182W L Band GaN High Power Module With 66% Power Added Efficiency Based On European Technologies

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Abstract

This paper deals with the design, manufacture and test of a high efficiency power amplifier for L-band space borne applications. The circuit operates with a single 36 mm gate periphery GaN HEMT power die allowing both improved integration and performance as compared with standard HPA design in a similar RF power range. A huge effort, dedicated to the packaging environment as well as the device's characterization and modelling, has eased the circuit optimization. Test results demonstrate performance up to 182 W RF output power with an associated 66 % PAE under 50 V supply voltage using a single GaN power bar.

INTRODUCTION

Most of the budget constraints driving the design of space borne microwave equipments focus on the power amplifier stage : DC power consumption, thermal management, mass and volume. Although demonstrating very large RF power capability, the TWTA solution [1-3] suffers from needing large volume and heaviness in the L/S frequency band. In contrast, the SSPA approach offers advantages of better integration and cost efficiency. In this context, the advent of Wide Band Gap technology, providing transistors with ten times higher power density compared to Gallium Arsenide devices, makes this second option increasingly meaningful [4-5]. Yet this breakthrough comes with new challenges such as the component reliability and proper thermal management in a harsh environment. The optimization of the package environment enables mitigation of the thermal stress hence reliability challenge. This paper demonstrates the essential steps towards the successful test of a breadboard paving the way for future space borne power equipments.

TECHNOLOGY AND COMPONENT OVERVIEW

HEMT devices of 0.5 µm gate length including via-holes were developed with the GH50_10 commercially qualified process from the European foundry UMS (United Monolithic Semiconductors), using an AlGaN/GaN heterostructure epitaxy on a SiC semi insulating substrate. A source-terminated field plate is implemented in order to reduce the electric field and to improve the reliability. Main DC target characteristics are 250 mS/mm trans-conductance, 425mA/mm saturated drain current, -2.5 V pinch-off voltage and more than 200 V drain to source breakdown voltage. In addition, a special effort on the optimization of the gate metallization has allowed to reducing the leakage gate current to less than -200 µA/mm.

The key idea of the design is to reach the targeted RF power up to 180 W with minimum combination losses and optimum PAE. Hence a single die approach. With a 36 mm total gate periphery, the device being selected stacks 15 cells, each consisting of 6x400 µm gate fingers. The layout integrating via-holes minimizes the source inductance, thus improves the available RF gain within a 4.95x0.95 mm² compact die.

POWER BAR CHARACTERIZATION AND MODELLING

As the characterization of a thirty RF ports device, being essential as basis for the subsequent modelling, is challenging in particular with regard to potential instability issues and de-embedding, this required the development of a dedicated test vehicle and associated TRL calibration kit as shown in Fig. 1. Several versions depending on the carrier material in use, from basic Copper Tungsten to the novel

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Silver Diamond based composite, have been manufactured so as to assess the impact of the package performance in terms of thermal dissipation, then electrical behaviour.

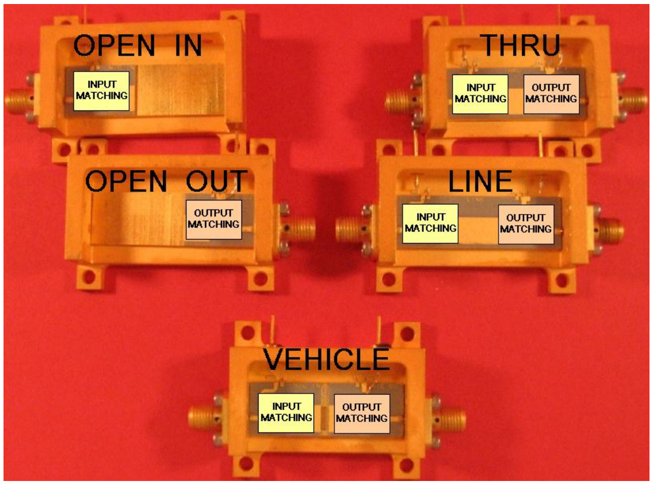

Fig.1 Power bar test vehicle and associated calibration kit

Apart from enabling a convenient bias point and stability margin, the aim of the vehicle's matching circuits is to provide each of all fifteen transistor cells of the power bar with the best Smith chart coverage when operating a multi-harmonic load-pull test in the SMA connector plans. Fig. 2 shows the design approach involving electromagnetic simulation of the micro strip line impedance transformer. While all transistor cells impedances can be reached at fundamental and third harmonics of the 1.3 GHz operating frequency, the second harmonic is mainly located in the vicinity of low impedance area corresponding to the optimum location for the targeted RF power and PAE levels.

