A study of BER Degradation due to Self-interference caused by AM-AM/PM Nonlinearities

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Abstract: This paper investigates the degradation in uncoded BER due to self-interference ISI caused by nonlinear gain compression and phase rotation in the transmission path. A QPSK scheme is simulated and the probability density functions of the nonlinear distortion effects are analysed with respect to the BER degradation. The results show that AM-AM nonlinearity produces more self-interference ISI and BER degradation than AM-PM nonlinear distortion. The pdfs of these distortions are obtained empirically and their statistics (variance and skewness) are used to expla in the change in shape of likelihood functions that determine BER in the presence of Additive White Gaussian Noise.

1. Introduction

Behavioural AM-AM/PM characteristics are often used to model nonlinear power amplifier operation [1] in both simulation and analysis. In analysis, this is done by fitting a polynomial to the power transfer characteristics. It is known that the gain compression of a nonlinear transfer function is responsible for spectral regrowth and is typically quantified as Adjacent Channel Power Ratio (ACPR). The ACPR is an adjacent channel interference (ACI) effect that potentially degrades the performance of another channel. Typically, the power leakage level must comply with a specification regulated by a standards body to ensure that ACI does not cause substantial degradation in an adjacent channel. In addition, the regrowth or the gain compression is related to the in-band distortion or self-interference ISI in a digitally modulated signal [2, 3]. This type of distortion is due to higher odd order terms generated in a nonlinear system. For a digital radio, the level of this distortion is crucial to the system performance and because it is a digital system, it is most appropriate to quantify the distortion in terms of system Bit Error Rate (BER) performance. BER simulations are carried out in the presence of AM-AM or AM-PM distortion and Additive White Gaussian Noise (AWGN). BER curves are obtained for different levels of distortion and justified by observing the conditional probability density functions (pdfs) of the received signal samples.

2. Simulation and Experimentation Setup

The nonlinear power and phase transfer characteristics are shown in Figure 1 and the corresponding AM-AM/PM models are implemented using Agilent's ADS computer simulation platform. Although these models usually have a certain gain in amplifier operation, the gain is normalised to 0 dB as we are only interested in the effect of compression. In order to demonstrate the self-interference ISI effect of the nonlinear compression and phase rotation, a linear set of gain and phase models is needed for benchmark purposes. The linear set has a constant attenuation and phase shift. Monte Carlo BER simulations (> 90% confidence interval) are carried out and the BER performance obtained with nonlinearities is compared with its linear counter part. An uncoded QPSK scheme with Root Raised Cosine filtering of roll-off factor 0.2 is considered. Figure 2 shows a schematic of the system under test together with the relevant average bit energy, E_b, and the one-sided noise density, N_0, parameters. The power level is fixed for a given simulation run in order to specify the amount of nonlinear distortion, while the noise level is changed. The distortion increases with increasing input power. The BER results are shown in the following section. ISI samples are collected using an Error Vector Magnitude (EVM) sink prior to the threshold detector. The ISI samples can be taken from the I or Q components of the QPSK constellation. The measured values are plotted as a conditional pdf conditioned on data '+1' (see Figure 3).

3. Simulated Results: BER Performance

Simulations were carried out at two distortion levels, 0.2 dB and 3dB Output Power Back-Off (OBO), referred to the maximum output power as shown in Figure 1. At 3dB OBO, Figure 4a shows that the BER degradation is mainly due to the linear attenuation and phase shift. The results show that the in-band distortion is not significant. At 0.2dB OBO a further 1 dB degradation above the linear AM case at a BER of 10^{-5} is obtained. In the PM case, the increase in degradation is small.

4. Conditional pdfs of the Self-interference ISI

Although the EVM_{rms} gives an indication of the level of self-interference ISI due to nonlinearity, a more quantitative describtion of the BER degradation can be obtained from the conditional probability density functions of the signal and ISI. In this section the AM-AM/PM induced interference, as measured empirically, are reported and shown in Figure 5. Only I-component's pdfs are shown as the Q-component pdfs are identical. It can be seen from Figure 5a that the most significant difference between the pdfs is the spread, s, which is proportional to the distortion level.

In addition, all the pdfs are asymmetrical especially for small OBO values. As such the 'skewness' of the conditional pdf relates to the amount of ISI and hence the BER degradation. The 'skewness' is the 3rd order central moment and is a measure of the symmetry of the distribution and is given by:

$$Skewness, \quad v = \frac{E[(X - \bar{x})^3]}{(s^2)^{3/2}} \qquad (1)$$

$$\text{where} \quad s^2 = E[(X - \bar{x})^2]$$

Near saturation (i.e. 0.2dB OBO) the spread of the AM-pdf (Figure5a) is increased and is skewed towards the zero threshold boundary while at 3dB OBO the spread is small and the skewness is almost zero. In the presence of AWGN, the joint pdf will be the convolution of the Gaussian noise pdf and the signal AM-pdf [4]. Due to the spread and skewness, the tail of the joint pdfs are shifted towards the zero threshold and it is more likely that the distorted signal plus noise values will cross the threshold. This explains why at 3dB OBO there is negligible BER degradation while at 0.2dB OBO there is further 1dB degradation. Also, the conditional PM-pdf exhibits a bimodal characteristic, showing two peaks equally distributed and equi-distant about the nominal signal value. Its skewness is effectively almost zero. Hence, the PM-induced ISI is negligible.

