X-band wideband 5W GaN MMIC power amplifier with large-signal gain equalization

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***Abstract*—We present a wideband GaN MMIC power amplifier, designed to be the unit cell of a balanced module. A wideband output matching network, based on a two-section transformer, is adopted to compensate for reactive effects over the entire bandwidth. A reactive network is inserted at the input for gain equalization at compression; the resulting input reflectance will be controlled by the balanced configuration. According to simulations the MMIC shows, in the 7-14 GHz band, power gain ranging from 6.8 to 8 dB, output power always > 5 W, drain efficiency between 43% and 59% at power saturation. Preliminary measurements on the first run have comparable gain and slightly lower output power on a narrower bandwdith; the output efficiency goal is, however, achieved only on the lower part of the bandwidth. A second-run redesign is in progress.**

***Index Terms*—Gallium nitride, MMICs, power amplifiers, wideband, X-band**

I. Introduction

The GaN on SiC HEMT MMIC technology is undergoing an impressive development, both in the quality of the active devices, and the accuracy and repeteability of the passive structures. High power density provides advantages in terms of circuit size, and therefore reduced reactive effects, for similar power levels, with respect to other technologies [1]. These features can be very helpful for flexible front-ends, especially for the development of broadband circuits and subsystems. This is an emerging trend in the wireless range from 1 to 4 GHz [2] (e.g. digital television broadcasting, mobile communications), or in X-band (e.g. point-to-point wireless backhaul, radar applications) [3]. Multi-octave GaN-based MMIC power amplifiers (PAs) have been already realized with distributed architectures [1], [3], [4]. While this approach is able to provide exceptionally wideband amplifiers, it relies on rather complex structure, requires large chip sizes, and gives low efficiency levels. To achieve bandwidth of the order of one octave, PA design strategies typically rely on balanced topologies yielding good gain equalization, together with low return loss in the whole bandwidth.

In the present work, a wideband GaN MMIC class AB power module for the 7 to 14 GHz band, with gain higher than 7 dB, and 5 W output power is developed. Since the final goal is the realization of a balanced hybrid power amplifier, the input mismatch is used for gain equalization, while the output broadband matching is designed to optimize efficiency and power performances on the whole band. The inherently high return loss obtained will be controlled by the balanced topology. Output matching is based on output power matching, accounting for the drain-source and drain-gate device capacitances, it is realized with a two-section transformer to compensate reactive effects over the entire bandwidth. The input matching network is optimized for gain equalization at compression. The proposed stage demonstrates the effectiveness of the design method, showing satisfactory results in terms of power, gain and efficiency over the entire X-band. The complete balanced amplifier design will be addressed according to the characterization results on the single stage prototype.

II. Design strategy

To evaluate the load seen by the device intrinsic current generator, the simplified equivalent circuit of Fig. 1 is adopted [5]. C_{OUT} is the equivalent capacitance across the voltage controlled current source, and includes the effects of both C_{DS} and C_{GD}. Z_{INT} represents the intrinsic load seen by the active device current source, while Z_{E} is the corresponding impedance at the external device plane. Z_{INT} is firstly chosen

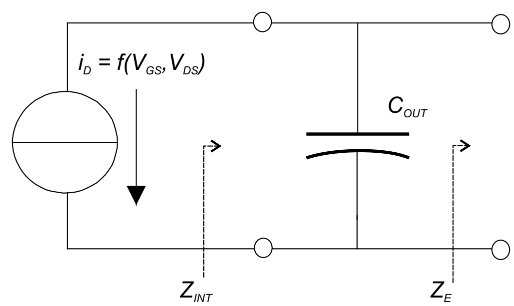

Fig. 1: Simplified output equivalent circuit of the active device.

