

# USE OF THE WIPL-D AND NEC4 MODELING CODES IN THE DESIGN OF A SPECIALIZED HF ANTENNA FEED FOR THE 305 METER ARECIBO RADIO TELESCOPE

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## ABSTRACT

The performance of a Yagi-Uda type feed antenna for the 305-meter spherical reflector at the Arecibo Observatory is modeled and optimized using the WIPL-D [1] and NEC4 Method of Moments codes. The Arecibo radio telescope has primarily been used for work above 50 MHz using large line feed antennas or point feed (horn or small dipoles) antennas and corrective optics to substantially eliminate the effects of spherical aberration. Ionospheric modification experiments at HF frequencies below 10 MHz had been conducted at the observatory using a separate high-power transmitting antenna array at a geographically distant location. In this work, an attempt was made to integrate the HF antenna with the main observatory reflector. The reflector surface, ground screen, and the suspended steel platform, along with the candidate Yagi-Uda feed antennas were modeled for both radiation and impedance performance. The NEC4 code modeled the reflector and all other structures using wires or as a wire grid, while the WIPL-D code used conducting plates for the reflector, ground noise reduction screen, Gregorian optics dome, and parts of the Yagi-Uda feed antenna, and wire segments for the remainder of the feed antenna and platform structure. Both codes were in substantial agreement and the performance of the overall system at HF was found to meet or exceed requirements. An additional concern with high E-field values near the transmitting antenna was studied using the WIPL-D program exclusively.

## 1. Introduction

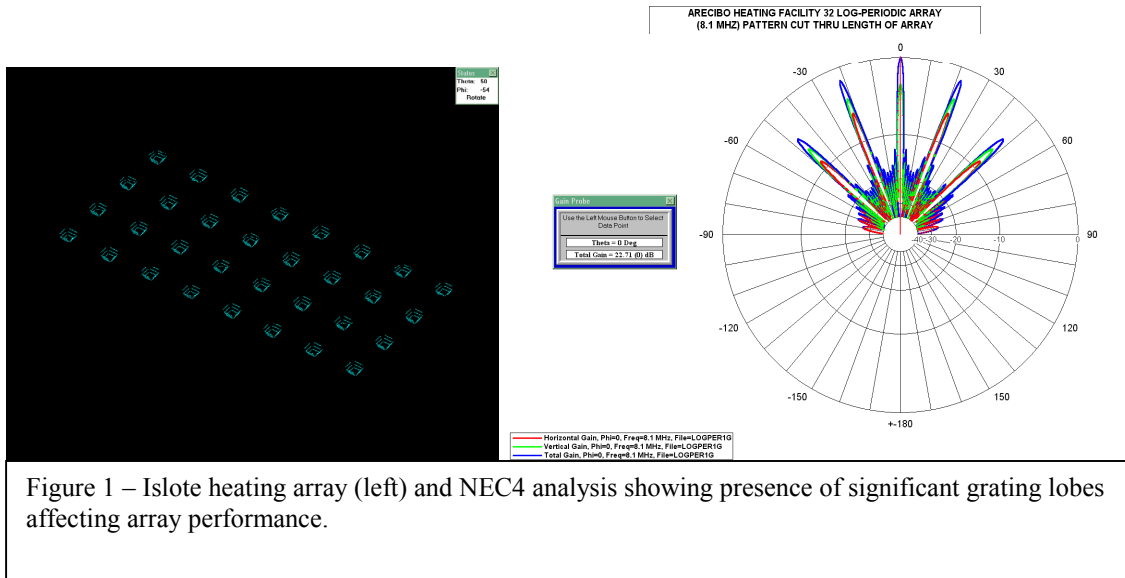
The design of antenna systems is made substantially easier by using computational modeling techniques in place of rigorous analytical analyses. However, each particular antenna modeling code has its own characteristic strengths and weaknesses, so the use of more than one code in analyzing a particular problem can greatly increase the confidence in the performance of the final design. Certain codes are better at modeling particular geometric features than others. In this paper we describe the design and analysis of an antenna system for transmitting a beam of high-power HF radiation using the 305-meter diameter spherical reflector at the Arecibo Observatory in Puerto Rico [2]. The model includes the reflector surface covering an area of approximately 20 acres, the ground noise reduction screen along the circumference of the reflector, the lattice steel platform suspended 450 feet above the apex of the reflector, the solid aluminum spherical dome protecting the Gregorian corrective optics system and antenna feeds which are suspended from the platform, various steel suspension and support cables, and the HF feed antenna design itself.

