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# A Compact Wideband High Power Amplifier in GaN Technology with 47% peak PAE

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**Abstract** — This article presents a 4-6GHz power amplifier in a 0.25 $\mu$ m GaN integrated technology from UMS foundry. Two unit power cells are combined to increase output power. A new power combiner based on a stacked balun is presented. It has the advantage of occupying a much smaller area than a conventional one. The measured circuit exhibits a peak output power of 37 dBm together with a peak PAE of 47% at 4GHz.

**Index Terms** — GaN. High power amplifier (HPA), power combining, vertically stacked balun.

## I. INTRODUCTION

One of the main advantages of GaN based integrated technologies is the ability to deliver a high output power over a wide frequency range. Various applications can take advantage of this property such as electronic warfare communications and radar systems. For example, radars in S, C, X and Ku bands for military applications or meteorological radars in C-band and base stations for cellular phones can be mentioned. Usually to increase the delivered power from the emitter side, a solution is to parallelize unit power cells in the power amplifier (PA) [1], [2]. In MMICs, power combining is generally achieved through current combination [3]. This approach exhibits good performances in terms of efficiency at the expense of an important occupied area. The MMIC stacked balun approach allows reducing drastically the combiner size while keeping efficiency performances. The MMIC vertically stacked balun concept is introduced in [4].

This chip has been realized within the SIMCLAIRS competed program, a European consortium. For characterization matters required in the consortium, the power amplifier is voluntary unmatched in the input because it is meant to be driven by a separated driver stage. With proper matching, this chip achieve much larger bandwidth performances from. This circuit has been implemented in the GH25 integrated GaN process from UMS foundry. Power devices are HEMT 0.25 $\mu$ m transistors. This technology node permits to deliver high output power up to 20GHz.

Section 2 will focus on the amplifier architecture and the innovative power combiner design. In section 3 measurement results will be presented for both linear and non-linear behavior and section 4 will present simulation results of a C to X-band high power amplifier (HPA) based on the same topology. To the author's knowledge this circuit is the first demonstrator of a HPA MMIC using a stacked balun as a power combiner.

## II. ARCHITECTURE

### A. HPA structure

For power enhancement, a differential structure has been adopted. The electrical schematic of the realized HPA is presented in Fig. 1. The unit power cell is made of a GaN HEMT of 8\*125 $\mu$ m resulting in a total gate width of 1mm. A stabilization network made off a serial RC network ( $R$ ,  $C$ ) is placed on the transistor gate to avoid low frequency self-oscillation. Each cell is biased directly through the inductor  $L_b$ ,  $C_{bp}$  acts as a by pass capacitor to cut the DC component. Both cells are recombined out of phase in the stacked balun, which perform the differential to single mode conversion. This balun is used in the marchand configuration (the termination of the secondary is left open). Unit cells receive their supply through the balun middle point.

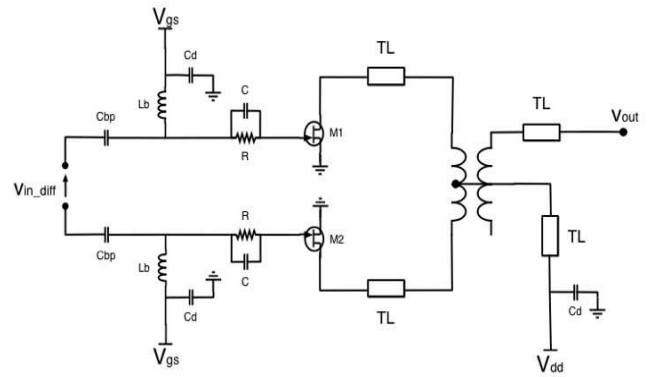


Fig. 1. Differential to single power amplifier architecture

The supply is set to 25V and the gate bias is adjusted in order to achieve a DC current consumption of 80mA/mm; this results in a total DC power consumption of 4W for the entire HPA. This biasing value has been selected to both respect the founder recommendations for reliability, be able to deliver 5W of output power, and achieve best efficiency possible.

