Physical Construction and Measurements Report
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Construction

The PCB layouts designed in ADS were exported as Gerber files and then used by following the instructions that were shared by Jackson. For all Chebyshev, branchline, and coupler boards, ADS produced a top-copper file (cond.gbr) and a second copper-layer file (cond2.gbr). In circuitPro PM2.7, we created a new job using a single-sided template and imported these Gerber files with the "use layer name" option turned off. We then mapped the files manually so that cond.gbr was assigned to the TopLayer and cond2.gbr to the BoardOutline so the CircuitPro would both mill the copper pattern and cut out the final board from a $152\,mm \times 152\,mm$, $1.6\,mm$ thick FR-4 panel. After importing, we checked the CAM view to make sure the traces, ground area, and outline matched the ADS design and that there were no unintended copper islands.

Toolpaths were generated using the production/CAM wizard. Isolation milling of the RF traces and the rub-out of the surrounding copper were assigned to the small end mill, while the board outline was assigned to a 2 mm counter router configured as an "End Mill long 2 mm" tool. The correct physical tools were loaded into the machine's magazine by matching the color-coded ring IDs to the entries in the tool list, and the tool was calibrated. The FR-4 panel was then fixed to the LPKF ProtoMat table, and the job was run. Next, the machine milled the top layer, then removed the unwanted copper around the structure, and finally routed the board outline to separate the finished PCB from the panel.

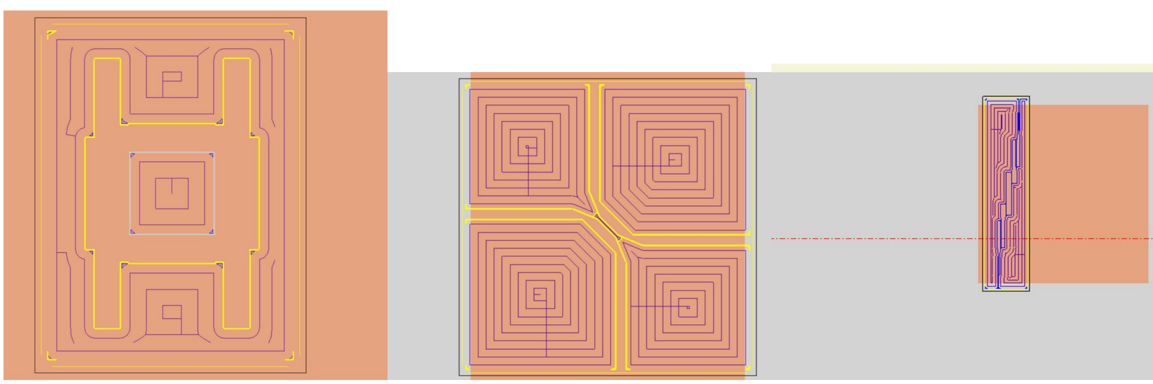

Figure 1. Preliminary LKPF Tool Paths.

Mistakes

A big initial mistake we made was setting the mill depth incorrectly. We had initially set the mill depth at $32\,\mu m$. This is less than the actual thickness of the copper ($35\,\mu m$), which caused significant tearing of the copper sheet. Instead of cutting through the copper, the mill tore it up (Figure 2). This was amended to $80\,\mu m$ mill depth, which fixed the tearing problems.

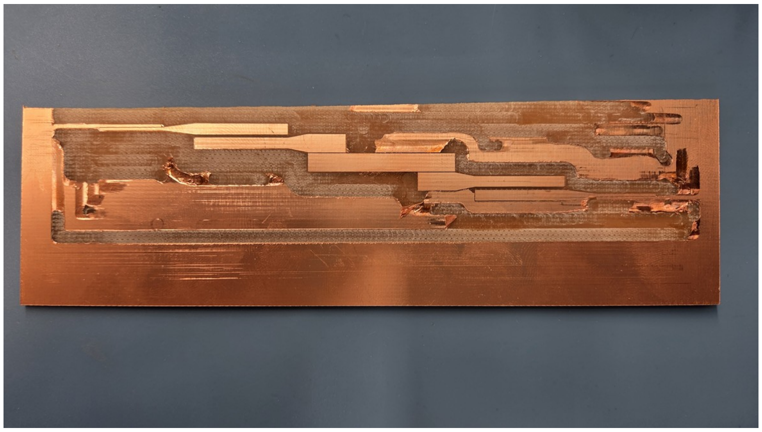

Figure 2. Incorrect Mill Depth.

