YIELD OPTIMIZATION:
THE GOAL OF THE NEXT GENERATION
MICROWAVE CAD SOFTWARE

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YIELD OPTIMIZATION: THE GOAL OF THE NEXT GENERATION MICROWAVE CAD SOFTWARE

Optimization Systems Associates Inc.
Dundas, Ontario, Canada

Optimization Systems Associates Inc.

Milestones in Yield Optimization

Bandler begins formal exploitation of parameter tolerances in circuit optimization in 1969-70

cost-driven worst-case design with optimized tolerances (1972)

optimal centering and tolerance assignment integrated with tuning at the design stage (1974)

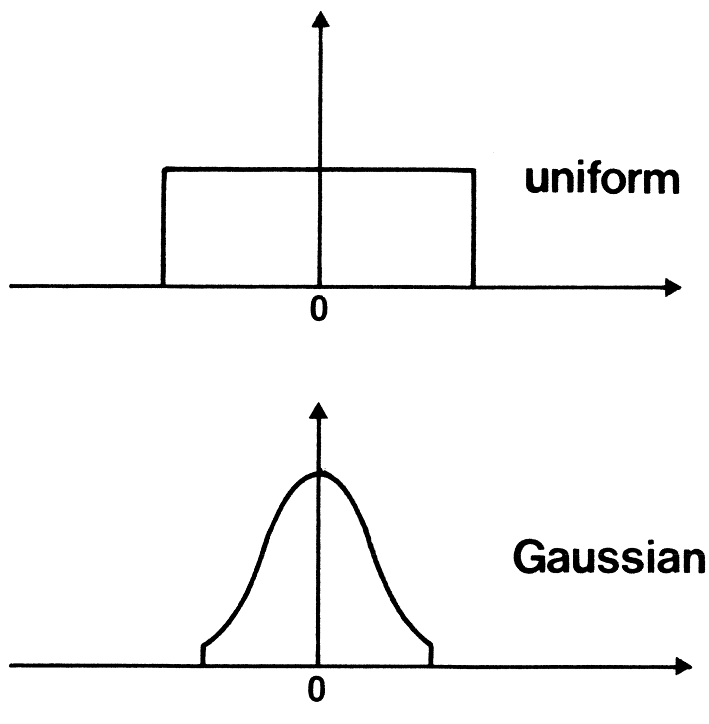
integrated approach to microwave design with parameter tolerances, model uncertainties, mismatches and reference plane uncertainties (1975)

yield-driven optimization using general statistical distributions (1976)

optimal tuning and alignment at the production stage (1980)

foundation of multi-circuit ℓ_1 yield optimization (1987)

world's first yield-driven design features for Super-Compact (1987)


uniform
0
Gaussian
0

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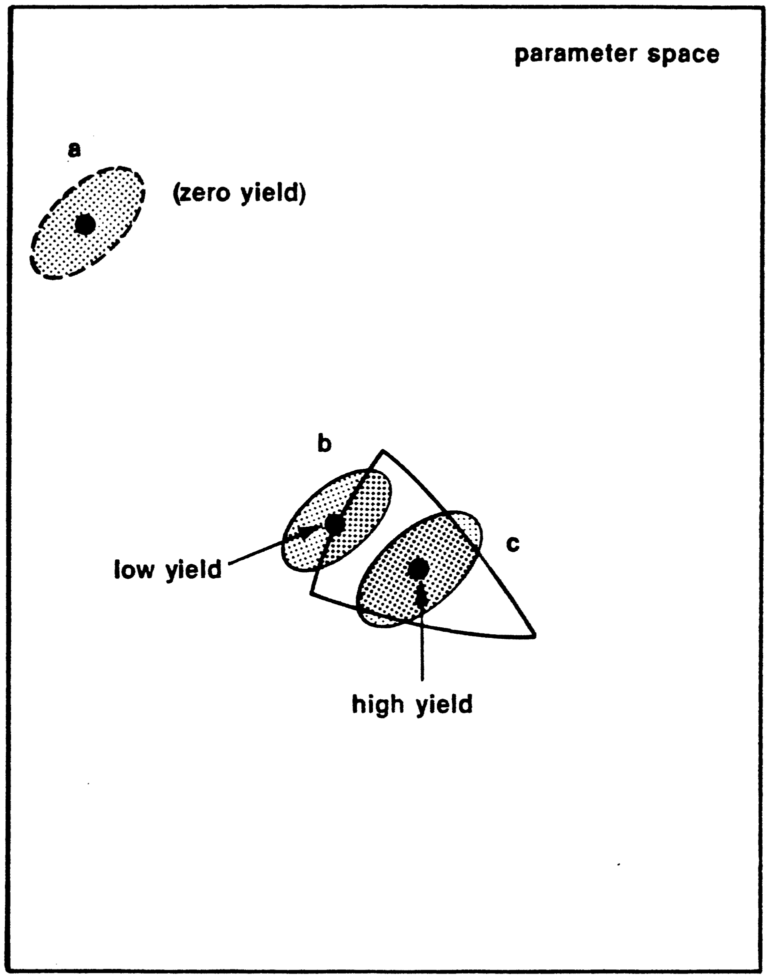

