APPLYING GCMAC TO PREDISTORTION IN GSM BASE STATIONS

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ABSTRACT

Predistortion in GSM has been introduced to deal with saturation in amplification at Base Transceiver Stations (BTS). This paper will focus on the elements and architectures in signal predistortion for one carrier and multicarrier modulations. The GCMAC neural network has been introduced as predistorter to provide the design with adaptive, digital and practical features. Some results are included. These results show how the predistortion architectures proposed allows working in saturation regimen. This point is important since it gives flexibility in reassignment of cells by increasing the coverage when necessary. It also improves amplification characteristics avoiding co-channel interference, aging, intermodulation distortion, etc.

1. INTRODUCTION

The spectrum is a scarce resource and there is an ever-increasing interest in using high-efficiency modulations as QAM and GMSK. However, these modulations are sensitive to the non-linearities of the transmission system. One of the most significant non-linearities is that introduced by the amplifier. This element becomes critic in BTS's with large coverage. It also causes troubles when reassigning cells after one BTS falls.

The amplification distortion has two effects in the signal spectrum. On the one hand, it deforms and enlarges the spectrum within the bandwith. On the other hand, it causes harmonics to appear at the multiples of the carrier frequency. A design including high power amplifiers (HPA´s) working at low efficiency is not a suitable solution. Notice that in mobile communications the batteries play an important role. Usually, the amplifiers used are types AB working far from saturation. The distortion introduced is permissible but not desirable: intermodulation products rise along with the number of carriers and the harmonics must be suppressed with a canceller. Besides, the efficiency could be improved. An effective solution is to apply linearization to the amplifiers using predistortion techniques. This linearization method cancels non-linearities in magnitude or phase. In addition, the predistortion scheme may be designed in an adaptive way so effects such as temperature, aging, etc may be compensated.

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In the present text, a model for the amplifier and the role of the GCMAC neural network as predistorter are discussed. Then, the architectures adopted and some results are exposed.

2. Predistortion in GMSK

The predistortion [7] is introduced to linearize the response of the amplifier. The role of the GCMAC neural network as predistorter is to transform the input signal *x(t)* into another signal *s(t)*. The signal *s(t)*, once applied to the amplifier, provides a linear amplified version of the original signal *x(t)*. This is known as signal predistortion. This section focuses on the GCMAC and the amplifier. The GMSK modulation [6] aspects will be taken into account.

2.1 Amplifier

Solving a model for the amplifier is not a trivial task. There is an extensive documentation for TWT amplifiers [8] and also for solid state amplifiers [2]. Both models study the effect of the amplification on the envelope of the signal, as they are narrowband models. On the contrary, no model has been found to study the non-linear effects for constant envelope signals as one carrier GMSK ones. A new broadband model has been design to study these aspects.

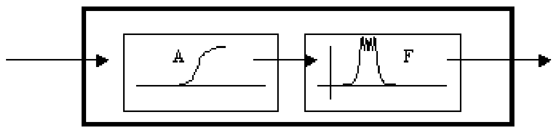
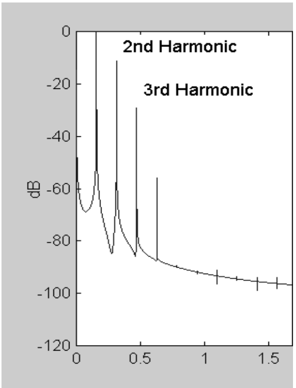


Figure 1: amplifier model.

This model contains two blocks as shown in Figure 1. The first one is a memoryless non-linear curve that models the input-output response to narrowband signals. The second one is a filter that models the broadband behavior of the PA. The design is based upon the commercial solid state amplifiers.

The amplifiers used in the BTS´s have a PSD like that depicted in Figure 2: 35dB and 40dB for the second and third harmonics. If the back-off (distance from saturation) is reduced, the PSD may look like the one in Figure 3.



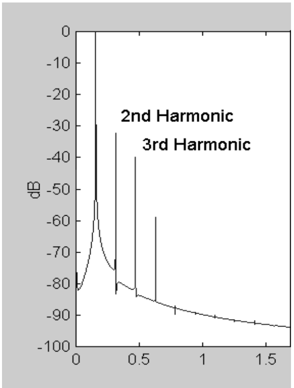


Figure 2: PSD for a non-saturated amplifier.

