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12/5-9-94 JSC (1)

UCRL-ID-115730

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November 1993

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TSAR Modeling of a TEM Horn and Surrounding Structure

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I. Introduction

Modeling of a TEM horn was performed with the TSAR FDTD electromagnetics code. The modeling was done in stages, beginning with the simplest case, the bare antenna itself. Complexity was added in the form of a dielectric lens, an enclosing cylinder, a layer of absorber inside the cylinder, resistive terminations between the horn and cylinder, and a flat plate over all, electrically separate from the cylinder. The final configuration included all of the above, plus a ring of ferrite inside the cylinder, just ahead of the horn. A cut through the complete finite-difference model is shown in figure 1.

Predictions of the far-field were made at roughly ten degree increments, more closely spaced near boresight, in both vertical and horizontal planes, through the antenna's centerline. Time histories at those points were evaluated, and from the time histories power densities were calculated. Both time histories and power densities will be presented for the configurations modeled.

II. Model Construction

The finite-difference model was built using the standard TSAR procedure. First a solid model of the complete structure was created with MGED (Multi-Device Graphics Editor). This representation consists of a continuous description of the complete object, with no symmetry invoked and all the parts for the final model included. Anastasia, the program which samples the solid model and creates a finite-difference mesh, was then used to create the grids which were used in the calculations.

Initially, only the horn itself was meshed, then more parts were added as the complexity of the model was increased. By first creating the complete model, then meshing only parts of it, possible difficulties with separate solid models were avoided.

Because of the shape of the horn antenna and the fact that TSAR uses cubical cells which do not conform well to a curved surface, it

was necessary to grid much finer than the standard 10 cell per wavelength rule at the highest frequency of interest. Early models at 7mm and 5mm resolution were tested, (14 cells and 20 cells per wavelength, respectively), and the decision was made to use the 5mm, 20 cell per wavelength model (at 3 GHz in free space). This still allowed 12 cells per wavelength in the dielectric lens region.

III. Simple Antenna

Once the solid model was built and meshed, the first calculations involved only the antenna itself, with no surrounding structures. Some results from experiments were available for the basic case and for the next step, the addition of a dielectric lens. Initially, the output from the code did not show the pulse sharpening with the addition of the lens. After discussions with Dr. Buchenauer at the Phillips Lab, it was determined that higher frequency content in the source radiator was required. A Gaussian pulse, down 3 dB at 3 GHz from its peak value, was selected to match the experimental data. The increased higher frequency content brought about the pulse sharpening on boresight, bringing the code results into reasonable agreement with the experimental data.

For the simplest cases, comparisons were run using different planes of symmetry. Because an FDTD program is memory- and compute-intensive, we wished to maximize the amount of symmetry invoked. A model of one-half the antenna, with a perfect magnetic conductor (PMC) vertically along the antenna's centerline, was compared to a one-quarter antenna model, which used a horizontal perfect electric conductor (PEC) in addition to a vertical PMC. Agreement between the two models was excellent until well above the upper frequency limit set by the cell size, so for models up to the inclusion of the flat plate, the quarter antenna model was used. A cut through the centerline of the model is shown in figure 2. (The imaged lower half is also shown).

To excite the problem, a single E-field node was driven in the throat of the antenna. The waveform used was the above mentioned Gaussian pulse, with a peak of 1 volt/meter. Full-width at half-maximum for the pulse was $10 \Delta t$. Far-field test points were located at a 5 meter distance, in both horizontal and vertical planes. For most of the runs, the theta component was selected, (see fig. 2), as this matched the antenna polarization. Selected runs were also made with phi-polarized output, but the results were orders of magnitude down from the theta-directed values, and consisted almost completely of noise, so they are not included here.

All the comparisons for the different configurations modeled will be made with the results of the Gaussian input pulse. Since the variations in response with changes in the model were of interest, it was decided to simply plot the results from the Gaussian excitation. Scaling to higher input voltages for a Gaussian pulse requires only a simple multiplication. Plots of the impulse response on boresight and ten degrees off boresight will be added as an appendix. Plots for all configurations are made with identical scales amplitude and time, so that comparisons between the configurations may be easily made. Power density plots will also be plotted on the same vertical scale as the largest power density response.

With the antenna alone, (no lens), the maximum absolute field value occurred on boresight, ($\theta=90$, $\phi=180$), $1.6\text{E-}03$ V/m, as shown in figure 3. This corresponds to a peak power density of $6.8\text{E-}09$ W/m². The pulse dies out rapidly, decaying in approximately 2.4 ns.

Figures 4 through 16 show the θ component in the vertical plane. Moving off boresight vertically, the peak field value diminishes steadily. Up to ten degrees off boresight, this is due to the interaction between the direct pulse and the diffracted pulse from the edge of the cone. Note that the direct radiation alone, the first negative-going peak in the plots, is almost undiminished through $\theta = 80$ degrees. Only after θ reaches 70 degrees is the direct pulse clearly reduced in amplitude. Moving further off boresight, the fields continue to decrease, down to a peak amplitude of about $1.25\text{E-}04$ V/m at ninety degrees off boresight ($\theta = 0$).