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Statistical Analysis and Yield-Driven Design Input File Example

```
*
* DESIGN CENTERING EXAMPLE: FILE CEN01.DAT
*
BLK
  CAP  1    0    C 4PF        #ND 5%#
  IND  1    2    L ?8NH?      #UD 15%#
  RES  2         R 550
  TWO  2    3    4   Q1
  PRC  4         R 5          #ND 5%#    C ?14PF?
  SRL  2    3    R ?154?      #ND 10%#   L ?24NH?
  RES  3         R 300
A:2POR1     3
END
FREQ
  10MHZ STEP 250MHZ 1000MHZ 250MHZ
END
OPT
  A MS11 -8.0DB LT MS22 -8.0DB LT MS21 9DB 10DB
+ W 2
END
STAT
  A MS11 -8.0DB LT MS22 -8.0DB LT MS21 9DB 10DB
END
(data section for Q1)
.
.
```

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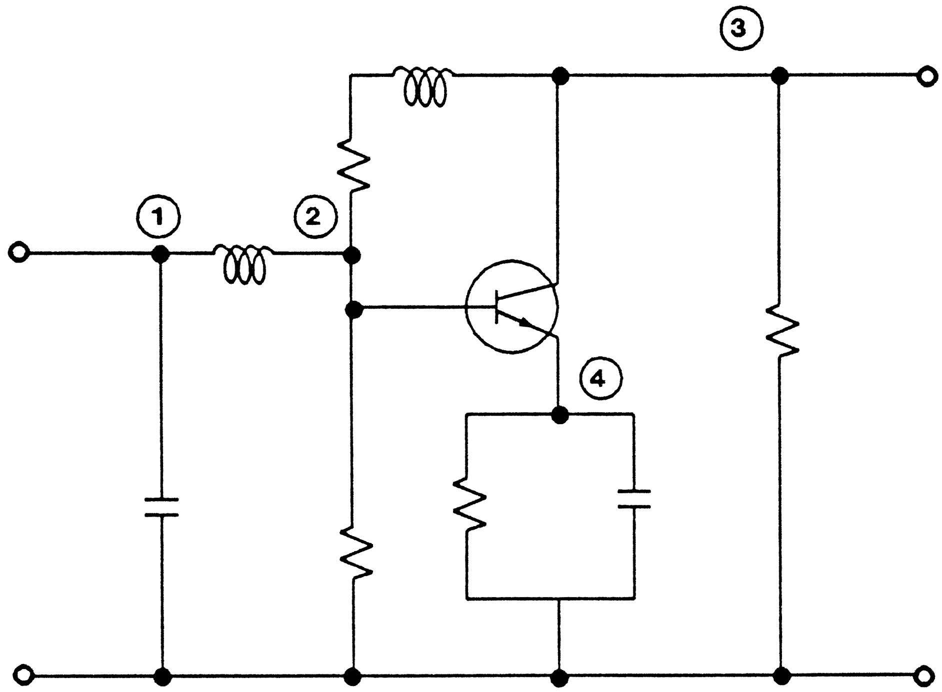


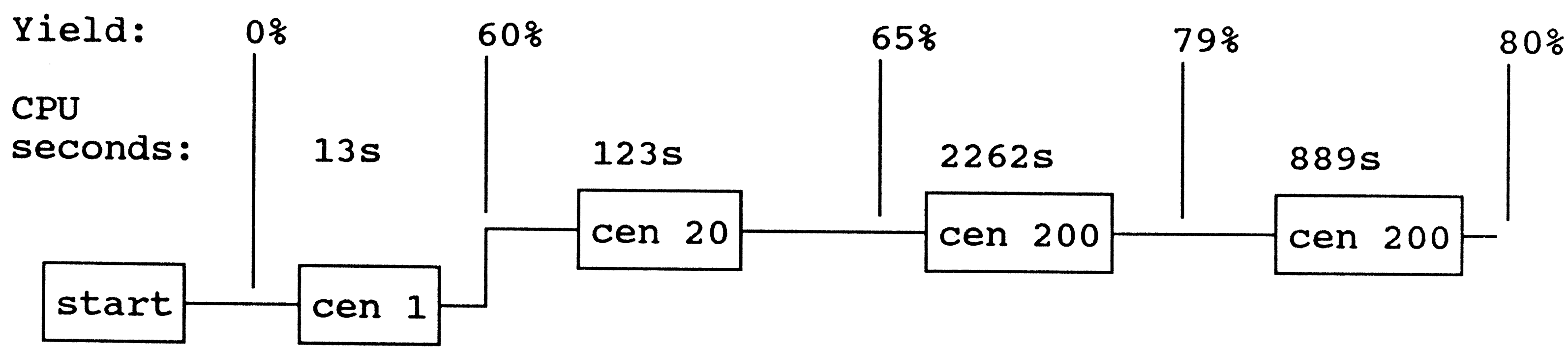
Statistical Analysis and Yield-Driven Design
Command Level Example

CMD > CEN
Number of outcomes <20> : 15
Gradient, Random or Quit? (G/R/Q): G
..
Initial Variables and Gradients

Variables			Gradients	
(1):	8.0000	NH	(1):	2.2392
(2):	14.000	PF	(2):	24.992
(3):	154.00		(3):	-203.40
(4):	24.000	NH	(4):	72.516

Obj. F.= 7.00000 Yield Est.= 53.33%
----****----

..
Number of iterations? (x/<0>): 50 N
..
CMD > STAT NH
Number of trials? (n/<0>): 300
..
Number of additional trials? (n/<0>): <RET>


Yield:
0%
60%
65%
79%
80%
CPU seconds:
13s
123s
2262s
889s
start
cen 1
cen 20
cen 200
cen 200

Statistical Analysis and Yield-Driven Design
Results of Optimization

.
.

