11-17 Physical Optics Modeling of Antenna in Cavity

We mount antennas over a cavity to limit radiation, for example: spirals, Section 11-16 Interlog and sinuous, and Section 5-11 Dipole in Cavity. While many of these antennas can be accurately modeled by using the method of moments (MOM), the models can contain many elements and require long runtimes in analysis. In many cases we just use simple analytical models for the pattern: Section 1-8 with cosine functions or Section 7-5 Gaussian beams. The Gaussian beam approximation includes a near-field approximation and produces more accurate results when used to feed scattering elements, such as, paraboloidal reflectors or plate elements either by using physical optics or GTD analysis. Far-field models can be properly biased to produce accurate currents on scatterers by including gain and input power when computing incident electric field: Section 1-2. However, these remain point source models with decreased accuracy when scatterers are nearby. By including a finite size cavity, equivalent currents are spread over a physical model to produce more accurate physical optics (PO) analyses. Some MOM analyses allow the extraction of currents that can be used in PO but still require the long runtimes of the initial analysis while ignoring the coupling to scatterer currents in the initial analysis.

Spiral Cavity PO Model

The spiral radiates primarily from an active region that will be modeled as a traveling-wave current loop containing full phase cycles depending on the radiation mode and polarization. The effective dielectric of the material in the cavity reduces both its dimensions and diameter of the traveling wave loop.

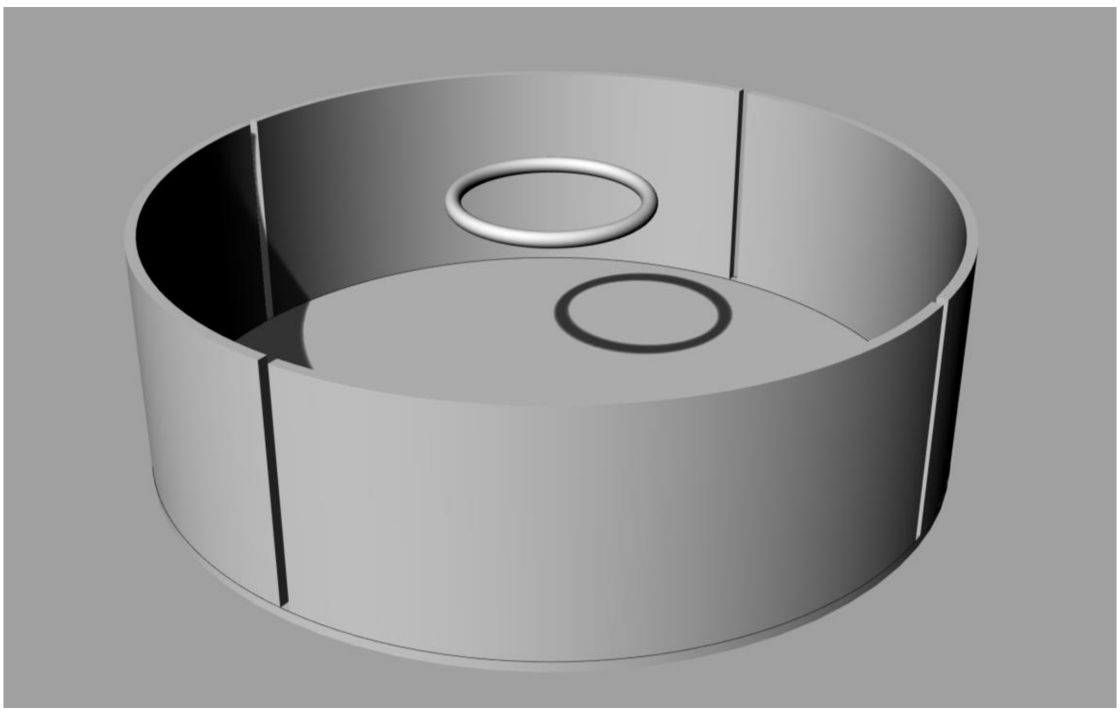

Figure 11-17.1 PO Model of Mode 1 Spiral/Sinuous Antenna in Cavity showing iterative PO Quarter Cups

The following model produces patterns similar to measurements depending on radiation mode.

Loop diameter (in free-space) λ: 0.24062 (mode 1), 0.50971 (mode 2), 0.77954 (mode 3)

Cavity diameter (in free-space) λ: 1.0226 (mode 1), 1.4336 (mode 2), 1.786 (mode 3)

Cavity Depth (in free-space) λ: 0.30 (mode 1), 0.40 (mode 2), 0.42 (mode 3)

An iterative PO, Section 2-4.2 starts with modeled currents on the traveling wave current loop that radiate to excite initial currents on the cavity base and the sides which have been divided into four sections as shown in Figure 11-17.1. The cavity gaps are only notional to illustrate that they are separate. Iterative PO computes the final currents in the cavity's 5 parts due to radiation of each part on the facing parts. Three iterations are sufficient for convergence when only including the additional currents excited by neighboring objects. The final currents are the sum.

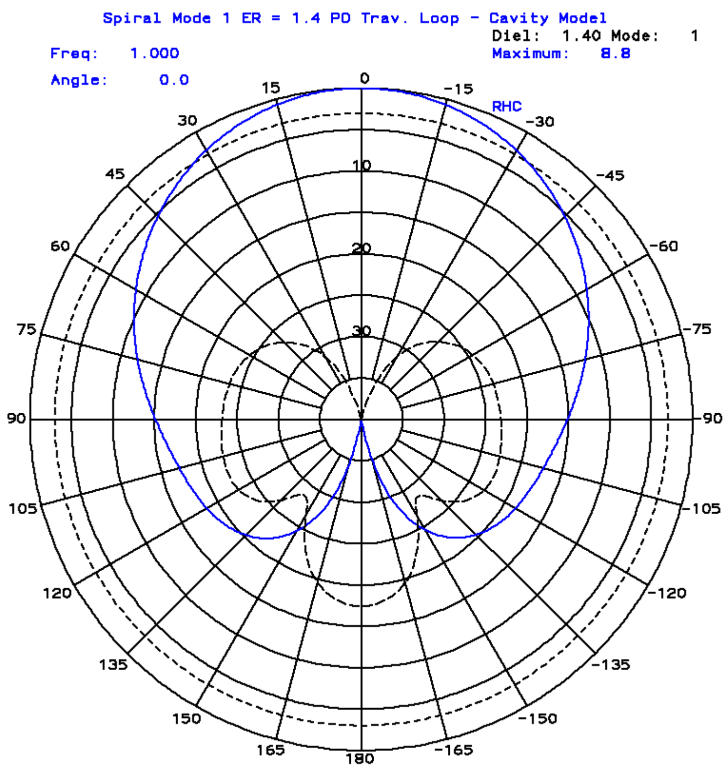

Figure 11-17.2 Spiral Mode 1 ER = 1.4 Far-field PO Traveling Wave Loop – Cavity Model 1

A second model does not divide the cavity walls into 4 parts. Model 2 performs a 2nd order iterative PO where every patch individually receives radiation to excite new incremental currents from every other patch except for itself. Instead of only 5 elements as in model 1, the 2nd order model uses every patch as the number of elements and produces patterns without the four-folded symmetry of quarter-cylinder model.

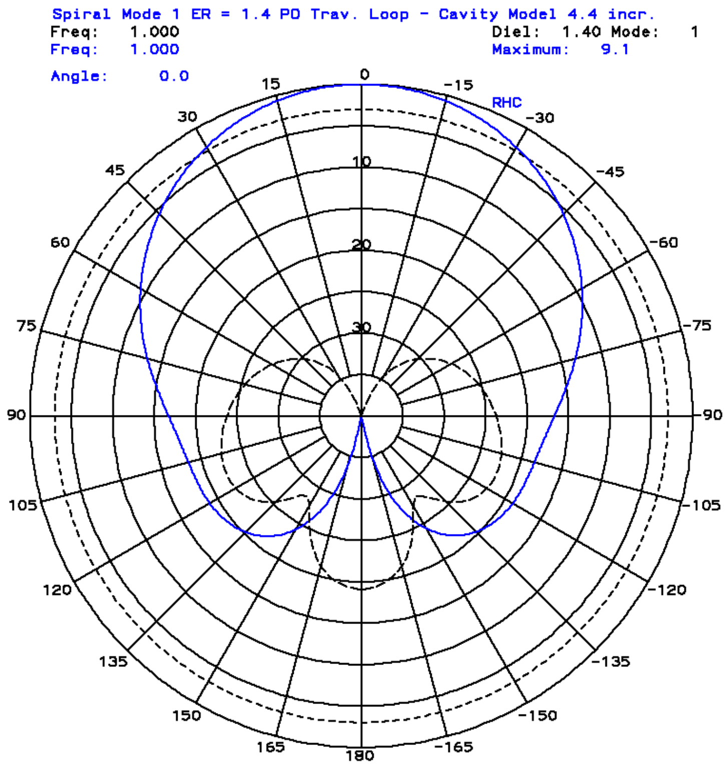

Figure 11-17.2 Spiral Mode 1 ER = 1.4 Far-field PO Traveling Wave Loop – Cavity Model 2

The initial model starts with a unit magnitude current on the traveling wave current loop. The pattern shape is independent of the level of currents on the model and produces a gain larger than actual in the PO model. The pattern is integrated to compute directivity and the current amplitude on the traveling wave loop adjusted so that the new value produces the correct directivity. Loading the cavity with lossy material reduces gain with minor effect on pattern shape. When computing far-fields, the PO patches can be greater than λ/7 but must be finer for near-fields depending on the distance from patches.

