Development of Radiation-Hardened Millimeter-Wave Diagnostics for D-T Fusion Reactors

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Radiation-hardened electronics are indispensable for the sensing and control systems of compact fusion reactors, where intense neutron radiation can cause performance degradation, signal distortion, or even catastrophic failure of electronic components. These failures can severely compromise the accuracy and reliability of critical diagnostic data. Millimeter-wave receivers, key elements in fusion reactor diagnostics, demand intrinsically radiation-hardened electronics to deliver precise and dependable measurements. In a collaborative initiative, UC Davis and Cornell have developed a prototype of compact millimeter-wave receivers using gallium nitride (GaN), a material renowned for its inherent radiation resistance owing to its wide bandgap.

The prototype GaN-based millimeter-wave diagnostic chip, designed as a passive receiver, operates across a frequency range of 75 to 110 GHz and was fabricated using HRL T3 processing. A notable achievement is the successful demonstration of a W-band GaN-based system-on-chip receiver utilizing HRL T3's 40 nm GaN technology. This compact receiver chip, with dimensions of just 3 × 5 mm², integrates essential components such as a 75–110 GHz RF Low-Noise Amplifier (LNA), mixer, Intermediate Frequency (IF) amplifier, and Local Oscillator (LO) chain. Furthermore, ongoing efforts are focused on advancing radiation-hardened electronics for higher frequencies. Leveraging GaN-on-SiC technology, a low-noise amplifier operating at 104–121 GHz has been developed, achieving a saturated output power of 17.6 dBm for high signal-to-noise ratio diagnostics. Building on these successes, we are developing advanced radiation-hardened millimeter-wave diagnostic solutions tailored for Fusion Plasma Physics (FPP) and future fusion reactors, ensuring robust and reliable diagnostics in extreme radiation environments.