DEVICE AND CIRCUIT APPROACHES FOR IMPROVED LINEARITY AND EFFICIENCY IN MICROWAVE TRANSMITTERS

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ABSTRACT

This paper presents several power amplifier approaches that promise to significantly improve efficiency, while meeting the linearity requirements of advanced, spectrally efficient wireless systems. The approaches include: a) use of active integrated antenna structures that provide harmonic terminations for high efficiency Class F amplifiers; b) integrated dc-dc converters for power conditioning and envelope restoration; c) switching mode amplifiers based on bipolar transistors with controlled saturation; and d) the use of band-pass delta-sigma modulators to tailor input signals.

INTRODUCTION

To reduce the power consumption of a wireless transceiver, greatest leverage is often provided by the output power amplifier. This paper describes a series of novel concepts to increase output power amplifier efficiency, while maintaining adequate linearity. The concepts have been developed within the Multidisciplinary University Research Initiative on "Low Power, Low Noise Electronics for Mobile Wireless Communication".

LINEARITY REQUIREMENTS

Amplifier efficiency must be increased while meeting system linearity specifications. Signals with time-varying envelope, such as generated by QPSK and other spectrally-efficient modulation formats, provide the greatest challenges, due to the need to avoid spectral regrowth and preserve modulation accuracy. Multicarrier CDMA systems are being actively pursued to provide broad bandwidth video and data in addition to voice. Such systems are of particular interest for Defense applications, because of the associated antijam, low probability of intercept features, and the ease of overlaying such a system on regions of the spectrum already used. The amplifier linearity challenges within such systems are very severe, because the peak to average power ratio is particularly high. We studied MC-CDMA requirements, with data encoded (using QPSK) on 8 separate carriers which are combined, amplified and transmitted. We determined the spectral and temporal characteristics of the signals, before and after passing through distorting amplifiers. As shown in fig.1, we characterize the adjacent channel power through frequency domain simulations. We show that by proper control of phases among the different carriers, the peak-to-value power ratios can be minimized (to values on the order of 4dB). ACPR can be minimized with power backoff values on the order of 3dB.

Amplifier efficiency is also impacted by the fact that wireless transmitters are typically used at power levels well below their maximum output capability (to conserve

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power and reduce interference)[1]. Frequently amplifier efficiency falls off dramatically from its peak value at maximum power. It is critically important to maintain efficiency at lower output power levels.

ACTIVE INTEGRATED ANTENNAS FOR CLASS F AMPLIFIERS

To provide better efficiency than achievable with conventional class AB operation, control over output waveforms by harmonic tuning is well known. In a compact transmitter structure, the integration of the power amplifier with the antenna is an attractive possibility, since impedance levels can be optimized for highest efficiency, rather than to connect to 50 ohms transmission lines. We show here that with proper amplifier design, it is possible to present an output impedance to the amplifier by the antenna that has optimal values at all the harmonics of interest, thus yielding an integrated Class F amplifier. Fig.2 shows the input impedance of an amplifier designed to achieve desired matching at the fundamental (2.55Ghz), as well as specified values at second and third harmonic. Fig.3 shows the integrated structure combining the antenna with a GaAs MESFET-based amplifier, which achieves 63% efficiency. Novel MMICs using photonic bandgap structures to control impedances at different frequencies have also been demonstrated.

DC-DC CONVERTERS FOR IMPROVED EFFICIENCY

To maximize the efficiency of Class A and AB amplifiers, and to restore the linearity of switching mode amplifiers, it is highly desirable to vary the power supply voltage in accordance with the requirements of the time-varying input envelope. We have demonstrated a boost dc-dc converter utilizing GaAs HBTs which can be modulated at rates up to 1MHz, which is capable of efficiently converting power from a fixed (3V or 5V) supply to variable voltage as needed by the transmitted signal. The circuit approach is shown in fig.4. Fig.5 shows a representative output waveform. Efficiency of the converter at present reaches 74%. The overall efficiency of the combined amplifier/dc-dc converter can be significantly better than that of a constant voltage system, because of the tendency to operate the amplifiers at powers well below the value which maximizes their efficiency. Fig. 6 compares the efficiency at specific output powers, as well as a representative power usage probability curve. The long-term average efficiency using the dc-dc converter is higher by x1.45.

APPLICATION OF BANDPASS DELTA-SIGMA MODULATION

An additional approach is to use a switching mode amplifier (inherently efficient but with poor linearity for conventional signals), and provide to it a binary level (“digital”-like) input signal that properly encodes the amplitude as well as phase of the desired output. Audio frequency Class S (or “switching-mode”) amplifiers succeed in achieving this using pulse-width modulated binary input signals. While this approach cannot be directly used in the microwave region because of the high clock frequency required, we have found that the output of band-pass delta-sigma modulators can be used. Fig.7 shows an input sinusoid, the resulting binary level signal, and the resulting output after output filtering. Simulated amplifier efficiency is on the order of 70% for 850MHz amplification, using HBTs.

