A Ka-Band Class F MMIC Amplifier Design Utilizing Adaptable Knowledge-Based Neural Network Modeling Techniques

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Abstract — **This paper describes the first implementation of an adaptable knowledge-based neural network (AKBNN) model in a high efficiency Class F MMIC (monolithic microwave integrated circuit) amplifier design at Ka-band in a .25um GaAs PHEMT technology. A single-stage amplifier based upon the AKBNN model employed shows comparable results to measured performance of a gain of 7.5dB, a PAE of 35%, and an output power of 17dBm.**

I. Introduction

Highly efficient circuits and components are an integral part of communication systems and are favorable in increasing a system's reliability. MMIC designers often try to optimize a transistor's performance or implement special circuit design techniques (such as a class F configuration) in order to realize high efficiency operation of amplifiers at lower (UHF-VHF) microwave frequencies. However, at extremely high frequencies and even millimeter wave frequencies, it becomes difficult for the MMIC designer to optimize output circuits (tuning harmonics) for high efficiency operation due to delicate and lengthy equipment calibration procedures and complicated and expensive equipment needed. In addition, MMIC designers find that most traditional device models breakdown beyond pinch-off and above 26GHz. Recently, an alternative to traditional modeling approaches is to incorporate neural networks [1-2].

This paper describes the first implementation of an adaptable knowledge-based neural network model in a high efficiency Class F MMIC amplifier design at Ka-Band. The designed is based upon Triquint Texas process for .25um MMW GaAs PHEMTs. An adaptable KBNN modeling technique is used to model both the multi-bias small signal s-parameters over the frequency range of 5GHz-35GHz and large-signal I-V characteristics of a device with a gate periphery of 300um. To verify the model's performance at an operating bias of Vds= 3V and Idss/3, measured device characteristics were compared with model results. In this paper, an overview of the development and implementation of the AKBNN model will be presented. Finally, several single stage amplifier designs were tested and compared with model AC, DC, and harmonic balance simulations (power, compression, and efficiency).

II. AKBNN Model development

COMSARE has developed a new model that combines empirical expressions with neural networks which is better suited for newer device technologies. This model is easier to develop than traditional models and is adaptable to an expansive range of applications. This new model is a hybrid of a traditional FET model and neural network elements. This adaptable neural network FET model has the capability of being dynamically reconfigured by the user such that any element of the traditional FET model can be exchanged for a neural network component. A neural network component is defined by an electrical element such as a resistor, capacitor, or current source whose value is mathematically equated by a neural network. Further information concerning the model can be found in [3]. This paper will only highlight model's performance.

DC and multi-bias small-signal S-parameter measurements (5GHz- 35GHz) were taken on the device in order to determine the quality of the device under test, to determine optimal points for model extraction, and, when no information is available on the device, to determine the needed compliance values stated above. The user specifies bias points that are adaptively selected and S-parameters are measured over a calibrated frequency range. In nonlinear regions of the I-V characteristic (i.e., near the knee, and breakdown and pinch-off) curves, the bias points are densely spaced. The total number of points is determined by the degree of non-linearity of the device and the conditions defined by user. The following information noted below is needed for integration of model parameters in CAD environment.

1. Adaptive measurement of Ig and Id over bias
2. Adaptive measurement of S-parameters over bias and frequency

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3. Extrinsic parameter extraction (Ls, Ld, Lg, Rs, Rd, Rg) through the use of Agilent's IC-CAP extraction software tool.
4. Intrinsic parameter extraction (Cgs, Cgd, Cds, Ri, Rds) through an in-house extraction program.

Once the device characteristics (Igs, Ids, Cgs, Cgd, and Cds) have been obtained, they are trained as a function of bias using an in-house knowledge-based neural network engine. The Cds parameter, however, is not highly bias-dependent therefore in most cases it is held constant. The engine produces a weight file for each trained parameter that is then integrated into an equivalent circuit model instance in Agilent's ADS (Advanced Design System). Figures 1-3 illustrates the model's DC, AC performance for a 300um device biased at drain voltage of 3V and Idss/3.

