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V-band (55-75 GHz) MIR System-on-chip Advancement for Fusion Plasma Diagnostics

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The Davis Millimeter Research Center (DMRC) and the Princeton Plasma Physics Laboratory (PPPL) have been developing millimeter wave diagnostics to visualize electron density and temperature fluctuations in magnetic fusion plasmas. Specifically, Electron Cyclotron Emission Imaging (ECEI) is a passive radiometric technique measuring electron temperature fluctuations while Microwave Imaging Reflectometry (MIR) is an active radar imaging technique employed to reconstruct electron density fluctuation images. Until recently, these instruments have been comprised of a combination of discrete waveguide components and board level surface mount components employing quasi-optical coupling. However, in recent years, there have been dramatic advances in monolithic millimeter wave integrated circuit (MMIC) technology making possible system-on-chip (SoC) solutions employing both silicon and GaAs/InP/GaN manufacturing processes for customized instruments. Very recently, our team has realized a state-of-the-art E-band (70-80 GHz) receiver array using commercially available integrated circuits (ICs) for ECEI [1, 2]. In a proof-of-principle demonstration on DIII-D, the resultant liquid crystal polymer (LCP) [3, 4] substrate-based horn-waveguide array was shown to overcome major limitations such as space inefficiency, inflexible installation, poor noise shielding, and prohibitively high cost of conventional discrete components.

Here, we focus primarily on silicon-based technologies which are attractive at providing low-cost and potentially unprecedented levels of integration of analog, digital, and microwave circuitries. Nowadays, semiconductor manufacturers have successfully shrunk the gate length of transistors into the level below tens of nanometers thereby permitting the CMOS transistors to reach hundreds of gigahertz frequency. In a proof-of-principle demonstration, we are replacing the current 4-tone discrete component DIII-D MIR system [5] with in-house designed V-band (55-75 GHz) transmitter and receiver chips which have been fabricated and tested [6]. On the receiver side, the CMOS chip provides >30 dB signal amplification over 20 GHz bandwidth with 10-20x reduction in noise temperature compared to the previous system. Presently, most of the mm-wave imaging diagnostics are compromised by strong environmental noise and inefficient front-end down-conversion arising from the lossy Schottky diode mixer mounted on the printed antenna. This new approach allows the entire receiver to be packaged in a sealed horn-waveguide structure providing compactness, noise isolation and EMI suppression, and far simpler assembly [7]. Recently, the transmitter module including board-level architecture to overcome the challenges of high-frequency IC packaging has been fabricated and tested. The V-band transmitter module with waveguide terminals is capable of transmitting eight independent frequencies within 55-75 GHz simultaneously. Laboratory characterization of the entire transmit/receive system will be reported with the system to be installed on DIII-D after the long-term opening.

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