Device Characterization and modeling

DC-to-Daylight

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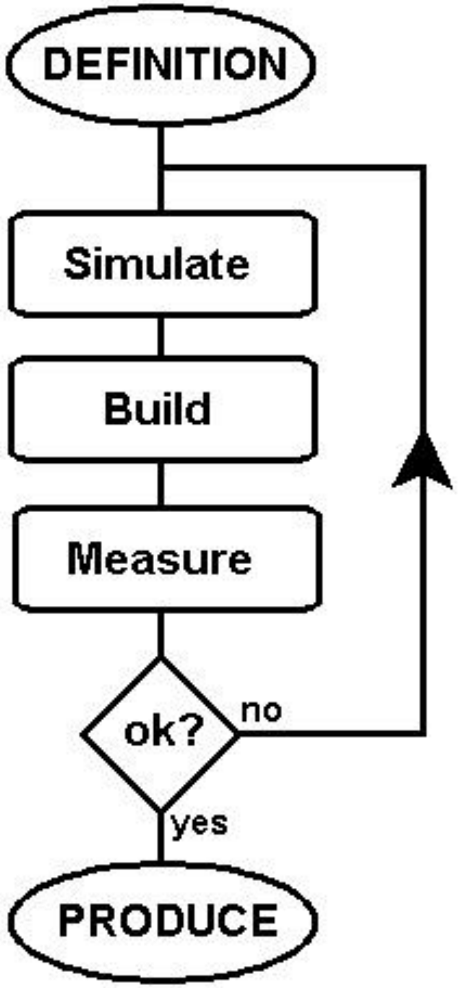
Content

- Introduction
- DC characterization/modeling
  - Pulsed IV
- Capacitances
- AC small-signal measurements
  - For modeling
  - For verification
- Noise and noise parameters
- Power and load-pull measurements

Introduction

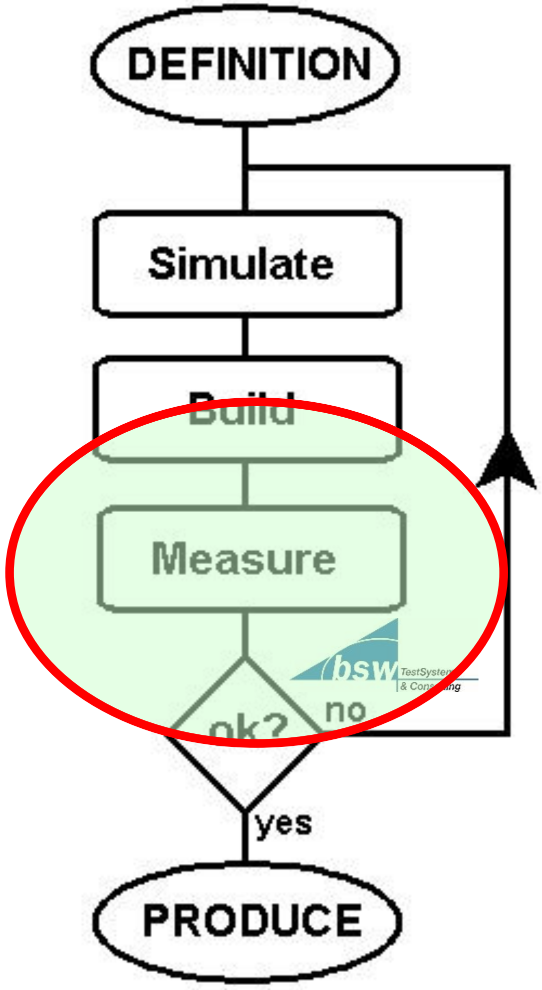
- Design Cycle
- Iterative process
- Need good models
  and measurement capabilities
- Gain experience:
  competitive advantage!



Introduction

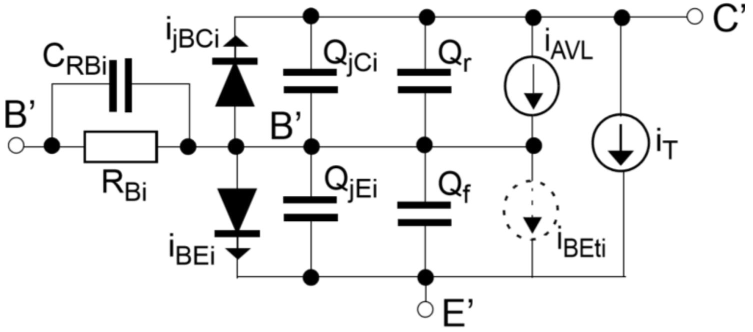
- *bsw* TestSystems and Consulting
- Measure:
  Turn-key meas. systems
- Build:
  component advice and sales
- ok?:
  consulting & training services

