Development of an electron cyclotron emission imaging system

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Prototype components for our electron cyclotron emission imaging system, such as the electronically variable reflective surfaces (EVRS) (see Fig.1), have been produced. However, the fabrication of finalized components is taking longer than anticipated in the last report, so final assembly and first light for the full imaging system is now expected later this year. This report will cover two major issues that were encountered and resolved since the last report:

1) Printed circuit board (PCB) fabrication through external manufacturers became exceedingly expensive and time-consuming, so the entire PCB fabrication process had to be brought in-house. This is described further in *"Printed Circuit Board Fabrication Facility: SEE Fab"*.
2) The reflectance spectra of the first batch of EVRS prototypes, measured in the anechoic microwave test chamber, revealed flaws in both the simulation methodology used to design EVRS and aspects of how designs are physically implemented.

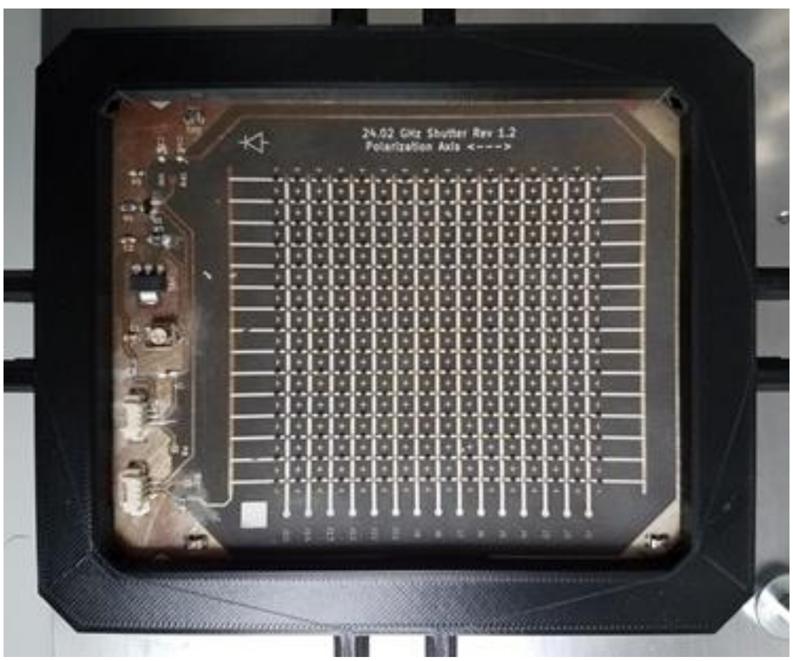

Fig. 1. The first EVRS prototype, chemically etched on RT Duroid 5880, in its mounting frame.

The physical implementation flaws had readily apparent solutions. For example, the ground plane included around the edges, meant to slightly stiffen the first prototypes, produced too much unwanted reflection and will be removed in future designs.

The simulation errors, on the other hand, were more difficult to parse. An EVRS candidate design is simulated as a unit cell with periodic boundary conditions. The simulation package, the "MIT Electromagnetic Equation Propagation" or "Meep" package, stores the simulation geometry and electromagnetic fields on a regularly spaced lattice, excites the fields with a defined current pulse, propagates the fields by timesteps, and computes integral quantities of the fields . In this case the Poynting flux is used to characterize EVRS reflectance and transmittance. It had been observed across many simulations that 10% to 40% excess electromagnetic flux exited the unit cell compared to what had entered, despite there being no gain medium in the structure. This was clearly a simulation convergence error, and some modest convergence improvements had been made prior to experimentally measuring the reflectance, but it was only after experiments were performed that the root cause of the simulation error was identified: the pillbox used to compute the electromagnetic flux entering and exiting the EVRS unit cell was too thin. Meep does not carry out any adaptive meshing, so the available memory of the computer used to run the package can easily become a limiting factor. The EVRS unit cell had therefore been made as thin as possible in the direction normal to the array, with very little simulated empty space above and below the array structure, to minimize the required memory. The flux measurement planes were spaced so closely to radiating structures that they unintentionally fell within the Fraunhofer distance at higher frequencies, which conflated near field flux with far field flux in the simulated reflectance and transmittance spectra and caused the excess