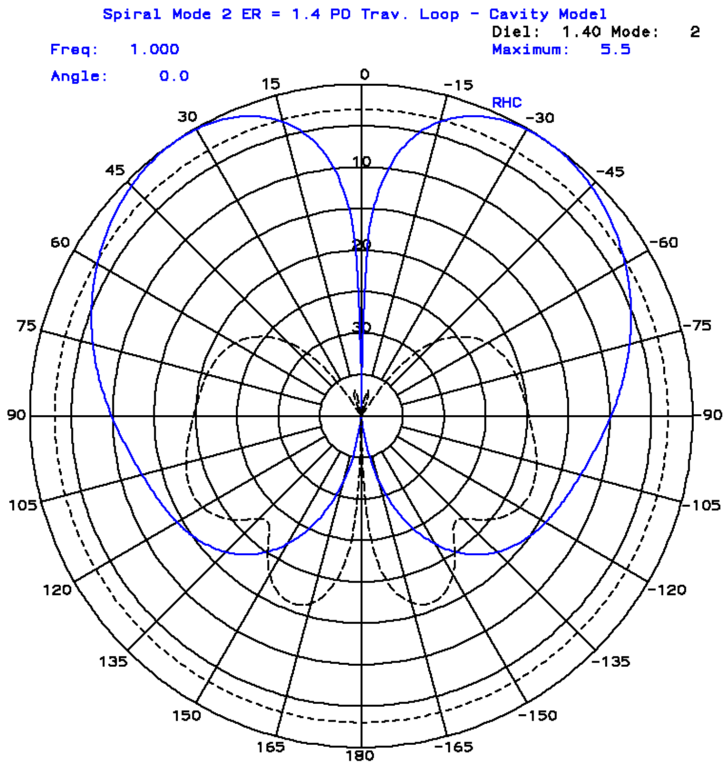

Figure 11-17.3 Spiral Mode 2 ER = 1.4 Far-field PO Traveling Wave Loop – Cavity Model 1

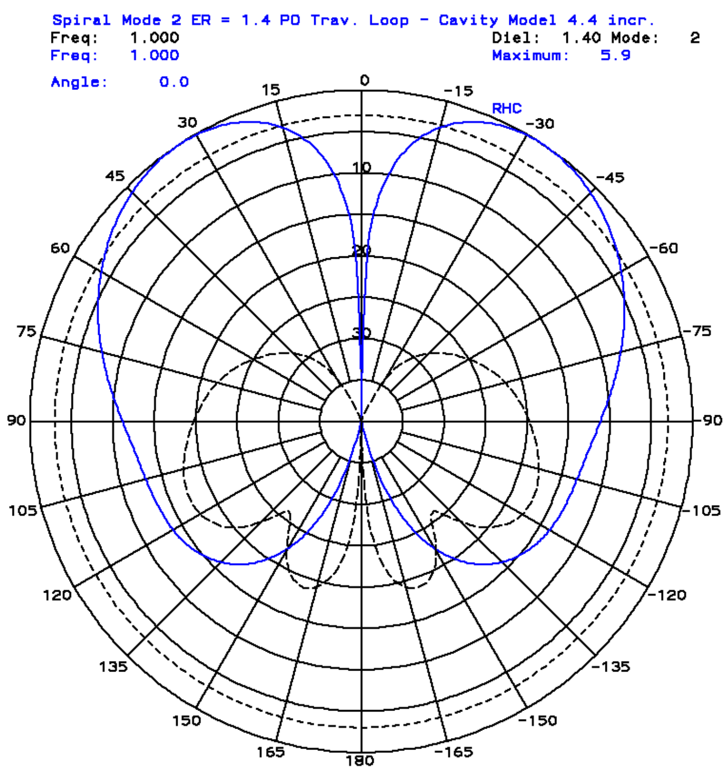

Figure 11-17.3 Spiral Mode 2 ER = 1.4 Far-field PO Traveling Wave Loop – Cavity Model 2

The near-field pattern was computed at a radius = 0.6λ centered approximately halfway up the cavity whose lower corner is located 0.533λ from the center. The following figures illustrate that good patterns depend on finer and finer patch increments.

We compute an equivalent near-field gain by assuming the antenna radiates from the reference point as a point source radiator given the near-field E_{nf} in V/m for an input power of 1 watt at a radial distance R_{nf} in meters to the field point. By rearranging Eq. (1-4), we obtain an equation for equivalent gain.

$$Gain(dB) = 20Log(E_{nf}R_{nf}\sqrt{\frac{4\pi}{\eta}})$$

The antennas of this section have similar gain because they have similar sizes. Second, the pattern shown below changes little at a small distance from its center. The equivalent gain and beamwidth in the near-field differs little from the far-field.

