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LETTER

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3.5–3.8 GHz class-E balanced GaN HEMT power amplifier with 20 W Pout and 80% PAE

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Abstract: In this study, balanced and single ended class-E power amplifiers (PAs) were designed and realized for 3.5–3.8 GHz band by using Gallium Nitride high electron mobility transistor (GaN HEMT). Realizations were made on low loss Rogers RT5880 dielectric material which has 0.254 mm thickness and 2.2 dielectric constant. Proposed balanced class-E PA has approximately 20 W (43 dBm) output power with 80% peak power added efficiency (PAE) and shows a very favorable combination of output power, PAE and suppressed even order harmonics compared to the single ended class-E PA prototype.

Keywords: balanced power amplifier, harmonic powers, GaN HEMT

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

In current competitive wireless communication market, one apparent strategy for a company to stay competitive is to lower product development cost. Manufacturers and product developers are seeking ways to build high performance devices that is operating at lower power. In base station applications, one module is responsible for a large portion of the power consumption called the power amplifier (PA). In general, the higher the output power of the transmitter, the higher the PA consumption as a percentage of the total. The efficiency of the PA has a direct impact on the cost of the wireless communication system. Increasing the efficiency of the PA in a base station transmitter results in reduced direct current power, reduced heat sinking requirements and increased reliability due to reduced junction operating temperatures. In addition, the reduction in input power significantly reduces the cost of amplification. As a result, efficient power amplification is highly desirable especially for base station applications [1].

In this paper, balanced and single ended class-E PAs were designed for 3.5–3.8 GHz frequency band by using GaN HEMTs. Because of their superior performance over the silicon based transistors, GaN HEMTs have been used extensively to build the microwave PAs today. In this work CGH40006P transistor from CREE is used. Because of the fact that the balanced PAs are symmetrically driven, the RF input signal has to be divided into two parts as balanced and unbalanced with element of 180° hybrid coupler [2]. These two signals are amplified separately and combined with hybrid coupler at output. The proposed balanced class-E PA; doubles the output power, suppresses the even order harmonics and increases the PAE compared to the single ended class-E PA [3].

2 Design of balanced power amplifier

2.1 Proposed load network topology

For class-E PAs, it is generally sufficient to present high impedances at the 2^{nd} and 3^{rd} harmonic frequencies [1]. Fig. 1 shows the proposed topology to realize the class-E conditions in order to get the higher efficiency by properly terminating the 2^{nd} and 3^{rd} harmonics. Line-1 has $(\lambda/4)$ length at the 3^{rd} harmonic of the fundamental frequency and so it serves as an impedance inverting transformer at this frequency. Line-2 has $(\lambda/2)$ length at 3^{rd} harmonic therefore, it presents short-circuit termination at point A. With the

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aid of the impedance inverting property of the line-2, this termination is reflected as an open circuit across the drain terminals of the transistor which is necessary for the class-E operation. Line-4 and line-3 have the lengths of $(\lambda/4)$ at the 2^{nd} harmonic. Therefore, the current at this frequency is open circuited at point A. Since the line-2 is selected with a high characteristic impedance, it presents very high impedance at the same point. Therefore, very high impedance for the 2^{nd} harmonic current is also provided across the DS terminals of the transistor. Line-6 is used in order to transform the $50\,\Omega$ load to a real impedance value to provide an optimum termination across the transistor output terminals which is required for the class-E operation.

