DIGITAL PULSE WIDTH MODULATED (PWM) MICROWAVE SIGNAL USING A HIGH EFFICIENCY CLASS-E AMPLIFIER

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A high-efficiency class-E power amplifier is proposed for digital PWM microwave signal amplification in the improved Kahn Technique transceiver. The benefit of using a class-E power amplifier in this design approach is to improve efficiency of the power amplifier due to its switching mode operation, theoretically 100 % with ideal conditions. In this paper a class-E amplifier is designed for the transceiver application of the improved Kahn technique using the MWT-8 GaAs FET at 2.4GHz, with 70% drain efficiency (η_d).

1. Introduction

In modern wireless communication systems, high efficient circuits are required to transmit and receive data with less consumption of DC power in order to preserve the lifetime of the battery and to reduce the size of the heat sink of the transistors.

The conventional Kahn technique was introduced in the 1950s to improve efficiency, by envelope elimination restoration (EER). In this method, the input signal is split into two branches: one carries the envelope and the other one deals with the phase information [1]. Although the Kahn technique improves efficiency, it requires the power transistors to operate in the linear modulation capability. The power amplifiers are generally designed to produce the optimal efficiency with a certain bias voltage. However, in the Kahn technique the reduction of power dissipation is not realizable because of the variation of the DC supply [2].

Recently, the Kahn technique has been improved [2] by digitalizing the envelope instead of the RF signal, which increases the efficiency of the circuit. In this paper a pulse width modulation is tested using a class-E power amplifier at 2.4 GHz. The digitalized envelope is not filtered as in the Kahn technique; consequently the output signal linearity is not deteriorated. A band pass filter is used only at the output of the system after the class-E power amplifier.

The class-E power amplifier (PA) operates as a switch that enables a high efficiency [3]. The drain-voltage drops to zero when the switch is on-state and the drain-current waveforms is maximum. In the off-state, the current is zero and the voltage is high. In this way the power consumption is minimized [4], therefore an efficiency of 100% can ideally be obtained.

Section 2, describes the design of a class-E power amplifier, with theoretical aspects, simulations and measurement results. Section 3 presents, the implementation of the class-E into the improved Kahn Technique, using Pulse Width Modulation.

2. Design of a Class-E Power Amplifier

2.1. Theory

In the on-state, a class-E PA is equivalent to a constant resistance R_s. In the off-state, it is acting as a constant capacitor C_s. The load impedance for the output matching network at the fundamental frequency is given by [4]

$$Z_{net} = \frac{K_0}{\omega_s C_s} e^{j\theta_0} \simeq \frac{0.28015}{\omega_s C_s} e^{j49.0524^\circ} \qquad (1)$$

where, C_s is the output intrinsic capacitance of the transistor (C_{ds} for a MESFET), K_0 and θ_0 are constants equal to 0.28015 and 49.0524° defined in [4] respectively.

The DC and output powers for a class-E are established as

$$P_{dc} = \pi\omega_s C_s V_g^2 \text{ and } P_{out} = \eta_d P_{dc} \qquad (2)$$

with V_g the gate voltage, P_{dc} the DC power, Pout the output power and η_d the drain efficiency.
The drain efficiency (η_d) is defined by

$$\eta_d = \frac{1+\left(\frac{\pi}{2}+\omega_s C_s R_s\right)^2}{\left(1+\frac{\pi^2}{4}\right)\left(1+\pi\omega_s C_s R_s\right)^2} \qquad (3)$$

The approximate maximum frequency of the class-E PA is given by

$$f_{max} \simeq \frac{I_{max}}{56.5 C_s V_{ds}} \qquad (4)$$

with V_{ds} the drain voltage (V), I_{max} the peak current for the transistor.

2.2. Power Amplifier Class-E: Simulations and measurements

Fig.1 shows a picture of the class-E PA. The simulations were performed with Agilent ADS using the model of the MWT-8 provided in the library. The substrate used is the RT/Duroid 5870 with e_r*=2.33* and *h=31* mil. The bias voltages chosen are: *Vds=4.3V* and *Vgs= -3.03V* after some tuning.

The design methodology [3] [4] was followed in order to design this class-E power amplifier. Fig. 2 shows simulated and measured output power and gain versus the input power at *2.4* GHz.