- Pre-dominantly in µwave/RF



Introduction

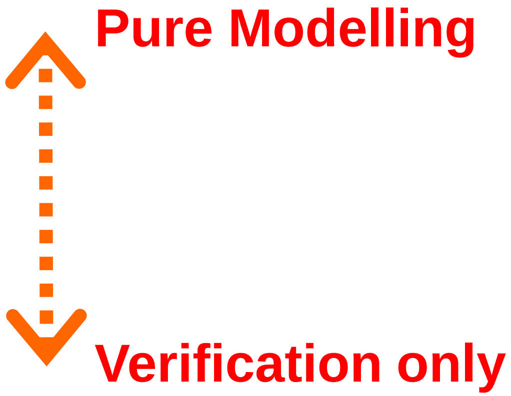
- Semiconductor active device ‘compact’ model:
  - Set of equations or circuit topology
  - Set of parameters
- To create a compact model for use:
  - Choose the topology (‘Model’)
  - Perform many measurements over wide operating range
  - Calculate or extract a basic set of parameters
  - Improve by fitting (all) parameters for good agreement between measurement and simulation.



$$i_T = c_{10}\,\frac{\exp(v_{B'E'}/V_T) - \exp(v_{B'C'}/V_T)}{Q_{pT}}$$

Introduction

- Typical workflow to generate a compact device model:
  - DC characterization/extraction
  - C(V) Measurements
  - Transient or AC small-signal measurements
  - Low frequency Noise or noise parameters
  - Large signal, power and load-pull measurements

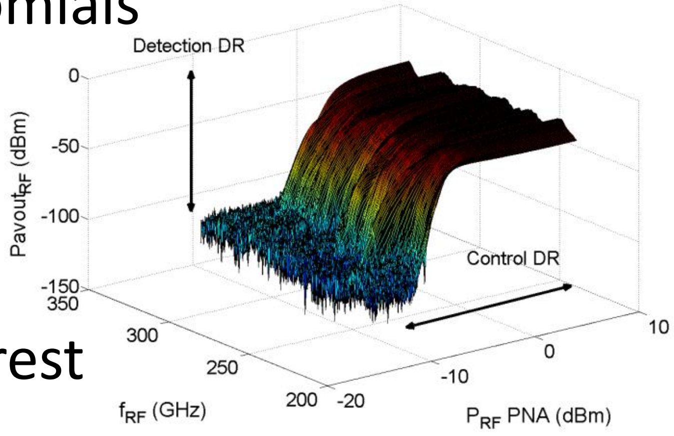


Pure Modelling

Verification only

Introduction

- Semiconductor active device ‘behavior’ model:
  - Huge database of measurements at all modes of operation
  - Set of equations that ‘summarize’ the behavior, e.g. polynomials
  - Set op parameters for the equations (e.g. X-parameters)

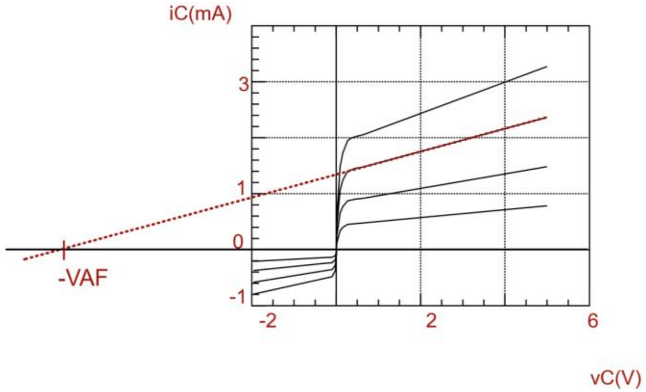


- To create a behavior model for use:
  - Perform many measurements over operating range of interest
  - Store as database or fit parameters for the equations
- Model verification is inherent

Introduction

- Many different Models for
  - Many different applications
    - Digital ⬄ analog
    - Low ⬄ high voltage/current
    - Low ⬄ high ⬄ very high frequency
  - Many different devices and technologies
    - Field-effect, bipolar transistor
    - Si, GaN, GaAs, InP, …
- Foundries supply active device models
  - For standard applications

DC Measurements



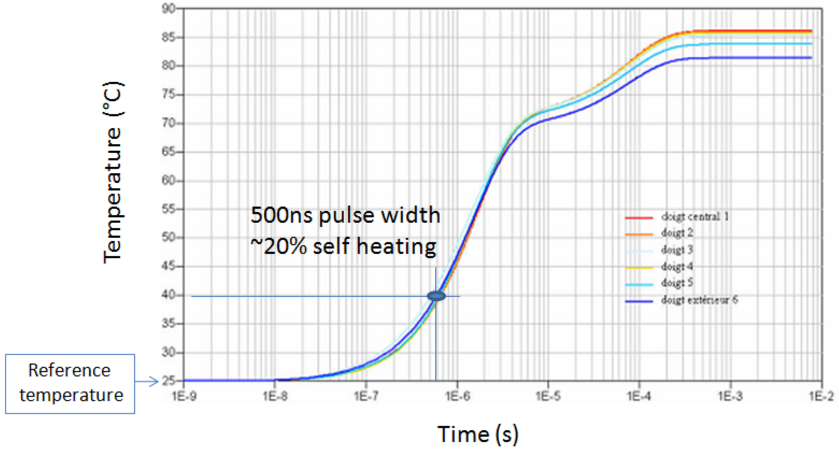
- Collect DC curves
- Extract parameters

- For all devices and applications

- Equipment:
  - Power supplies and IV meters
  - Curve-tracer
  - SMU’s

Device issues on DC

- Temperature increase
  - Isothermal measurements?