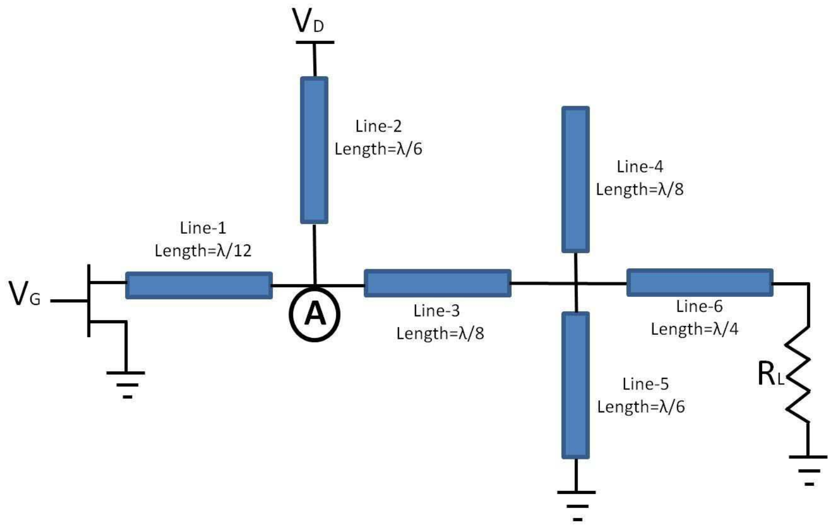

Fig. 1. Proposed single ended class-E load network.

2.2 Realization of the balanced PA

As we know, single ended class-E PAs have odd and even order harmonics and these harmonics decrease the efficiency of the PAs [3]. In order to cancel even order harmonics and increase the efficiency, 2 single ended PAs can be combined with aid of 180° hybrid couplers as shown in Fig. 2. In this work, a ultra wideband and low loss 180° hybrid coupler is used derived from wilkinson power divider where the output ports are combined with $(\lambda/4)$ phase inverting and non-inverting suspended microstrip lines (SMLs) [7]. With this technique frequency sensitivity of the 180° hybrid coupler was decreased. Thus, even order harmonics up to sixth were reflected back to the transistor. At the input, the RF signal was divided into two parts with equal amplitude and 180° out–of–phase and amplified by single ended PA blocks separately. At the output, the hybrid coupler combines the amplified signals with 180° out–of–phase and generates output signal [3].

3 Implementation and experimental results

For purpose of comparison, 2 prototype boards (balanced PA and single ended PA) were realized on a Rogers RT5880 PCB material. Photographs of

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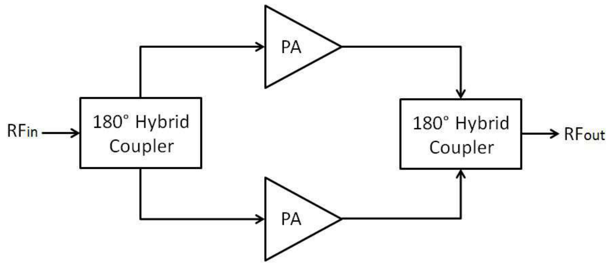

Fig. 2. Diagram of the simplified balanced PA.

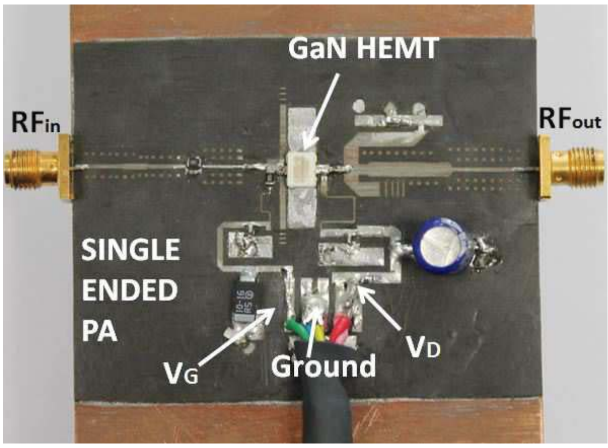

Fig. 3. Prototype of the single ended class-E PA.

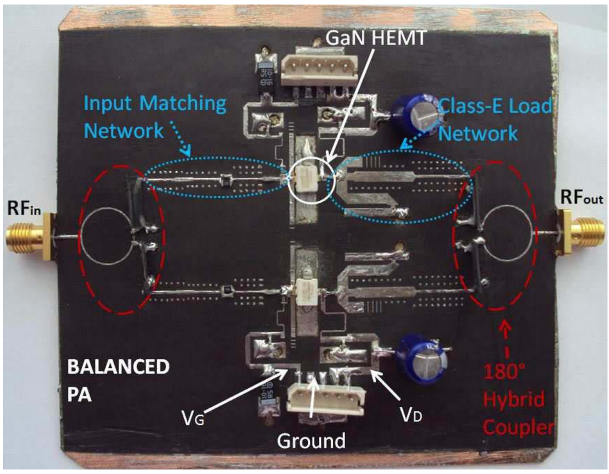

Fig. 4. Prototype of the balanced class-E PA.

the prototypes are shown in Fig. 3 and Fig. 4.