Figure 3: PSD for a saturated amplifier.

To sum up, when studying multicarrier signals, the model described in ([saleh81]) may be used. On the contrary, if the input is a one-carrier GMSK, the model described above will substitute the amplifier.

2.2 GCMAC Neural Network as predistorter

From a structural point of view, the GCMAC (Generalized Model Articulation Controller) ([1] and [4]) was born to emulate the behavior of the human's cerebellum in manipulation and control task. The architecture of the GCMAC is given in Figure 4. The equation (1) summarizes the behavior of the neural network. The weight vector is updated with a first order adaptation law given by the minimization of the mean square error.

$$y = \sum_{j=1}^{M} w_j \phi_j(x) \quad (1)$$

The most remarkable reasons to suggest the GCMAC in signal predistortion are its simplicity, low computational cost, its quick convergence, and its properties as function approximator ([5]).

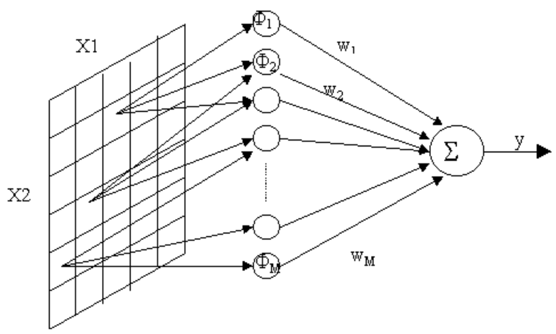


Figure 4: Architecture of the GCMAC

3. Predistortion in One Carrier GMSK

Being the GMSK a constant envelope modulation, the more important distortion effects take place at the harmonic frequencies. Furthermore, any scheme design to reduce both the intermodulation products and the harmonics must deal with the information at carrier frequency. The carrier frequency is located around 1 GHz. Since the present DSP devices work at sampling rates no higher than 200 MHz, it is obvious that a predistorter cannot work this way.

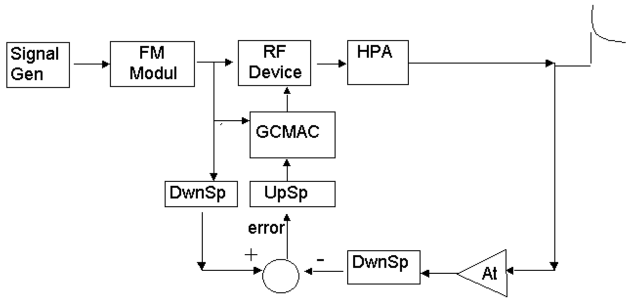


Figure 5: Downsampling predistortion scheme.

This work proposes a new predistortion scheme using downsampling in the data acquisition stage. This does not mean a new technique at all. Downsampling techniques have been widely used in oscilloscopes for many years. Oscilloscopes capture a signal period with samples from many of them. A downsampling predistortion scheme could be that of Figure 5. In this architecture, the original signal is down-sampled and compared to the output signal once attenuated and downsampled. The GCMAC block learns the inverse of the amplifier response. Then it hands this information to the RF device. The RF device implements the inverse function.

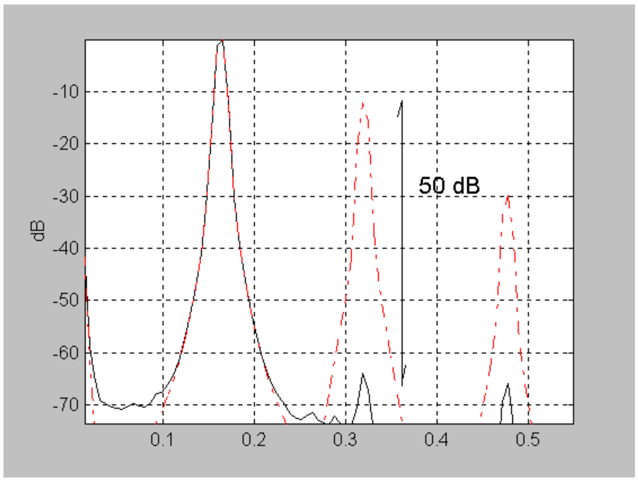


Figure 6: Harmonics in amplification with and without predistortion. The amplifier saturated.