(1): 9.6931	NH		(1): 65.828
(2): 5.1598	PF		(2): -33.352
(3): 311.56			(3): -119.50
(4): 59.748	NH		(4): -163.99

.
.
.

(15/ 50) Obj. F.= 29.4900   Yield Est.= 80.50%
----****----
Local minimum -- gradient search cannot improve
CPU time = 2261.85 Secs.   28000 Function evaluations

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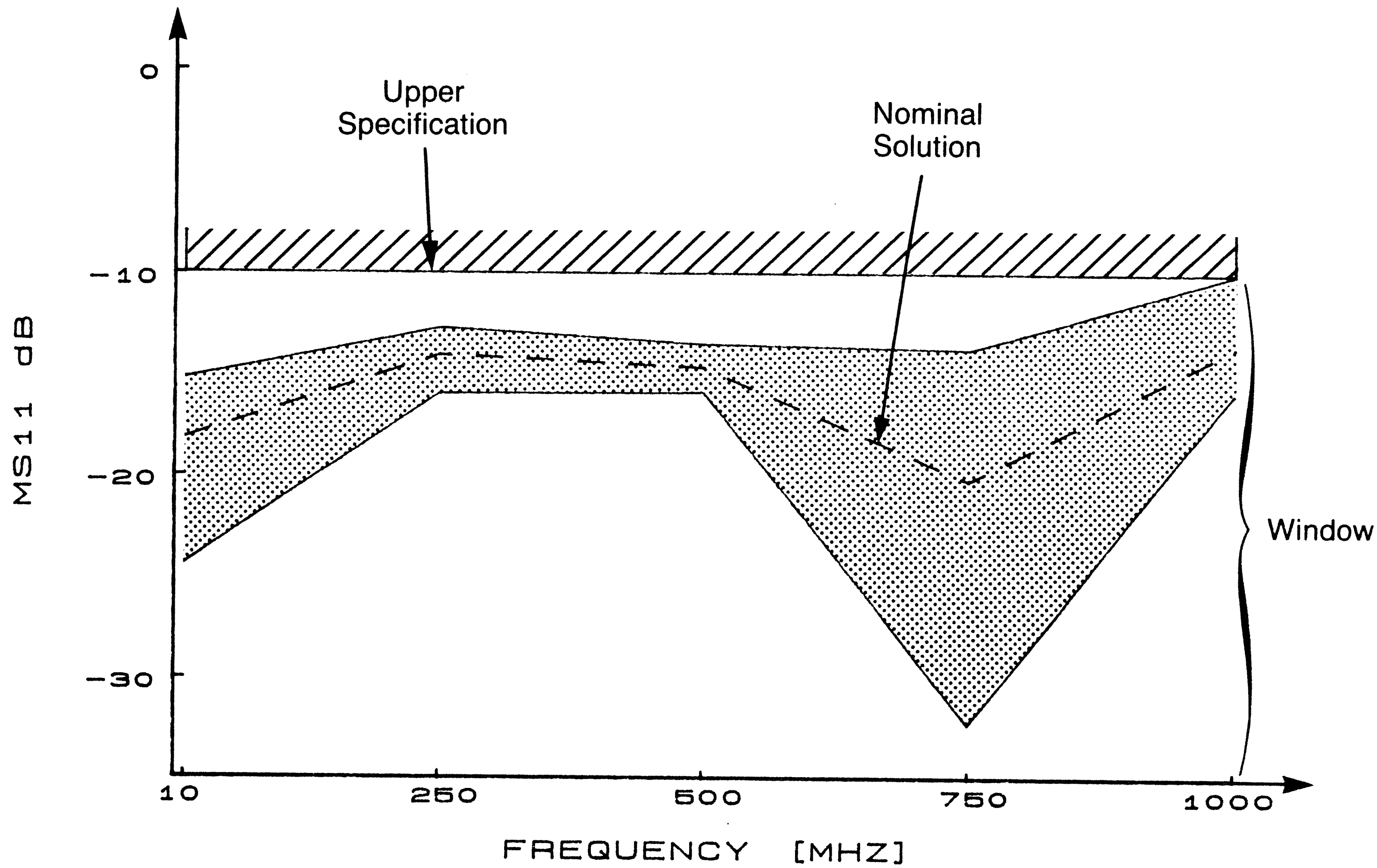
Design Yield = 80%



