

# Simulations and Measurements of a Circular Waveguide Septum Feed

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This article describes the author's efforts to establish a simulation setup without excessive computation time, along with accurate measurement methods to verify the performance

This is the first of two articles describing a number of time domain solver 3D EM field simulations of an antenna feed consisting of a circular waveguide with a septum polarizer and two external

coaxial connector ports. Measurements of the actual  $S$ -parameters of a constructed feed were then compared to the simulations, to determine which mesh and solver settings afforded good accuracy without excessive computation time.

This first article concentrates on the feed alone without a reflector. Significant energy is reflected back into a feed when it is placed at the prime focus of a parabolic reflector. To examine these effects, the second article will concentrate on modeling and measurement of the entire antenna.

## Introduction

Circular polarization is used for satellite communications, radio astronomy and for amateur radio Earth-Moon-Earth (EME) experimental communications, especially at 1296 MHz. Previously, the authors used feeds with external hybrid couplers, or with numerous tuning screws, to create circular polarization. The tuning screws are used to create phase shift by periodic loading of the waveguide as described by Simmons [1]. Feeds for amateur radio EME operation require two ports because transmit and receive are done with opposite sense polarization, RHCP for one and LHCP for the other. The prior feeds with tuning screws had excellent performance

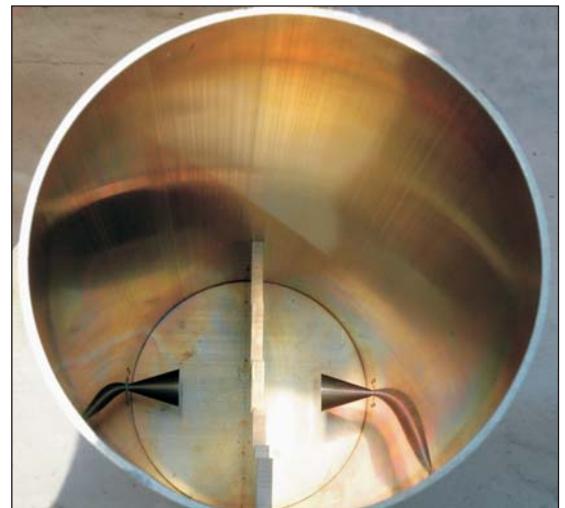


Figure 1 · View of the inside of the circular feed, showing the two probes and stepped septum.

while pointed at the sky but only when new and dry. However, tuning was very critical and the reflections from the parabolic dish antenna disturbed the pattern and the isolation. When the feed was wet or the tuning screws became corroded, its performance degraded. Feeds that use two orthogonal probes and an external quadrature hybrid suffer from unnecessary losses in both the transmit and the receive circular polarization ports.

The use of a sloping or stepped septum in the H-plane to create circular polarization was briefly described in Volume 9 of the MIT Rad Lab series [2]. The proposed use was for creating circular polarization in a very compact form factor for a rotary joint. The first real development of the septum waveguide feed was by Bill Parris of Westinghouse in the mid-

1960s. The first published paper was by his colleagues and presented in 1967 [3]. References [4, 5, 6] are related papers. The early septum feeds were built in square waveguide. The first published circular septum feed was published in 1991. This concept was later adopted by Czech radio-observatory engineers as well as amateur radio operators and several versions were made for different frequency bands [7].

One of the authors (Galuscak) and his advisory professor Pavel Hazdra at the Czech Technical University of Prague improved the design by using modeling software to optimize the steps of the septum using mode matching. Their goal was to produce the best possible axial ratio of RHCP to LHCP over a narrow frequency range. They found that using five steps produced far better results than either a straight sloped septum or one with an exponential curve. Their simulations showed an axial ratio circularity of 0.1 dB, with measurements showing around 0.2 dB.

