From August 2010 *High Frequency Electronics*

Simulations and Measurements of a Prime Focus Dish with a Circular Septum Feed

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Real-world performance is compared to simulations, to determine the optimum setup for accurate and repeatable future simulation of microwave feeds exposed to relections

This is the second article of two parts. This article concentrates on the impact of placing the previously simulated and measured feed [see July 2010 *High Frequency Electronics*] at the prime focus of a parabolic reflector. Since significant energy is reflected back into the feed, we wanted to determine how much effect this would have on the isolation between the two ports of the circularly-polarized feed. The simulation results and actual measurements were compared and found to correlate with very good accuracy. The match at each of the two ports is relatively unaffected at the design center frequency, whereas the port to port isolation is reduced by the reflections.

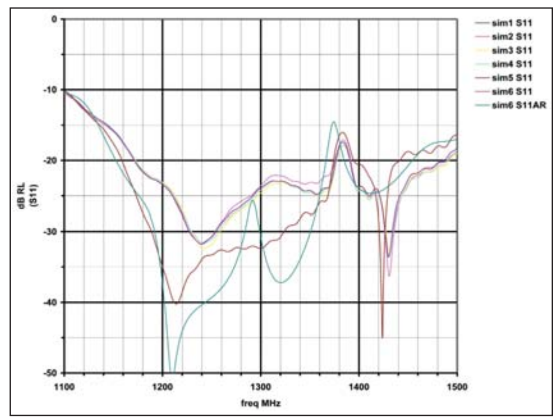

Figure 1 · Comparison of six S_{11} simulations of the feed with a 10 lambda dish.

Simulation First Steps

Clearly, trying to accomplish a Transient Solver simulation of a very large structure could require too many mesh cells to simulate without a cluster of supercomputers running in parallel. As mentioned in the first article, these simulations were done with Microwave Studio 2009 by CST on a single computer with a substantial amount of memory. The only high quality dish of intermediate size that we had available for accomplishing the measurements was approximately 12 feet in diameter. Actual measurements are 357 cm and f/d = 0.375. We did not want to begin our simulations with a dish this large because it would take too long to simulate. Instead, we began by using a hypothetical dish that was 10 lambdas (231.5 cm) in diameter with f/d = 0.35. This allowed us to try different meshings and compare their results to see if we could use sub-gridding to reduce the total number of meshcells. Our simulation problem was compounded by the fact that the structure of the feed was imported from a 3D CAD program as a SAT file and this file contained some rather small features and discrepancies between interfaces. We ran five successful simulations of the feed plus 10 lambda dish and additionally re-simulated the first simulation with the auto-regressive (AR) filter enabled. This filter is used when there are strong resonances in a structure to either reduce simulation time or to remove ringing.

Simulation Settings

We begin by presenting a table of the number of mesh cells and the simulation time for each of the runs.

Simulations 1 and 6 meshed the entire volume including the space in front of the dish

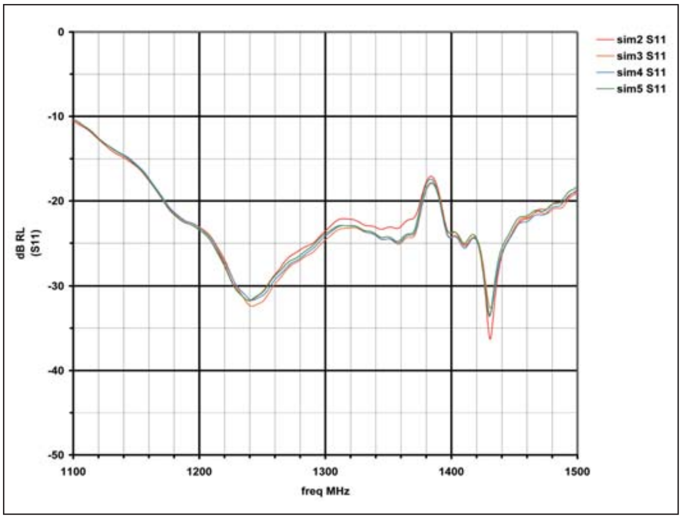

Figure 2 · Comparison of four S_{11} simulations of the feed with a 10 lambda dish.