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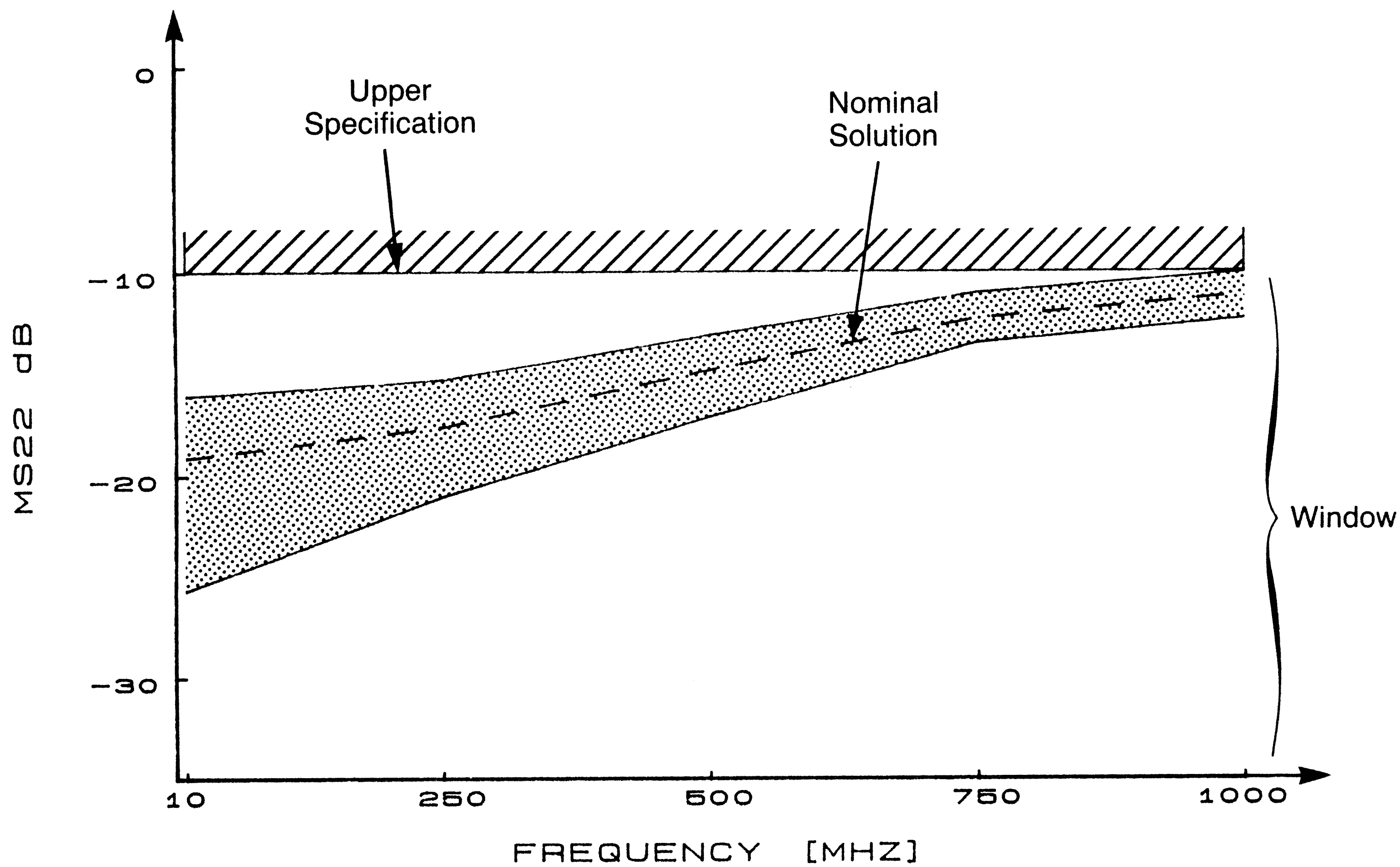
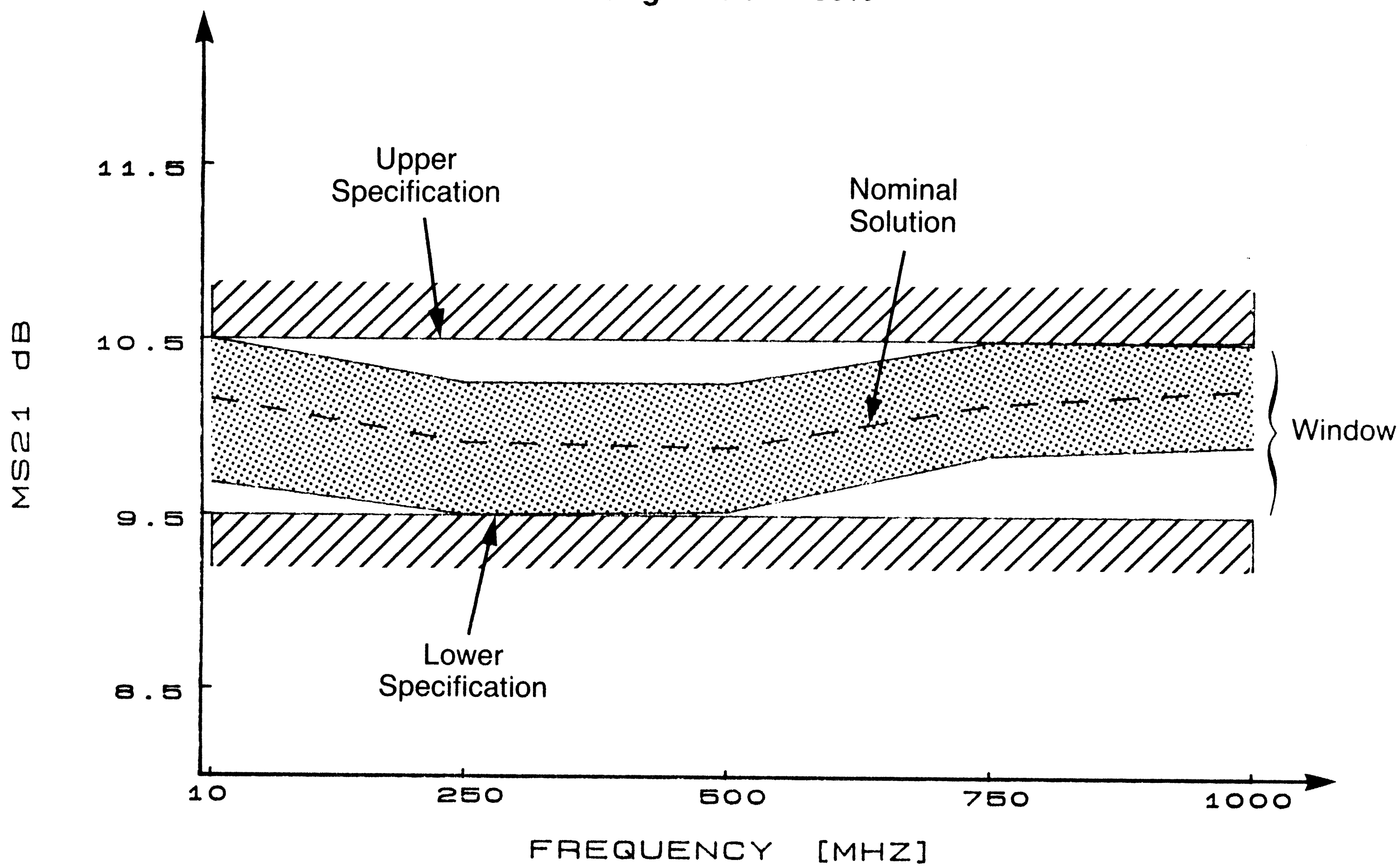
Design Yield = 80%



