A GSM-EDGE High Power Amplifier utilising Digital Linearisation

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Abstract — **This paper describes a single-carrier UHF linear power amplifier for use in GSM-EDGE base station applications. The amplifier employs a sophisticated digital predistortion linearisation system as a method of improving both efficiency and signal vector error (SVE), whilst maintaining a relatively simple architecture. A key benefit of the technique is that it provides an RF input/output interface without the requirement for a local oscillator, which is traditionally required when employing a digital lineariser in an RF amplifier.**

I. Introduction

GSM-EDGE (Enhanced Data for GSM Evolution) is a technology enhancement to the current GSM system which allows a maximum data rate of 384kbps to be deployed in the same channel bandwidth as the existing system. GSM-EDGE achieves its improved data rate (and hence spectral efficiency) by changing the modulation format from GMSK to 3π/8-shifted 8-PSK. The filtering necessary to ensure that this new modulation format still conforms to the required spectral mask has the effect of introducing an envelope variation onto the transmitted signal. Consequently the RF power amplifier within the transmitter must now preserve this envelope variation (to prevent spectral spreading and a degradation of the signal vector error of the data points) and hence must be linear or linearised.

This paper describes the use of a novel digital linearisation technique in order to preserve both the spectral mask and signal vector error of an EDGE signal, whilst still being backwards-compatible with an existing GSM signal.

II. GSM-EDGE signal Characteristics

The 3π/8-shifted 8-PSK modulation used in the EDGE system, after filtering to meet the required spectral mask, is characterised by a 3.2dB peak-to-mean ratio. The constellation diagram (Figure 1) shows that although there is an envelope variation on the EDGE signal, the signal transitions do not pass through the origin in the complex plane and hence the instantaneous dynamic range over which the power amplifier must operate is lower than that of, for example, a two-tone test (with equal tone amplitudes).

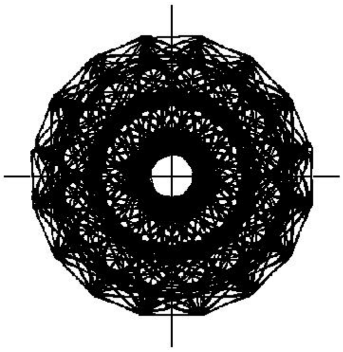

Figure 1: EDGE constellation diagram

The EDGE spectral mask requirement is somewhat unusual in a number of respects. It is largely based on the GSM mask, with some minor concessions, and consequently does not suffer from a stringent first adjacent channel requirement (unlike IS-95 CDMA, for example). The key mask points from a linearity point of view are generally at the 400kHz and 600kHz offset frequencies. As these offsets are not generally dominated by third order distortion from an amplifier, a simple third-order only lineariser will not achieve a sufficient level of mask improvement to meet the EDGE requirement. A more sophisticated lineariser is therefore required if the maximum benefit (in efficiency terms) is to be obtained from the lineariser.

A further major reason for employing linearisation in an EDGE PA is to improve signal vector error (SVE) of the transmitted constellation points [1] (characterised by an error vector magnitude – EVM). Improving this parameter has a major impact on the decoding margin available at the receiver and hence on the range, coverage and interference immunity of the network. It is therefore of significant benefit to the customer and hence there is a strong incentive to improve this parameter to well beyond that required to meet the GSM-EDGE specification.

II. Existing Digital Linearisation Techniques

A. Mapping Predistortion

A mapping predistorter [2] employs two look-up tables, each of which is a function of two variables (I_{IN} and Q_{IN}), as shown in Figure 2. This type of predistorter is capable

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of excellent performance, but at the expense of a significant storage and/or processing overhead for the look-up tables and their updating mechanism and a low speed of convergence. The low convergence speed results from the need to address all points in the I/Q complex plane before convergence can be completed.

