MICROWAVE POWER AMPLIFIER EFFICIENCY IMPROVEMENT WITH A 10 MHz HBT DC-DC CONVERTER

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Abstract

This paper presents a technique for raising power efficiency in portable wireless transmitters by integrating a variable voltage output dc-dc converter together with a MESFET RF power amplifier. Significant increases in power efficiency are obtainable over a large range of output power levels. The system includes an envelope detector, a closed feedback loop, and a pulse width modulator operating at 10 MHz. A 300mW transmitter is shown for which battery life can be extended by over 1.4 times.

Introduction

Efficiency and linearity of the microwave power amplifier are critical requirements for portable communication systems. Many advanced modulation formats require high linearity to preserve modulation accuracy and minimize spectral regrowth, and are thus operated near Class A with associated higher quiescent power dissipation. To allow for the required variation of RF signal envelopes, with modulation schemes such as QPSK, or multicarrier signaling, amplifiers usually operate with large peak to average power ratios. In addition, variation in output power over a slower time scale is required to accommodate changing distance between mobile and base, as well as fading due to natural geography. Unfortunately, the operation of RF power amplifiers in Class A or AB and at less than maximum output power causes a significant drop in efficiency. This is illustrated schematically in

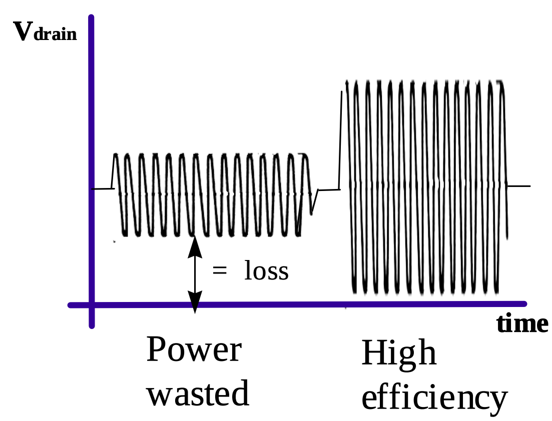

Figure 1: Microwave amplifier loss mechanism

Figure 1 which displays the drain waveforms of a MESFET microwave amplifier Several techniques exist for increasing final amplifier efficiency. Buoli [1] developed a linear regulator power drive whereby the V_{DD} supply voltage for the RF amplifier was obtained from a dual voltage source, varied in accordance with the signal level, and showed savings in power dissipated by the output stage. A related technique for raising the efficiency, due to Kahn and Raab [2] comprises a Class-S high level amplitude modulation scheme to provide time varying V_{DD} according to the RF signal envelope.

This work discusses efficiency improvements obtainable using a high frequency dc-dc converter which converts battery potential to an optimal power

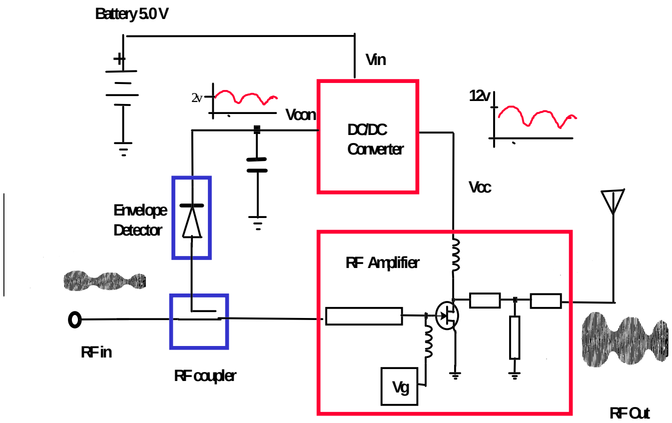

Figure 2: System block diagram

supply voltage for the output RF amplifier. A pulse width modulated boost converter with an operating frequency of 10 MHz is demonstrated and implemented with GaAs HBT's. This represents almost an order of magnitude increase in switching speed over present power converter systems. High switching frequency is advantageous in that it allows smaller inductors and capacitors to be used. Operating at 10MHz also allows any sidebands caused by converter ripple to be outside critical frequency bands of interest for most communication standards. Moreover, the potential for rapid modulation of the output converter voltage can be utilized in RF envelope tracking. By providing a voltage to the final RF amplifier that optimally follows the envelope of the signal to be transmitted the efficiency is increased. Linearity can be potentially increased as well since the amplifier may be designed to operate at higher voltages - away from PA transistor saturation effects.

In this work we present a power supply system for a 4 GHz power amplifier in which the input battery voltage of 5V is boosted to a variable voltage output up to 9V depending on the envelope. A block diagrams is shown in Figure 2.