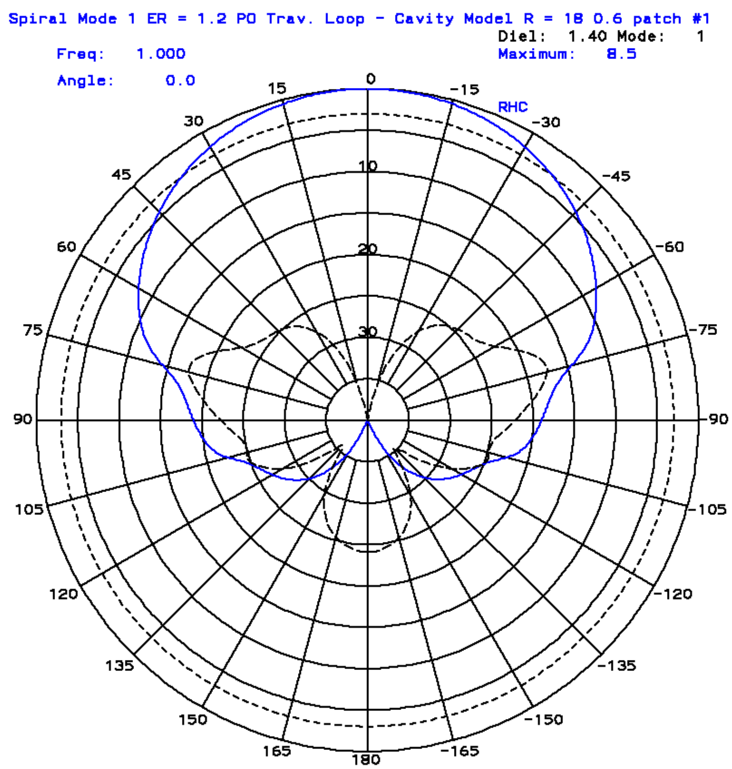

Figure 11-17.4 Near Field at R = 0.6λ using 0.02λ current patches (4672) Model 1

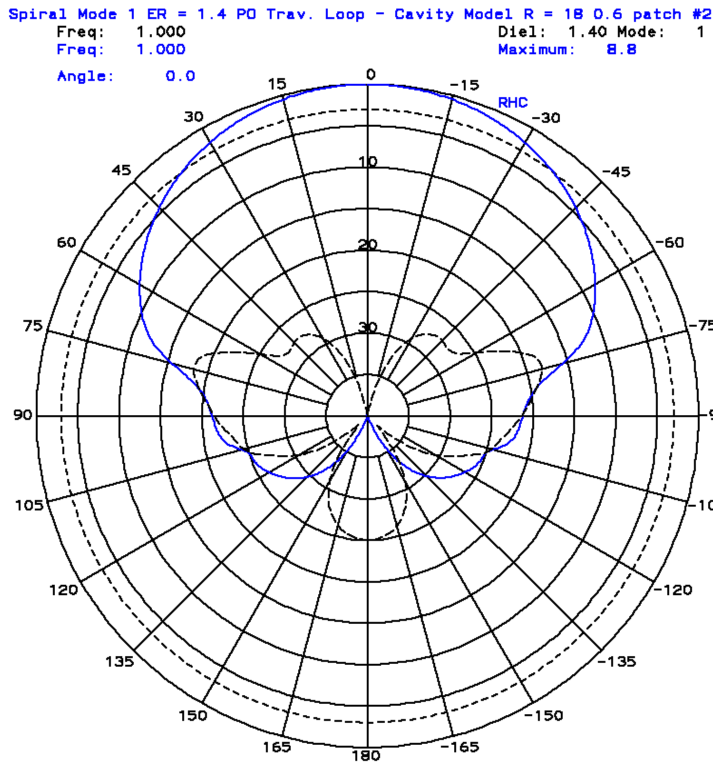

Figure 11-17.4 Near Field at R = 0.6λ using 0.02λ current patches (4672) Model 2

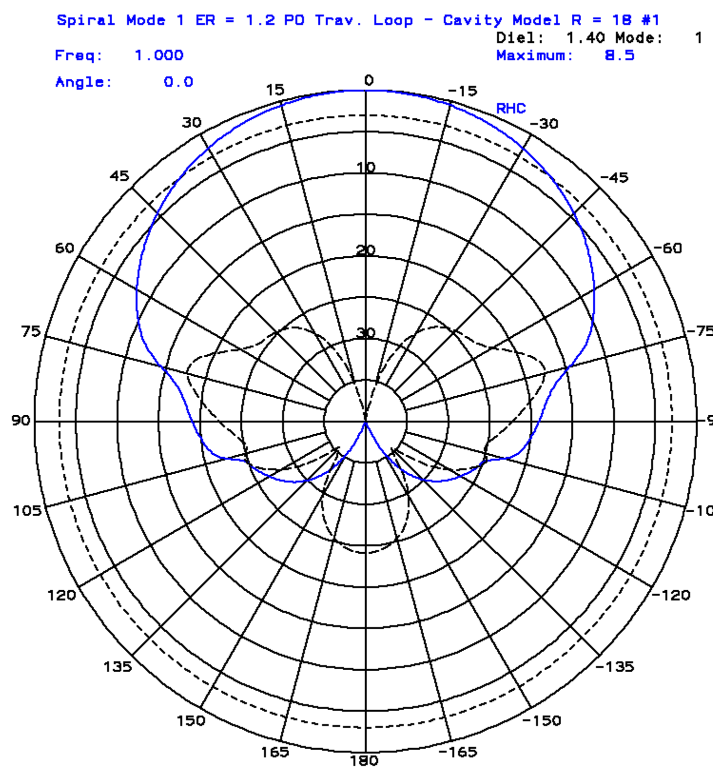

Figure 11-17.5 Near Field at R = 0.6λ using 0.037λ current patches (1448) Model 1

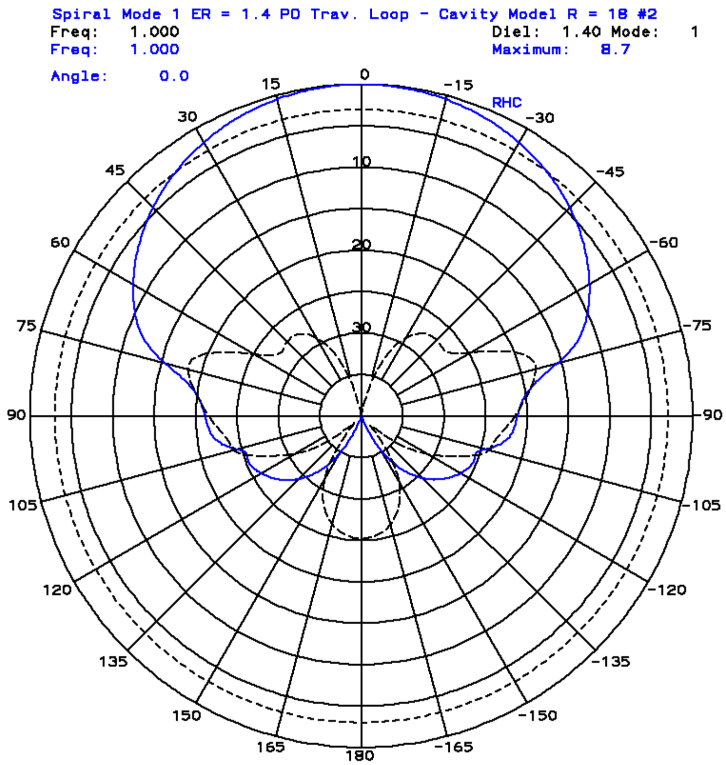

Figure 11-17.5 Near Field at R = 0.6λ using 0.037λ current patches (1448) Model 2

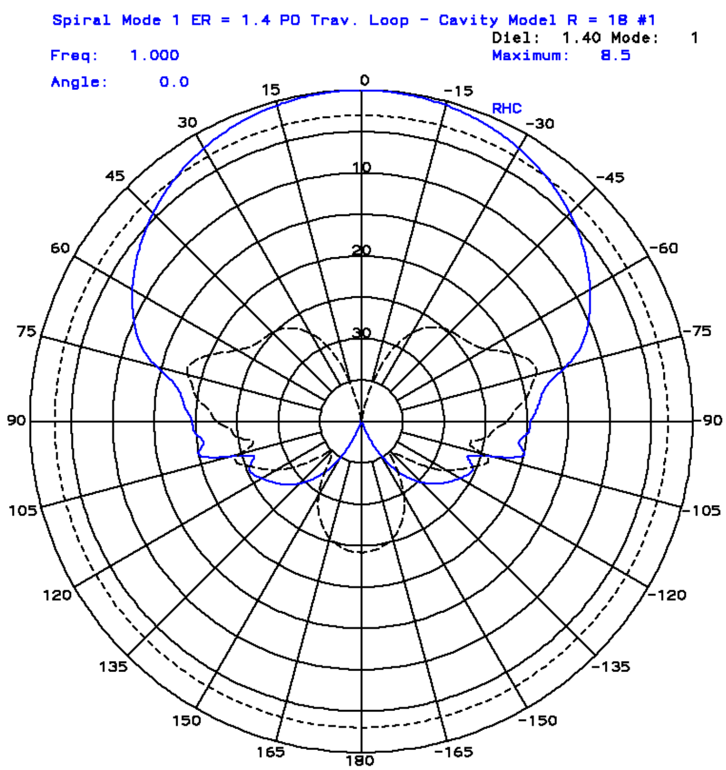

Figure 11-17.6 Near Field at R = 0.6λ using 0.073λ current patches (428) Model 1

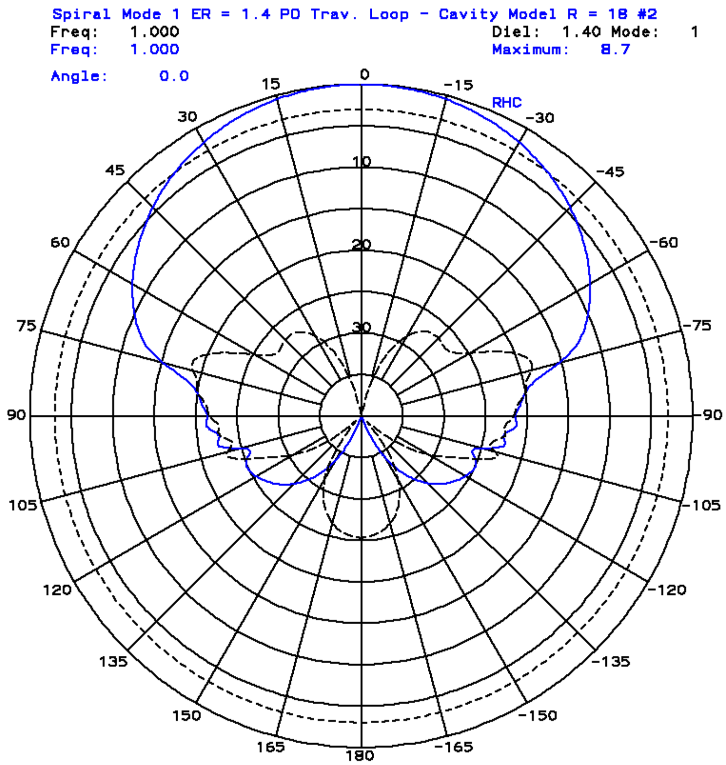

Figure 11-17.6 Near Field at R = 0.6λ using 0.073λ current patches (428) Model 2

Sinuous/ Interlog Cavity PO Model

These antennas radiate linear polarization and can be modeled using a resonant current loop as in Section 5-18. Figure 11-17.1 illustrates the physical model where the loop has a Cosine(mode ϕ) or Sine(mode ϕ) initial unit current. The magnitude of the loop current is modified so that the pattern radiated gain matches directivity found by integrating the pattern as done in the spiral model. With a cosine distribution the antenna radiates E_{φ} along the x-axis and E_{θ} along the y-axis for mode 1 feeding.