Design Yield = 80%



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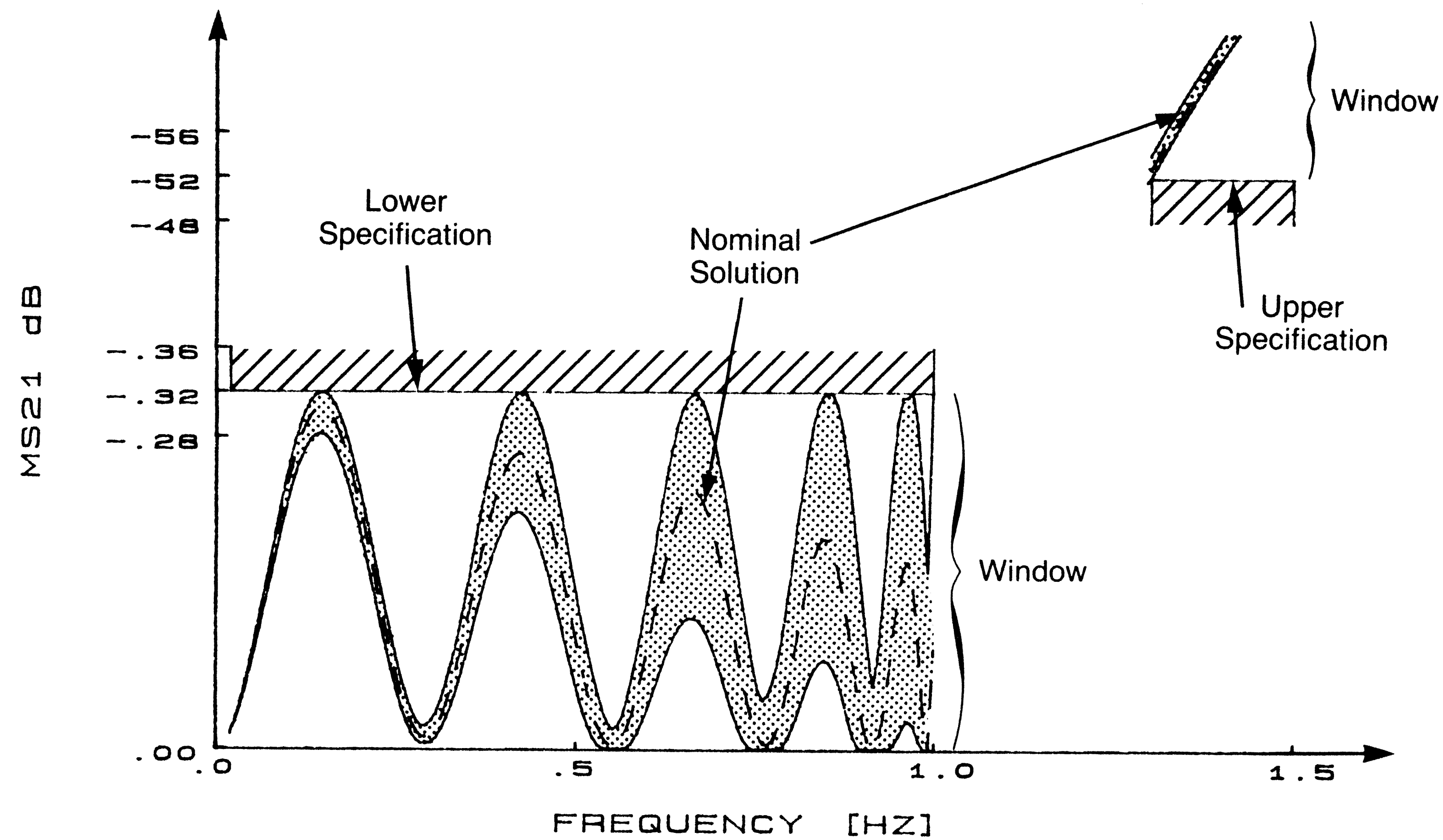
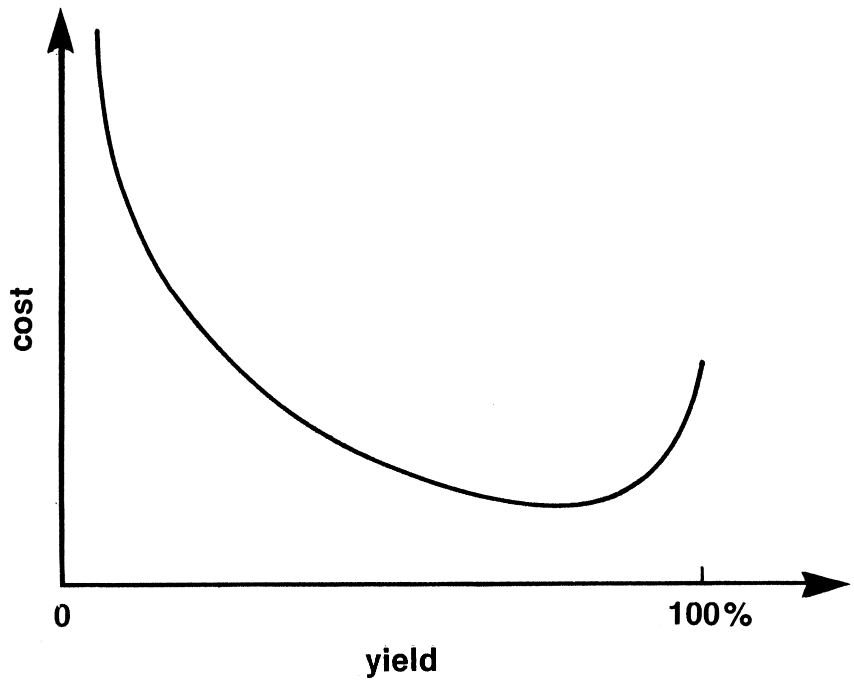
Design Yield = 78%




