# System-on-Chip integrated circuit technology applications on the DIII-D tokamak for multi-field measurements

Yuan Zheng[1], Guanying Yu[1], Ying Chen[1], Calvin Domier[1], Yillun Zhu[1], Neville Luhmann Jr. [1]

*1) University of California at Davis, Davis, CA, USA*

*E-mail : zyzheng@ucdavis.edu*

System-on-Chip (SoC) integrated circuit technology is being employed in the DIII-D Microwave Imaging Reflectometer (MIR) and Electron Cyclotron Emission Imaging (ECEI) microwave imaging diagnostics systems to replace the quasi-optical mini-lens legacy approach [1-3]. Benefiting from their improved signal-noise-ratio and spurious signal rejection and integration, the SoC diagnostic systems represent a breakthrough for the measurement of fusion plasma electron density and temperature fluctuations.

A new V-band (55 ~ 75 GHz) MIR system comprised of CMOS transmitter and receiver arrays is being developed for the 12 x 8 channel density fluctuation measurements [4]. Based on the latest testing results, the upgraded System-on-Chip V-band MIR system provides 10x times increase in signal gain on the receiver side compared with the previous quasi-optical Schottky diode based dual-dipole receiving antenna array. In addition, the previous four probe frequency transmitter has been upgraded to eight simultaneous and variable probe frequencies by the V-band SoC transmitter module, with an output power of 0 dBm at each frequency as in the previous system. In addition, an F-band receiver chip has been designed and fabricated for high field side temperature fluctuation measurement by ECEI. The measured RF-to-IF conversion gain of the F-band chip is above 5 dB while working at 110 ~ 140 GHz, which is 25 dB larger than the previous dual-dipole antenna approach.

These SoC based diagnostic instruments combined with other state-of-the-art DIII-D diagnostics are opening up new physics studies. For example, the Radial Interferometry Polarimetry (RIP) system [5], (developed by the UCLA team), can provide information concerning the line-integrated turbulent density fluctuations and radial magnetic field fluctuations. In addition, the SoC MIR and ECEI systems are able to measure co-located density and temperature fluctuations simultaneously. Then, correlating with the RIP, the 2D SoC microwave imaging diagnostics system has the potential to localize interferometric measurement of turbulent fluctuations at the pedestal. Specifically, the current W-band SoC ECEI system is located 15° toroidally with respect to the RIP system on the DIII-D tokamak. With delicate magnetic equilibrium, it is possible to choose the ECEI channel from the 2D array and the RIP channel on the same magnetic field line at the pedestal. Correlating RIP with ECEI/MIR, the line integrated density and magnetic fluctuation measurement with RIP is localized at the pedestal.

**References**

[1] Wang, Y., et al. "Millimeter-wave imaging of magnetic fusion plasmas: technology innovations advancing physics understanding." Nuclear Fusion 57.7 (2017): 072007.

[2] Zhu, Yilun, et al. "New trends in microwave imaging diagnostics and application to burning plasma." IEEE Transactions on Plasma Science 47.5 (2019): 2110-2130.

[3] Zhu, Y., et al. "W-band system-on-chip electron cyclotron emission imaging system on DIII-D." Review of Scientific Instruments 91.9 (2020): 093504.

[4] Zhu, Yilun, et al. "Wide Bandwidth Millimeter-wave System-on-Chip Development and Applications." 2020 45th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz). IEEE, 2020.

[5] Chen, Jie, et al. "Faraday-effect polarimeter diagnostic for internal magnetic field fluctuation measurements in DIII-D." Review of Scientific Instruments 87.11 (2016): 11E108.