84th ARFTG Microwave Measurement Conference

ARFTG 84th WORKSHOP

The New Frontiers for Microwave Measurements

December 3rd, 2014

Boulder, Colorado

St. Julien Hotel

84th ARFTG
Topic: *The New Frontiers for Microwave Measurements*
December 3rd, 2014, Boulder, Colorado
www.arftg.org

Workshop Title: "*New Techniques and New Applications for Microwave Materials Measurements*"

Workshop Organizers:

Name : T. Mitch Wallis
Affiliation: NIST
Email: mwallis@boulder.nist.gov
Co-Chair: Michael Janezic, NIST

Workshop Description:

Historically, the development of radio frequency devices and systems has required reliable, quantitative electromagnetic characterization of materials. Today, the demands of new applications are pushing state-of-the-art electromagnetic materials measurements to new frontiers. The ongoing emergence of more and more applications in the millimeter-wave regime has in turn extended the need for electromagnetic materials metrology to new frequencies. Additionally, nanotechnology has revealed new classes of materials such as graphene and carbon nanotubes, which have required new approaches to microwave materials measurements. Furthermore, new work in non-traditional application areas such biology and medicine has led to the development of new strategies for characterization of biologically-important materials. This workshop brings together speakers from a variety of backgrounds to create a snapshot of the current state-of-the-art in microwave materials measurements and to forecast emerging techniques and applications.

Schedule (Wednesday, December 3rd, 2014):

- 13:20 – 13:25: Welcome
- 13:25 – 14:10: Speaker 1
- 14:10 – 14:55: Speaker 2
- 14:55 – 15:25: Coffee break
- 15:25 – 16:10: Speaker 3
- 16:10 – 16:55: Speaker 4

List of Speakers

1. Speaker's Name: Andrew Gregory	**Confirmed:** yes
Affiliation: NPL; Teddington, UK	
Presentation Title: Current trends in the measurement of the dielectric properties of materials at microwave frequencies	
Email: Andrew.Gregory@npl.co.uk	

Abstract: The presentation will give a metrologist's perspective of new techniques and new applications for measuring the complex permittivity of materials RF and microwave frequencies. Topics that will be discussed include:

- The development of microwave microscopes for measuring complex permittivity at the nano-scale and micro-scale, which is one of the most active areas of research at the present time. An overview of the various types of microwave microscope that have been developed will be given, including a description of an instrument based on a resonant cavity that has been developed at the National Physical laboratory. Applications of microwave microscopes will also be discussed.
- Measurement of the dielectric properties of Tissue Equivalent Materials (phantoms) to support measurement of SAR (Specific Absorption Rate). In many parts of the world human exposure to non-ionising radiation is limited by legal frameworks, such as the Physical Agents Directive in the European Union. With greater exploitation of the spectrum, changes in regulations, and the increasing use of body-worn devices, new requirements for SAR measurement have arisen.
- For industrial processing. The application of RF (e.g. 27 MHz) for drying in industrial processes is well-established, but there is much scope for greater exploitation of high-power microwaves for energy-efficient processing. Microwave measurement of complex permittivity can also be used for process monitoring.

2. Speaker's Name: Michael Havrilla | **Confirmed:** yes

Affiliation: Air Force Institute of Technology; OH, US

Presentation Title: Theory, Fabrication, Measurement and Application of Complex Media

Email: Michael.Havrilla@afit.edu

Abstract:

Rapid advances in material fabrication capability (e.g., 3D printing) have made the realization of engineered complex media (i.e., biisotropic, anisotropic and bianisotropic media) possible in the last couple decades. Continued improvement in manufacturing is pushing the barriers on the development of evermore exotic materials such as hyperbolic metamaterials. One of the primary interests prompting the explosive interest in complex media is the added control over scattered electromagnetic fields due to the increase in the number of constitutive parameters. Isotropic media are characterized by the 2 well-known scalar parameters of permittivity and permeability. In general, it requires 4, 18 and 36 parameters to describe biisotropic, anisotropic and bianisotropic media, respectively. Although the increase in parameter space provides more control over electromagnetic response, the penalty to pay is the added complexity in theoretical analysis and the added difficulty in obtaining a sufficient number of unique measurements for accurate material characterization. Some questions that naturally arise in the area of complex media research are: Are 36 parameters always required to characterize a material? How does symmetry influence material properties? What types of experimental systems have sufficient measurement diversity to characterize complex media? How must calibration schemes be modified to accommodate complex media? What are some of the emerging applications of complex media?

The goal here is to help address some of the above questions by first briefly reviewing the theoretical fundamentals of biisotropic, anisotropic and bianisotropic media and some common fabrication schemes. Next, the role of symmetry and Neumann's principle are discussed since they strongly influence the form of the constitutive parameters of complex media. Existing material characterization measurement techniques are reviewed followed by new techniques under development. Subsequent challenges of measuring complex media and calibrating these measurement systems are also discussed. Emerging applications of complex media are included in the final discussions as well as future challenges.

3. Speaker's Name: Hao Xin

Confirmed: yes

Affiliation: U. of Arizona; Tucson, AZ, US

Presentation Title: **GHz to THz Characterization of Nano-Materials for High Frequency Applications**

Email: hxin@ece.arizona.edu

Abstract:

Microwave engineering has been an exciting forefront of modern technology and one of the major enablers of the fast expanding information era. Since its formal establishment in the nineteenth century, this classic field has experienced many revolutions powered by discoveries of new materials and inventions of related devices. Rapid developments in nanotechnology in recent years have offered exciting possibilities for revolutionary discoveries in many branches of human endeavor. Nano-materials and associated devices are being widely studied and developed for applications in electronics, optics, biology, energy, etc. Though it has been suggested that nano-materials (such as carbon nanotube (CNT), graphene, etc.) based devices may work well in the microwave or even THz range, most of the previous measurements were done at DC or lower frequency ($f < 300$ MHz). The characterization techniques of nano-materials in the GHz to THz spectrum are important for both fundamental research and practical applications before proposed components such as antennas, interconnections and circuit building blocks can be realized. In this talk, we will present our work on a diverse range of nano-materials including various carbon nanotube samples, graphene samples, metallic nano-particle dispersed dielectrics and fluids. These materials are characterized in broad frequency spectrum from microwave to THz using a number of techniques ranging from integrated microfluidics to time-domain THz spectroscopy.

4. Speaker's Name: James C. Booth	**Confirmed:** yes

Affiliation: NIST; Boulder, CO, US

Presentation Title: Metrology for Complex Electromagnetic Systems

Email: booth@boulder.nist.gov

Abstract:

We describe our efforts to quantify electromagnetic interactions with matter through measurement of the electromagnetic material properties described by the dielectric permittivity, magnetic permeability, and/or electrical conductivity, at frequencies from dc to 100 GHz. We focus on complex material systems, such as biologicals, superconductors, ferroelectrics, magnetoelectrics, piezoelectrics, nanostructured materials, and colloids. Our approach relies heavily on microfabrication of custom measurement devices, such as microfluidic-loaded circuit elements, combined with on-wafer error correction and measurement techniques, as well as multi-physics based finite element simulations. We apply these techniques to enable accurate measurements of sub-nanoliter fluid samples, to obtain information on the electromagnetic response of chemical mixtures, as well as colloidal samples incorporating both organic and inorganic nanoparticles. Such broadband measurements allow us to quantify the dynamics of polarization processes in these complex fluidic environments.