Modeling the New Arecibo Dual Band High Frequency (HF) Facility

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Abstract: The use of a High Frequency (HF) Facility at Arecibo is essential for understanding the interaction between powerful HF radio waves and ionospheric plasma. In September 1998, Hurricane Georges destroyed the Islote Heating Facility which was located northeast of the Observatory. Reconstruction of the Isolate Facility is not feasible due to government regulations and other factors. A new HF facility that uses the 305 meter main dish of the Arecibo Observatory as a reflector is proposed.

I Introduction

The Islote Heating Facility consisted of a 4 X 8 Pyramidal LP array which produced an average gain of 23 dBi from 3 to 8 MHz. The new HF feed design is a crossed-Yagi antenna that will operate at 5.1 and 8.175 MHz. The lower portion of the band at 3.175 will require separate implementation and will be addressed with a future proposal.

For each of the two frequencies, the feed must support a bandwidth of 100 KHz for both circular polarization modes. Average radiated power will be 600 kW with amplitude modulation for a peak power of 2 MW. With the gain of the dish, the effective radiated power (ERP) of the feed will be 140 MW continuous wave (CW) with a peak ERP on the order of 450 MW. With such large power requirements, the antenna design must include design features to handle large electric fields and high currents.

Along with modeling impedance and gain, several near field calculations were made to locate points of high field values to determine the probability arcing and corona formations. Spheres were placed at the ends of the antenna for reducing fields, and the impedance of the open-wire transmission lines were selected for adequate spacing.

A Dual band circularly polarized feed was achieved by using a crossed-Yagi design with a switchable matching stub. Operation at both frequencies is achieved with a unique arrangement of multiple elements and open-sleeve feeding all on the same boom. The parallel matching stub is connected across the driven element feed gap to match the antenna to the open wire transmission line and to cancel out any reactance. Since the stub length is frequency dependent, a switch is needed to adjust the length when changing frequencies.

II MOM Model

The initial antenna model was constructed and tested with NEC 4.1, GNEC, and WIPL-D [1]. Design optimization was preformed using NECOPT [1]. Each of these programs had their own strengths and weaknesses. GNEC was able to solve for a full Method of Moments (MoM) solution for the two lower frequencies at 3.175 and 5.1 MHz with efficient use of computational time. The wire segment model grew too large at 8.175 MHz for efficient NEC computation. WIPL was used to model the design at the highest frequency of 8.175 MHz and to confirm the NEC results at the lower frequencies. WIPL was able to model 8.175 MHz efficiently by modeling the main reflector with plates instead of wire segments as in the NEC model. NEC was able to provide model optimization through NECOPT while WIPL was extremely useful for near field analysis.

At the time of the initial NEC and WIPL modeling the available computer technology was not able to simulate the large HF Facility design within reasonable computing times. With the initial modeling of the HF facility completed in 1999 [1], new techniques and improved computational power were needed to compile all the results and models under one platform that would include the advantages of both NEC and WIPL. FEKO was recently added to the collection of computational tools for modeling the HF facility to provide a final design. This program provided the full MoM solution similar to NEC but also provided accurate near field modeling and simpler geometry entry.

The NEC model of the upper platform and azimuth arm were imported into the FEKO model. This saved days of work from re-entering the segment model of the upper platform. The main reflector, corona spheres, and Gregorian dome were constructed using FEKO commands. The completed Arecibo Observatory model shown in Figure 1 was entered into FEKO for analysis.

