COMPRESSION ANALYSIS
OF A HIGH POWER BJT AMPLIFIER

J.W. Bandler, R.M. Biernacki, Q. Cai
and S.H. Chen

SOS-94-3-R

March 1994

COMPRESSION ANALYSIS
OF A HIGH POWER BJT AMPLIFIER

J.W. Bandler, R.M. Biernacki, Q. Cai
and S.H. Chen

Simulation Optimization Systems Research Laboratory
and Department of Electrical and Computer Engineering
McMaster University, Hamilton, Canada L8S 4L7
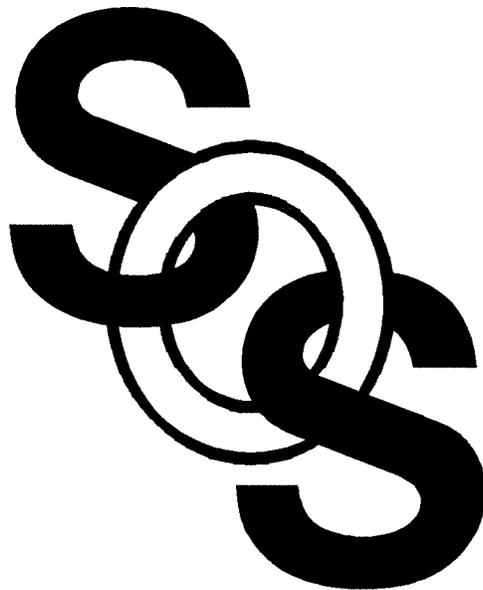
Introduction

harmonic balance (HB) technique: an efficient method for nonlinear steady-state circuit analysis

application of HB method to nonlinear analysis and design of microwave circuits such as amplifiers, mixers and frequency doublers

analysis of high power amplifiers may be a challenge to HB solvers since the strong nonlinearity of the circuits may cause problems such as non-convergence

the success of the simulation depends on the accuracy of models and the intelligent use of nonlinear HB simulators

compression analysis of a BJT high power amplifier:

> parameter extraction for the BJT model
> small-signal and large-signal analysis
> Monte Carlo statistical simulation
> sensitivity analysis

MEE Benchmark of CAD Vendors

nonlinear CAD benchmark by Microwave Engineering Europe of software vendors with products significantly beyond the entry level (November, 1993)

nonlinear simulation of a bipolar transistor power amplifier originally designed by R. Jennings and P. Perry at University College Dublin, Ireland, for communication applications around 2 GHz

the amplifier worked well in practice but proved very difficult to simulate using nonlinear HB simulators

OSA, Hewlett Packard, EEsof and Compact Software participated

Circuit Structure and Characteristics

a single bipolar transistor (the Avantek AT64023) biased for
a constant collector current (100 mA) and a constant
collector emitter voltage (16 V)

distributed elements for input and output matching circuits
realized in microstrip on standard 1.5 mm FR4 board

a high power driver to saturate other high power devices
being tested under nonlinear operation

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

Circuit Schematic
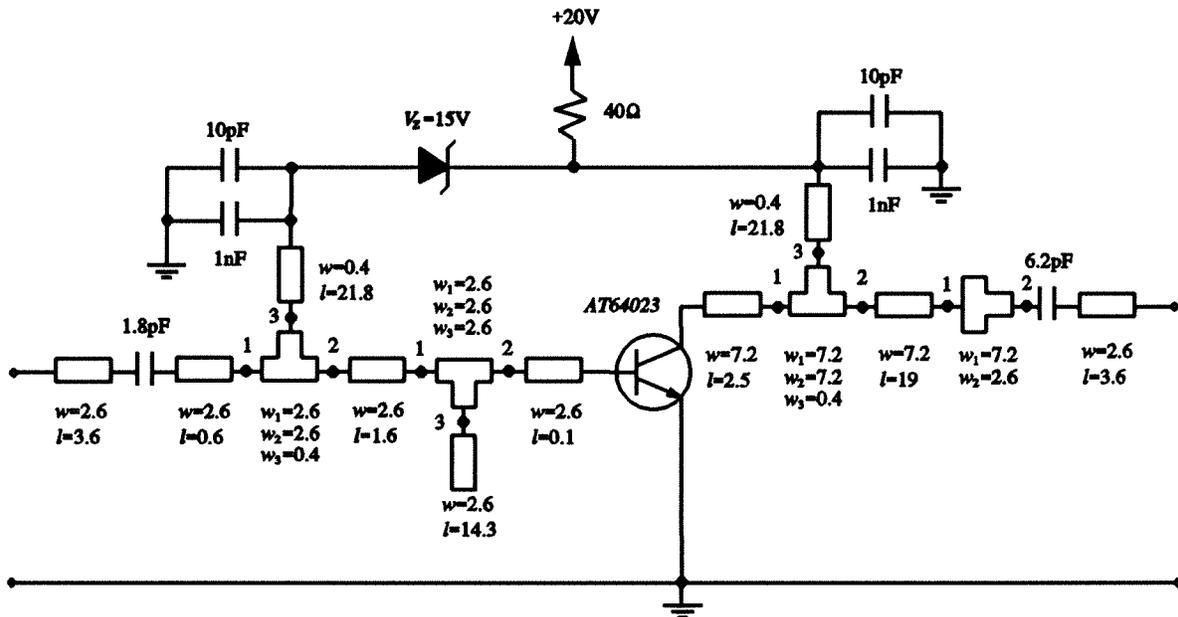
units: mm
substrate thickness 1.5 mm
relative dielectric constant 4.75
metallization: 35 μm thick copper

