Development of electron cyclotron emission imaging optics

L.E. Henderson, H.L. Clark, C.A. Gagliardi, and D.P. May

We are developing optics that function in the 15-65 GHz band in order to image Electron Cyclotron Emission (ECE) from the plasma inside the Cyclotron Institute's Electron Cyclotron Resonance Ion Sources (ECRIS). ECE correlates directly to the energy, number density, and magnetic confinement of plasma electrons, so these optics will allow us to characterize the dominant dynamical population in the plasma interior with spatial resolution not previously available.

Given that the operating wavelengths are comparable to lens dimensions, conventional optical calculations for the lenses had to be supplemented with simulations of Maxwell's equations in the MEEP software package.

The optics inside the plasma chamber take advantage of existing radial ports in our ECRIS, so no ion source modifications are necessary. A cemented stack of alumina and PTFE lenses will couple ECE from the plasma midplane into an alumina-filled waveguide array, which will then transport the image out of the ECRIS. Conventional relay optics were ruled out by the small diameter of the access pipe (dia. 3.81 cm) and comparable operating wavelengths ($\lambda = 0.46 - 2.0$ cm). In fact, obtaining an image with any useful resolution would be impossible without filling the radial port opening (dia. 1.905 cm) with a high-index material like alumina (n = 3.1) to temporarily reduce the image wavelengths. Alumina and PTFE also have known, minimal dispersions in the desired frequency band.

Outside the ECRIS, the image will be routed to the receiver array by PTFE lenses and aluminum mirrors, as shown in Fig. 1.

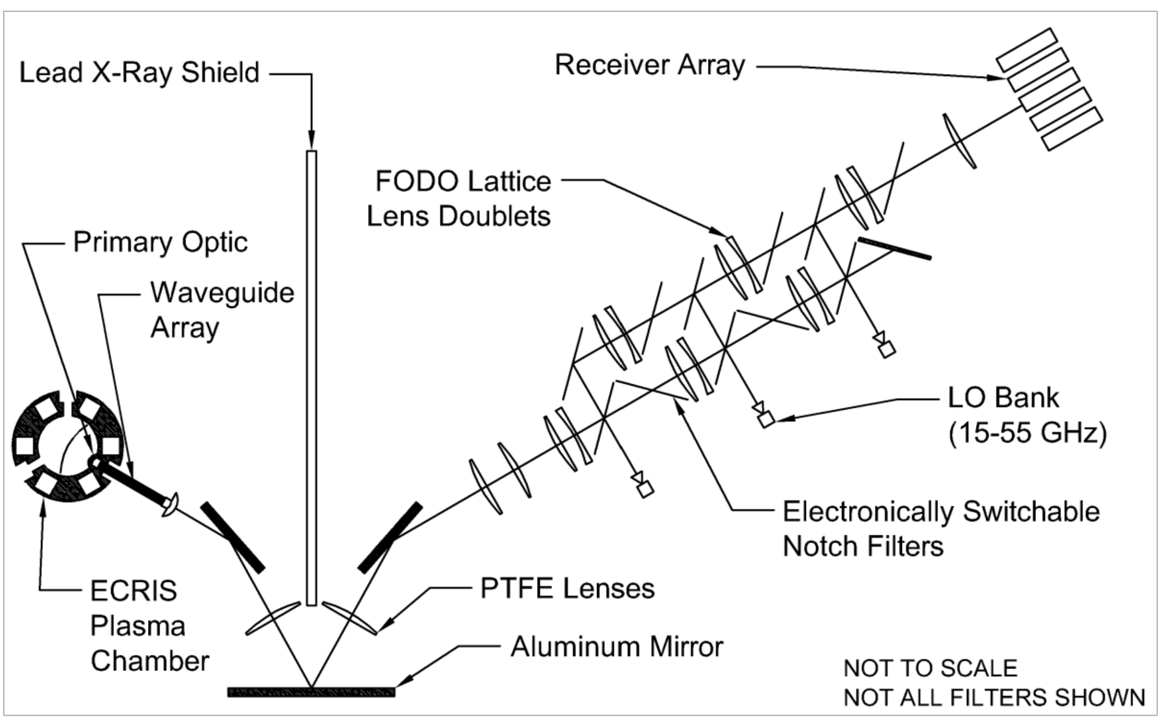

FIG. 1. ECE optical train.

Each receiver in the receiver array will convert the signal to much lower frequencies before digital sampling, which is known as a heterodyne receiver. However, since a fully electronic receiver array for the entire 15-65 GHz band would require the duplication of many expensive components in an unwieldy waveguide network, some of the electronics that typically follow the receiver antennas will be replaced with equivalent optical elements preceding the receiver antennas.

To enable this receiver design, the recent work has been focused on developing novel optical elements: a suite of free-space microwave notch filters with electronically controllable reflectivity. Activating one set of filters routes both the desired signal band and a known 'local oscillator' onto the receiver array's optical path (at a reasonable signal-to-noise ratio), and the filter design allows for switching thousands of times per second. Performing this signal preparation in free space means that the first stage mixing, from 15-65 GHz down to 0-8 GHz, can be completed with a single diode attached to each receiver antenna. Secondary mixing and amplification stages can then be built with more conventional electronics.

Each filter is a 2D array of copper antennas, connected by PIN diodes and resistive carbon traces, which will be fabricated on a PTFE substrate using standard printed circuit board manufacturing techniques. The resistive carbon traces are essentially invisible to incident electromagnetic radiation, so they are useful for supplying a bias current to the PIN diodes. The DC bias current controls the AC impedance of the PIN diodes, which in turns controls the damping of each antenna. Since a damped antenna cannot re-radiate EM radiation efficiently, the reflectivity of the filter is therefore controlled by the bias current. Given the wide range of AC impedances that PIN diodes can achieve ($0.7\ \Omega < R_{AC} < 5000\ \Omega$), MEEP simulations have shown the existence of essentially non-reflective (~3%) and reflective (>95%) filter operating modes. Additionally, simulations show high reflectivity only manifests in a single, specified band (-3dB width of ~4 GHz) within the nominal 15 - 65 GHz design band. Each filter for this camera will have at least two layers to extend the bandwidth.