Figure 6 shows the PSD for a test tone. The amplifier here works under saturation conditions. The continuous line is the result for predistortion. The dotted line is the amplification response with no predistortion. The figure shows 50dB between both second harmonics. This result may justify suppressing the canceller. At least it allows working in saturation regimen. The predistortion guarantees a control on the levels of the harmonics.

4. Predistortion in multicarrier GMSK

This section assumes that the combination of the carriers takes place before amplification. Under this asset the signal to be amplified is given in the Equation (2).

$$s(t) = \frac{1}{\mathrm{N}} \sum_{n=1}^{N} s_n(t) \qquad (2)$$

Where $s_n(t)$ is the signal coming from the n-th CPM modulator.

The signal $s(t)$ is a non-constant envelope signal that becomes very sensitive to non-linear distortions. Thus, after power efficient amplification, the transmitted signal suffers from a remarkable increment of the intermodulation products; this means interference in the adjacent channels and losses in the transmission quality. These non-linear effects in the output signal can be softened by backing-off the amplifier's operation point, that is, reducing the output power level. The reference level (back-off = 0 dB) is the maximum output power (saturation). This simple strategy provides linearity but it implies losses in the signal to noise ratio.

4.1 Architecture of Multicarrier BTS

Using the predistortion scheme depicted in Figure 7 and Figure 8 can reduce the losses in the output power level. The proposed architecture mixes in the base band *N* CPM signals, the *N* independent sources of information. A single digital signal processor (DSP) controlling the 25 MHz of the BTS transmission bandwith may carry out this task. From now on, some features will be described.

Baseband modulator in CPM

The *N* binary sources are processed in *N* parallel branches. Each branch converts bits into a stream of 2-PAM symbols. Then, these symbols are filtered by a gaussian and a unit-step response digital filters (oversampled with an *L* factor) to produce the phase response. Finally, the quadrature modulator (implemented with *look-up* tables, LUT) produces a complex digital signal in baseband $s_l[k]$, given by the expression (3) and (4).

$$s_l[k] = e^{j\left(\omega_c k + \Phi[k;\mathbf{a}_k]\right)} \qquad (3)$$

$$\Phi[k;\mathbf{a}_k] = 2\pi h T_m \sum_{l=-\infty}^{k} \sum_{n=-\infty}^{\infty} A_n g(lT_m - nT_s) \qquad (4)$$

Where $\mathbf{a}_k$ is the binary vector input to the filter at instant *k*, *h* the modulation index (*h*=0.5), $g[k]=g(kT_m)$ the gaussian pulse sampled with a period T_m, and $T_s=T_b$ the symbol or bit period ($T_s=3.7\mu s$). The signals obtained this way are combined at the output providing the signal *s[k]* . The proposed scheme is depicted in Figure 9.

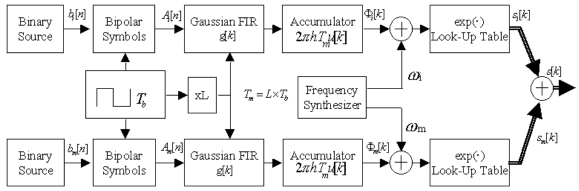


Figure 7: Architecture of the Multicarrier predistorter. Baseband combination of CPM carriers.

As it was discussed above, the signal *s[k]* has no constant envelope, which seriously limits the use of efficient power amplifiers. For this reason we propose to apply the adaptive predistortion scheme illustrated in Figure 10. Some characteristics of the predistorter will be discussed below.

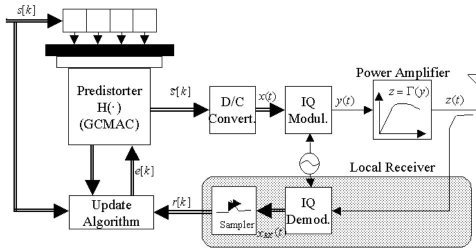


Figure 8: Architecture of the Multicarrier predistorter. Predistorter.

Main branch

The signal *s[k]* is quantified and introduced to the GCMAC. The GCMAC, provides the output attending to the expression in (1). The resulting signal is frequency shifted by a non-ideal quadrature modulator [3]. The signal *y(t)* is the input to the power amplifier. The amplified signal is $z[t]=\Gamma[y(t)]$.