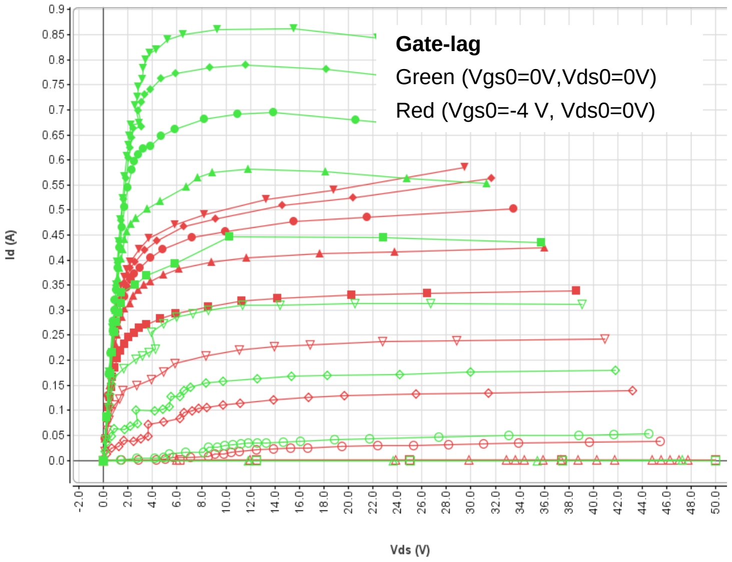


500ns pulse width
~20% self heating

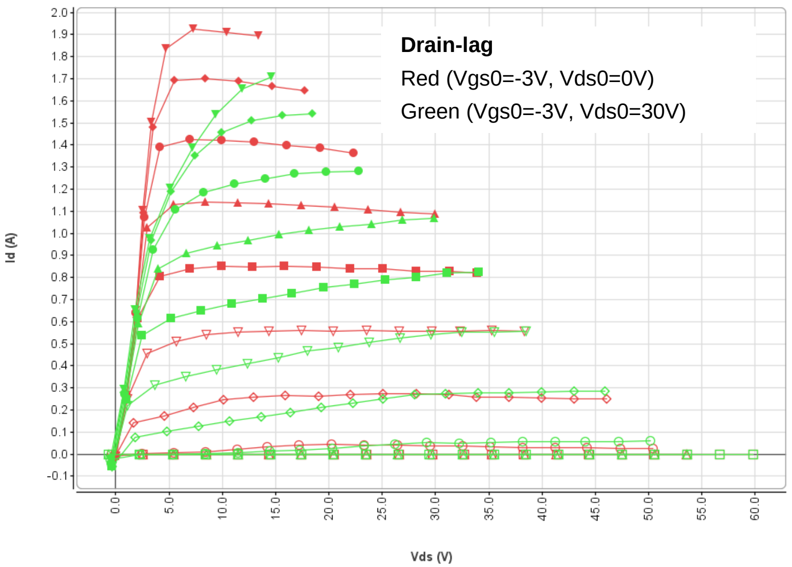
Reference temperature

- Traps, memory effects

Gate-lag: decrease of drain current

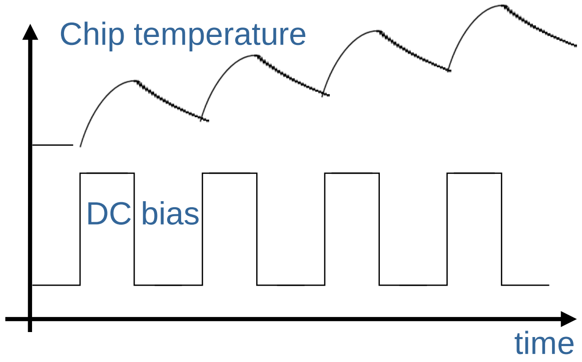


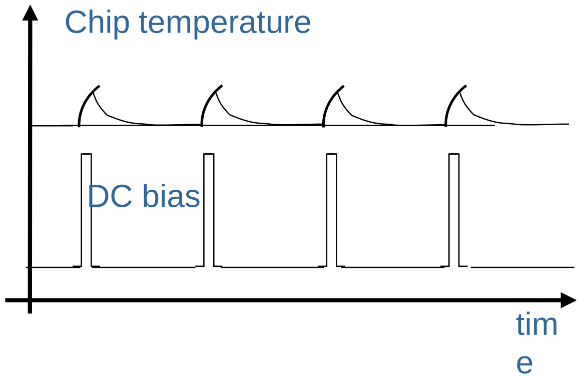
Drain-lag: increase of Vknee



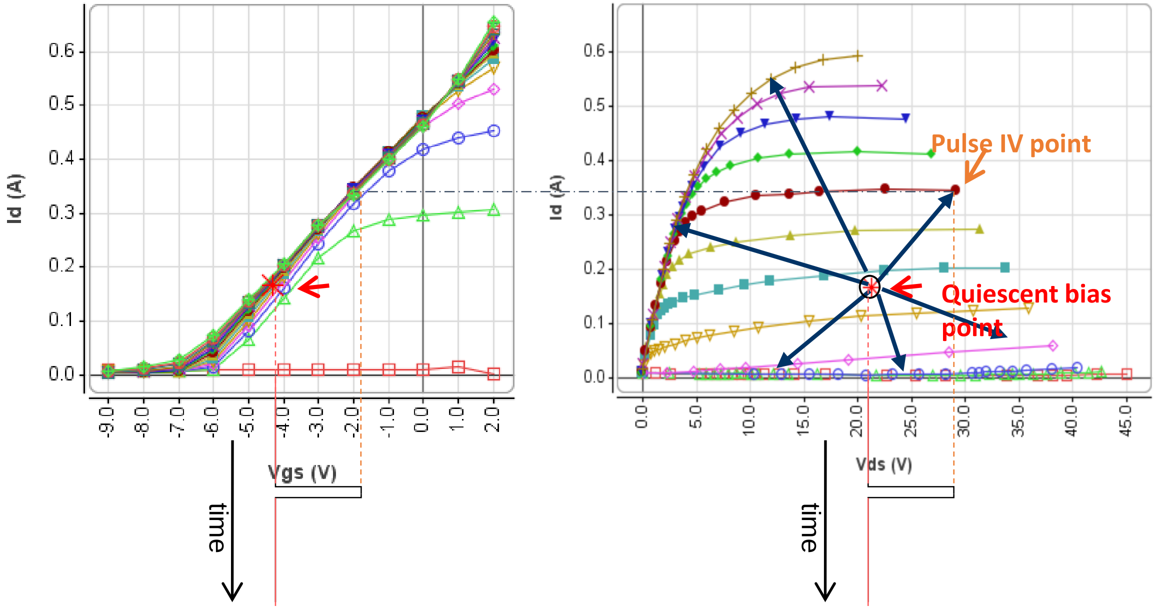
Pulsed IV Measurements

- Low duty-cycle