The optimization methodology was published in 2006 at a EuCAP conference [8]. A detailed article was published the following year which included comparisons with previous square feeds [9]. Simulations at that time required simplifications and shortcuts in the modeling so they could be done with the software and computer limitations. We decided to revisit the simulation because we now have at hand much more powerful software and 64-bit computers with huge amounts of memory.

### Simulation Setup

The feed model was created by Galuscak and Hazdra then converted into a SAT file. All dimensions were carefully made the same as the manufactured feed except for the two coaxial ports. The model contains generic 50 ohm coaxial ports with air dielectric that do not represent the actual Type N and Type DIN 7-16 connectors on the real feed. As seen

Sim.	Accuracy	Sub-cycles	Fill limit	PBA timestep	Stability factor	AR filter
1	-40 dB	4	70	.45	.9	no
2	-60	4	70	.45	1	no
3	-40	4	70	.45	1	no
4	-40	4	70	.45	1	no
5	-60	4	70	.45	1	yes
6	-40	4	70	.45	1	yes

Table 1 · Transient solver settings.

Sim.	Lines/wavelength	Lower Mesh Limit	Mesh line ratio	PBA or FPBA	PBA fill limit
1	26	5	10	PBA	97%
2	22	5	10	PBA	99%
3	28	5	10	PBA	99%
4	28	5	10	FPBA	99%
5	28	5	10	PBA	99%
6	28	5	10	PBA	99%

Table 2 · Mesh settings.

later, this introduces mainly a difference in time delay between the simulation and the measurements. The software used for simulation was CST Microwave Studio 2009 [10]. The computer had two Xeon processors with eight cores and 64 GB of memory.

The far field pattern simulations and measurements done earlier were deemed to be very accurate by measurement in an anechoic chamber, and therefore, it was unnecessary to redo them. This project concentrated on the  $S$ -parameters of the antenna and the impact of the reflections from the dish surface on these parameters.

The Integral solver within CST Microwave Studio is well suited to large structures and also produces good accuracy for far field patterns. This uses the Multilevel Fast Multipole Method (MLFMM). However, it is unsuited for accurate  $S$ -parameter simulation. Therefore, the Transient solver was used even though it requires far more memory and time.

The same feed structure was simulated six times, each with different solver or mesh settings. The parameter that caused the most significant change in  $S$ -parameters was the

Sim.	Number of Mesh Cells	Simulation Time
1	6,554,416	4 hr 36 min
2	3,415,100	4 hr 41 min
3	5,806,080	3 hr 54 min
4	5,806,080	2 hr 36 min
5	5,806,080	1 hr 39 min
6	5,806,080	3 hr 54 min

Table 3 · Comparison of number of mesh cells and simulation time.

selection of Fast Perfect Boundary Approximation (FPBA) in place of PBA. The Tables 1 and 2 list the settings for each of the six simulations. Table 3 compares simulation times.

### Simulation Results

The simulations produced complex paired  $S$ -parameters and also scalar Return Loss and Isolation data. The first step was to focus on the similarities and differences seen in the results among the six simulations. The following graphs show the plots of the scalar Return Loss (match) of the ports of the feed. Note that the ports within the simulation model are simplified air dielectric and identical. Therefore, only one port was analyzed in each simulation.

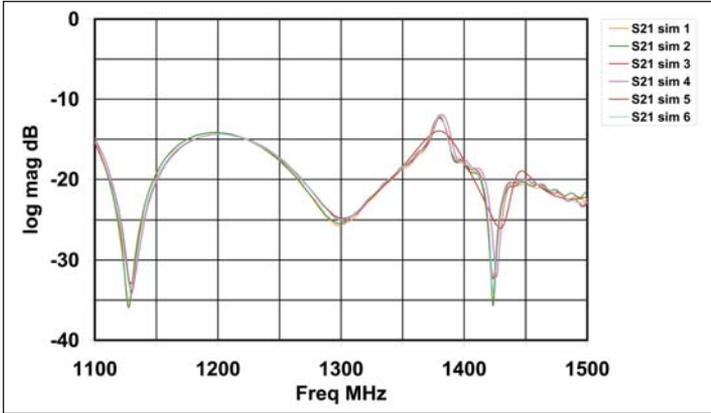


Figure 2 · Comparison of six  $S_{21}$  simulations of the feed.