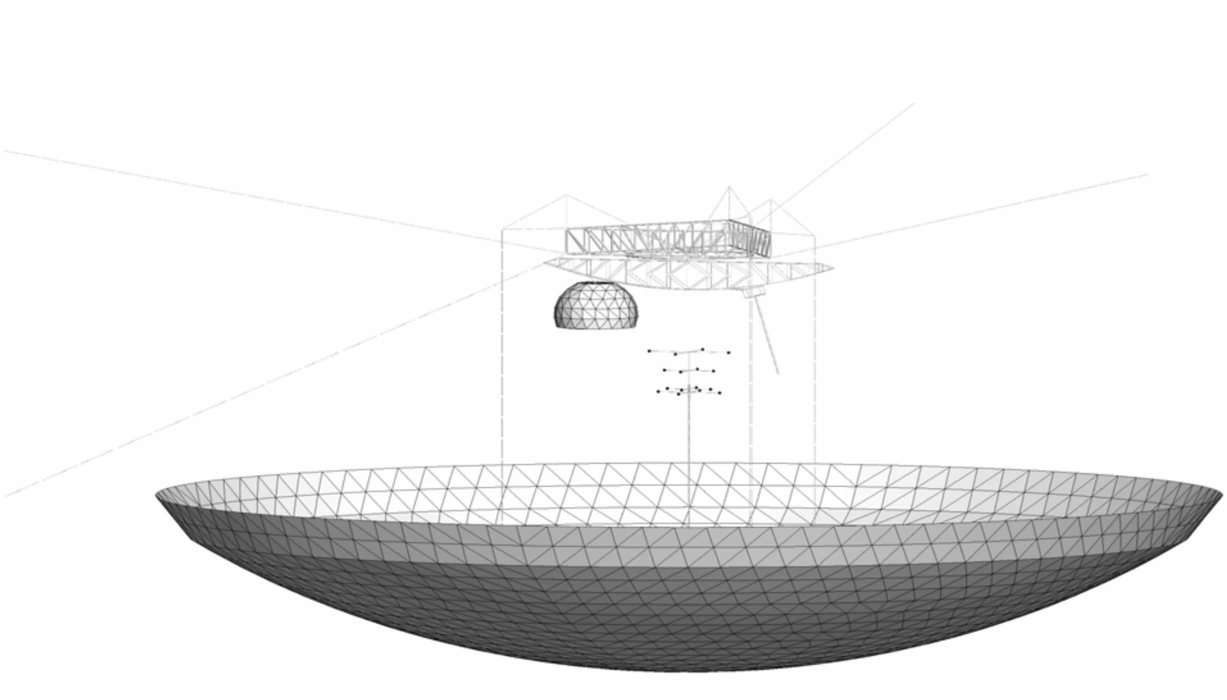

Figure 1: Full FEKO Model of Arecibo.

The proposed new HF interactions feed antenna is shown in Figure 2. The design uses a crossed-Yagi which directs the beam towards the main reflector. Only the bottom element is driven with the open-wire transmission line. The longest two elements are tuned to resonate at 5.1 MHz acting as a driven element and a reflector. At 8.1 MHz the energy from the driven element couples into the secondary driven element and the smaller reflector resonates to create a crossed-Yagi at the higher frequency.

Tuning and design changes were made to obtain desired results when the antenna was fed with four voltage sources. The use of voltage sources allowed for antenna tuning without having to deal with mismatch with the open-wire transmission line. After the antenna was tuned, the transmission line was connected for the finial simulation data.

