Design of a 5W GaN MMIC power amplifier for Ka-band application

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INTRODUCTION

With the advent of 5G mm-wave and new Space and Satcomms applications, there is significant demand for increasingly higher power levels in MMIC format along with higher dc to rf efficiencies at the mm-wave frequencies. Many of these emerging applications will be focused on delivering active antenna arrays, where the need for a small form factor is implicit. Each element is serviced typically by a front-end module whose size must be logically confined to the half wavelength separation of each antenna. Accessing higher efficiencies in compact integrated designs is reliant on extremely accurate nonlinear characteristaion data and models which is a particular challenge at these frequencies. This paper will give an overview of the chosen 0.15um GaN process, summarise initial loadpull performance evaluation on preliminary unit cell devices and the design of a 23-30GHZ 5W GaN on SiC MMIC with 18dB gain for 5G and Satcomms application. The design flow employs the Focus-mesuro active loadpull system which generates a Cardiff PHD behavioural model, together with an inhouse IconicRF compact (equation based) GaN FET model.

PROCESS OVERIEW

The chosen process features a 0.15μm T gate with an source-coupled field-plate to enhance gain and reduce the peak electric field at the gate-drain region. The threshold voltage, Vto is -2.85V and a maximum drain voltage are targeted at 20V Vdd, and a future option of 24V is planned. The 3-terminal breakdown, Vdg is greater than 120V and the Fmax >90GHz (2x75μm). Idmax is >1A/mm for a single finger 75μm device. Power performance is >3.5W/mm and PAE ~50% at 28GHz.

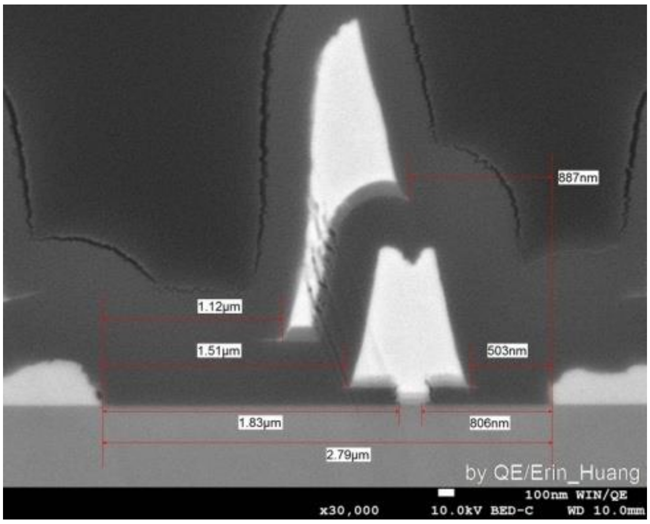

Fig. 1. T-gate and source-coupled field plate cross section

The passive components in the process are a 215 pF/mm^2 high-density MIM capacitor and an 50Ohm/sq TaN thin-film resistor. Two layers of gold metalisation enable airbridge and thick microstrip transmission lines to a total of 5μm thickness. The 4inch wafers are thinned to 100μm thickness incorporate 30x60μm slot backside vias, and 5.5μm backside metal. Non-wet film enables eutectic die attach and there is an additional option of AuSn die attach service. The roadmap includes switch and LNA versions in addition to the baseline power amplifier version which is planned to be fully released in mid 2019.

POWER PERFORMANCE AT 29GHZ

To determine baseline unit cell power performance, a series of load pull measurements were taken on a Mesuro Focus active load pull system to establish peak gain, power and power added efficiency performance at 29GHz on a preliminary 2x75μm unit cell. The active system enables a higher reflection coefficient to be achieved than a passive tuner system these frequencies. Peak efficiency of 54.9% (Drain efficiency) was achieved with 26.8dBm Pout and linear gain of 9.1dB. Peak power of 27dBm was achieved with 50% drain efficiency as shown in Table 1.

Table 1. Summary of 29GHz fundamental load pull on 2x75μm NP15 unit cell, bias Vdq = 20V, 15mA.

