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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
MIT UHF REPEATER ASSOCIATION

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From: Daniel B. Sheen
Subject: Compact 1420 MHz Septum feed for the WR66

This memo describes the design and construction of a 1420 MHz dual circular polarized septum feed (shown in Figure 1) for the recently refurbished WR66 antenna on the Green Building at MIT. The new design is predicted to achieve an installed gain of about 36.2 dBi, representing an aperture efficiency of about 62%. Combined with Ultra Low Noise LNAs from CMT, designed for the DSA2000[1] array, the noise temperature of the system is calculated to be below 30 kelvin, and the completed system is expected to achieve a noise floor below 40 kelvin even allowing for interconnect loss and additional front end filtering requirements. This represents a G/T ratio aproaching 22dBK^{-1} for 60 degree elevation pointing angles.

Figure 1. The compact circular septum feed under free-space test

Background and Prior Work

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[1] S. Weinreb and J. Shi, "Low Noise Amplifier With 7-K Noise at 1.4 GHz and 25 °C," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 69, no. 4, pp. 2345-2351, April 2021, doi: 10.1109/TMTT.2021.3061459.

Prior to the pandemic, the WR66 antenna utilized an unchoked square septum feed of the OK1DFC design. This feed was tuned to perform acceptably both for Earth Moon Earth communication (EME) at 1296MHz, and for radio astronomy at 1420 MHz. With the newly refitted antenna system, we wish to abandon this compromise tuning in favor of separate feeds which are optimized for these different applications. A new feed optimized for 1420MHz operation is therefore required.

The OK1DFC design and its variants have been extensively reviewed by W1GHZ and other authors,[2] and I will not address it in depth here. In general, these feeds perform well on dishes with F/D ratios around 0.36, making them well suited to the WR66, however, their sidelobe suppression is relatively poor for radioastronomy applications and allows for higher spillover than we might desire. Additionally, the square geometry, while easy to construct, is ill-suited to efficiently feeding a round dish, and results in decreased BOR efficiency as discussed by Kildal[3]

Clearly the new feed therefore should not use a square waveguide design. However, general observation around MIT suggests that circular polarization is still desirable, primarily due to the high-RFI environment in the surrounding area which tends to be littered with linearly polarized sources.

A notional set of design goals for the new feed were thus, in no particular order:

1. Dual circular polarization
2. Near 100% radiation efficiency
3. Minimum spillover temperature
4. Maximum G/T ratio
5. Strong out of band signal suppression

A likely candidate for such a design was found in the work of Marc J. Franco[4], who described a 5-step septum polarizer design and HE11 beamformer using circular waveguide. Replication of his design in HFSS showed good agreement with his results following scaling to 1420 MHz. This feed is extremely attractive for it’s very high sidelobe suppression (35dB below the main lobe) however, its taper is steeper than we desire for WR66, and would represent a taper of more than 20dB by the edge of the reflector (~69 degree half angle), somewhat more than we desire for maintaining reasonable aperture efficiencies.

Additionally, the design is quite large, requiring a total length of 4.3 wavelengths, or about 90cm behind the antenna focal plane. This space is not safely available inside the radome due to the

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[2] Wade, Paul. Analysis of the OK1DFC Septum Feed, 2003. http://www.ok1dfc.com/EME/Technic/septum/W1GHZanalysis.pdf

[3] P. Kildal and Z. Sipus, "Classification of Rotationally Symmetric Antennas as Types BOR /sub 0/ and BOR /sub 1/," in *IEEE Antennas and Propagation Magazine*, vol. 37, no. 6, pp. 114-, Dec. 1995, doi: 10.1109/MAP.1995.482130.