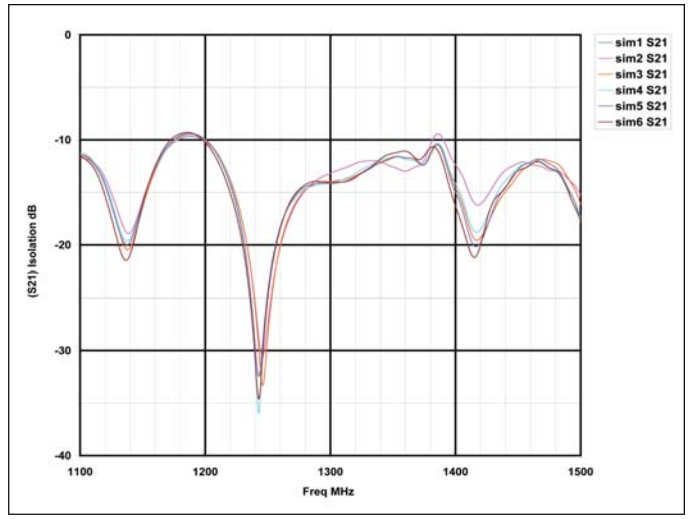

Figure 3 · Comparison of six S_{21} simulations of the feed with a 10 lambda dish.

and took almost 11 days or nearly 1 million seconds even with eight processor cores. Because this feed produces circular polarization it was not possible to utilize symmetry planes in order to reduce the simulation complexity and time. The other simulations used subgridding so that small structures had a very fine mesh and the large volumes had far fewer mesh cells.

Let us examine the simulation results before showing the mesh settings:

Simulations 1 and 6 were identical settings; therefore, the plots coincide. The experiment of applying a post AR filter of simulation 6 produced unusable results. We will now show just the plots of simulations 2 - 5 together in Figure 2.

Figure 3 shows the plots of all simulations of S_{21}, which is the isolation between the ports. The experiment of applying a post AR filter of simulation 6 produced unusable results so it is left off of the figure.

Sim.	Number of Mesh Cells	Simulation Time
1	470,784,600	261 hr 14 min
2	247,066,512	36 hr 9 min
3	41,896,879	29 hr 47 min
4	27,008,825	13 hr 20 min
5	35,829,780	28 hr 30 min
6	470,784,600	261 hr 3 min

Table 1 · Number of mesh cells and simulation time.

Mesh Settings and Sub-Gridding

Simulations 1 and 6 were identical and finely meshed the entire volume without sub-gridding. Simulations 2 and 3 both used the same sub-gridding. A vacuum cylinder was placed around the outside of the entire feed and extended past the opening. Then another larger vacuum cylinder was placed between the open mouth of the feed and extended all the way to the dish surface. These two cylinders became the boundaries for sub-gridding so that they would include finer meshing which would hopefully produce higher accuracy. The rest of the volume surrounding the dish had far less meshing which resulted in fewer mesh cells. The vacuum cylinders representing the subgrid volumes is shown in Figure 4. These are blue in the figure.

A further attempt was made to reduce the simulation size by removing the vacuum cylinder between the feed and the dish. We wanted to see whether this adversely affected the results. The remaining vacuum cylinder is shown in blue-grey in Figure 5.

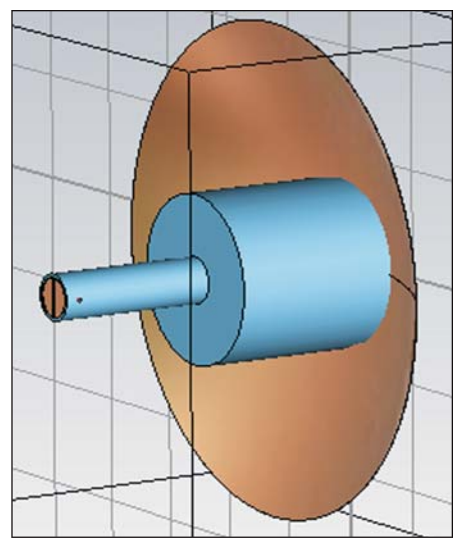

Figure 4 · Sub-gridding vacuum cylinders used in simulations 2 and 3.

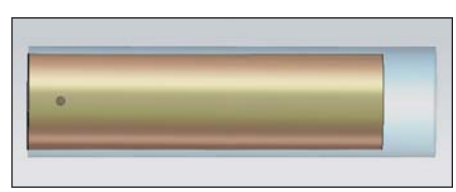

Figure 5 · Sub-gridding vacuum cylinder used in simulations 4 and 5.