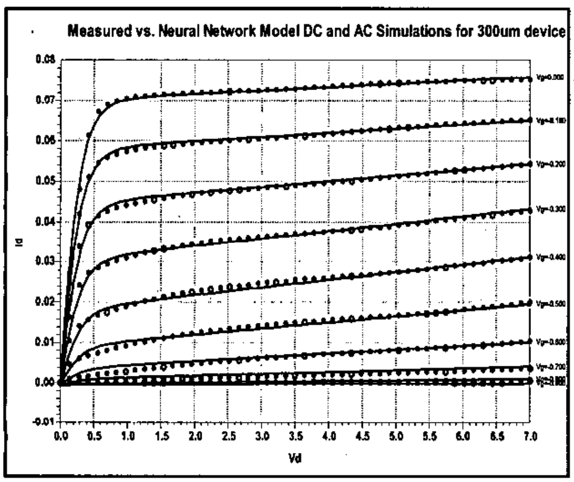

Fig. 1. Measured vs. AKBNN Model I-V Results. Model in symbol, measured in solid.

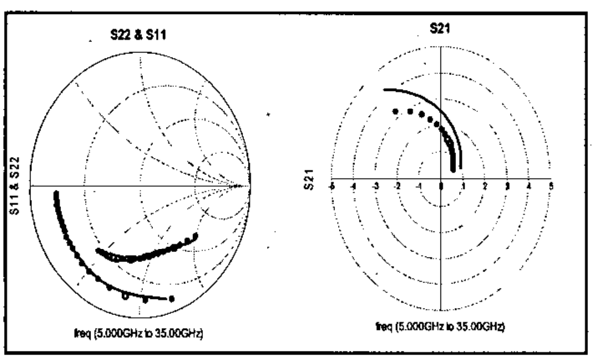

Fig. 2. Measured vs. AKBNN Model S-Parameter Results (S22, S11, S21). Model in symbol, measured in solid.

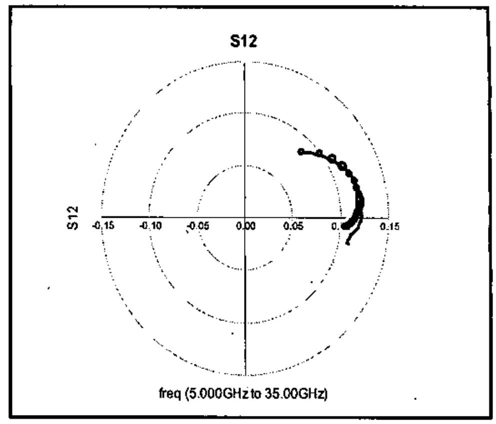

Fig. 3. Measured vs. AKBNN Model S-Parameter Results (S12). Model in symbol, measured in solid.

Modeled power simulations incorporating the AKBNN were compared with measured results (See Figure 4. and Figure 5.) As can be seen in Figures 4.and 5. the AKBNN is able to predict compression, power, gain, and efficiency at 5GHz. This information illustrates the model's capability of predicting comparable power and efficiency performance at microwave frequencies.

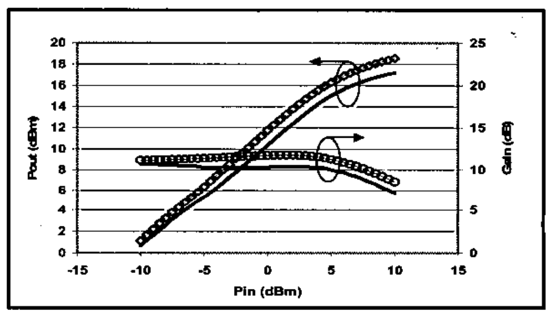

Fig. 4. 5GHz neural network power and gain response vs. measured power and gain responses for a 300um device at a bias Vds=3V.

