Accurate Non-linear Large Signal Physics-based Modeling for Ka-band GaN Power Amplifier Design with ASM-HEMT

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Abstract — This paper presents for the first-time a physics-based non-linear large signal model for Ka-band GaN power amplifier design using the new industry standard ASM-HEMT compact model. A novel methodology combining the effectiveness and accuracy of modeling the intrinsic device region with ASM-HEMT, and distributed effects at Ka-band with electromagnetic (EM) simulations is developed. The intrinsic semiconductor region for each finger of the GaN HEMT device is modeled with ASM-HEMT, and in a multi-finger device, the single finger model is coupled with EM simulations capturing distributed effects accurately. The developed non-linear model shows excellent accuracy with measured non-linear data for a commercial GaN-HEMT device, and with measurements performed on a Ka-band MMIC power amplifier.

Keywords — Compact models, GaN HEMTs, Power Amplifiers, ASM-HEMT

I. INTRODUCTION

Non-linear high-frequency modeling of GaN HEMTs is a very active area of research due to the appealing properties of the GaN-based material system. In order to exploit the optimal performance from GaN-based devices it is essential for accurate, robust, and scalable high-frequency non-linear models to be developed. Recently, physics-based GaN compact models [1] have emerged as an attractive alternative to the typical empirical modeling approaches due to both their insightful and powerful capabilities. Amongst the physics-based models is the ASM-HEMT [2] compact model which has been recently selected as an industry standard compact model for GaN. ASM-HEMT models the intrinsic GaN HEMT device operation with surface-potential-based formulations. The physical formulations of the model accurately captures the GaN HEMT device electrostatics, charge transport in the channel, non-linear access region resistance, and other effects within the device. Accurate non-linear large signal model results for several GaN HEMTs with ASM-HEMT for frequencies up to 5 GHz have been shown. However, large-signal Ka-band physics-based model have not been presented. The latest works on Ka-band large-signal models are [3], [4] which use empirical formulations. In this paper, a physics-based large signal model for GaN HEMTs at Ka-band is presented for the first time.

At Ka-band distributed effects due to device layout become important. A novel methodology to model intrinsic region of each finger of a multi-finger device with ASM-HEMT, and connecting all fingers with EM simulations is presented. Excellent agreement between model simulations with small- and large-signal measurements at Ka-band are shown. A Ka-band power amplifier (PA) is designed with the device, and is measured. Excellent model agreement with the PA measurements are also shown.

II. MODEL DEVELOPMENT

At mm-wave frequencies, traditional equivalent lumped element networks begin to lose their validity. This is attributed to their inability to account for intrinsically distributed phenomena, such as, the propagation of signals along the gate and drain metallization as well as coupling effects. In a multi-finger device there exists a significant degree of phase difference between the RF gate voltage standing wave at the input of the gate manifold. As the manifold feeds each gate finger of the device, the node of the standing wave is seen to be situated at the inner-most gate fingers, while the anti-node is located at the outer edge gate fingers. Hence, the RF gate voltage is different at each gate finger. Furthermore, the distributed properties of the metallization demand to be accounted for as they have a direct impact on the device performance [5]. To this end, 3D electromagnetic (EM) simulations with carefully configured ports can be utilized in order to characterize all of the device metallization, and in turn, account for the unwanted parasitic effects through means of the resultant S-matrix. As the ASM-HEMT model is an intrinsic GaN HEMT model which includes access region parasitic...
elements, it is deemed possible that the ASM-HEMT model can be embedded into the EM S-matrix such that the source and drain terminals of the model are in direct correlation to the delta-gaps between the source and drain device metallization. This allows for a more elegant and efficient modelling solution as there are no requirements for approximate de-embedding procedures. However, it is important to note that with the notion of embedding the ASM-HEMT model into the S-matrix, there exists an importance as to the placement of the TML ports in the EM simulation. Any discrepancies between the TML port placement and the calibration reference plane of the measured data will result in frequency dispersion effects. The ASM-HEMT model can then be embedded into the passive EM structure where the model is a direct replacement for the intrinsic gate region of the device. A schematic is shown in Fig. 1. The number of gate fingers within the device corresponds to the number of ASM-HEMT models to be linked to the EM structure. In order to allow for an efficient modelling process, the models are placed as sub-circuits into the schematic in order to allow for the tuning of a singular ASM-HEMT parameter set.

Each single finger ASM-HEMT model, share the same model parameters. A commercial GaN HEMT with four fingers, and 100 µm single finger width is modeled with efficient model extraction routine presented in [2], [6]. The high-field effects from [7] have been also accounted for in the model. First, an accurate I-V model for the pulsed I-V measured data is shown in Fig. 2. Next, multi-bias small-signal behavior of the device is modeled. The model extraction discussed in [2] is used with proposed model structure. Accurate multi-bias S-parameter results were obtained. Here due to space limitations we only show the key figure of merit maximum available gain ($G_{\text{MAX}}$) in Fig. 3 to serve as small-signal validation of the extracted model. The model is tuned for accuracy corresponding to the bias points of interest for the intended application of a Ka-band MMIC PA.

Large signal simulations were performed and compared against measured data of the device. The bias point of interest is $V_d = 20$ V, and a quiescent drain current ($I_d$) of 30 mA/mm. Fig. 5 depicts a comparison of the measured and modeled large signal device behavior for several load conditions. The proposed model is shown to capture device behavior accurately for both output power and power added efficiency at 10 GHz. This large signal model is used to validate model performance under tuned conditions at 29 GHz. Owing to the physical model structure, excellent accuracy for tuned large signal model behavior at 29 GHz is observed, as shown in Fig. 6.

A three stage GaN-on-SiC CW Ka-band power amplifier with 18 dB power gain, 30% PAE and more than 6 W saturated output power was used in order to validate the developed model for the end application. The power amplifier board, supplied by Altum RF [8], is shown in Fig. 4. The PA was measured for small- and large-signal behavior. The proposed model is compared with the measured PA performance and an excellent model agreement for both small- and large-signal behavior is observed as shown in Fig. 7 and Fig. 8.
Fig. 5. Measured and modeled large signal model at several load points for (a) PAE versus output power and (b) Gain versus output power.

Fig. 6. Comparison of the measured device data and extracted ASM-HEMT model output power, $P_{\text{OUT}}$, power added efficiency, PAE and gain at 29 GHz.

Fig. 7. Comparison of the measured 3 stage Ka-band GaN MMIC PA performance with the ASM-HEMT model for small-signal gain (dB $S(2,1)$) and input return loss (dB $S(1,1)$).

Fig. 8. Comparison of the measured 3 stage Ka-band GaN MMIC PA performance with the simulations performed with the ASM-HEMT model for output power, gain and PAE versus input power.

**REFERENCES**