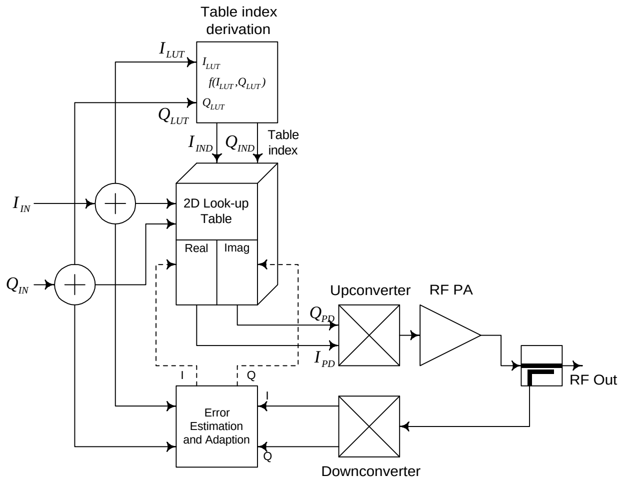

Figure 2: Block diagram of a mapping predistorter

B. Constant Gain Predistortion

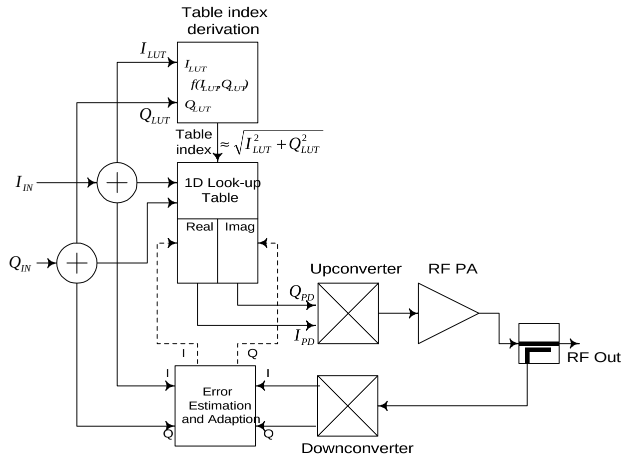

Figure 3: Block diagram of a constant gain predistorter

This type of predistorter (Figure 3) requires only a single-dimensional look-up table, indexed by the signal envelope [3]. It is therefore a much simpler implementation and requires significantly less memory for a given level of performance and adaption time.

Its principle of operation is in utilising the look-up table to force the predistorter and associated PA to exhibit a constant gain and phase at all envelope levels; the overall transfer characteristic is then linear:

$$G_{PD}\left(I_{IN}(t), Q_{IN}(t)\right) \times G_{PA}\left(I_{PD}(t), Q_{PD}(t)\right) = K \qquad (1)$$

C. Local Oscillator Issues

The traditional method of employing digital linearisation within an RF input/output amplifier system is to use one local oscillator signal to downconvert the RF input signal and another (or possibly the same one) to re-upconvert to RF following the predistortion process. Whilst this is not an excessively complex process, it does require an additional high-quality synthesiser (over and above that required in the transmitter which has generated the RF input signal). The main problem with this lies in the additional interface required to the base-station in which the amplifier is operating, in order to transfer the channel information to allow the local oscillator frequency (or frequencies) to be set. Most base-station manufacturers desire a simple RF in/out interface and any further interfaces are a significant disadvantage. The new technique outlined below does not require any knowledge of the frequency on which it is operating and therefore preserves the simple RF input/output interface desired by the base-station manufacturers.

D. Other Desirable Features

There are a number of further requirements placed upon this type of amplifier by virtue of the system in which it must operate. It must be capable of dual-mode (GMSK and PSK) operation to ensure backwards compatibility with the existing GSM/DCS services. This allows for a smooth upgrade path independent of the hardware installation rate.

Power consumption of the lineariser is also important in low-power installations as it can have a significant impact on the overall efficiency of the amplifier. In general, the hardware complexity of the lineariser should be kept to a minimum to ensure that the overall efficiency is maximised.

In general, digital predistorters lend themselves better to systems with a digital, rather than an RF, input. Whilst it is clearly possible to provide this type of interface in an overall system, it is generally more difficult to define for an outsourced item and is usually highly customer-specific.

III. RF INPUT/OUTPUT DIGITAL LINEARISER

Figure 4 shows an outline block diagram of the RF input/output digital linearisation technique. The RF input signal is sampled and detected before A/D conversion and feeding the digital signal processing block. This signal is modified by AM-AM and AM-PM look-up tables which in turn drive an AM and PM modulator block acting upon the main input signal. The output of this block is a predistorted version of the input signal and feeds the RF PA. The output from the PA is sampled, downconverted and digitised in order to provide the digital controller with a measure of the predistortion improvement. The controller then modifies the look-up tables in the light of the information from the output sample and the overall result is an improved ACP and EVM from the complete system (relative to an unlinearised PA operating at the same power level).

