GaN Technology in Satellite Communications

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Abstract **- Satellite communications have become a valid alternative to conventional communications, through fiber or copper, in situations of catastrophe or even as complement to improve the quality of the services provided at a worldwide scale. Recently, radio frequency (RF) engineers have worked towards a reliable solution to replace the travelling wave tube amplifiers (TWTA) on board of the satellite payload. Despite the TWTAs reveal a good performance, its weight, size and cost are a serious technical problem to the main satellite manufacturers. However, this scenario tends to change due to the exploitation of the Gallium Nitride (GaN) technology in high power, high efficiency and higher frequency applications. The objective of this work involves an implementation of a power amplifiers (PA) in class B, resorting to a GaN transistors, for the 5.8GHz frequency band which is often used in uplink transmissions for C-band communications.**

The best results achieved till now in this work were 34.1dBm of output power, 62.5% of drain efficiency at saturation and a small-signal gain of 17dB.

Index Terms **– C-Band, Class B, Efficiency, Gallium Nitride Technology, Output Power, Power Amplifier**

I. Introduction and Motivation

THE growth of the demand for services with better quality and robustness, for high density population areas, led to the increasing usage of satellite communications. Consequently, it has been verified that satellites actually carry all kind of data around the world, particularly the recent commercial contents such as High Definition Television (HDTV), digital radio, internet trunking and other broadband mobile services. Satellites are also on the frontiers of such advanced applications as telemedicine, distance learning, Voice over Internet Protocol (VoIP) and Video on Demand (VoD). In addition to that, in military applications, a typical usage of such satellites is the restoration of communication capability in case of disasters: hurricanes, earthquakes or tsunamis, in which all communication means can be severely damaged over a long period of time.

The lower frequency bands are becoming increasingly congested, so in the last couple of years other solutions have been exploited to occupy the upper frequency bands (for example Ka band and above). Ka band is one of the most recent frequency bands that received a huge amount of money for research, because it is necessary to develop a supported technology that is capable to operate at very high frequencies and provide good performance characteristics as power and efficiency in radio frequency (RF) circuits with reduced dimension. New antenna approaches combined with the proper power amplifiers (PAs), can offer the real drive necessary to fulfill the requirements in Ka band. For instance, active multifeed and multibeam antennas can generate the overall output power by active beamforming.

On the other hand, the breakthroughs sensed in software defined radio (SDR) and cognitive radio (CR) promise more efficient and flexible approaches to truly generalized radios front-ends that are able to use whichever communications waveforms. Thus, the research is also centered in the digital processor, the heart of this reconfigurable payload, because it manages the connectivity by configuring the analog front-ends and treats the data by adjusting the frequency operation of the channels. This element allows potentially maximize the payload bandwidth and the power utilization over satellite lifetime. However, the performance of the reconfigurable payloads strictly depends on the performance of the higher power section.

In the space domain, the TWTAs and Klystron amplifiers continue to cover the majority of the amplifying stage onboard of satellites. Until the 70's, all satellites and earth stations dedicated to satellite communications included, in its system architecture, a PA belonging to this category due mainly to the intrinsic capability to handle high power levels combining also high linearity and efficiency required to establish communication links from and to Earth using multicarrier signals. In other words, the TWTAs are components that allow to achieve the claimed performance for this type of communication links, but due to its constant working, they need a high supply voltage (in the range of several thousands of volts) that diminishes their reliability. Furthermore, every solutions based on these technologies are expensive, heavy and bulky, which are aspects not appreciated by the satellite industry.

GaN technologies appear to be a key element for the future of space industry. For instance, due to the high power density of GaN devices, it can be achieved a given power target with much less combining of power amplifiers. Thus, the satellite communication systems will have advantages of compact size, low mass and low cost, suitable for low-cost small satellites where the physical size, mass, power consumption and cost pose serious restrictions.

The GaN importance to the future of space applications has been recognized and so several European projects have been initialized as the "GaN Reliability Enhancement and Technology Transfer Initiative" (GREAT) from European Space Agency (ESA) and "AlGaN and InAlN based microwave components" (AL-IN-WON). The main objective of these projects was to accomplish intensive tests to GaN technology in order to attempt the production of elements

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capable of exploiting properly all the potential of the higher frequency bands.