Device Model for the Bipolar Transistor

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

some discrepancies noticed between the model provided by Avantek and the measured S-parameter data also provided by Avantek

the reason for such discrepancies can be attributed to the still fairly common "disjoint" modeling of small- and large-signal operation of the transistor

model refinement for a better S-parameter fit using the parameter extraction capabilities of OSA90/hope assuming that the S-parameter measurements are more reliable

OSA90/hope employs unified DC, small-signal and large-signal modeling and ensures consistent responses from the DC, small-signal and HB analysis

Small- and Large-Signal Simulation

small-signal linear and large-signal nonlinear HB simulation of the amplifier using OSA90/hope

16.35 dB small-signal gain and 26.6 dBm output power at 1 dB gain compression at 2 GHz obtained using the model provided by Avantek

10.74 dB small-signal gain and 23.43 dBm output power at 1 dB gain compression at 2 GHz obtained using the optimized model extracted from the measured S parameters given by Avantek

12.2 dB small-signal gain and 23.0 dBm output power at 1 dB gain compression at 2 GHz measured for the actual circuit
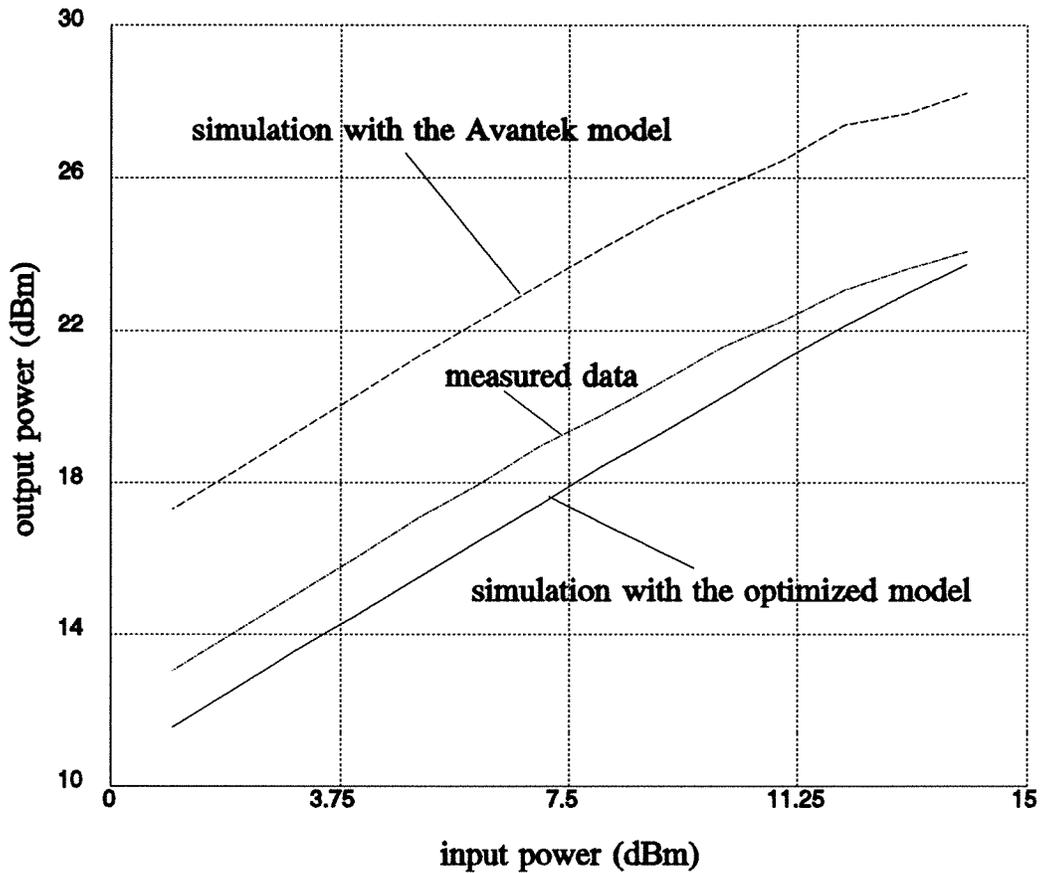
Small-Signal Gain of the Amplifier
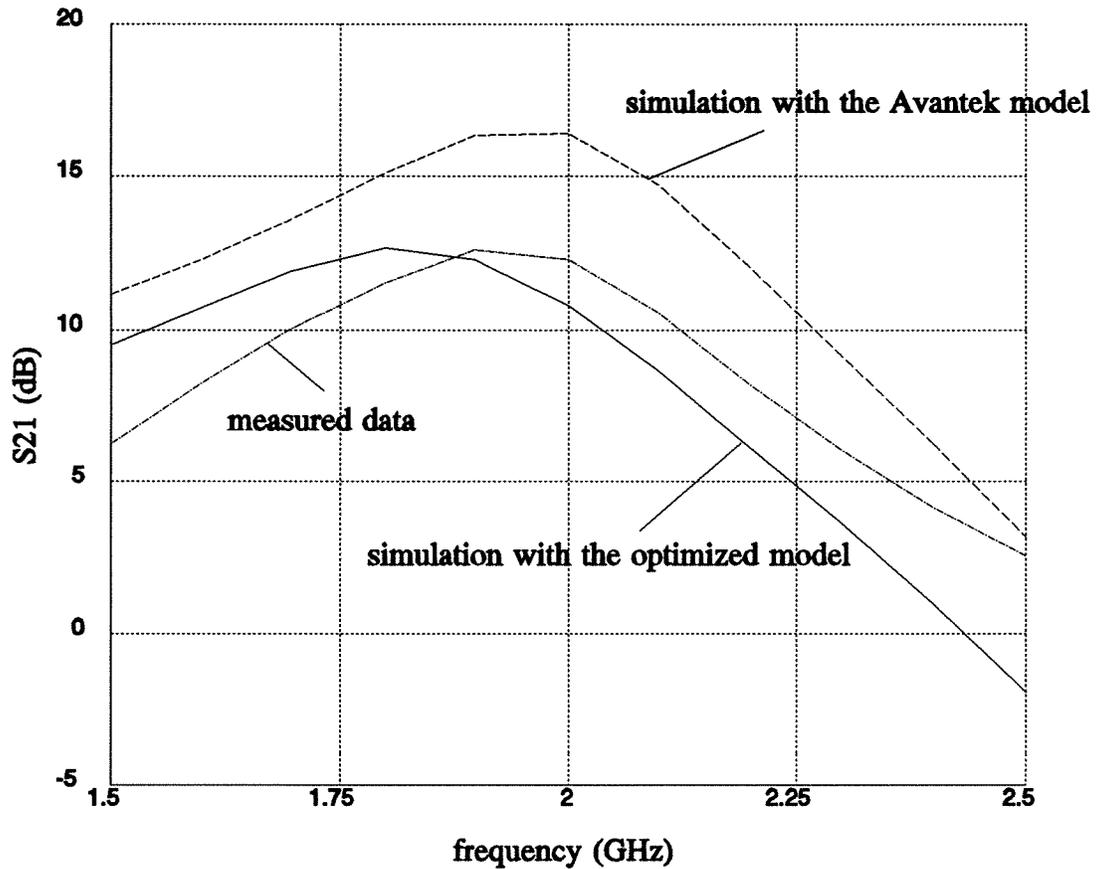
measured data not supplied to participants