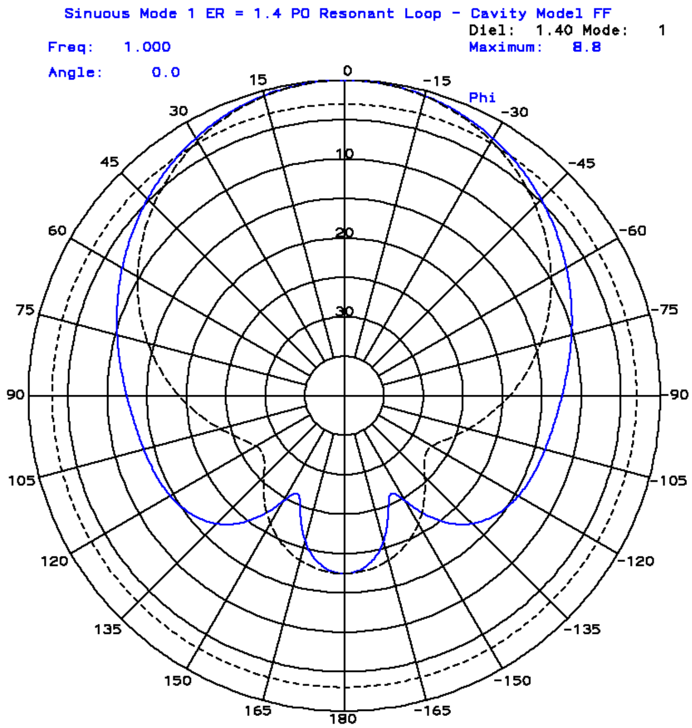

Figure 11-17.7 Sinuous Mode 1 ER = 1.4 Far-field PO Resonant Current Loop – Cavity Model: Solid: *E*$_\varphi$ x-axis plane (0˚), Dashed: *E*$_\theta$ orthogonal plane (90˚) Model 1

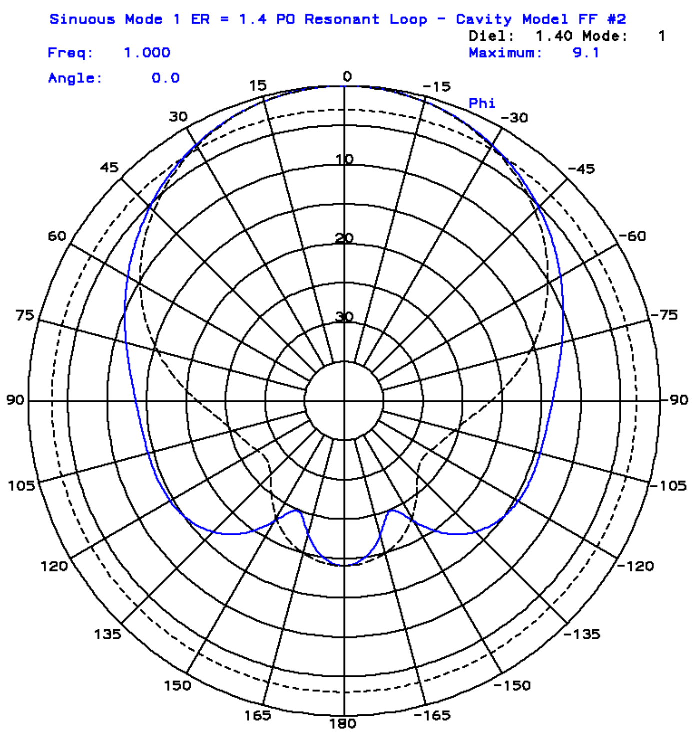

Figure 11-17.7 Sinuous Mode 1 ER = 1.4 Far-field PO Resonant Current Loop – Cavity Model: Solid: *E*$_\varphi$ x-axis plane (0˚), Dashed: *E*$_\theta$ orthogonal plane (90˚) Model 2

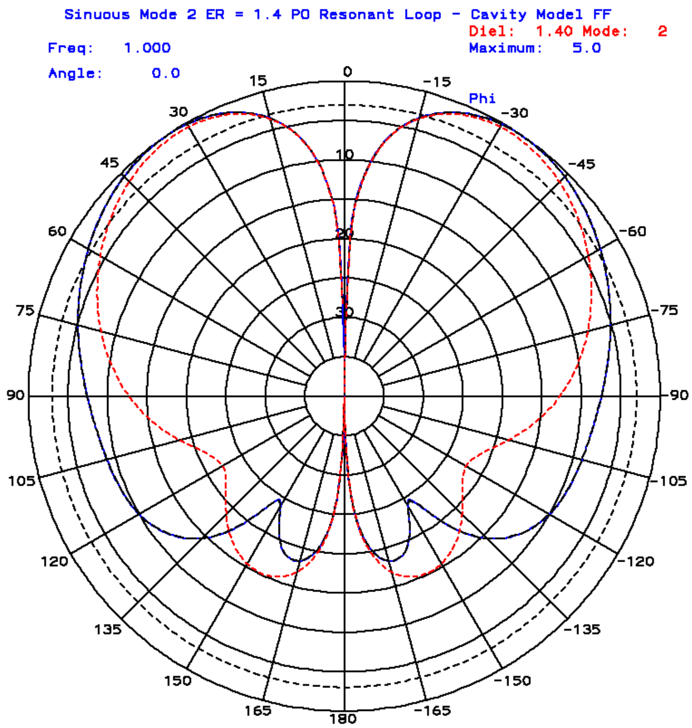

Figure 11-17.8 Sinuous Mode 2 ER = 1.4 Far-field PO Resonant Current Loop – Cavity Model: Solid: *E*$_\varphi$ principal planes (0˚ and 90˚), Dashed: *E*$_\theta$ diagonal planes (45˚) Model 1

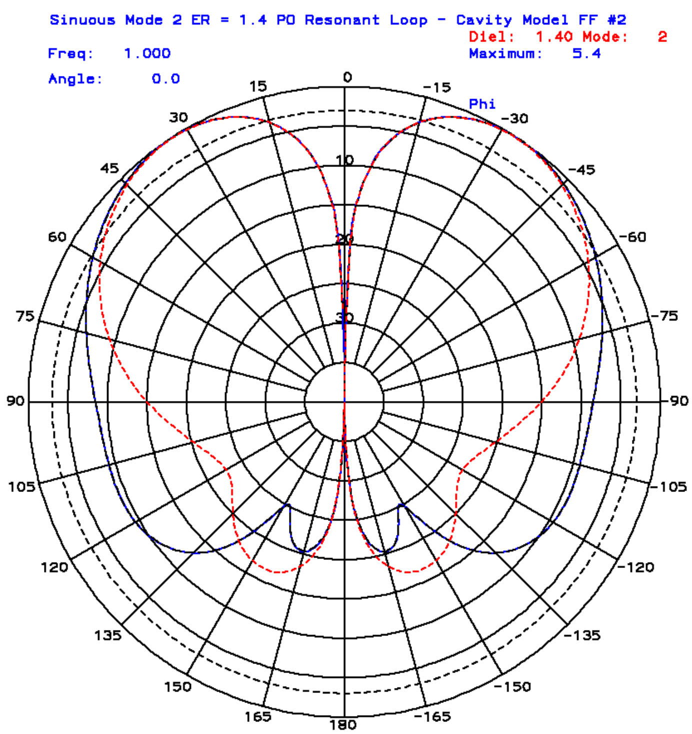

Figure 11-17.8 Sinuous Mode 2 ER = 1.4 Far-field PO Resonant Current Loop – Cavity Model: Solid: E_φ principal planes (0˚ and 90˚), Dashed: E_θ diagonal planes (45˚) Model 2

