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A Distributed Power Amplifier Design with a High Power Gain

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***Abstract*— In this paper we present a distributed power amplifier that has a good gain-bandwidth product in comparison with other recent discrete distributed power amplifiers. A TGF2023-01 bare die transistor with 0.25µm GaN HEMT technology is utilized in our work. Our distributed power amplifier provides a better matching that leads to a more flat frequency response and uses tapering technique for both gate and drain transmission lines to boost the output power and efficiency. This design demonstrates a 41.6 dBm saturated power and a 22.2 dB small signal gain from DC to 3.4 GHz with a power added efficiency (PAE) of 27%.**

Keywords*— *Power amplifier, distributed amplifier, traveling wave amplifier, gain-bandwidth product, transmission line, GaN HEMT.

I. Introduction

Power amplifiers play a significant role in high frequency systems. They are usually used to enhance the power level in the final stages of transmitters.

Today's communication systems require more bandwidth day by day. However, packaged high frequency transistors are conventionally matched to 50Ω over a narrow bandwidth [1]. Also, the gain (S_{21}) rolls off at a rate of 6 dB/octave with frequency [1]. For these reasons, careful considerations must be taken into account in order to design a broadband amplifier.

Several techniques have been used to reach a higher bandwidth in power amplifier design [2]-[6]. Compensated or resistive matching network, negative feedback, balanced structure and distributed amplification are some of these techniques [1]. For example, in a recent attempt in [7] an f_T_doubler technique is used for this purpose.

Distributed power amplifiers (DPA) are based on an interesting circuit design idea that makes use of transmission line theory along with conventional amplifier design to achieve a high gain-bandwidth product. This idea is rooted on absorbing the parasitic capacitances of the transistors into the transmission lines which are connected to the drain and the gate and hence results in improving the bandwidth.

This paper utilizes this technique to design a distributed power amplifier with a high gain-bandwidth product. The rest of the paper is organized as follows. Section II describes the principle of distributed amplifiers and Section III discusses the proposed design and the methods that are used. In section IV, the results are demonstrated and compared with those of the previously published works.

II. Distributed Power Amplifier Principles

The idea of DPA was proposed by Percival in 1937 [8]. It was first used to design broadband vacuum tube amplifiers. It did not receive so much attention until a publication by Ginzton *et al.* in 1948 [9]. This type of circuits is also called traveling wave amplifier. As we said before, DPA is a circuit-design technique in which the parasitic capacitances of the transistors that could limit the bandwidth of the amplifier are absorbed in both input and output transmission lines. Hence, the effect of these capacitances reduces and the bandwidth of the amplifier improves.

The basic representation of a DPA is shown in Fig. 1. In a DPA, two transmission lines are connected to the inputs and outputs of several active cells (e.g. transistors). In most cases, these transmission lines are microstrip lines. As the input signal wave goes down on the gate line, each active cell responds to it by putting a complementary wave on the drain line, one after another. If the propagation constant of the input and the output lines are the same, the output signals sum in phase. The reverse directed waves are not in phase. In contrast to the multiplicative property of the gain of a cascade of active cells, the gain of a DPA has additive property. As a result, DPAs are not expected to have very high gains. The input and output transmission lines are terminated by Z_g and Z_d to minimize the reflections. Detailed discussions and analytical investigations that illustrate the principle of operation of DPAs are available in [1] and [10]. However, the numerical CAD procedure is needed for optimization and more accuracy.

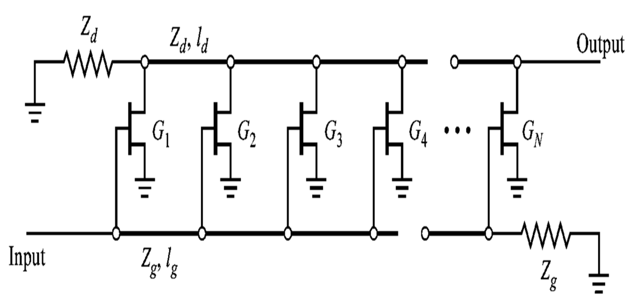

Fig. 1. An N-stage distributed amplifier.