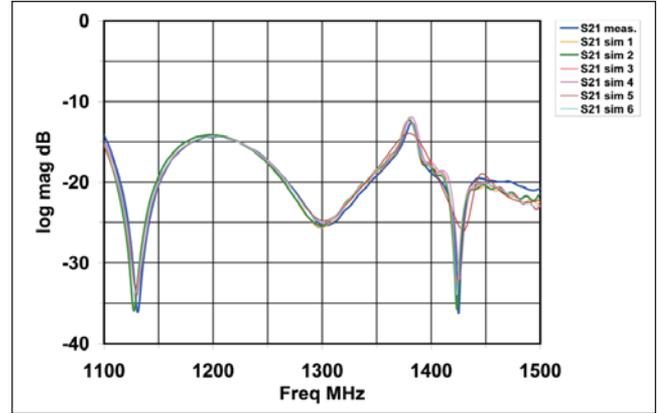


Figure 3 · Comparison of actual measurement data  $dB(S_{21})$  with the simulations of the feed.

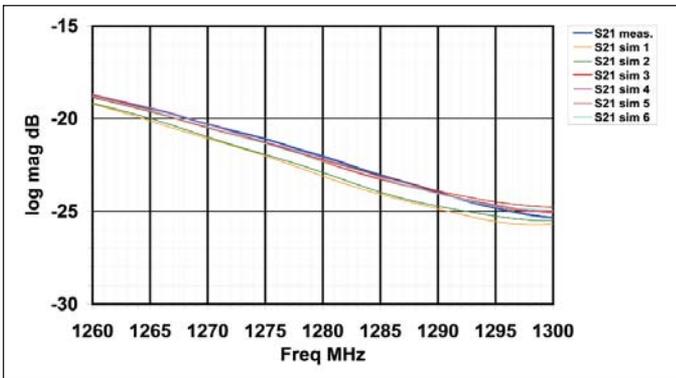


Figure 4 · Comparison of actual measurement data with the simulations of the feed over the frequency span of 1260 MHz to 1300 MHz.

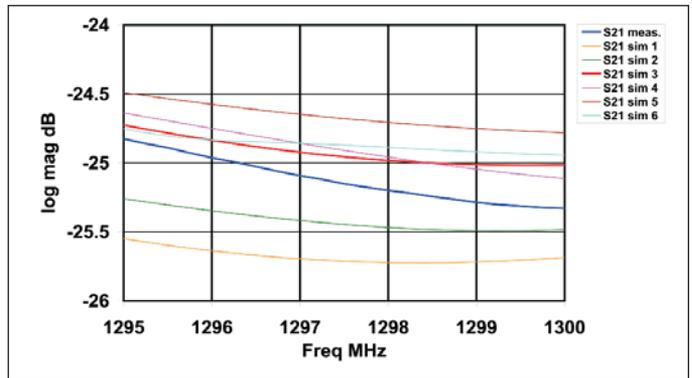


Figure 5 · Comparison of actual measurement data with the simulations of the feed over the narrow frequency span of 1295 MHz to 1300 MHz.

In Figure 2, note that the application of the AR filter in simulations 5 and 6 smoothed the response curves. The use of FPBA in simulation 4 shifted the frequency slightly. Now we will compare these simulations to the actual measurement data.

Figure 3 shows excellent correlation between the measurement of the manufactured feed with the simulations. Simulation 2 seems to be the best match, in general. Since this feed was designed to provide the highest quality circular polarization and far field pattern between 1260 MHz and 1300 MHz, and amateur radio EME operation is generally at 1296 MHz, the following two figures will show the accuracy of the simulations over this limited bandwidth.