to optimize the power behavior, i.e. to ensure the simultaneous voltage and current swing across the intrinsic drain current generator, then Z_{E} is derived deembedding the contribution of C_{OUT} on the frequency band of interest. In the whole band, the output matching network has to transform the external $50\,\Omega$ load to Z_{E}. We met this target in two steps: a two-section impedance transformer moves the impedance between real values, maintaining a broadband behaviour, while a short length transmission line adjusts the imaginary part required by Z_{E} (see Fig. 2). The reactive input network is designed to compensate the gain reduction *vs.* frequency of the active

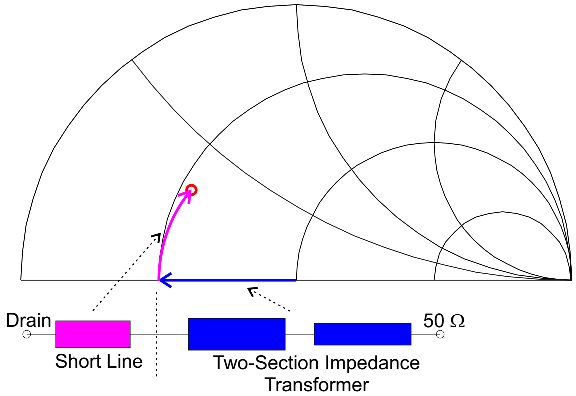

Fig. 2: Matching network design strategy, at center frequency.

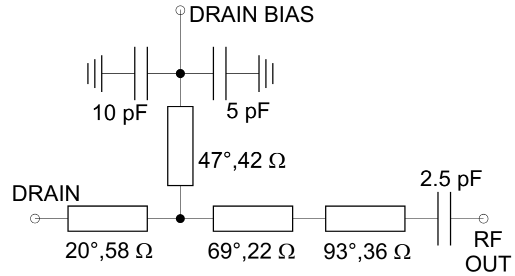

Fig. 4: Schematic of output matching network. Line phase lengths refer to center frequency (10.5 GHz).

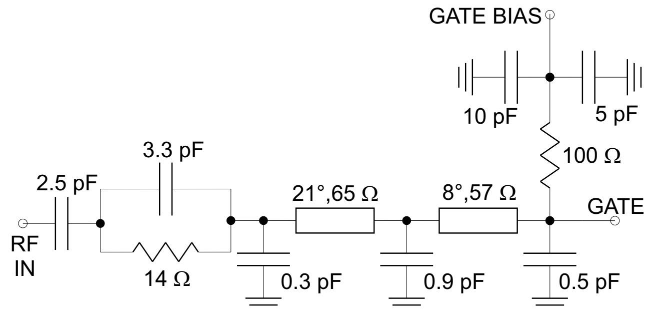

Fig. 5: Schematic of the input matching network. Line phase lengths refer to center frequency (10.5 GHz).

device, an approach that does not allow to keep under control the input VSWR. The adoption of a proper balanced topology, for example using Lange couplers, will provide solution to this issue.

The described design procedure has been applied to a MMIC single-ended power amplifier with octave bandwidth (7-14 GHz), covering the full X-Band, based on the 0.25 μm HEMT AlGaN/GaN on SiC monolithic process provided by Triquint Semiconductor [6]. The selected device has a periphery of 10x100 μm: the bias is 10% I_{DSS} Class AB condition, with 28 V of drain voltage. From analysis on the active device model, for a good trade-off between delivered output power and efficiency, the identified intrinsic optimum load Z_{INT} is around 50 Ω, while $C_{\mathrm{OUT}} = 0.35$ pF. The calculated load impedance Z_{E} is plotted in Fig. 3, and is implemented in a distributed architecture as illustrated in Fig. 4. Input network