Another major mistake we made was not recognizing the mill’s ability to cut out the final components, leaving a wide band of FR4 around the final components. For the Chebyshev bandpass filter, the design was too large for the mill to cut away excess material. We solved these problems by using a bandsaw and belt sander to remove excess material, leaving clean final components.

Figure 3. Belt Sanding Excess Material Away

Measurements of the Chebyshev Bandpass Filter

In Figure 4. the S_{21} of the actual Chebyshev bandpass filter (red) compared to the Momentum EM simulation of the filter (blue), and the schematic simulation (magenta) can be seen. While in Figure 5. the S_{11} of the actual Chebyshev bandpass filter (red) compared to the Momentum EM simulation of the filter (blue), and the schematic simulation (magenta) can be seen. Our designs behaved pretty similarly to the Momentum simulations overall, with some frequency shifting occurring due to differences between the simulated dielectric permittivity and the actual dielectric permittivity. As can be seen in Figure 4, there is a recognizable passband and no strong response at the visible harmonics.

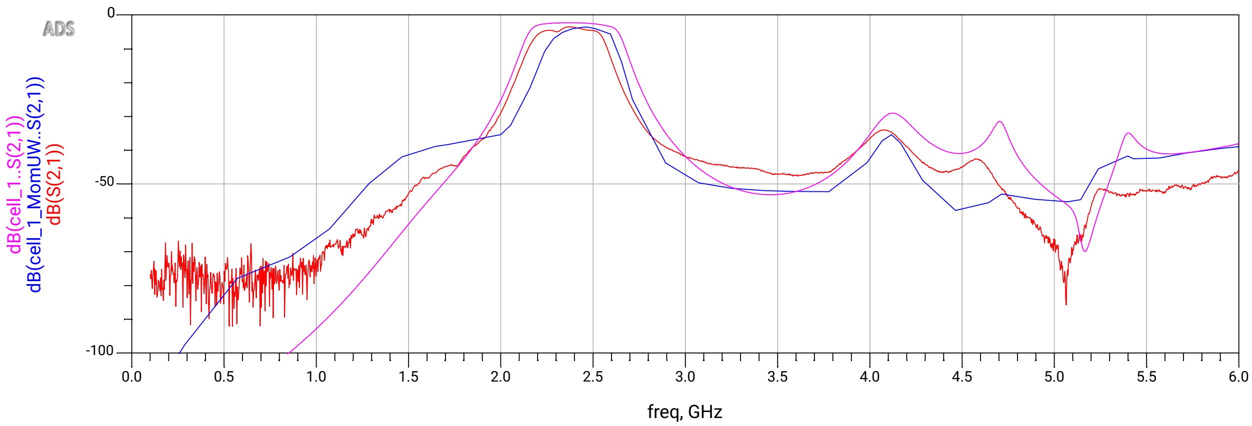

Figure 4. $S_{21}$of the manufactured Chebyshev filter compared to simulations.