5. Conclusion

The self-interference ISI can be assessed readily by EVM measurements which are subsequently used to adjust the nominal signal-to-noise ratio (SNR). From this an estimate of the BER reflecting the degradation due to nonlinearities can be calculated [5]. EVM is a baseband time-domain measurement technique in which the composite errors may include other sources such as ISI due to filter mismatch. Although in simulation these effects can be isolated, it is preferable to evaluate the BER performance of a nonlinear subsystem analytically. This can be done when the conditional pdfs of the self-interference are known and given that the conditional pdfs can be determined from the AM-AM/PM characteristics. The analysis of BER using this technique is the subject of further investigation by the authors.

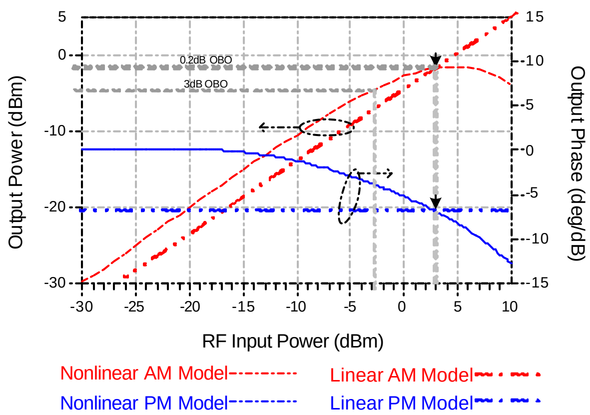


Figure 1: Power and Phase Transfer Characteristics

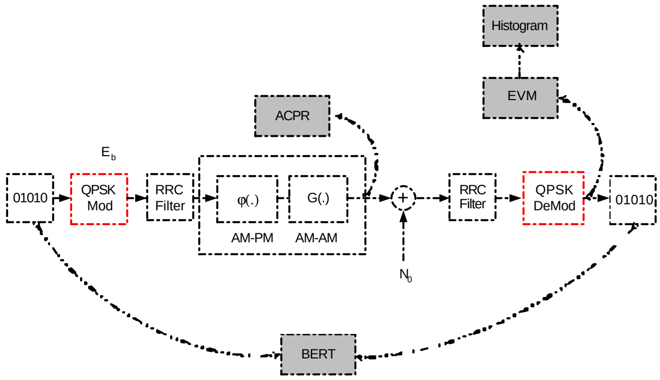
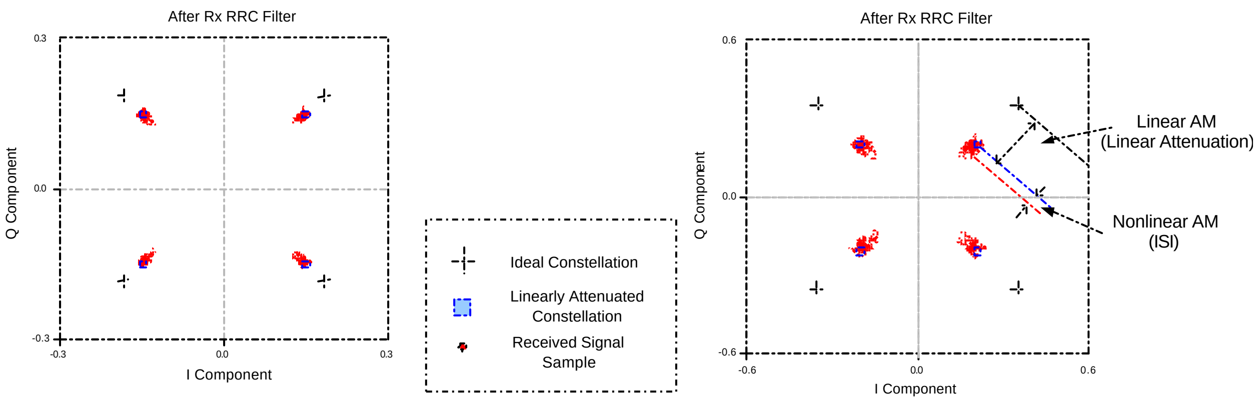


