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OF A HIGH POWER BJT AMPLIFIER

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ABSTRACT

In this paper we present the compression analysis of a BJT high power amplifier circuit. This problem has posed serious difficulties to available CAD programs. The bipolar transistor is modeled by a SPICE model. Extraction of the model parameters was performed by fitting the model responses to published typical S-parameter data. In addition to compression analysis of the amplifier we carried out statistical analysis using Monte Carlo simulation and sensitivity analysis. All simulations and optimizations were performed by our CAD software system OSA90/hope, in particular by our nonlinear harmonic balance simulator.

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SUMMARY

Introduction

The harmonic balance (HB) technique is an efficient method for nonlinear steady-state circuit analysis [1-3]. It has been widely applied to nonlinear analysis and design of microwave circuits such as amplifiers, mixers, frequency doublers [4-7]. However, HB analysis of high power amplifiers may be a challenge to HB solvers [8] since the strong nonlinearity of the circuits may cause problems such as non-convergence. The success of the simulation depends to some extent on the intelligent use of nonlinear HB simulators.

In September 1993, Microwave Engineering Europe (MEE) initiated a nonlinear CAD benchmark to challenge the most advanced HB simulators. The problem was the nonlinear simulation of a high power BJT amplifier.

The amplifier was designed by Jennings and Perry for communication applications around 2 GHz with less than 1 W output power [8]. The amplifier worked well in practice but proved very difficult to simulate using nonlinear HB simulators.

The difficulty came from the characteristics of the transistor. It is a classic power BJT with a poor S_{12} (i.e., the device must be regarded as bilateral), an electrically large package, and an emitter ballast resistor. Therefore, the success of analyzing this circuit depends largely on the accuracy of the model for the transistor.

We used OSA90/hope [9] to investigate the performance of this amplifier. In this paper we present compression analysis of the amplifier. This includes model parameter extraction for the transistor, nonlinear harmonic balance (HB) simulations, statistical analysis and sensitivity analysis.

Circuit Structure and Characteristics [8]

The schematic of the amplifier is shown in Fig. 1. It consists of a power BJT (the Avantek AT64023) and a number of distributed elements. The BJT is biased with a constant collector current (100 mA) and a constant collector emitter voltage (16 V). The distributed elements for input and output matching circuits are realized in microstrip on standard 1.5 mm FR4 board. The amplifier was designed to provide a high power driver to saturate other high power devices being tested under nonlinear operation.

The configuration of the amplifier results in a very narrow band response centered at 2 GHz with the power characteristics having been somewhat sacrificed in favour of good impedance and gain characteristics [8].

