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A Broadened Numerical Analysis for the Ideal MF Antenna for DGPS Applications

Background

The US Coast Guard operates 87 networked ground based reference stations as part of the Nationwide Differential Global Positioning System (NDGPS). Each site broadcasts GPS satellite corrections via 100 bps or 200 bps Minimum Shift Keyed (MSK) signal modulated onto a 285 kHz – 325 kHz carrier frequency at up to 5000 Watts. The result is a penetrating ground wave capable of reaching users facing obstructions such as geographic terrain and urban canyons that is highly resistant to jamming. The choice in frequency and limitations to site footprint forces an electrically short antenna with an earth ground plane. An optimized antenna has been designed, implemented, and tested using GNEC. Most of the modeling was performed from 1999 to 2002 and since then, advancements have been made, culminating in the availability of several commercial grade codes. The code of interest is FEKO, which is similar to GNEC in that is uses a Method of Moment (MoM) algorithm to solve for currents on thin wire antennas. Further investigation showed potential improvement in accuracy by allowing greater flexibility in modeling the ground plane of the antenna. The two models differ in that GNCE uses sinusoidal weighted residual method while FEKO uses linear Galerkin weighted residual method, so the results should be different.

Methodology

The antenna of interest is a 150-foot tower with 6 Top Loaded Elements (TLE) which lead from the top of the tower downward at a 45 degree angle. The length of each top loading element is 150 feet, which minimizes the reactive antenna impedance and helps bring the antenna closer to a near reasonant frequency. The tower is just under 1/20 wavelength, but with the top loading has a natural resonant frequency of about 600 kHz. In practice, the antenna coupler consists of a series inductor to cancel the reactance and a matcher is used to step the remaining resistance (order of 2-3 Ohms) to 50 Ohms. The antennas, in generally, are inefficient, and a large ground plane is needed to broadcast an acceptably strong ground wave. The ground plane used for this model consists of 72 copper ground radials of #8 copper, which are run 330 feet radially outward from the antenna (1/10 wavelength). The purpose is to keep most of the energy as flat as possible and aid the propagation of a ground wave, which is usable for up to 400 km for the purposes of the paper. The helps prevent the generation unwanted skywaves, which could actually interfere with receiving locally generated groundwaves. The purpose of the antenna is to broadcast local corrections, so he most important challenge of this antenna is calculating the reactance of the antenna for proper installation and maintaining this match for all weather conditions.

The previous model used GNEC for numerical analysis. Since the basis functions of GNEC are sinusoidal, it is possible to calculate exact results since it is well known that the currents on the antenna are sinusoidal as well, and are spanned by the basis functions. The user interface is line-by-line text input, with a graphical geometry checker to ensure nodes are placed correctly and segmentation matches the desired effect. The code is limited in that wire meshing is all that is easily available and modeling surfaces requires careful approximation. Soil characteristics are available using a Sommerfield ground plane with parameters of relative permittivity and conductivity. Excitation was modeled as a 100 V voltage source, which is placed just above the ground plane on its own segment, 2.5 feet long. The source feeds into a lossy inductive load, with a fixed resistance of 1.2 Ohms, which is used to improve the calculation of antenna resistance. The inductive load is adjusted until the antenna reactance crosses zero at +/- 0.1 kHz of the desired frequency, which is 301 kHz for the example constructed. The tower of the antenna was modeled the wire form of a triangular prism, which closely matches the physical implementation of the antenna. The ends of the prism are two wire tetrahedrals. The bottom one, which connects to the antenna coupler segment, is physically correct. The top one was created to taper the currents and force them to a single point. Each of the TLEs were attached to the single point and led downward. Actual wire thicknesses were implemented and perfect electric conductors were assumed. The ground plane was limited to 36 radials since the code available only accepted a single junction of 50. Thus, only ½ of the radials were modeled so a pessimistic result is calculated. GNEC's Sommerfield ground plane starts on the x-y plane and the beginning of the ground radial must be at this plane. However, it allows for ground radials to e buried, so the radials were modeled as starting at the origin and leading down to 2.5 feet, which is the approximate depth in practice. Meshing is built into wire construction and was kept to 20 feet per segment for topside elements and 10 feet per segment for ground elements. This seemingly sparse discritization still satisfies the requirement for all segments to be smaller than 1/40 wavelength. Further, it undesirable to make the segments too fine since this is MoM code, which can diverge if too many segments are used.