cost
0
100%
yield

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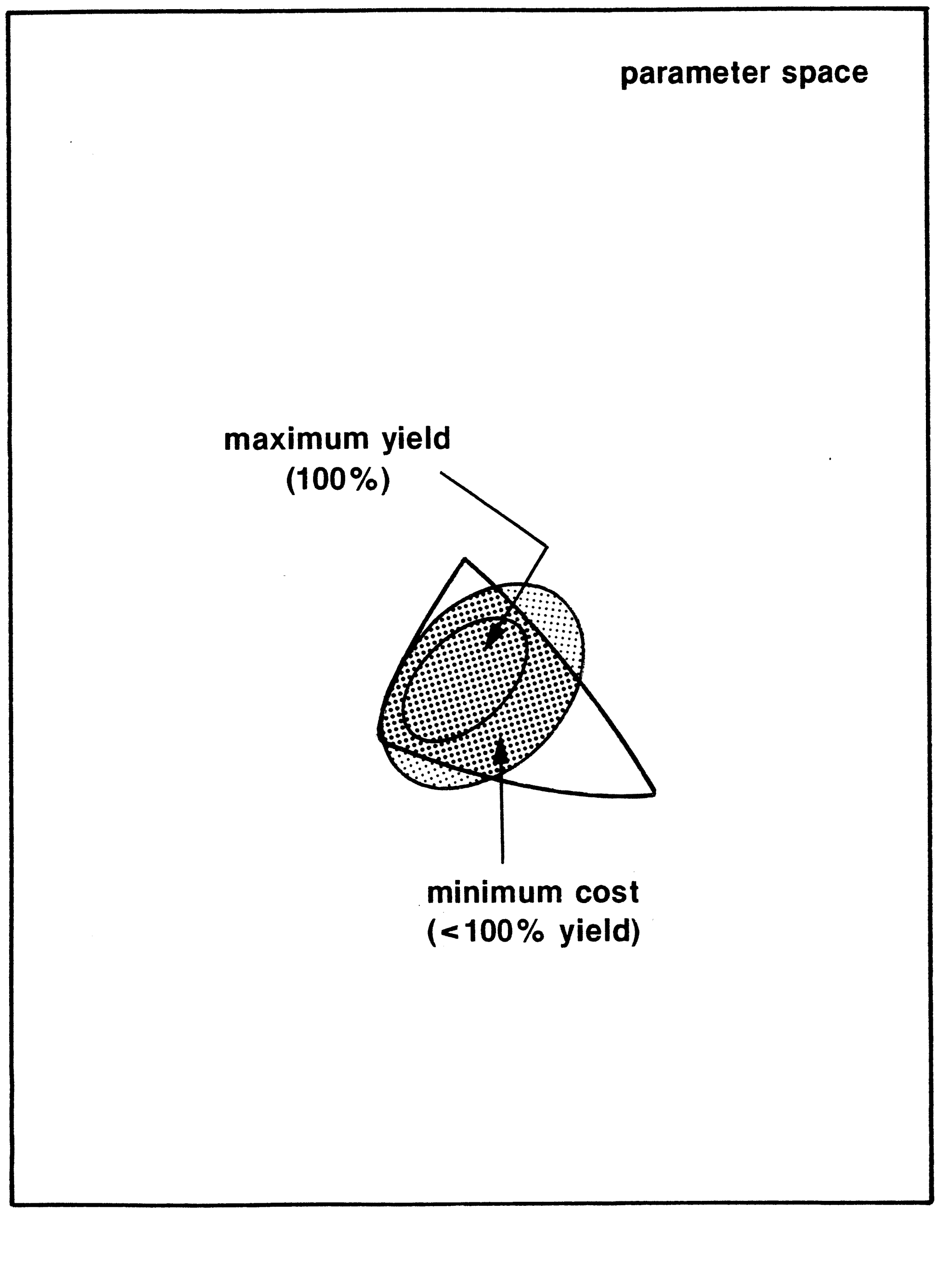

