Effect of FET Model Parameters on Simulation of RF Amplifiers

K. Smith, K. Eccleston

University of Canterbury, Dept. Electrical and Computer Engineering.
Email: kjs66@student.canterbury.ac.nz

Abstract

Accurate FET Model parameters need to be determined to give accurate simulation results for RF amplifiers. The accuracy required varies depending on the application of the final amplifier. For Doherty amplifiers, a high accuracy is required for the transfer characteristic of the amplifier. An amplifier was simulated using a model obtained from data sheet information, and then built. Measurements were taken, and new model parameters were determined, in order to improve the accuracy of the simulation results. The new parameters gave significantly improved results, with only a small discrepancy in the amplifier transfer characteristics at high power levels.

Keywords: FET model, RF amplifier, Doherty amplifier

1 Introduction

The Doherty technique [1] is a method used to improve the efficiency of a RF amplifier. It uses two amplifiers, connected with quarter-wave transmission lines, as shown in Figure 1. Its ideal, theoretical efficiency characteristic has two peaks - one at maximum input power, the other at 6dB back-off (see Figure 2). At low power levels (before the first efficiency peak), only the main amplifier is operating. After that point, the peaking amplifier turns-on. In practice, the peak at 6dB back-off doesn't occur, in part due to the soft turn-on behavior of the transistor in the peaking amplifier [2].

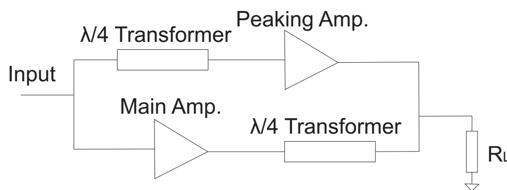

Figure 1: The classical Doherty architecture

Theoretical investigations have shown that the transfer characteristic of the transistors have a major effect on the output characteristics of a Doherty amplifier, as well as the transfer characteristics of its amplifiers. This is especially true for the peaking amplifier at the turn-on point. As such, it is highly desirable to find a transistor model for simulation that accurately reflects real results, especially at low power levels.

In this paper, the Statz model [3] was used. The transistor transfer characteristic was the main focus of this research, as a transistor's drain-current source is its main non-linearity. Hence, most of the DC parameters were optimised, while only one AC parameter was optimised.

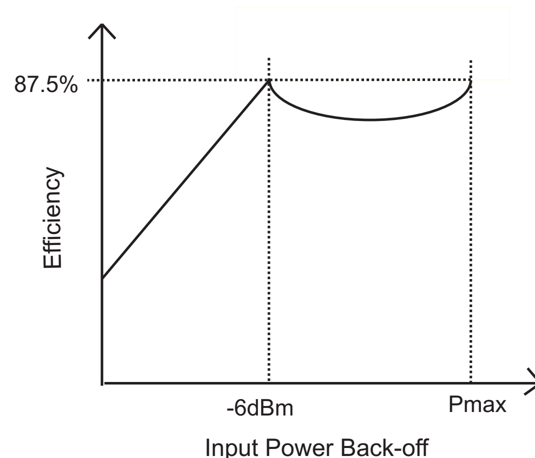

Figure 2: Theoretical efficiency of an ideal Doherty amplifier

A class-A amplifier operating at 770 MHz was designed and simulated. The design simulations used a transistor model whose parameters were based upon transistor data-sheet information [4, 5]. This circuit was constructed and tested of which both RF and DC measurements were obtained. Using these results, a new set of model parameters were developed. The new simulation results were compared to both the original simulation results and the measurements.

2 Simulation Model and Parameters

The Statz model uses the following DC equations:

$$I_d = \frac{\beta(V_{gs} - V_T)^2}{1 + b(V_{gs} - V_T)} \left\{1 - \left(1 - \frac{\alpha V_{ds}}{3}\right)^3\right\} (1 + \lambda V_{ds}) \quad \text{for } 0 < V_{ds} < \frac{3}{\alpha}$$

$$I_d = \frac{\beta(V_{gs} - V_T)^2}{1 + b(V_{gs} - V_T)} (1 + \lambda V_{ds}) \quad \text{for } \frac{3}{\alpha} \geq V_{ds} \qquad (1)$$

β, V_T, b, α, and λ are the parameters of the model, with V_{gs} and V_{ds} being the gate-to-source, and drain-to-source voltages, respectively. The parameter β determines the saturation current, V_T is the turn-on point of the transistor, and b determines the nature of the transfer characteristic. The parameter α affects the size of I-V characteristic's triode region (by moving the knee point), while λ determines the slope of the saturated drain current region is.

The model has a number of other parameters, most of which are of no interest here. However, the parameters for the RF resistance between the drain and source (R_{DS}) and for the breakdown voltage (V_{BR}) do need to be mentioned, as they have a significant effect on the RF transfer characteristics, while having no effect on the I-V transfer characteristic. An increase in R_{DS} brings about a corresponding increase in output power (and hence gain and efficiency). A decrease in V_{BR} increases the curvature of the efficiency characteristic at maximum power.