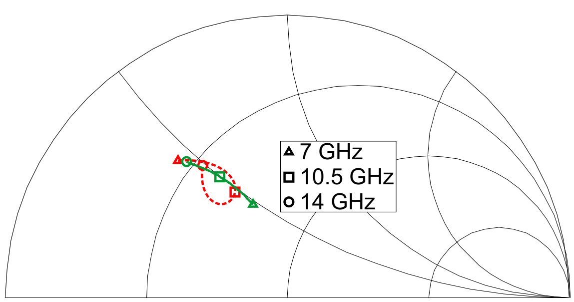

Fig. 3: Optimum load impedance for the adopted device (continuous green line) and synthesized impedance (dashed red line).

and bias tees are optimized through CAD simulation to enforce also the unconditional stability, and are implemented with a semi-lumped two-section impedance transformer, see Fig. 5. A picture of the fabricated MMIC (chip size 1.6x4.6 mm^2) is shown in Fig. 6.

III. Results

Fig. 7 shows the simulated scattering parameters S_{11}, S_{21}, and S_{22} in the frequency range 6-15 GHz, with bias at V_{DS}=28 V, I_{D}=10% I_{DSS}=100 mA: the rather high value of S_{11} is consistent with the design strategy before described, moreover it correctly decreases with frequency since, due to gain reduction, a lower degree of mismatch is required. Fig. 8 shows instead the simulated output power, efficiency and power gain for the frequencies of 7 GHz (lower limit of the band), 10.5 GHz (center frequency), and 14 GHz (upper limit of the band). The provided bias is V_{DS}=28 V, I_{D}=10% I_{DSS}=100 mA. Fig. 9 reports gain, power, and efficiency in compression (input power level of 30.5 dBm), evaluated over the entire bandwidth (7-14 GHz). Over the whole band, the simulated efficiency is always higher than 43% (maximum is 59%), the output power exceeds 5 W, while the transducer gain is higher than 6.8 dB, with a ripple lower than 1.2 dB. A preliminary characterization campaign has been performed on a first tape-out of the MMIC. Fig. 10 reports the measured efficiency, output power and gain at compression. The deviation from expected results (particularly significant for the efficiency) is probably due to a non accurate modelling of the non-linear device over the entire bandwidth. The re-design for a second run is in progress using an updated model.

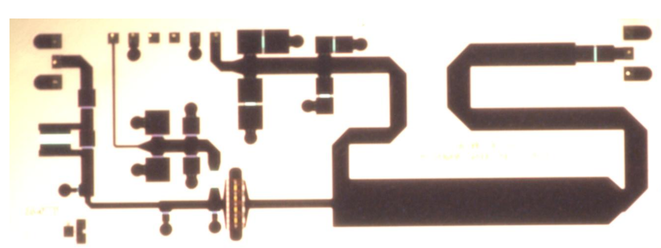

Fig. 6: Microscope picture of the designed MMIC.

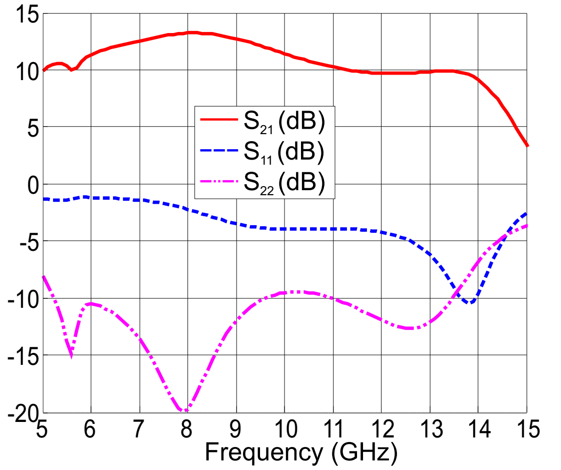

Fig. 7: Simulated scattering parameters S_{11} (blue dashed lines), S_{21} (red solid lines), and S_{22} (magenta dot-dashed lines). Bias V_{DS}=28 V, I_{D}=10% I_{DSS}=100 mA.