[4] M. J. Franco, "A High-Performance Dual-Mode Feed Horn for Parabolic Reflectors with a Stepped-Septum Polarizer in a Circular Waveguide [Antenna Designer's Notebook]," in *IEEE Antennas and Propagation Magazine*, vol. 53, no. 3, pp. 142-146, June 2011, doi: 10.1109/MAP.2011.6028434.

need for mechanical clearance with the radome wall. Additionally, the weight of this feed would have been excessive (optimistically, perhaps 25 pounds).

However, this design became the starting point for a new compact and lightweight septum feed much better suited to the WR66 antenna which will be described below.

Physical Design

The new feed designed for WR66, shown under test in Figure 1, is an extremely compact circular septum feed less than 18 inches long. Unlike the design proposed by Franco, it utilizes a new 4-step septum optimized for its performance in the 1420MHz radio astronomy band. In place of an over-moded waveguide transition to generate an HE11 mode, a dual ring chapparal horn design is utilized to approximate a gaussian profile. The exact cross sectional dimensions of this design are given in Figure 2 for the 1420MHz optimized design. Notably, this is in fact shorter than a corresponding OK1DFC style feed would have been.

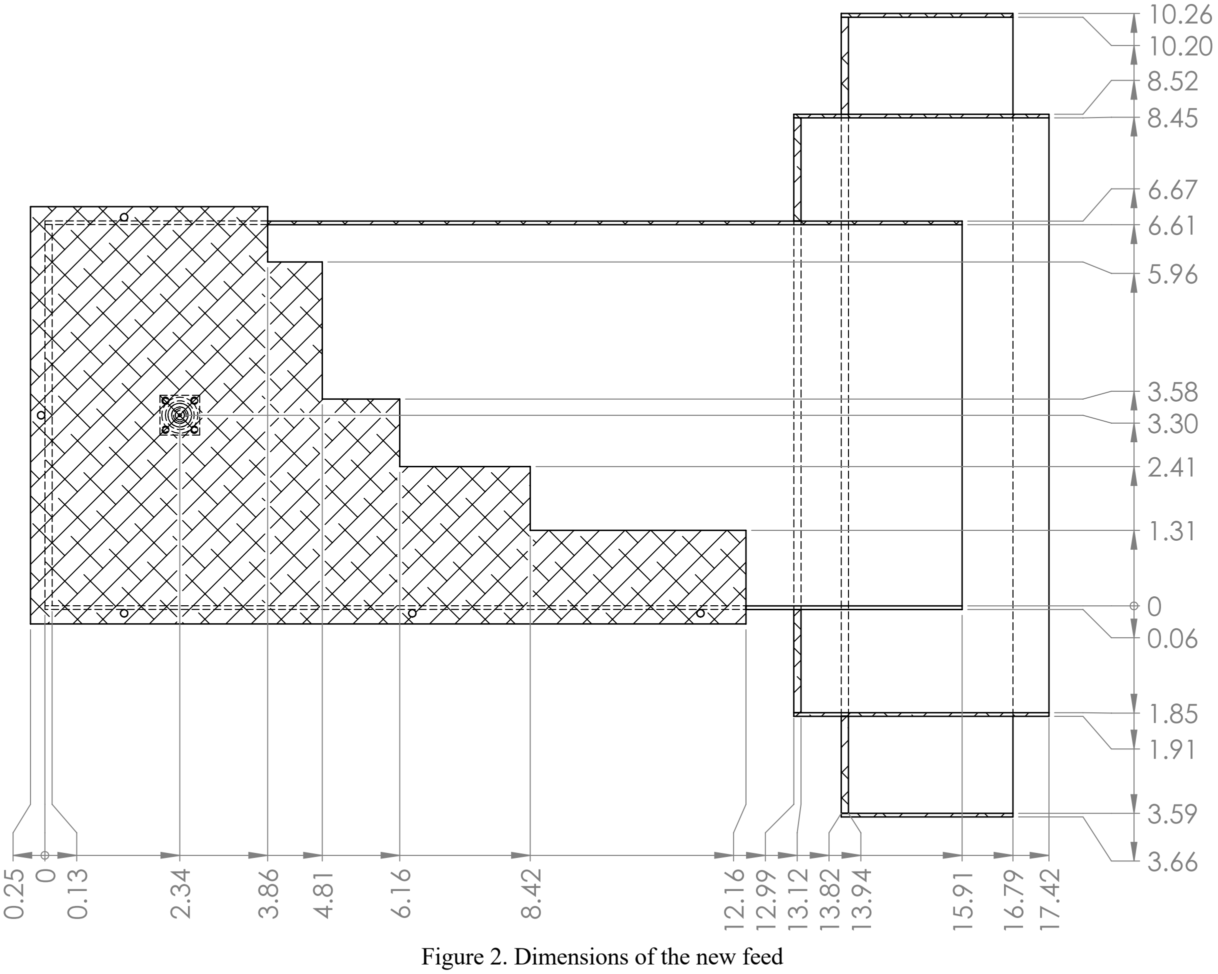

Figure 2. Dimensions of the new feed

The feed was built from multiple different sizes of aluminum sheet, cut to order from a company called SendCutSend[5]. The round walls of the waveguide and choke rings were made from 1/16th

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[5] https://sendcutsend.com

inch 6061 aluminum, the end plates of the waveguide and rings were made from 1/8th inch 6061 aluminum, and the septum was cut from 0.040” aluminum sheet. The septum was found to have a tendency to warp during assembly, so should likely be made thicker in future designs.

The input probe dimensions are shown in Figure 3. The probe is made from brass, and soldered to the center conductor of an N type connector (Amphenol 082-6712-433358) with the Teflon dielectric trimmed back flush to the waveguide wall. Several other components are included to provide a good ground connection for the outer conductor, and to adapt the flat flange of the connector to the circular wall of the waveguide.

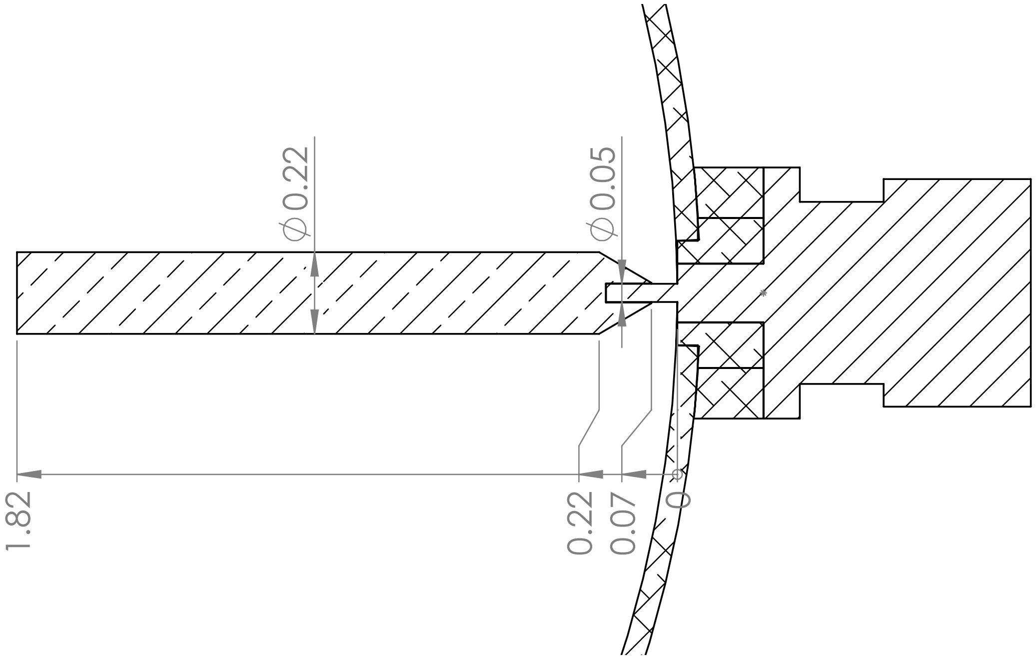

Figure 3. Input probe dimensions

Design Approach

The new feed was designed systematically in Ansys HFSS roughly as follows:

1. A model of a 4 step circular waveguide was created, fed by three waveguide ports. The two half-guide input ports considered only the a single TE mode, while the output port considered two orthogonal polarizations. An initial guess at the septum dimensions was taken from Franco, and then the septum was optimized to maximize the input port isolation, minimize reflection coefficient, and minimize axial ratio at the output port.
2. A model of the input coax to waveguide transition was created with the septum polarizer, and the same optimization performed as in step 1.
3. Separate from the simulation of the polarizer. A model of the choke was created and fed with a linear TE11 mode. Initial values of the ring diameters were chosen to approximately match the zeros of the antenna point spread function, and the choke depths were chosen as ¼ wavelength. The profile was then optimized for low return loss, and a beam profile with a taper and sidelobes suitable for the WR66. In this case, a taper of

about 15dB at the edge of the reflector, and minimal azimuthal variation. The resultant profile is shown in Figure 4.

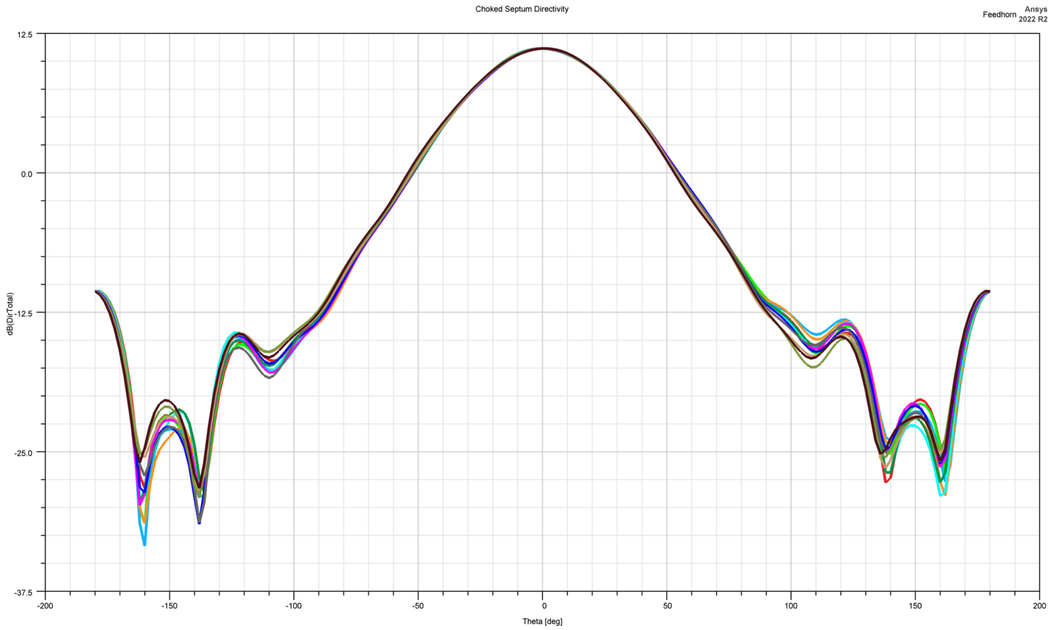

Figure 4. Simulated feedhorn radiation pattern

4. Finally, the full feed was combined and modeled to verify performance (Figure 5). It is worth noting that the port isolation is lower than we might hope, however, it is more than high enough to allow for accurate polarimetry measurements. In future revisions there is room for better optimization. Note also that this is further degraded by the dish to about -18dB, however, this is not truly reflective of polarization isolation since that effect is primarily the result of fields emitted by the feed being reflected back from the dish with the reverse polarization, which is primarily relevant in transmit applications.

