TECHNOLOGY BRIEF

NEXT STEP FUSION

Microwave Profile Reflectometer for Electron Density Profiles

A compact, multi-band swept-frequency reflectometer for magnetic confinement fusion (MCF) devices — deployable standalone or combined with an electron cyclotron emission radiometer in a single modular port-plug unit, with frequency coverage tailored to your machine.

THE MEASUREMENT

A profile reflectometer launches a frequency-swept microwave beam into the plasma; each frequency reflects at the cutoff layer set by the local electron density and magnetic field, and the round-trip delay locates that layer. Sweeping the band therefore yields the electron density profile — and with it the plasma position — from small-aperture antennas, with no large ports, no lasers and no beam lines. That robustness and real-time capability make reflectometry a leading density diagnostic for future fusion power plants. Our system targets a density profile every 250 µs (ten averaged 20 µs sweeps) with spatial resolution of order 0.5 cm (assessment in progress).

THE SYSTEM

- **Multi-band, dual-polarization probing** — O-mode (K/Ka bands, 18–40 GHz) and X-mode (Q/V bands, 33–75 GHz) in one compact front end, covering the density gradient region across plasma scenarios.
- **Fast swept source** — a VCO-driven sweep covers a full band in ~20 µs, fast enough to outrun turbulent density fluctuations.
- **Robust detection** — phase-locked oscillators and hardware IQ detection identify the reflectometry beat frequency reliably even in unfavorable signal-to-noise conditions.
- **Full profiles, not fragments** — direct measurement of the gradient region is complemented by software reconstruction of the full density profile using physics-informed neural networks.

ONE HARDWARE CORE, TWO TOKAMAKS

Our prototype is designed for two machines at once: DIII-D (2.0 T) and TCV (1.4 T), with band selection driven by each device's density and field — and it restores a profile reflectometry capability at DIII-D. The design is backed by TRAVIS ray-tracing synthetic diagnostics [1], and the prototype deliberately uses proven discrete RF components; on-chip millimeter-wave modules developed with UC Davis [2] provide the upgrade path to radiation-tolerant, serially produced units for power plants. Plasma testing — validated against each machine's existing reflectometry and Thomson scattering systems — is planned on TCV in late 2026 and on DIII-D in early 2027.

FROM PROTOTYPE TO YOUR DEVICE

n_e and T_e from one port — the reflectometer shares a single port plug, power supply and protection with our ECE radiometer, delivering two core kinetic profiles from one compact unit.

Integrated or fully standalone — the modular architecture means the reflectometer can be delivered on its own, with further modules added later without redesign or disruption to the installed system.

Customized for machine — frequency plan, polarizations, antennas and port geometry are derived from your field, density and access constraints, exactly as done for the DIII-D/TCV pair.

Industrial delivery — unified data acquisition, calibration and control software across all modules, backed by a controlled supply chain with off-the-shelf parts and replacement units for minimal downtime.

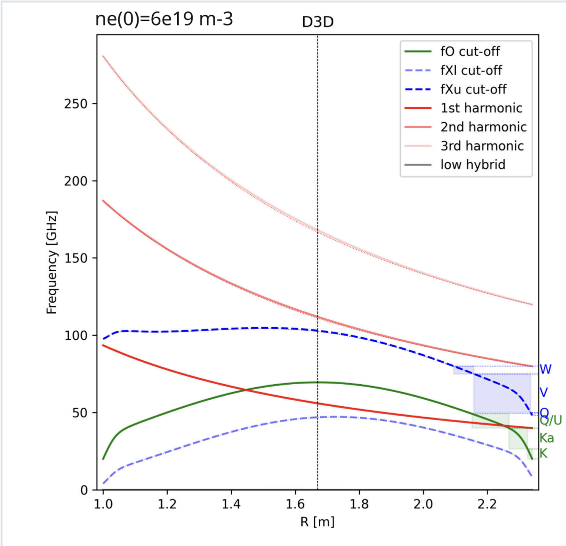

Fig. 1. Frequency band selection for the DIII-D prototype: O-mode and X-mode cutoff profiles with the selected K/Ka and Q/V probing bands, placed clear of the electron cyclotron harmonics.

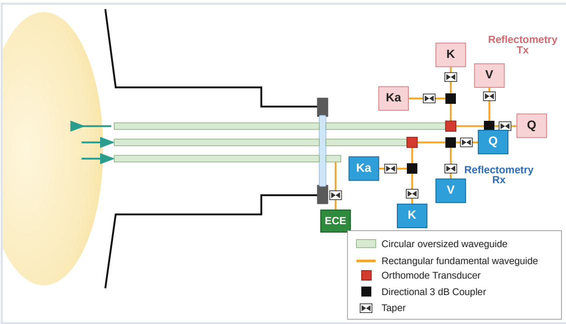

Fig. 2. Joint transmission line concept: tapers, directional 3 dB couplers and orthomode transducers combine the K/Ka and Q/V bands onto compact oversized circular waveguides — one launch line, one receive line and an ECE channel — through a single port and vacuum window.

MODULAR DIAGNOSTICS PLATFORM

This reflectometer is a module of the **Modular Diagnostics Platform (MDP)** — Next Step Fusion's port-plug-integrated microwave diagnostic solution for next-generation MCF devices and future fusion power plants.

The MDP minimizes in-vessel footprint through **shared antennas and transmission lines**, uses maintainable, standardized modules, and employs physics-informed models to reconstruct plasma parameters beyond what is directly measured.

REFERENCES

1. N. B. Marushchenko, Y. Turkin, H. Maassberg, "Ray-tracing code TRAVIS for ECR heating, EC current drive and ECE diagnostic," Comput. Phys. Commun. 185, 165–176 (2014), doi: 10.1016/j.cpc.2013.09.002.
2. Y. Zhu et al., "W-band system-on-chip electron cyclotron emission imaging system on DIII-D," Rev. Sci. Instrum. 91, 093504 (2020), doi: 10.1063/5.0022057.

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*Planning density diagnostics for your device?
Talk to us at the design stage.*