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High Power High efficiency GaN Class E Power Amplifier for Commercial Defence

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Abstract: **-- In this paper, a class E power amplifier in GaN on SiC HEMT process with high efficiency for Commercial Defence application is presented. The proposed class E amplifier in 3.0-3.5 GHz band delivers 112-136 W output power with power added efficiency better than 60% and drain efficiency better than 65%. PA demonstrates a large signal gain of 11 dB at 1 dB compression point. These results are verified by harmonic balance simulations.**

Index Terms— class-E, power amplifier, GaN, HEMT

I. INTRODUCTION

Achieving high efficiency in microwave amplifiers is important for reducing the size and weight, and increasing the output power, battery lifetime, and reliability of the portable wireless transmitters. Efficiency is maximized by minimizing power dissipation in switching device and choosing appropriate time for device turn ON. This is accomplished using Class-E topology [1]. Implementation in [1] uses open circuited stub that limits the bandwidth of PA. We used radial stub to achieve higher bandwidth. Class-E amplifier is suitable as an auxiliary amplifier in Doherty configuration without the need of elaborate switching requirement. GaN HEMT Technology allows high drain voltages of order of 100 volts and high power density of 4-9 W/mm of gate width.

II. CIRCUIT ANALYSIS OF CLASS E PA

A. Operation of Class E PA

Fig. 1 shows ideal Class-E power amplifier topology using transistor as a switch indicates that it has zero on resistance. The circuit includes output capacitance C1, a series tuned circuits consisting of L1, C2 and a series load RL. The circuit is properly designed to give Class E operation delivering ideally 100% efficiency [2]. The switch is open during

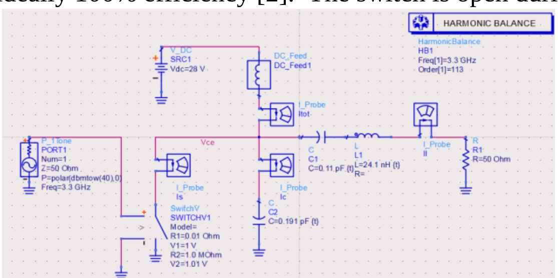

Fig. 1 ideal Class-E power amplifier set up in ADS

the off-state and short circuit during ON-state. When a switch is in OFF-state, energy is stored in form of voltage across C1. For an ideal switching operation, the parameters of Class-E PA [3] can be expressed as

$$R_L = 0.5678 \frac{V_{dc}^{2}}{P_{OUT}} \qquad (1)$$

$$C_1 = \frac{0.0292}{f_O \cdot R_L} \qquad (2)$$

Where Vdc is the bias voltage, Pout is the output power of Class E PA. From above equation it is clear that, at a fixed bias voltage, lowering the value of C1, higher the operating frequency can be achieved [3]. The peak drain voltage ideal across switching device in ideal class-E PA is 3.65 times of supply voltage for 50% duty cycle. GaN HEMT has high breakdown voltage and high saturation velocity suitable class-E PA design at high frequency.

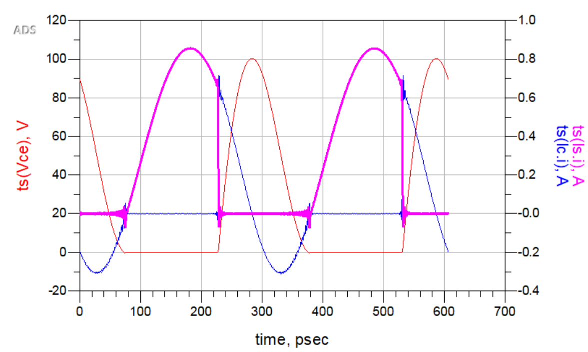

Fig. 2 Voltage and Current waveforms of Ideal Class E amplifier.

Fig. 2 shows the Voltage VCE across the shunt capacitor C1, current through the shunt capacitor and the switch. When the switch will be ON, current Is flows entirely through the switch, and when the switch is OFF, Ic flows entirely through the shunt capacitor. At switch ON voltage across the shunt capacitor is ‘0’ and current thro it also ‘0’ this is lossless switching as the power store on shunt capacitor at switch ON is zero.

B Assumptions Made in the Analysis

For the ideal Class E PA as shown in fig.1, there are several assumptions made in the simplified analysis are as follows.

1) Transistor modelled as switch, turns ON and OFF immediately..

2) The switching device has zero on-resistance and infinite off-resistance.

3) The shunt capacitor C1 is the output capacitance of the transistor and is assumed to be linear in the ideal Class E analysis.

4) The inductance of DC feed is infinite.

5) There are no losses in the circuit except the load RL. Therefore, all of the dc power is dissipated in RL (100% efficiency).

6) The external load network has a high Q factor so the output voltage shapes a sinusoidal waveform at the switching frequency.

Using Fourier series and well-known Class E conditions [2], [4] a set of non-linear equations is obtained. This set of non-linear equations can be solved which yields analytical expressions for relation between the circuit element and parameters like supply voltage Vdc, output power POUT and operating frequency ω.

