LINEARITY AND EFFICIENCY ISSUES IN RF POWER AMPLIFIERS FOR FUTURE BROADBAND WIRELESS ACCESS SYSTEMS

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ABSTRACT

Linearity and power efficiency in transmit front ends are conflicting requirements demanding innovative solutions for present and future wireless mobile systems. The demand is greater in energy constrained mobile units, especially as signal bandwidths increase and other unit parts require a greater share of the available energy. This paper briefly reviews modern linearising techniques for the high power transmit amplifiers and reports on efforts to evolve system and behavioral level performance measures and quantifying techniques which will aid processes such as the design, specification and evaluation of linearisers and their overall contribution to transmit channel performance.

INTRODUCTION

The bit rate requirement for upcoming 3G mobile system is up to 2Mb/s and that forecasted for future broadband wireless fixed and mobile (4G) accesses (BWA) is of the order of 100Mb/s [1,2]. However while bit rates are increasing, there is a conflicting requirement to reduce power consumption, especially in mobile units so as to extend battery life. In the latter greater sophistication and size of displays further increase power drain. Spectral efficiency of available bandwidth is, as always, a key system design requirement. This has already led to the use of non-constant envelope modulation (NoCEM) schemes, e.g. the bandwidth efficiency of OFDM being so much better than CDMA [3]. This trend looks set to continue. NoCEM schemes should ideally experience linear transmission to avoid impairment and to keep 'spectral splatter' into adjacent frequency bands below specified limits.

Classically, to obtain satisfactory linearity over the transmitter's dynamic range the RF power amplifiers (PA) are simply 'backed-off' from saturation into their linear operating region. Along with this, efficiency improvements may be obtained by dynamic biasing or envelope tracking, while the required transmit power is maintained. Various solutions to achieve this have been implemented in existing handsets. However the power inefficiency is still significant. Typically, at maximum transmit power, the PA may consume as much as 75% of the battery power, impinging directly on its talk-time life.

The design of PA linearising and efficiency improvement schemes, and architectures, is attracting much attention in recent years [4,5,6& 7]. These attempt to reduce the effective PA compression and phase variation effects to meet air interface specifications, while maximising the PA efficiency. Included among them are feedforward, envelope elimination and restoration (EER), Cartesian feedback, and predistortion techniques. Each of these has its own advantages and disadvantages. While to date the power overhead of their presence variously limits the transmit path efficiency improvement achievable, nonetheless all these methods, depending on the circumstances, can contribute linearisation improvement benefits at or nearer to saturation PA operation.

The core concept of these linearisation techniques are presented in the following sections, together with early results on the evolution of system and behavioral level performance measures and quantifying techniques which will aid processes such as the design, specification and evaluation of linearisers and their overall contribution transmit channel performance. Results have been derived using a predistortion lineariser, but the measures are transferable.

LINEARISATION TECHNIQUES

Feedforward Linearisation

A feedforward lineariser consists, as shown in Fig. 1. of the PA (the nonlinear distortion effects of which are to be reduced), an error amplifier (EA), couplers, and delay elements (d). All blocks operate at RF. Some of the RF input signal is fed through the 180° delay line. The rest is fed to the PA. A sample of its output is coupled off and compared with the delayed version of the input signal. If the PA is linear, and the coupling is correctly set, then these signals will be identical and the signal into the EA will be zero (-an initial calibration procedure). Nonlinearity distortion of the signal in the PA will result in an RF error signal at the output of combiner which is then linearly amplified in the EA and coupled back to a properly matched delayed PA output, ideally cancelling all the unwanted components in that signal, leaving only the amplified wanted signal to be radiated from the antenna [4]. The technical challenge is to maximise the distortion cancellation over the dynamic range of life of the amplifier and from a system point of view to obtain measures and an assessment impact of whatever compensation is achieved, and the likelihood of deterioration of performance with aging, temperature variations etc.

The auxiliary EA is a critical part for successful linearisation. It should be linear, so as not itself to introduce any additional impairment, and have small and stable propagation delay. The technique is sensitive to parameter variations such as the change of temperature or power level; thus additional adaptive control circuitry is required.

For a given structure, power efficiency will be effected by the coupling factors between the two arms and by the choice of EA (power rating) and its operating point. For a typical system, output coupler with 8 to 10 dB coupling is used. EA operates at approximately 25 % of the PA power. Output coupler and delay-line loss is around 1.5 dB power loss. This results in 5 to 10 % of DC to RF efficiency for a feedforward cellular amplifier [8].

