System Level Simulation Benefits from Frequency Domain
Behavioral Models of Mixers and Amplifiers

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Outline

• Introduction

• Frequency Domain Black-Box Models: Concepts

• Practicalities:  - Time Delay Invariance
                 - Linearization
                 - ANN + Volterra Series

• Examples: Simulation and Measurement Based

• Conclusions
Introduction (1)

- Simulators significantly decrease time-to-market for RF/microwave designs
- Problems experienced with large-signal behavior:
  - model accuracy
  - circuit complexity
Introduction (2)

- Solution: Frequency Domain Behavioral Models
  - Application Specific
  - Can Be Derived from Measured Data
    (fast accurate transistor model)
  - Can Be Derived from Simulated Data
    (reduce complex circuits)
Frequency Domain Behavioral Models? (1)

\[ B_{ij} = F_{ij}(A_{kl}) \]

“Describing Function”
Frequency Domain Behavioral Models? (2)

Set of Experiments

NNMS Measurements $\rightarrow \begin{bmatrix} A & B \\ A & B \\ \vdots & \vdots \end{bmatrix}$ $\rightarrow$ Harmonic Balance Simulations

Approximate $F(A)$ by $G(A, \alpha, \beta, \ldots)$

Find $\alpha, \beta, \ldots$ minimizing

$$\int \|F(A) - G(A, \alpha, \beta, \ldots)\|^2 dA$$

experimental $A$
Frequency Domain Behavioral Models
Accurately Describe:

- Compression characteristic
- AM-PM
- PAE
- Harmonic Distortion
- Fundamental loadpull behavior
- Harmonic loadpull behavior
- Time domain voltage & current

Influence of bias and fundamental frequency can be included
Practicality 1: Time Delay Invariance

Describing Function $F(A)$ is fitted by $G(A, \alpha, \beta, \ldots)$ parameters.

$G(A, \alpha, \beta, \ldots)$ has a very important constraint: delaying $A$ has to result in same delay for $B$.

Mathematically expressed:

for every $\tau$

$$G(A e^{j\omega \tau}, \ldots) = G(A)e^{j\omega \tau}$$
Practicality 2: Linearization (1)

In general superposition

$$F(A + A') \neq F(A) + F(A')$$

Harmonics are relatively small

Superposition harmonics only OK
Practicality 2: Linearization (2)
Practicality 3: Curve Fitting (1)

$ANN = \text{smooth multidimensional fitters}$

$V_{\text{collector}} = 4.5 \text{ V}$

Si BJT
Fund @ 1.8 GHz
Practicality 3: Curve Fitting (2)

HDA (Output in dBm)

Input Power (dBm)

ANN artifact

Combine with Volterra Series for accurate low power behavior.
Example Applications:
1.8 GHz Silicon Power Transistor (1)

Measurement Setup

\[ A_{11} \]

\[ A_{ij} \neq A_{11} \]

\[ Z_{match} \]

E4142 - BIAS

NNMS

TUNER
Example Applications:
1.8 GHz Silicon Power Transistor (2)

Results
Example Applications:
Models based on Harmonic Balance Simulations

- Gilbert cell mixer
  - 20 transistors
  - Behavioral Model

- Amplifier
  - Transistor + matching circuit
  - Behavioral Model

Comparison
Cascaded Detailed Circuits versus Cascaded Behavioral Models
Slow: Generally Applicable
Fast: Application Specific
Example Applications:
Comparison of Behavioral Models and Circuits

[Graph showing RF output power and phase vs. IF input power for 1GHz, 2GHz, and 3GHz.]
Conclusion

- Frequency domain behavioral models for mixers and amplifier circuits can be constructed based on:
  - time-invariant describing functions
  - linearization
  - curve fitting techniques
- The models can be based on simulations or measurements
- The models increase simulator efficiency, accuracy