The purpose of the HF transmitting system is to support the use of ionospheric modification experiments by the atmospheric sciences community operating under the auspices of the National Science Foundation. These experiments involve the transmission of more than one megawatt of RF energy at low HF frequencies to locally modify the plasma of the ionosphere in the area above the observatory. The main spherical reflector and a line feed antenna are then used at 430 MHz to study the effects on the ionospheric plasma using incoherent scatter radar techniques. Destruction of the HF array during Hurricane Georges in 1998 and the inability to rebuild at the original site due to environmental and other considerations required the development of an alternate solution to continue ionospheric modification experiments at Arecibo. The authors were tasked with determining whether it is feasible to use the primary reflector to perform the ionospheric heating function with a comparable electrical performance to that of the previous facility at Islote, PR. In this work, the performance of the Islote facility was first studied using the NEC4 code to establish a performance benchmark for comparison. The next step was to determine the optimal way to illuminate the 305-m reflector without the presence of the other structures of the telescope. This was done using the NECOPT [3] optimizer routine and the NEC4 code. Once this was complete, the remaining structures were added to the model and the performance optimized to account for their effects. The requirements for the antenna were that it accept an input power to 2 megawatts, that it be capable of right-hand and left-hand circular polarization (and be switchable in real-time between the two), and that it operate at frequencies of 3.175, 5.1, and 8.1 MHz with a bandwidth at each frequency of about 50 kHz. Further mechanical and operational requirements were also made to ensure that operations at HF have a minimal impact on other radio astronomy observations at the observatory.

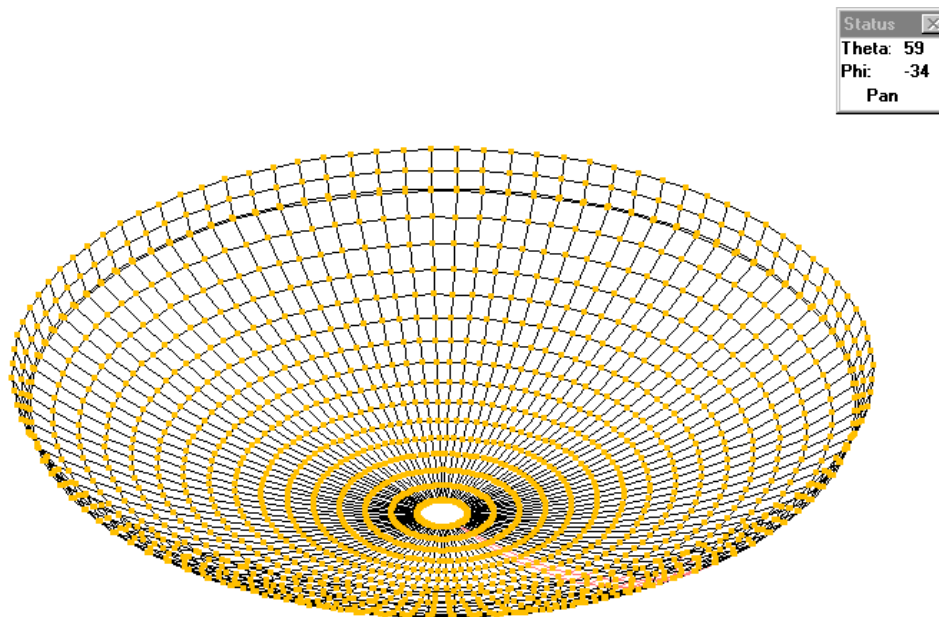
## **2. FEED ANTENNA DESIGN AND MODELING RESULTS**

The first task performed was to model the existing array of 32 log-periodic antennas at the Islote site using the NEC4 code. An expected result was the appearance of grating lobes at the higher frequencies due to the large electrical spacing between array elements. Since the only desired beam direction was directly overhead, it is clear that this antenna system was not providing the best performance for the application. Figure 1 shows the effect of the grating lobes at 8.1 MHz. It is clear that by using the spherical reflector fed from a single antenna, then the problem of grating lobes can be eliminated, thus giving such a system even better performance than that of the log-periodic array used previously.