While capable of giving significant linearity improvement over wide bandwidths, feedforward is expensive to implement in hardware, requiring bulky tuning components and has other disadvantages mentioned. It can be quite effective for multicarrier basestation applications [9].

Envelope Elimination and Restoration (EER)

EER was initially developed for SSB and TV transmitters but there are number of articles which consider its implementation with multicarrier modulation schemes for future generation of wireless systems [10]. Also known as Kahn technique [11, 12], it ideally combines the attributes of both linearisation and efficiency enhancement. In EER the envelope of the RF signal to be amplified is extracted, amplified linearly and separately, and applied as modulation to the dc power supply of the RF PA, Fig.2. The RF signal containing the phase information, but with the envelope information removed (i.e. forced constant envelope), is applied to the input of the PA. The original signal envelope is thus restored to the efficiently amplified RF signal. Best efficiency is possible with classes C,D, E and F PAs. In practice implementation of EER has some challenging problems. Among these the main ones are the linearity of the envelope amplifier and the phase coherency between the envelope and the main 'phase' signals in the restoration process.

Cartesian Feedback

Cartesian feedback demodulates a portion of the PA output signal and negatively feeds this back at baseband through differential amplifiers to the I/Q modulator with the complementary error signal thus compensating for the PA distortion if the loop gain is correct, Fig.3. Good linearity improvements result (for the complete transmit path), but it is inherently narrowband. Disadvantages [13, 14]., besides the requirement for an extra I/Q demodulor, include stability which depends upon loop gain, the phase shift introduced by the PA and its compensation, time delays in the circuit and loop-filter bandwidth. Loop delays may themselves be a source of output distortion. The main advantage of the cartesian feedback system is its simple implementation and applicability to any modulation scheme.

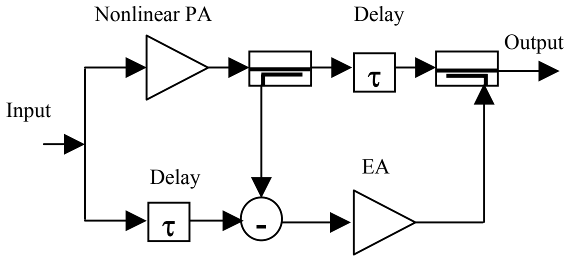

Fig.1. Feedforward amplifier.

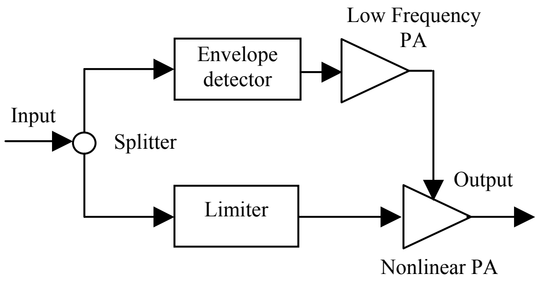

Fig.2. EER.

Predistortion

Here the inverse characteristic of the PA is realized at RF and used to cancel the PA non-linearity, Fig.4. A low-cost solution, it consists of an open loop and inherently stable circuit having the advantage of lower power consumption compared to other techniques, [5]. Due to temperature, aging, power level, frequency change effects means to suitably adapt the predistorter are desirable, and need to be evolved. Its relatively simple and wideband nature makes it attractive for future broadband, NoCEM schemes, e.g. multicarrier OFDM modulation [14,15, 16].

Some practical results were obtained while simulating the predistortion lineariser. Typical amplitude (AM/AM) and phase (AM/PM) characteristics of the PA are shown in Fig. 5. Input and output power back-off (IBO, OBO) are relative to saturated power i.e. IBO=Pin-Psat; etc. PA and predistorter were modeled by a 4 coefficient power series model (in MATLAB), with sampling frequency set to avoid aliasing. A basic reference measure is to find the linearisation improvement (LI) as a function of IBO to 3rd, 5th and 7th order intermodulation distortion for a two equi-powered carrier input test, as shown in Fig. 6. Of more interest is the improvement brought to the modulation fidelity of a digitally modulated signal. Error vector magnitude (EVM) [17,18] variation is one such measure. Figures 7 and 8 show EVM effects and adjacent channel power ratio (ACPR) [19] results with and without the presence of equally effected adjacent channels, caused by PA with and without linearisation for the relatively constant envelope π/4-DQPSK (IS-136) mobile radio signal.

