Influence of Envelope impedance termination on RF behaviour of GaN HEMT power devices

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Abstract – **The influence of envelope source and load terminations on the RF performance of high power GaN amplifiers is investigated. An error-corrected two-tone measurement system has been developed enabling load- and source pull measurements in the envelope frequency bandwidth. Measured results on a 0.5µm-HEMT with a gate width of 8x125 µm show a variation of 1 dB output power and 8 % PAE.**

Index terms - **GaN power device, memory effects, source- / load pull**

I. INTRODUCTION

Mobile telecommunication systems of third generation offer extended communication facilities. To establish needed high data rates, digital modulation schemes with non-constant envelope like e.g. QPSK have been implemented. The modulated signals contain high frequency and low frequency (envelope) components, due to intermodulation. Also modulation bandwidth has been extended to enable use of e.g. wideband code division multiple access (WCDMA).
These requirements demand a steady improvement of the RF front-end's performance, providing a combination of high output power, power added efficiency (PAE) and linearity.

Due to applied modulation schemes, when characterising PA transistors and circuits, also low frequency signals have to be investigated to study linearity.

Sevic et al. [6] have proposed an envelope load-pull system, using a combination of a semi-automatic impedance network and a bias tee. Williams et al. [2] have proposed a two-tone time domain measurement system and investigated envelope termination effects on efficiency with a HBT device.

In this paper, an envelope source- and load-pull measurement system is presented, being an extension of an inhouse realised active RF load-/ and source-pull system [1]. It comprises active load modules to avoid extensive use of different electronic signal generators.

To demonstrate the system performance, measurements have been done to study the effect of the envelope terminations on RF behaviour on a GaN HEMT.

II. MEASUREMENT SETUP

A schematic diagram of the measurement setup is shown in Fig.1. Goal of the measurement system is to characterise thermal and electrical memory effects in power transistors and amplifiers.

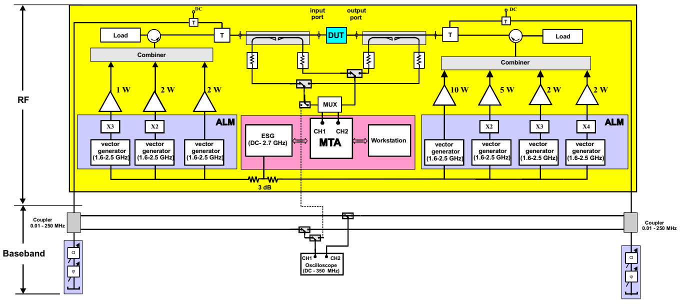

Fig. 1: Schematic diagram of the measurement system.

In the current stage of development, passive envelope load-pull networks are established on input and output side of the transistors. The measurement system concept consists of one signal source, therefore the problem of synchronisation between multiple signal sources is avoided. For controlling harmonic RF source and load reflection coefficients, frequency multipliers are introduced to establish a frequency conversion to the desired harmonic. Via an active load- and source-pull, arbitrary passive and active load configurations can be adjusted. The different signal paths are connected to a combining network. Isolators are introduced to minimise standing waves on the transmission lines. Via bi-directional couplers, impinging and reflected waves are coupled out and fed via a switch multiplexer to the MTA. To establish an envelope source- and load pull, the RF load-pull concept is transferred to the envelope frequency region. A combination of high- and low frequency bias tees is used to separate the low frequency signal from the DC and RF signal. The envelope source-/ and load pull has preliminary been realised with passive components. Couplers are used to feed the signals via a switch multiplexer to an oscilloscope.

Controlling software has been developed for the analysis of the present tones. Power levelling for both tones has been introduced to ensure a constant impinging wave.

III. ENVELOPE LOAD- / SOURCE PULL MEASUREMENTS

Measurements are performed on a 8x125 µm GaN HEMT device provided by the Ferdinand-Braun-Institut für Höchstfrequenztechnik (FBH), Berlin. A bias setting of V_{DS} = 24 V, and V_{GS} = -3.1 V is applied, with a quiescent current of I_D = 90 mA, using a class AB mode. Stimulus is a two-tone signal with tones at 2.1444 and 2.1445 GHz.

In a first measurement series, RF load termination is set to a match to ensure variations of RF behaviour due to a variation of envelope terminations. During the envelope source and load pull, open, match and short terminations are compared. In a second series, the transistor was optimised towards maximum output power resulting in a reflection coefficient of $\Gamma_L = 0.95 \angle 132^\circ$. For this RF setting, envelope load pull measurements were repeated using a higher number of load pull measurement points.

Based on a first measurement series, output power (Fig. 2), power added efficiency (Fig. 3) and the lower intermodulation product of 3rd order (Fig. 4) have been plotted as input power sweep for envelope load pull. With these measurements, the RF load termination was set to 50 ohms. At 10 dBm, input power, the 1 dB compression point is reached, at 16 dBm, the 3 dB compression point is given. Concerning output power, a variation of 0.15 dB at 1 dB compression point and of 0.6 dB at 3dB c.p. could be observed.