The wire-grid model of the main reflector and ground screen used in the NEC4 analyses are shown in Figure 2. At a frequency of 3.175 MHz the model contains 3100 segments. To speed analysis for iterating the placement of different types of feed antennas and varying their spacing relative to the reflector, a Numerical Green's Function was written for the reflector and ground screen at each particular frequency using the NEC WG option. Each candidate feed antenna design then used the GF card to import this result, thus



eliminating the need to calculate the effects of the reflector and ground screen structure for each analysis and speeding up computations. At the time of the analysis, there was a small open area in the center of the dish which was used for hauling equipment up to the platform. This was modeled as a circular opening in the center of the reflector to account for the reduced surface area. Since that time this gap has been filled in thus slightly (but most likely negligibly) increasing the effective area of the reflector.



A number of different feed antennas were considered and analyzed. First, a pair of simple dipoles was used. The dipoles were arranged orthogonal to each other in a horizontal plane above the reflector. By exciting the dipoles 90 degrees out of phase, circular polarization is generated. Figure 3 shows the geometry of the crossed dipole arrangement above the reflector and the radiation pattern predicted by NEC at the spacing with the maximum gain obtained by the optimizer.

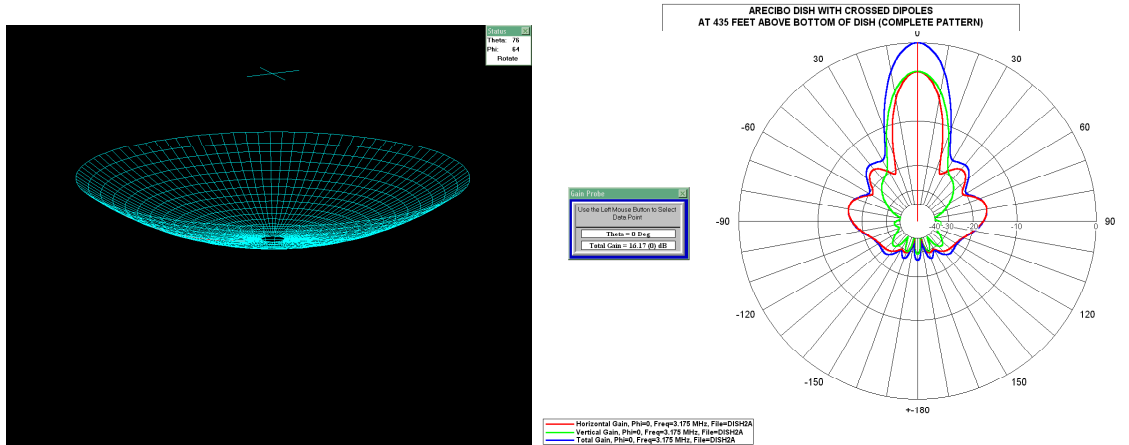


Figure 3 – a) Crossed dipole antenna above dish. b) NEC4 radiation pattern showing overall gain from crossed dipole and dish reflector.

The total gain from the crossed dipole array, at 16.1 dB, did not meet the desired goal of equaling the performance of the Islole array at about 22.7 dB. Other antenna configurations were tried using NEC4 and NECOPT, including 2, 3, and 4 –element crossed Yagi-Uda antennas, and novel loop Yagi and triangular Yagi designs. Through numerous trial runs using the NECOPT program, the 2-element crossed Yagi and the loop Yagi antennas were found to give the best combination of gain and polarization performance for the basic case of just the feed antenna and the reflector.