As a starting point for determining accurate model parameters, a 770MHz class A amplifier circuit was simulated in AWR Microwave Office (MWO), and constructed. The basic circuit layout is shown in Figure 3. A FLK017WF microwave power FET was used. During simulation a Statz model [3] was used to represent the FET of which the parameters were extracted from information in the transistor datasheet [4, 5]. This model has been successfully used in microwave amplifier simulation [4, 6]. 1 shows the model parameters that were fine tuned in this work.

The amplifier was constructed, and tested to confirm that it performed as expected. The test results indicated that while the amplifier gave similar results to those predicted by the simulation, the efficiency and gain were both significantly underestimated, and the transistor transfer characteristic was offset. A picture of the completed amplifier is shown in Figure 4.

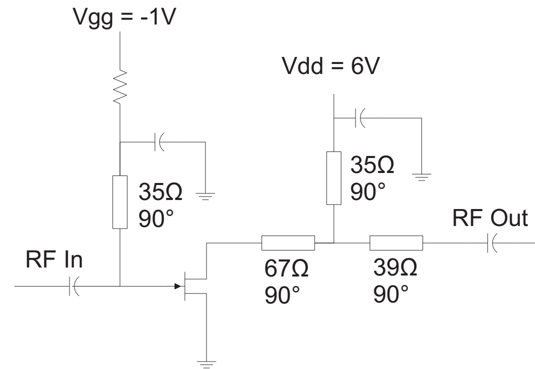

Figure 3: Class A amplifier circuit diagram

Parameter	Original	New 1	New 2
β	0.205	0.045	0.045
V_T	-2	-2.4	-2.4
b	6	0.829	0.829
α	2	2.33	2.33
R_{DS}	400	400	720
V_{BR}	15	15	14.2

Table 1: The DC model parameters used

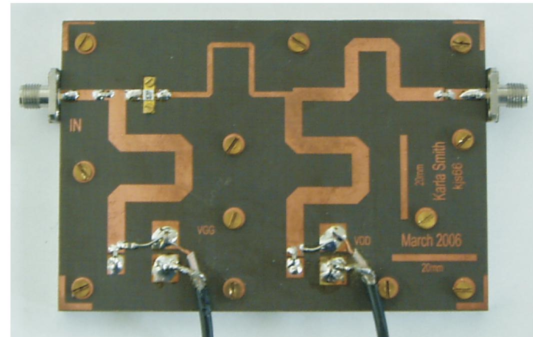

Figure 4: Photo of constructed amplifier

New model parameters were established that more accurately reflected the measured results. It was decided to first optimise the parameters that affect the transistor gate voltage to drain current transfer characteristic, as this was the most important characteristic. To determine the optimum parameters, the measured results for the transfer characteristic were imported into MWO, and β, V_T and b were modified using the tuner function, until the simulation results fit the measurements (see Figure 5).

It can be seen that the new parameters offer an improved match. The parameters were optimised to have a close fit at the turn-on point, as opposed to a close fit higher up the curve, as it is the turn-on of a transistor that is of particular interest when looking at Doherty amplifiers.

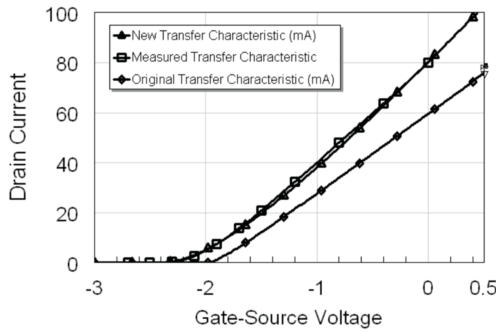

Figure 5: Non-linear gate-drain transfer characteristic of the transistor

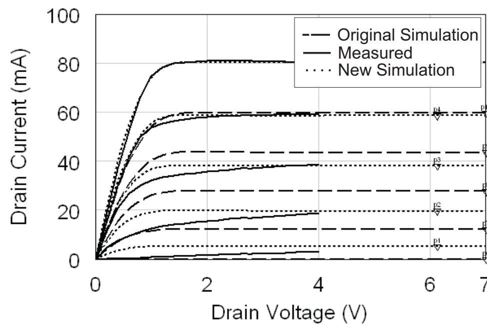

Figure 6: I-V characteristic of the transistor

Once the parameters that effect the transistor transfer characteristic had been determined, α was optimised. This parameter affects the triode region of the I-V characteristic of the transistor, but have no effect on its transfer characteristic. Once more, measured data was imported into MWO, and the tuner function was used to determine the best fit. It can be seen in Figure 6 that the original simulation's knee was slightly too far to the right, while its prediction that the curve would flatten completely is correct.