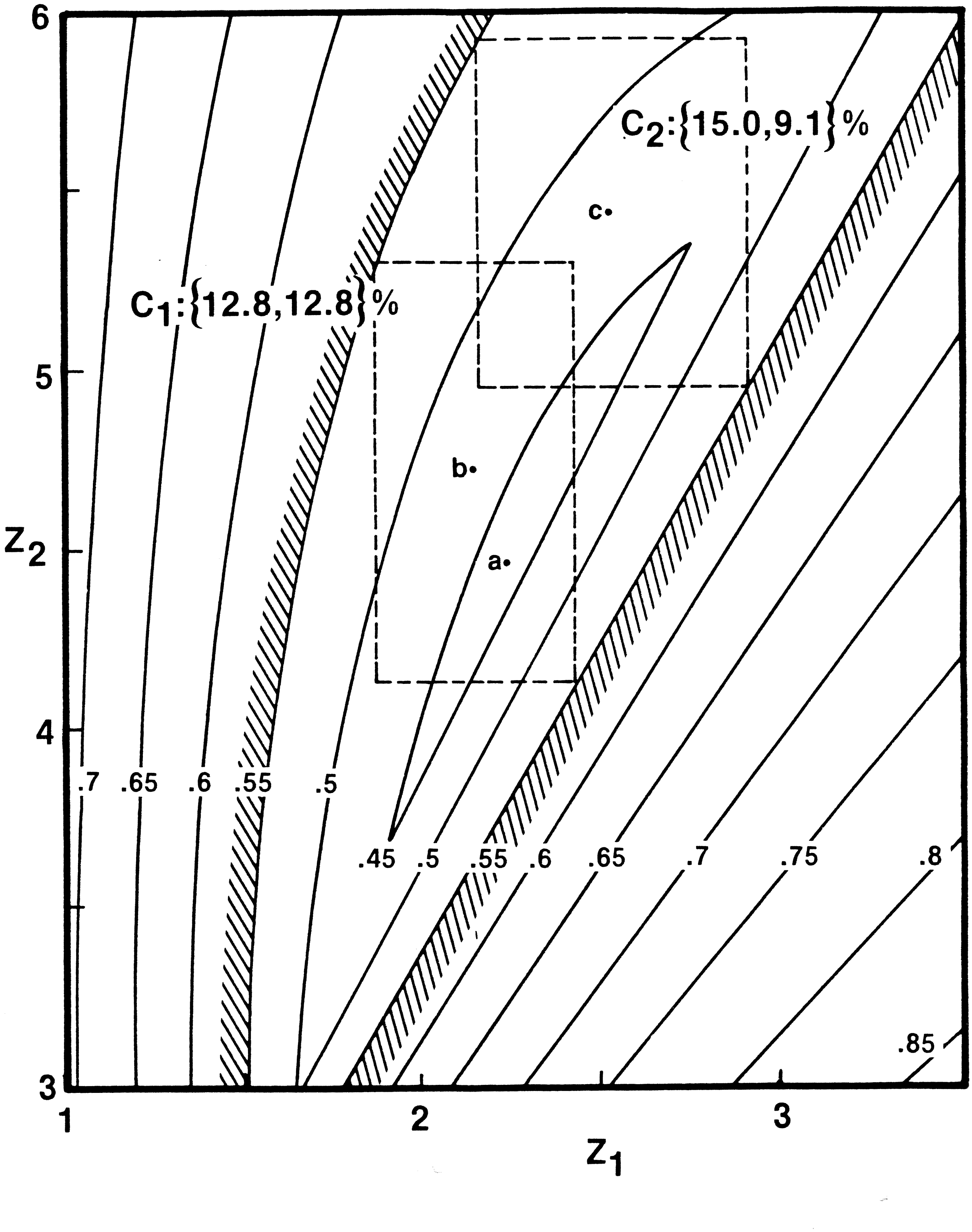

C1:{12.8,12.8}%
C2:{15.0,9.1}%
a
b
c
.7
.65
.6
.55
.5
.45
.5
.55
.6
.65
.7
.75
.8
.85
6
5
4
3
1
2
3
Z2
Z1