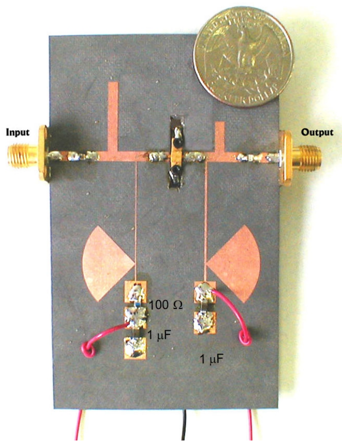

Fig. 1 Photograph of the class-E PA

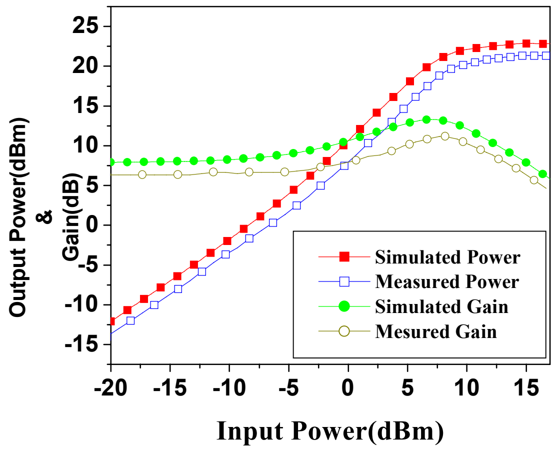

Fig. 2 Simulated and measured output power and gain versus input power at the *2.4* GHz.

Fig. 3 shows the power added efficiency (PAE) and drain efficiency with respect to the input power. The maximum PAE obtained is *64*% and the maximum drain efficiency is *70*% at *2.4* GHz with *20* dBm of output power and a gain of *10.83* dB. It can be observed in Fig. 4 that the measured drain efficiency is greater than *60*% from *2.3* GHz to *2.5* GHz. Similar to the PAE which is better than *57*%. The output power is also maximum in this range of frequencies. The peak of each curve is reached at *2.4* GHz: η_d= *70*%, PAE=*64*%. These measurements were performed with an input power of *9.5* dBm.

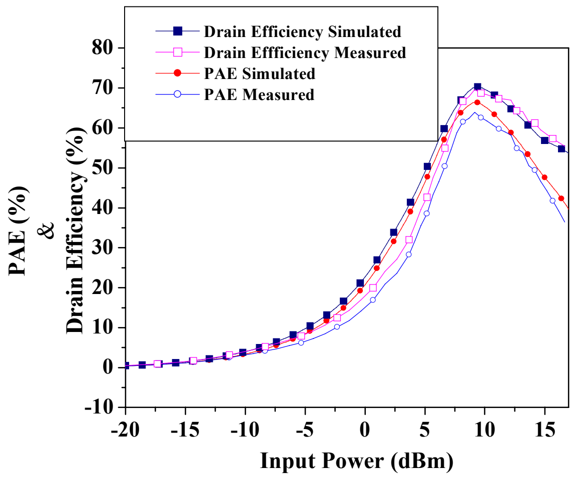

Fig. 3 Power-added-efficiency (simulated, measured) and drain efficiency (simulated, measured) versus input power for the *2.4* GHz MWT-8.

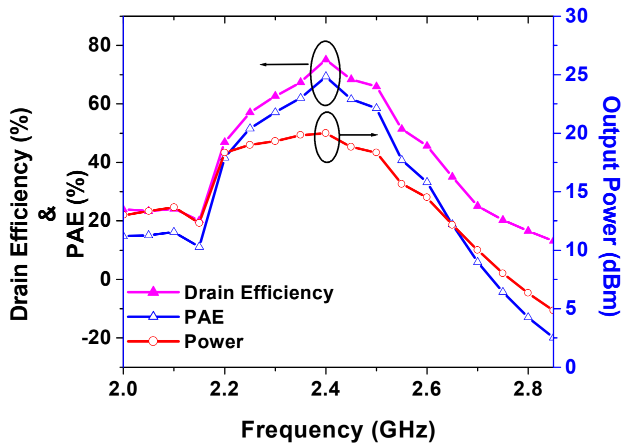

Fig. 4 Measured output power, PAE and drain efficiency versus frequency for the *2.4* GHz PA, with a determined input power of *9.5* dBm.