We will see the mesh settings in Table 2 and the transient solver set-

Sim.	Lines/ wavelength	Lower Mesh Limit	Mesh line ratio	PBA or FPBA	PBA fill limit
1	22	5	10	PBA	99%
2	14	5	10	automatic	99%
3	18	5	10	automatic	99%
4	18	5	10	FPBA	99%
5	20	5	16	FPBA	99%

Table 2 · Mesh settings.

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

Table 3 · Transient solver settings.

tings in Table 3. The settings for simulation 6 are not shown because they are identical to those of simulation 1.

It was not apparent why the S_{21} result for simulation 2 differed from the tight grouping of the others. This simulation was set with fewer lines per wavelength yet the number of mesh cells generated was almost as large as simulation 1, which did not include sub-gridded vacuum volumes. Unfortunately, no dish of this size was available to make measurements.

Simulation Results With a Reflector

One of the authors had a spun aluminum dish with a very good surface accuracy. It was made for use up to 20 GHz. The size was a bit large, 12 feet in diameter. When we first tried to simulate this with the same feed model the number of mesh cells was over 500 million and the amount of memory in the computer was insufficient to run this. We were able to simulate it by simplifying the feed ports. Instead of modelling the two ports as fine coaxial structures, we placed waveguide ports on the rear of the simulation model of the feed. This reduced the number of mesh cells to a manageable size: 142,027,280 mesh cells. The simulation time was 48 hr 13 min. We used PBA meshing and 15 lines per wavelength. The simulation was done with the plane of the mouth of the feed at the prime focus of the reflector. That actual phase center of the feed may be slightly inside.

The simulation results shown in Figures 6 and 7 are using a modified feed model with two waveguide ports. As we will see in the comparison with measured data, the S_{11} is most accurate at the design center frequency and the S_{21}, which is the port to port isolation, is accurate over the entire range.

Measurements With An Actual Reflector

The next step was to set up a measurement system of the feed and the real 12 ft dish. The dish was placed on flat pavement facing up towards the sky to avoid reflections from nearby objects. A custom structure made entirely of thin wood was designed and built by Jim Moss. This structure held the feed vertically in a cage yet allowed it to slide up and down so the distance to the dish surface could be adjusted. The feed was

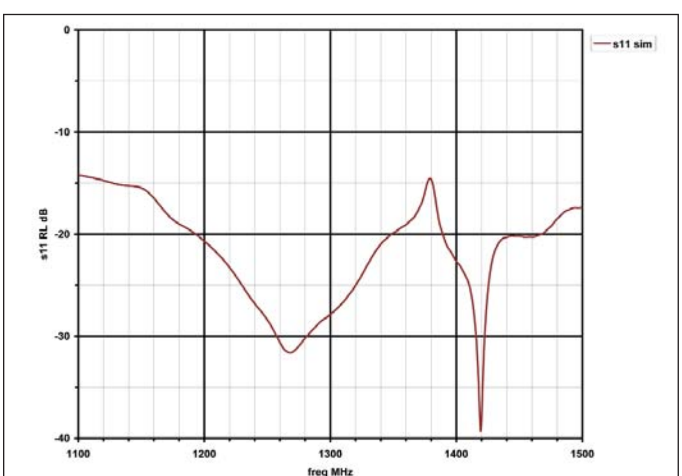

Figure 6 · Simulation of S_{11} (RL) of the feed with a 12 ft dish.

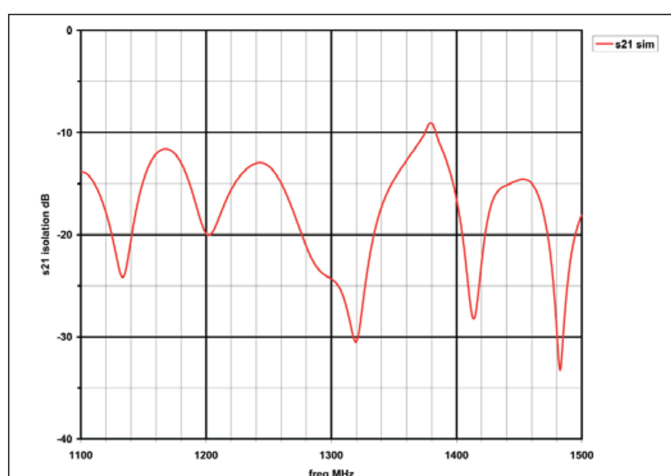

Figure 7 · Simulation of S_{21} (isolation) of the feed with a 12 ft dish.