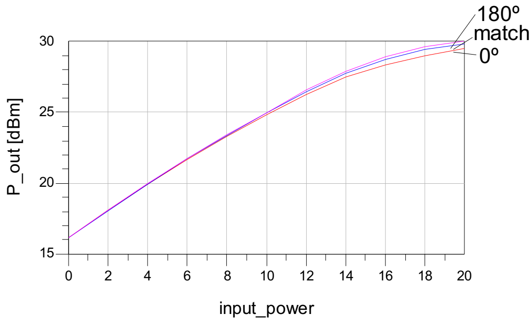

Fig. 2: Output power for envelope load pull at RF load termination of 50 ohms.

In Fig. 3, PAE over input power is depicted, a variation of PAE of 0.6 % resp. 3.7 % could be observed.

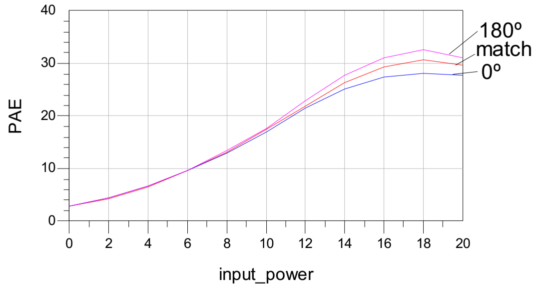

Fig. 3: Power added efficiency for envelope load pull at RF load termination of 50 ohms.

In Fig. 4. the IM 3 lower products are depicted. A variation of 2.4 dB resp. 2.5 dB are visible at 1 and 3 dB compression point.

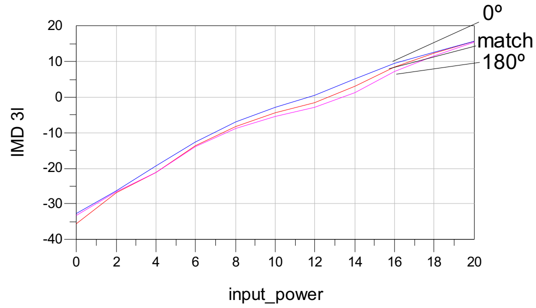

Fig. 4: Intermodulation products of third order for envelope load pull at RF load termination of 50 ohms.

In a second measurement series, an envelope source pull is performed, also with a RF load termination of 50 Ohm. Measurements resulted in a negligible effect on RF behaviour, showing variations of 0.1 dB output power resp. 0.05 dB at 1 and 3 dB compression point (see Fig. 5). Variations in PAE are less than 0.6 % resp. 0.15 % (see Fig. 6). Also variations in the intermodulation products were limited to 0.15 dB resp. 0.3 dB (see Fig. 7).

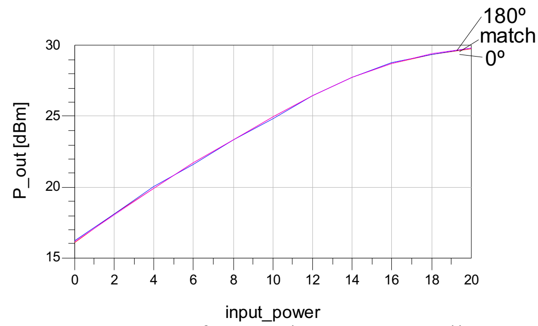

Fig. 5: Output power for envelope source pull at RF load termination of 50 ohms.

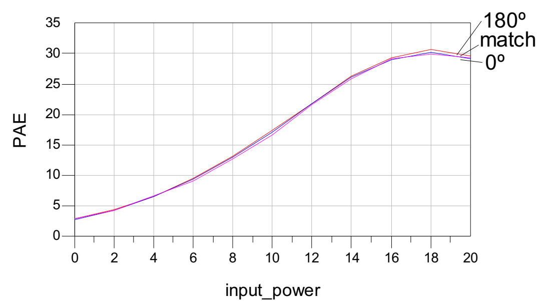

Fig. 6: Power added efficiency for envelope source pull at RF load termination of 50 ohms.

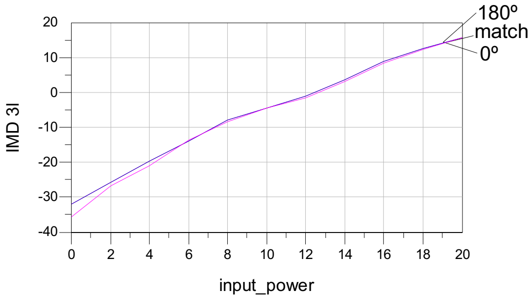

Fig. 7: Intermodulation products of third order for envelope source pull at RF load termination of 50 ohms.