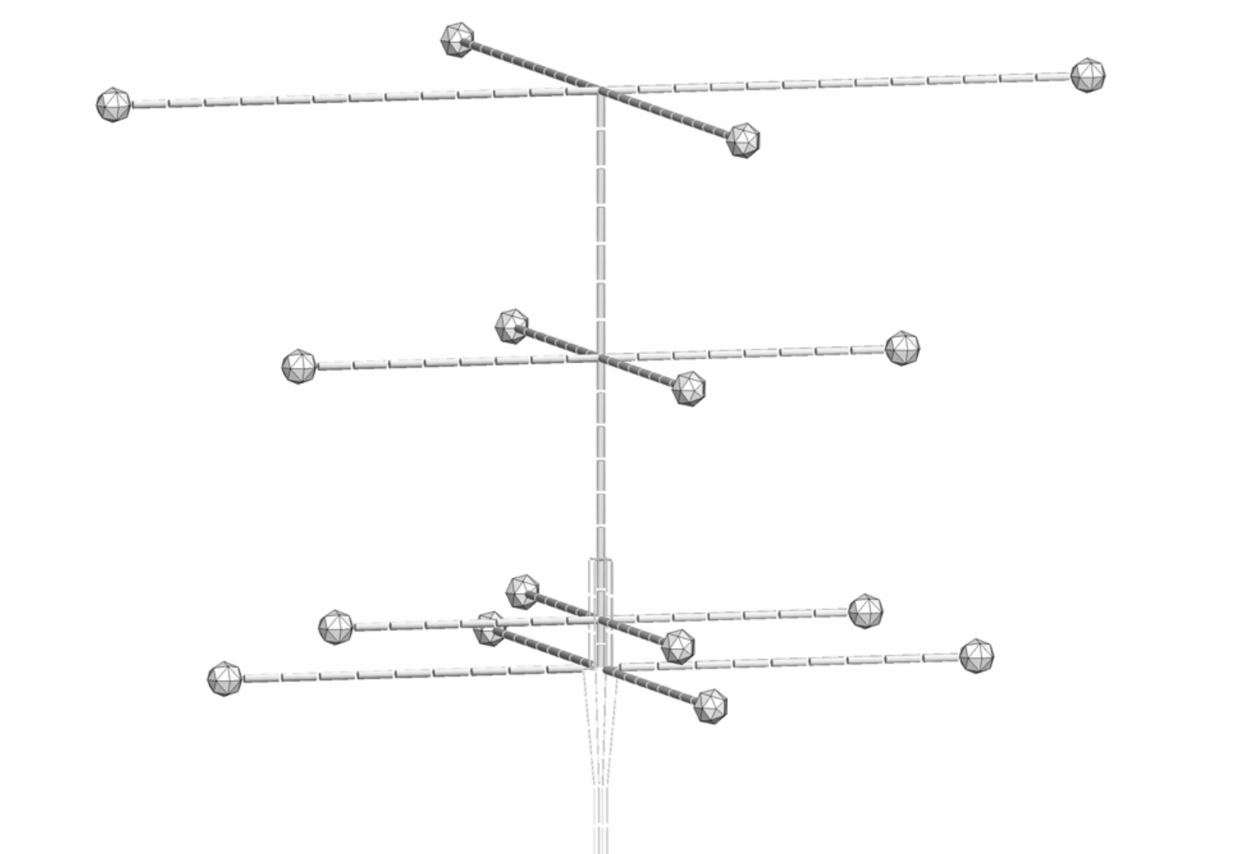

Figure 2: HF Feed antenna.

III Dual Band Tuning

At both the frequencies of 5.1 and 8.175 the driven element impedance was designed to have input impedance on the order of 25 -j120. This large reactance value was then used to increase the parallel resistance of the antenna to 450 Ohms for impedance matching with the open-wire transmission line. The match was achieved with a parallel stub that canceled the parallel reactance. Iteration was used to find the correct value of series resistance and reactance that produced the needed parallel resistance for the lowest reflection.

Equations 1 and 2 were used to convert the series input resistance and reactance of the antenna into its equivalent parallel resistance and reactance. Then, the tuning stub was adjusted to cancel the parallel reactance. By converting the combined parallel impedance and the tuned stub back to an equivalent final series impedance results in this desired final input impedance having a large real part with minimum reactance. . Ideally the parallel reactance would completely cancel and the input impedance would simply be equal to the parallel reactance.

$$R_P = \frac{R_S^2 + X_S^2}{R_S} \tag{1}$$

$$X_P = \frac{R_S^2 + X_S^2}{X_S} \tag{1.1}$$

$$R_S = \frac{R_P * X_P^2}{R_P^2 + X_P^2} \tag{2}$$

$$X_S = \frac{R_P^2 * X_P}{R_P^2 + X_P^2} \tag{2.1}$$

A resistance of 28.45 ohms was chosen as an estimate for calculating the reactance using Equation 1 that was needed for a parallel resistance of 450 ohms. Then, multiple iterative runs were used to tune for the desired antenna input impedance. Over small length changes, the dependency of the series reactance of the antenna can be considered a linear relationship with the antenna length. Runs number 1 and 2 shown in Table 1 was used to establish impedance results for linear interpolation. The third run used these results to determine the final antenna length.