II. Work Objectives

This work had as the core objective the design and implementation of a highly-efficient and highly-linear MMIC power amplifier based on GaN technology that operates at the Ka-band (more specifically, centered around 30GHz) and it was inserted in the scope of a European-funded project entitled "**GaN** powered Ka-band high-efficiency multi-beam transceivers for **SAT**ellites" (GaNSAT), wherein the core partners are Evoleo Technologies (Portugal), EFACEC (Portugal), Airbus D&S (France), Ferdinand Braun Institute (Germany), Mier Comunicaciones (Spain) and University of Kent (UK). However, due to a couple of constraints in the project, it was not possible to accomplish this initial task until the end of September 2014 (end of my MSc). So, the initial objectives were adapted to the technical limitations available in the Institute of Telecommunications – Aveiro, being designed and produced a PA for a 5.8GHz frequency band biased in class B with limited harmonic control. The 5.8GHz frequency band is exempt of license in Europe, so it can be used for relevant applications. One of them is related with satellite communications and corresponds to uplink transmissions for C-band.

III. Implementation Details

The active device acquired was a TGF2023-02-01, a discrete 1.25mm GaN on SiC in die, fabricated in accordance with a process named TQGaN25 exclusively from TriQuint and recently recognized as a new milestone reached on GaN reliability and heavily supported for prestigious identities as US Air Force and US Navy. The model for simulation was provided by Modelithics.

The main characteristics of this transistor are a frequency range between DC and 18GHz, high breakdown voltage (100V), a maximum output power of 38dBm@3GHz and a maximum efficiency @P3dB of 72%.

The substrate used for the PAs design was Duroid 6010, highly recommended to high frequency RF applications such as patch antennas, PAs and LNAs integrated in satellite communications systems, aircraft collision avoidance systems and ground radar warning systems because of its high dielectric constant for circuit size reduction (ε_r = 10.3), tight and thickness control of the electric constant for repeatable circuit performance and lower losses until the X-band frequencies ($\tan\delta$ =0.0023).

IV. Significant Obtained Results

S-parameters, continuous wave (CW), 2-tone and modulated signals were performed to evaluate the performance of the implemented PA (Fig.2).

S-parameters revealed the maximum transduction gain at 5.55GHz being close to 17dB. The small-signal gain measured is lower than the predicted in the simulations.

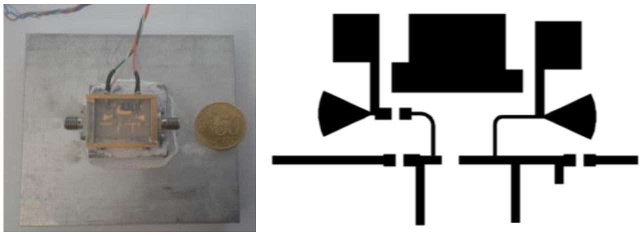

Fig. 1. Power amplifier implementation (left) and circuit layout (right).

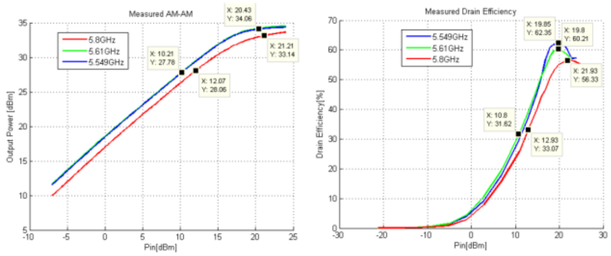

Fig. 2. Illustrative measured results of the implemented GaN PA.

CW tests showed that PA can provide an output power of 34.1dBm (2.55W) and 62.5% of drain efficiency at saturation. Again, these values are a bit lower than the ones obtained in the simulations. Moreover, the AM-PM curve was measured and pointed to a highly linear PA until reach the saturation region.

Two-tone measurements allowed to quantify the effect of the third order distortion component on the input signal and infer about the PA linearity through the IMR calculation.

Finally, modulated signals were used to assess the phase error inserted by the PA when it is necessary to amplify signals of high PAPR, such as QAM and OFDM.

V. Conclusions

The great motivation for this work comes from the crescent maturation and exploitation of the GaN technology which have been sensed during the last decade to high power, high efficiency and upper frequency bands scenarios.

The differences verified between simulations and measurements can be explained based on a couple of reasons, namely: 1) The technical limitations from the production process inserts important inaccuracies such as the size of the bondwires cannot be controlled neither equally replicated because they are handmade. 2) Confirmation by the results that the transistor model provided cannot reproduce correctly the real behavior of the used transistor.

VI. Next Career Plans

I would like to deeply thank this opportunity provided by the MTT-Society because this award was extremely stimulating to finish my master degree work in RF field and an important contribution for my success as engineer.

In addition, this award can also have a great impact if other paths are decided in the future, like if I want proceed to a PhD degree.