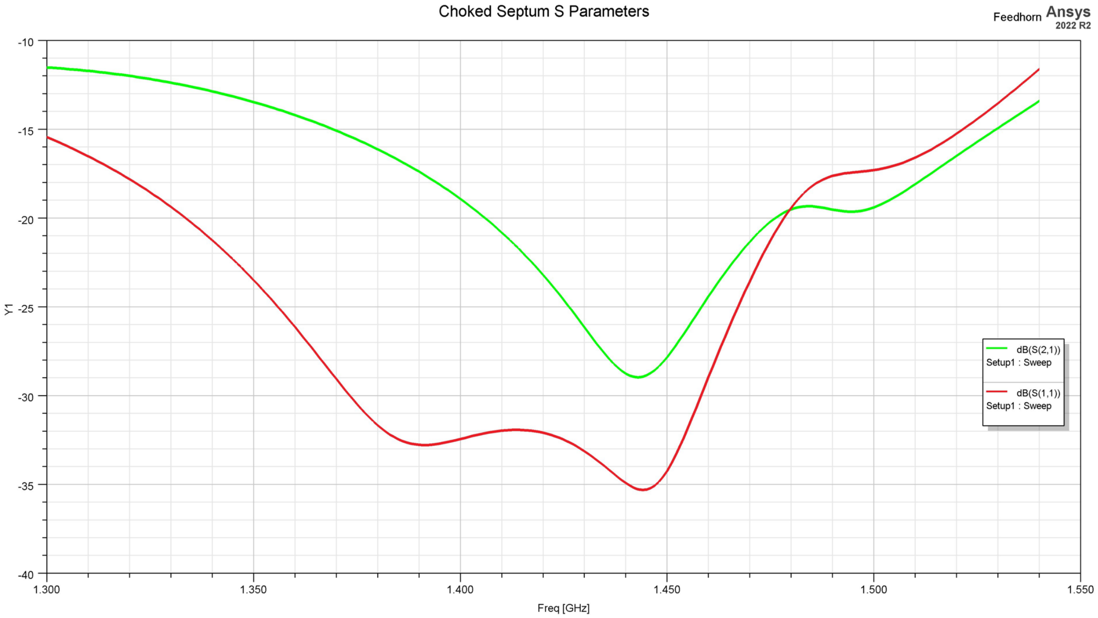

Figure 5. Predicted antenna S parameters in free space.

After the initial models of the feedhorn were completed, the full radiation pattern in the presence of the reflector was analyzed using a hybrid FE-PO simulation in HFSS. The resultant beam pattern was exported and analyzed using a custom python script to calculate the performance of the full antenna system at different elevation angles. The beam pattern is shown in Figure 6, showing excellent sidelobe suppression and minimal spillover.