Run number	Driven element length	Series impedance	Parallel resistance
1	9.5	28.72-j108.10	435.60
2	9.45	28.18-110.96	465.09
3	9.475	28.44-j109.52	450.19

Table 1: Iterative data of the driven length to determine input impedance at 5.1 MHz.

After determining the needed series impedance for the desired parallel resistance, the parallel reactance was determined using Equation 1.1. The parallel input impedance for the driven length of 9.475 meters was (450.19-j116.91). The length and characteristic impedance of the shorted tuning stub was chosen using equations three and four to have a reactance of +j116.91 to cancel the parallel reactance, leaving only the desired 450 input impedance.

$$X_L = jZ_O * Tan(\beta / l) \tag{3}$$

$$Z_O = 276 * \log(b / a) \tag{4}$$

where

$$\beta = \frac{2\pi}{\lambda}, \; l = \text{ Stub length, and } \; \frac{b}{a} = \text{ conductor spacing / conductor radius}$$

The matching stub separation b was determined by the feed gap of the antenna while the radius was picked large enough to handle currents on the order of 600 amps. The stub length was calculated to be 2.659 m long. As with the series reactance, linear interpolation was used with small stub length adjustments to determine the required length. An impedance of (548 +j8.0) was reached. This gave a VSWR of 1.22:1 when matched to 450 ohms. The optimizer provided in FEKO was also used to improve the impedance match. Figures 3 and 4 show representative VSWR results for the HF feed at 5.1 and 8.175 MHz.

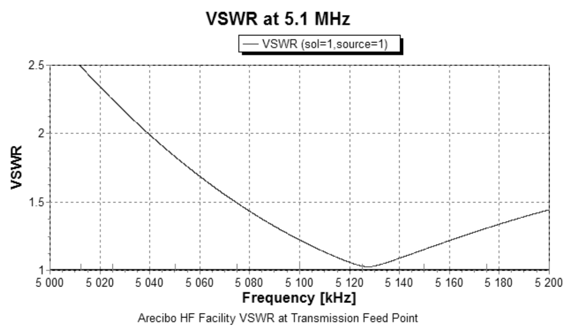

Figure 3: VSWR plot of HF Facility centered at 5.1 MHz.

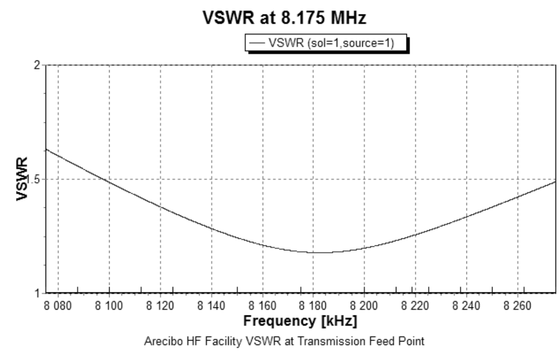

Figure 4: VSWR plot of HF Facility centered at 8.175 MHz.

IV Near Fields

Measurements of near field intensities were needed to determine and prevent the possibility of corona generation and arcing. Near field cuts were made on both the open-wire transmission line and at the spheres attached to the antenna ends. Field measurements were made at the maximum power of 2 million watts at 5.1 MHz. Figures 5 and 6 show the instantaneous electric field values at the junction between the HF feed and the 450 Ohm transmission line. The plots predict field values on the order of 100 kV/m at the antenna feed point.