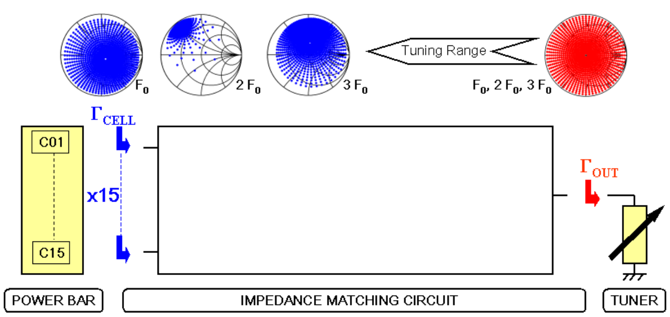

Fig.2 Simulation of the multi-harmonics impedance transformer @ 1.3 GHz

Beside the variation of the electrical performance that can be partly due to manufacturing yields, the load-pull characterization campaign clearly shows the improvement related to the carrier material in use: Silver Diamond based composite with more than 600 W/mK thermal conductivity provides with much better RF performance in addition to the expected diminished junction temperature.

Following the characterization campaign which has proven the UMS GH50 wide band gap technology performance, a full custom electro-thermal model has been developed and optimized, with regard to the reference test results in order to assess both the electrical performance and thermal management. In particular, a dedicated thermal circuit based on ANSYS simulation and modelling of the power bar allows a consistent prediction of the averaged junction temperature over each of the fifteen transistor cells. The test results related to the power bar characterization vehicle have been used to refine the preliminary model built from the basic stacking of the transistor cell representation, thus taking many parasitic and thermal effects into account.

AMPLIFIER DESIGN AND MANUFACTURE

Based on the above detailed device characterization, the quiescent bias point was set to 900 mA for both optimal electrical performance and thermal management, corresponding to $I_{DSS}/17$ under 50 V supply voltage. Thus defined, the optimum multi-harmonic impedance at the power bar gate and drain interfaces was the target for the amplifier design step. The development of input and output matching circuits based on a ceramic substrate with high dielectric constant was used to finding a compact solution at L-band.

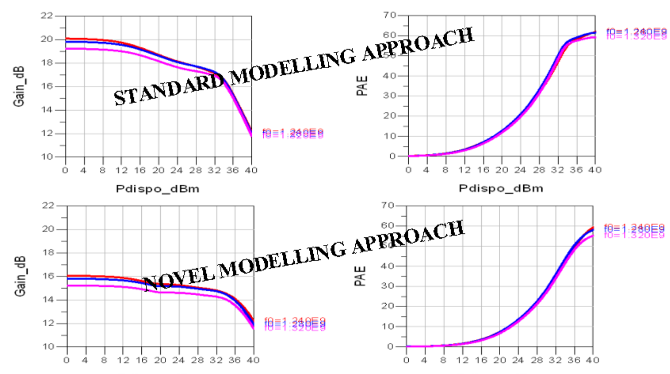

Fig.3 Impact of the power bar modelling approach on the HPA module's simulated performance

The thermal management improvement due to the novel AgCD based package has been clearly simulated thanks to the thermal model with up to 30 °C junction temperature decrease as compared with basic CuW material (Fig. 4). Also the temperature gradient across the 4 mm height power bar has been significantly diminished, which shall be of high benefit with regard to the device 's stability behaviour and efficiency. This constitutes a determinant breakthrough towards the case temperature's reachable range of operation for the HPA module, but also the GaN component's reliability margin.