III. THE PROPOSED DESIGN

DPAs have low efficiency. In conventional DPA, the drain current wave of each transistor sees identical impedance in forward and reverse paths. So this current wave gets divided equally and only half of the wave propagates toward the output port. This results in a low efficiency. The same discussion is applicable to the gate line. In order to improve the efficiency of a DPA, there are some techniques available. One of these techniques is tapering, which can be applied to both drain and gate lines. It leads to a nonuniform DPA. This method encourages the signal wave to choose the forward path. It makes the forward path more suitable by gradually decreasing the impedance of the line. The tapered line gets wider progressively and the signal wave sees a smaller impedance in the forward path and a bigger impedance in the backward path. Therefore, a bigger part of the signal wave propagates toward the forward path. As a result, the reflected power is smaller using the tapered technique in comparison with that of a conventional DPA. For this reason, the drain efficiency and power added efficiency (PAE) increase. In our design, we used tapering technique for both of the drain and the gate lines.

Another method to improve the DPA performance is using a matching network at the input port. Having a better matching at the input port means less power reflections. As a consequence, a higher power enters the system. Because of that, the S_{11} is improved and the bandwidth is increased. In addition, a better input matching implies that some of the high frequency loss of the gate line is compensated. Therefore, the small signal gain (S_{21}) increases and remains flat over a wider range of frequencies. This means we can obtain a wider bandwidth.

In this design, we utilized both of the aforementioned strategies combined with GaN HEMT on SiC technology in order to improve the performance of our distributed power amplifier.

IV. RESULTS OF THE PROPOSED DESIGN

First, our distributed power amplifier design is simulated in ADS (Advanced Design System) software using a nonlinear model provided by Modelithics Inc. Then it is implemented on RO3010 substrate and GaN HEMT die transistors are connected to the PCB by bonding wires. The aimed centre frequency is 2GHz. Fig. 2 demonstrates the scattering parameters of the amplifier versus frequency. The measurement results are recorded using E8363B vector network analyser of Agilent Technologies.

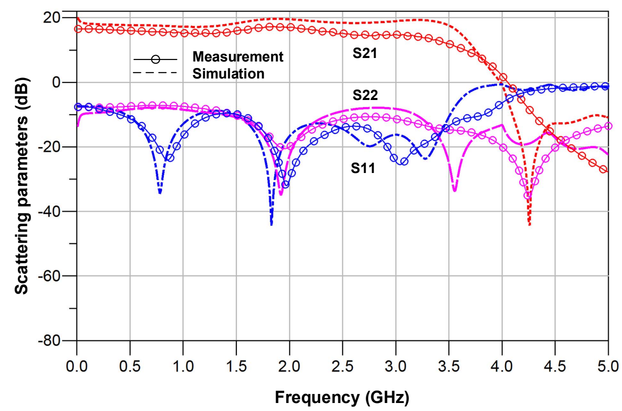

Fig. 2. Small signal performance (S_{21}, S_{11}, S_{22}) of the proposed distributed power amplifier.

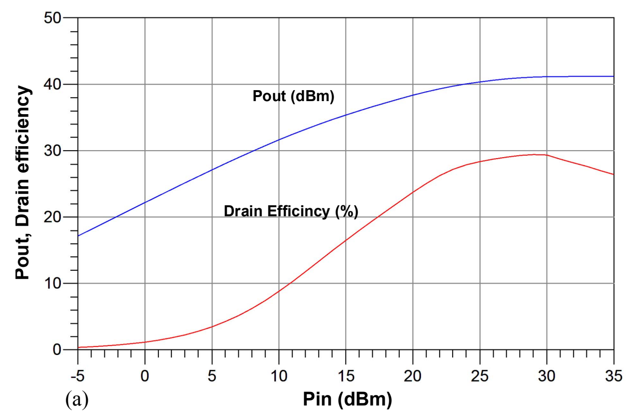

Fig. 3. a) Output power and drain efficiency. b) Power gain of the proposed distributed power amplifier.