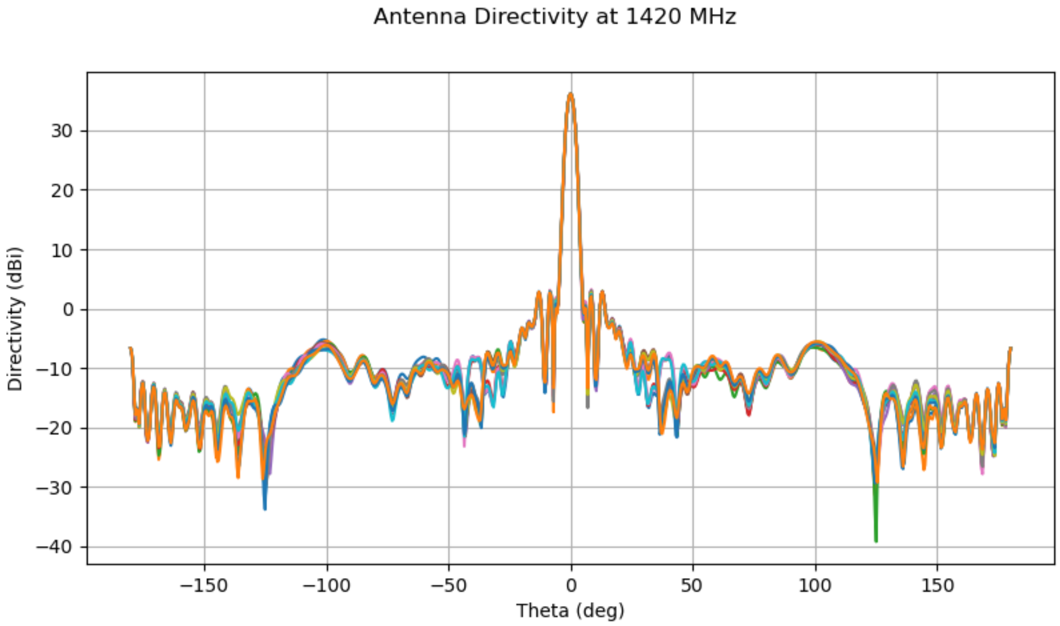

Figure 6. Modelled antenna beam pattern for WR66 with the compact choked septum feed

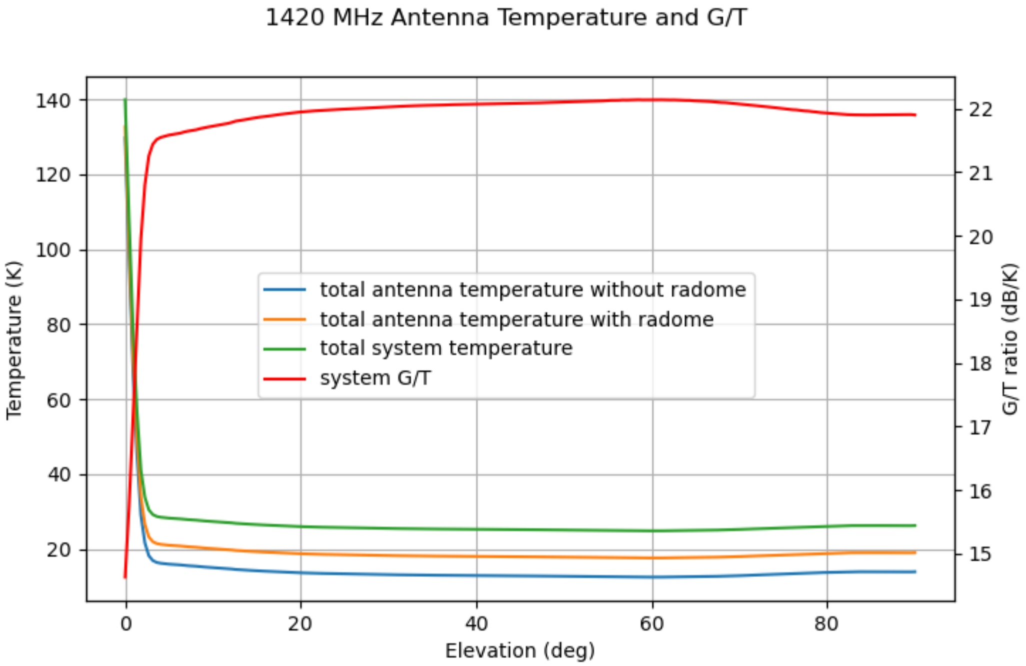

Figure 7. Modelled antenna and system temperature and G/T ratio for WR66 with the compact choked septum feed

Integrating over the antenna pattern to compute the antenna temperature yields the results of Figure 7. As can be seen, for elevation angles above about 5 degrees, the expected antenna temperature falls well below 20 degrees kelvin. Even with radome loss and the LNA temperature contributions included, this gives a predicted system temperature of under 30 kelvin across most elevation angles. This will likely suffer slightly from feed spar scattering and interconnect losses not modelled, but it paints an extremely promising picture of the performance we can realistically expect from the system. It seems likely that additional losses will be sufficiently small to hold the system temperature below 40 kelvin.