Construction of the platform model required the extensive use of measured drawings provided by the Arecibo Observatory as well as over 200 photographs taken of the platform and the structures on it. The NEC4 platform model contains over 120 individually-placed wires, and with symmetry includes over 380 wires and contains 4619 segments including the wire-grid model of the dome protecting the Gregorian feed system. The same model geometry was entered into the WIPL-D program, except that the reflector, ground screen, and Gregorian dome were modeled as conducting plates using the simple geometric object commands in WIPL-D. Figure 4 shows the appearance of the WIPL-D model. The suspension and tie-down cables were omitted from this analysis since their long electrical lengths result in minimal effect on the radiation pattern.

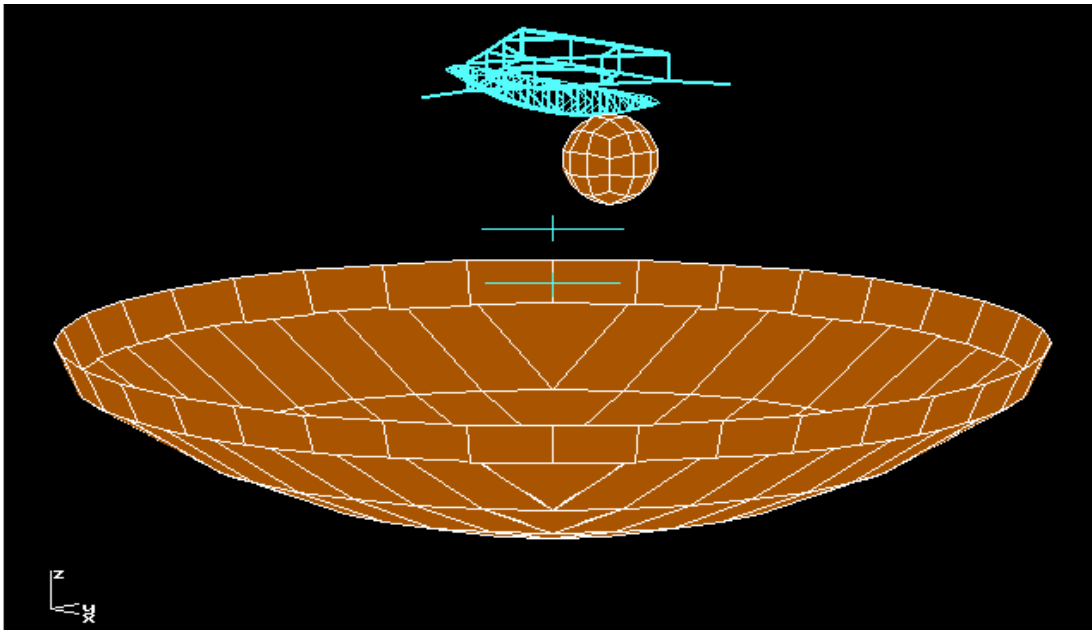


Figure 4 – WIPL-D model of Arecibo 305-m dish, ground screen around dish, spherical Gregorian dome, 2-element Yagi feed antenna, and platform. Conducting plates are shown in orange, wires in blue.

Once the optimal location for the antenna was found for each operating frequency using NECOPT, the results were verified using the WIPL-D code. Figure 5 shows a comparison of the gain versus angle results for the overall system including the feed, the reflector, ground screen, and platform model between NEC4 and WIPL-D at 3.175 MHz, and Figure 6 shows the comparison at 5.1 MHz.

