

# SYNERGISTIC DESIGN OF DSP AND POWER AMPLIFIERS FOR WIRELESS COMMUNICATIONS

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Co-design of DSP algorithms and power amplifier characteristics can lead to improved efficiency and linearity through a variety of strategies, including: a) DSP control over bias conditions, particularly the power supply voltage; b) predistortion; and c) DSP generation of digital input signals for switching amplifiers. We envision for the future a generation of “smart power amplifiers” in which DSP optimisation of amplifier parameters is carried out for changing environments.

## 1 Introduction

One of the most important challenges for component design posed by mobile communication systems is to maximise the power efficiency of the handset power amplifier, which is a main determinant of battery talk-time. At the same time, with spectrally-efficient modulation formats such as QPSK, the amplifier linearity must be sufficiently high that adjacent channel power generation is kept within strict bounds. Compounding these problems is the fact that the output power of a handset typically varies over many orders of magnitude as a result of changing multipath and shadow fading. Fig.1 shows a representative output power distribution on a short time scale (resulting from QPSK modulation) and on a longer time scale (as a result of time-varying fading). The average power is much less than the maximum rated amplifier power. In conventional amplifiers, the efficiency decreases dramatically if the output power is backed off from the full rated power, leading to overall efficiencies in the range of only 2-10%.

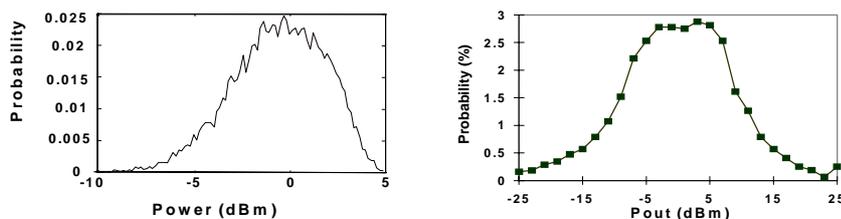


Fig. 1: a) Output power probability distribution for short (microsecond) time scales; b) output power probability distribution for long (millisecond) time scales, for representative CDMA transmitters.

By combining DSP functions with the power amplifier design new approaches are possible to overcome this problem. DSP technology is already a key component of digital communication systems. Moreover, DSP capabilities are rapidly advancing both towards higher throughput and lower power, with the scaling of CMOS transistors. Future systems can leverage this benefit of Moore’s Law for the benefit of the analog electronics.

## 2 Bias controlled amplifier

In traditional power amplifiers dc bias conditions are kept relatively constant as the signal input power changes. Since the biases must be set to accommodate the maximum output signal, efficiency performance suffers with low output signal conditions. In present wireless handset designs, the output bias current is varied with the signal level over a wide range, typically by an

analog bias subcircuit, or by exploiting the intrinsic characteristics of Class AB amplifiers. Voltage bias variation is an additional dimension, necessary in order to maintain efficiency at peak levels over a range of output powers. This can be implemented with a dc-dc converter that transforms battery voltage to a value optimized for the instantaneous output power. We have implemented dc-dc converters with compact size and very rapid response (on the order of the signal envelope for IS-95 CDMA waveforms), that can be used to adjust voltage bias. Fig.2 illustrates the architecture under development.

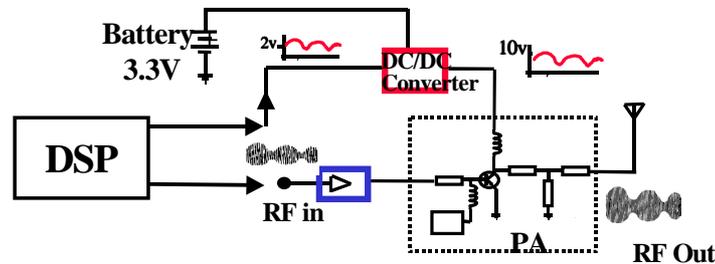


Fig. 2: Architecture of power amplifier with dynamically changing supply voltage.

The efficiency improvement is illustrated with the data of fig.3, which shows the efficiency vs output power measured with the amplifier under fixed power supply voltage, and with the use of the converter to provide variable voltage. Despite the limited efficiency of the converter (80%) the overall system efficiency increases dramatically (by factor of x1.4) since the efficiency for relatively low output powers is improved.

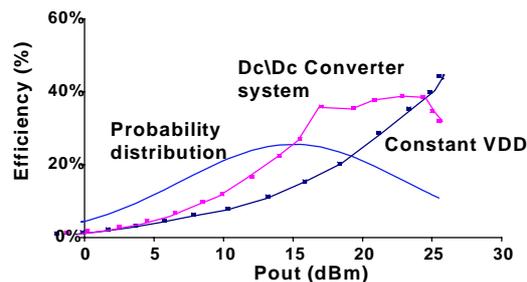


Fig.3: Experimental measurements of efficiency of amplifier with dynamic supply voltage, and a corresponding amplifier with fixed voltage. Also shown is the output power usage probability distribution.

In order to implement the bias variation, it is possible to use an analog envelope detector. But use of a DSP provides considerably more flexibility, since the relationship between desired power supply voltage and output power can be optimized. At the same time, the dynamic response characteristics of the dc-dc converter can be taken into account (accommodating the finite response time of the converter, for example). The DSP computes the envelope of the signal, followed by the appropriate control voltage, and computes a suitable delay and pre-emphasis.