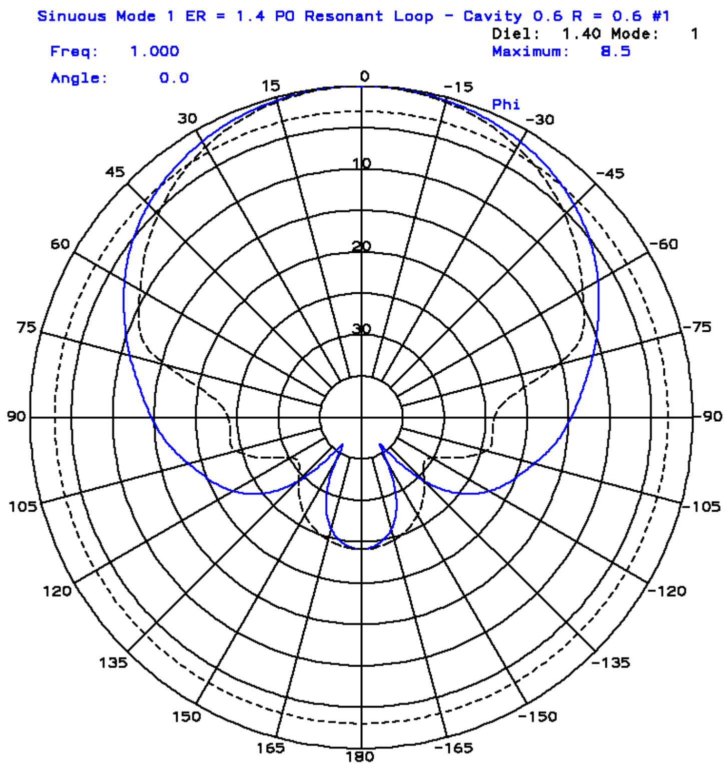

Figure 11-17.9 Sinuous Mode 1 Near Field at R = 0.6λ using 0.02λ current patches (4672) Model 1

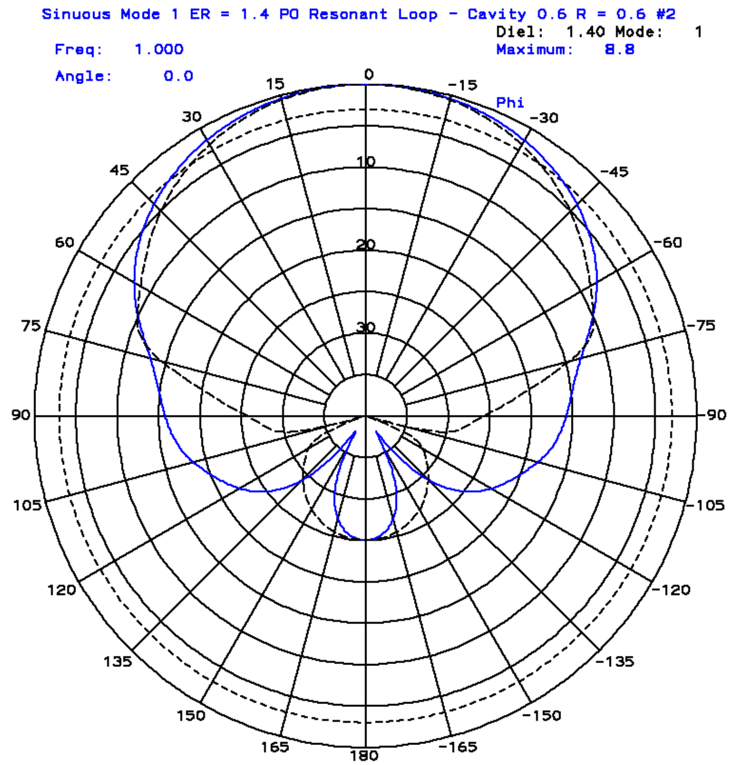

Figure 11-17.9 Sinuous Mode 1 Near Field at R = 0.6λ using 0.02λ current patches (4672) Model 2

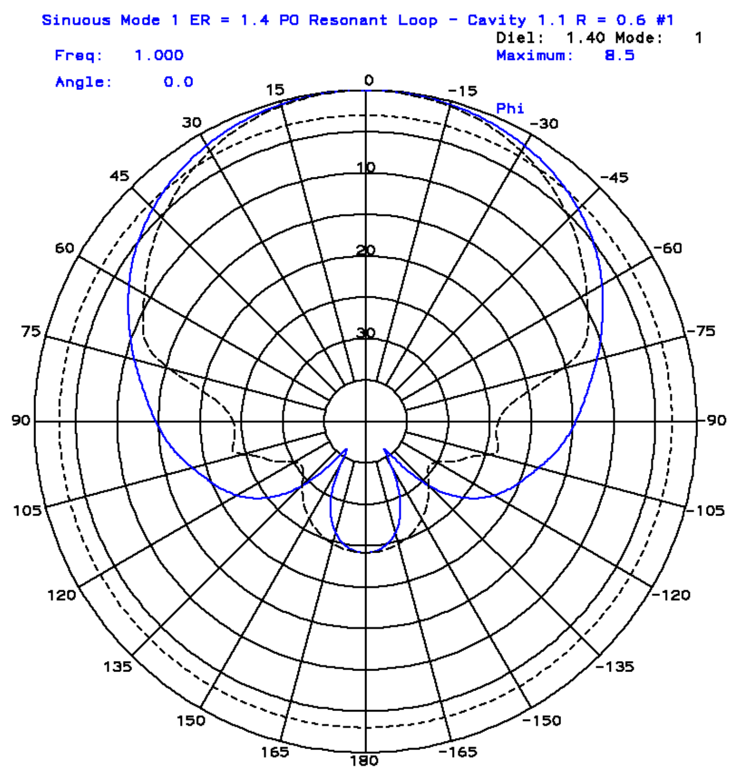

Figure 11-17.10 Sinuous Mode 1 Near Field at R = 0.6λ using 0.037λ current patches (1448) Model 1

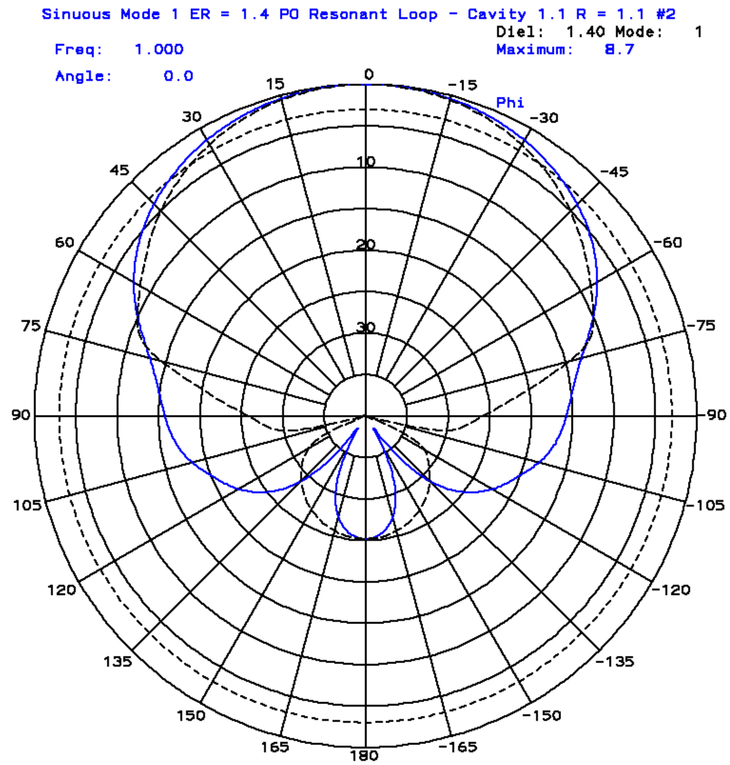

Figure 11-17.10 Sinuous Mode 1 Near Field at R = 0.6λ using 0.037λ current patches (1448) Model 2

