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Modelling Spectral Regrowth and the Effect of Packet Size

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Abstract: Traditionally nonlinearity has been characterized by two-tone intermodulation distortion. However, for digital radio, modelling spectral regrowth is much more important. There is currently much interest in modelling spectral regrowth in microwave power amplifiers for wireless communications. The ability to predict spectral regrowth or, more specifically, Adjacent Channel Power Ratio (ACPR), has a direct impact on design to achieve acceptable linearity performance. Since there is a trade-off between linearity and efficiency the amount of back-off can significantly affect power amplifier efficiency and thus, for example, talk-time for a mobile handset.

Many wireless communications systems, such as GSM, use Time Domain Multiple Access (TDMA) schemes, sending signals in bursts (or packets). Using a behavioural model which can predict ACPR given an estimate of input signal statistics, it is shown that ACPR is highly dependent on the input signal statistics and it is dependent on the length of the packet.

1. INTRODUCTION

In cellular radio systems optimum spectrum utilization has resulted in channels that are very close or slightly overlapped, see Fig.1(a). A certain amount of signal appears in the adjacent channels due to modulation limitations and in some systems because of channel overlap. Also the effect of nonlinear amplification of a signal is to increase the relative distortion levels in the adjacent channels—a process called spectral regrowth (SR) [3].

The effect of SR is mitigated in many systems by not using adjacent channels in the same geographical cell. However it is still necessary to establish a lower limit on the ratio of the power in the main channel to the amount of power induced in the adjacent channel. This ratio is known as the adjacent channel power ratio (ACPR). It is much more convenient (conceptually and for measurement and simulation) to use intermodulation distortion (IMD) characterization to quantify nonlinear performance. IMD is generally determined by considering the response of two equal amplitude input tones, of frequencies f_1 and f_2 in Fig.1(b).

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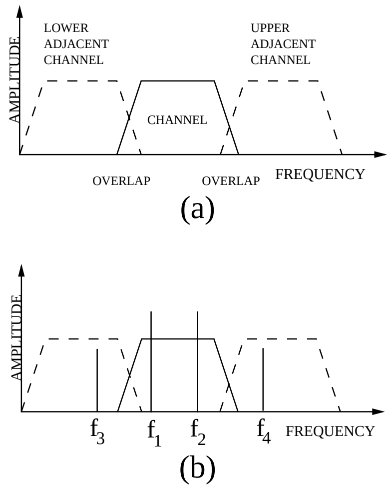


Figure 1: Spectra of a cellular wireless system: (a) indicating relative locations of main channel and upper and lower channels; and (b) showing the discrete spectra resulting from a two-tone input signal

The so called third order intermodulation distortion ratio (IMR3) is the ratio of the power of the lower, $IM3_L$, (or upper, IMR_U) intermodulation tone, here at $f_3 = 2f_1 - f_2$ (or $f_4 = 2f_2 - f_1$) to the power in one of the original input tones. IMD determination is an adequate performance measure for signals such as FM modulated signals that can be represented as a number of discrete tones. A digitally modulated signal fills the spectrum in a channel and cannot be represented as a collection of discrete tones. Neither can it be represented as narrow band noise as the signal has a complex autocorrelation.

TDMA based schemes such as GSM send their data in bursts or packets, rather than a continuous signal. It is the purpose of this paper to show that ACPR is highly dependent on the input signal statistics and the length of the packet.

2. BEHAVIOURAL MODELLING OF SPECTRAL REGROWTH

AM-AM and AM-PM measurements provide a convenient characterization of a nonlinear amplifier yielding an envelope behavioural model [4]. This must be transformed into a baseband equivalent behavioural model [5] before it can be used. This procedure was applied to an RF driver amplifier yielding a 13th order, odd order only, complex power series [5].

Recently a statistical nonlinear analysis technique was developed which can efficiently predict SR in a nonlinear amplifier with a digitally modulated signal [4,5]. Evaluation of the autocorrelation parameters of the output signal is obtained by substituting the autocorrelation function of the input signal into the baseband equivalent complex power series. It is straight forward then to determine the output spectrum from the output statistics and so determine ACPR. The response of the amplifier considered previously was investigated with a CDMA signal at 1900 MHz. The measured and calculated results are shown in Fig.2. $ACPR_U$ and $ACPR_L$ indicate ACPR in the upper and lower adjacent channels respectively. Good agreement is achieved across a wide range of output powers.