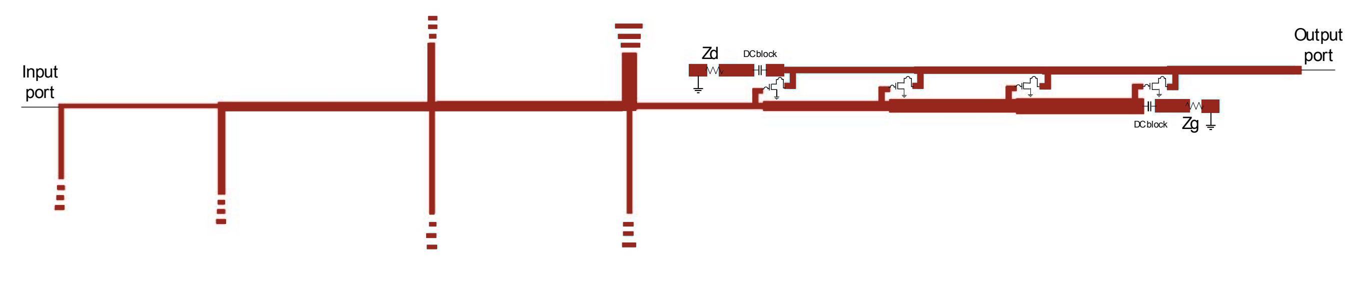

Fig. 4. Layout of the proposed distributed power amplifier design.

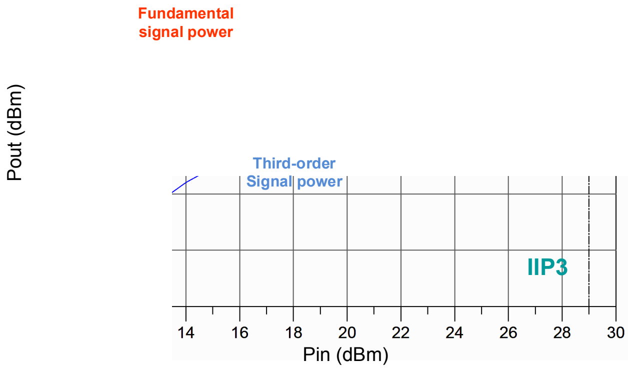

Fig. 5. Input third-order intercept point.

As can be seen in Fig. 2, a flat bandwidth of DC-3.4GHz is achieved and the gain changes are less than ±1.5 dB over the entire bandwidth. Fig. 3 shows how the output power varies by increasing the input power.

According to Fig. 3, the output saturated power (P_{sat}) is 41.1 dBm (~13 watts) and the output 1dB compression point is 40 dBm (10 watts). The dynamic range of the amplifier, which is defined as the range where the amplifier has a linear power gain is 22 dBm. The layout of our design is displayed in Fig. 4 and the fabricated distributed power amplifier is presented in Fig. 6.

As we know the extrapolated point, where the curves of the fundamental signal and the third order distortion product meet is the Intercept Point (IP3). At this point, IM3 is equal to 0 dBc. Fig. 5 demonstrates the third-order intercept point of the amplifier. It can be seen that the input power level at this point (IIP3) is equal to 29 dBm and the corresponding output power (OIP3) is 45 dBm. Table 1 summarizes the performance of our distributed power amplifier design. Generally, distributed amplifier structure is known for its gain-bandwidth product. So, the figure of merit that has been used is as follows:

$$FOM = Gain \times Bandwidth_{(GHz)} = (\frac{P_{out}}{P_{in}}) \times Bandwidth_{(GHz)} \quad (1)$$

A comparison between this work and some recently published similar discrete PAs is presented in table 1. As can be seen, our designed distributed power amplifier shows a high output power and a good gain-bandwidth product in comparison with the other works.