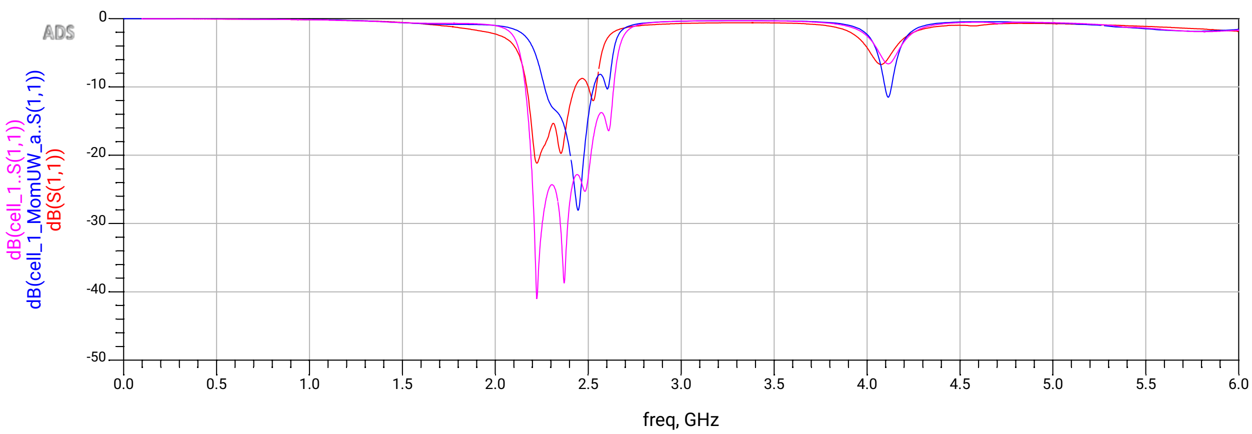

Figure 5. $S_{11}$of the manufactured Chebyshev filter compared to simulations.

Measurements of the Coupled Line Coupler

Jackson was gracious enough to let us use the pre-calibrated VNA in the RF laboratory, so we were able to get good measurements of all the connections for the coupled line coupler. In Figure 6, the through response of the coupler can be seen, in Figure 7, the reflection coefficient for one of the ports can be seen, in Figure 8, the coupling of the coupler can be seen, and in Figure 9, the isolation of the coupler can be seen. The isolation and coupling fall slightly short of the specs, but only by approximately $2\,dB$. The through response was approximately $5\,dB$, and the reflection was approximately $20\,dB$. Overall, the coupled line coupler performance is satisfactory for the substrate provided, and the simulations matched the physical design fairly well.

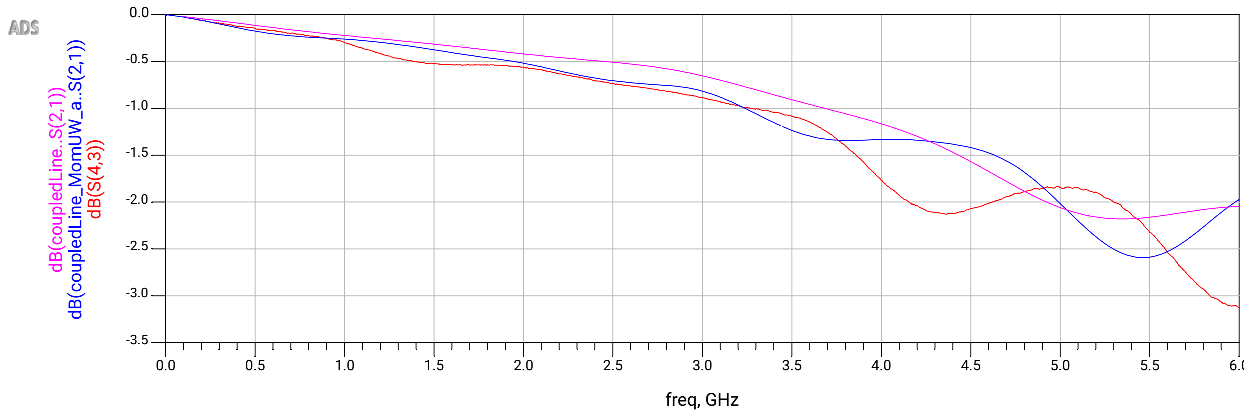

Figure 6. Coupled line coupler through, manufactured compared to simulations.