BIPOLAR TRANSISTORS WITH REDUCED SATURATION CHARGE

HBTs provide advantages of high drive capability and high power density along with high frequency response. They would be the devices of choice for the dc-dc converters and switching mode power amplifiers, except that if they are operated in the saturation regime, they suffer from

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charge storage. We demonstrated that with a suitable double heterojunction device, having wide bandgap collector as well as emitter, this saturation charge storage is suppressed [3]. Figs.8 and 9 illustrate the device geometry, and measured results for transient waveforms using a sinusoidal input. The GaInP DHBTs also have a lower "knee voltage" (Vcesat) than their single heterojunction counterparts.

SUMMARY

Harmonic termination with active integrated antennas, dc-dc power converters, band-pass delta sigma encoded input signals, and bipolar transistors which avoid saturation charge storage are approaches that can lead to improved power amplifier efficiency together with linearity. These advances can be used individually, or they can be combined together to yield the most dramatic advances in efficiency.

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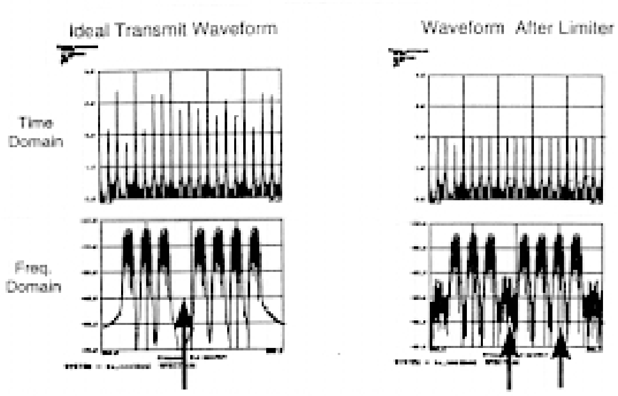

Fig.1: Simulated time and frequency domain representations of multicarrier CDMA signals. The approach to ACPR measurement is illustrated.

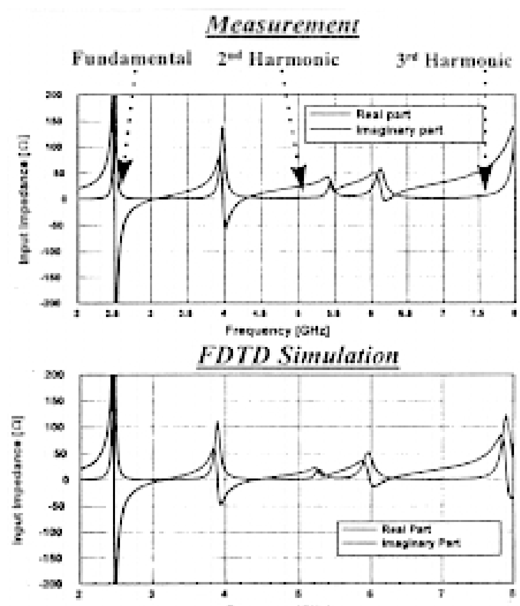

Fig.2: Simulated and measured input impedance for an antenna designed to optimize the behavior of a GaAs MESFET-based Class F amplifier at 2.55GHz.

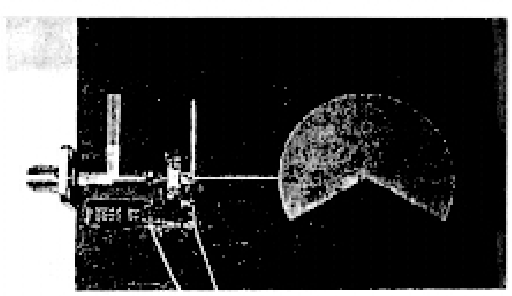

Fig.3: Photograph of Class F amplifier with Active Integrated Antenna.

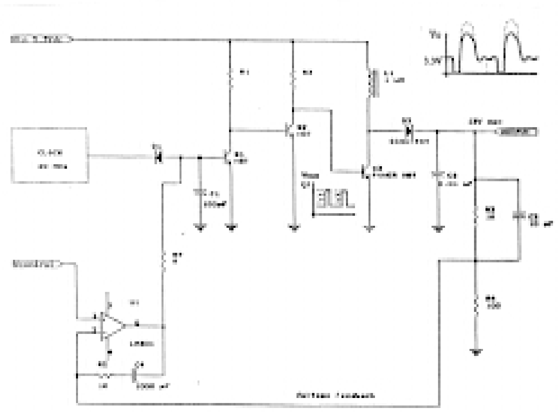

Fig.4: Circuit schematic of HBT-based boost dc-dc converter.

