**Introduction**

- The goal of this research is to integrate microwave-frequency Large Signal Network Analysis capabilities with commercially available National Instruments’ PXI modular instrumentation and LabVIEW environment.
- The Microwave Research Group at the University of Colorado has decades of experience in UHF through millimeter-wave transmitters, including recent X-band (10-GHz) MMIC implementations in GaN. Our aim is to extend the frequency range and capabilities of available commercial instrumentation provided by NI.
- The proposed instrumentation development will enable new types of measurements such as those required for harmonically-terminated PAs, various transmitter architectures (Doherty, outphasing and supply modulated PAs), as well as microwave transistor rectifiers. The time-domain characterization is expected to provide dramatic improvement in RF circuit design capabilities.

**LSNA calibration algorithm**

LSNA calibration algorithm consists of 3 steps at each RF frequency:

1. A relative VNA calibration creates an error-term matrix related to ports 1 and 2:

   $\begin{pmatrix}
   a_1 & b_1 \\
   a_2 & b_2 \\
   \end{pmatrix} = K \begin{pmatrix}
   1 & \beta_1 & 0 & 0 \\
   \gamma_1 & \delta_1 & 0 & 0 \\
   0 & 0 & \alpha_2 & \beta_2 \\
   0 & 0 & \gamma_2 & \delta_2 \\
   \end{pmatrix} \begin{pmatrix}
   r_1 \\
   r_2 \\
   r_3 \\
   r_4 \\
   \end{pmatrix}$

2. The power calibration gives $|K|$

3. The phase calibration yields $\arg\{K\}$

Power and phase calibration are performed at an auxiliary reference plane ($P_{aux}$) after its own 1-port SOL coaxial calibration:

$\begin{pmatrix}
\alpha_{aux} \\
\beta_{aux} \\
\gamma_{aux} \\
\delta_{aux} \\
\end{pmatrix} = K \begin{pmatrix}
1 & \beta_{aux} \\
\gamma_{aux} & \delta_{aux} \\
\end{pmatrix} \begin{pmatrix}
r_1 \\
r_2 \\
\end{pmatrix}$

- **Power** calibration at $P_{aux}$ reference plane requires the connection of a power sensor. According to the measured value, in dBm, we can calculate $|K_{aux}|$ such as:

  $|K_{aux}| = \frac{10^{(Power-10)/20}}{r_1 + \beta_{aux} r_2}$

- **Phase** calibration at $P_{aux}$ is performed by connecting a direct receiver (e.g. $r_3$) at $P_{aux}$:

  $\arg\{K_{aux}\} = \arg\left\{\frac{r_3}{r_1 + \beta_{aux} r_2}\right\}$

- **Reciprocity** transfers the absolute calibration from $P_{aux}$ to ports 1 and 2 ($P1$ and $P2$):

  $K = \pm \sqrt{\frac{1}{\text{Det}(M)}}$

  with

  $M = \begin{pmatrix}
  1 & \beta_1 \\
  \gamma_1 & \delta_1 \\
  \end{pmatrix} \begin{pmatrix}
  1 & \beta_{aux} \\
  \gamma_{aux} & \delta_{aux} \\
  \end{pmatrix}^{-1}$

**Measurement Setup for Envelope Tracking Application**

The setup includes two LSNA simultaneously. One is dedicated to RF (sampler based downconversion), the other one samples directly the LF stimulus. The purpose is to investigate low-frequencies $f_2$ of the DUT under RF large signal conditions.

**LSNA (Large Signal Network Analyzer)**

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- **RF Source**
- **RF Driver**
- **RF Coupler**
- **GaN HEMT**
- **RF Coupler**
- **RF Bias Tee**
- **RF LSNA**
- **RF Source**
- **RF Driver**
- **RF Coupler**
- **GaN HEMT**
- **RF Coupler**
- **RF Bias Tee**
- **RF LSNA**
- **RF Source**
- **RF Driver**
- **RF Coupler**
- **GaN HEMT**
- **RF Coupler**
- **RF Bias Tee**
- **RF LSNA**

**Conclusion**

This new project will enable a new RF measurement capability by enabling an instrument that currently does not exist on the market. Some additional benefits include:

- Frequency range extension of NI RF instrument products currently available;
- Sampler architecture offers a unique multi-scale time analysis possibility (e.g. signal and carrier domains);
- can be implemented with various ADCs and downconverters (e.g. THAs);
- 100% LabVIEW environment;
- goal is to offer open-source LabVIEW software for user measurement flexibility.

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**Table: Time-domain instrumentation for non-linear devices**

<table>
<thead>
<tr>
<th>Name</th>
<th>Manufacturer</th>
<th>Receivers</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTA (requires two synchronized)</td>
<td>HP</td>
<td>Sampler</td>
<td>Discontinued</td>
</tr>
<tr>
<td>LSNA</td>
<td>Agilent</td>
<td>Sampler</td>
<td>Discontinued</td>
</tr>
<tr>
<td>PNA-X + Nonlinear option</td>
<td>Agilent</td>
<td>Mixer</td>
<td>$$$</td>
</tr>
<tr>
<td>ZVA + Nonlinear option</td>
<td>Rohde and Schwarz</td>
<td>Mixer</td>
<td>$$$</td>
</tr>
<tr>
<td>SWAP X- 402</td>
<td>VTD</td>
<td>Sampler</td>
<td>Discontinued</td>
</tr>
</tbody>
</table>