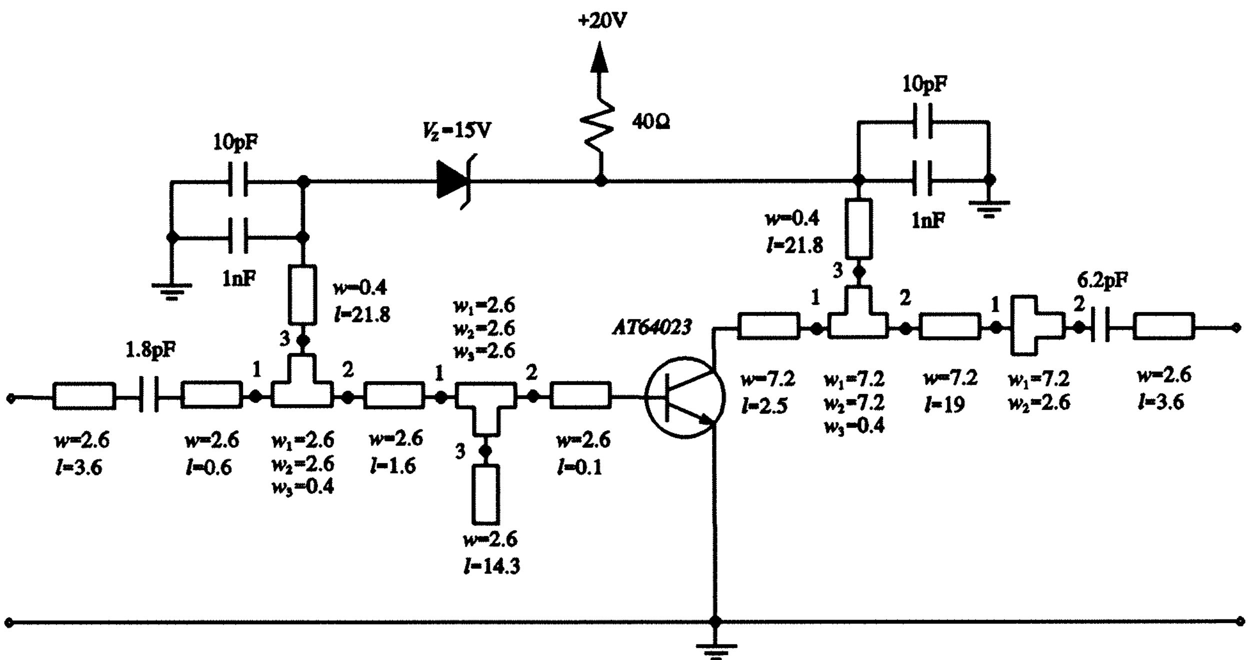

Fig. 1 The power amplifier circuit. Dimensions are in mm. The substrate thickness is 1.5 mm. The relative dielectric constant is 4.75. The metallization is 35 μm thick copper.

Device Modeling for the Bipolar Transistor

The model of the BJT used for simulation is the SPICE Gummel-Poon nonlinear model augmented by a diode circuit to model the distributed base capacitance and resistance and a package model provided by Avantek [10]. OSA90/hope employs unified and seamless modeling, where the small-signal model is derived from the large-signal model. Therefore, our linear and nonlinear models should always agree and our linear and nonlinear HB simulations give consistent small-signal responses.

When the Gummel-Poon model with the parameters specified by Avantek [10] was applied to small-signal simulation, we noticed some discrepancies between the simulated S parameters and the average measured S-parameter data also provided by Avantek [10]. The reason for such discrepancies can be attributed to the still fairly common "disjoint" modeling of small- and large-signal operation of the transistor.

Assuming that the S-parameter measurements are more reliable than the model provided by Avantek we performed model refinement for a better S-parameter fit using the parameter extraction capabilities of OSA90/hope. The only drawback of this procedure is that the data represents the average values and, as a whole, may not form a consistent set of S parameters for any particular transistor.

Fig. 2 shows the match between the measured S parameters and the simulated S parameters using the model provided by Avantek. Fig. 3 shows the much improved match using the optimized model.

