Frontier Microwave Technology for Fusion Reactor Diagnostics

Ying Chen[1], Pin-Jung Chen[1], Robert Hu[2], Yilun Zhu[1], Jo-Han Yu[1], A-V Pham[1], Omeed Momeni[1], Calvin Domier[1], Jon Dannenburg[1], Neville Luhmann Jr.[1]

[1]*University of California, Davis, Davis, CA 95616*
[2]*National Yang Ming Chiao Tung University, Hsinchu, Taiwan 30010*

Corresponding Author Email: amzhu@ucdavis.edu

The next generation of fusion reactors, exemplified by projects like DEMO following ITER, confront the monumental task of proving the viability of the generation of electricity through thermonuclear fusion. However, this pursuit comes with heightened complexities in diagnostic methodologies, particularly in the realm of microwave-based diagnostics. The increased neutron fluence necessitates substantial reductions in vessel penetrations and the elimination of internal diagnostics, thereby posing significant challenges. Microwave-based diagnostics must now deliver essential operational insights for reactors, including plasma position, shape, and predictive analysis of potential dangers. Several challenges loom, notably in meeting higher frequency and power requirements, minimizing diagnostic apertures, enhancing accuracy, integrating diagnostics at higher levels, and ensuring reliability. After seven years of dedicated research, our team successfully pioneered a system-on-chip (SoC) approach, leading to the development of active transmitters and passive receiver modules that found practical application in real-world settings, notably within the DIII-D project where arrays of the modules have supported electron cyclotron imaging (ECEI) and microwave imaging reflectometry (MIR) instruments. With an impressive yield rate exceeding 91%, attributed to robust design principles, foundry fabrication process improvements, and advanced packaging techniques, our work has reached a significant milestone. Furthermore, in 2023, we achieved a breakthrough in developing high radiation-tolerant, wide bandgap GaN microwave chips, a crucial advancement for diagnostics in challenging environments. To maintain the integrity of diagnostic signals over extended plasma distances, a substantial increase in transmitter power has become imperative. Leveraging their expertise in high-frequency/power microwave System-on-Chip technology, the UC Davis team achieved a remarkable milestone by successfully developing microwave instrumentation applications up to 330 GHz. Notably, the utilization of stacked Heterojunction Bipolar Transistors (HBTs) has enabled significant output power ranging from 20 to 24 dBm, marking a crucial advancement in the field. These achievements represent a pivotal leap forward in fusion diagnostic technology, marking substantial progress toward establishing reliable and efficient plasma diagnostics for the next generation of fusion reactors.

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