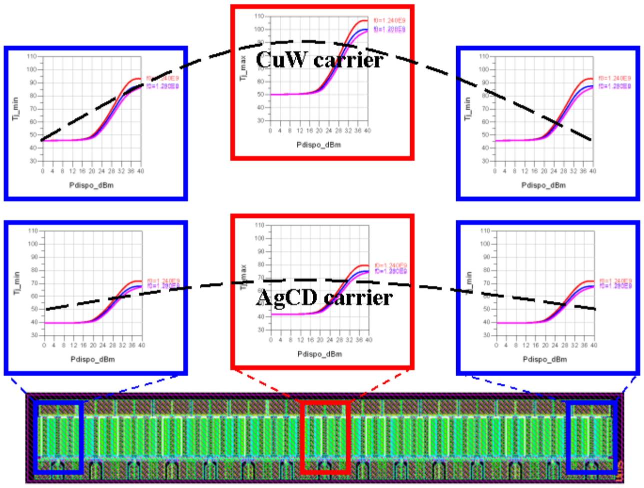

Fig.4 HPA design - simulated thermal management performance

AMPLIFIER TEST RESULTS WITH STANDARD CUW PACKAGE

A dedicated test bench has been built for relevant small and large signal measurement with a mastered thermal environment insuring proper heat sink at the breadboard backside interface. The measurement requires the consistent sizing of the output attenuator in terms of power handling capability and attenuation range for proper protection of the output detector.

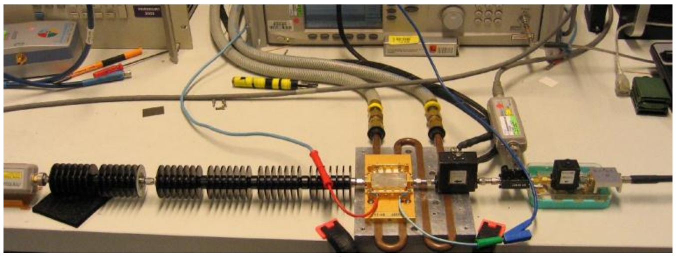
Fig.5 HPA module test bench for electrical characterization

The demonstrator test campaign has first focused on the measurement and analysis of Copper Tungsten package based modules. The CW mode test results at 1.3 Ghz (Fig. 6) confirm the circuit's remarkable prediction capability when moving from the simple transistor cell stacking configuration, being too much optimistic, to the global power bar modelling approach.

The amplifier exhibits more than 125 W CW mode output power with 55 % minimum PAE for less than 3.9 dB compression over 120 MHz frequency bandwidth. A maximum of 60 % PAE associated to 140 W RF power has been reached at 1.25 GHz.

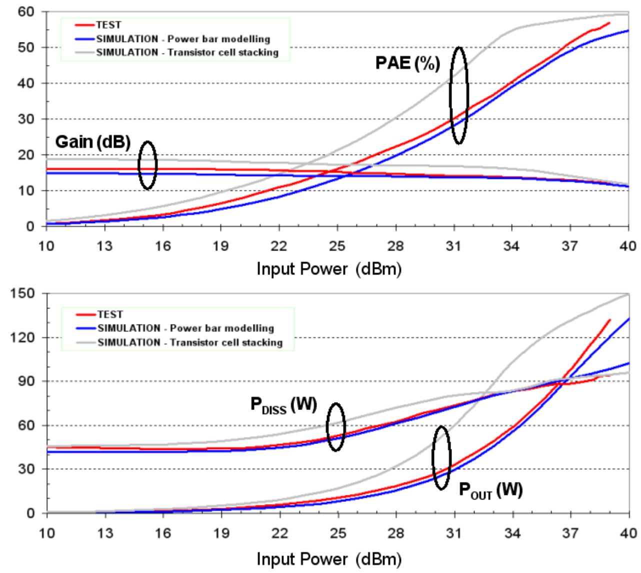

Fig.6 CW mode large signal performance at 1.3 GHz

IMPROVED RESULTS WITH NOVEL AGCD PACKAGE

In the frame of AGAPAC project, a novel package solution including the use of AgCD material for the base plate, enhancing the dissipation power capability, has been developed for L-band applications with preserved footprint for easier integration within the existing equipments. This solution also includes resized DC feedthroughs for bias current level handling (up to 30 A) and RF feedthroughs for convenient multipactor margin management (validation at 700 W RF power).

