Design of a 5.8 GHz, 0. 4 W Class E Power Amplifier for Wireless Applications

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ABSTRACT

A class E power amplifier working at 5.8 GHz with a MESFET transistor as switching element has been developed. The circuit was implemented with lumped elements and transmission lines. An output power of 0.4 W at 50 % PAE was obtained at 5.8 GHz. Simulations of the amplifier are presented within this paper. This result represents state of the art in output power and efficiency with a class E amplifier at this frequency.

I. INTRODUCTION

Wireless portable applications have become extremely popular and consumers start to demand longer battery life of their products. Due to the consumers' demand developers has to take power consumption in mind when designing. In a portable transmitting application the majority of the power is consumed in the power amplifier. Particularly the rapid development of mobile communication systems has put efficiency of PAs in focus. Mobile terminals are battery operated devices and the talktime of a handset will strongly depend on efficiency of the power amplifier in it. More efficient PAs will enable a smaller and lighter battery and/or a longer talktime, and consequently will make the final product more attractive in the market. Therefore, there is a strong interest to pursue development of PAs with a high efficiency of power amplification.

Theoretical drain efficiencies of 100 % can be achieved with switching mode amplifier like Class E. The principle was first described by Ewing in 1964 [1], who demonstrated an amplifier with 20 W output power and 94 % efficiency at 500 KHz. In the mid seventies the Sokals [2] developed this technique and reported an amplifier with an output power of 26 W at 96 % efficiency in the MHz range frequencies.

In this paper a class E power amplifier working at 5.8 GHz with a MESFET transistor as switching element has been developed. The circuit was implemented with lumped elements and transmission lines.

II. THE CLASS-E PRINCIPLE OF OPERATION

The ideal topology of the Class E amplifier is shown in Figure 1. The circuit includes a transistor operated as a switch, a shunt capacitor, C_1, an RF choke, L_1, a tuned circuit L_0-C_0, and the load resistor, R_L. The capacitance C_1 includes the parasitic capacitance across the transistor. The L_0-C_0 circuit resonates at the fundamental frequency of the input signal and only passes a sinusoidal current to the load R_L. Nonidealities associated with implementing the series resonator are lumped into jX, which is termed the excessive reactance. jX primarily serves to adjust the phasing in the L-C harmonic resonator.

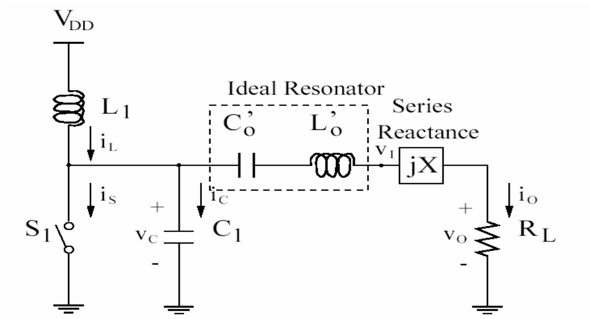

Fig. 1. The ideal model of Class-E power amplifier

The transistor switch S is ON in half of the period, and OFF in the other half. During the time interval t_1, the switch is open and the current through it is zero. During the time interval t_2, the switch is closed and the voltage across it is zero. Since the voltage and current waveforms of the switch do not overlap, the power dissipation in the switch is ideally zero.

