Advances in Solid State Power Amplifiers for All Platforms

Workshop Organizer: Naresh Deo, Visionary Solutions, USA

Solid State Power Amplifiers (SSPA) are finding increasingly greater number of critical applications in a wide range of platforms and business sectors, often replacing tube-based amplifiers, such as TWTA. These include communication systems, remote sensing instruments, scientific and industrial equipment, test equipment, and a wide range of defense applications. SSPAs are becoming the power amplifier of choice in transmitters for communication links and radars for all platforms from Space and airborne to ground and ocean-based systems. For many applications and specific technical requirements SSPAs offer definite advantages over tube-based solutions.

This growth in the suitability and/or superiority of SSPAs is fueled by many recent technical developments as well as some of their inherent advantages over tube-based power amplifiers. Set of critical considerations when selecting a microwave or millimeter wave power amplifier is their SWaP-C (Size, Weight and Power Consumption, and Cost) together with its operational reliability. The ultimate selection of SSPA or TWTA is based on the frequency range, power output requirements and several other constraints.

In this workshop we will provide information and insight from a set of highly experienced speakers on technological advances and innovations in solid-state power amplifiers. These developments have enabled many systems operating in the microwave and millimeter wave to sub-Terahertz frequency domain. SSPAs have the potential to revolutionize the industries and fuel many emerging applications. Recent advances have contributed to technical feasibility, economic viability and commercial success of SSPA for virtually every transmitter and source in microwaves through sub-terahertz domains. Some of the topics covered in this workshop will include:

1. Semiconductor devices (Gallium Nitride, Indium Phosphide HBT, etc.)
2. Thermal Management Methods
3. Power Combining and Packaging
4. Multipaction and RF breakdown considerations
5. Device qualification and reliability evaluation
6. **Success stories, notable accomplishments and lessons learned**
7. Comparative study and Future trends

This workshop will be particularly valuable to technologists, mission and payload planners, designers and developers of almost any microwave or millimeter wave system or equipment involving power amplifiers.

Workshop Presentation Overview

Introduction/welcome- Workshop Organizer- Naresh Deo

Background and Motivation for Development of Solid-State Power Amplifiers- Presenter- Naresh Deo, Visionary Solutions, California

During the past 5 years some very significant advances have been made in both design methodology and manufacturing technologies for the implementation of amplifiers for transmitters for satellite-based equipment and associated ground terminals for communications and remote-sensing applications. Additionally, many defense, scientific, industrial and commercial applications also require power amplifiers suitable for their specific needs. Solid State Power Amplifiers (SSPA) are finding increasingly greater number of critical applications in a wide range of platforms and business sectors, often replacing tube-based amplifiers, such as TWTA. These recent technological developments have dramatically reduced the size, weight, power consumption and cost (SwaP-C) of power amplifiers, making them highly desirable for most applications. These developments include both evolutionary enhancements in technology in the last decade as well as highly innovative concepts in design and production that would fuel the growth of new applications and business cases in coming years. Some of the most prominent innovations and advances leading to this progress will be presented in this workshop together with updates on developments of past decade.

Today's communication systems on all platforms (Space, ground, airborne and mobile) are required to perform at much higher power level than their predecessors and generally communicate at higher radio frequencies with very wide bandwidth, at much higher data rates/throughput. Similarly, defense, remote sensing/radars, test equipment and other emerging applications demand significantly greater performance and lower SWaP-C than ever before.

Emergence of new technologies and implementation techniques for solid-state power amplifiers for critical applications will be described. Design and fabrication methods for devices, modules and complete SSPAs will be presented in the balance of this workshop. Important considerations in the design and physical realization of SSPAs will also be discussed.

IC Development of Efficient mm-Wave and THz Power Amplifiers and Sources using advanced InP HBT Technologies- Presenter- Dr. Zachary Griffith, Teledyne Scientific Company, Thousand Oaks, California

This talk will review current results and new IC development from the 250-nm and 130-nm InP HBT scaling nodes – examples include a compact 220-GHz PA with 60-mW output power and 28% power-added-efficiency (PAE), and a 0.5-W 90-140 GHz InP HBT PA chip

four-way combined in rectangular waveguide demonstrating peak 1.35-W in D-band. Results from new designs will also be presented. Additionally, this talk will review the InP HBT technology and how it has been used to improve the performance of high frequency test and measurement equipment, as well as mm-wave and THz sources.

100-300 GHz power amplifier design- **Presenter- Prof. Mark Rodwell, Doluca Family Chair, Department of Electrical & Computer Engineering, University of California, Santa Barbara, California**

This presentation will describe 100-300 GHz power amplifier design principles, including applications, performance comparison across process technologies, transistor design for power amplifiers, transistor constraints on power amplifier circuit performance, selection of power-combining technique, and recent IC results.

Advances in Gallium Nitride Power Amplifier Technology and Applications- **Presenter: Naresh Deo and Associates**

Power amplifiers operating in the microwave and millimeter wave frequency ranges have achieved unprecedented performance and reliability due to remarkable developments in device technologies based on Gallium Nitride (GaN). Solid state power amplifiers that utilize GaN based devices have achieved performance that challenges TWTA for a wide range of applications. Gallium Nitride offers significantly higher efficiency for generating exceptionally high RF power levels at high junction temperatures compared to most other solid-state device technologies with reliability that exceed virtually all power amplifier types. Recent advances in manufacturing processes and packaging techniques have further enhanced their potential for highly demanding and mission critical applications. In this presentation we will describe some of the key developments and innovations that have enabled SSPAs to achieve very low SWaP-C for most platforms and emerging needs. State-of-the-art results achieved by commercial and research sectors will be shown to demonstrate the true potential of this technology. Specifically, critical applications in Spaceborne transmitters will be discussed.

Power Combining for High Power SSPAs- Methods and Results- **Presenter: Lisette Zhang, Technical Director- Engineering, QuinStar Technology, Torrance, California**

Single devices typically cannot achieve the high output power required for most applications of power amplifiers. Therefore, power from multiple devices or modules must be combined to attain the specified power levels and linearity. A review of power-combining techniques for high-power Ka-, V-, and W-band solid-state power amplifiers

implemented in GaN or GaAs MMICs is presented. Key **on-chip** approaches such as corporate and series–parallel networks, H-Tees, radial power combiners, transformer-based current/voltage combining, and distributed architectures are compared with respect to SWaP-C, loss, bandwidth, thermal conductivity and integration density. **Off-chip** Hybrid and spatial methods, including waveguide hybrids, coaxial combiners and radial power combiners are highlighted for their scalability to high millimeter-wave power levels for spaceborne systems. Recent innovations such as broadband transformer-coupled networks, reconfigurable matching, and massively phased arrays are summarized. The review outlines practical trade-offs in combining architectures for next-generation SSPAs targeting Space radar, SATCOM, and 6G.

Design Considerations for Critical Missions and Space Applications-

Presenter: Naresh Deo and Associates

Thermal Management, Multipaction/RF Breakdown, Reliability/Qualification and more-

Most significant considerations connected with SSPAs for critical missions and Space use will be described with technological solutions and design justification methodologies. These include- thermal, structural, RF multipaction, manufacturing and cost. Qualification methods and reliability assessment will also be discussed.

Wrap-up/Panel Discussion (all presenters)