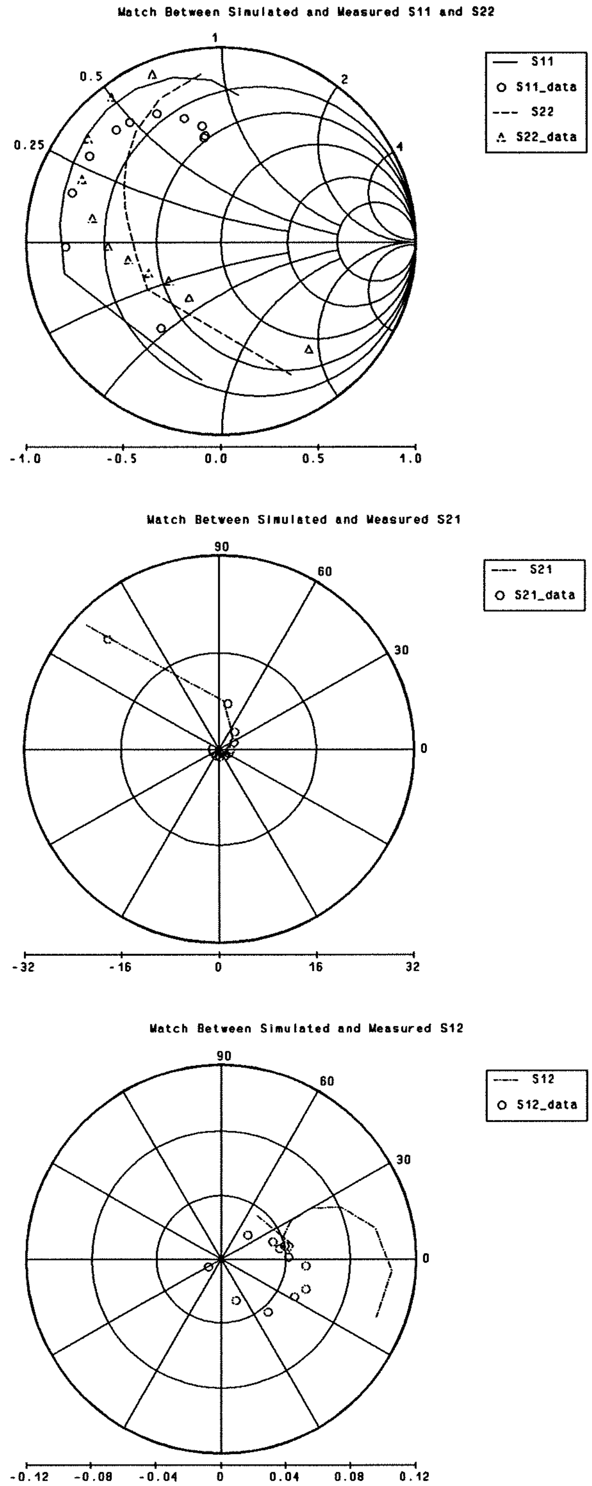

Fig. 2 S-parameter match using the model provided by Avantek. The solid and dashed lines are the simulated S parameters. The o and Δ are the typical (average) S parameters [10].