### B. Power combiner design

The power combiner is typically the component that occupies the larger die area in an MMIC HPA. In this design, a vertically stacked balun is introduced here to act as a power combiner. By stacking both windings instead of putting them on a same layer, the occupied area is drastically reduced. Power transfer is then made through vertical coupling. The stacked balun has been optimized to have minimal insertion loss in the frequency band of interest. The balun has been designed to be matched to power cells output optimal impedances without any matching network between the power cell and the balun. These optimal impedances have been obtained from load pull simulations at several frequency points. Electromagnetic simulations of the standalone balun performed with the Agilent Momentum software. The balun exhibits minimal insertion loss of 0.7dB in the [4GHz-6GHz] band. It is mandatory that the balun is exactly symmetrical so both cells see the exact same impedances. Otherwise, one cell would drain more current than the other resulting in self-heating and destruction of this cell.

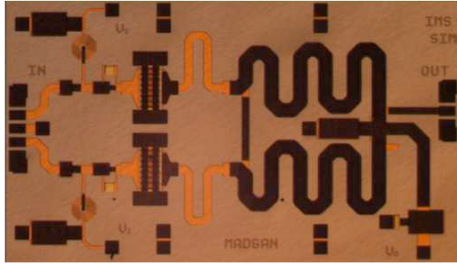


Fig. 2. Chip photography (3.3mm\*1.9mm)

Fig. 2 is photography of the realized chip, it occupies an area of 6.27mm<sup>2</sup>. In the next section, measurement results will be compared to simulation for both linear and non-linear behavior.

### III. MEASURED PERFORMANCES

The measured S-parameters are presented in Fig. 3 from 2GHz to 12 GHz. A peak gain of 11.2dB is observed at 4GHz and the gain remains over 7.8dB from 2.8GHz to 6GHz. A low pass RC filter placed on each transistor gate to prevent low frequencies oscillation explains the strong gain decrease under 3GHz.

$S_{22}$  and  $S_{11}$  plots prove that the circuit is stable from a linear point of view, because they always of negative values. Moreover, K-factor has been checked to be over unity. Output matching has been optimized to increase output power and efficiency instead of small signal behavior.

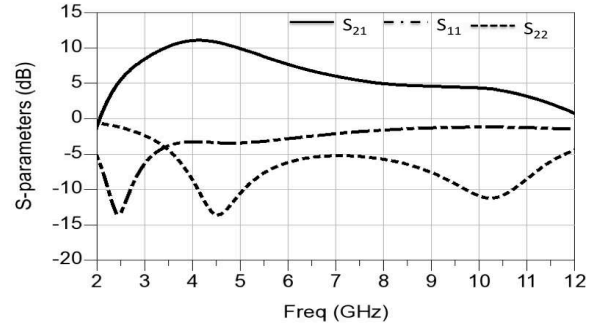


Fig. 3. Measured linear gain from 2GHz to 12GHz

Non-linear measurements are presented in Fig. 4, 5 and 6; output power, PAE and gain are plotted respectively. For each plot 3 frequencies points are presented: 4GHz, 5GHz and 6GHz. Due to input power delivery limitations in the measurement setup, plots do not show output power saturation and thus the PAE decrease after reaching a maximum value. However, looking at output power curves, saturation is almost achieved so the PAE will not increase by more than 2 %. The HPA delivers 37dBm, 35.2dBm and 33.5dBm at 4GHz, 5GHz and 6GHz respectively. For the same frequency points, maximum PAE values are 47%, 38% and 17.5%. These results are in good agreement with simulation results. Table 1 summarizes measurement and simulations results for linear gain, output power, efficiency and power gain for an input power of 27dBm.

This HPA occupies a reduced area of 6.27mm<sup>2</sup>. This is an encouraging step towards HPA integration. Indeed, many HPA, found in literature [5] and [6], are capable to deliver more than 100 W of output power but they suffer from their size making them not suited for embedded applications.