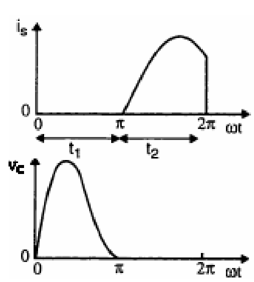

Fig. 2. The characteristic Class-E waveforms

When the switch is off, the current through the RF choke splits between the two branches containing C_1 and R_L. The capacitance C_1 starts charging and produces the

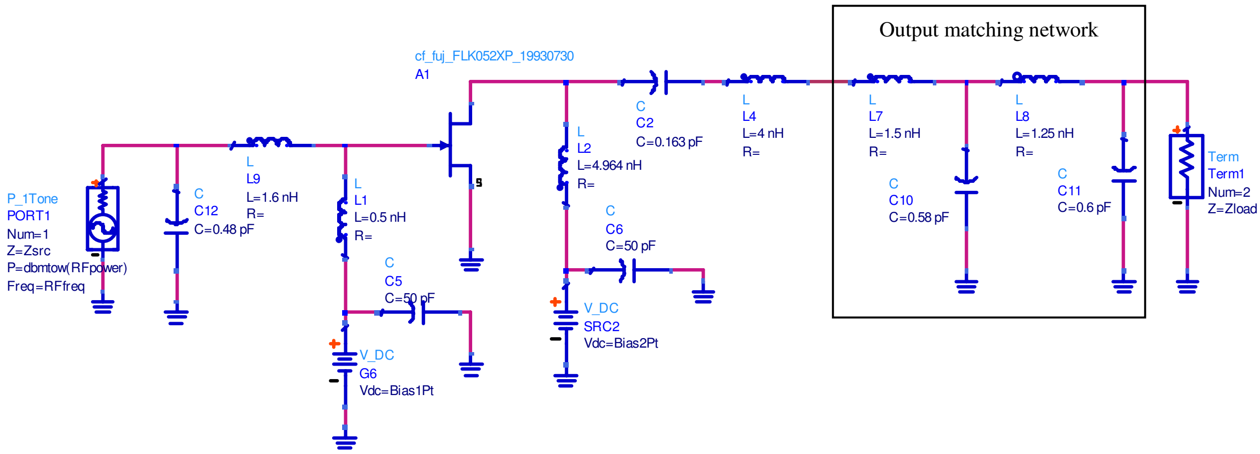

Fig. 3. Designed circuit diagram of Class E amplifier at 5.8 GHz

voltage across the switch. When the switch turns on, any charge stored on the capacitor C_1 will be discharged to the ground resulting in a power loss. In order to avoid this power loss, the circuit must be designed such that the voltage across the switch reaches zero at the turn on time of the switch as shown in Figure 2.

In the ideal case the efficiency of a class E amplifier is 100%. However, in practice the switch has a finite on-resistance and the transition times from the off state to the on state and vice versa are not negligible. Both of these factors results in power dissipation in the switch and reduce the efficiency.

III. CLASS E DESIGN

Having reviewed the principle of operation of the Class-E power amplifier, in this section we will present two class-E amplifiers operating at 5.8 GHz. One of them is a lumped elements based circuit and the other is a transmission lines based circuit. Simulation of the circuit performed with the commercial software ADS (Advanced Design System) by Hewlett Packard. Ideal models are used for all the passive components and FLK052 MESFET model is used for the transistor.

The real Class E circuit used in this paper is slightly different compared to the circuit in figure 1. First the parallel capacitor C_P is completely absorbed by the output capacitance of the transistor. Secondly the RF-load, which is about 5 Ω, is transformed to 50 Ω by a 2-stage transformation network. The input match of the amplifier was implemented with a series inductor and a parallel capacitor. Finally the Q_L-value of the series resonant network was chosen to be low, of the order 5, in order to have low sensitivity of the circuit to the series resonator values. The complete Class E circuit can be seen in Figure 3.