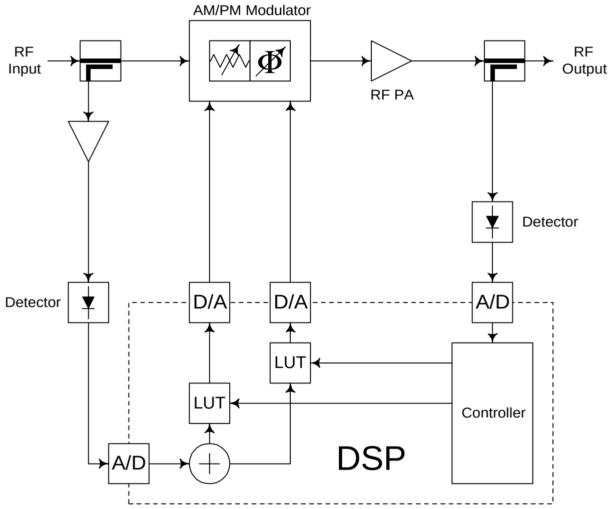

Figure 4: Block diagram of the GSM-EDGE digital linearised power amplifier

IV. RESULTS

The results presented in this section are from 900MHz PA and lineariser, where appropriate. Variants have also been produced at 850MHz, 1800MHz and 1900MHz.

The amplifier characteristic when using EDGE modulation is shown in Figure 5 (for the AM-AM characteristic) and Figure 6 (for the AM-PM characteristic). A 'best-fit' linear approximation is shown in each case and it is this which provides the basis for the predistortion linearisation. Note the cusp in the AM-AM characteristic. Although this feature is relatively well backed-off from the 1dB compression point, it is such a severe feature that it can have implications on the ACP mask specification, particularly at the critical 400kHz and 600kHz offset points. Measuring the characteristics by the method shown (i.e. using actual EDGE modulation) provides a more accurate picture of the shape of the amplifier transfer characteristics than using pulsed or swept network analysis methods.

Figure 7 shows how the amplifier transfer characteristic varies with temperature across a range of -10 to +60 centigrade at three frequencies across the operational bandwidth (bottom, middle and top). This clearly shows that the degree of non-linearity present changes markedly with temperature and hence the lineariser must be adaptive in order to compensate for temperature variations.

Figure 8 demonstrates the improvement in the linearity of the amplifier transfer characteristic following the linearisation process. Both gain compression (at the upper end of the operational range) and expansion (in the middle of the range) are corrected, hence demonstrating the sophistication of the lineariser.

Table 1 summarises the key performance parameters of the amplifier and illustrates, in particular, the EVM improvement provided by the lineariser. This has significant benefits to a network operator and hence is becoming an increasingly key parameter. Note also the excellent efficiency figure in EDGE mode, again resulting from the application of linearisation. The lineariser achieves the required ETSI mask with a margin of at least 3dB at all points, and in many cases, significantly more.