Construction

The feed was primarily assembled by TIG welding, shown in Figure 8. In large part this went extremely smoothly, but it highlighted a few weaknesses of the design that should be fixed in future iterations. All told, assembly took about 5 hours over two nights.

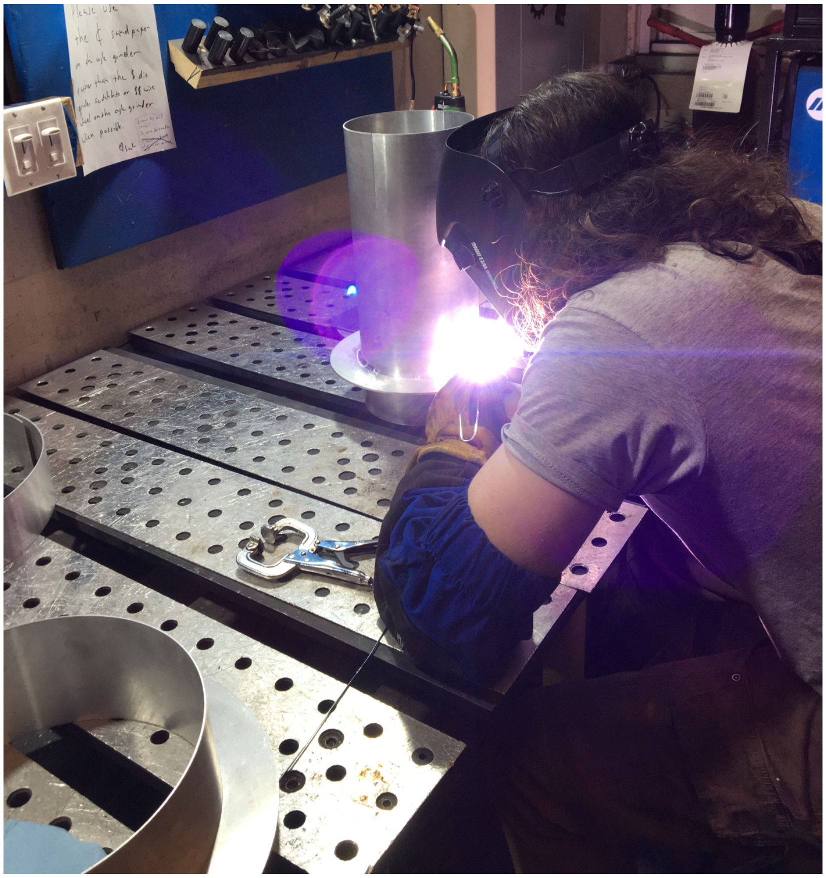

Figure 8. Jonhenry Poss assembling the 1420MHz feed

Notes for future design improvement include:

1. Welding the main circular waveguide section proved difficult. Adding ribbing to the exterior to force it into shape would help.
2. The thin septum was prone to deformation and should be redesigned to be the same thickness as the waveguide wall in future versions.
3. Some additional alignment jigs for the choke would simplify construction substantially.

Manufacturing the input probes proved quite straightforward, however, the interface adapters to fit them to the curvature of the waveguide were difficult to machine in house and should probably be sent out for CNC machining in future. The input probes are shown in Figure 9 and Figure 10

Figure 9. Completed input probe assemblies prior to insertion into the feed. Note that the choice of brass for the outer conductor sleeve was made for machining convenience for the prototype, and should probably be aluminum in future designs.

Figure 10. Input probes installed in the antenna

Measured Performance

The measured performance of the feed in isolation (pointed skyward) is shown in Figure 11. The region between 1.3 and 1.55GHz fairly closely matches the model predictions of HFSS. However, there is a strongly evident difference in the return loss of channels 1 and 2 below about 1.43GHz. This appears to be primarily due to warping of the septum polarizer during manufacture. Further tests are needed to determine whether this affects the polarization performance of the feed, but it will clearly need to be addressed in future revisions of the design.