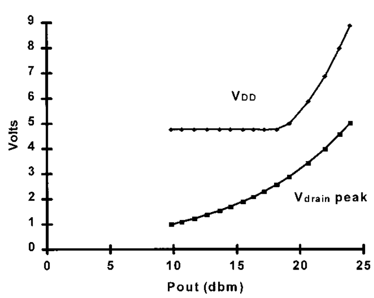

Figure 3: V_{DD} vs P_{OUT}

The power amplifier is implemented with a GaAs MESFET which exhibits limited gain sensitivity to changes in V_{DD} supply voltage in Class A operation. If the RF output is to be small, a low V_{DD} is provided; on the other hand, when full power is needed, the V_{DD} is raised to accommodate the required signal swing. In this manner, by always providing the optimal V_{DD} voltage to the PA, large savings in power can be realized. The relationship of V_{DD} Vs Pout in our system is shown in Figure 3 along with the peak voltage seen on the PA MESFET drain.

One benefit of using a boost converter is that as the input voltage drops due to battery depletion, the required V_{DD} voltage level can still be maintained. This is favorable over a step down approach where the highest level V_{DD} can only be that of the battery itself.

The incoming RF envelope is extracted by using a series diode detector and simple 1 pole filter. This varying DC signal is used as a reference for a high speed operational amplifier, LM301 (not shown) which compares the detected envelope voltage to that of the converter output itself thereby closing a feedback loop and regulating the output of the converter. The gain of the loop is set so that 9.0 volts is supplied to the MESFET amplifier at full power out (25 dbm). Below 0 dbm output, the PWM is off and the converter only supplies 4.7 V which is the battery voltage minus a Schottky diode drop.

Besides reducing filter component size, a second benefit of high frequency switching is that the bandwidth of the modulated output may be higher. Working at 10MHz allows a transient response of less than 1 microsecond when shifting from one level to another. This is important when attempting to follow a rapidly modulated envelope. Figure 4 displays the response to a step change in control voltage.

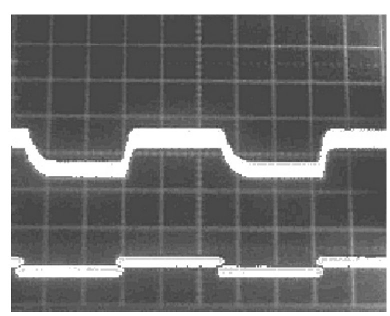

Figure 4: Dc-dc converter dynamic response
Vertical: 2V/cm
Horizontal: 1 μ S/cm
Top: V_{DD} output, Bottom: $V_{CONTROL}$

Circuit Description

The boost or ringing-choke converter (minus the feedback loop section), is schematically shown in Figure 5. The converter, together with the associated drive circuitry, were implemented in hybrid form using a AlGaAs/GaAs HBT developed for high voltage switching at Hughes Research Labs [3]. Inductor value is set at 300 nH, limiting the dc output power maximum to 1 watt. Output voltage is rectified using a 1 A Schottky diode. The output capacitance is set at a small value of 0.01 µF, consistent with low ripple and fast dynamic response. DC-DC converter power efficiency at 1 watt is 74%. Output ripple is less than 1Vpp.

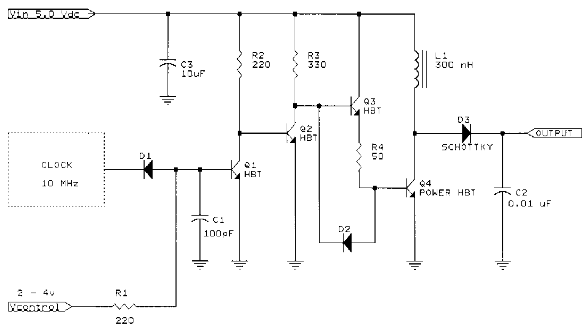

Figure 5: Dc-Dc Converter

The pulse width modulator produces a drive to the power switch HBT whose duration is a function of the control voltage which is used to charge the ramp capacitor C1. When this capacitor has reached the forward bias Vbe of Q1, a pulse is provided to the switching HBT by virtue of an inverter stage and emitter follower. This last stage was required owing to the low beta of the power HBT ($\beta \approx 40$)..

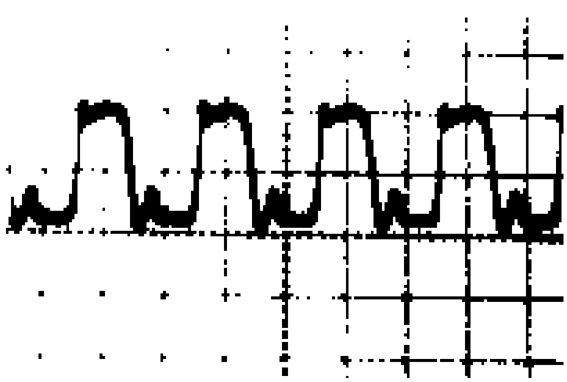

Figure 6: Power HBT switch Q4 collector
Vertical: 5V/cm. Horiz: 50 nS/cm

In this boost converter, the longer the power switch, Q4, is on, the more energy is stored in the flyback inductor, L1, resulting in a higher output voltage. By design the maximum ON time of this topology is 50%. The collector waveform of the power HBT is shown in Figure 6.

The MESFET amplifier used had a peak efficiency of 35% with output power of 300 mW when run class A, at 9 V input. Third order IMD , as shown in Figure 7, was down over 30 db when run either from the battery or from the dc-dc converter.