Tuned for:	Max	Mag	Phase/deg	Linear Gain	Linear Pout	Gain at Compression	Pout at Compression	Efficiency at Compression	PAE at compression	Compression
Pout (dBm)	27	0.7	58	9.1	18.4	6.9	27	50	39.8	2.2
Drain Eff (%)	54.9	0.8	58	9.1	19.3	6.6	26.8	54.9	42.9	2.5
Gain (dB)	13.7	0.89	70	13.7	16.8	10.7	21.8	22.8	20.9	3

With power added efficiency performance a critical parameter, this initial series of load pull was followed up with second harmonic load/source pull measurements to assess impact of second harmonic terminations at this frequency, it was observed that optimised terminations are important and can result in efficiency improvement of several percentage points over the non-optimal termination case.

ICONICRF COMPACT AND CARDIFF MODEL APPROACH

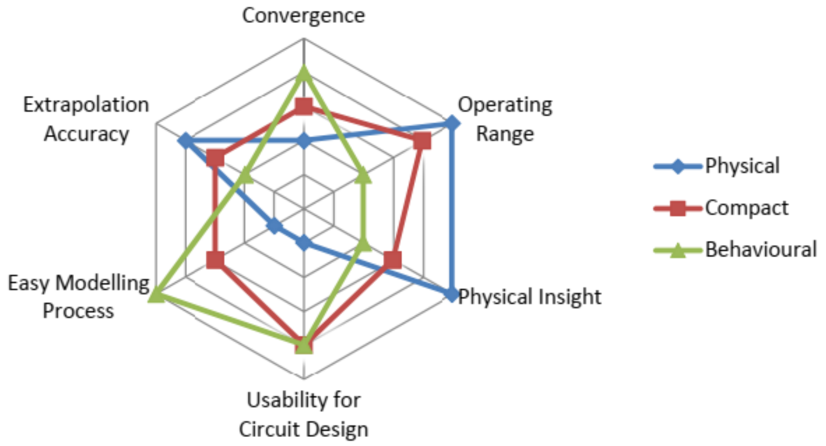

Figure 2 Comparing the main model type features and capability – physical, compact and behavioural.

A fast and extremely accurate means of enabling nonlinear PA design to target high efficiency operation is to convert measured loadpull data into a polyharmonic type behavioral model such as the Cardiff model supported by Focus [1]. The active loadpull system is shown in figure 3. This essentially allows efficient and accurate reproduction of the measured loadpull data within the circuit simulator eg harmonic balance. For the 5W design this was key to achieving the highest possible efficiency in the design. The limitation of the behavioral model is the inabililty to easily simulate arbitrary frequencies – which is inconvenient for testing outside the measured space. The alternative and more common approach is to use a compact or equation based nonlinear device model such as that of the IconicRf GaNFET model. Our optimal design flow employs both options in parallel, allowing the accuracy of the behavioral model with the additional flexibility of the compact model. The compact model also enables the necessary stability and tolerance/sensitivity simulations to be carried out. Comparison of the model types and their strengths and weaknesses is given graphically in figure 2.