III. PROPOSED CLASS-E PA

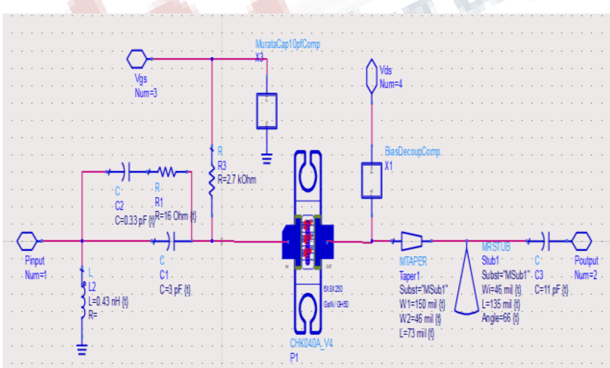

Fig. 3 Schematic diagram of proposed Class E PA

The packaged UMS GaN HEMT, CHK040A_V4, is used as an active device for the class-E PA. The tuned resonant circuit consisting of tapered line and radial stub that presents open circuit at second harmonic and impedance match at fundamental frequency in class-E PA. However, unintended harmonic componentat output and power loss in the pass band occur due to the limited performance of the L-C resonant circuit in ideal PA, so output characteristics such as gain and efficiency are degraded. Therefore, the tuned resonant circuit is replaced with the harmonic suppression network with the λ/4 open-stub taper as well as radial stub that gives higher bandwidth to improve the performance of a class-E PA, as shown in fig.3. To verify that the proposed harmonic-suppression network can block harmonic components, the harmonic balance simulation of Class E amplifier performed in Advanced Design System (ADS).

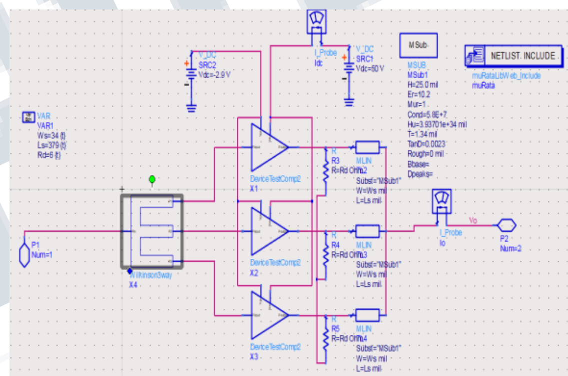

Fig. 4 Three stage Balanced PA

Fig 4 shows, three Class E PA in balanced configuration using input and output Wilkinson’s divider / combiner.

IV. SIMULATIONS RESULTS

In order to verify the circuits operated in class-E mode, five-tone harmonic-balance analysis is used to simulate the circuits with Advanced Design System Software. A CHK040A_V4 GaN/GH_50 package transistor model is used for simulation. A proposed Class E PA circuits are simulated at 3.0 to 3.5 GHz and the simulated results are shown in fig 5 . Results from our design are compared to state of the art PA a currently available in the market in Table 1.

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	CREE CMPA2735075D	[1]	[3]	Proposed PA
Pout (W)	75		10	112-136
PAE (%)	60%		72	Better than 60%
Frequency (GHz)	2.7 -3.5 GHz.		3.5	3.0-3.5 GHz
Gain (dB)	20		10.5	11.5
DE (%)	----		79	Better than 65%

Table 1. Comparison to previous work

V. CONCLUSION

We have proposed high-efficiency Class E Power amplifier using three 40 W packaged GaN devices from UMS in balanced configuration to deliver approximately 120 W Power. HEMT device has advantage of a good thermal velocity, a high breakdown voltage and a high power density. Harmonics are suppressed using the λ/4 radial stub and taper and the efficiency of Class E Power amplifier is improved . The peak PAE of 72.1% with a power gain of 10.5 dB was achieved at output power of better than 135W. Moreover, high PAE better than 65% were maintained in the wide bandwidth of 3.0-3.1 GHz. The experimental results show that the proposed Class-E PA can deliver high efficiency and high power for 3.0-3.5 GHz commercial defence applications

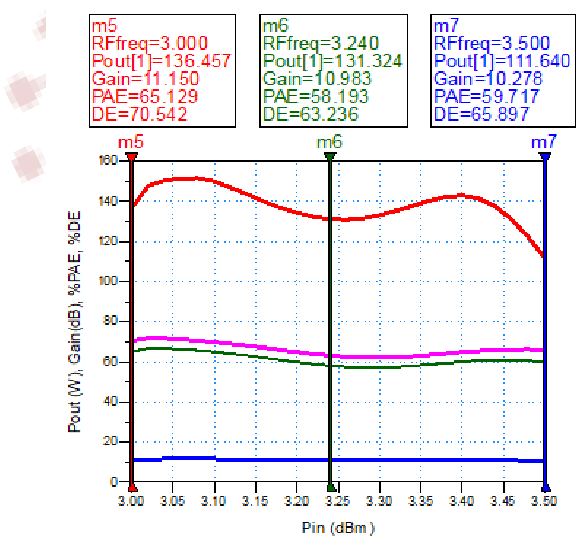

Fig. 5 Simulated Pout, %PAE, Gain and %DE of Class E PA

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