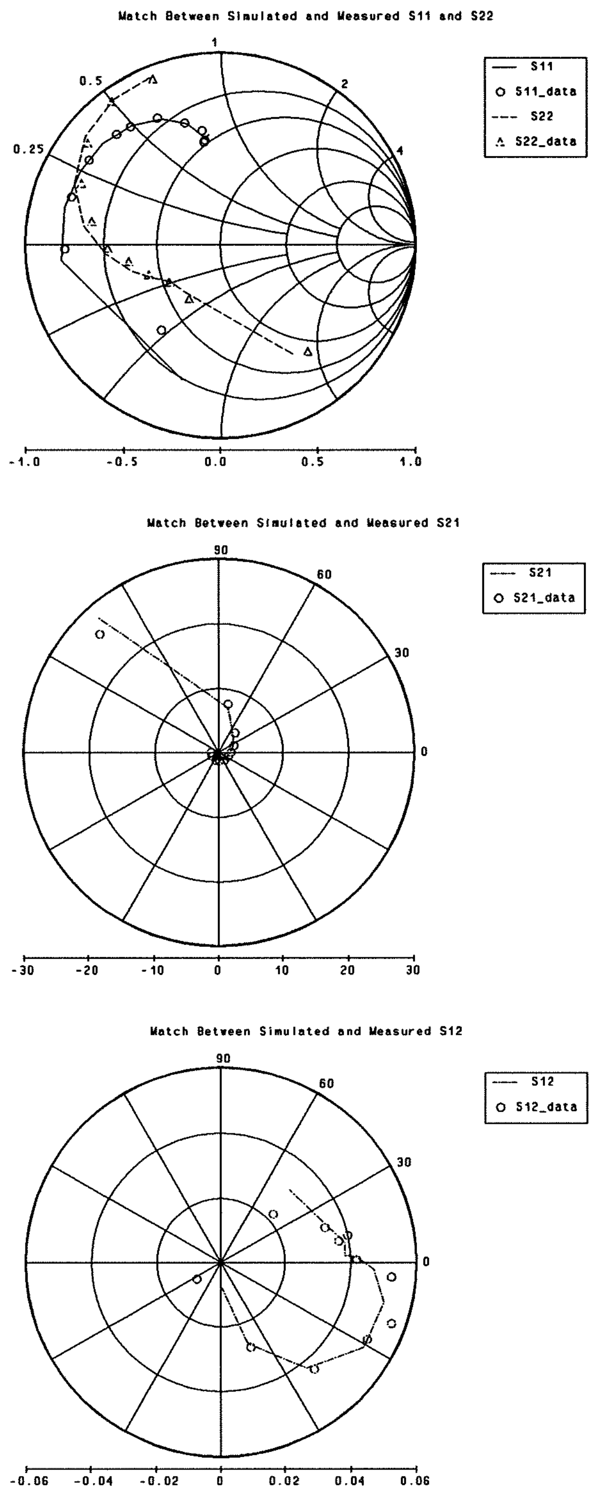

Fig. 3 S-parameter match using the optimized model. The solid and dashed lines are the simulated S parameters. The o and Δ are the typical (average) S parameters [10].

Small- and Large-Signal Simulation

Using OSA90/hope, we performed both small-signal and large-signal HB simulations of the amplifier with the BJT model provided by Avantek and our optimized model extracted from the S-parameter data.

16.3 dB small-signal gain and 26.6 dBm output power at 1 dB gain compression at 2 GHz were obtained using directly the model provided by Avantek. 10.7 dB small-signal gain and 23.4 dBm output power at 1 dB gain compression at 2 GHz were obtained using the optimized model. The measured values are 12.2 dB small-signal gain and 23.0 dBm output power at 1 dB gain compression at 2 GHz [8]. The simulation results using the optimized model are much closer to the measurements. The small-signal gain versus frequency and the output power versus input power of the amplifier are shown in Figs. 4 and 5, respectively.

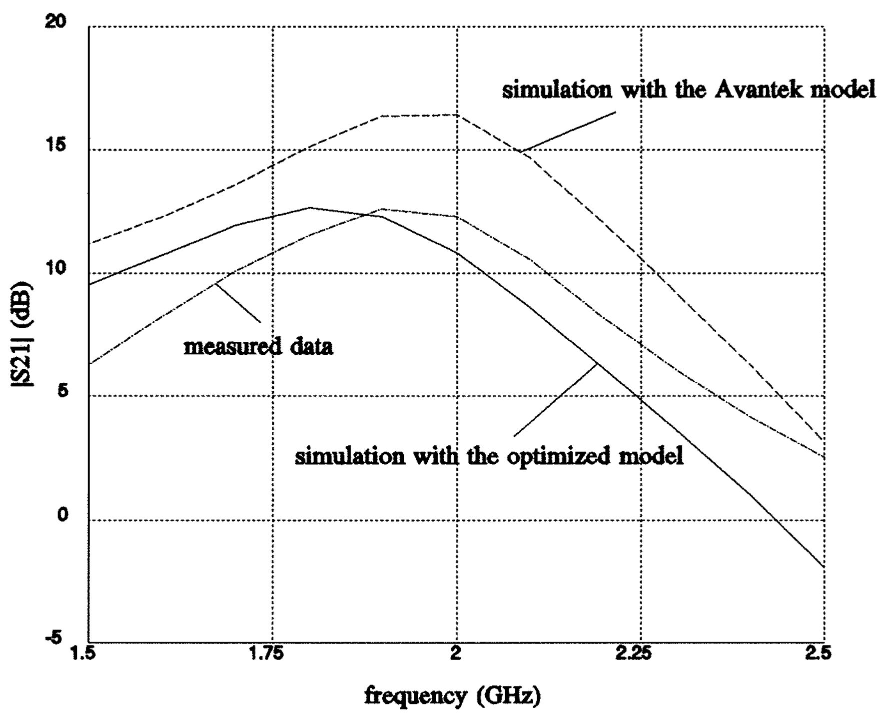

Fig. 4 Small-signal gain versus frequency of the amplifier.