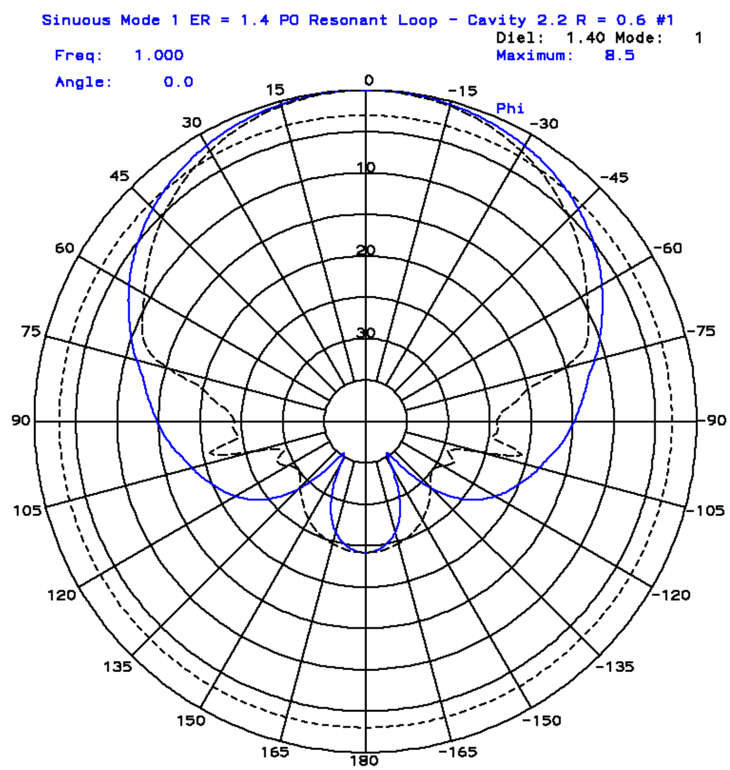

Figure 11-17.11 Sinuous Mode 1 Near Field at R = 0.6λ using 0.073λ current patches (428) Model 1

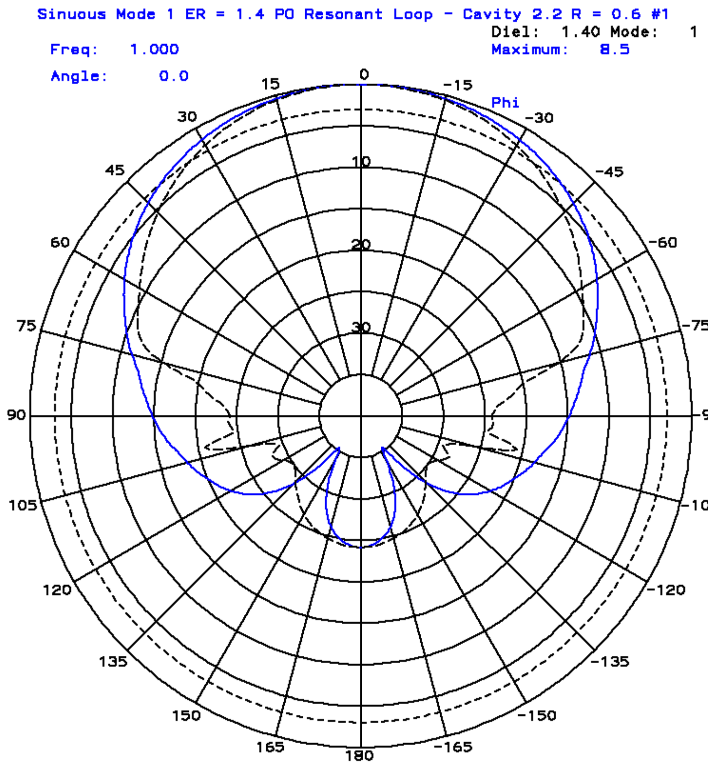

Figure 11-17.11 Sinuous Mode 1 Near Field at R = 0.6λ using 0.073λ current patches (428) Model 2

Turnstile Dipole Cavity PO Model

Section 5-11 illustrates a turnstile dipole mounted in a cavity along with a catalog of designs. The parameters of these designs were computed by using MOM (NEC wires with the cavity as a mesh). This model can compute the impedance of the dipole by using MOM or parallel wires in a PO mutual coupling analysis.

A second model does not divide the cavity walls into 4 parts. Model 2 performs a 2nd order iterative PO where every patch individually receives radiation to excite new incremental currents from every other patch except for itself. Instead of only 5 elements as in model 1, the 2nd order model uses every patch as the number of elements and produces patterns without the four-folded symmetry of quarter-cylinder model.

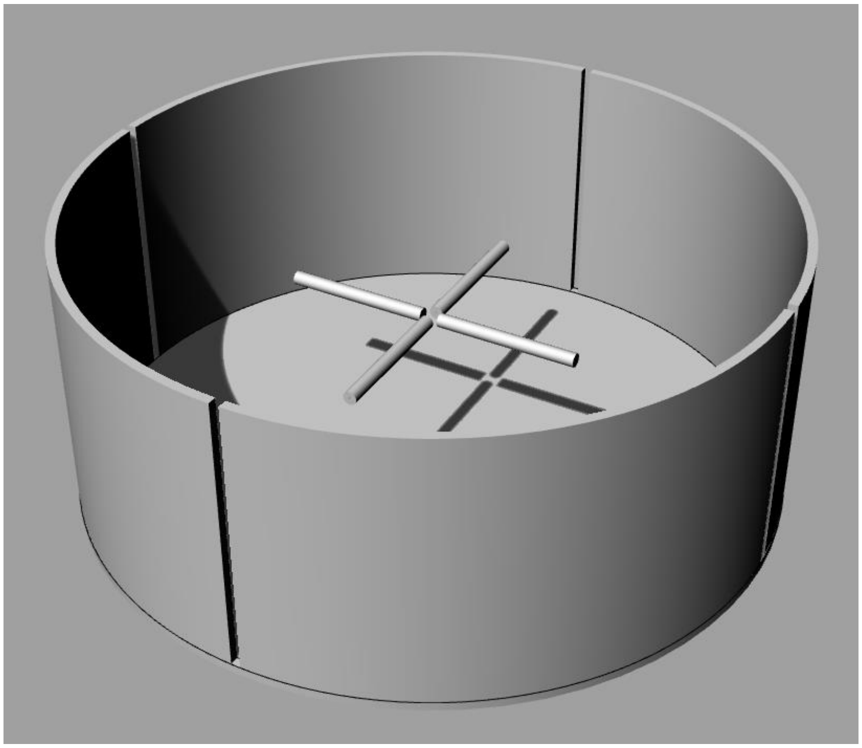

Figure 11-17.12 PO Model of Turnstile Dipole in Cup Cavity with iteration segments: 189 total current patches

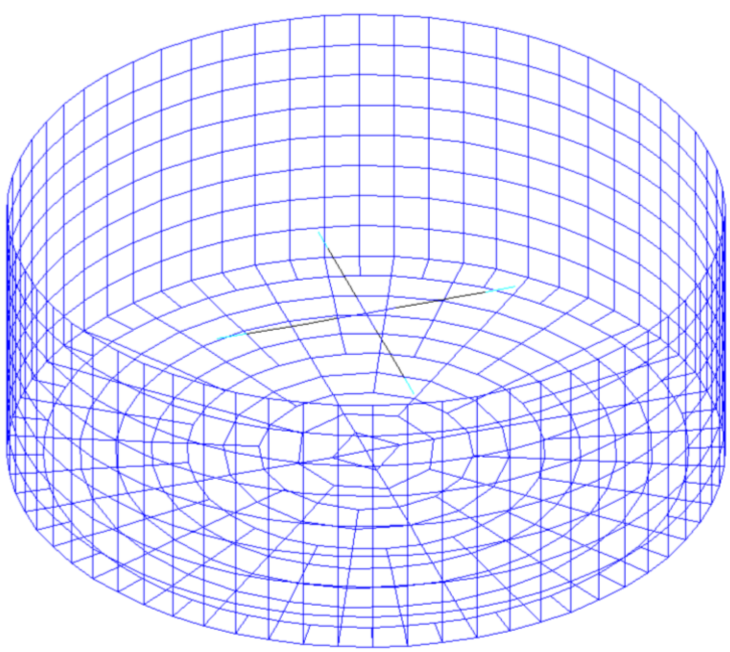

Figure 11-17.13 NEC Model with 1584 segments

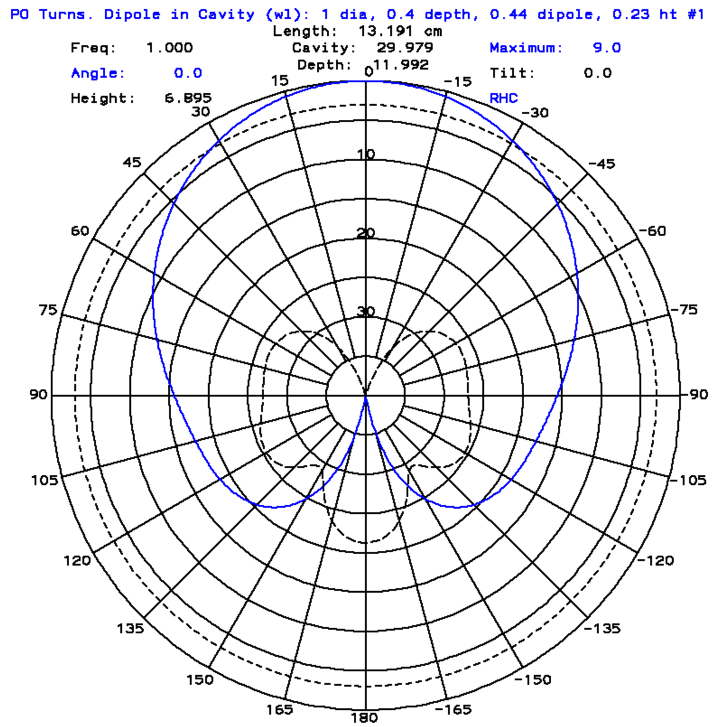

Figure 11-17.14 PO model of RHC Turnstile Dipole in Cavity using iterative PO cavity analysis 189 patches Model 1

