Linearisation of high power amplifier with optimised zone 0 terminations

B. Bunz, A.Z. Markos, A. Ahmed and G. Kompa

University of Kassel, Fachgebiet Hochfrequenztechnik
Wilhelmshöher Allee 73, D-34121 Kassel, Germany, Tel: +49-561-804-6535, Fax: -6529
E-mail: bunz@hfm.e-technik.uni-kassel.de, http://www.uni-kassel.de/fb16/hft/bunz.html

Abstract – This paper presents an investigation of optimum zone 0 source and load terminations for high power amplifiers. Measurements with an error-corrected two-tone measurement system have been performed to determine optimised terminations, which are then implemented into the matching networks via an optimised bias circuitry. Measurements with a 4 W Filtronic GaAs HEMT resulted in a 1.2 dB variation of the output power and 10 dB the IMD 3 products by 10 dB.

Index terms - power transistors, memory effects, source- / load pull, amplifier

I. INTRODUCTION

GaAs offers a mature technology towards high linear power amplifier applications. To establish high data transfer rates, high modulation bandwidths as well as complex modulation schemes using non-constant envelope (e.g. QPSK) have been established.

When driven under two-tone and multi-tone stimulus, terminations in different zones influence the RF behaviour [1-4]. The frequency conversions for a two-tone stimulus are demonstrated in fig. 1.

![Fig. 1: Frequency conversions in a transistor for a two-tone stimulus.](image)

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 (zone 0) 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. The zone 0 terminations have been realised with passive terminations.

The results of the measurements are then implemented in an high power amplifier design.

II. MEASUREMENT SETUP

A schematic diagram of the measurement setup is shown in fig. 2.

![Fig. 2: Schematic diagram of the measurement system.](image)

The measurement system concept consists of one signal source to avoid problems with synchronisation between multiple signal sources. 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 fed via combining networks and isolators to the DUT. Via bi-directional couplers, impinging and reflected waves are coupled out and fed via a 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 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

For an investigation of the envelope impedance terminations, first on a GaAs pHEMT (Filtronic FPD 400 AF), two tone measurements were performed. Fundamental center frequency was 900 MHz with a tone.
spacing of 100 kHz. While zone 0 source pull resulted in negligible RF variations, only zone 0 load pull results are presented. In figure 3, the output power of the lower main tone is displayed. While a maximum of output power with an envelope short termination is given, a minimum of the output power with an open can be observed. In figure 4 the intermodulation products are displayed. Concerning the intermodulation products of third order, a maximum with an open termination is given, while a minimum is apparent with a short termination. Only one half of the Smith chart is displayed because of the variation of the envelope termination showing an axial symmetry with the $\text{Im} \ \text{Gamma} = 0$ axis [2]. Thus for amplifier design, a broadband envelope termination approximating a short should be designed.

![Fig. 3: Lower output tone as function of input power for different envelope load terminations.](image1)

![Fig. 4: Lower third intermodulation product as function of input power for different envelope load terminations.](image2)

**IV. BIAS CIRCUIT DESIGN**

Bias circuits in amplifiers are required to deliver the supply voltages and currents to the DUT and keep them constant without disturbing the RF path. In classical PA design the bias circuit is usually designed to provide high impedances as compared to the impedances of the input/output of the device and the matching circuits. This is to prevent RF power loss, which degrades the efficiency of amplifiers. In this approach the zone 0 terminations are undetermined.

Thus, in the bias circuit, lumped capacitors have been added to realize a low broadband impedance. The length of a $\lambda/4$ line bias network is optimized in such a way that to create a parallel resonance at the design frequency (900MHz) of the amplifier using a shunt capacitor at the drain side of the network as shown in figure 5.

![Fig. 5: Optimized bias network.](image3)

In that way a high electric resistivity is given at the design frequency while maintaining low impedances at envelope frequencies.

**V. HIGH POWER AMPLIFIER DESIGN**

Two realisations of the amplifier were compared to each other. In one realisation a classical bias network design was performed, in a second realisation, an envelope termination of a short was realised (see fig. 6). The measurement results shown in figure 7 and 8 validate the measurement results obtained with zone 0 load-pull. While the variation of output power of the main tones is limited by 1 dB, the intermodulation products of third order could be reduced by more than 10 dB. So the optimization of the bias networks offer one possibility to linearize an amplifier.

![Fig. 6: Realisation of high power amplifier.](image4)

![Fig. 7: Characterisation of amplifier without optimized envelope termination.](image5)

For the optimised amplifier, a single tone characterisation has been performed and resulted at the 1 dB compression point in 34.5 dBm output power and 47 % PAE.
VI. CONCLUSION

A investigation of optimum zone 0 terminations has been performed and a short has been found to result in a maximum C/IMD ratio. The terminations have been realised in a high power class A HEMT-based amplifier design. Two realisations (without, with optimised bias circuit) have been realised and resulted in an improvement of the ratio C/IMD by 10 dB.

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