- Select proper quiescent point
  - low/current/low voltage
  - high current/low voltage
  - high voltage/low current

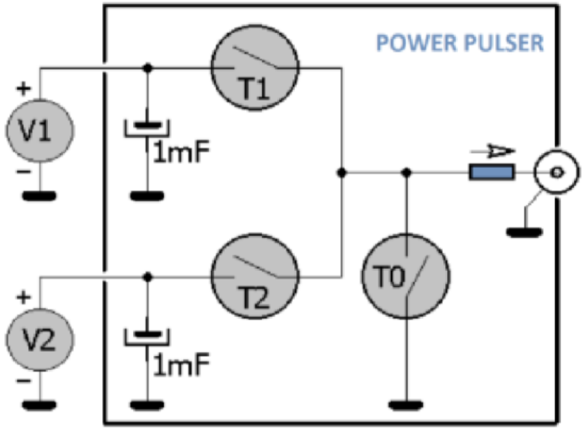


Pulsed IV Measurements

- Hardware with
  - 2 power supplies per channel
  - Sync’d switching between channels

- For power and switching devices
  - GaN

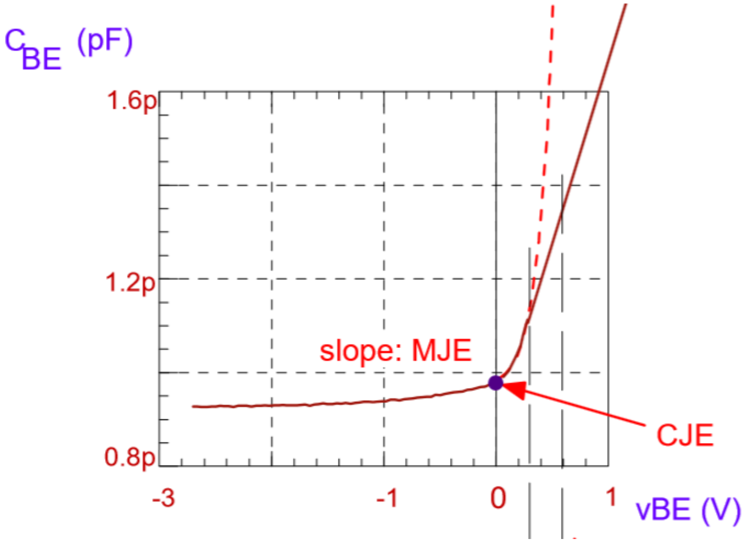
- Issue’s:
  - Pulse shape
  - Short pulses are ~ RF