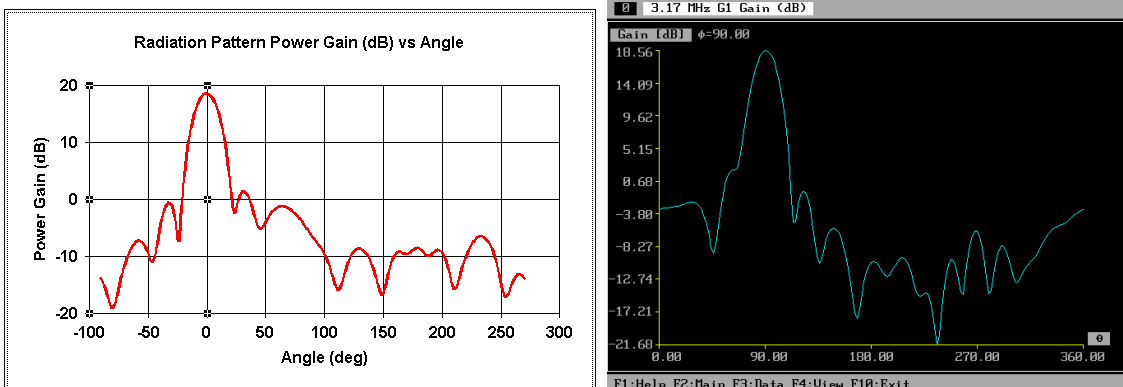


Figure 5 – Total gain versus angle results for NEC4, left, and WIPL-D, right, at 3.175 MHz.

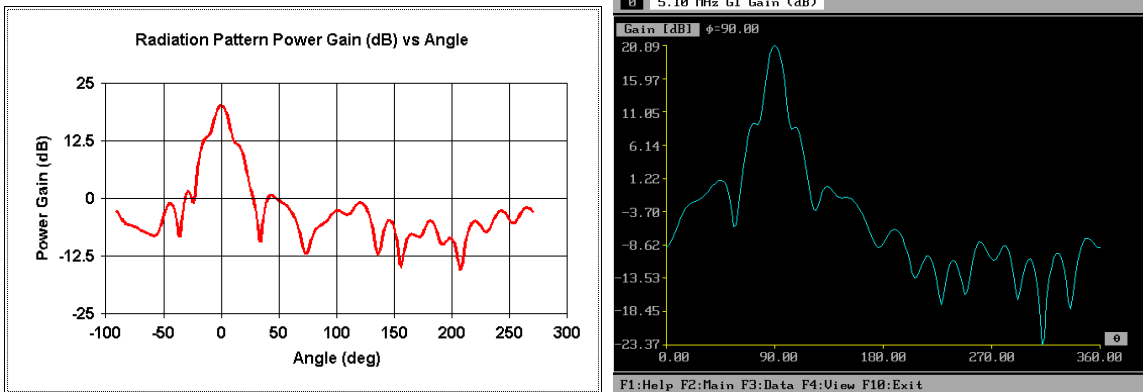


Figure 5 – Total gain versus angle results for NEC4, left, and WIPL-D, right, at 5.1 MHz.

Because of computational hardware limitations at the time of the original work, attempts to analyze the radiation pattern at 8.1 MHz using the NEC4 code resulted in a matrix solution too large to solve in a timely manner. The WIPL-D code, with its more efficient solver and automatic optimal segmentation was able to solve this problem overnight, and the result is shown in Figure 7. The results at 5.1 MHz and 8.1 MHz show substantial agreement with respect to main lobe and side lobe positions and magnitudes.