Given the periodic boundary conditions, padding the unit cell with extra empty space was the only available solution to this problem. Fortunately the simulations could be moved onto particular nodes in the Cyclotron Institute's computing cluster that allowed for the use of far more memory per simulation. Ensuring the padding distance exceeded the Fraunhofer distance across all frequencies guaranteed that only far fields contribute significantly to the final result, and along with other code revisions that help with numerical stability, the simulations now appear to be convergent with errors generally under 1%.

The new EVRS simulations have finally begun to validate intuitions about EVRS designs and inform the equivalent circuit model that will be used to describe their performance. By varying which elements of the EVRS structure are simulated and the geometric and material parameters of those elements, a correspondence between the physical EVRS parameters and the equivalent circuit elements is being built up systematically.

In the course of building this correspondence, the nature of the inductive and capactive coupling between cells will be studied (see Fig. 2). The resonance characteristics of arrays with only a few cells will be compared with the resonance characteristics of arrays of infinite size implied by single cell simulations with periodic boundary conditions. How quickly the reflectance spectra of the smaller arrays approaches that of the infinite arrays depends upon how the coupling fields fall off with distance and direction, so it should be possible to distinguish between inter-resonator coupling via surface waves and isotropic radiation. This can be studied for a variety of substrates, substrate thicknesses, and radiator shapes quite easily with the updated simulation code.

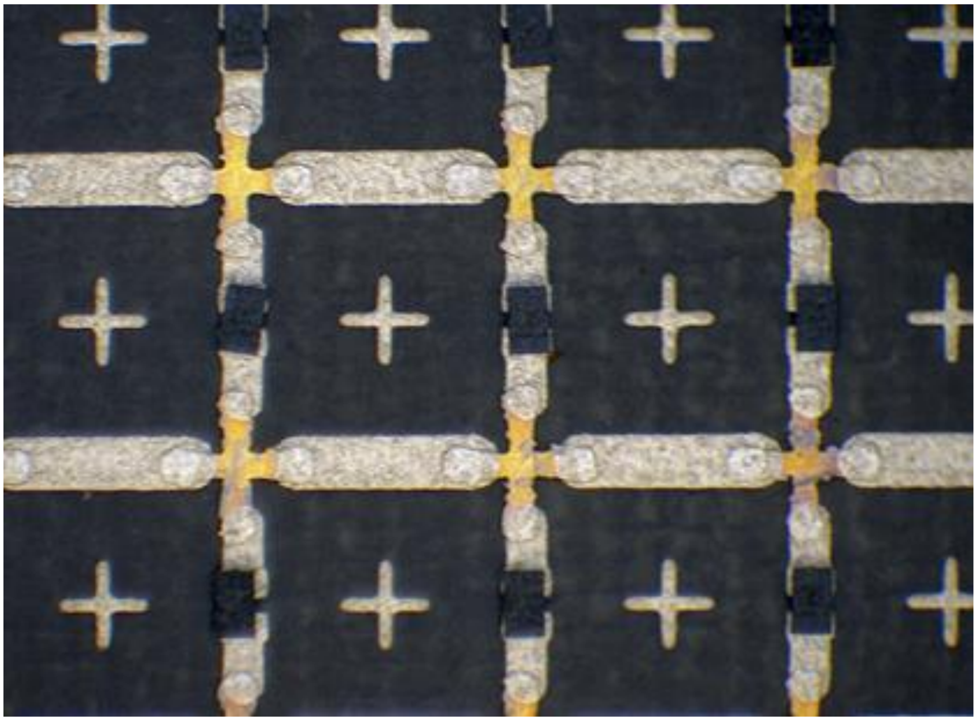

Fig. 2. Close-up of EVRS prototype, with conductive paste traces connecting resonators and PIN diodes. Resonator shape defects due to poor chemical etching are clearly visible. The alignment crosses will be omitted in future versions to further reduce unwanted reflectance.