Large-Signal Network Analysis: Going beyond S-parameters

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Large-Signal Network Analysis
“Going beyond S-parameters …”

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Network Measurement and Description Group
Outline

• What is “Large-Signal Network Analysis”?  
• Data Representations and Signal Classes  
• Large-Signal Network Analyzer Hardware  
• Calibration Aspects  
• Example Applications  
• Conclusion
What is “Large-Signal Network Analysis”?

• Put a DUT in realistic large-signal operating conditions
• Completely and accurately characterize the DUT behavior
• Analyze the network behavior using these measurements
Data Representations

- Physical Quantity Sets
  - Travelling Waves (A, B)
  - Voltage/Current (V, I)

- Representation Domain
  - Frequency (f)
  - Time (t)
  - Envelope
Signal Class: Modulated Signals

• Periodically modulated carrier
• e.g. transistor excited by a modulated 1 GHz tone (modulation period = 10 kHz)

Freq. (GHz)

DC
10 kHz
1
2
3

• Spectral components $X_{hm}$
Modulation: Frequency Domain

**Fund @ 1.9 GHz**
- Incident signal (a1)
- Transmitted signal (b2)
- Reflected signal (b1)

**2nd @ 3.8 GHz**
- Incident signal (a1)
- Transmitted signal (b2)
- Reflected signal (b1)

**3rd @ 5.7 GHz**
- Incident signal (a1)
- Transmitted signal (b2)
- Reflected signal (b1)
Modulation: Time and Envelope Domain

![Graph showing modulation in time and envelope domain]

- **$B_2$ (Volt)**
- **Fundamental envelope**
- **3rd harmonic envelope**

**Time** (normalized)
LSNA Hardware

- **Computer**
- **4 MHz A-to-D**
- **RF-IF converter**
- **Attenuators**
- **TUNER**

**RF bandwidth:** 600MHz - 50GHz

**max RF power:** 10 Watt

**Modulation bandwidth:** 8 MHz

**Needs periodic modulation**

(1 kHz typical)
Calibration Aspects: The Error Model

\[
\begin{bmatrix}
a^D_1 \\
b^D_1 \\
a^D_2 \\
b^D_2
\end{bmatrix}
= K_h \exp(j\varphi_h)
\begin{bmatrix}
1 & \beta_h & 0 & 0 \\
\chi_h & \delta_h & 0 & 0 \\
0 & 0 & \varepsilon_h & \phi_h \\
0 & 0 & \gamma_h & \eta_h
\end{bmatrix}
\begin{bmatrix}
C_1 a^{R1}_h \\
C_2 b^{R1}_h \\
C_3 a^{R2}_h \\
C_4 b^{R2}_h
\end{bmatrix}
\]

DUT quantities

RF amplitude error

IF error

RF phase error

RF relative error

Raw quantities

RF amplitude error

IF error

RF phase error

RF relative error

Raw quantities
RF Calibration

• SOLT (coaxial) or LRRM (on wafer)

Combined with

• HF amplitude calibration with power meter
• HF harmonic phase calibration with a periodic pulse (characterized by a nose-to-nose calibrated scope)
Harmonic Phase Reference Generator Characterization

Reference generator

Sampling oscilloscope
Example Applications: FET Breakdown Current

V_{gs} (V)  

V_{ds} (V)  

I_{gs} (mA)  

I_{ds} (mA)  

Time (ns)  

(transistor provided by David Root, Agilent Technologies - MWTC)
High Speed Digital Waveform Measurements (10 & 40 Gbit)

DCA Data

LSNA Data

See Offset
See Ripple
See Pattern-Dependent Jitter
See Overshoot
Modeling based on Large-Signal Measurements

• Classic large-signal models are derived from DC and small-signal S-parameters

• Recent approach is to improve and derive the large-signal models directly from large-signal measurements
Empirical Model Improvement
(by Dominique Schreurs, IMEC & KUL-TELEMIC)

GaAs pseudomorphic HEMT
gate l=0.2 um  w=100 um

“Power swept measurements under mismatched conditions”
Optimized Model

Time domain waveforms

Gate voltage
Gate current

Frequency domain

Gate voltage
Gate current

Voltage - Current State Space

Drain voltage
Drain current
Black-Box Frequency Domain Models?

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

“Describing Function” fit by ANN or polynomials
Behavioral Model under Modulation: 1.9 GHz RFIC (CDMA)

Incident signal (a1)

Transmitted signal (b2)
Apply Fitting to Describing Function

- For our example we use a piece wise polynomial (3rd order)
Model Verification - Spectral Regrowth

---model

---measured

Output signal

Amplitude (dBm)

Frequency Offset from Carrier (MHz)
Conclusions

• The dream of accurate and complete large-signal characterization of components under realistic operating conditions is made real

• The only limit to the scope of applications is the imagination of the R&D people who have access to this measurement capability
Coordinates

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