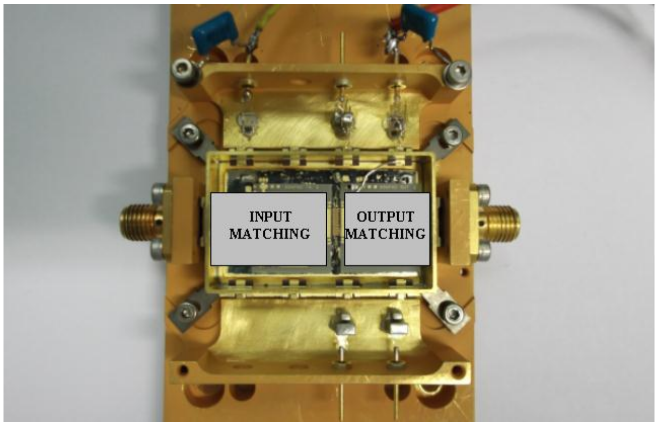

Fig.7 HPA breadboard with novel AGAPAC L-band package

The same amplifier circuit design has been integrated and manufactured within this package (Fig. 7). CW mode large signal performance have been compared through a portfolio of five samples including both CuW and AgCD based packages as shown on Fig. 8. One can underscore two distinct traces depending on the package variable with significant improvement when moving from CuW to AgCD configuration: 3.7 down to 3.4 dB gain compression, 138 up to 182 W RF output power, and 58.7 to 66.4 % associated power added efficiency have been obtained at maximum RF power operation.

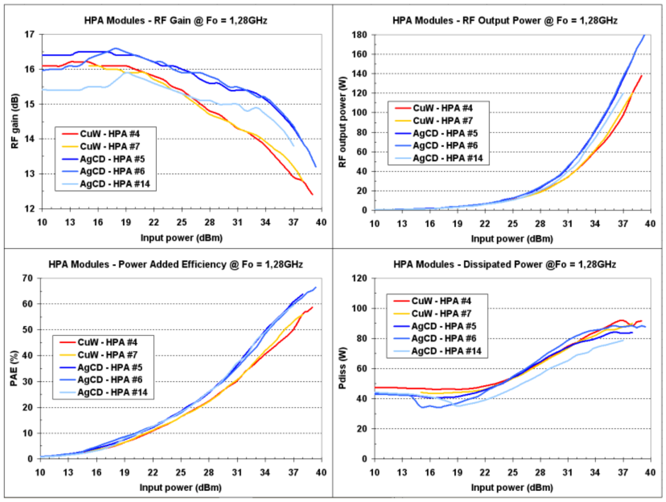

Fig.8 CW mode large signal performance versus package configuration at 1.28 GHz

THERMAL MANAGEMENT ASSESSMENT

Although it does not allow to directly reach the junction temperature parameter, an easy experience using a thermal camera has allowed to quickly provide with a preliminary assessment of the thermal management performance by comparing the measured surface temperature at the centred power bar device for both package configurations. Particular care has been taken to insure the best heat sink at the module's backside interface, thus making comparative assessment valuable at 25 °C reference temperature. The 33 °C drop confirms the benefit of the AGAPAC package.

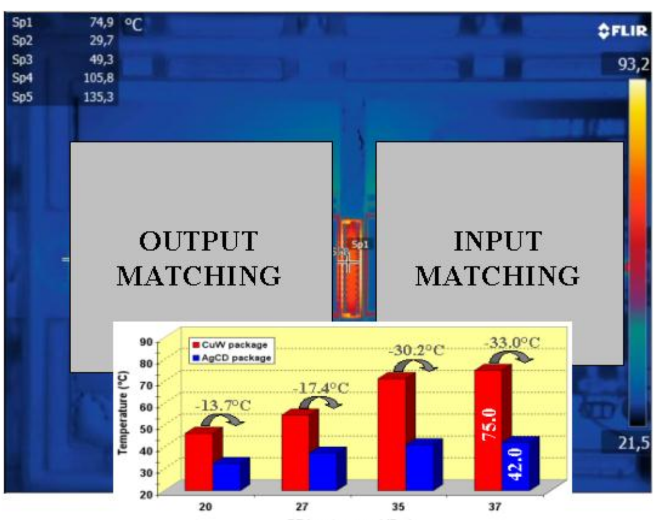

Fig.9 Thermal management performance assessment

CONCLUSIONS

A fully European supply chain has been developed in the frame of AGAPAC project to provide with a space compatible solution for very high power applications at L-band, including the use of very promising wide band gap technology with ten times higher power density capability, with regard to conventional III-V devices, and the design of a customized package. This last is able to cope with much higher constraints in terms of multipactor phenomena and thermal management linked to the power dissipation ability. This solution allows very large GaN components to operate at 5W/mm power density and much improved reliability conditions.

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ACRONYMS

AGAPAC: Advanced GaN Packaging CW: Continuous Wave DC: Direct Current GaN: Gallium Nitride HEMT: High Electron Mobility Transistor HPA: High Power Amplifier PAE: Power Added Efficiency RF: Radio Frequency SSPA: Solid State Power Amplifier TWTA: Traveling Wave Tube Amplifier