To the greatest extent possible, the model created in FEKO was replicated as closely as possible to preserve the geometry and force the comparison to focus on the difference of basis functions. Though FEKO uses linear basis functions to model the currents on the wires, this is an approximation that is already widely held and modeled under approximations for the Hertzian dipole, which this antenna clearly satisfies. Thus, the error should be very small and the interest of the paper lies in comparing results from GNEC, since it is possible to extract exact solutions.

Due to the plethora of geometric shapes available in FEKO and its careful handling of each shape, the model could not be exactly constructed, but reasonable approximations were made. The largest deviation came to the tower itself, which was modeled as a thin wire. This choice was made to keep the tower the same size as the coupler and excited segment and avoid incorrect mating and meshing of elements. Constructing a prism for the tower is a considerable risk, which my undergraduate advisor had reservations for supporting. After being more familiar with MoM code through the class, it is clear to see this is because it saves segments and avoids confusing the code with thinking the three wire elements will be interacting more than they actually are in reality. The other geometric departure from the model was in the burial of the ground plane. FEKO does not permit any part of the segment to cross the x-y plane below z=0, so the radials were kept above ground and modeled as counterpoise. All above ground wire segments were assumed to be thin. Attempting to make the segments the actual diameter forced the suggestion of using cylinders, which are problematic to feed and connect properly.

FEKO's user interface allows different materials, both conductors and dielectric materials, to be easily imported and applied for wire segments, discs and planes. The wide availability for the parameters led to the creation of 8 models:

- PEC material for topside elements, infinite PEC ground plane
- PEC material for topside elements, thin copper disc of radius 330 feet for ground
- PEC material for topside elements, 36 copper radials with no dielectric material
- PEC material for topside elements, 36 copper radials with Sommerfield ground
- Real conductors for topside elements, infinite PEC ground plane
- Real conductors for topside elements, thin copper disc of radius 330 feet for ground
- Real conductors for topside elements, 36 copper radials with no dielectric material
- Real conductors for topside elements, 36 copper radials with Sommerfield ground

The Sommerfield ground was modeled using relative permittivity of 7 and conductivity of 0.0015 S/m, which is characteristic of rich, loamy soil, which is what was used on site for actual construction.

Results

Parameter	Actual	NEC	PEC – INF	PEC - Disc	PEC - CP	PEC - SOM
uH	160.29	134.79	98.5	100.1	108.45	97.5
Max Current			0.13427	0.9837	-4.792	-4.63
Max Power			4.872	4.918	4.9198	4.83235
Slope - Phase		23	48	70	74	36
CPU time			0.5	3	2	6

Table I: Perfect Conductor Model Comparison

Parameter	Actual	NEC	REAL-INF	Real –Disc	REAL - CP	REAL - SOM
uH	160.29	134.79	80.2	75.75	90.75	79.75
Max Current			0.7334	0.10455	0.10214	0.10081
Max Power			3.667	3.7412	3.6868	3.6348
Slope - Phase		23	3.2	4	3	2.4
CPU time			0.5	3	2	6

Table II: Real Conductor Model Comparison

The first execution of FEKO reported a warning stating that due to the large reactive portion of the antenna, the real portion would be compromised to provide reasonable reactive results. It also recommended using double precision numbers, which was easily implemented. However, even after those changes were made, the real resistance was consistently reported between 134-137 Ohms, which is nearly 2 orders of magnitude away from the expected and actual measurement observed. Its failing was not unexpected, though, as errors are also possible in NEC, which usually errors to reporting negative real resistance, which voids all other calculations. So FEKO's advantage is having a more robust integrity routine, which reports suspected failures and adjusts the troublesome parameter to a number safely within the laws of physics.

The infinite ground plane models consisted of 67 segments for above ground segments, which were computed using FEKO LITE on a HP Laptop using a 1.79 GHz Athlon 32 bit processor with 2 GB RAM. The other models were too large for LITE and were executed using the lab's Dual Core Intel Dells, which have 1.6 GHz processors and 1 GB RAM. The disc models required surface meshing with 2976 triangles. The mesh requirement was relaxed to 20 feet per segment to prevent overflow even on the professional license. The Counterpoise (CP) and Sommerfield (SOM) models used 1289 segments, which clearly exceeded the 100 segment FEKO LITE capacity.