Capacitances

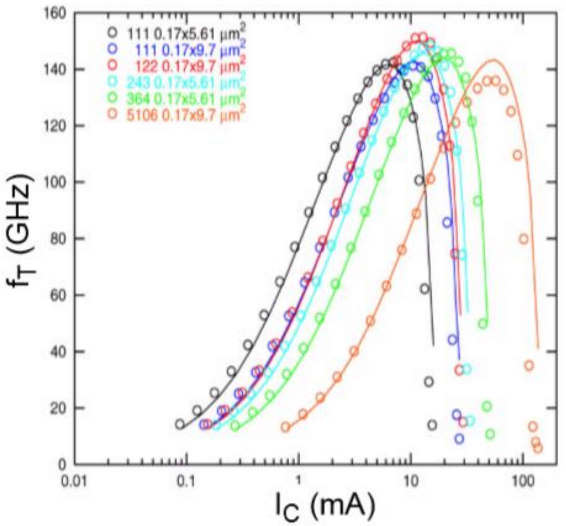
- Capacitances are linked to charges
  - Voltage dependent
- For all devices and applications

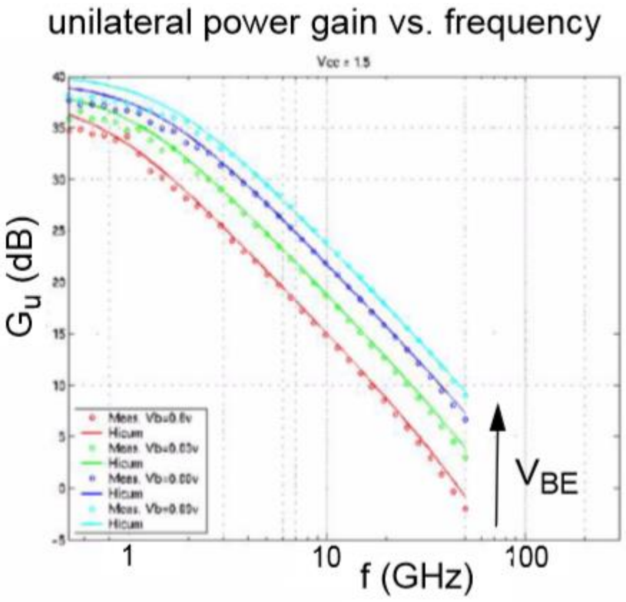
- Measure with
  - CV meter
  - from small-signal S-parameters



AC Measurements

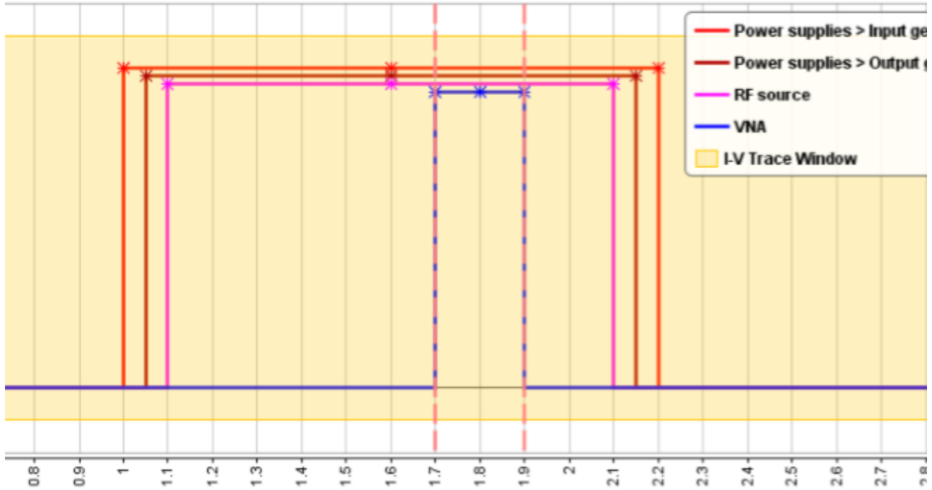
- Measurements to determine:
  - Transit/delay times
  - Capacitances
  - Parasitic R’s
  - Package model, RLCtl’s
- Needed in many models
- Verification of analog, small-signal behavior
- Equipment:
  - Dedicated test equipment
  - Vector Network Analyzer – up to mmWave frequencies!