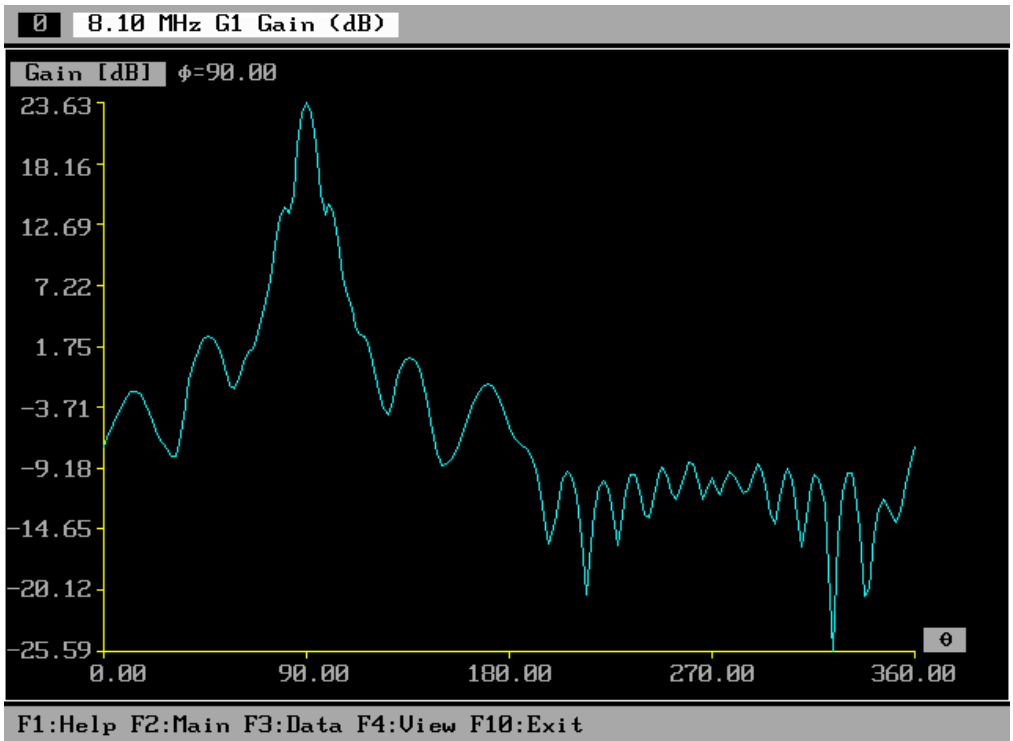


Figure 7 – WIPL-D analysis of gain versus angle for the overall antenna system at 8.1 MHz.

In addition to radiation pattern and gain, the magnitude of the E-field in the vicinity of the feed antenna elements was calculated using WIPL-D. Unlike the Islole array, where the total transmitted power was divided among 32 sets of log-periodic antennas in an array, this antenna would only divide the power into two driven elements. With a maximum input power of 1 megawatt to each driven element, and being in a high humidity tropical environment, there was also a need to ensure that the E-field would not be high enough to cause corona or other air breakdown effects. Figure 8a shows the field magnitudes in the vicinity of the end a 6-inch diameter antenna element with 300 kW power applied. Figure 8b shows the field magnitude in the vicinity of a 6-inch diameter antenna element with an 8-foot diameter conducting ball. These plots were made using MATLAB based on numerical data extracted from a WIPL-D nearfield analysis.

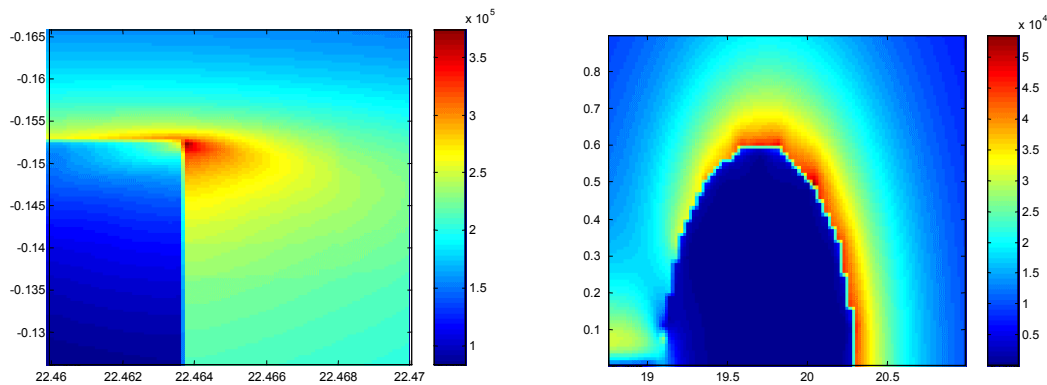


Figure 8 a, b – Left: Total magnitude of E-field at end of 6 inch diameter conducting dipole antenna element with 300 kW of power accepted. Right: Total magnitude of E-field around 8-foot diameter corona reduction ball on end of dipole, 300 kW accepter power.

