Variable Termination Unit for Noise-Parameter Measurement

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Outline

- Motivation and background
- VTU design
- VTU characterization
- Noise-parameter measurements with VTU
- Conclusions and future work

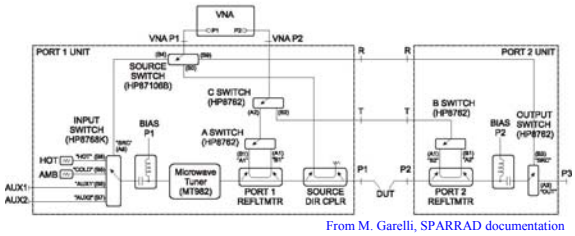
Motivation and background

- Interest and need for accurate measurements of noise properties
  - Rapid developments of low noise amplifier
  - Packaged and on-wafer types
- *IEEE* noise parameter
  - T_{min}, R_n, and complex Γ_{opt}
  - Challenges in measurements and data analysis

- Noise-parameter measurement method
  - Source-pull
- Previous approach (manual connection)
  - Time consuming
  - Repeatability needs improvement
- Variable termination unit (VTU)
  - automated, accurate and highly reproducible

Other possible options

- Tuner system



From M. Garelli, SPARRAD documentation

- Real-time measurements
- Sophisticated architecture
- VNA presented on-line

- Electronic calibration module

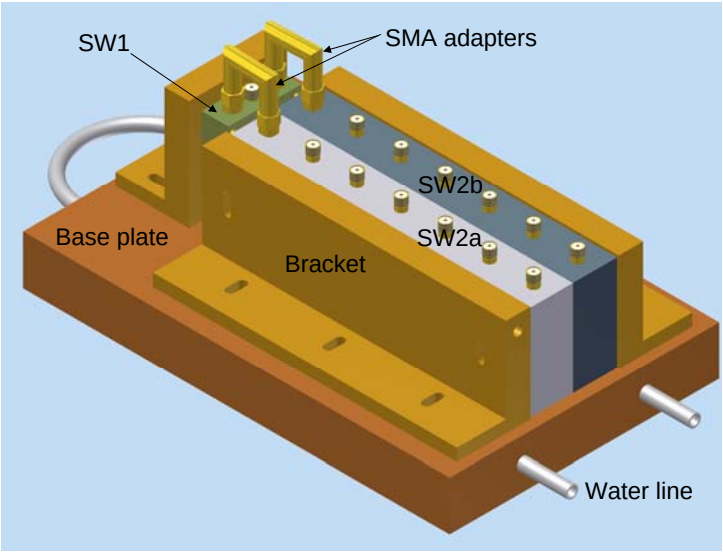
From Agilent E-cal manual

- Compact multi-impedance provider
- Limited states
- Active devices (T_{out})

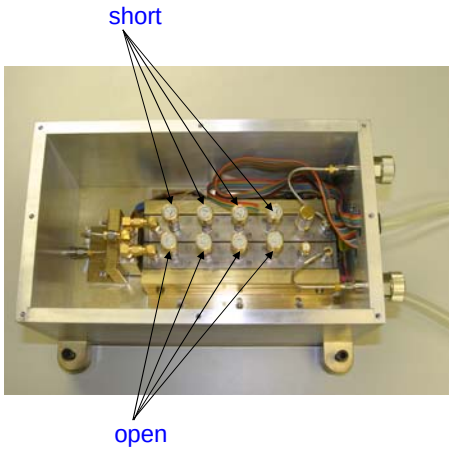
Design of VTU

- **Termination selection**
  - Minimization of measurement error propagation
  - Enough impedance distribution for data fitting redundancy
  - Variable input noise temperature (cold, ambient, and hot)
- **Temperature stabilization**
  - Noise power emitted from passive terminations is temperature dependent
- **Vibration control**
  - Repeatability concern, especially true for on-wafer environment