It was decided to get the best fit on the knee point of the top curve, as this is the one closest to the amplifier's operating region. It is to be noted that changing α does not alter the gate-to-drain transfer characteristic.

3 Results

Figures 7 and 8 compares simulation and measurement of the output power and efficiency versus input power respectively. It can be seen that the model with updated parameters (V_T, β, α and b) offers improved accuracy compared to the original model. It can be seen that the original simulation had an output power that was approximately 3dB lower than the measured results (until the compression point). This had a flow-on effect to the gain and efficiency, meaning they were also significantly underestimated. This is to be expected, as the original transistor transfer characteristic underestimated the drain current. With the new parameters, the output power was approximately 1dB below the measured results, until the compression point. The gain and efficiency were correspondingly increased.

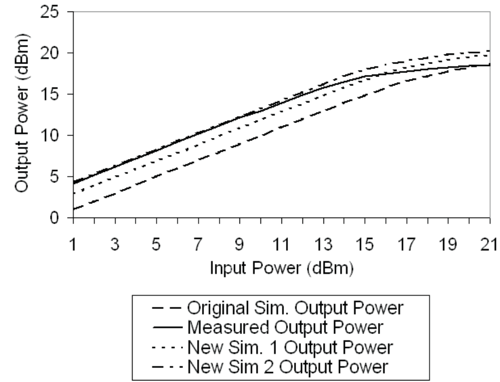

Figure 7: Transistor output power at 770 MHz

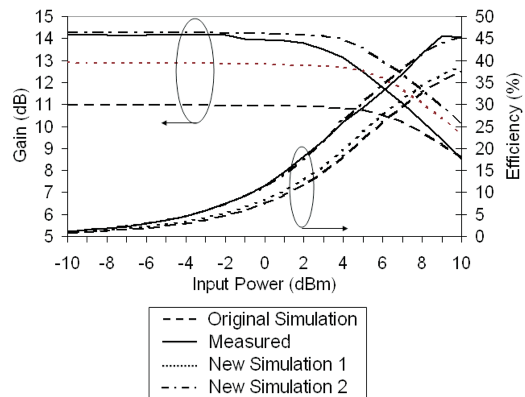

Figure 8: Transistor gain and efficiency at 770 MHz

The output power and gain (at low power) and the efficiency were still significantly underestimated in the new simulation model. To further improve the accuracy of the simulation, the model's drain-source resistance (R_{DS}) was increased, and its break-down voltage (V_{BR}) was decreased. As it is difficult it measure the output conductance and the break-down point directly, these parameters were modified based on the RF measurements.

The gain, efficiency and output power curves all increased as a result of the increase in R_{DS}, giving an improved match to the measured results at low power. Decreasing V_{BR} brought the final efficiency value down to the correct maximum, without modifying the rest of the characteristic, by increasing the curvature of the graph at maximum input power. The final simulation results are shown in Figures 7 and 8 (New Sim. 2).

The gain and output power at high power levels are still overestimated, compared to the measured

values. However, the efficiency characteristic is the most important of the three RF transfer characteristics, and the final simulated result is very close to the measured one.

The parameters for the original simulation, and New Sim. 1 and 2 are given in Table 1.

4 Conclusion

In this work we have shown that RF power amplifier simulation accuracy can be significantly improved by tuning only a few parameters of the transistor model. The DC I-V characteristic was fine-tuned to fit DC measurements. The RF output resistance and breakdown voltage were fine tuned so that the simulated efficiency and output power versus input power fitted the measurements. The ability to fine-tune the model will ensure that the amplifier simulations are sufficiently accurate for investigations of a Doherty amplifier.

References

[1] W. H. Doherty, "A new high efficiency power amplifier for modulated waves," *Proc. of the IRE*, vol. 24, no. 9, pp. 1163–1182, Sept. 1936.

[2] N. Srirattana, A. Raghavan, D. Heo, P. E. Allen, and J. Laskar, "Analysis and design of a high-efficiency multistage Doherty power amplifier for wireless communications," *IEEE Trans. Microwave Theory Tech.*, vol. 53, no. 3, pp. 852–860, Mar. 2005.

[3] H. Statz, P. Newman, I. W. Smith, R. A. Pucel, and H. A. Haus, "GaAs FET device and circuit simulation in SPICE," *IEEE Trans. Electon. Devices*, vol. ED-34, no. 2, pp. 160–169, Feb. 1987.

[4] O. Kyaw, "Balanced single-ended dual-fed distributed power amplifier," Master's thesis, National University of Singapore, 2003.

[5] K. W. Eccleston, "Design considerations for the dual-fed distributed power amplifier," in *Proc. Asia-Pacific Microwave Conf.*, pp. 205–208, 2000.

[6] K. W. Eccleston, "Compact dual-fed distributed power amplifier," *IEEE Trans. Microwave Theory Tech.*, vol. 53, no. 3, pp. 825–831, Mar. 2005.