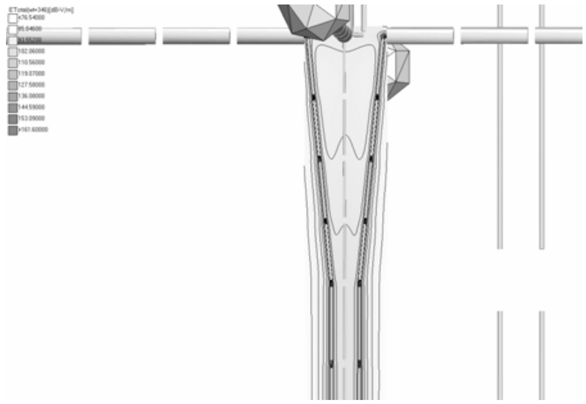

Figure 5: Near Field Contour plot

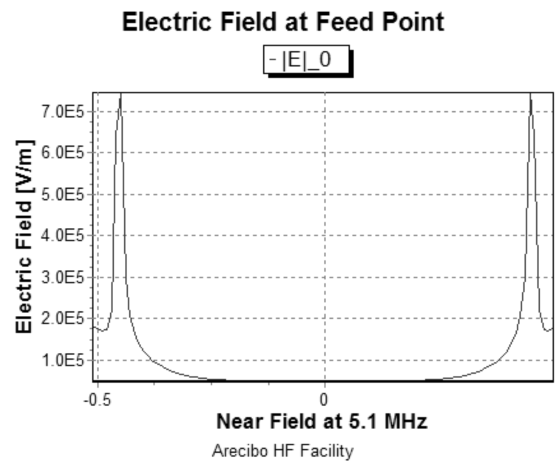

Figure 6: Near Field at Feed Point

Figures 7 and 8 show the instantaneous field values at one of the spheres on the driven element. The field intensity on the sphere surface was on the order of 170 kV/m. Since the sphere was constructed from plates connected to a modeled wire segment, artificial field values were also predicted on the connection between the wire and the sphere and should be ignored in this small region.

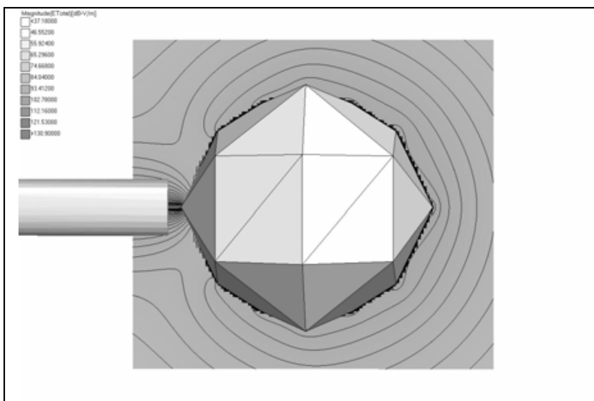

Figure 7: Near Field on Sphere

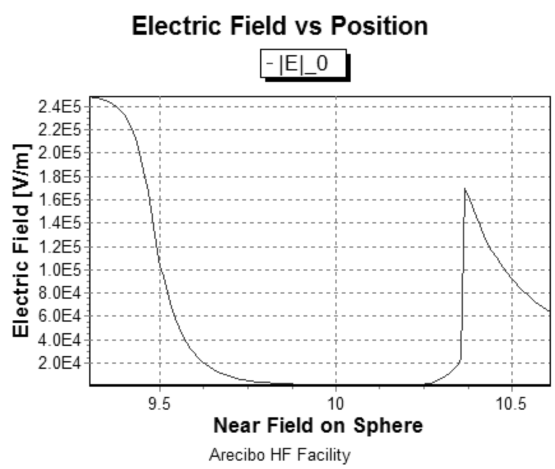

Figure 8: Near Field on Antenna Axis

V Far Field Patterns

The new HF facility antenna is expected to have gains that either meet or exceed those of the Islote Heating Facility. Along with high gains, the circular polarization rejection between right hand circular (RHC) and left hand circular (LHC) is important. Figure 9 shows the far field gain plot at 5.1 MHz. Far field patterns of the antenna without the main reflector were made to check the beam width. Full illumination of the dish without spillover was necessary to achieve the highest system gain. Optimization using NECOPT was able to locate the height of the antenna between 400 to 430 feet above the dish [1].