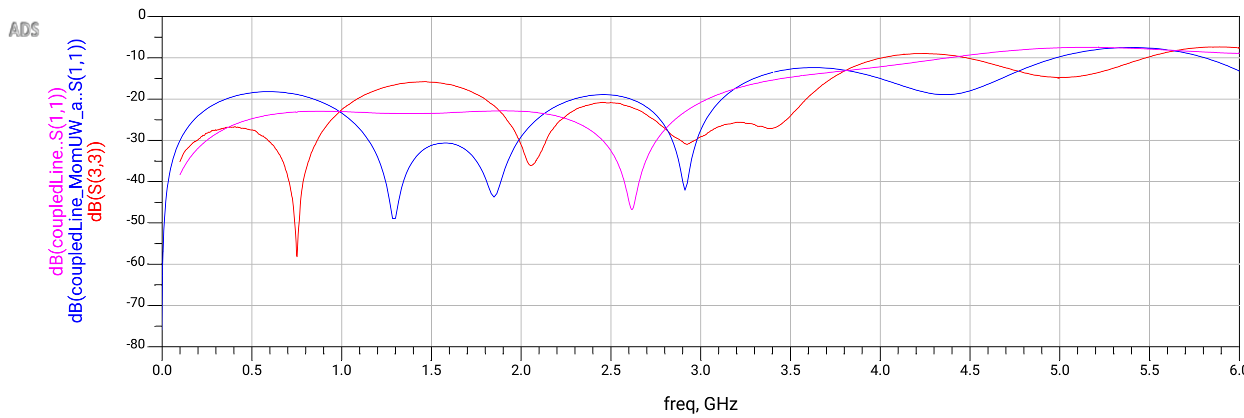

Figure 7. Coupled line coupler input reflect, manufactured compared to simulations.

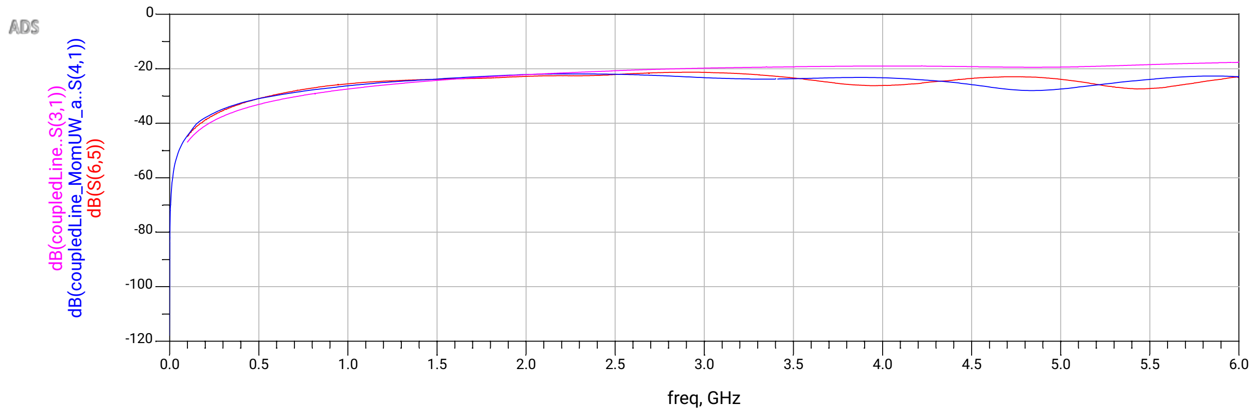

Figure 8. Coupled line coupler coupled response, manufactured compared to simulations.

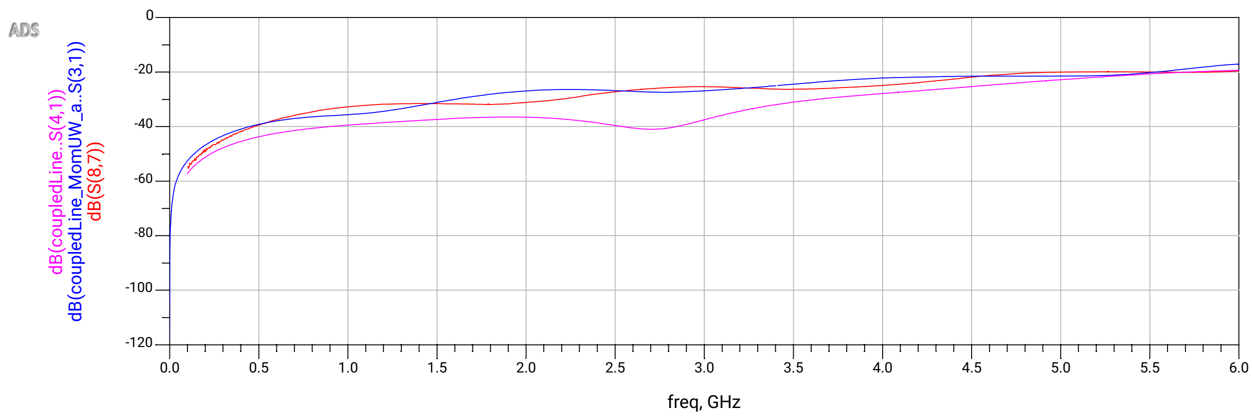

Figure 9. Coupled line coupler isolation, manufactured compared to simulations.