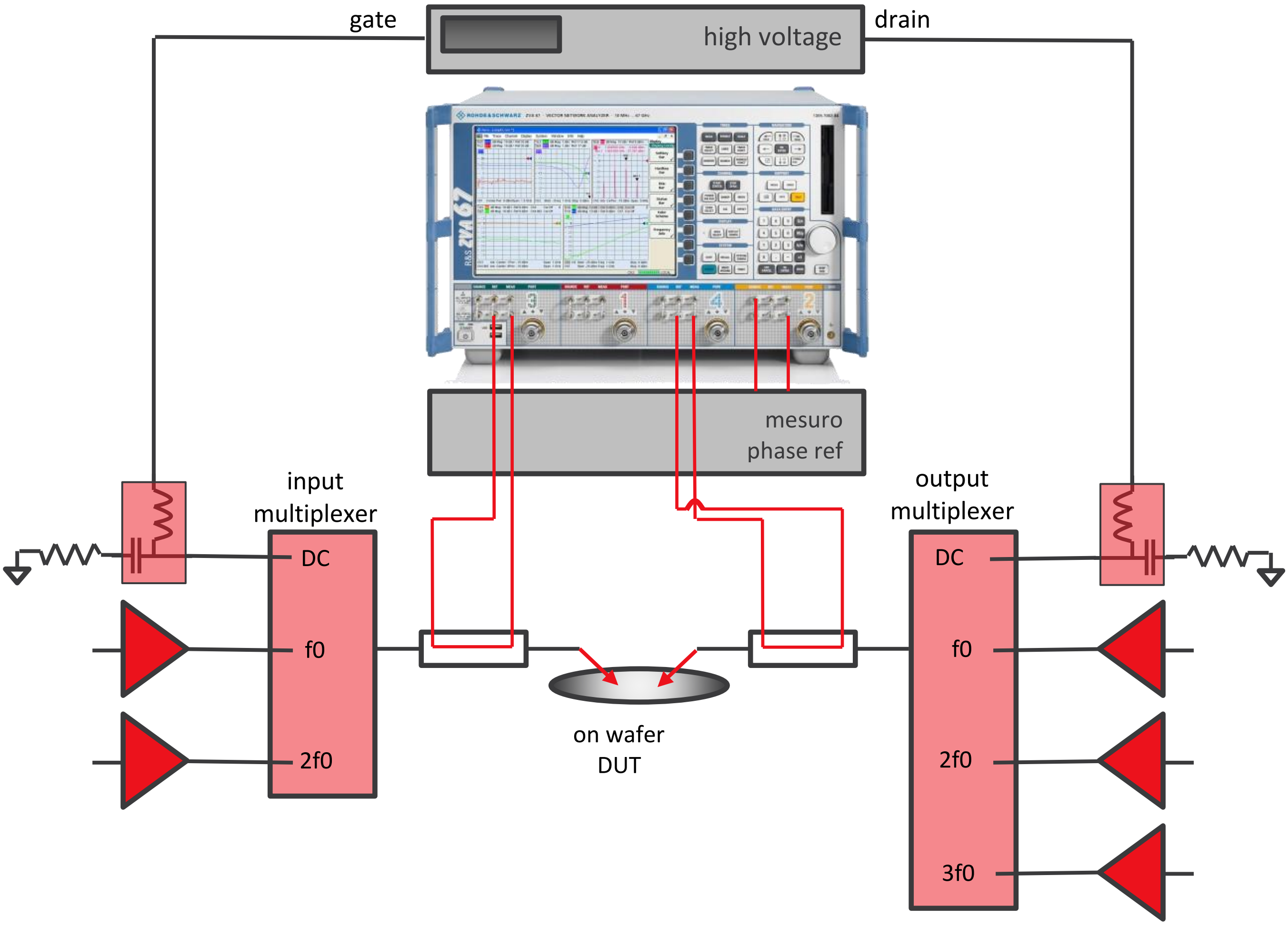

Figure 3 A generalized version of the Focus-Mesuro on wafer active loadpull system used to capture the behavioural model data.

A 5W GAN MMIC HIGH POWER AMPLIFIER FOR 23-30GHZ

Based on the active load pull results, a Cardiff plus behavioural model was generated for an 8x50µm unit cell for use in the 5W MMIC PA design. This design of the 3 stage 5W PA, which was optimised for fundamental efficiency performance and targeted 18dB gain with 37dBm peak Pout. The design uses low pass transmission lines and shunt MIM caps to implement the matching circuits. The 26GHz PA is shown in figure 4 and has a size of 2.8 x1.75mm illustrating the compact form factor for a MMIC exhibiting this power level performance at 26GHz. It is estimated that a comparable performance GaAs design would utilise at least a factor of two in area. The fabricated MMIC measured on wafer achieved a Psat of 37dBm across 24-29GHz and power added efficiency over 35% across the 23-26GHz band as shown in figure 5, along with a typical gain of 18dB. 6dB Back off PAE was measured at between 18 and 25%; a state of the industry result.