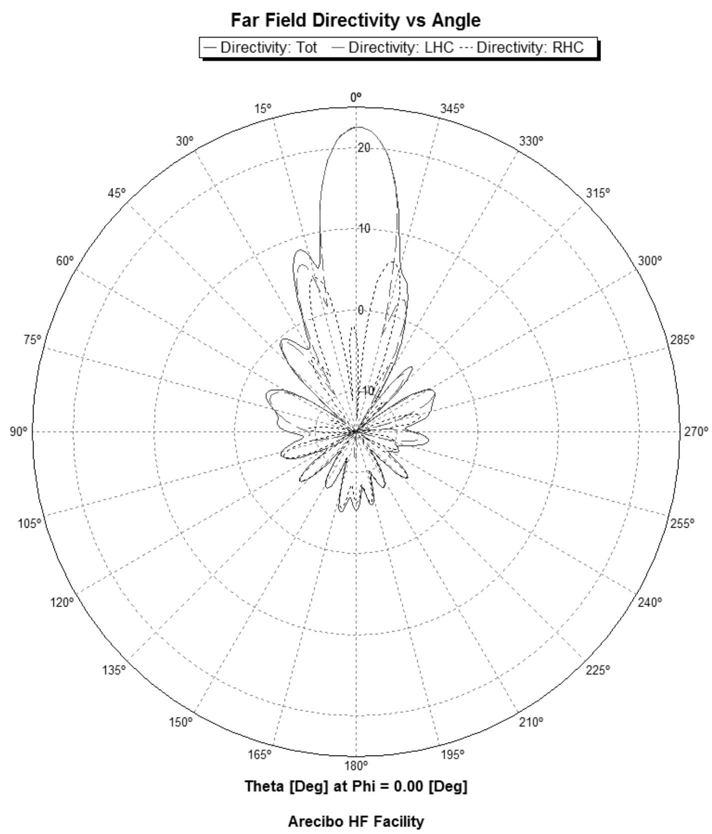

Figure 9: Far Field Gain plot at 5.1 MHz

The gain at 5.1 MHz is 22 dBi and at 8.175 the Gain has been calculated to be 25 dBi. At the peak radiation the circular polarization rejection is 25 dB. By changing the excitation of the feeds by ±90º, the polarization can be changed from RHC to LHC.

Conclusions

The current computational power used to solve the FEKO model would have also been able to run the full NEC and WIPL-D models. However, NEC and WIPL still lacked in the geometry entry and data post processing. The model entry and processing interface provided with FEKO 4.1 made integrating the NEC and WIPL-D files into FEKO relatively effortless. Using the available geometry inputs in FEKO, major improvements to the dish, Gregorian dome, and ground screen were made as compared to previous modeling using just NEC and WIPL-D. With these model improvements and full MoM solution, FEKO was able to finalize the antenna design and make the necessary field measurements to insure proper operation. The crossed-Yagi feed design will not only be a replacement for the Islote facility but will provide a performance improvement as well.

Acknowledgments

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References

[1] J. K. Breakall and M. W. Jacobs, “HF Ionospheric Heating Using the Arecibo Spherical Dish Reflector”, Technical Document, The Pennsylvania State University, June 1999.

[2] M. P. Sulzer and S. A. Gonzalex, “The New Arecibo Ionospheric Interactions Facility: A Modern High Frequency Instrument for Upper Atmospheric Research,” NSF Proposal 0333481, April 2003.