Converting the Counterpoise models to Sommerfield was easily obtained by setting the infinite ground plane. However, this setting tripled the computing requirements and actually led to greater error in matching inductance. Both PEC models exhibited error in the currents, which is of some concern because these two models actually had the closest match of any of the FEKO models.

The towers with real materials had dramatically flatter phase plots, which were much flatter than observed in practice. There was little difference computationally or to input the parameters. The inaccuracy of the slope of the phase would lead future modeling problems of this type to simply consider the PEC solution. The error is likely due to the use of thin wires with real materials; in practice, the materials have large enough surface to mitigate this issue. Thus, the real materials may be appropriate if using cylindrical geometric shapes, but with thin wire models, PEC produces the best results for this situation.

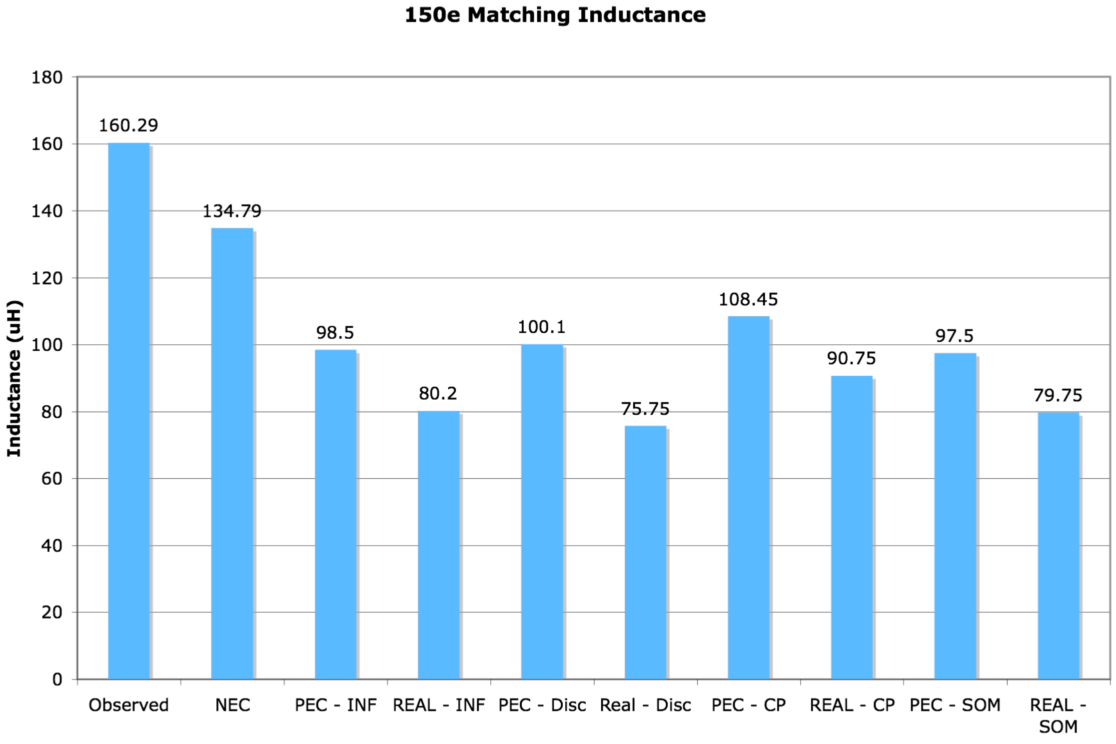
Conclusion

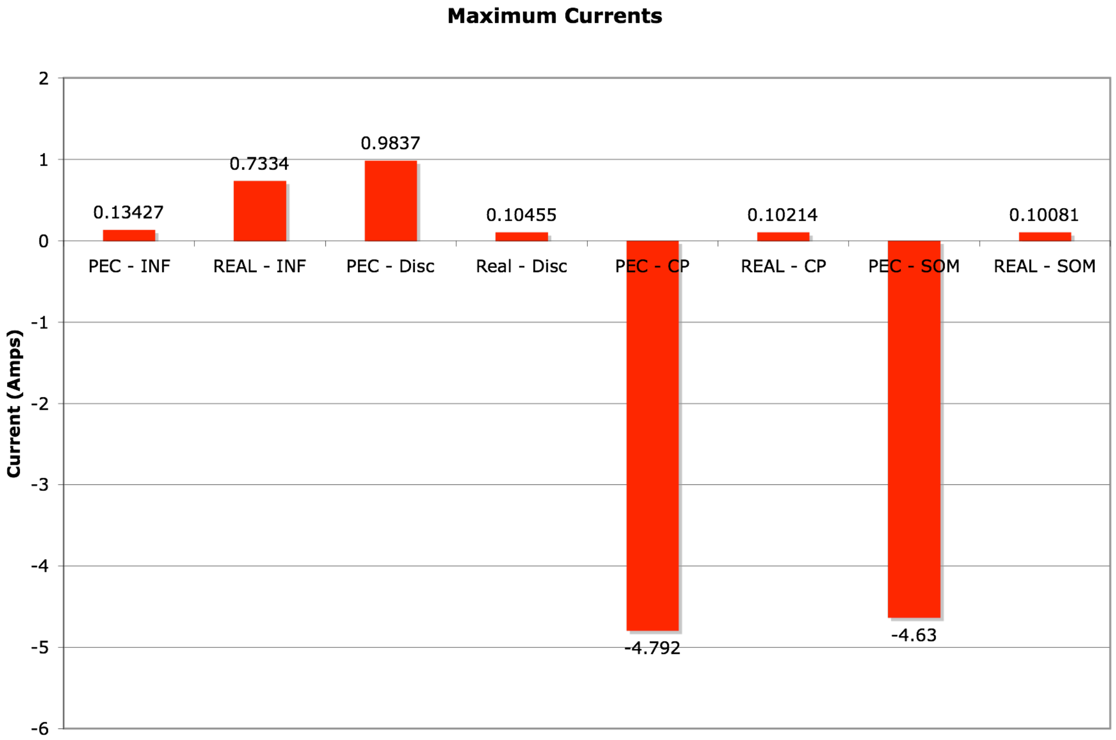
In general, the FEKO models produced the same results which were comparable to previous results obtained with NEC and observed values. Modeling the ground plane was easier in FEKO and more options were available, but accuracy was not improved and computational time was extended. FEKO LITE's solution using the infinite ground plane served as a baseline to check stability of the other models as increasing accuracy was attempted by refining the ground plane to more realistic conditions.