3. Improved Kahn Technique based on the PWM with Class-E power amplifier

3.1. Theory

The integration of the class-E PA in the improved Kahn technique and pulse width modulation has been demonstrated [2]. In this approach, the Kahn transmitter based on Envelope Elimination Restoration (EER) technique [1], [5] is combined with the digital modulation concept [2].

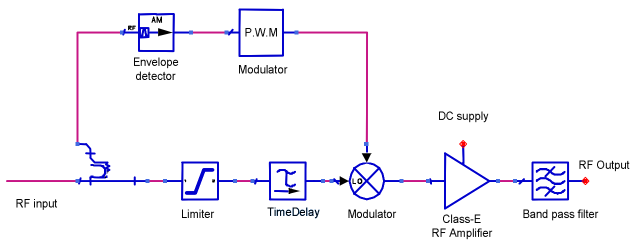

Fig. 5 Block diagram of the improved Kahn technique based on the pulse width modulation with a class-E amplifier.

Fig. 5 shows the schematic of the improved Kahn circuit. The input RF signal is split into two branches an envelope and a carrier. The envelope is digitized by a PWM in the upper branch and modulated on the carrier extracted by a limiter in the lower branch. The modulator restores the envelope to the phase-modulated carrier. The band pass filter at the output is used to lessen the quantization noise introduce by the pulse width modulator.

In the conventional Kahn technique, it is necessary to have a linear modulation capability of the PA. In the pulse width modulator the semiconductor technologies can perturbate the digitalization of the RF frequency. Therefore the improved method provides the advantage of suppressing the pulse width noise and the output signal linearity is not affected.

3.2. Simulations

The first step of this work is the integration of the class-E power amplifier, described in the previous section, into the improved Kahn technique. The input used was a two tone signal with a carrier frequency at 2.4 GHz and with a modulated frequency of 10 MHz. A transient simulation was used to simulate this system between 200 ns and 400 ns. The input power was -34 dBm, the output power was 23 dBm with a DC power consumption of 0.3W. A P.A.E of 70% was obtained for the improved Kahn technique.

Fig.6 shows the waveforms of input and output voltage of the improved Kahn technique system.

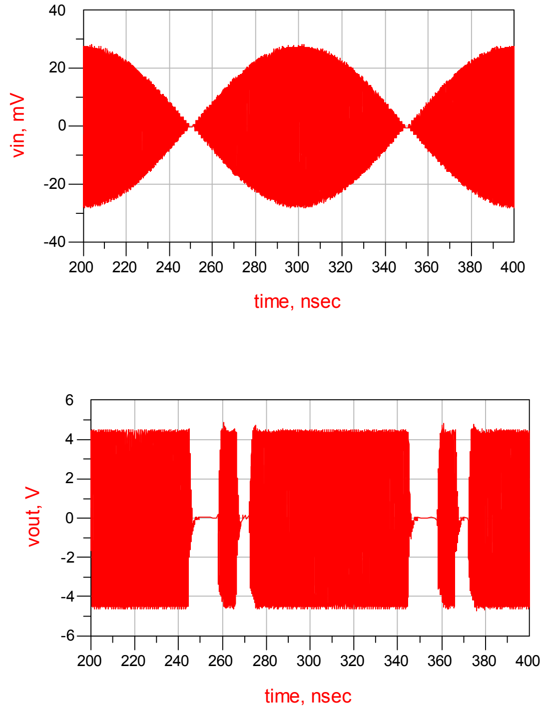

Fig. 6 Simulated input and output voltages of the improved Kahn technique.

4. CONCLUSION

An improved Kahn technique transceiver employing high-efficiency class-E PA has been proposed for digital PWM microwave signal amplification. A Drain efficiency of *70* % was obtained for the PA at *2.4* GHz in class-E mode operation by both simulations and measurements. In addition, the improved Kahn technique using the high efficiency class-E PA has been demonstrated by simulation. A PAE of 70% was obtained for this circuit.

References

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