Figure 8 · Construction of the feed support structure.

Figure 9 · Feed supported above the dish.

held by a rope with a pulley so this adjustment could be done while the entire structure was placed over the dish.

In Figure 9 you can see the cloth measuring tape hanging from the feed. The measuring tape was very flexible and it was at least six feet from the author which made it very difficult to get an accurate absolute distance measurement. The feed was moved up and down in fine increments from 50 inches to 55 inches. Since the prime focus of the dish was calculated to be around 52.7 inches, the finest steps were done near that distance.

Measurements were done with the equipment listed in "Notes on Measurement Equipment." The data from the calibrated vector network analyzer was downloaded directly into Excel on a notebook computer via a GPIB interface bus. The measurements were impartial and equivalent to a double-blind test because the author and his assistant, Paul Zander were only able to see whether the data was transferred successfully but were unable to see any plots or comparisons to the simulated data. All four S-parameters were measured at each distance from the vertex of the dish.

When a feed is placed at the prime focus of a parabolic reflector, some of the energy from the central portion of the dish is reflected back into the feed. This was described in detail by Silver [1] from work done in the Rad Lab of MIT. In summary, the effect of the reflected energy on the impedance of the feed depends on the constructive or destructive interference of the waves at the feed. Thus the degree of curvature (f/d) of the dish and the diameter of the dish have the largest effect because these determine how far the prime focus of the dish is from the vertex and that is where the feed will be situated. The further the feed is located from the

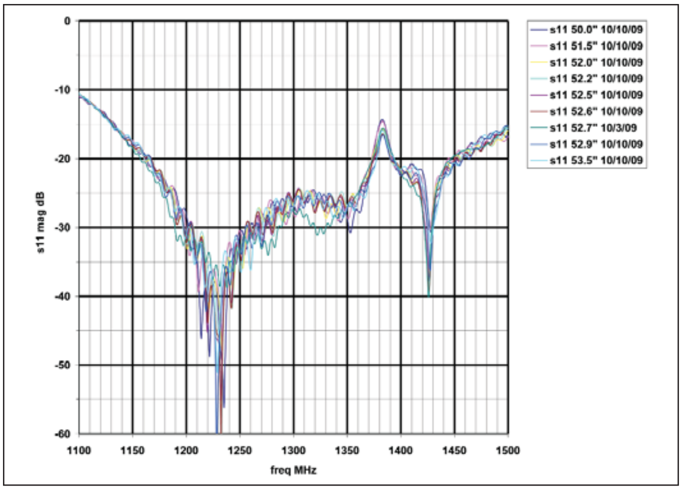

Figure 10 · Measured S_{11} of the feed with an actual 12 foot dish, placed at various distances from the vertex.

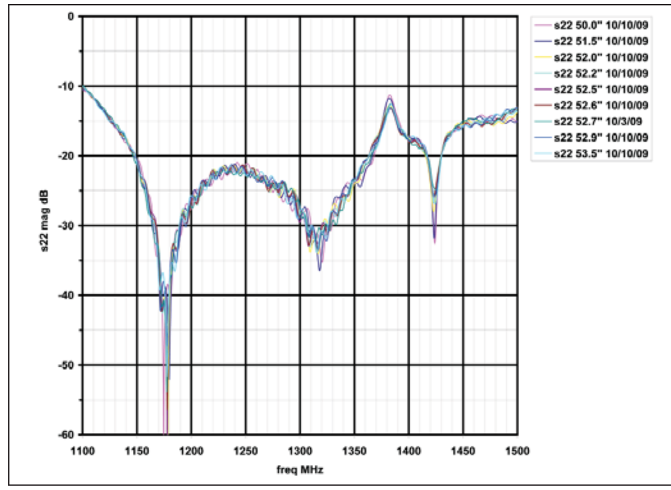

Figure 11 · Measured S_{22} of the feed with an actual 12 foot dish, placed at various distances from the vertex.