TABLE I  
COMPARISON BETWEEN MEASUREMENTS  
AND SIMULATIONS @  $P_{IN}=27dBm$

		4GHz	5GHz	6GHz
$P_{out}(dBm)$	sim	36.6	35.3	33.5
	meas	37	35.2	33.5
PAE(%)	sim	52	37	21
	meas	47	38	17.5
Gain(dB)	sim	8.7	8.3	6.4
	meas	9.2	7.4	6.2

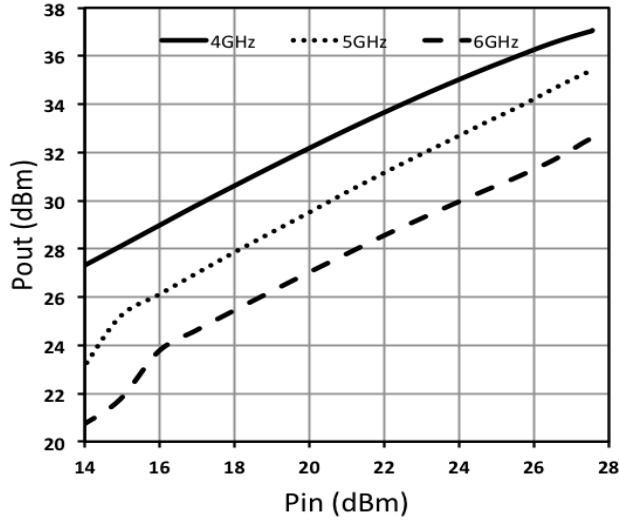


Fig. 4. Measured Pout vs. Pin @4GHz, 5GHz and 6GHz

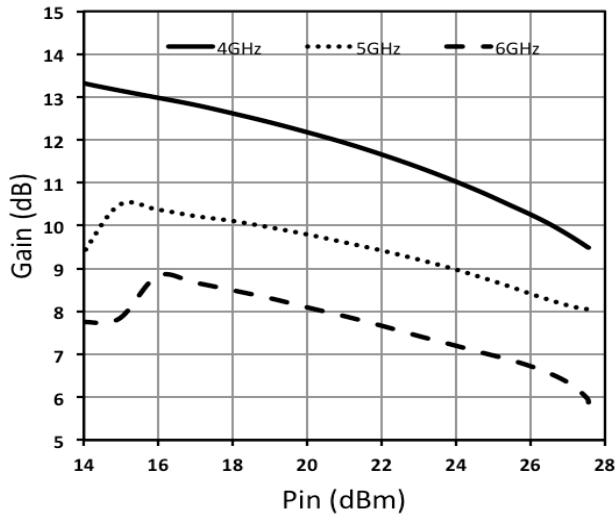


Fig. 5. Measured PAE vs. Pin @4GHz, 5GHz and 6GHz

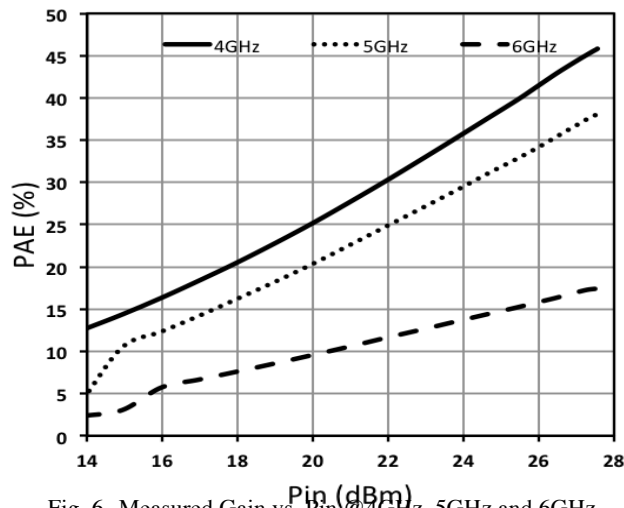


Fig. 6. Measured Gain vs. Pin @4GHz, 5GHz and 6GHz

#### IV. C-BAND TO X-BAND SIMULATED HPA

As mentioned earlier, this HPA has been voluntarily left unmatched in the input as it is meant to be driven by a preliminary stage. However to demonstrate the wideband abilities of this power stage, simulations with a matched input from 4GHz to 11GHz have been performed and are presented in the following. The demonstration of an innovative, compact and very efficient power combining technique has been done through measurements of the HPA presented in this article. In fact, the output balun can act as a low loss power combiner from 4GHz to 11GHz, a frequency band in which it exhibits less than 1dB of insertion loss. Non-linear simulations have been performed to evaluate output power, efficiency and gain performances from C-band to X-band. To simulate proper input matching, the input impedance has been swept from 50Ω at 4GHz to 5 Ω at 11GHz as one would do performing source-pull on a single transistor expect it is done on the overall HPA here. Simulation is performed at  $P_{in}=29\text{dBm}$  from 4GHz to 11GHz, results are plotted in Fig. 7.

In average, output power, PAE and associated gain respectively reach values of 35.5dBm, 34% and 6.5dB over the full frequency range. From 8.5GHz to 10.5GHz an output power greater than 35dBm is achieved together with an efficiency higher than 30%. The maximal efficiency reaches a value of 51% at 4.6GHz.