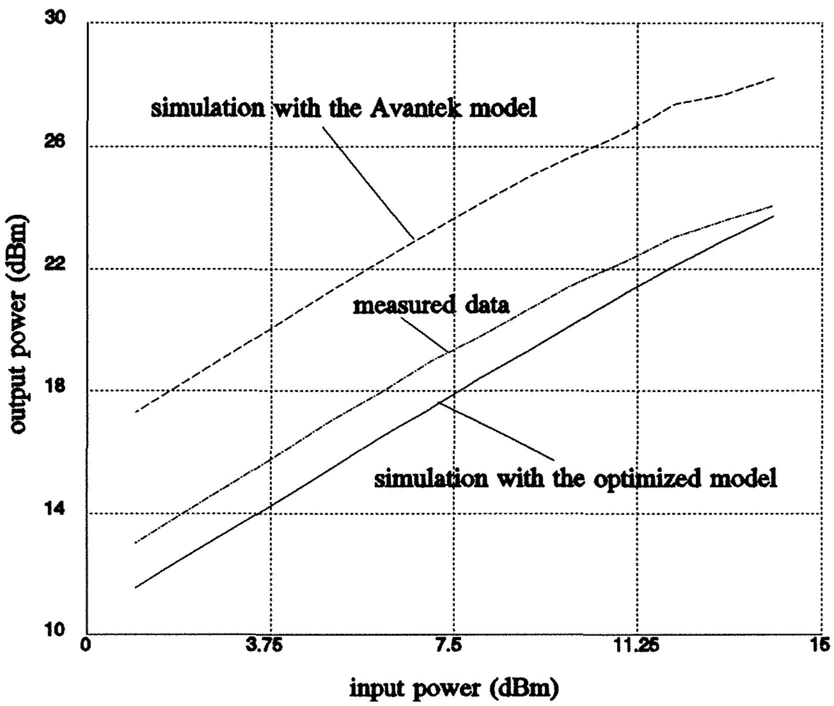

Fig. 5 Output power versus input power of the amplifier.

Statistical Analysis

The differences between the model provided by Avantek and the model obtained from the *S* parameters reveal the uncertainties associated with the device model. For an engineer to be confident with the design, a single simulation based on a single model may not be sufficient.

This motivated us to conduct statistical analysis of the amplifier to investigate the effect of parameter tolerances of the transistor model on the output power. The nominal parameter values were chosen as the average of the values provided by Avantek and the values of the optimized model. Tolerances were assigned to the model parameters according to the differences between the models. Monte Carlo simulation was carried out using 100 outcomes. The output power versus input power at 2 GHz is shown in Fig. 6.

The output power at 1 dB gain compression at 2 GHz are spread between 23.2 dBm and 27.2 dBm. This reflects the model uncertainty and is illustrated by the histogram shown in Fig. 7.