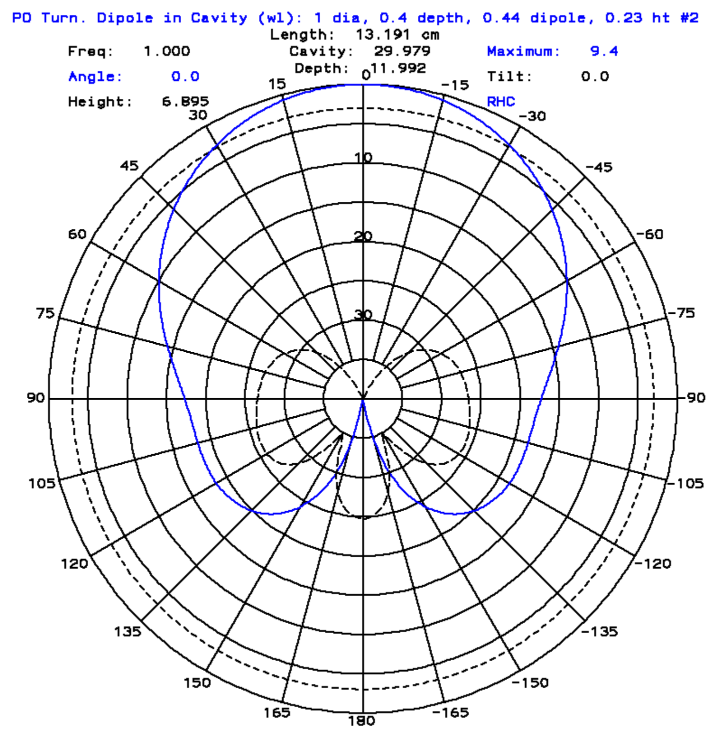

Figure 11-17.14 PO model of RHC Turnstile Dipole in Cavity using iterative PO cavity analysis 189 patches Model 2

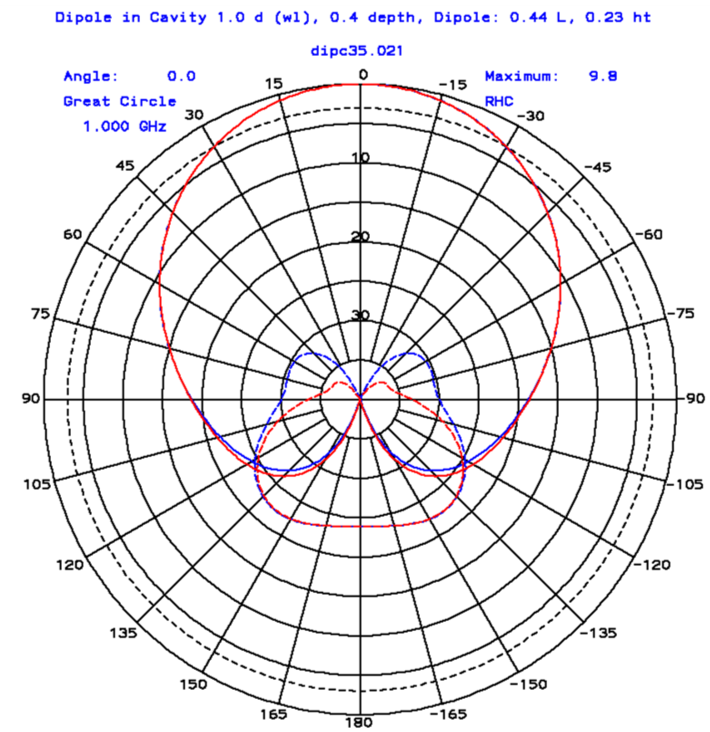

Figure 11-17.15 NEC model of RHC Turnstile Dipole in Cavity 1584 segments

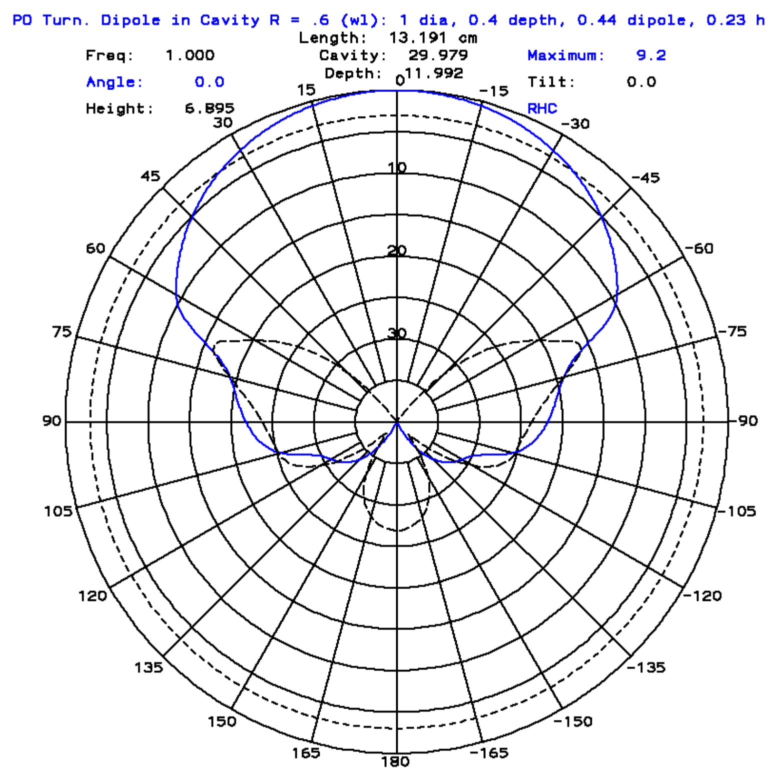

Figure 11-17.16 Near Field at R = 0.6λ using 0.02λ current patches (5246) Model 1

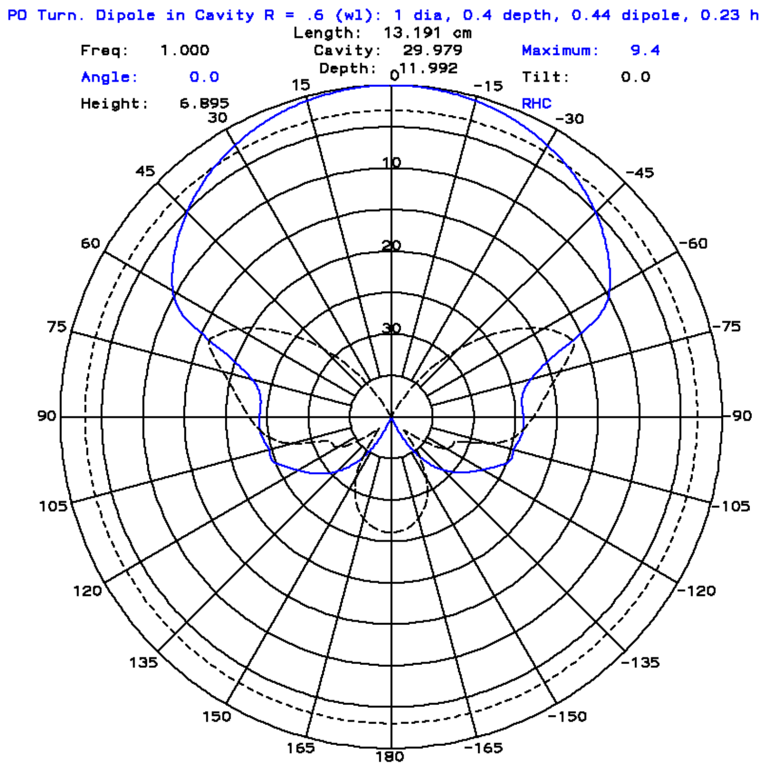

Figure 11-17.16 Near Field at R = 0.6λ using 0.02λ current patches (5246) Model 2