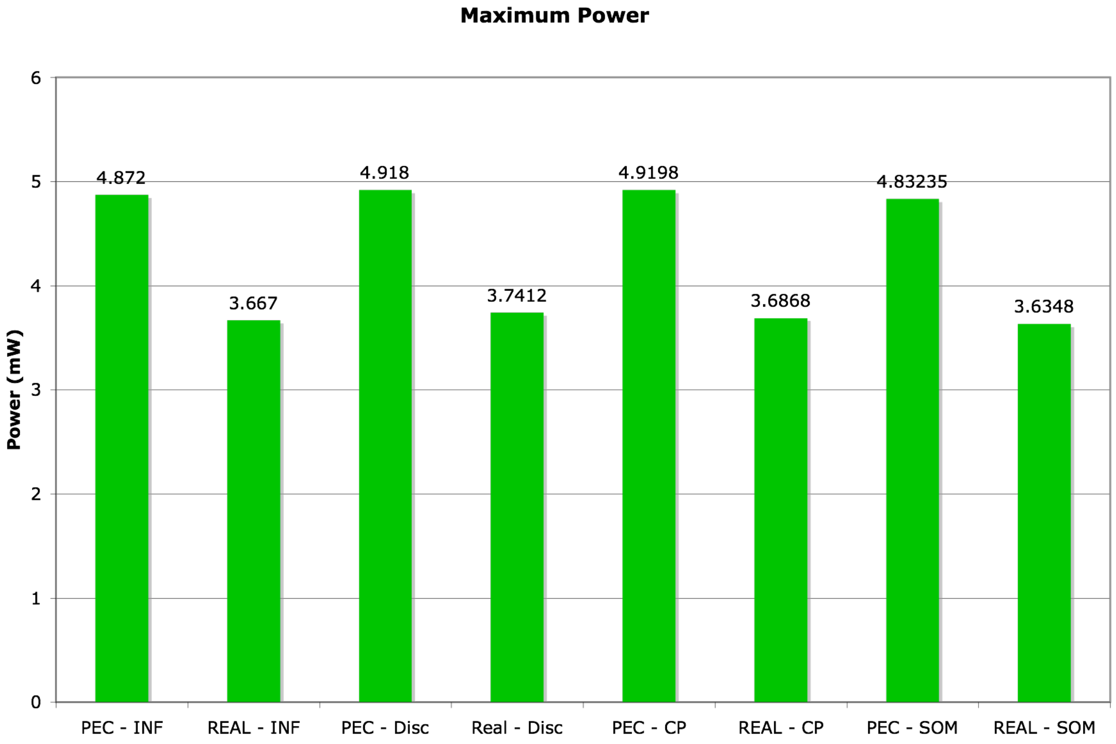
References

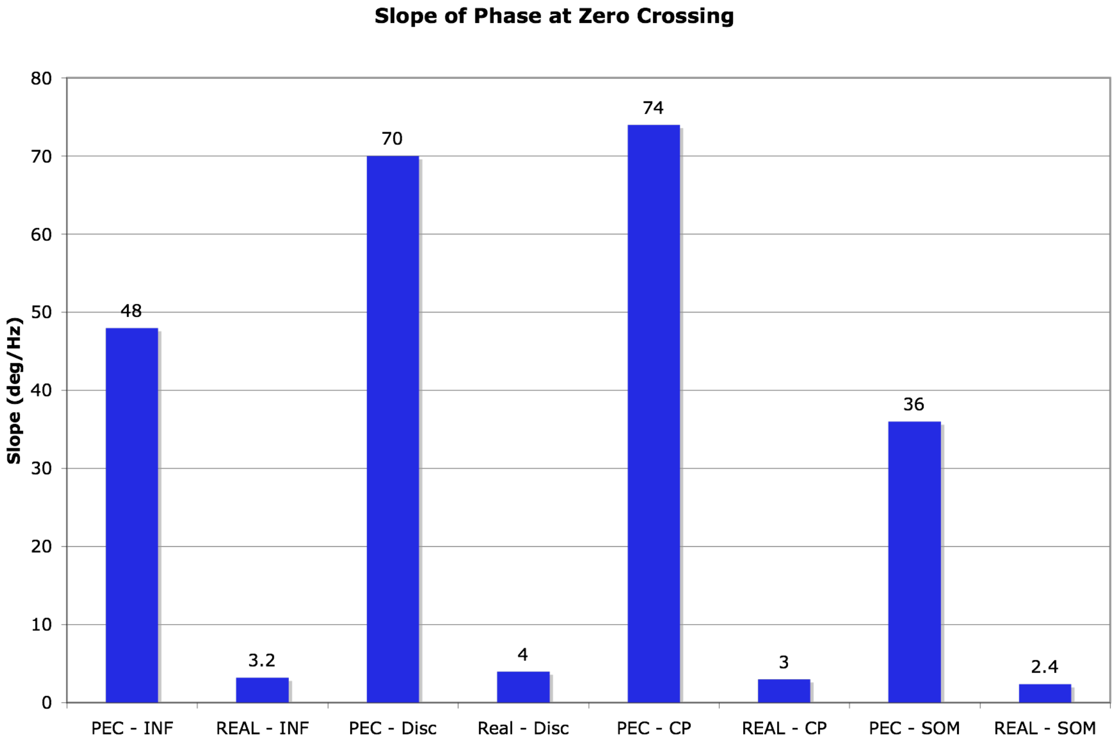
a. Treib, C. A., Parsons, M. W., Wolfe, D. B., McKaughan, M. E., "Engineering the Ideal MF Antenna for DGPS." *Proceedings of the Institute of Navigation*. Sept 2003.
b. Treib, C. A., Parsons, M. W., Wolfe, D. B., Gingras, P.K., "Engineering an All Weather Antenna Tuning Unit for DGPS." *Proceedings of the Institute of Navigation.* Sept 2005.
c. Nautel White Papers, J. Pinks www.nautel.com