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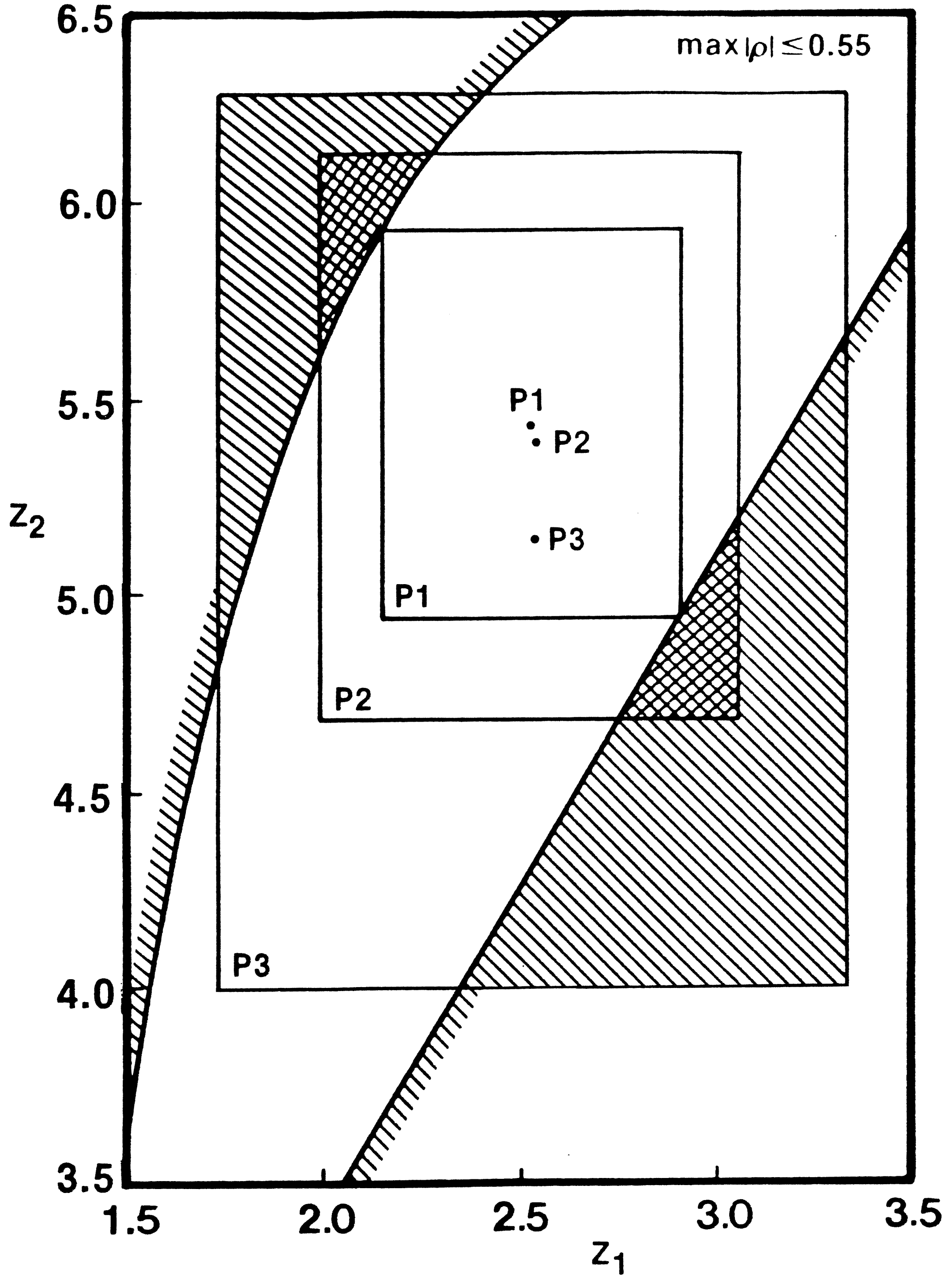

Hierarchical Statistical Modeling

correlated — device response (e.g., S parameters of a FET)

correlated — equivalent circuit model parameters

independent

abstract variables	process/ geometrical variables	process disturbances

Hierarchical Treatment of Device Statistics

device statistical model includes the overall effect of device statistics, chip statistics and wafer statistics

inter-device correlations originate from chip and wafer statistics

inter-chip correlations originate from wafer statistics

device statistics

chip statistics

wafer statistics

Major Approaches to Statistical Modeling

process / geometrical based approach

- small number of statistically independent variables
- normal distribution generally applicable
- physical / empirical formulas required

equivalent circuit based approach

- models are generally available
- distribution functions may not be simple, for example bimodal
- parameter correlations may be complicated and meaningless
- number of statistical variables may be large

Nonlinear Parameter Extraction

accurate large signal device models are vital to nonlinear analysis / optimization

such device models should be extracted from measurements at DC, fundamental frequency and higher harmonics

efficient nonlinear parameter extraction using harmonic balance technique and adjoint network concepts