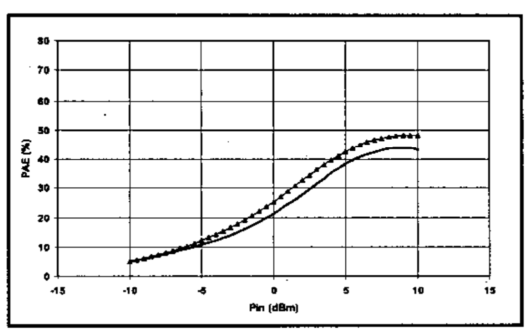

Fig. 5. A look at PAE. Measured vs. ANN model results for the 300um device at a bias Vds=3V. Measured in solid modeled in symbol.

II. CLASS F AMPLIFIER DESIGN

A Ka-band class F amplifier design was implemented in ADS. This work was based on a novel technique that can be employed to realize high efficiency operation of power amplifiers at microwave frequencies. In order to achieve high efficiency performance, the amplifier design incorporates an output circuit that is tuned to pass the fundamental, short (suppress) the second (even) harmonics, and provide an open to the third (odd) harmonics, also known as class F operation [4].

For these designs, the device is biased for class AB operation and the input matching network is designed for maximum power transfer from the source to the device. The output matching network is consistent with conventional class F operation such that the second harmonic is terminated with at short impedance, the third harmonic is terminated with an open impedance, and the fundamental is terminated to achieve highest power. In order to test feasibility of concepts, three single-stage topologies were employed. However, only the topology incorporating Class F impedance matching will be discussed here. The design incorporated a fundamental conjugate input match which included the proper fundamental, 2[nd], and 3[rd] harmonic output matches. To achieve the proper 2[nd] harmonic termination, a $\lambda/8$ open-circuited stub at the fundamental frequency was placed close to the device. To achieve the proper 3[rd] harmonic termination, a $\lambda/12$ open-circuited stub at the fundamental frequency was placed a $\lambda/8$ wavelength away from the first stub. The distance between the second and the third harmonic termination was optimized to achieve the open impedance for the third harmonic at the output of the device. Figure 6. illustrates the layout for the single-stage design for both appropriate second and third harmonic terminations.

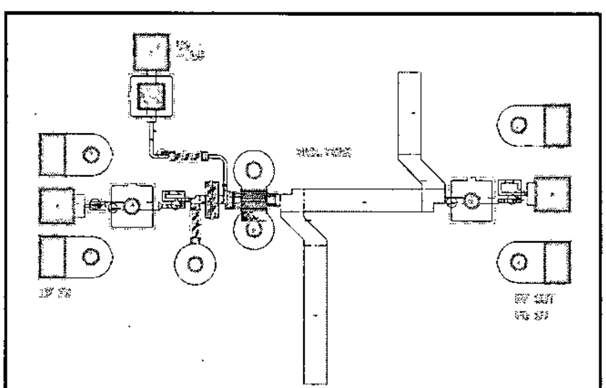

Fig. 6. Layout of single-stage Ka-band amplifier design.

III. CLASS F AMPLIFIER RESULTS

For the small-signal measurements, the designs were tested on-wafer with a drain bias of 3V. The s-parameter data along with the simulated results for class F tuning is shown in Figure 7. The design that incorporates class F tuning exhibits a measured gain of 8.5dB at 25GHz and quickly rolls off to 7.4 dB at 29GHz.

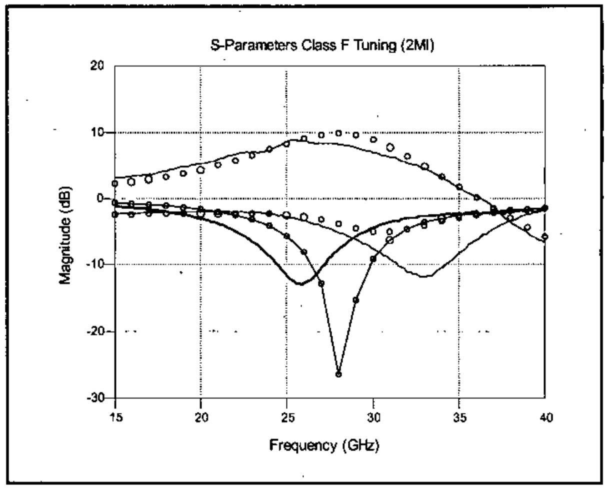

Fig. 7. S-parameter modeled simulations vs. measurements. (o) – KBNN, (solid) – measured. Bias Vds=3V, Ids=50mA

