ARFTG-NIST Short Course on Microwave Measurements

Nov. 28th – 29th, 2017
Boulder, Colorado

ABSTRACT

---

1. **Microwave Power Measurements and Uncertainties**
   Ron Ginley, NIST

   The basic aspects of microwave power measurements will be covered. These include definitions of what we measure, the traceability path for power, different types of power detectors, the considerations for calibrating power detectors such as simple systems and mismatch factor and uncertainty involved in power measurements. Several practical examples are also given.

2. **VNA Measurements, Calibrations and Uncertainties**
   Ken Wong, Keysight Technologies

   This module of the short course covers the fundamental principle of vector network analyzer measurements, error models, calibration methods and standards. Calibration errors and uncertainty analysis principles will be presented as well.

3. **Time-domain measurements for microwave applications: What the manual doesn't tell you**
   Paul Hale, NIST

   The differences between high-speed real-time and equivalent-time oscilloscopes will be discussed along with digitizing receivers and the errors inherent in these instruments. Methods for traceably calibrating the instruments with particular emphasis on equivalent-time oscilloscopes will be presented. Some examples of digital and RF measurement configurations will be described with particular attention to achieving the highest possible accuracy and precision.

4. **RF & Microwave Noise Measurement**
   Gary Simpson, Maury Microwave

   Noise is a major factor in the design of low noise amplifiers and receiver front ends. It can hide a low level signal and prevent a reception of that signal. This presentation will introduce sources and nature of noise, and the effects of noise on communication systems, primarily emphasizing thermal noise. It will cover the definition and application of noise figure, as well as noise parameters and their application to amplifiers and receivers. Emphasis will be placed on the measurement methods of noise figure and noise parameters.

5. **<u>Connectorized Millimeter-Wave S-Parameter Measurements</u>**
Jon Martens – Anritsu

Connectorized S-parameter measurements take on some new dimensions at mm-wave frequencies in terms of changes in component modeling, repeatability characteristics and calibration choices. These behaviors will be discussed with a primary focus on 1 mm and smaller coaxial connectors and on comparisons to relevant waveguide performance. The parameterizations of the measurements (in terms of power sweeps, transient S-parameter responses, etc.) also may change at these higher frequencies and some of those aspects will also be covered.

6. <u>Waveform and Modulated-Signal Traceability for Millimeter-Wave Applications</u>
Dylan Williams, NIST

Modulated-signal traceability requires capturing correlations in the uncertainty analysis, and has only recently become possible. Dr. Williams will discuss how modulated-signal traceability is achieved at NIST, and the wide variety of related problems in metrology being addressed at NIST.

7. <u>Microwave metrology of nano-electronic devices and nanomaterials</u>
Mitch Wallis, NIST

The ongoing miniaturization of electronic devices has led to the discovery of new nanomaterials and new phenomena at the nanoscale. In turn, this has led to the design, fabrication, and development of RF nanoelectronic devices that incorporate nanoscale elements or nanomaterials, such as carbon nanotubes, semiconducting nanowires, or graphene. Reliable, accurate, on-wafer measurements of such devices are critical to their optimization and commercialization. To this end, a full framework, including measurement, modeling, and validation, has been developed for on-wafer characterization of RF nanoelectronics. The calibration approach is based on the on-wafer, multiline thru-reflect-line technique. Further, this framework addresses the inherent impedance mismatch between RF nanoelectronic devices and commercial test equipment. Finally, circuit and finite-element models are used to extract circuit and material parameters for the devices.

8. <u>New Methods for Data Analysis and Management</u>
Aric Sanders, NIST

Fundamental traceable measurements of microwave quantities such as impedance and power are of primary concern to engineers and measurement staff across research laboratories and industry. These measurements can benefit from advances in modern computing techniques. In this short course we will discuss different models for better measurement work flows, data representation and storage. In addition, we will discuss better methods to implement such technologies to make them generally available to a wider audience.

9. <u>Vectorial large-signal measurements</u>
Dominique Schreurs, KU Leuven

The lecture focuses on vectorial large-signal measurements, which means that both amplitude and phase of nonlinear signal spectra are characterized. The instrument architectures to achieve such measurements are explained, highlighting the respective benefits and drawbacks. The lecture proceeds with covering calibration and de-embedding processes, and finally also the corresponding measurement uncertainty is discussed.

10. Microwave Radiometry for Internal Body Temperature Measurements
Prof. Zoya Popovic, University of Colorado, Boulder

This talk introduces measurement challenges related to near-field radiometry for internal temperature measurements of the human body. First an experimental Dicke radiometer is presented; it operates in the 1.4-GHz quiet band for centimeter penetration into tissues with minimized radio-frequency interference (RFI). The total blackbody power from a tissue stack is received by a probe placed on the skin, designed to receive a high percentage of the total power from a buried tissue layer. Temperature retrieval for sub-surface tissue layers is performed using near-field weighting functions obtained from full-wave simulations. The radiometer is demonstrated to track the temperature of a phantom muscle tissue layer under phantom fat and skin layers within a fraction of a degree. It is shown that RFI can be reduced through use of a second probe and adaptive processing. Measurements on the human cheek show good agreement with independent thermocouple measurements inside the mouth. Both radiometer and model calibration, as well as alternative circuit architectures, are discussed.

11. Application of Vector Nonlinear Microwave Measurements to Modeling and PA Design
Patrick Roblin, Department of Electrical and Computer Engineering, The Ohio State University

The advent of nonlinear vector network analyzers (NVNA) has stimulated the introduction of new paradigms in microwave engineering for (1) the measurement, (2) the modeling and (3) the design of nonlinear microwave circuits such as microwave power amplifiers and oscillators. In this lecture the behavioral models used for the representation of the measured multi-tone multi-harmonic data will be reviewed. This will include the general multi-harmonic Volterra functions for CW periodic nonlinear RF excitations, the X-parameter/S-function approximations for mildly nonlinear RF excitations and their extension for modulated multi-harmonic signals. Circuit-based nonlinear microwave models can also be directly extracted from large-signal measurements. Examples of SOS-MOSFET and GaN models extracted and verified using a few real-time active load pull (RTALP) measurements will be presented. NVNA's also find application in the design of power amplifiers (PA). Examples of Doherty and Chireix amplifiers design designed with a *nonlinear embedding device model* will be presented together with the verification of the resulting transistor operation using NVNA measurements.

12. Application of RF I-V Waveform Measurements and Engineering
Paul J. Tasker, Cardiff University, UK

In the design of high efficiency microwave power amplifiers (PA's), it is a well-established fact that the fundamental theoretical understanding is best undertaken by considering the time varying voltage and current waveforms present at the transistor terminals. However, typically microwave measurements, and CAD design approaches, undertaken to support, or perform, power amplifier design are typically done in the frequency domain. For example; load-pull measurements and simulations. Hence, high frequency PA design and optimization has had to follow alternative strategies. Microwave measurements systems can now be configured to measure and engineer current and voltage time varying waveforms. This has led to a revival of high frequency PA design strategies based on waveforms, so called "waveform engineering". This has triggered new theoretical insight, the “continuous modes”, and advances in the approaches of utilizing measurement data during CAD design, “behavior models”. All these aspects will be reviewed in this presentation.