PHYSICS-BASED DESIGN AND YIELD OPTIMIZATION OF MMICs

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

SOS-91-2-S

September 1991

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Outline

introduction

physics-based models (PBMs) for active and passive devices

statistical models

yield-driven design optimization

yield optimization of a three stage X-band amplifier

conclusions

Introduction

yield-driven design is an indispensable part of MMIC design methodology

equivalent circuit based yield optimization

- using equivalent circuit models (ECMs) for devices
- statistical properties assigned to the parameters of ECMs
- high computational efficiency
- difficult to represent the actual statistical properties of the devices
- nonunique solutions

physics-based yield optimization

- using PBMs for devices
- statistical properties assigned to physical parameters
- reflecting actual statistical properties of the devices
- more computational time required
- great, likelihood of realistic results

The Goal of This Paper

address physics-based design and yield optimization of MMICs

emphasize the use of PBMs

illustrate statistical models

demonstrate FAST gradient-based yield optimization

PBMs for FETs

model parameters relate directly and clearly to physical reality

PBMs for FETs based on the Khatibzadeh and Trew model

parameters include device geometry, material parameters and process parameters

PBMs for Passive Devices

passive devices represented in general by their n-port Y matrices

the entries of Y are calculated from equivalent circuit components

the expressions of the equivalent circuit components are derived from (simplified) device physics

Statistical Models

a prerequisite for accurate yield-driven design

model statistics originate from random variation of physical parameters

statistical models can be created at:

device response level (from measurements)
statistical properties assigned to the device responses

equivalent circuit parameter level
statistical properties assigned to the elements of equivalent circuits

physics-based parameter level
statistical properties assigned to the physical parameters of the devices

Yield-Driven Design Optimization

formulated as a one-sided ℓ_1 optimization problem

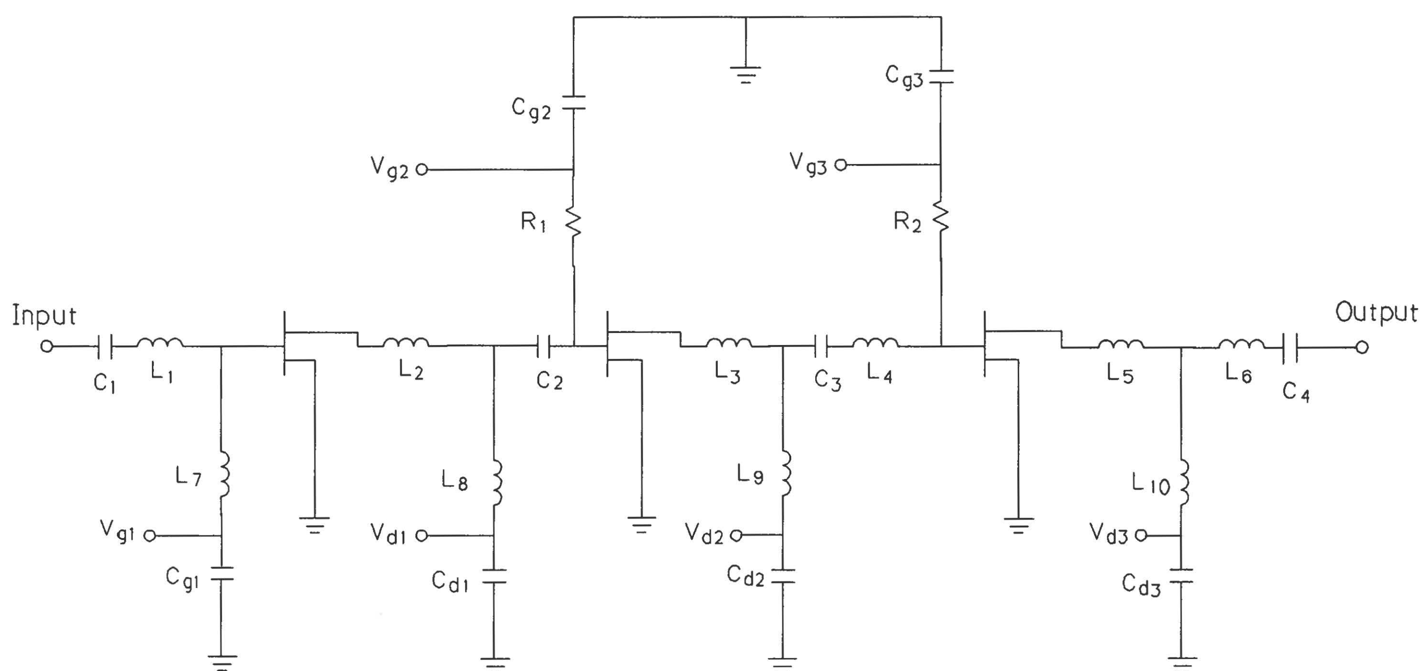
statistics of the PBM parameters are modelled by multidimensional normal distributions