VTU illustration

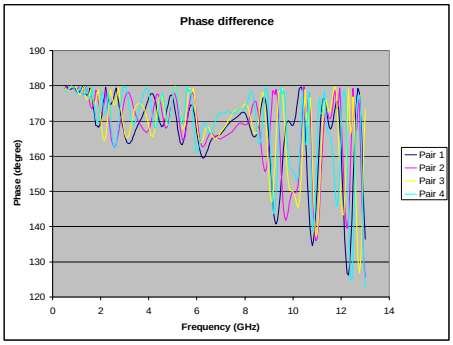


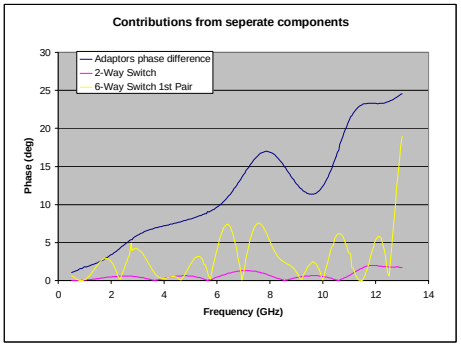
Old and new VTUs



VTU Characterization

- Phase match on paired ports





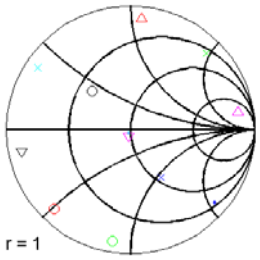
Phase mismatch appears larger at higher frequencies

SMA adapters contribute the most of phase mismatch

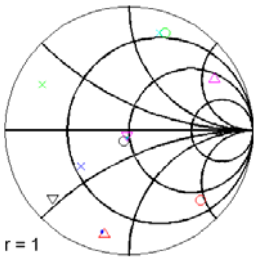
VTU Characterization

- Impedance coverage
  - Satisfactory coverage of four quadrants of the Smith chart at all integer frequencies (1-12 GHz)