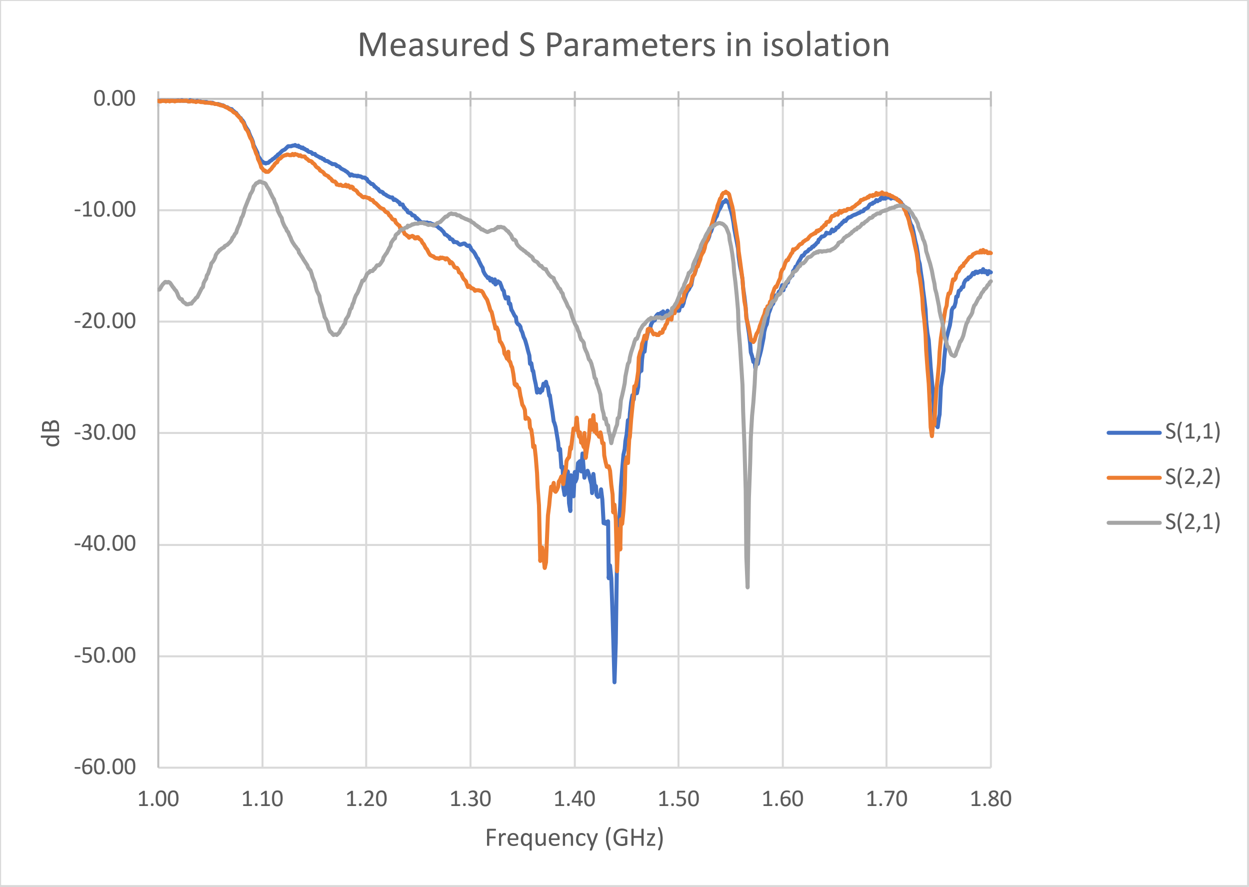

Figure 11. Measured S parameters of the feed in isolation