### 3 Amplifier with predistortion

Amplifiers with higher efficiency than Class A introduce nonlinearities into the output signal, which can lead to objectionable adjacent channel power ratio (ACPR). One approach to reduce this to acceptable levels while retaining an efficiency improvement is with predistortion of the signal fed to the amplifier. Fixed analog predistortion is frequently used. DSP-based predistortion offers a powerful new set of possibilities, since the functions implemented can be flexible, and can be made adaptive to accommodate drift in amplifier characteristics. Excellent results are being reported in laboratories around the world. We implemented DSP-based predistortion in the voltage bias controlled amplifier, since the varying power supply voltage induced changes in gain, which constitutes a source of AM-AM conversion. The DSP used a

fixed, rather than adaptive, algorithm in this instance. Fig. 4 illustrates changes in the output spectrum of an IS-95 CDMA signal with and without the use of predistortion in the amplifier.

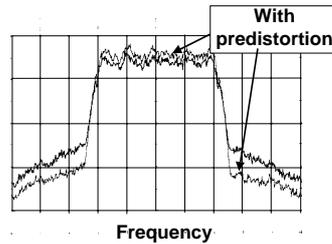


Fig. 4: Measured output spectra for CDMA signal in dynamic supply voltage amplifier with and without predistortion via DSP.

#### 4 LINC amplifier

In addition to architectures in which DSP is used to control and optimise an analog amplifier, there are other scenarios in which DSP is used to generate fundamentally new signals to drive amplifiers, in order to obtain higher efficiency. One such scenario is the LInear amplification with Nonlinear Components, or LINC amplifier, illustrated in fig.5.

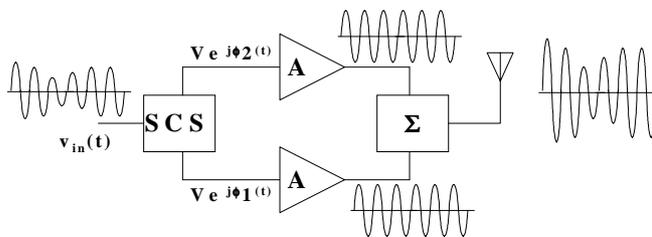


Fig.5: Schematic architecture of LINC amplifier.

DSP is used in a signal component separator, which derives from the input signal two separate signals that have constant envelope (but time varying phase) such that when the signals are summed, the appropriate output waveform (with time-varying envelope) is recovered. With the constant envelope signals, highly nonlinear amplifiers (such as Class E amplifiers) can be employed. For the practical implementation of this approach, the two amplifiers in the two channels must be very accurately matched regarding amplitude and phase. We have developed a DSP-based approach to calibrate the system, and derive appropriate signal distortions to be introduced into the two channel inputs to maintain high accuracy in the overall output.

#### 5 Class S amplifier

An additional approach to improve overall efficiency is to use amplifiers in switching mode (such that the transistors are “on” or “off” during a major fraction of the rf cycle), as shown in fig.6. The input signals to the amplifier are digital in nature, to control the switching state of the transistors. In order to generate waveforms with time varying envelope (after filtering), pulse-width modulation can be used, or alternatives employing digital pulses of fixed duration. We have investigated amplifiers using the band-pass delta-sigma algorithm to generate digital signal streams that encode analog communication signals of interest. The unavoidable extraneous signal power present in the digital waveform (“quantization noise”) is spectrally shaped to lie out of the signal band of interest, and can be separated with a bandpass filter at the amplifier output. Fig. 7 shows representative waveforms for a test amplifier with this design. The output frequency in the example shown, however, is only 10MHz; future work is required to efficiently scale up the frequency to the microwave region.

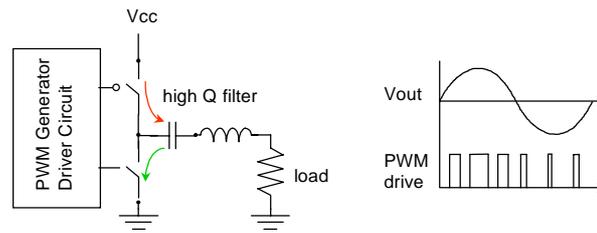


Fig. 6: Schematic structure of Class S amplifier, together with representative output and drive signals.

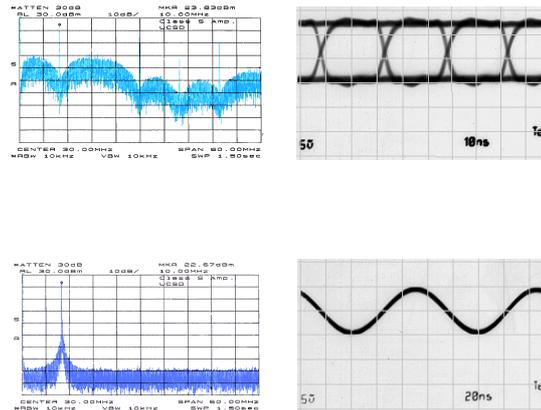


Fig. 7: Experimental waveforms and spectra for band-pass delta-sigma Class S amplifier. The upper curves show the amplifier inputs (digital signals); the lower curves show the output (after the output filter).

## 6 Future possibilities

DSP provides flexibility in the design of waveforms to be used as amplifier analog input signals or to control amplifier bias. In future “smart” power amplifiers, numerous amplifier internal variables will be monitored by the DSP, and used to reshape the signals and biases. DSP can also be used to generate digital waveforms to control switching mode amplifiers. At present, the output of DSP is at baseband (or *if*); conventional mixer techniques are used to upconvert the signals to rf. As the speed of DSP advances, algorithms in which the DSP provides signals at rf can be envisioned (particularly for switching amplifiers, in which the inputs are inherently digital signals).

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