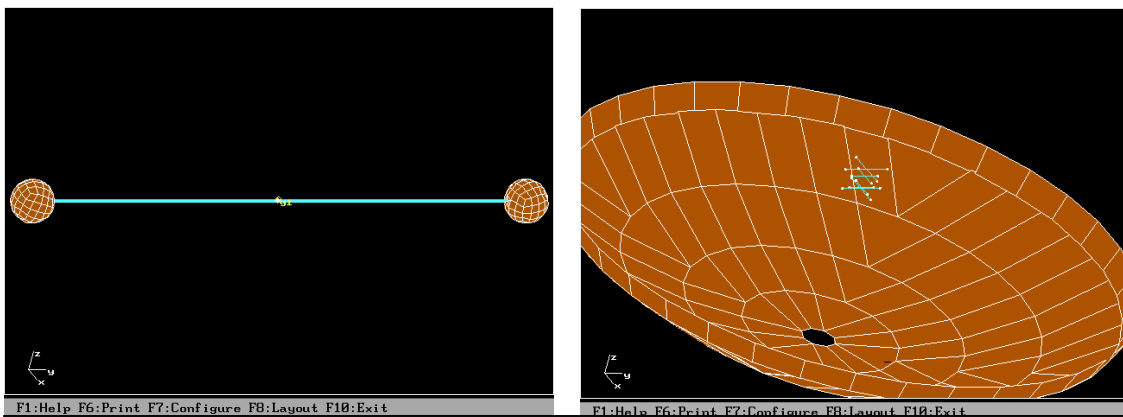


Figure 9 – Dipole element with corona reduction balls (left). Final antenna design consisting of interlaced Yagi antennas at 8.1 and 5.1 MHz with corona balls (right).

Figure 9 shows a dipole element with corona reduction balls on the ends, and the final interlaced Yagi antenna design operating at both 5.1 and 8.1 MHz. An additional benefit found to using such balls is that they substantially end-load the dipole elements, even

when used as parasitic elements in a Yagi-Uda antenna, thus allowing the dipole to be drastically shortened, improving the mechanical characteristics of the antenna at low frequencies where the radiating elements must necessarily be long due to the large wavelengths involved. Even with this reduction, the 3.1 MHz operation was eliminated from the final design because of the unwieldy length of the elements required [4].

### 3. Conclusion and Results

The NEC4 and WIPL-D codes were used in the design of a physically large, high power antenna for feeding the Arecibo 305-meter spherical dish reflector at HF frequencies. By using two codes for the design and analysis, optimization and independent verification of the radiation pattern results were obtained. The detailed structural geometry used allowed the designers to study the effects of asymmetries in the arrangement of the structures on the suspended platform and design an antenna meeting the design goals. Use of the WIPL-D code allowed the analysis at 8.1 MHz where the segmentation in NEC4 resulted in too large a problem to be solved using available hardware. WIPL-D also provided nearfield data used to design a method of minimizing the chance of corona discharge from the antenna.

### REFERENCES

1. B. M. Kolundzija, J. S. Ognjanovic, T. K. Sarkar, R. F. Harrington, *WIPL: Electromagnetic Modeling of Composite Wire and Plate Structures*. Artech House, Inc. Dedham, Massachusetts: 1998.
2. J. K. Breakall, M. W. Jacobs, R. W. Witmer, Jr, P. Piza, J. M. Stamm, "HF Ionospheric Heating Using the Arecibo Spherical Dish Reflector," Report to the National Astronomy and Ionosphere Center, Ithaca, NY, July, 1999.
3. J. K. Breakall, J. S. Young, R. J. Bauerle, A. I. McDowell and T.A. Erdley, "Numerical Electromagnetics Code Optimization Design Software (NECOPT)," *10<sup>th</sup> Annual Review of Progress in Applied Computational Electromagnetics*, Naval Postgraduate School, Monterey, CA, 1994.
4. J. K. Breakall and M. W. Jacobs, "Arecibo HF Antenna Feed System Additional Electrical Feasibility Issues," Report to the National Astronomy and Ionosphere Center, Ithaca, NY, September, 2000.