Gate and drain voltages were set to −4 V and 28 V, respectively. Measured frequency response, input-output power response and efficiency of the PAs are shown in Fig. 5 and Fig. 6. Measurement setup consists of a spectrum analyzer, a signal generator, a pre amplifier, 3 power supplies, attenuators and several 50 Ω coaxial cables. The balanced and single ended amplifiers are driven with 34 dBm and 31 dBm input power respectively, yielding a switch like class-E operation. From 3.5 to 3.8 GHz, balanced PA has output power of 43 dBm, with PAE between 75 to 80%. In the same frequency range, the

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power gain remains at 10 dB. For single ended PA, output power is 40 dBm, PAE is between 70 and 73% and the gain is the same as balanced PA. In single ended topology, even order harmonics, particularly 4^{th} and 6^{th}, could not be suppressed before the load. Furthermore, 2^{nd} harmonic is not perfectly shorted due to residual loss of the microstrip lines. In balanced topology, with aid of the ultra-wideband and low-loss 180° hybrid coupler; 2^{nd}, 4^{th} and 6^{th} harmonics were suppressed about 10 dB. All of these powers reflected back to the transistor make the balanced PA more power efficient.

In order to compare the balanced and single ended PA topologies in terms of even order harmonics, harmonic powers up to sixth were given in Fig. 7.

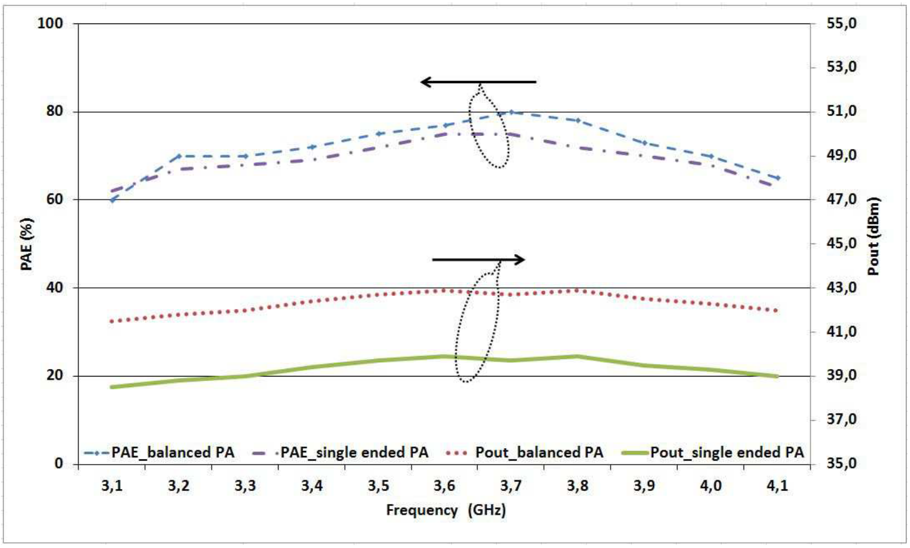

Fig. 5. Measured frequency response for the balanced and single ended prototypes.