In Figures 4 and 5, it is clearly

seen that the simulations agree with the measurement data within 0.25 dB at the frequency of interest, and within less than 1 dB over a wider range. This is quite remarkable given the manufacturing tolerances of the feed, as well as measurements that required the calibration and de-embedding of a pair of 12 foot coaxial cables plus an adapter between N and DIN 7-16.

We can learn from the results that it is useful to set the Transient simulator and Global Mesh Properties to use a minimum of 22 lines per wavelength, PBA meshing, and use -60 dB accuracy. Increasing the number of lines per wavelength to 28 does not seem to be necessary.

Next, we'll examine the simulation results of the  $S_{11}$  of the feed port.

In Figure 6, we see some interesting groupings and also differences among the six simulations of the same structure model. It shows that the simulation settings make a considerable difference while simulating port match. Simulation 4 stands out from the rest and it is the only one with the Global Mesh setting of FPBA. According to CST technical support, FPBA is efficient for very complex structures but not for this feed. They were able to make the accuracy of the  $S_{11}$  simulation more closely match the PBA by significantly subgridding and increasing the number of meshcells to 12 million. There are two other distinct groupings. Over the range of 1200 MHz to 1350 MHz, simulations 1 and 2 track each other, and simulations 3, 5, and 6 track on another.

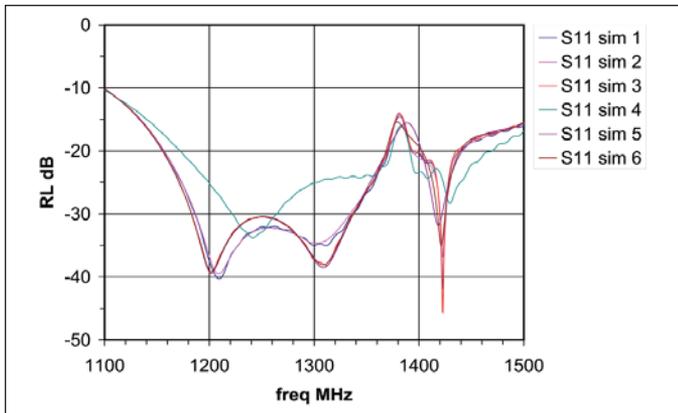


Figure 6 · Comparison of six simulations of the port  $S_{11}$ .

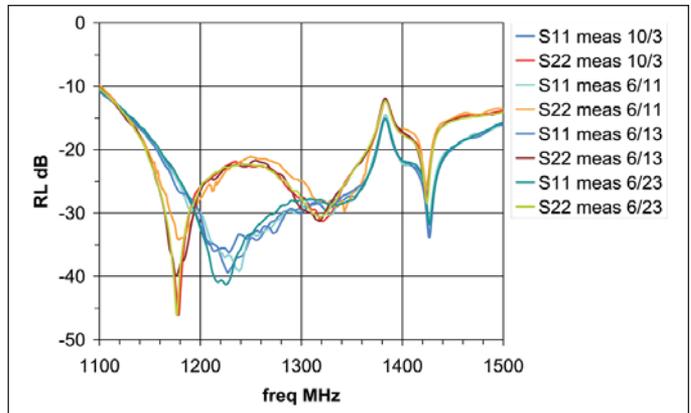


Figure 7 · Comparison of four different measurements of the actual feed.

The actual fabricated feed was measured four separate times. Different sets of coaxial cables were used twice, and some measurements had different coaxial adapters. There was an expected and noticeable difference in the return loss of  $S_{11}$  and  $S_{22}$  because port 1 on the actual feed is a Type N connector and port 2 is a DIN 7-16 connector, with different sizes, match, and delay.

Taking into account that the cables used were Times LMR400UF, which is not metrology cable, the ripple is likely imperfections in the cables. Given that different cables and adapters were used for the different measurements, the data is consistent and shows that the calibration procedure can be trusted.