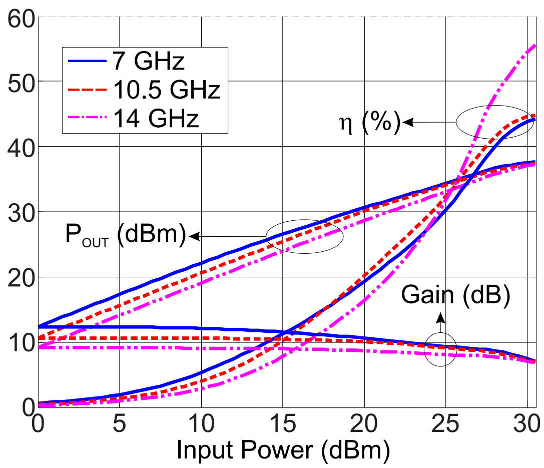

Fig. 8: Simulated output power, efficiency and power gain at 7 GHz (blue solid lines), 10.5 GHz (red dashed lines) and 14 GHz (magenta dot-dashed lines). Bias V_{DS}=28 V, I_{D}=10% I_{DSS}=100 mA.

IV. Conclusions

A MMIC GaN power amplifier designed to operate in the 7-14 GHz band has been presented. Simulated performances show gain from 6.8 to 8 dB, drain efficiency between 43% and 59%, and output power higher than 5 W. The wideband output matching network is based on a two-section transformer to compensate over the entire bandwidth device reactive effects. Input reactive network introduces the required mismatch to equalize the gain that, according to simulations, exhibits, in compression, ripple lower than 1.2 dB in the whole band. A redesign is in progress to correct for deviations arising in the first-run characterization.

Acknowledgment

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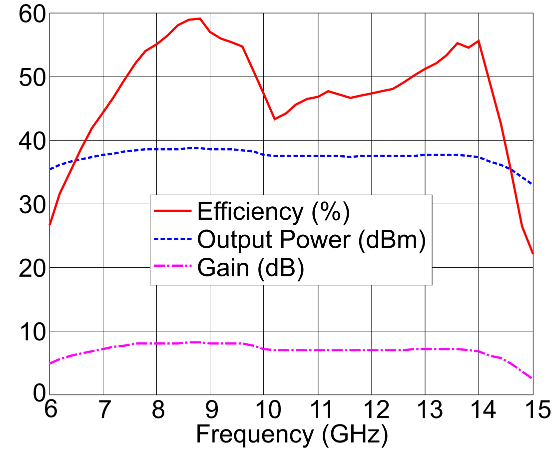

Fig. 9: Single tone amplifier behavior in terms of efficiency (red solid lines), output power (blue dashed lines) and transduced gain (magenta dot-dashed lines) $vs.$ frequency for a constant input power of 30.5 dBm . Bias V_{DS}=28 V, I_{D}=10% I_{DSS}=100 mA.

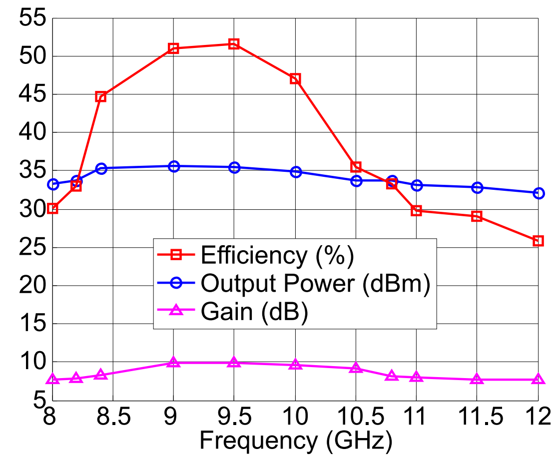

Fig. 10: Single tone amplifier measured behavior in terms of efficiency (red squares), output power (blue circles) and transduced gain (magenta triangles) *vs.* frequency at compression. Bias V_{DS}=28 V, I_{D}=10% I_{DSS}=100 mA.

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