Statistical correlations between parameters are considered

the efficient sensitivity technique FAST (Feasible Adjoint Sensitivity Technique) is employed to permit high speed gradient-based yield optimization

Yield Optimization using OSA90/hope

circuit diagram of a three stage X-band amplifier



Yield Optimization using OSA90/hope (cont'd)

design specifications:

in the passband (8GHz - 12GHz), gain = 14±2dB, VSWR < 2
in the stopband (below 6GHz or above 15GHz), gain < 2dB

design procedure:

nominal design using minimax optimization
yield optimization using the solution of nominal design as starting point
37 statistical variables, 16 design variables

results:

at the starting point, the yield is 47.5%
yield is improved to 78.5% at the solution

Conclusions

the ability to predict and enhance production yield is critical for the continued success of MMIC technology

the principle of physics-based design and yield optimization of MMICs is presented

the advantages of PBMs over ECMs in statistical analysis and optimization are emphasized

PBMs dealing directly with the lowest level of fabrication/technological parameters are essential for the next generation of microwave CAD

ASSUMED DISTRIBUTIONS FOR STATISTICAL VARIABLES

Variable	Mean Value	Standard Deviation (%)	Variable	Mean Value	Standard Deviation (%)
$N_d(cm^{-3})$	2.0×10^{17}	7.0	$d(\mu m)$	0.1	4.0
$L_G(\mu m)$	1.0	3.5	$S_{C1}(\mu m^2)$	532.7	3.5
$A_G(\mu m)$	0.24	3.5	$S_{C2}(\mu m^2)$	2278.9	3.5
$W_G(\mu m)$	400	2.0	$S_{C3}(\mu m^2)$	583.1	3.5
$W_L(\mu m)$	20	3.0	$S_{C4}(\mu m^2)$	468.7	3.5
$S_L(\mu m)$	10	3.0			

The doping density N_d, gate length L_G, channel thickness A_G and gate width W_G of the three MESFETs have the same distribution. The conductor width W_L and spacing S_L of the 10 spiral inductors $L_1, L_2, ..., L_{10}$ have the same distribution. d is the thickness of the dielectric film for all MIM capacitors. S_{Ci} is the area of the metal plate of MIM capacitor C_i.