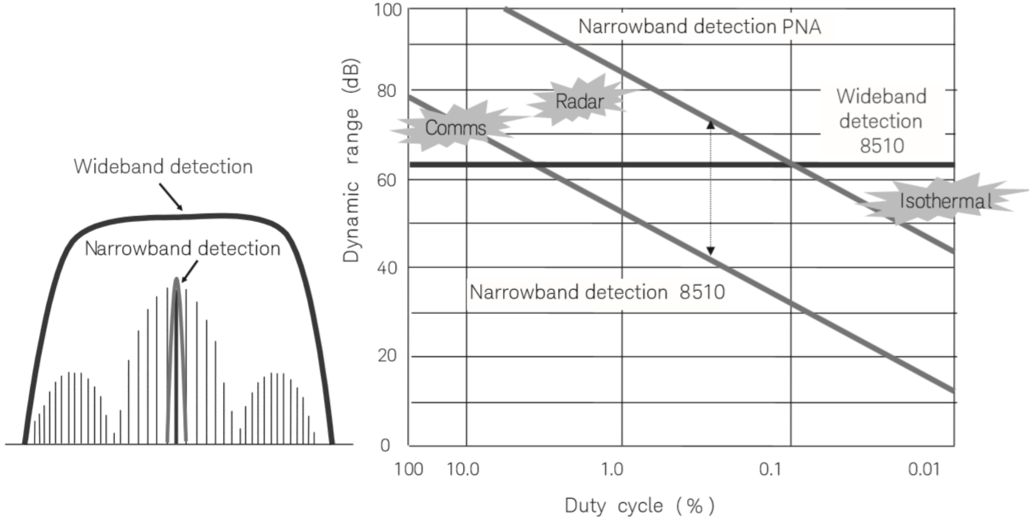




Pulsed S-parameters

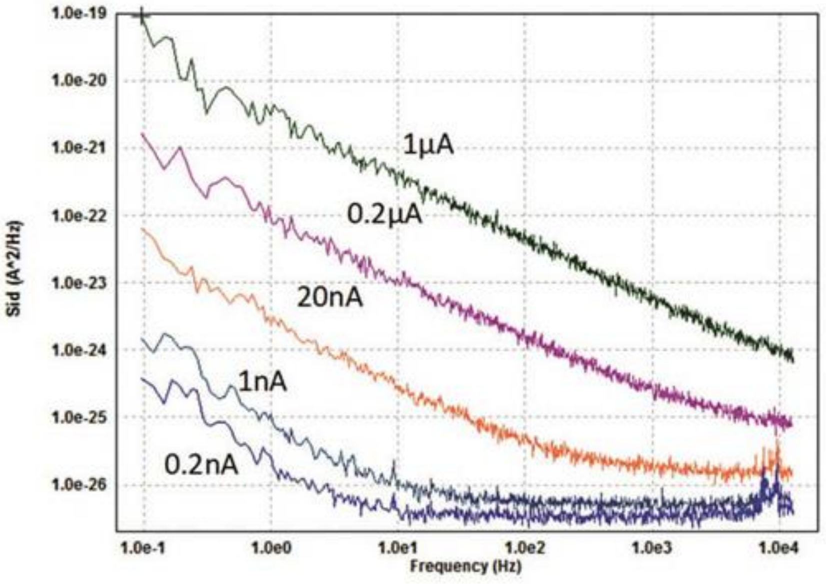
- S-parameters
  - in sync with PIV
- PIV-S issue:
  - Dynamic range

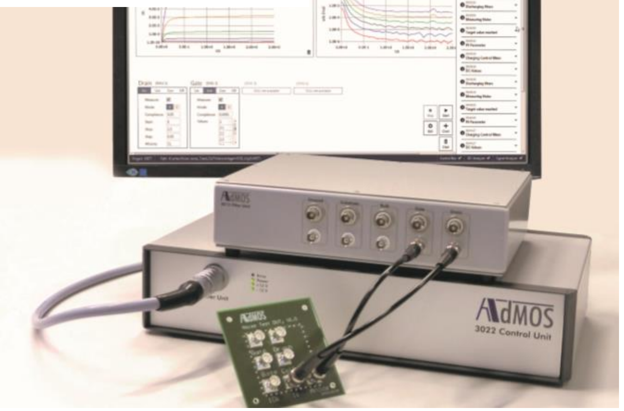




Low frequency noise

- Low frequency noise
  - 1/f noise
  - Channel noise
- Needed for
  - low noise, analog devices
  - Process control
- Equipment:
  - Dedicated setup





Noise Figure

- Signal to noise ratio degradation

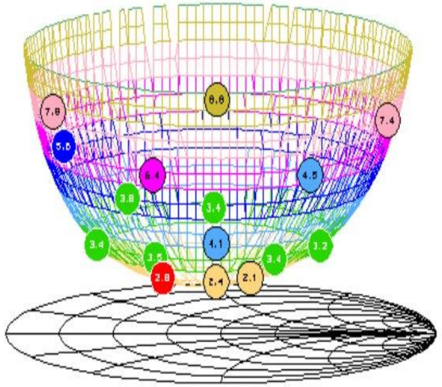
$$F = \frac{\left(S/N\right)_i}{\left(S/N\right)_o} = \frac{N_o}{GN_i}$$