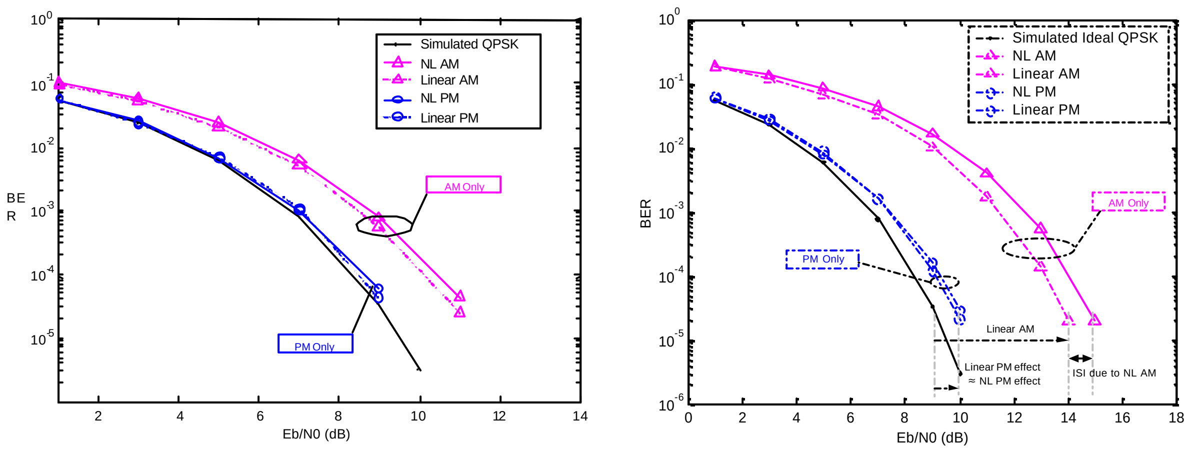
Figure 2: Lowpass-Equivalent Simulation Setup



3a) 3 dB OBO

3b) 0.5 dB OBO

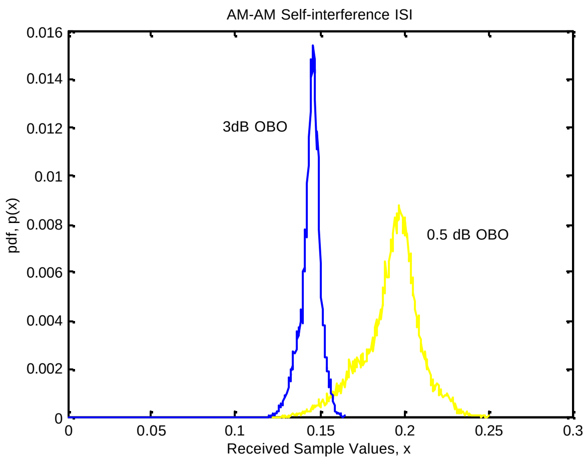
Figure 3: Constellation diagrams of QPSK for two distortion levels showing the ideal constellation, linear attenuation and the ISI (1000 symbols; 5 points/symbol; 64 filter taps)



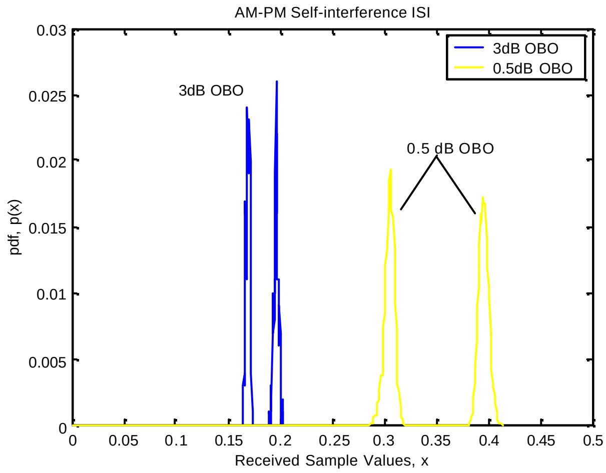
4a) 3dB OBO

4b) 0.2dB OBO

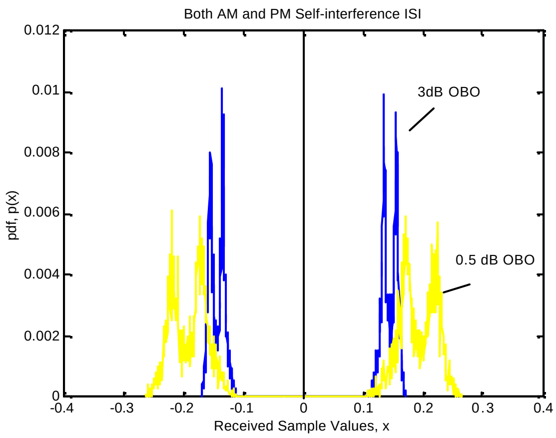
Figure 4: BER vs Eb/N0: Degradation due to AM-AM/PM Nonlinearities



5a) AM-pdf conditioned on data '+1'



5b) PM-pdf conditioned on data '+1'



5c) Likelihood pdf due to both AM and PM (conditioned on data '-1' and '+1' - a mirror image of each other)

10 000 signal samples at the receiver are collected and distributed over 1000 bins

Figure 5: pdfs of the self-interference ISI caused by AM-AM/PM

References

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