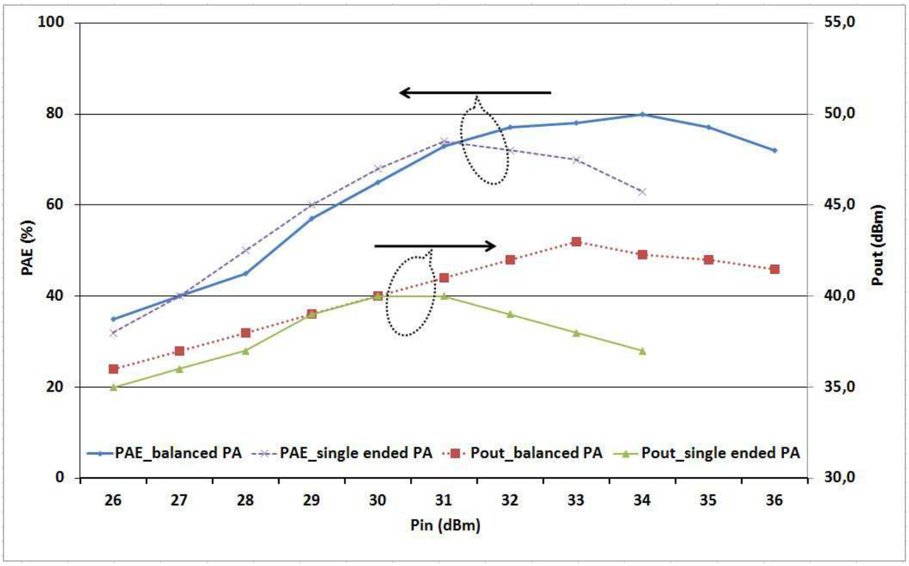

Fig. 6. Measured input-output power response and efficiency for the balanced and single ended prototypes.

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As it can be seen from the figure below, balanced PA configuration has about 10 dB suppressed even order harmonics but also has nearly same odd harmonic powers. Table I shows a summary of the measured results compared with other high-efficiency amplifiers that have so far been reported in the literature over the same frequencies.

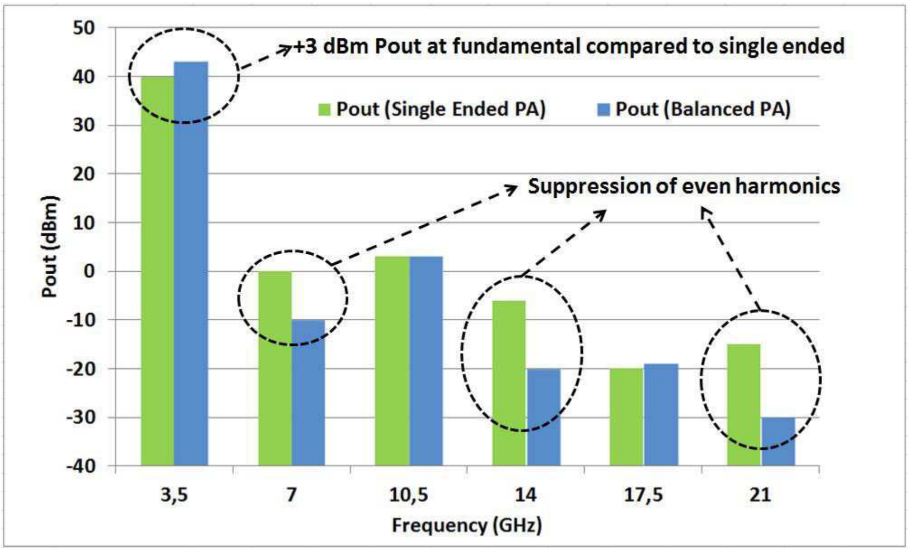

Fig. 7. Comparison of harmonic powers of the balanced and single ended prototypes.

Table I. Comparison of characteristics.

Ref.	Frequency (GHz)	PAE%	Transistor
[4]	3.5	78	GaN HEMT
[5]	3.5	72	GaN HEMT
[6]	3.5	58	GaN HEMT
This work	3.5–3.8	80	GaN HEMT

4 Conclusion

This letter proposes a 20 W balanced class-E PA using GaN HEMTs. With proposed balanced class-E PA, state-of-the-art peak PAE performance (80%) was achieved over the 3.5–3.8 GHz band, even order harmonics were suppressed about 10 dB and output power doubled compared to the single ended prototype. This balanced PA topology offers a good solution for the applications which need much lower harmonic content, much more output power and efficiency.

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