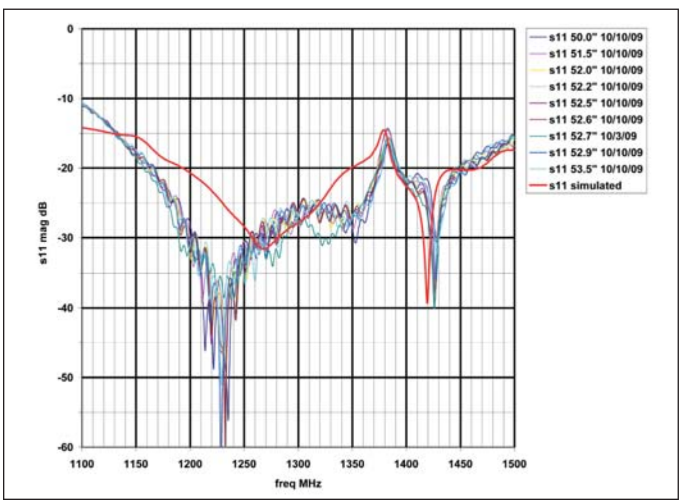

Figure 12 · Measured S_{11} of the feed with an actual 12 foot dish, placed at various distances from the vertex, compared with the simulation.

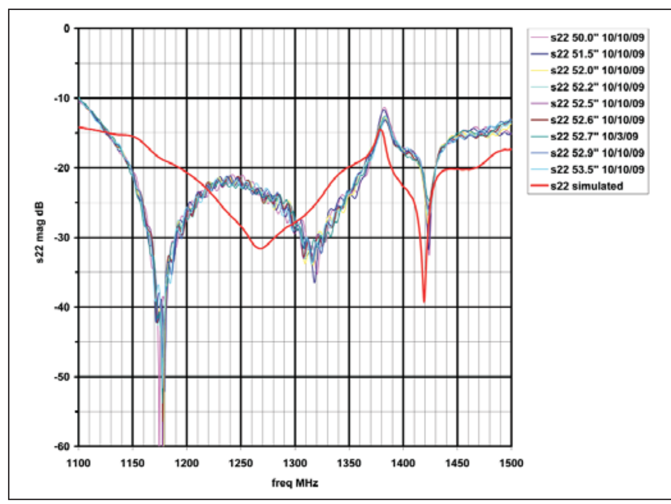

Figure 13 · Measured S_{22} of the feed with an actual 12 foot dish, placed at various distances from the vertex, compared with the simulation.

dish, the smaller the reflected energy will be at the feed. In the special case of a circularly polarized feed with two separate ports for both polarities simultaneously, we must remember that when RHCP is transmitted from the feed, the reflection from the surface of the dish is mirrored and becomes LHCP. Therefore, the reflected energy affects the opposite port on the feed. This also has an adverse effect on the S_{21} and S_{12} which represents the port to port isolation.

The following plots in Figures 10 and 11 show the measurements of the two ports with the feed at various distances from the vertex of the dish. The feed ports are 50 ohm coaxial ports, type N on port 1, and type DIN 7-16 on port 2.

Figures 12 and 13 show these same plots with the simulated data superimposed for comparison. As previously described, in the simulation we used waveguide ports in place of the actual coaxial ports. Since we are comparing waveguide ports to coaxial ports, the S_{11} and S_{22} were only accurate at the design center frequency of the septum which is 1296 MHz.

Figures 14 and 15 shows the comparison of the these same measurement plots with the data from the feed alone pointed at the open sky.

Both ports show that there was minimal impact on their impedance by the reflections from the dish. Since the match achieved better than 25 dB return loss at the design center frequency of 1296 MHz, neither transmitters nor receivers would be affected.

We will now examine the effect of the reflection on the port to port isolation.