These results validate the ability of such a topology to act as a C-band to X-band high efficiency HPA. Indeed, only source impedance has been swept to obtain results presented in Fig. 7, everything else in the circuit has not been changed and is exactly same as what shown in Fig.1 and detailed in sections 1,2 and 3.

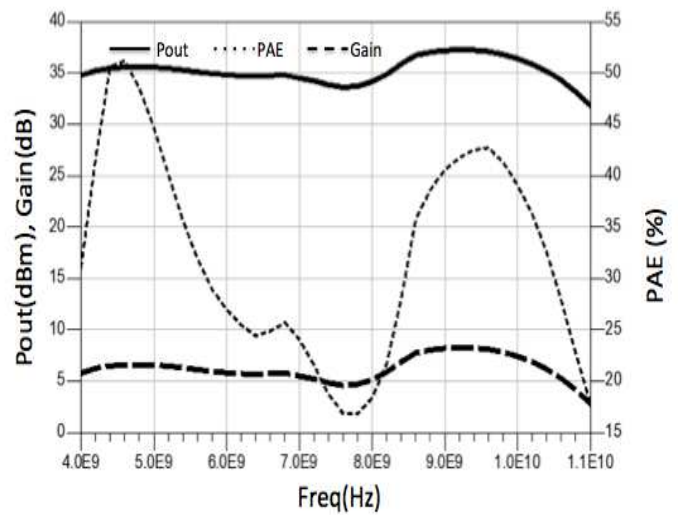


Fig. 7. Input matched Simulated Pout, PAE and Gain @  $P_{in}=29\text{dBm}$

## V.CONCLUSION

The demonstration of an innovative, compact and very efficient power combining technique has been done through measurements of the HPA presented in this article. This opens the door to the realization of smaller size HPAs in the future. The realized HPA exhibits an output power of 5 W and a PAE of 47% at 4 GHz. The main perspective is to extend wideband performances of this HPA to target even more applications such as multi antennas communicating systems or electronic warfare. This has been demonstrated in section 4 where an average PAE of 34% from 4GHz to 11GHz is reported. Moreover, to increase output power too, the principle of the vertically stacked balun can be extended to parallelize more than 2 cells by connecting baluns in serial and realize a distributed active transformer (DAT). This open the door to the realization of C-band to X-band HPAs delivering more than 10 Watts with PAE greater than 30% with a drastically reduced die size compared to actual state of art.

## ACKNOWLEDGEMENT

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AEROPORTES France, acting as the Consortium Leader, SELEX Galileo Ltd, THALES UK Ltd and SAAB AB.

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