Design of 3.3 - 3.7 GHz GaN HEMT Balanced Class E Power Amplifier

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Abstract

Among power amplifiers, Class E circuits are very suitable for high efficiency power amplification applications in the radio-frequency. However, because of the single ended structure, these circuits suffer significant harmonic contents in the output and it is usually inevitable to design load matching networks very carefully to get low harmonic content. In this paper, the design of a balanced Class E power amplifier being symmetrically driven by two Class E circuits is studied. The balanced Class E circuit, under nominal operating conditions, has lower harmonic distortions, and the design of the impedance matching network for harmonic filtering becomes less critical. Practical design equations for Class E operation are given and simulation results graphically presented. It has been found that the proposed balanced GaN HEMT class-E amplifier can deliver the higher power, higher efficiency performances and lower harmonic distortion than single ended topologies for WiMax applications.

1. Introduction

Among switching mode power amplifiers, which reduce thermal problems induced by the high power power amplifier, the class-E power amplifier is a promising candidate for a high efficiency power amplifier topology, which has the advantages of simple circuitry and high frequency operation. Recently, gallium nitride high electron mobility transistors have been regarded as a promising candidate for high power applications because they exhibit very high power densities, high electron saturation velocity, high operating temperature, and high cutoff frequency compared to any other technologies [1]. In this paper, we report a balanced class-E amplifier using a GaN HEMT with high power and high efficiency for 3.3 – 3.7 GHz. The compensation elements with a series capacitor and a shunt inductor are inserted to compensate for the internal parasitic components of the packaged transistor. For experimental validations, a single ended and balanced class-E amplifier is simulated using a GaN HEMT NPTB00004 model from Nitronex and tested between 3.3 - 3.7 GHz band. To simulate balanced configuration 180^o hybrid ring coupler has been used shown in Figure 1. This ring coupler topology is different from classical ring couplers with its short circuited coupled lines [2]. For balanced configuration input and output ports divided and combined with this type of modified ring coupler. The simulation results showed that, balanced configuration have higher power, higher efficiency performance and lower harmonic distortion than single ended class-E power amplifier.

2. Theoretical Analysis

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, RL. 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 RL. L_0 and C_0 are modeled as ideal components. Non-idealities 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. 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 [3]. 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 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 [4].

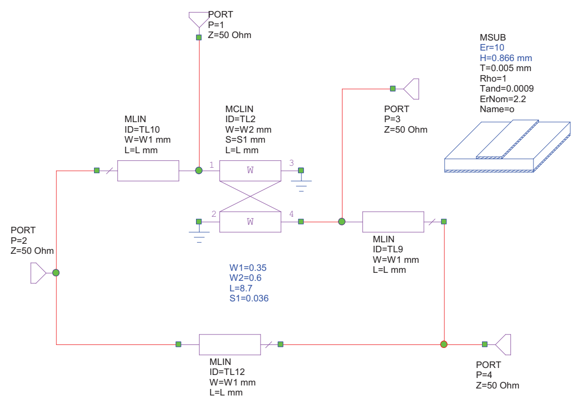

Fig. 1. 180^o Hybrid Ring Coupler

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 [3].

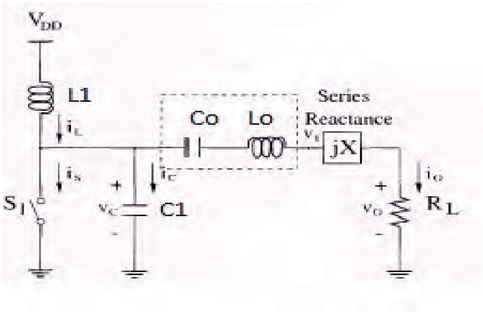

Fig. 2. Ideal Class-E Amplifier

3. Design Equations

During simulation of the circuit ideal models are used for all the passive components and NPTB00004 GaN HEMT 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. The parallel capacitor C_1 is completely absorbed by the output capacitance of the transistor. 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 2, in order to have low sensitivity of the circuit to the series resonator values. To design balanced configuration, ring coupler was designed for 3.3-3.7 GHz band seen in figure 2. The complete single ended class E circuit can be seen in Figure 3. By using equations (1), (2) and (3), class-E amplifier designed.

$$C_1 = \frac{1}{\pi \omega R_{dc}} = \frac{1}{5.4466 \omega R_L} \quad (1)$$

$$L_o = \frac{QR_L}{\omega} \quad (2)$$

$$C_o = \frac{1}{\omega Q R_L} \quad (3)$$

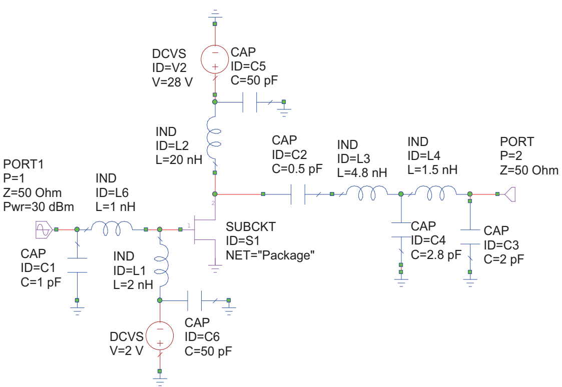

Fig. 3. Ideal Class-E Amplifier

4. Simulation Results

In figure 4, current & voltage waveforms and balanced configuration block schematic are shown. During the time interval 0.2 ns, the switch is open and the current through it is near zero. During the time interval 0.2 ns – 0.4 ns, the switch is closed and the voltage across it is near zero. In same figure, two class-e block connected symmetrically by using 180^0 hybrid couplers. In figure 5 power added efficiency of both single ended and balanced are shown. In 3.5 GHz single ended and balanced configurations have %47 and %51 efficiency respectively. In figure 6, output power at fundamental frequency and harmonic frequencies presented. With balanced configuration degradation of even and odd harmonics can be seen easily.