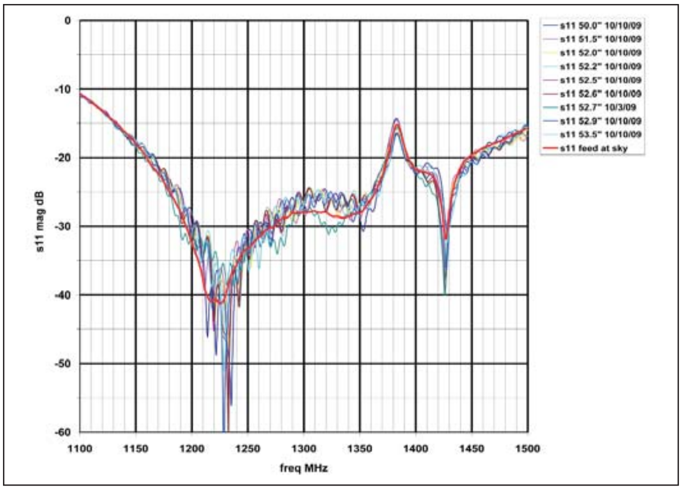

Figure 14 · Measured S_{11} of the feed with an actual 12 foot dish, placed at various distances from the vertex, compared with measurement of the feed pointed at open sky.

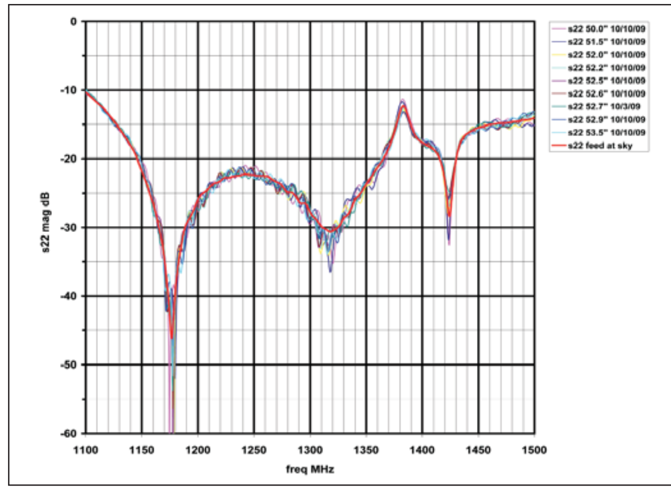

Figure 15 · Measured S_{22} of the feed with an actual 12 foot dish, placed at various distances from the vertex, compared with measurement of the feed pointed at open sky.

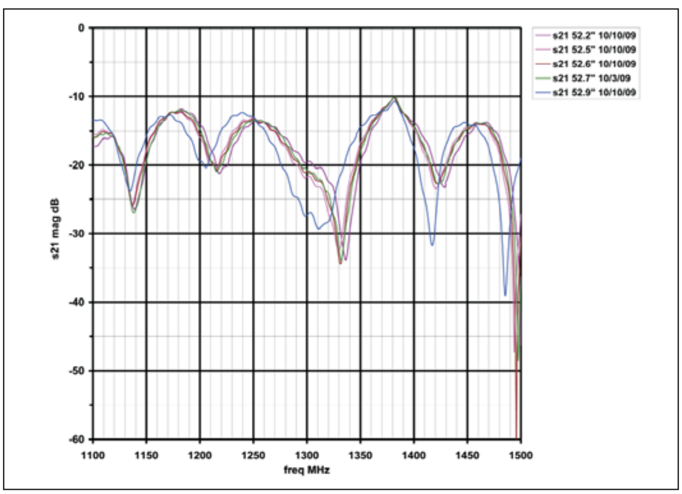

Figure 16 · Measured S_{21} of the feed with an actual 12 foot dish, place at various distances from the vertex.

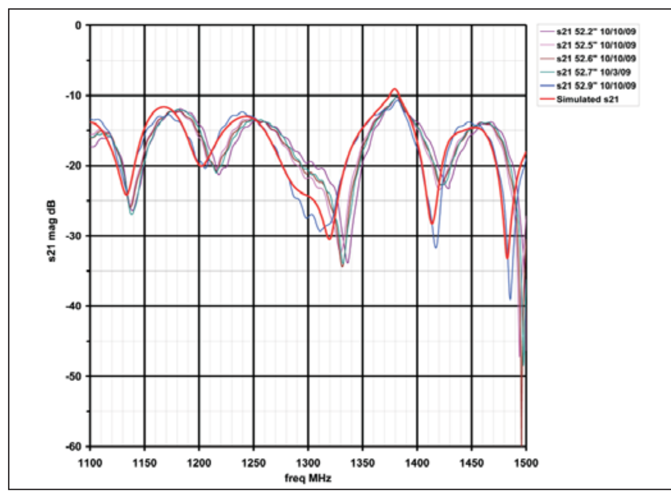

Figure 17 · Measured S_{21} of the feed with an actual 12 foot dish, compared with the simulation.