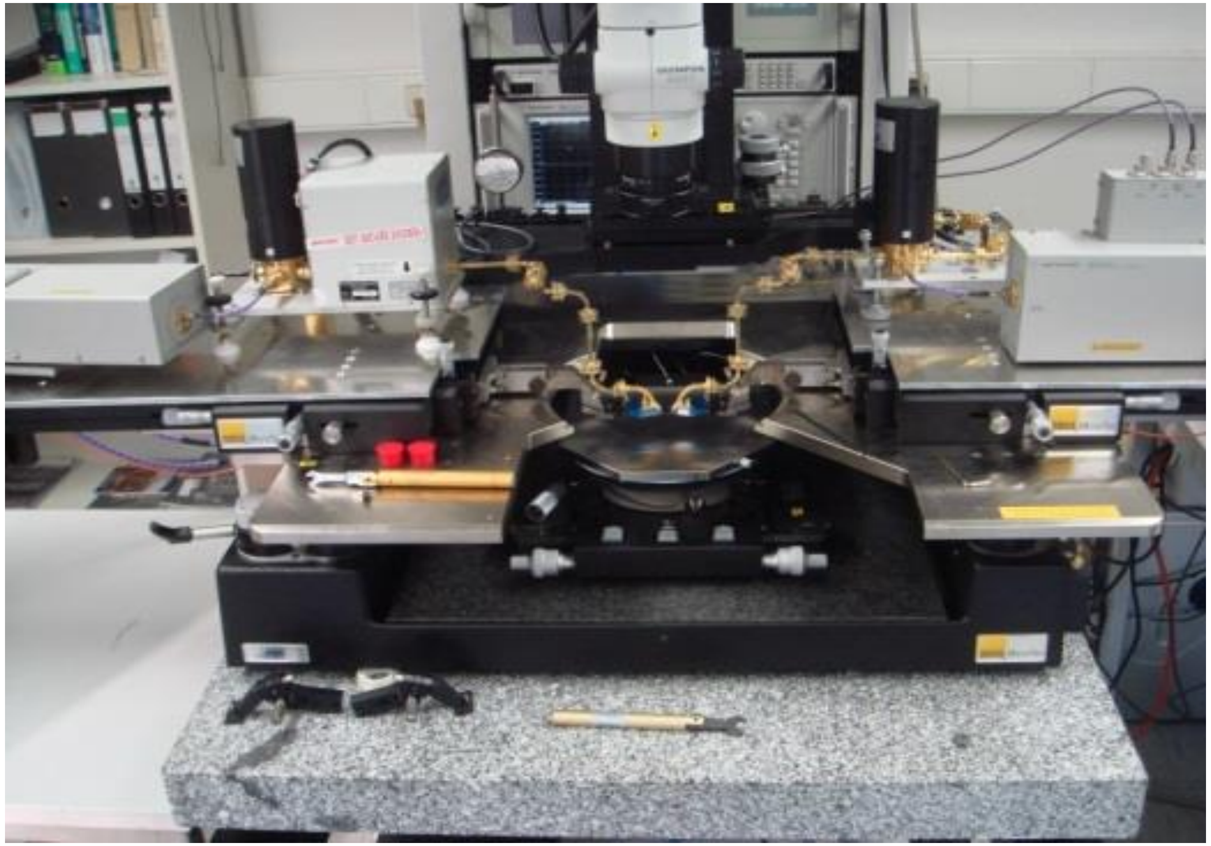
- Equipment:
    - Sensitive receiver: NFM, SA, VNA

Noise Parameters

- Dependency of ***F*** to source admittance
- For verification:
  - Quality of modeling
  - Quality of device operation
  - Quality of processing
- Needed for
  - low noise, analog RF/µwave devices
- Equipment:
  - Dedicated setup
  - Measure S+N

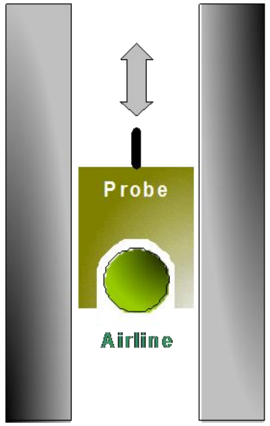
$$F(\Gamma_s) = F_{\min} + 4r_n \frac{\left|\Gamma_{opt} - \Gamma_s\right|^2}{\left(1 - \left|\Gamma_s\right|^2\right) \cdot \left|1 + \Gamma_{opt}\right|^2}$$