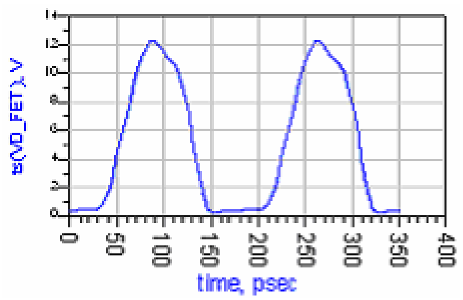

Fig.4. Voltage waveform of the Class E PA

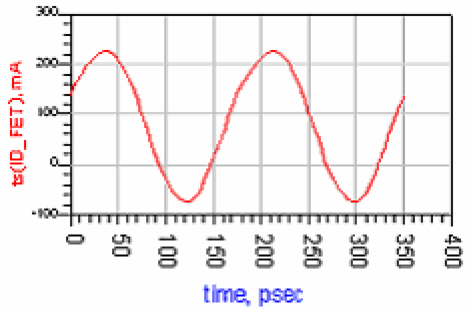

Fig.5. Current waveform of the Class E PA

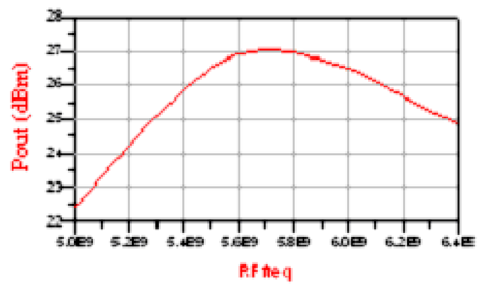

Fig.6. Output Power of the Class E PA

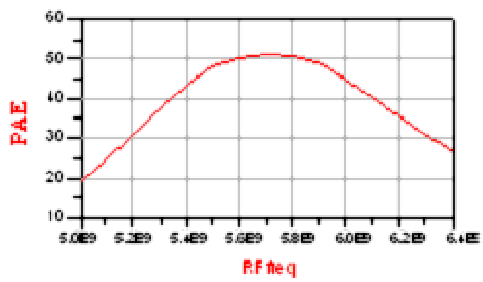

Fig.7. PAE of the Class E PA

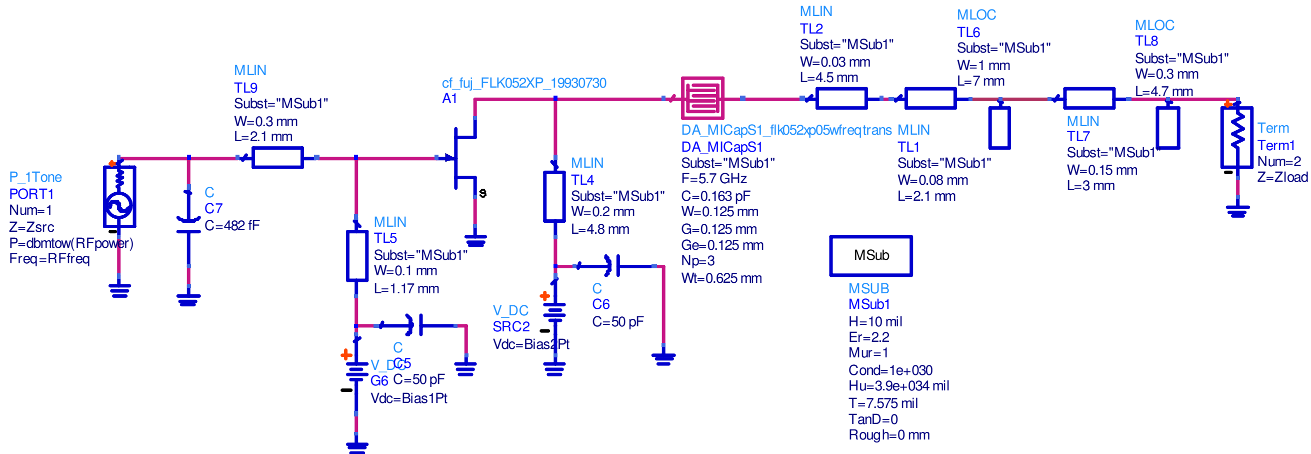

Fig. 8. Designed circuit diagram of Class E amplifier at 5.8 GHz

The lumped-element design generally works well at low frequencies, but two problems arise at microwave and millimeter-wave frequencies. First, lumped elements such as inductors and capacitors are generally available only for a limited range of values and are difficult to fabricate at the microwave and millimeter frequencies. In addition, at the microwave and upper frequencies the distances between a circuit's components are not negligible. For these reasons, transmission lines are often preferred over lumped elements at the microwave and upper frequencies.