Measurements Branchline Coupler

Jackson was gracious enough to let us use the pre-calibrated VNA in the RF laboratory, which is where all but the branchline isolation port data came from. Final branchline isolation data came from the EDC VNA after calibration.

The branchline coupler seemed to have a slight shift in electrical length in the real design. The isolation (Figure 13, 14.) and reflection (Figure 12.) plots seemed to have their minimum values shifted to a lower frequency range. However, values for the port 4 isolation and port 1 reflection were still in the 20dB range at the design frequency, meaning the overall design is still likely to work, but with more significant losses and worse matching. The two output, phase-shifted ports (Figure 10, 11.) had more loss than in the simulated designs but were very close (approximately 3.5dB), which is generally acceptable.

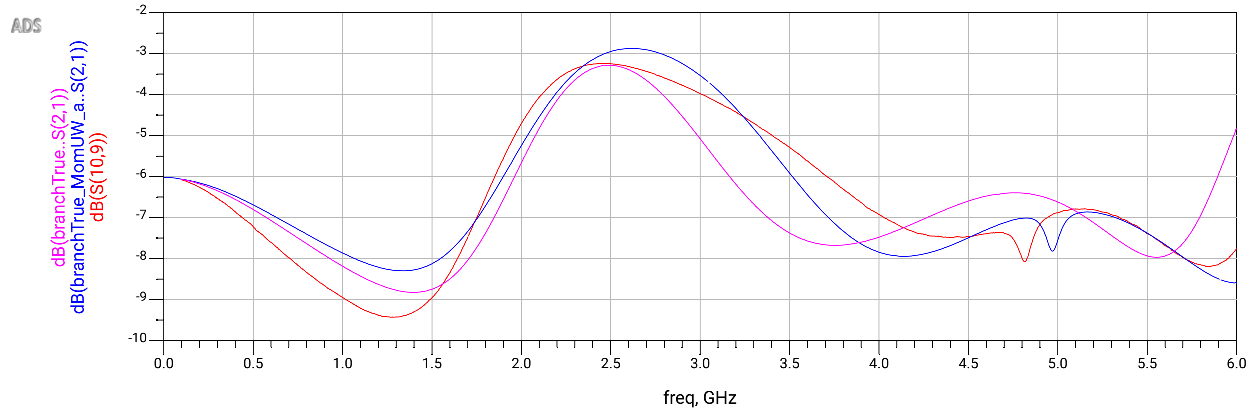

Figure 10. Branchline coupler port one output, manufactured compared to simulations.

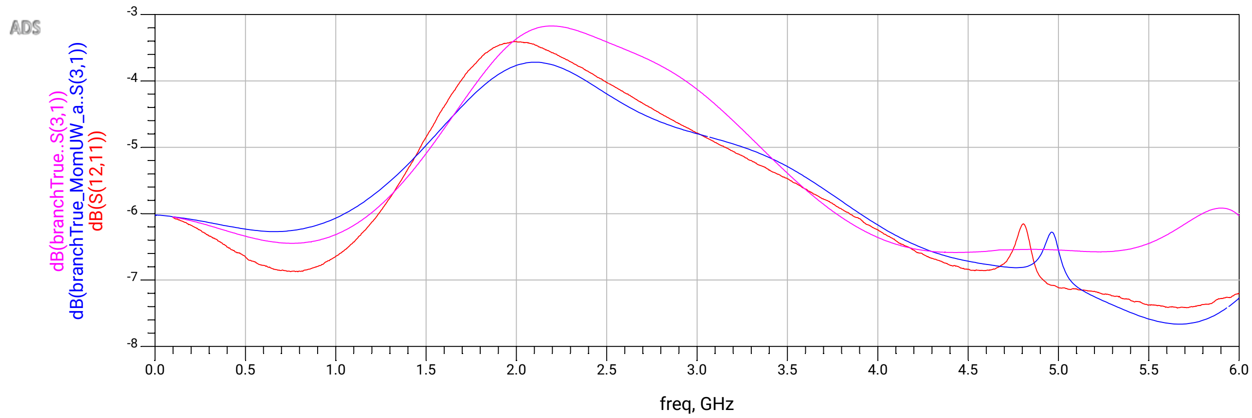

Figure 11. Branchline coupler port two output, manufactured compared to simulations.