Figures 8 and 9 illustrate the large-signal performance at 29GHz for class F tuning. The large-signal parameters are measured at a bias of Vds= 3V and Ids = 42mA where the highest measured PAE = 35.2% with a corresponding output power, 17.98dBm. Figure 10 shows the simulated response of the current and voltage waveforms at a simulated peak PAE = 30.8% and Pout=18dBm.

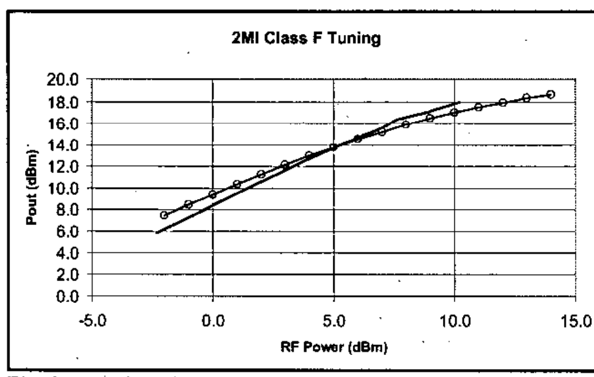

Fig. 8. Pout data. (-o-) – KBNN, (solid) – Measured. Bias Vds=3V, Ids=42mA

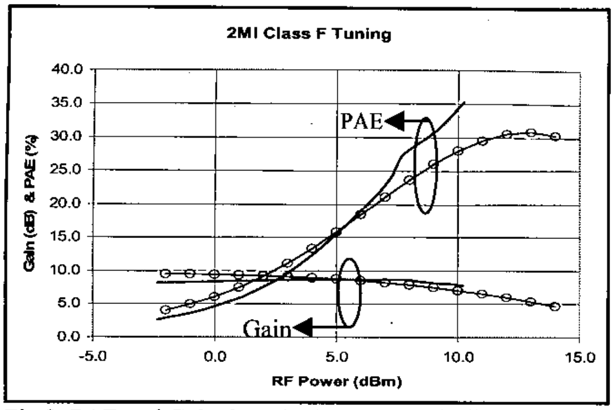

Fig.9. PAE and Gain data. (-o-) – KBNN, (solid) Measured. Bias Vds=3V, Ids=42mA

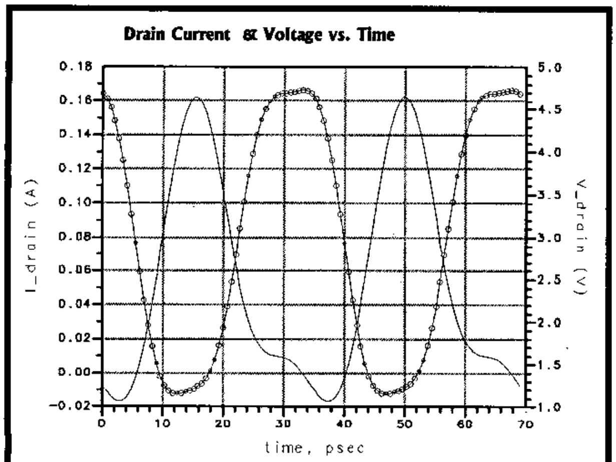

Fig. 10. Simulated drain current and voltage waveforms at simulated peak PAE. (-o-) – voltage, (solid)- current

In Figure 9, peak PAE was not obtained due to insufficient input power drive.

V. Conclusion

This is the first implementation of an Adaptable Knowledge-Based Neural Network (AKBNN) Model into a Class F amplifier at 29GHz. The model's performance shows good agreement with measured small-signal and large-signal parameters. The model is also able to predict class F waveforms for the device's voltage and current characteristics.

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