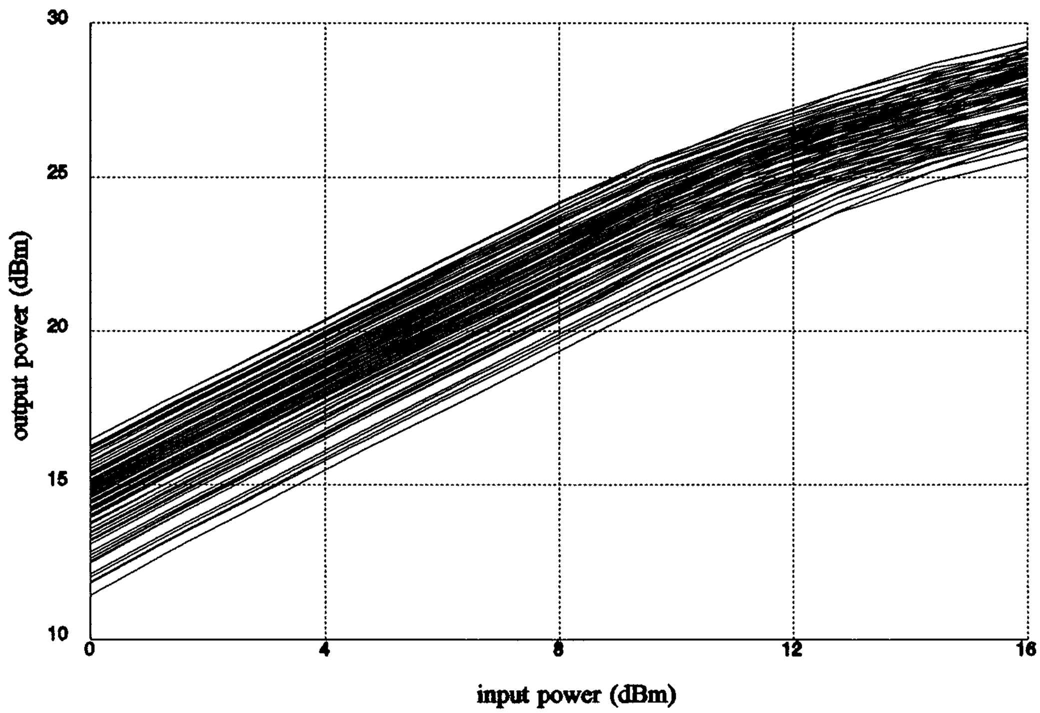

Fig. 6 Monte Carlo sweep of output power versus input power at 2 GHz.

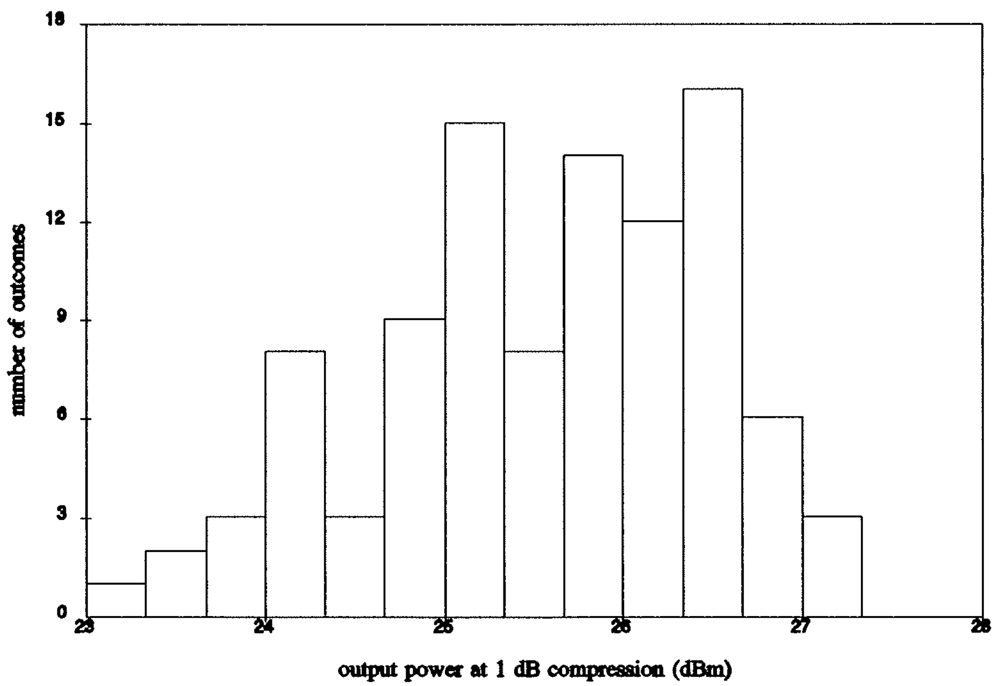

Fig. 7 Histogram of output power (dBm) at 1 dB gain compression at 2 GHz for assumed model uncertainty.

Sensitivity Analysis

We have further investigated the sensitivity of the output power at 1 dB gain compression at 2 GHz w.r.t. the elements in the input and output matching circuits on a minimax design basis. The result shows that the response is more sensitive to the following parameters: the length of the open stub in the input matching circuit, the widths and lengths of the microstrip lines in the output matching circuits, than to the other parameters in the circuits.

Conclusions

We have presented the compression analysis of a high power BJT amplifier [8]. Parameter extraction was employed to refine the published Gummel-Poon model [10] of the transistor. Better agreement between our simulation results and the measurements of the amplifier has been obtained using the refined model rather than the Gummel-Poon model provided by Avantek. The statistical analysis by Monte Carlo simulation indicated that the BJT model accuracy is very important in the circuit simulation. Our sensitivity analysis identifies the circuit elements critical for the design.

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