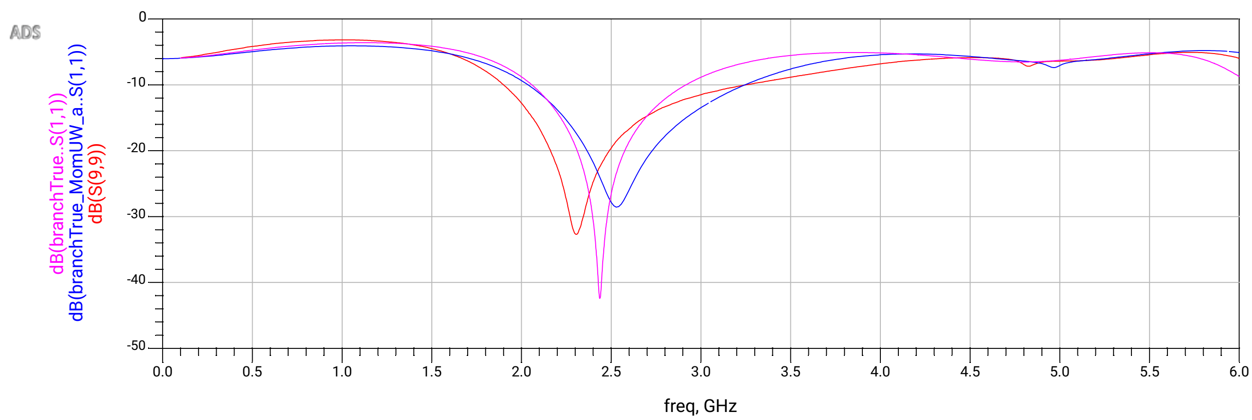

Figure 12. Branchline coupler input reflection, manufactured compared to simulations.

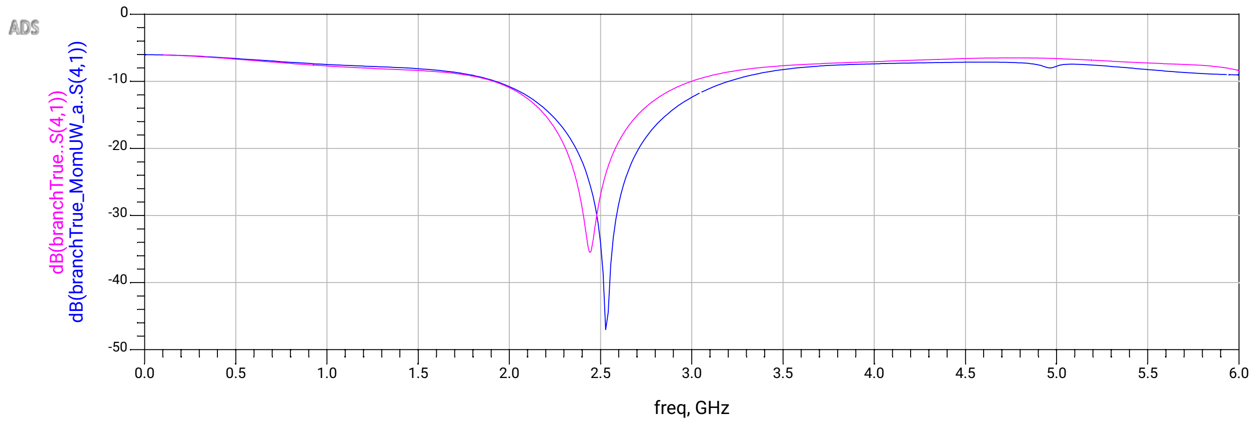

Figure 13. Branchline isolation port simulations only.