Output Power vs. Input Power of the Amplifier

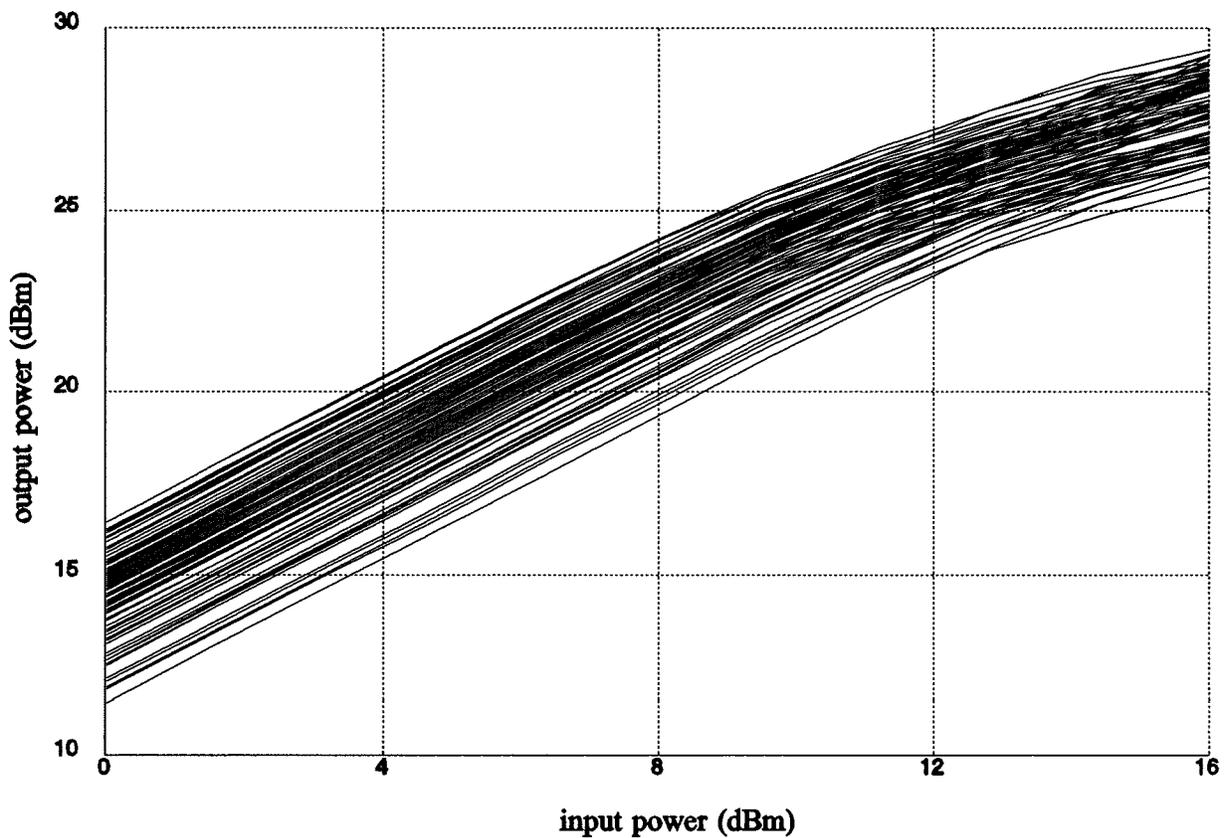measured data not supplied to participants

Statistical Analysis

investigation of the effects of parameter tolerances of the transistor model on the output power

Monte Carlo simulation using 100 outcomes by assigning tolerances to the model parameters

Monte Carlo Sweep of Output Power vs. Input Power

Sensitivity Analysis

sensitivity analysis of the output power at 1 dB gain
compression w.r.t. the elements in the matching circuits

the response is more sensitive to

> the length of the open stub in the input matching
> circuits

> the lengths of the microstrip lines in the output
> matching circuits

Conclusions

we have presented the compression analysis of a high power
BJT amplifier

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

this exemplifies potential problems with vendor-supplied
device models and a limited confidence the designer should
have in such models

different model implementations in different CAD packages
and different parameter extraction procedures may
contribute to this problem

it is more reliable to establish the model from measurements
in a consistent manner within the same CAD environment

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

References

[1] V. Rizzoli, A. Lipparini and E. Marazzi, "A general-purpose program for nonlinear microwave circuit design," *IEEE Trans. Microwave Theory Tech.*, vol. 31, 1983, pp. 762-770.

[2] K.S. Kundert and A. Sangiovanni-Vincentelli, "Simulation of nonlinear circuits in the frequency domain," *IEEE Trans. Computer-Aided Design*, vol. CAD-5, 1986, pp. 521-535.

[3] J.W. Bandler, R.M. Biernacki, S.H. Chen, J. Song, S. Ye and Q.J. Zhang, "Analytically unified DC/small-signal/large-signal circuit design," *IEEE Trans. Microwave Theory Tech.*, vol. 39, 1991, pp. 1076-1082.

[4] "Non-linear CAD benchmark," *Microwave Engineering Europe*, November 1993, pp. 11-15.

[5] *OSA90/hope™*, Optimization Systems Associates Inc., P.O. Box 8083, Dundas, Ontario, Canada L9H 5E7, 1993.

[6] *Microwave Semiconductors GaAs and Silicon Products Data Book*, Avantek Inc., 3175 Bowers Ave., Santa Clara, CA 95054, USA, 1989.