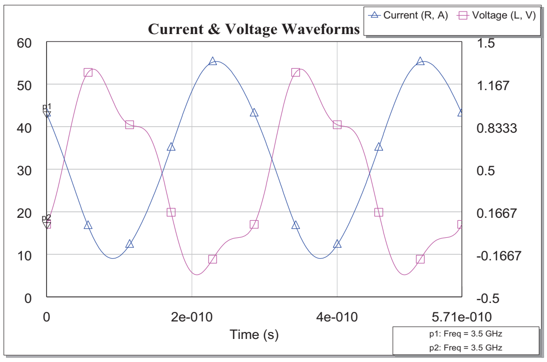

Fig. 4. Current & Voltage Waveforms

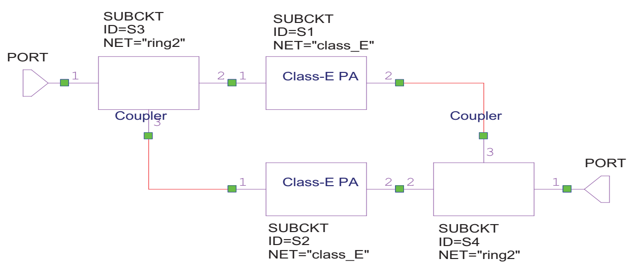

Fig. 5. Balanced Class-E Amplifier

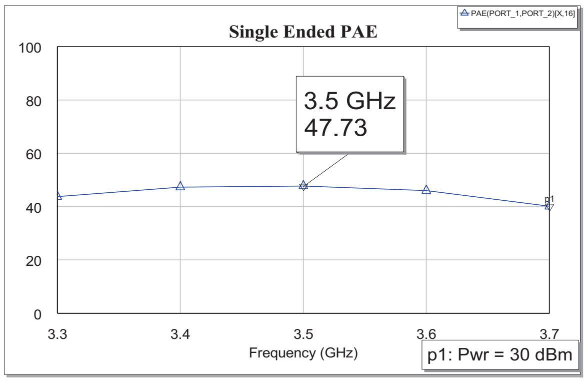

Fig. 6. PAE – Single Ended Class-E amplifier

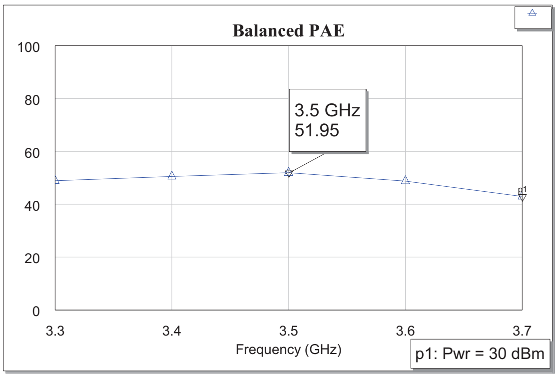

Fig. 7. PAE – Balanced Class-E amplifier

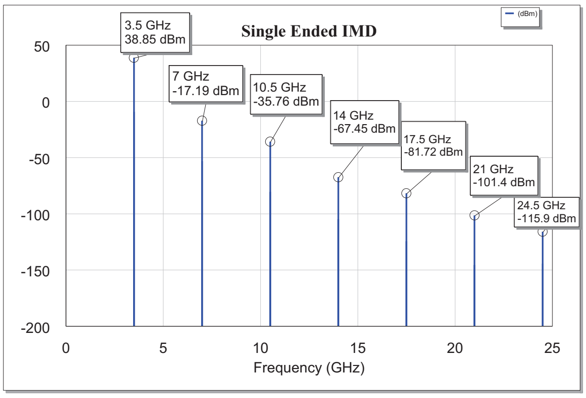

Fig. 8. IMD – Single Ended Class-E Amplifier

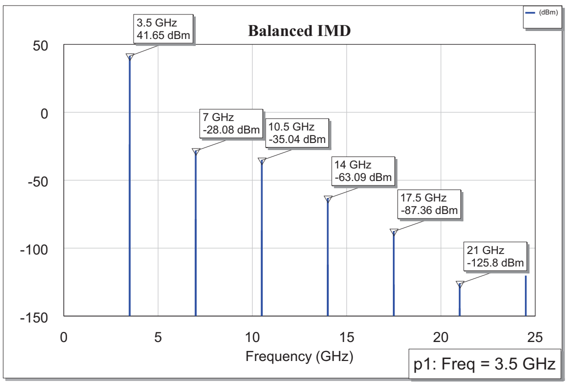

Fig. 9. IMD – Balanced Class-E Amplifier

5. Conclusions

In this paper, we have reported a high-power and high-efficiency balanced GaN HEMT class-E PA for 3.5 GHz WiMax applications. Balanced class-E PA was designed and simulated by using a GaN HEMT NPTB00004 from Nitronex and tested for between 3.3-3.7 GHz. The power added efficiency of single-ended and balanced configurations are 47% and 51% respectively with a gain of 9 dB and 12 dB was achieved at a Pout of 39 dBm and 42 dBm respectively. Additionally, the proposed balanced configuration showed the 3 dBm higher power, %4 higher efficiency, and about 15-20 dB lower distortion at several harmonic frequencies . The results prove that the proposed balanced GaN HEMT class-E amplifier can deliver the higher power and higher efficiency performances than single ended topologies for WiMax applications.

6. References

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