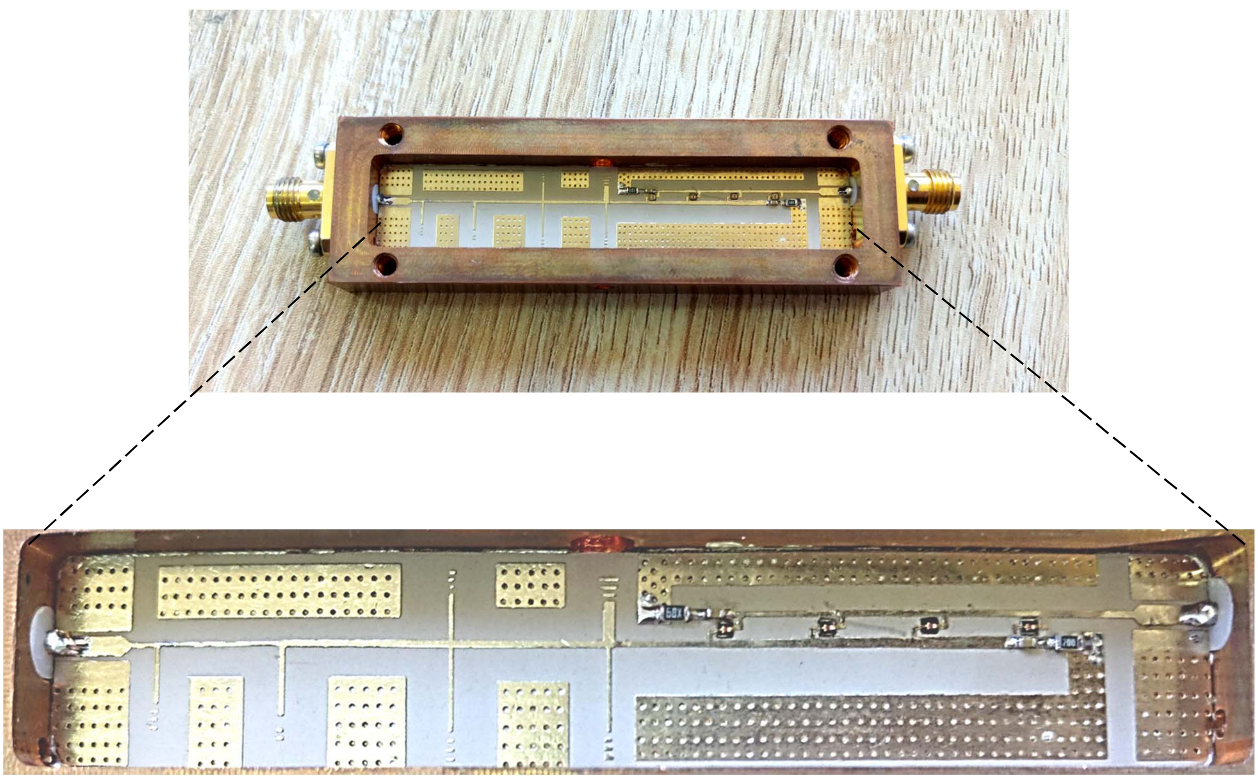
Fig. 6. Photograph of the fabricated distributed power amplifier (1 cm× 6.2 cm RO3010 PCB).

Table 1. Performance comparison.

Ref.	Bandwidth (GHz)	P_{out} (watts)	PAE_{max} (%)	$Gain_{max}$ (dB)	P_{out}/P_{in}	FoM
[2]	9-9.8	30	52	12	15.84	12.7
[3]	8.8-9.6	5.49	57	14	25.1	20.1
[7]	6.6-10.5	10	43	10	10	39
[11]	8.8-9.6	5.24	55	13	19.95	15.96
[12]	0.03-2.7	5	39.5	13	19.95	53.27
[13]	0.02-6	7.94	22	15	31.6	188.97
[14]	0.08-2.1	12.6	47	12	15.84	32
This work	DC-3.4	13	27	22	137.4	467.16

V. CONCLUSION

In this paper, we designed a power amplifier with a good gain-bandwidth product using discrete 0.25µm GaN HEMTs of TGF2023-01 by means of its corresponding nonlinear model provided by Modelithics Inc. This design attained 41.6 dBm output power (P_{sat}). It gives a flat gain bandwidth from DC to 3.4 GHz with less than ± 1.5 dB variations in the small signal gain (S_{21}). The gain-bandwidth product of our design is one of the highest among recent reported works and its overall performance outperforms the other competitors.

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