ASSUMED PARAMETER CORRELATIONS FOR THE THREE MESFETS

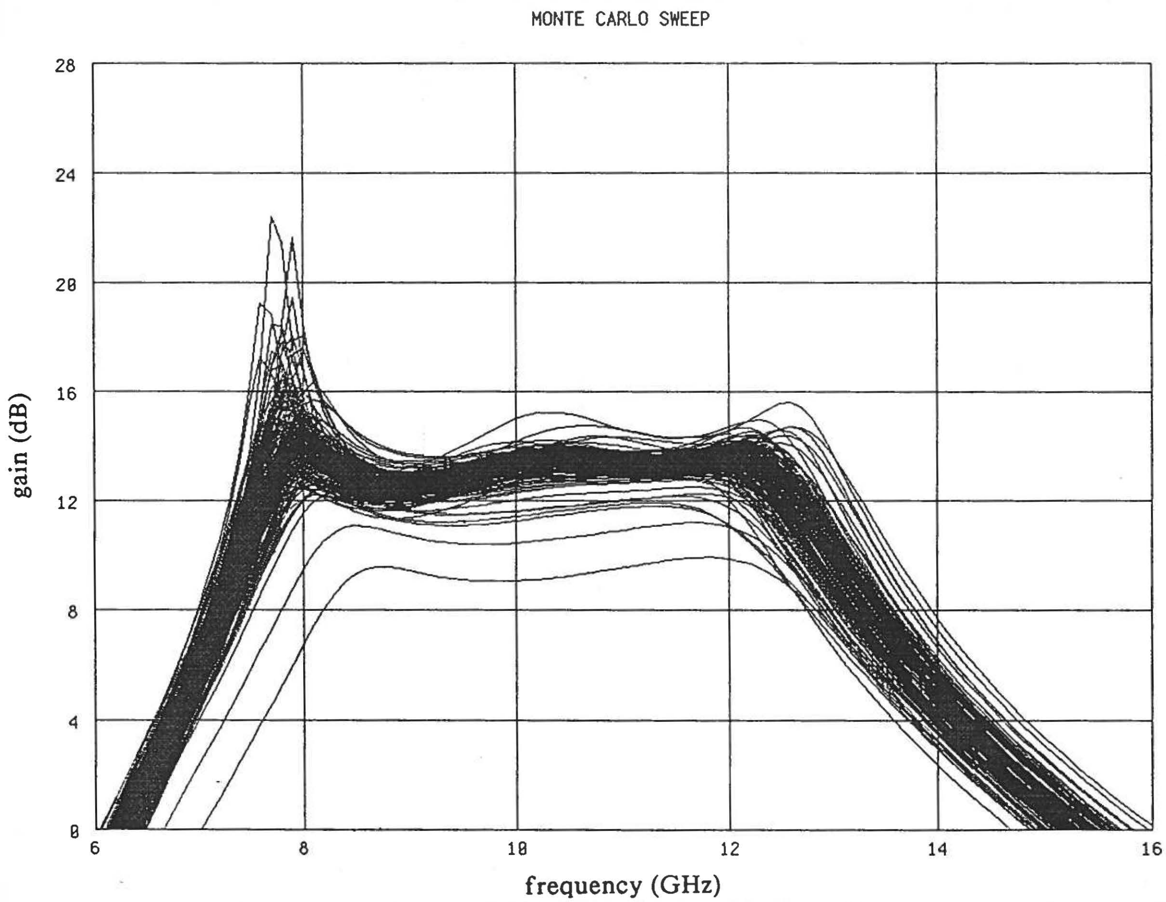
	A_{G1}	L_{G1}	W_{G1}	N_{d1}	A_{G2}	L_{G2}	W_{G2}	N_{d2}	A_{G3}	L_{G3}	W_{G3}	N_{d3}
A_{G1}	1.00	0.00	0.00	-0.25	0.80	0.00	0.00	-0.20	0.78	0.00	0.00	-0.10
L_{G1}	0.00	1.00	0.00	-0.10	0.00	0.80	0.00	-0.05	0.00	0.78	0.00	-0.05
W_{G1}	0.00	0.00	1.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.78	0.00
N_{d1}	-0.25	-0.10	0.00	1.00	-0.20	-0.05	0.00	0.80	-0.15	-0.05	0.00	0.78
A_{G2}	0.80	0.00	0.00	-0.20	1.00	0.00	0.00	-0.25	0.80	0.00	0.00	-0.20
L_{G2}	0.00	0.80	0.00	-0.05	0.00	1.00	0.00	-0.10	0.00	0.80	0.00	-0.10
W_{G2}	0.00	0.00	0.80	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.80	0.00
N_{d2}	-0.20	-0.05	0.00	0.80	-0.25	-0.10	0.00	1.00	-0.20	-0.05	0.00	0.80
A_{G3}	0.78	0.00	0.00	-0.15	0.80	0.00	0.00	-0.20	1.00	0.00	0.00	-0.25
L_{G3}	0.00	0.78	0.00	-0.05	0.00	0.80	0.00	-0.05	0.00	1.00	0.00	-0.10
W_{G3}	0.00	0.00	0.78	0.00	0.00	0.00	0.80	0.00	0.00	0.00	1.00	0.00
N_{d3}	-0.10	-0.05	0.00	0.78	-0.20	-0.10	0.00	0.80	-0.25	-0.10	0.00	1.00

DESIGN VARIABLE VALUES FOR YIELD OPTIMIZATION

Design Variable	Before Optimization	After Optimization	Design Variable	Before Optimization	After Optimization
$A_G(\mu m)$	0.24	0.243	n_{L3}	2.33	2.04
$N_d(cm^{-3})$	2.0×10^{17}	2.03×10^{17}	n_{L4}	2.29	2.34
$S_{C1}(\mu m^2)$	532.7	552.2	n_{L5}	2.32	2.39
$S_{C2}(\mu m^2)$	2278.9	1910.2	n_{L6}	1.84	2.08
$S_{C3}(\mu m^2)$	583.1	554.2	n_{L7}	1.49	1.50
$S_{C4}(\mu m^2)$	468.7	477.2	n_{L8}	2.65	2.82
n_{L1}	2.88	2.79	n_{L9}	2.43	2.48
n_{L2}	3.98	4.11	n_{L10}	3.27	3.35

n_{Li} is the number of turns of the spiral inductor L_i.

Gain Versus Frequency After Optimization (200 outcomes)



Gain Versus Frequency Before Optimization (200 outcomes)