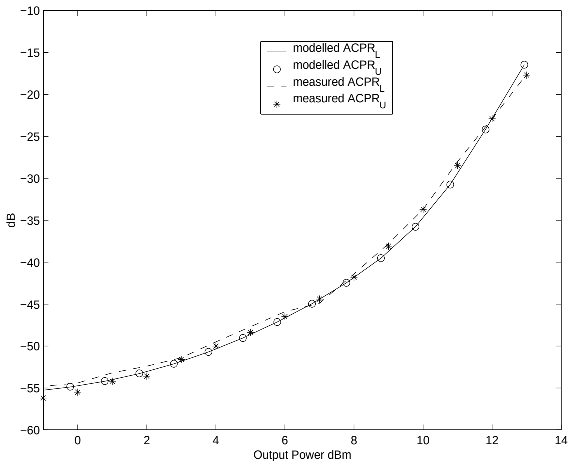


Figure 2: Measured and calculated ACPR for a CDMA input signal

3. VARIATION OF ACPR WITH PACKET SIZE

Work mentioned in the previous section was carried out with a data stream of 65536 symbols. This can be thought of as a very long packet and so approximates a (continuous) CDMA signal very well. If however, simulations are run for smaller packet sizes the predicted ACPR varies widely as can be seen in Fig.3:

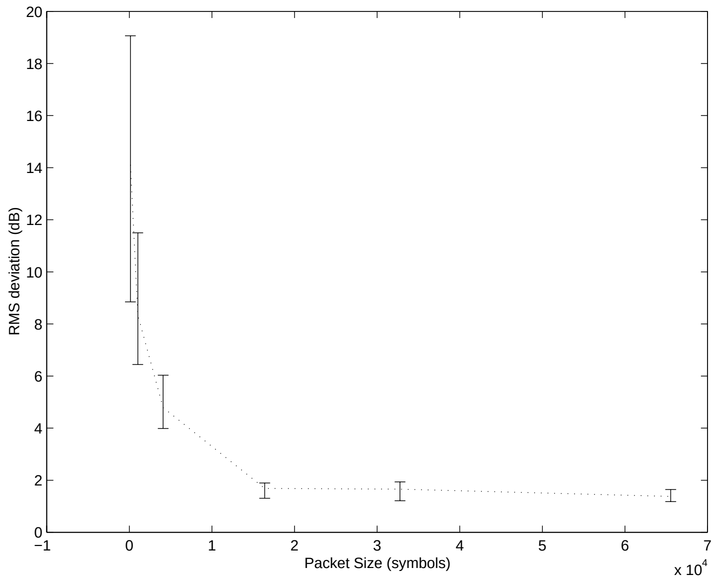
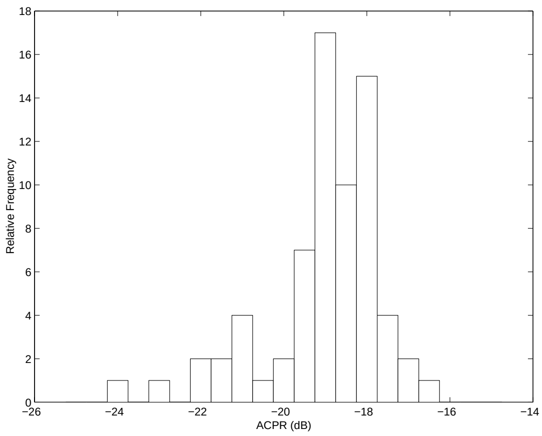


Figure 3: RMS variation in dB of simulated values of ACPR from measured values for the output power range shown in Fig.2

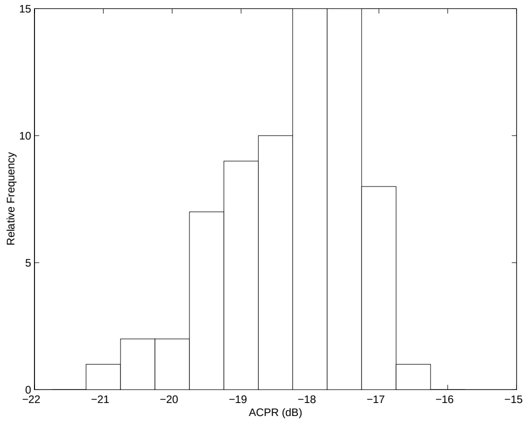
Ten simulation runs were performed for each packet size and in each packet the I and Q bit sequences varied widely. The error bars indicate results for 80% of the packets at each size (in order to eliminate possibly extreme results). Also the dotted line plots the average of the ACPR results at each packet size. The graph shows the RMS difference between simulated and measured values as a function of packet size. As can be seen, with small packet sizes the difference between measured and simulated ACPR values is very large and the variation in values is also very large. This variation and deviation from measured values decreases dramatically with increased packet size i.e. as the simulation approaches the continuous case.