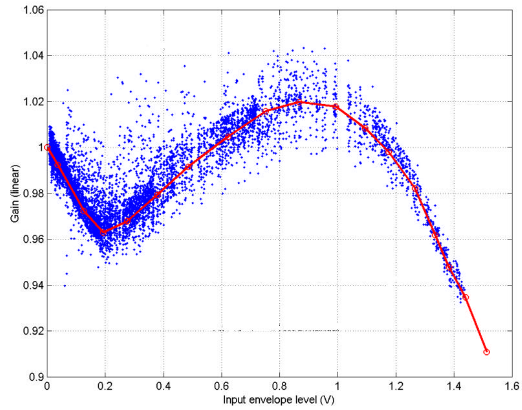

Figure 5: AM-AM characteristic of the power amplifier with EDGE modulation

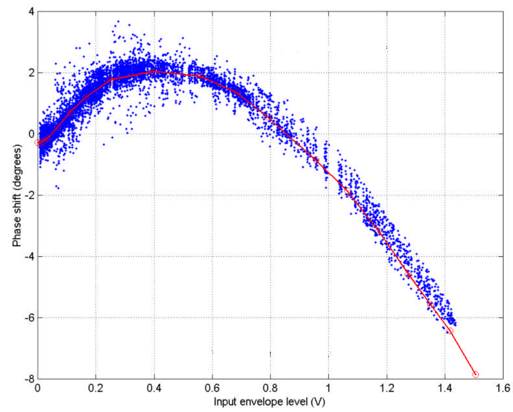

Figure 6: AM-PM characteristic of the power amplifier with EDGE modulation

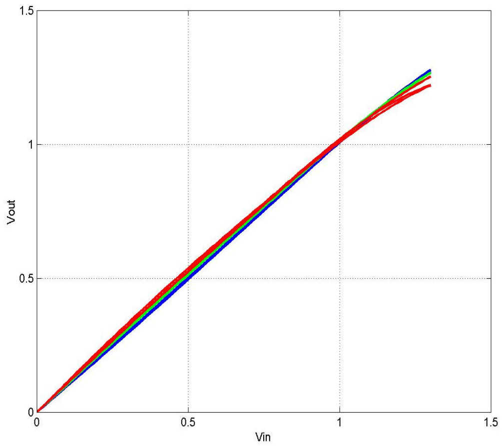

Figure 7: Temperature dependence of the amplifier transfer characteristic from –10 to +60°C at the bottom, middle and top frequencies within its operational range.

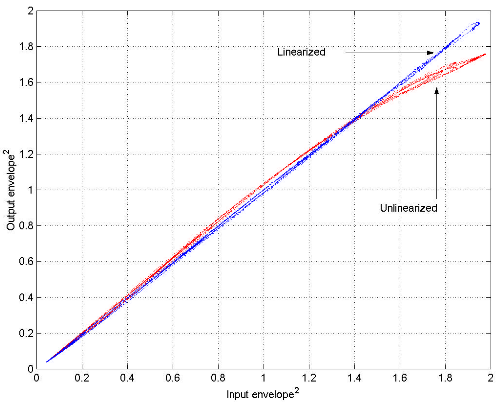

Figure 8: Amplifier transfer characteristic showing linearisation improvement.

Parameter	Before Linearisation	After Linearisation
Error Vector Magnitude	3.06%	0.5%
Output Power (Note 1)	22W	45W
Output Power (GSM mode, ETSI compliant)	60W	60W
Efficiency (Note 1)	22%	>30%
ACP Mask Performance		>3dB better

Note 1: EDGE mode, ETSI compliant, equivalent EVM

Table 1: Summary of the LPA results and specifications.

The output power capability, whilst achieving otherwise equivalent performance (same EVM, mask compliance etc.), roughly doubles from 22W to 45W – this is a significant benefit as it implies a significant saving in both physical size and in silicon costs.

Figure 9 illustrates the ACP improvement which is obtained by the lineariser. In this case, IS-136 modulation (π/4-DQPSK) is used, as this allows the improvement to be clearly seen. Around 20dB of improvement is evident from this figure. Note that the lineariser was not modified in any way in producing this result (i.e. the software was not optimised for this type of modulation, nor were any of the RF elements re-biased or otherwise altered).

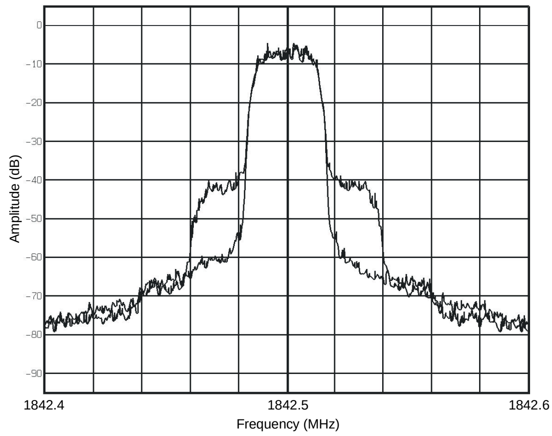

Figure 9: ACP improvement utilising the RF-input/output digital predistorter with IS-136 modulation.

V. Conclusion

This paper has described a UHF linearised power amplifier solution for single-carrier EDGE base-station applications. The novel RF input/output digital lineariser employed in the design has been shown to yield an exceptional efficiency (relative to backed-off solutions) and very low levels of signal vector error. The simplicity of the lineariser leads to a compact and cost-effective solution and one which is easily scalable to other frequency bands. It has also been illustrated to operate with other than the designed modulation format and is essentially modulation scheme independent.

Acknowledgement

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References

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