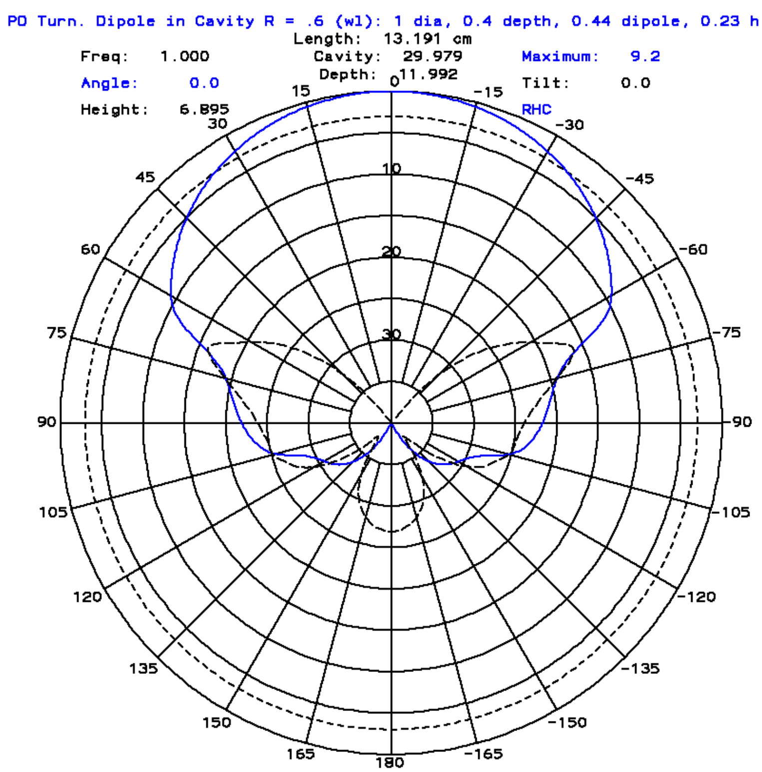

Figure 11-17.17 Near Field at R = 0.6λ using 0.04λ current patches Model 1

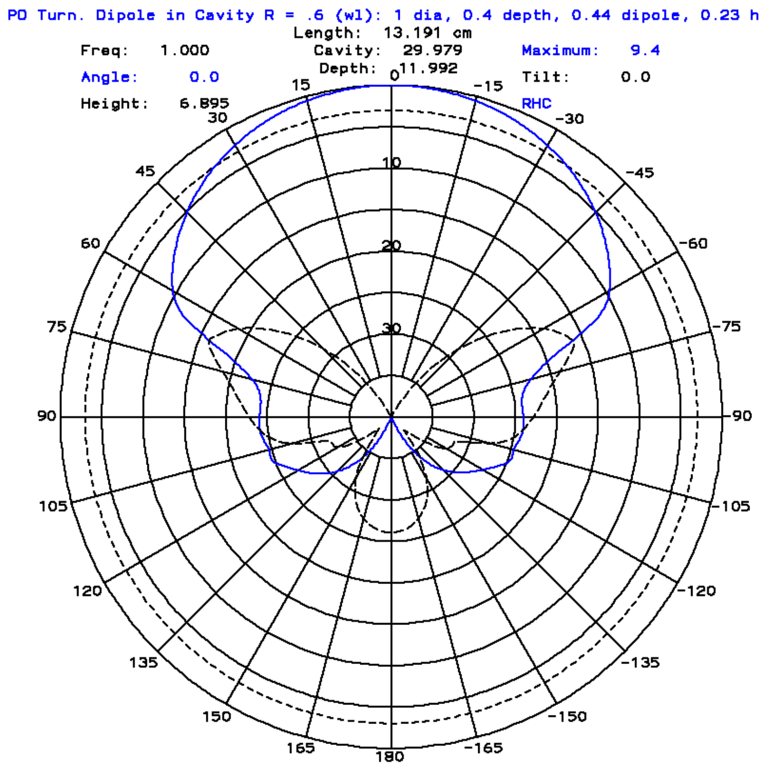

Figure 11-17.17 Near Field at R = 0.6λ using 0.04λ current patches Model 2

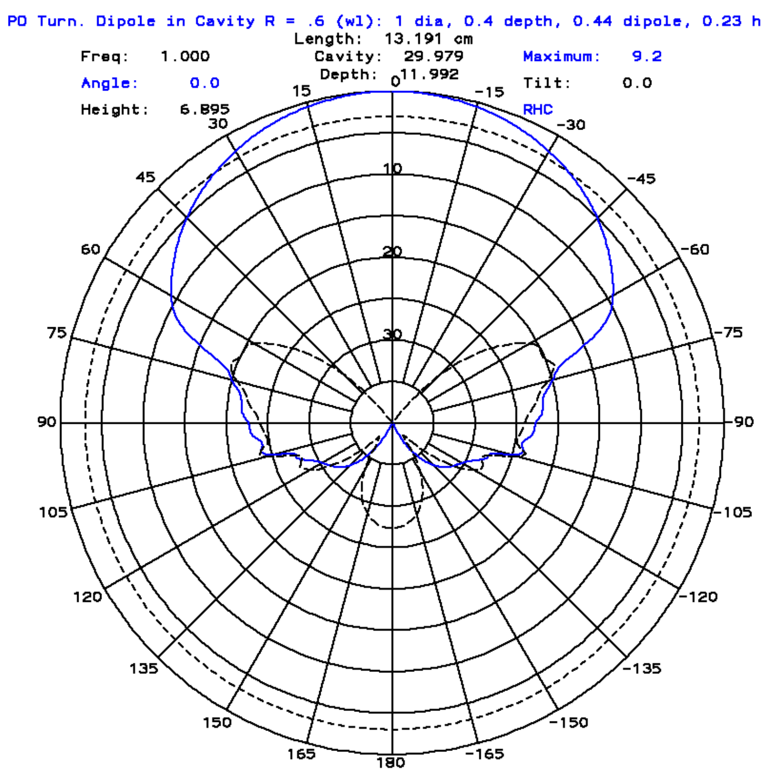

Figure 11-17.18 Near Field at R = 0.6λ using 0.08λ current patches (401) Model 1

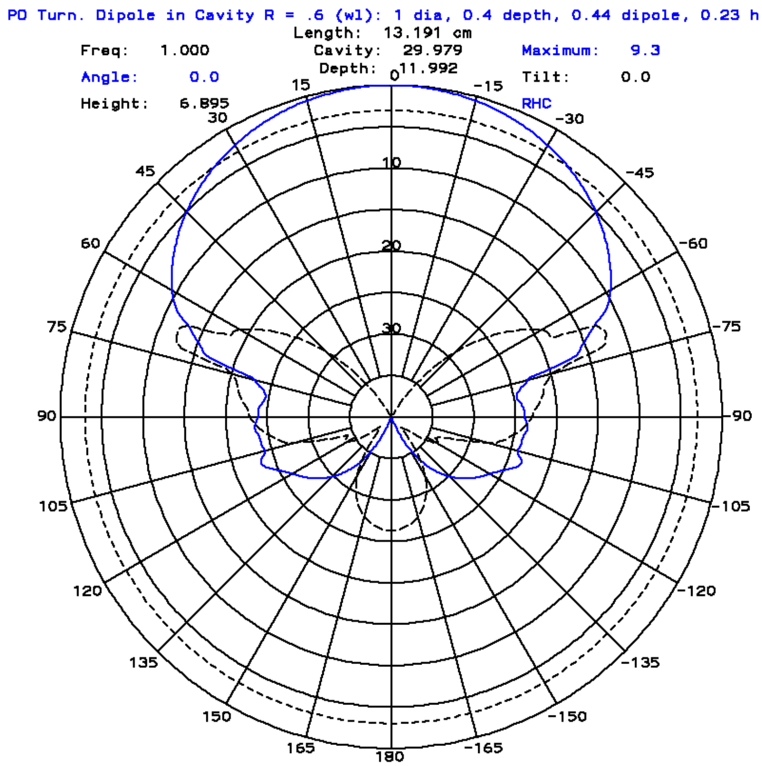

Figure 11-17.18 Near Field at R = 0.6λ using 0.08λ current patches (401) Model 2

Comparison of image coupling using model 2

Coupling to infinite ground plane: impedance = 54.9 + j3.6, Directivity – Gain = -1.05 dB

Coupling to cavity currents: impedance = 74.8 + j0.7, Directivity – Gain = 0.29 dB