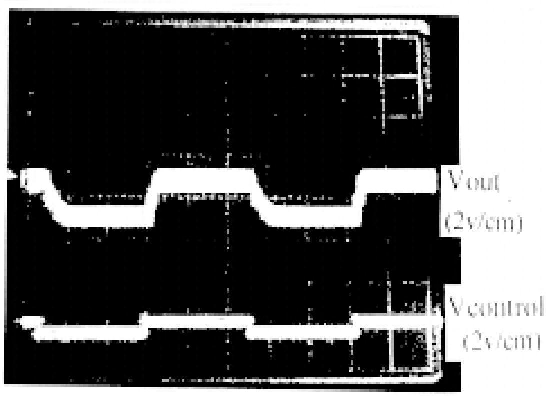

Fig.5: Input and output waveforms of boost dc-dc converter, showing capability for modulation on microsecond time scale.

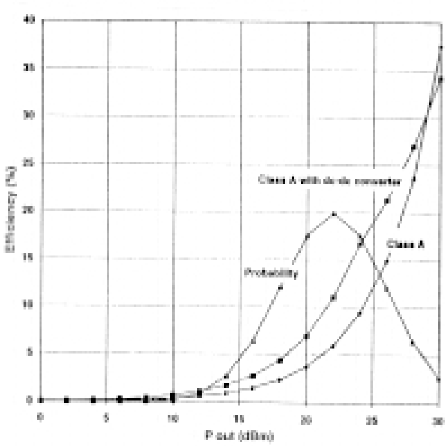

Fig.6: Efficiency vs output power of representative Class A amplifier with fixed power supply voltage, and one with dc-dc converter. Also shown is representative probability distribution of output power.

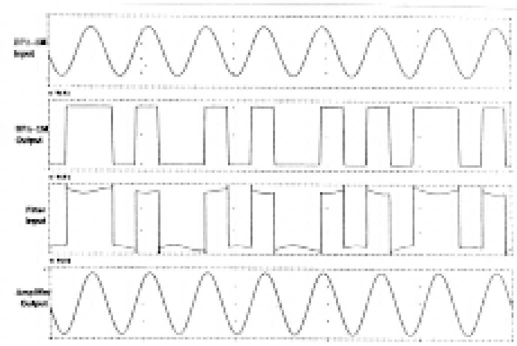

Fig.7: Simulated waveforms for a switching power amplifier using a band-pass delta-sigma modulator: a) input; b) bpds modulator output; c) amplifier output prior to filter; d) output after filter.

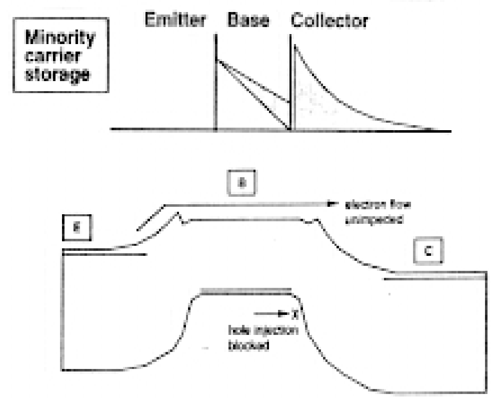

Fig.8: Band diagram of GaInP/GaAs/GaInP DHBT, illustrating effect of suppression of collector charge storage in saturation.

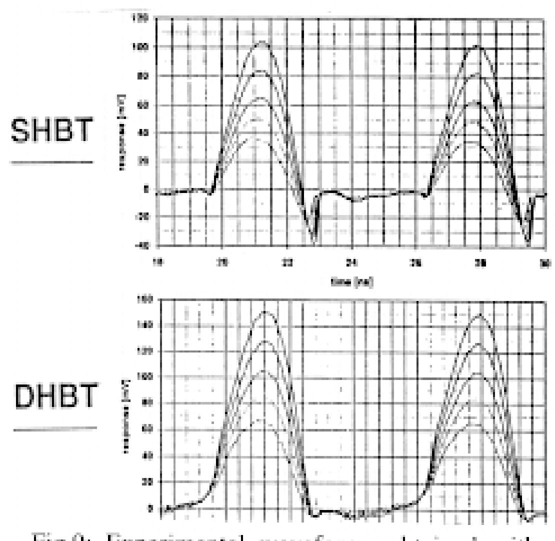

Fig.9: Experimental waveforms obtained with SHBT (conventional) and DHBT structures driven by sinusoids. The absence of stored charge for the DHBT is apparent.