Feedback loop

The feedback loop includes first a local receiver to obtain an estimation of the transmitted signal. The local receiver includes a directional coupler, a demodulator system –synchronized with the modulator- and a sampler to be tuned compensating the delays introduced in the loop. The sequence *r[k]* is compared to the reference signal *s[k]* giving an error signal. The error signal controls the parameters of the GCMAC neural network.

4.2 Performance analysis

Test1

This system has *N*=6 carriers along the radio channels *ch.*=5, 7, 11, 13, 19 and 23. The output back-off is [*BO*]=1 dB. The PSD shows that the reduction on the third intermodulation products larger than 25 dB, as shown in Figure 9.

Test 2

This test studies the intermodulation products of order 3 and 5. The system has two carriers as input (*N*=2) and μ=0.05. The modulation index has been set to h=0 to easy the task of measuring the intermodulation products. The results are shown in Figure 10.

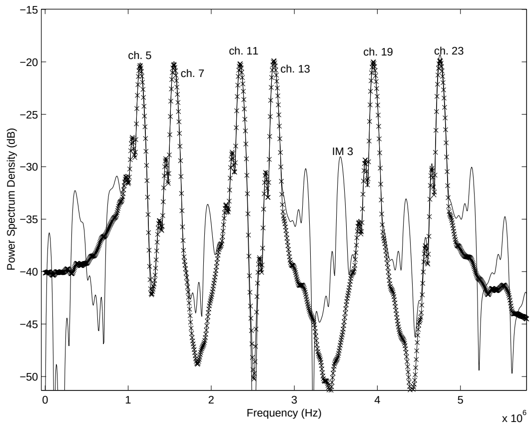


Figure 9: PSD with N=6. Continuous line: no predistortion. Symbol X: with predistortion.

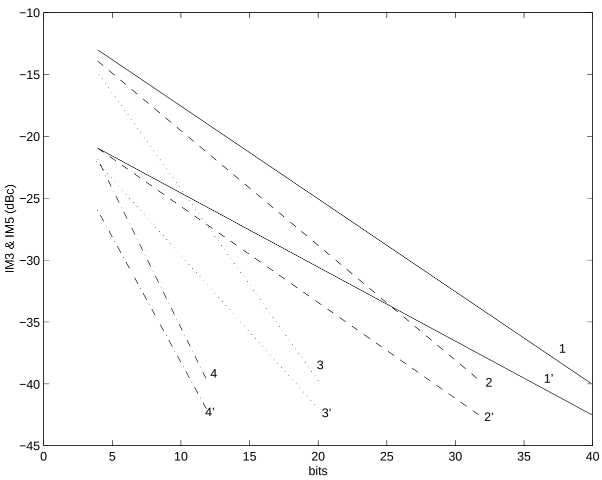


Figure 10: Temporal evolution of the 3rd and 5th order intermodulation products. Lines 1 and 1': system with [BO]=10 dB. Lines 2 and 2': [BO]=4 dB. Lines 4 and 4': [BO]= 10 dB.

It is obvious that the larger the back-off is set, the larger the cancellation of the intermodulation products grows. In this sense, the lines 3-3' and 4-4', with a back-off of 4 and 10 dB respectively, show a significant reduction in the 3rd and 5th order intermodulation products. This is not the case for a shorter back-off.

5. Summary

The present text involves the signal predistortion in amplifiers for GSM. GMSK, the modulation for this mobile telephony system, prove to be itself a robust modulation against the distortion introduced by these devices. However, a failure in a BTS with the subsequent reassignment of cells or a BTS with a large coverage may take advantages of a predistortion scheme. Predistortion architectures for both one carrier and multicarrier transmission have been proposed.

In the one carrier case, an amplifier model different from those given in the literature has been designed. With this model, harmonics aspects in GMSK may be studied. Downsampling has been introduced in predistortion to work directly on the output signal. The results obtained are satisfactory.

In the multicarrier case, a new BTS architecture has been proposed where the modulation, combination and translation to intermediate frequency are digitally implemented. As the proposed system combines the carriers before amplification, an envelope predistorter is needed. The predistorter, being digital, is completely integrated in the baseband transmission.

The neural network GCMAC has been chosen to approximate the ideal predistortion function. It combines fast convergence, hardware simplicity and approximation capacities.

Finally, it is important to point out that the models and architectures studied may be translated to the new mobile telephony standard UMTS. This will be a future line of work.

6. REFERENCES

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