The reflections from the dish back into the feed have a large effect on the port to port isolation. Figure 16 shows the measured S_{21} data, with the simulation results added in Figure 17. These figures show that small changes in distance have a very large effect on the isolation. The calculated prime focus distance to the phase center is approximately 52.7 inches. We took data from 50 to 55 inches. The plots include a smaller range of distances in order to increase readability.

Figure 18 zooms into the actual frequency range that this feed was designed to operate. It was not possible to accurately measure the feed to vertex distance with an accuracy of 0.2 in. The distances were relative and had some margin of error owing to the flexible measuring tape and distance of the observation (we did not want to walk on the reflector).

The key observation in both simulation and measurement is that isolation changed a great deal with a change in distance of 0.2 in., especially when near to the prime focus. Based on this finding, the transmitter and receiver must be designed to accommodate the minimum isolation of 20 dB. The simulation appears to be in good agreement with measured data, within the accuracy of the feed-to-dish distance measurements.

Summary

We have shown that the CST transient solver provides a very accurate simulation of port match and port to port isolation. The simplifica-

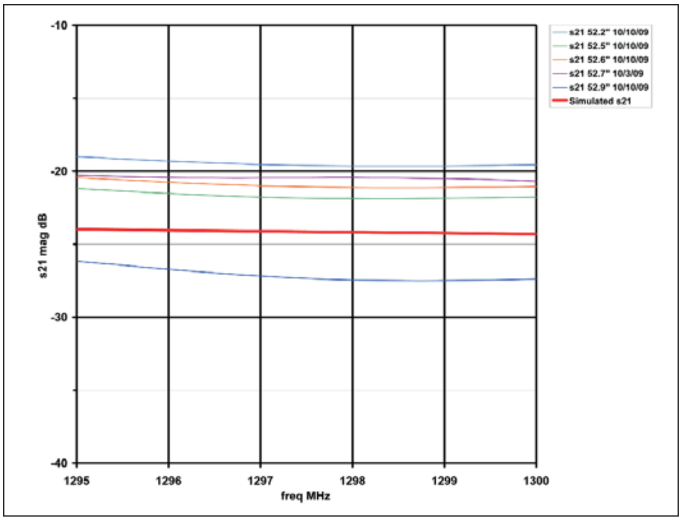

Figure 18 · Measured S_{21} of the feed with an actual 12 foot dish at various distances from the vertex, compared with the simulation, over a narrow range around the desired operating frequency.

tion of the ports in the model allowed a rather large structure to be simulated on a single computer. The simulation results of both the feed alone and the feed placed at the focus of a parabolic reflector produced excellent correlation to the measurements, especially considering that the feed has manufacturing tolerances and there are always measurement uncertainties. It was also demonstrated that the impedance match (S_{11} and S_{22}) were relatively unaffected by the reflections from the dish. The isolation (S_{21}) was significantly affected because this dish to the feed distance is not large compared to the wavelength. We are doing further research regarding various reflection mitigation techniques.

Acknowledgements

The authors would like to acknowledge the assistance of the following people:

· Temporary non-reflective feed support design and construction by Jim Moss.
· Assistance with all measurements by Paul Zander.

Reference

1. Samuel Silver, *Microwave Antenna Theory and Design,* MIT Rad Lab Series, Vol.12, pp. 439-448, McGraw-Hill 1949.

Author Information

Jeffrey Pawlan has been a consultant as owner of Pawlan Communications for 18 years. Prior to that, he worked for many companies in California in analog, RF, and micro-wave design. He has also taught engineering part-time. He has 13 years of higher education including a Doctorate degree. Jeffrey began his interest in microwave engineering at a young age and built his first dish feed for operation on 23 cm in 1961. He can be reached at jpawlan@pawlan.com

Rastislav Galuscak, Ing., studied radio-electronic engineering at the Technical University in Kosice, Czechoslovakia. He worked several years at a radio-telecommunication company as technician and later as a design engineer. Presently, Mr. Galuscak is a PhD student at the Czech Technical University. His interests are dish antennas, special antenna feeds and EME communication. He can be reached at om6aa@yahoo.com

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