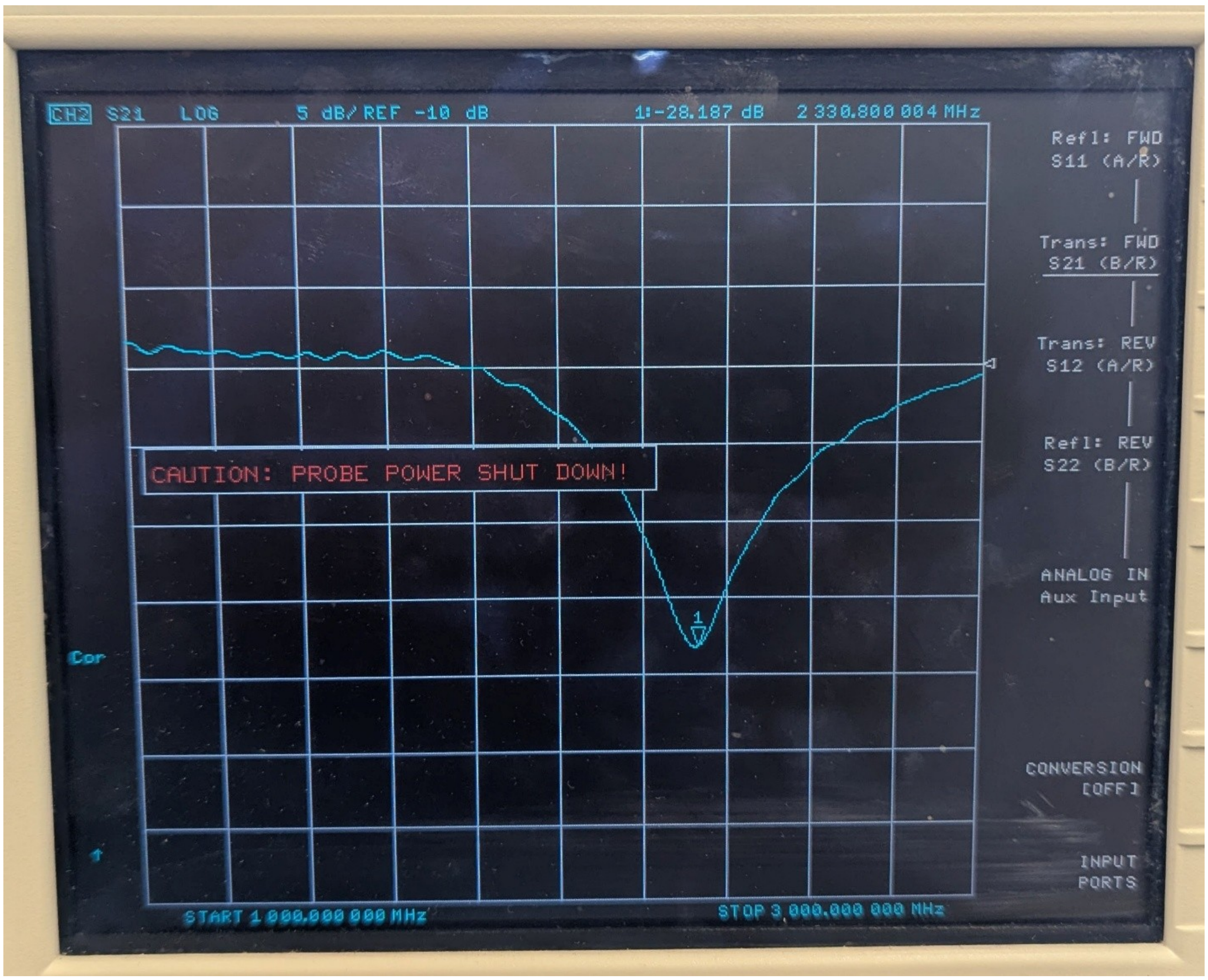

Figure 14. Branchline isolation port manufactured response.

Conclusion

Overall measurements and fabrication yielded solid results; the general shape of each S-Parameter plot was largely maintained, and values remained consistent in the target region. Generally, losses of the real designs were worse than schematic simulations, and the frequency response was generally shifted, which is to be expected given the FR4 substrate.