Appendix I: Graphical Comparison of Parameters

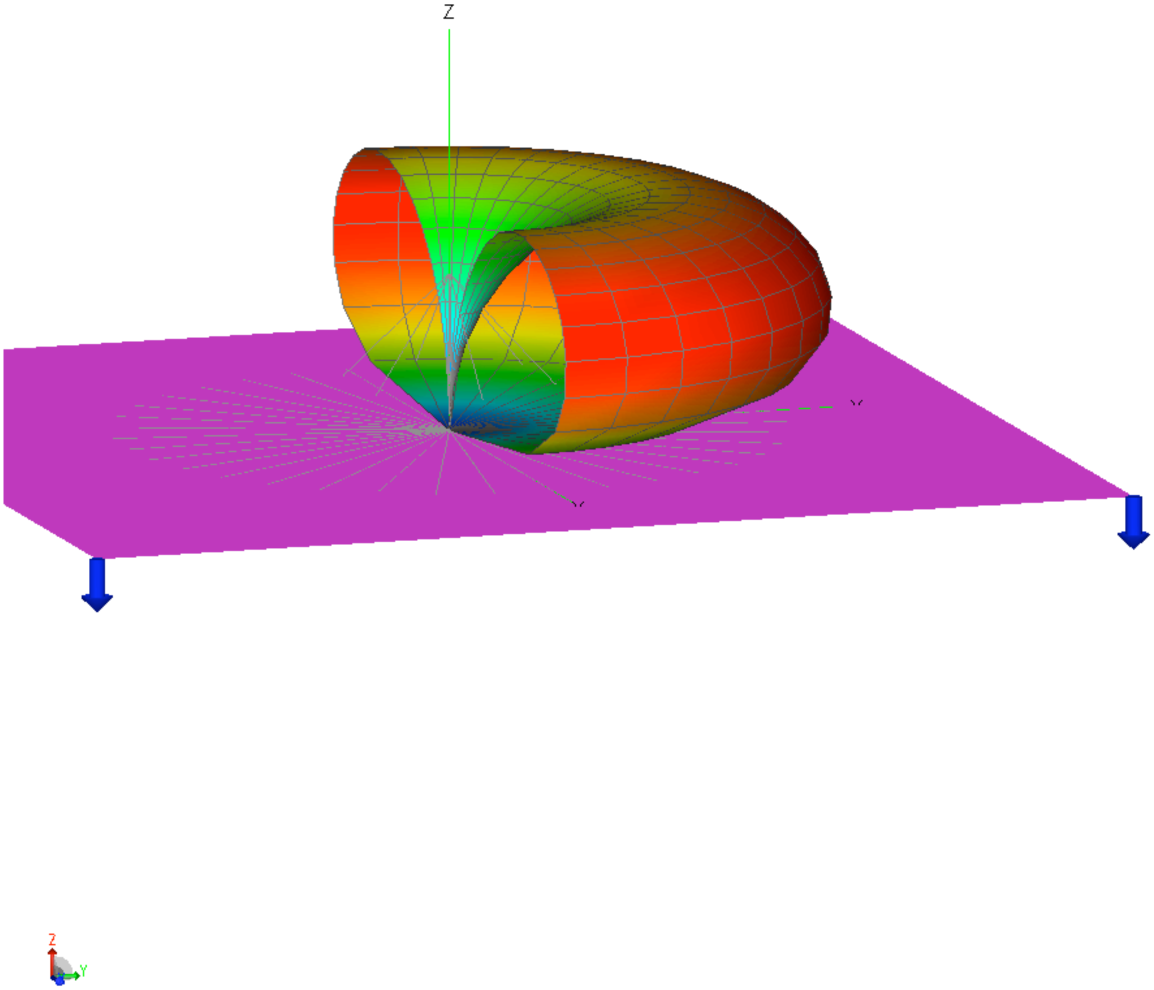





Maximum Power
Power (mW)
0
1
2
3
4
5
6
4.872
3.667
4.918
3.7412
4.9198
3.6868
4.83235
3.6348
PEC - INF
REAL - INF
PEC - Disc
Real - Disc
PEC - CP
REAL - CP
PEC - SOM
REAL - SOM


Slope of Phase at Zero Crossing
Slope (deg/Hz)
0
10
20
30
40
50
60
70
80
48
3.2
70
4
74
3
36
2.4
PEC - INF
REAL - INF
PEC - Disc
Real - Disc
PEC - CP
REAL - CP
PEC - SOM
REAL - SOM

Appendix II: FEKO Summerfield Far field Plot



Appendix III: FEKO Counterpoise Far field Plot