Introduction to Noise Parameters
Noise Parameters

Noise Figure:
• Noise Performance at one Impedance
• Typical – 50Ω Noise Figure

Noise Parameters:
• Noise Performance at any Source Impedance
Noise Parameters

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

Four Scalar Values:

- \(F_{\min}\)
- \(\Gamma_{opt} \rightarrow |\Gamma_{opt}|, \angle \Gamma_{opt}\)
- \(r_n\)
Noise & Gain Circles
Noise Parameters Measurement

General Method

- Set 4 Values of $\Gamma_s$
- For Each $\Gamma_s$, Measure $F$
- Solve 4 Simultaneous Equations for the 4 Values

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

Practical Method

Use Over-Determined Data:

- Measurement is Sensitive to Small Errors
- Measure at more than 4 \( \Gamma \)’s Values
- Use Least-Mean-Squares to Reduce Data

Use Noise Power Equation:

- Rigorous Solution
- Account for \( \Gamma \)hot and \( \Gamma \)cold of Noise Source
- Allows Hot/Cold or Cold Only Approaches

\[
P = kB\{[t_{ns} + t_0(F_1 - 1)]G_{A1} + t_0(F_2 - 1)\}G_{T2}
\]
Data Collection Methods

Traditional Method

- One Frequency at a Time
- Allows Ideal Impedance Pattern
- Based on 1969 Paper
- Used by everyone for almost 40 years

Very Time Consuming

- Can Have Drift Issues
- Data Scatter

Ultra Fast Method*

- Characterize One Set Of Tuner States
- Sweep Frequency at Each State
- Take Advantage of Fast Sweep of Modern Instruments

*Invented by Maury Microwave

US Patent 8,892,380
Typical Maury on-wafer noise parameters system
Noise Parameters System Photo
Noise Parameters Measurement Results

On-Wafer, 8-50 GHz, Fmin= 0.35 – 0.9 dB

Measured Data, No Smoothing Applied
Data Outliers and Noise Data Processing

- Transistor Data should be continuous
- Noise Measurements are Over-Determined
- Noise Data results should always come from one set of measured data.

Processing:
- Data Outlier causes change from good data
- Calculate Noise Parameters from Subsets to Remove Outliers
- Errors add or cancel at different frequencies
- Data Scatter vs Frequency is an Indicator of the measurement quality
- Removing outliers tends to reduce scatter
Noise Parameter Validation & Confidence in Measurements
Measurement Confidence

System Accuracy is established using known devices:
- Passive Verification Devices
- Active Device as Golden Standard
- Cascade Verification

System Repeatability must be a requirement:
- Measurement Repeatability
  - Multiple calibrations
  - Overlap bands with different tuners or receivers
  - Comparison with other Labs
- Benchmark with legacy ATN systems
A passive device tests accuracy of:

- S-Parameter Measurements
- Noise Calibration
- Noise Measurement
Passive Device Measurement

Two Options:
• Matched Passive Device $\rightarrow$ Some Errors are Masked
• Mismatched Passive Device $\rightarrow$ Better Test

Known Limitation: System is tested at a different Gain Range than Active DUT
Passive Device Measurement

6dB Mismatch comparison: NFmin

Fmin (dB)

Freq (GHz)

ATS_with NRM  Passive verification
Active Device as Golden Standard

• Challenges:
  • Selecting a stable bias condition for repeatable measurements
  • Device wears out over multiple touch-downs
  • Device performance can change over time

• Benefits:
  • System verification is established using similar DUT conditions

• Recommendations:
  • Multiple known devices based on reference measurements
  • Limit the usage of these golden standards to system verification only
1. Measure Noise
2. Measure S-Para
3. Measure Noise
4. Calculate Noise

**Advantage:** System is tested at same Gain Range as Active DUT
System Repeatability

• Measurement Repeatability
  • S-parameters
  • Multiple calibrations
  • Overlapping bands with different tuners (same or different setups)
  • Comparison between measurements at different sites

• Benchmark with legacy ATN system
Noise Measurement Repeatability

- On wafer Calibration measured over multiple days
- Excellent repeatability
  - Complete tear down and rebuilding setup
  - Multiple coaxial and on-wafer calibrations
Measurements at Different Sites

Maury (CA)  Modelithics (FL)

Raw Data

Processed Data
Benchmark With Legacy ATN System

- ATN/NP5
- ATS

![Graph showing NFmin (dB) vs Frequency (GHz) for ATN/NP5 and ATS](image)
Critical Variables that Affect Noise Parameters Measurements
**NRM** To increase the sensitivity of DUT noise measurement a LNA stage is required.
### Maury Microwave Noise Receiver

<table>
<thead>
<tr>
<th>Model</th>
<th>Freq range</th>
<th>Noise Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT7553B03</td>
<td>0.1-50GHz</td>
<td>10dB Typical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16dB Max</td>
</tr>
</tbody>
</table>

- Hold your solutions providers accountable!
- Published vs actual data comparison

On wafer calibration
Measurement Problems
- Too much attenuation
- Too low attenuation
- Receiver overload

• Maury SW has the ability to calibrate at multiple attenuation levels
• Dynamically chooses the right attenuation during DUT measurements
Shields cell phone and wireless signals that can interfere with noise measurements.

**Screened Room (Faraday Cage)**

- Noise calibration (0.8 to 8 GHz)
- Interference point at 1.9 GHz
• Need a good $\Gamma_S$ spread at every frequency
• Need to have the $\Gamma_S$ spread include high gamma values.

Typical $\Gamma_{OPT}$ DUT

Low $\Gamma_S$ spread

Bad $\Gamma_S$ spread

Good $\Gamma_S$ spread
• At some high-gamma states, oscillation could occur
• MMC Software detects oscillation states and removes them
• Points in the stability circle may not be unstable, they are only **Potential Unstable**, stability also depends on the output load
• **But most high-gamma states are useful** – \( \Gamma_{OPT} \) can be within stability circles