One of the sets of measurements was plotted with all six simulations in Figure 8. It is important to keep in mind that the simulations were done

with a structure having identical simplified air dielectric ports. They are closer in size to the Type N but have no loss or delay. The actual fabricated feed has two different ports and both have dielectric. Additionally, since the test cables were 12 feet long and imperfect, it is not possible to trust measurements approaching  $-30$  dB return loss. The inherent loss and mismatch of the cable along with flexing causes unavoidable errors.

The most significant source of differences is the delay of the connectors. So instead of comparing the scalar return loss, the complex  $S$ -parameter data from three of the simulations was compared with three of the measurements. Then a small delay was subtracted from the measured  $S$ -parameters to correspond to the connectors.

Figure 9 is a highly expanded Smith Chart view of the  $S$ -parameters.

$S_{11}$ ,  $S_{22}$ , and  $S_{33}$  (the two darker green and the purple traces) are simulated data.  $S_{88}$ ,  $S_{99}$ , and  $S_{1010}$  (the light green, red and blue traces) are measured data with their delays corrected. Now that appropriate delays have been addressed, the two groups of simulated and measured data can be seen to agree very well, except for a difference in loss. This confirms the accuracy of the simulations.

### Conclusion

This articles shows that properly done simulations of a complex two-port circular waveguide feed accurately reflect the actual performance of a fabricated feed. We recommend using the Transient Solver for accurate  $S$ -parameter simulations. Using FPBA mesh setting will run faster, but we recommend using PBA for final simulations as it was found to be more accurate.

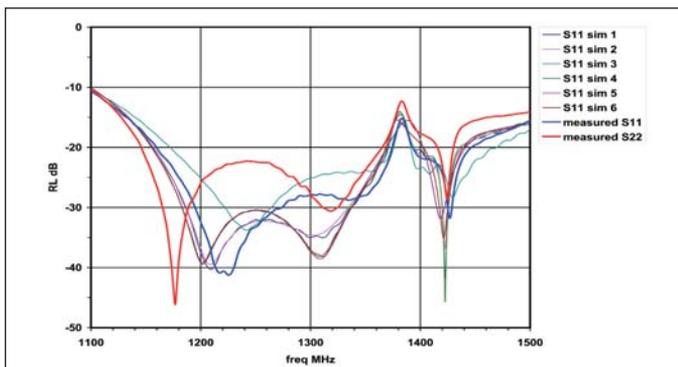
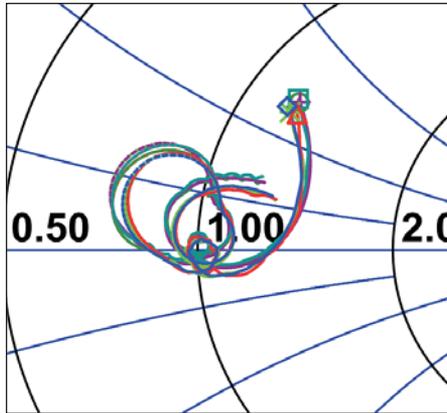


Figure 8 · Comparison of six simulations of  $S_{11}$  with actual measurements.

### Notes on Measurement Equipment

Vector Network Analyzer:	Agilent 8753ES
Type N calibration kit:	HP85054A
Type DIN (7-16) calibration kit:	Maury 2750F
Type N precision adapters:	Maury 8801K
Initial Type DIN 7-16 to N adapters:	Andrew (male and female)
Later Type DIN 7-16 to N adapters:	Rosenberger 60S153-K50N1 Rosenberger RT53S160-K50 Suhner (male and female) Maury 2706C



**Figure 9** . Complex S-parameter comparison of simulated and measured data.

The second article of this series will present the results of the significant challenge of transient simulations and measurements with this feed placed at the prime focus of a 12 foot parabolic reflector. The results will show the effect of the reflections from the central portion of the dish back into the feed.

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