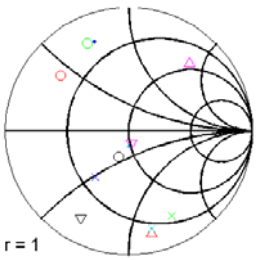
2 GHz



6 GHz

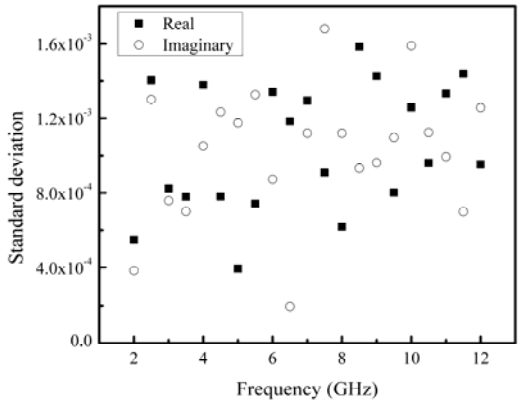


9 GHz

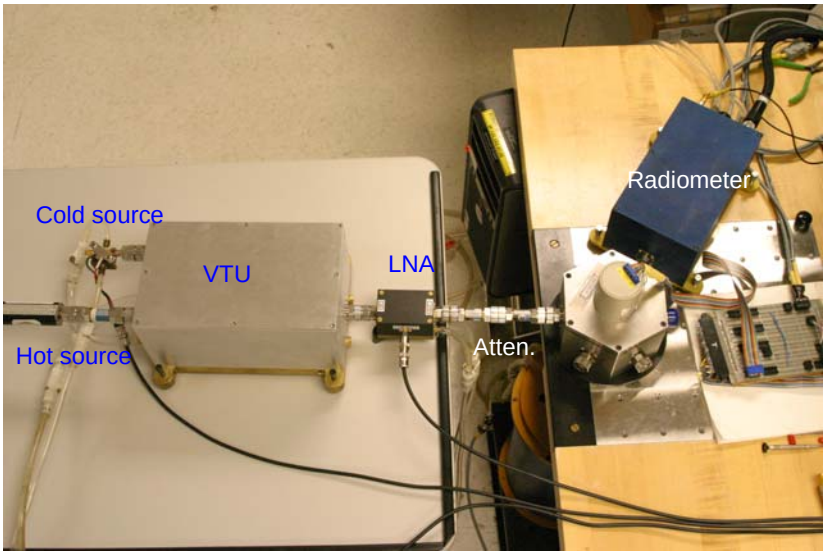


VTU Characterization

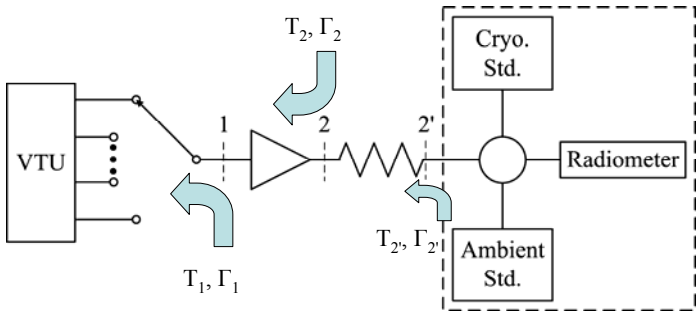
- Repeatability
  - Standard deviation of Γ < 3E-3 (Example: T3)



Noise-parameter measurements on a packaged amplifier

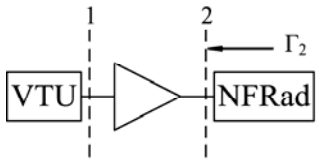


Noise-parameter measurement diagram

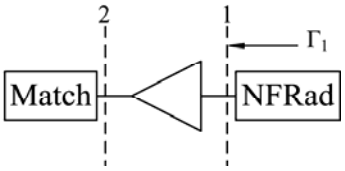


Noise-parameter fit

- Theoretical background
  - Noise wave representation (*X* parameters)
  - Additional by-product: reduced gain ($|S_{21}|^2$)



Forward



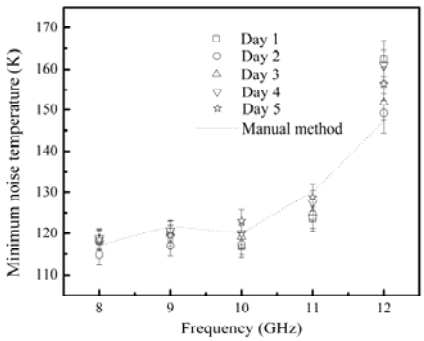
Reverse

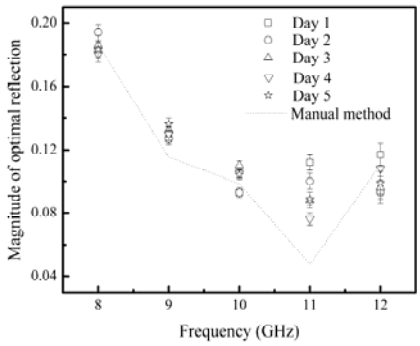
$$T_2 = \frac{|S_{21}|^2}{\left(1-|\Gamma_2|^2\right)}\left\{\frac{\left(1-|\Gamma_S|^2\right)}{|1-\Gamma_S S_{11}|^2}T_S + \left|\frac{\Gamma_S}{1-\Gamma_S S_{11}}\right|^2 X_1 + X_2 + 2\,\mathrm{Re}\left[\frac{\Gamma_S X_{12}}{1-\Gamma_S S_{11}}\right]\right\}$$

$$T_1 = \frac{1}{\left(1-|\Gamma_1|^2\right)}\left\{\frac{|S_{12}|^2\left(1-|\Gamma_S|^2\right)}{|1-\Gamma_S S_{22}|^2}T_S + X_1 + \left|\frac{S_{12}S_{21}\Gamma_S}{1-\Gamma_S S_{22}}\right| X_2 + 2\,\mathrm{Re}\left[\frac{S_{12}S_{21}\Gamma_S X_{12}^*}{1-\Gamma_S S_{22}}\right]\right\}$$

Noise-parameter results

- Uncertainty (type-A + type-B) of T_{min} is below 3%.





Conclusion and future work

- The VTU demonstrated highly repeatable performance.
- Time efficiency has been greatly improved by more than a factor of five.
- The VTU is a fully stand-alone and mobile unit.
- The on-going noise figure verification project indicates the functionality of VTU over the design frequency band (1-12.4 GHz).
- Future work includes the implementation of VTU in the on-wafer measurements on transistors.