In a third measurement series, the transistor was adjusted to a RF load termination optimised for maximum output power, resulting in a reflection coefficient of 0.95 ∠ 132º. For that setting an envelope load pull was performed. Output power variations of 0.25 dB resp. 0.5 dB at the 1 resp. 3 dB compression point occurring at 6dBm resp. 14 dBm input power leading to a maximum variation of 1 dB (see Fig. 8) could be noticed. At an input power of 20 dBm, a maximum variation of 1 dB could be seen.

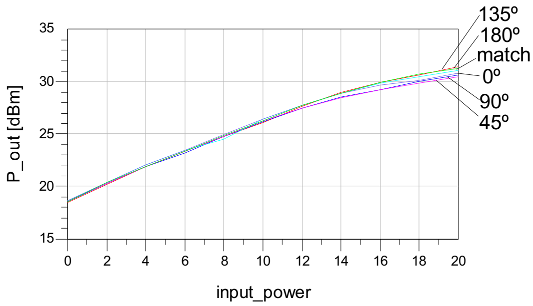

Fig. 8: Output power for envelope load pull at RF load reflection coefficient of 0.95 ∠ 132º.

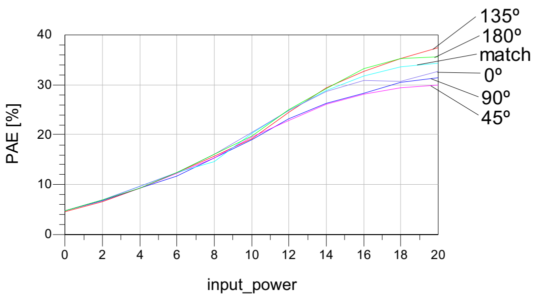

Fig. 9: Power added efficiency for envelope load pull at RF load reflection coefficient of 0.95 ∠ 132º.

Fig. 9 depicts power added efficiency over input power. At 1 dB compression point a variation of 0.8 % is given, leading to 3.1 % at 3 dB compression point towards 8 % maximum at 20 dBm input power.

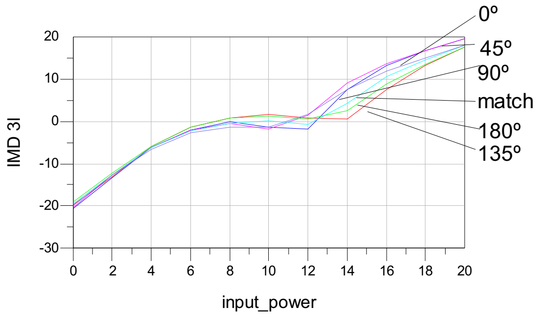

Fig. 10: Intermodulation products of third order for envelope load pull at RF load reflection coefficient of 0.95 ∠ 132º.

Intermodulation products are shown in Fig. 10. In this figure, reaching of a sweet spot is visible in between the 1 db and the 3 dB compression point. This effect is also described in [3]. Variations of 1.2 dB resp. 8.3 dB were measured.

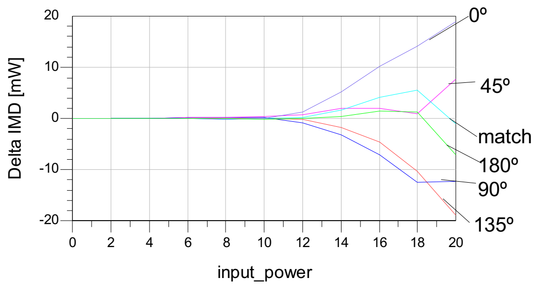

Fig. 11: Measured asymmetry between IMD3- lower and IMD3- upper for envelope load pull at RF load reflection coefficient of 0.95 ∠ 132º.

As further measurement, the asymmetry between the lower and upper intermodulation products of third order are shown in Fig. 11, indicating a critical drive level of approximately 10 dBm input power. The asymmetry of the intermodulation products is caused by vector summation of 2nd order non-linearity [5]. With a short termination, the asymmetry is kept at a minimum.

IV. CONCLUSION

Envelope source- and load pull measurements have been performed on a GaN 8x125 µm HEMT. While envelope source pull resulted in negligible effects on RF behaviour, envelope load pull resulted in a variation of RF output power of 1 dB and in a variation of PAE of 8 %. To the knowledge of the authors, this is the first time, that envelope source- and load pull measurements on GaN HEMTS have been reported.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the support from German Ministry of Education and Research (BMBF), and from the Information Society Technologies Programme of the EU under contract IST-1-507893-NOE "Top Amplifier Research Groups in a European Team (TARGET)". The authors also thank Dr. Würfl, FBH for delivering GaN HEMTs.

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