CONCLUSION

Various linearisation techniques together with their advantages and disadvantages were briefly reviewed. These include feedforward, envelope elimination and restoration, cartesian feedback and predistortion techniques. Also EVM modulation fidelity is proposed as a linearisation performance evaluation measure and some example of the benefits of applying linearisation were given. These early results indicate that developing and combining this EVM technique with good nonlinear PA and linearisation circuit models would seem to hold good promise for evaluating, designing and specifying transmit front-end systems operating with NoCEM signal structures.

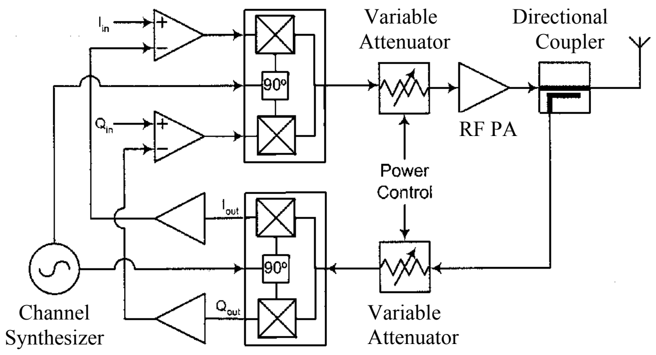

Fig.3. Cartesian feedback.

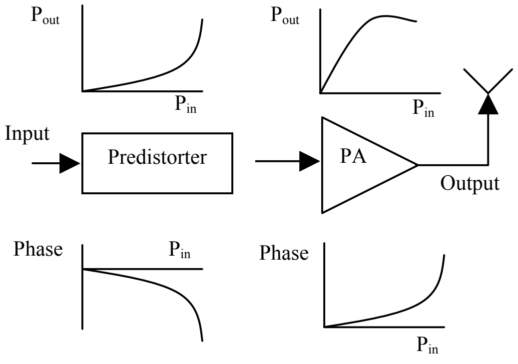

Fig.4. Predistorter.

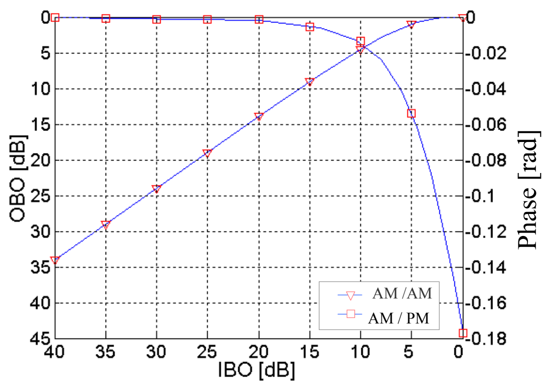

Fig.5. Characteristics of PA.

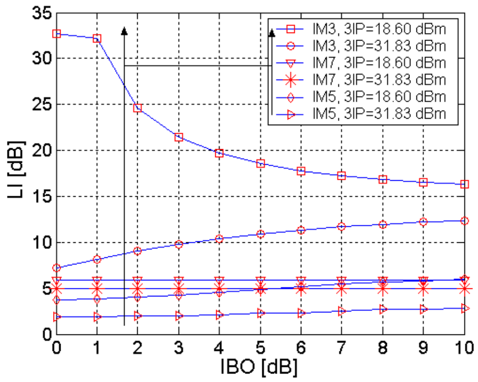

Fig.6. LI versus PA IBO.

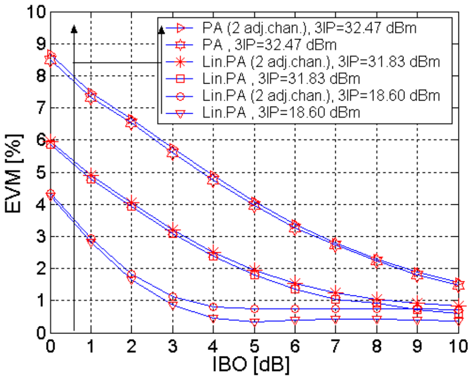

Fig.7. EVM versus PA IBO.

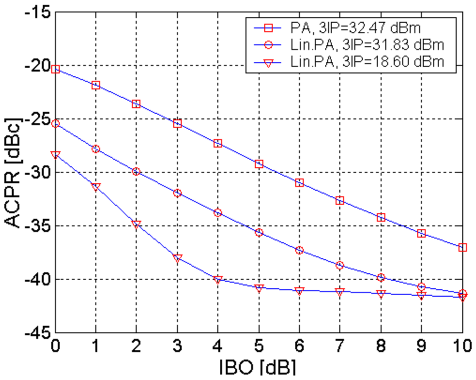

Fig.8. ACPR versus PA IBO.

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