Figure 8 shows a transmission- line class-E amplifier. This amplifier is designed based on the amplifier shown in Figure 3. The inductors are replaced with microstrip lines using Richard's transformation method and series capacitor is replaced with a microstrip interdigital capacitor. The lengths and widths are adjusted to give better performance.

Figure 4-5 and Figure 9-10 show the drain voltage and current waveforms of the class-E amplifier at 5.8 GHz. As a result of the non- ideality of the transistor switch, an overlap occurs between the drain voltage and current. This overlap causes a power dissipation that degrades the efficiency.

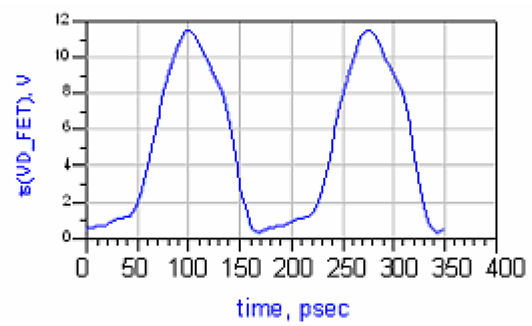

Fig.9. Voltage waveform of the Class E PA

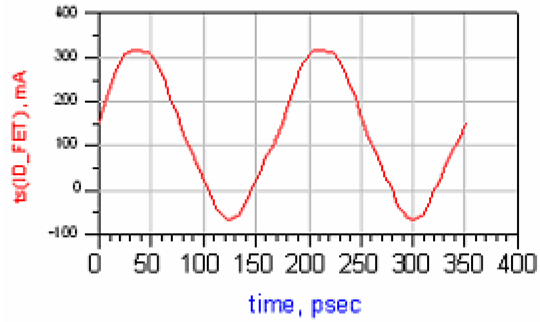

Fig.10. Current waveform of the Class E PA

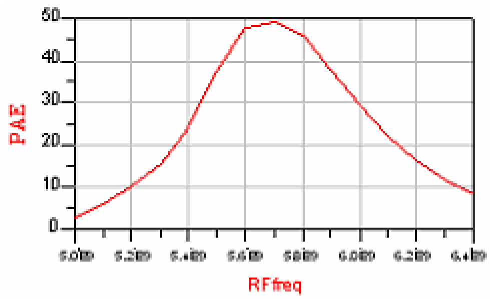

Fig.11. Output Power of the Class E PA

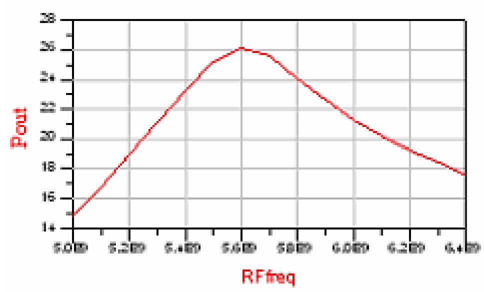

Fig.12. PAE of the Class E PA

Figure 6-7 and Figure 11-12 show the performance of both lumped element and transmission-line class E amplifiers. The PAEs are around 50%. The output powers are 27 dBm and 26 dBm respectively.

IV. CONCLUSION

One of the challenging blocks in the designing the handset for wireless communication transceiver is the power amplifier. This paper investigated the design of a Class E power amplifier operating at 5.8 GHz.

Two class-E amplifiers operating at 5.8 GHz are presented. One of them is a lumped elements based circuit and the other is a transmission lines based circuit. Both circuit show good performance with 50% PAE and have 500mW output power.

V. REFERENCES

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