This effect can also be seen in Fig.4 which is a convenient histogram of simulated ACPR values. Seventy simulation runs were carried out with an output power of 13 dBm. Packet sizes of 146 and 256 bits were used. Since normal GSM packets are 147 bits long these simulations give an indication of performance for GSM packets. As can be seen there is a 5-7 dB variation across the range of simulations. The reason for the large variation in ACPR values with small packet sizes is that from packet to packet the statistics of a small packet vary considerably. This is not the case for large packet sizes.

Fig.5 shows the simulated autocorrelation functions for 146, 256 and 131072 bit sequences. The 2 plots on each figure show the results of different runs of the simulation with packets containing different bit sequences. In Fig.5 the solid and broken lines correspond to ACPR's of (a) -19.48 dB and -18.1 dB; (b) -17.53 dB and -19.56 dB; and (c) -16.39 dB and -16.41 dB. Thus it is clear that the statistics of the signals vary considerably for small packet sizes, but are very stable for large packet sizes.

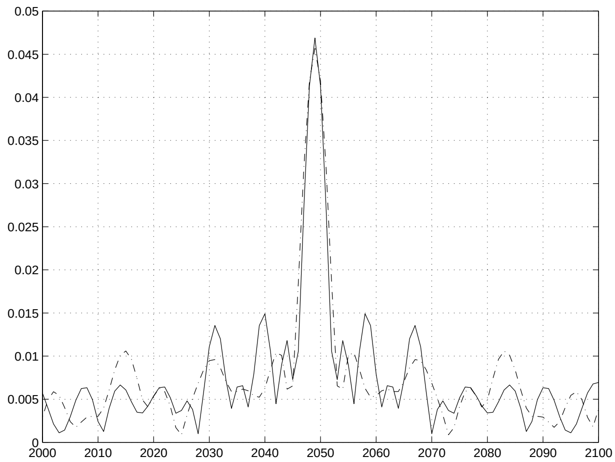


(a)

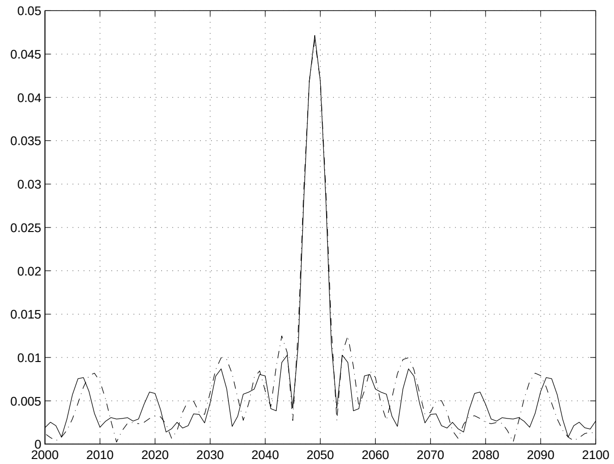


(b)

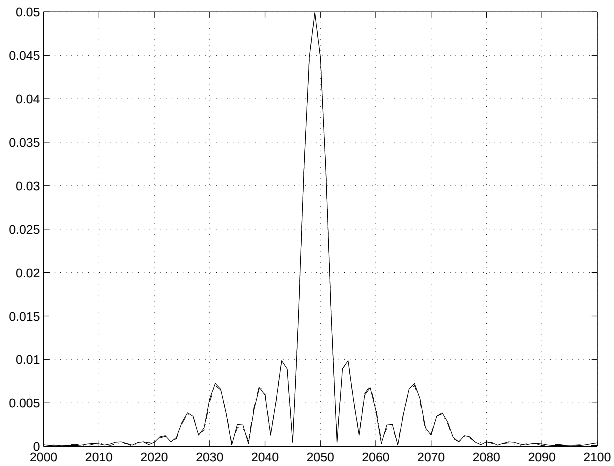
Figure 4: Histogram plot of ACPR variations across 70 simulation runs for (a) 146 bit packets and (b) 256 bit packets



(a)



(b)



(c)

Figure 5: Simulated autocorrelation functions for (a) 146 bit packets, (b) 256 bit packets and (c) 131072 bit packets. The autocorrelation function for two different packets are shown in each.

3. CONCLUSIONS

It has been demonstrated that signal statistics vary considerably for small packet sizes. It has also been shown that this in turn causes a variation in ACPR at the output of an amplifier. Thus it has been established that a relationship between ACPR and packet size exists. As a consequence of this it should be possible to optimize coding schemes to minimize variations in signal statistics and thus minimize ACPR.

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