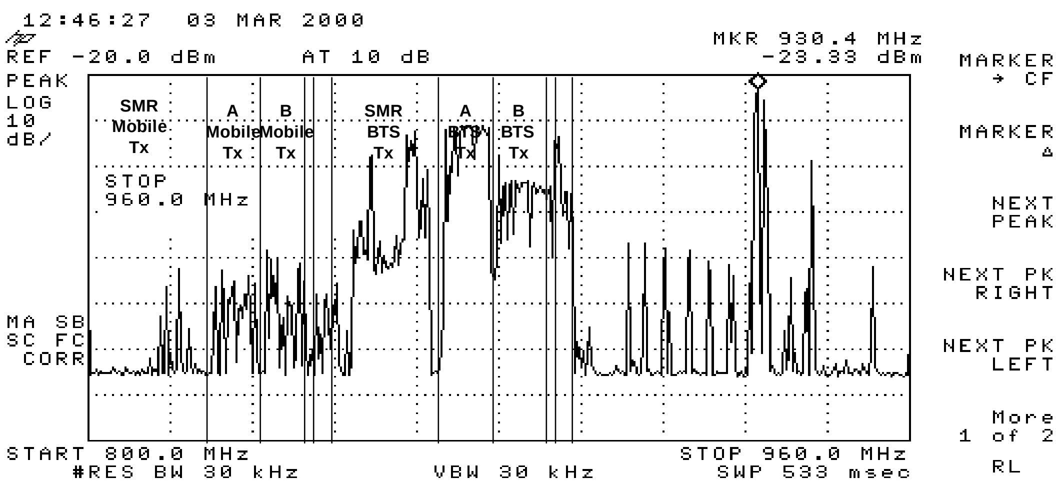


Simulations of IMD products (referenced to 850MHz)generated from three signals spaced within the SMR transmit band. The SMR signals used in the simulations were 1) –40dBm, 2) –20dBm and 3) 0dBm. Largest Cellular in-band IMD products were –105dBm, -50dBm and -23dBm respectively.

Note that in the last simulation the signal level of the SMR transmit is lower than expected because of de-sensitization of the receiver.

3. Out-of-Band Signals in Wireless Networks

Given the previous discussion on the theory of IMD and blocking how often does this occur in real wireless networks? The answer is that it happens surprisingly often and many of the base stations are not designed to take this into account as the equipment manufacturers assume that the interference problems were dealt with during the standards process. While blocking is simple to recognize, IMD problems are much more prevalent and can have an adverse effect on network performance. As an example of a typical rf environment entering a receiver see the spectral scan shown below.



Spectral scan of the 800MHz to 960MHz region in a suburban cell site.

	SMR Mobiles	A/B band Mobiles	SMR BTS T_x	A BTS T_x	B BTS T_x
Maximum Signal Level (dBm)	-62	-58	-32	-30	-42

For cellular providers, SMR base station transmit signals of the magnitude shown in this spectral scan will produce IMD in their band and degrade key performance metrics such as dropped or blocked calls. It is also extremely difficult to filter out these signals without affecting other receiver parameters, particularly the base station R_x noise figure. An increase in base station R_x noise figure will cause a weaker uplink and hence an imbalance.

In the case of CDMA or GSM, where the signal is now spread over a larger frequency range than the earlier analog or TDMA technologies, there is increased susceptibility to these problems as there is now a higher probability of incidence of a narrow band IMD colliding with the wide-band frequency.

4. Conclusion

Out-of-band interference is a growing problem faced by the operators of today's wireless networks. Increasing wireless usage and base stations designed for maximum sensitivity rather than selectivity are causing degradation in the overall performance of wireless networks. The fact that out-of-band interference can affect in-band performance is not intuitively obvious, however, in this paper we have tried to show the cause and effect to this phenomena with both some theory and real world data. Looking forward, with the trend toward more and more wireless usage, increasingly more attention must be paid to protect the spectrum you have paid for.