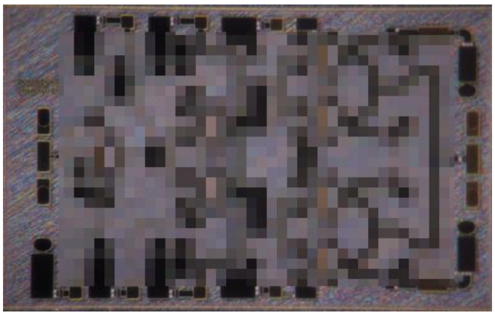

Figure 4. The ICP2637 5Watt 23-30GHZ GaN MMIC HPA, Size: 2.8x1.75mm

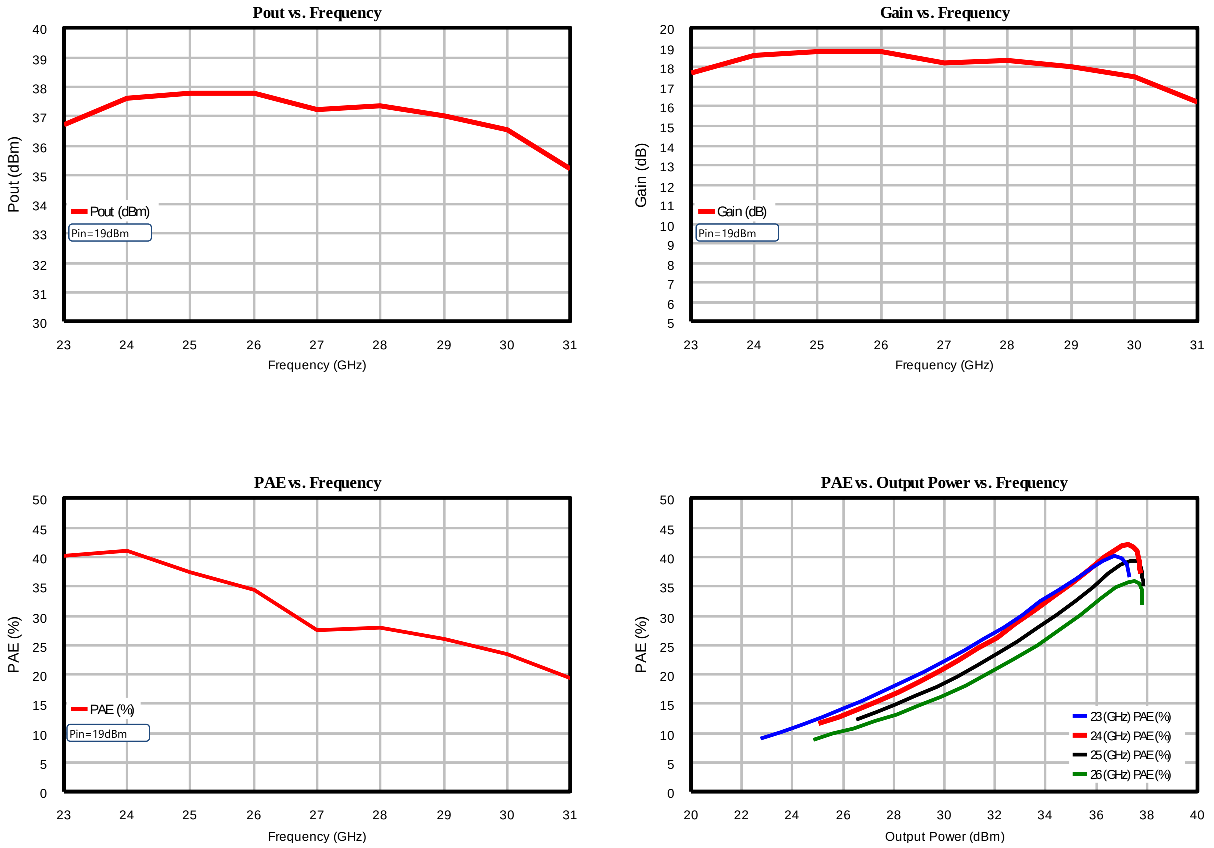

Figure 5. Measured Psat, Gain and PAE Performance of the ICP2637 5Watt 23-30GHZ GaN MMIC HPA

CONCLUSIONS

Both a Cardiff plus model and in house compact model was used in the design flow to generate a high efficiency 5W MMIC PA design at 22-29GHz on 0.15µm GaN on SiC technology. The measured rsuslts are in line or above current industry performance verifying the dual model design approach. Further GaN on SiC MMIC HPA designs at 28GHz and 20GHz are in development.

[1] Focus Micorwaves Inc, App note , ‘Behavioral Modeling, Cardiff Model the intuitve advanced behavioral model’