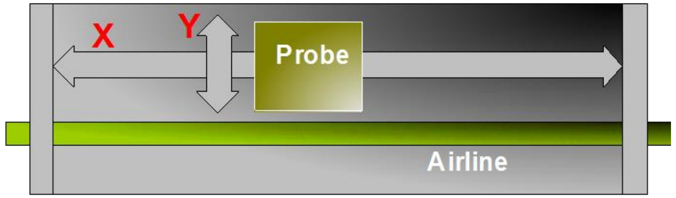




Large Signal measurements

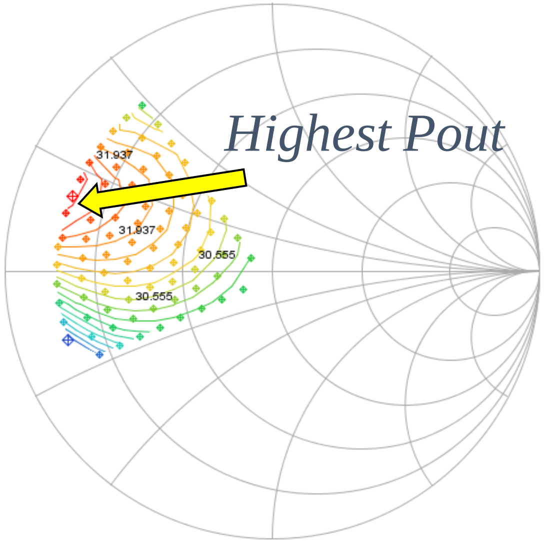
- Device excitation to the max
  - Clipping of waveforms
  - Increased distortion: H2, IM3, ACPR
- Difficult for compact model
  - Switch to behavior model
- Follow application
  - Optimize source/load impedances for best operation → use Impedance **Tuner**

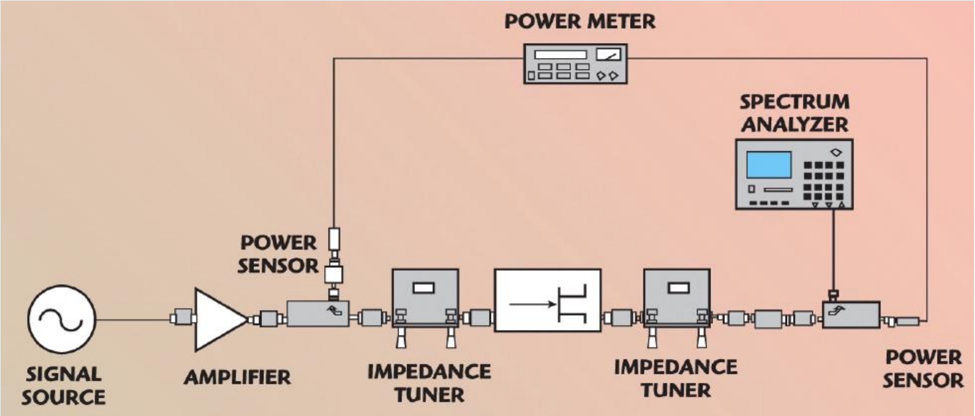


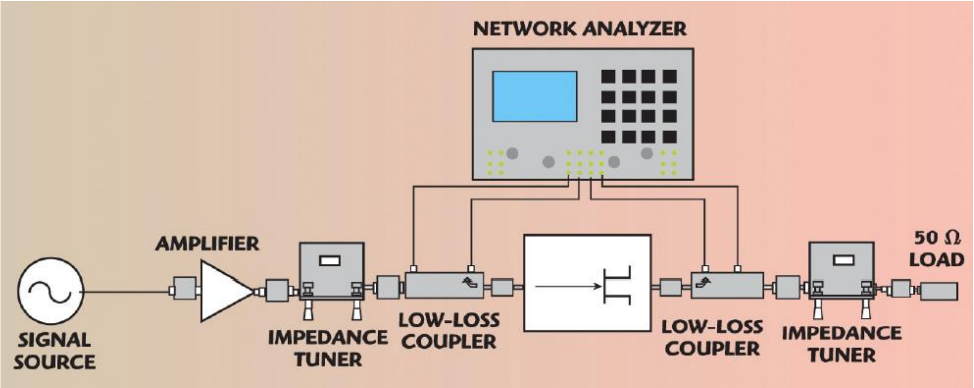


Source/Load-pull

- Large Signal measurement equipment:
  - Tuners
  - VNA
  - Amplifiers
  - Power meter
- Addressing accuracy:
  - Scalar LP: low
  - VNA based LP: good







Trends

- Smaller nodes become more difficult to model
  - Lower voltage/current
  - Higher frequencies
  - Importance of noise
- Even digital cells require more extensive analog design
- Increased use of behavior models for demanding applications
- New technologies entering old design area’s
  - E.g. GaN for switched mode power convertors
- 5G boost µWave/mmWave applications

Conclusion

- A Birds perspective is given about
  - Active device model types: Compact an Behavior
  - Characterization/measurement techniques for modeling: from DC to daylight
- The modeling work extends further into area’s of
  - Lower power (DC)
  - Higher power (DC&RF)
  - Higher frequencies
  - Complexer applications
- Trend is towards an increase of interest and need for modelling and characterization of active devices