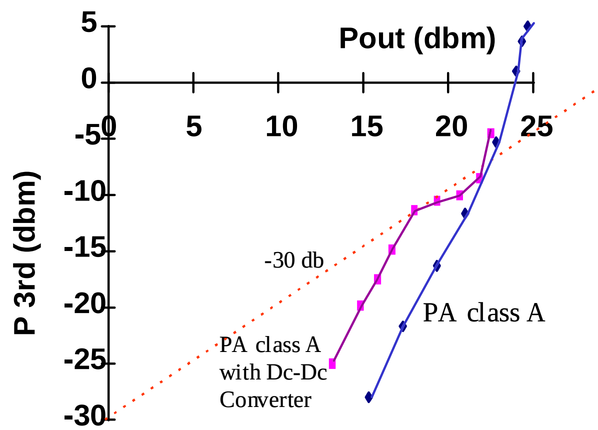

Figure 7: Third order IMD

Ripple in the dc-dc converter output may be expected to produce spurious microwave output tones separated from the fundamental output by ± 10 MHz. As shown in Figure 8, these spurious outputs are approximately 60 db lower than the fundamental.

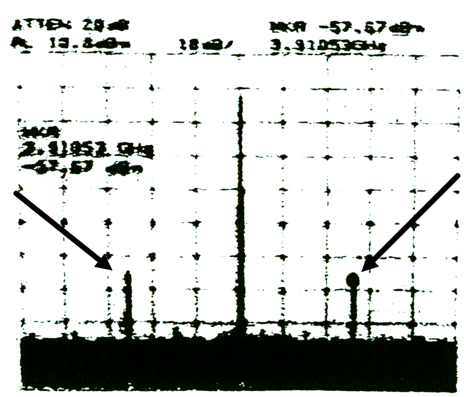

Figure 8: 10MHz components due to converter ripple

Efficiency Improvements

In this composite system, the total power efficiency is given by the product of the efficiencies of the RF amplifier and of the dc-dc converter. To properly gauge the effect of efficiency improvement on battery life, it is necessary to account for the probability of power usage $P(P_{OUT})$ which is a function of the output power, P_{OUT}. In representative mobile communication systems, this profile takes into account the peak to average power of the modulation, and power control characteristics associated with time-varying distance from the base station as well as the fading probability. In Figure 9 is shown a representative power usage profile, in which the most probable output RF power is only 158 mW for the amplifier (with maximum power of 300 mW). In many practical cases an even greater ratio of maximum power to average peak power is found[4]. On a dB scale, the probability density is approximately Gaussian.

From this, the long term average RF output power is given by:

$$\langle P_{OUT} \rangle = \int_{-\infty}^{+\infty} P(P_{OUT})\, P_{OUT}\, dP_{OUT} \qquad (1)$$

The long term average DC input power is given by:

$$\langle P_{IN} \rangle = \int_{-\infty}^{+\infty} P(P_{OUT})\, P_{IN}(P_{OUT})\, dP_{OUT} \qquad (2)$$

We define a power usage efficiency term as:

$$\eta_{USE} = \frac{\langle P_{OUT} \rangle}{\langle P_{IN} \rangle} \qquad (3)$$

η_{USE} correlates directly with battery current consumption. From the measured curves of η vs P_{OUT} for the amplifier with and without the dc-dc converter, the calculated values of power usage efficiency are:

η_{USE} = 15 % (9v battery)

η_{USE} = 22 % (dc-dc converter system)

Even with the limited efficiency of 74% for the dc-dc converter, the values of η_{USE} for systems using a dc-dc converter are 45% greater than those for just battery operation. A battery could have lifetime extended from 6 hours to more than 8 hours by this technique.

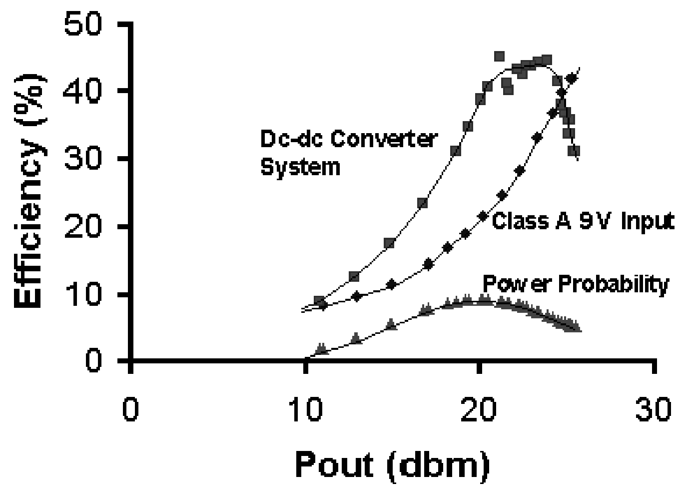

Figure 9: Efficiency comparisons vs P_{OUT}

Summary

An efficient 10 MHz dc-dc converter based on GaAs HBT's has been reported, which is capable of high modulation rate. When used in conjunction with an envelope detector and feedback loop, it can provide variable Vdd voltage to a microwave PA, increasing overall battery lifetime.

Acknowledgments

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