Similar results are seen in the horizontal plane, shown in figures 17 through 29. The direct wave is not noticeably diminished until 20 degrees off boresight ($\phi = 160$), although the peak value does steadily decay, down to approximately $1.7\text{E-}04$ V/m at 90 degrees off boresight ($\phi = 90$).

Plots of power density show a steady decrease in both planes as the test location moves off boresight. Included are plots of power density versus time in both the vertical and horizontal planes, and polar plots of peak power density versus angle in both planes, which show that the beamwidth is quite narrow, even before installing the dielectric lens. (Figures 30 through 57).

IV. Antenna and Dielectric Lens

The next set of calculations was performed with a dielectric lens added to the basic antenna. The lens is a section of a sphere, with a relative dielectric constant of 2.26. A cross-section of the mesh is shown in figure 58.

Figure 59 shows the E-field time history on boresight with the lens in place. Comparing the results with the no lens case, the pulse is delayed in time due to propagation through the dielectric. Constructive interference between the direct wave and the diffracted wave from the edge of the cone approximately doubles both the initial negative-going pulse and the largest positive pulse. The main body of the pulse is reduced in time from about 850 ps to about 525 ps.

The amplitude of the late time response is reduced relative to the peak-to-peak amplitude when the lens is added, from about 15% with no lens to about 8% with the lens. Also, there appears to be less constructive and destructive interference in the late time, resulting in more uniform ringing. The pulse dies out slightly sooner than with no lens, after about 2.2 ns.

Moving off boresight, a reduction in amplitude is immediately noticeable. In the horizontal plane, moving only 2 degrees off boresight reduces the peak-to-peak amplitude of the main pulse to about 87% of the value on boresight. The decay continues rapidly, so that at 20 degrees off boresight the peak-to-peak amplitude is reduced to approximately 14% of the boresight value. At 90 degrees off boresight, the peak-to-peak amplitude is only 7% of the boresight amplitude.

Similar behavior is observed in the vertical plane. Also noticeable is the loss of the higher frequency components off boresight. The reduction in the higher frequencies is noticeable even at 5 degrees off boresight vertically. When compared to the boresight response, the main body of the pulse is spread out in time, indicating a loss of the higher frequencies.

The reduction in amplitude off boresight continues in the vertical cut through 90 degrees, where the peak-to-peak value is approximately 5% of the boresight amplitude. Plots of the E-field in the horizontal and vertical planes with the lens in place are shown in figures 59 through 85.

In terms of power density, the maximum value on boresight is about $3.3\text{E-}08 \text{ w/m}^2$, ($3.3\text{E-}09 \text{ mw/cm}^2$). The fall-off as one moves off boresight is very apparent in the power density plots, figures 86 through 112, and a plot of peak power density versus angle, figure 112 B, shows how narrow the beamwidth is with the addition of the lens.

V. Addition of Canister

The next change to the model was to add a cylindrical can to the antenna and lens combination. The can was 2 meters in length and 65 centimeters in diameter. The antenna was mounted near the open end of the can, and the other end of the can was closed. The can was long enough such that reflections from the closed end did not interfere with the main body of the pulse. The antenna was not electrically connected to the can for this set of calculations. A cut through the centerline is shown in figure 113.

The most apparent effect of adding the can is the continued late time ringing. Rather than the pulse dying out after 2-3 ns., it continues ringing beyond 12 ns. with the can, and did not die out completely during the computed time record. A reflection from the closed end of the can may be identified about 6 ns. after the main pulse, with the other ringing resulting from the excitation of modes within the can.

Comparing the field history on boresight with the antenna/lens case, there is about a 12.5% reduction in peak-to-peak amplitude. This is almost entirely due to a reduction in the initial negative-going pulse, as the major positive peak is only slightly diminished. Since this occurs so early in time, it must be caused by diffraction from the open end of the can. This suggests that the distance from the antenna to the open end of the can could be an important design consideration.

The can also induces changes in the initial ring-down phase, the first nanosecond after the main peak. With the can in place, there is more energy in this portion of the waveform, and since it is still early in time, could be caused by interaction between the antenna structure and the can.

Moving off boresight, a trend similar to that with no can is observed. The amplitude is reduced as the angle from boresight is increased. Beyond 10 degrees off boresight, though, the amplitude with the can is clearly reduced from the case with no can. The initial pulse is almost entirely eliminated as the move from boresight continues. The reduction is a little more apparent in the vertical plane than the

horizontal. Very little energy remains at 90 degrees off boresight in either case, however.

Plots of the fields are shown in figures 114 to 140. Power densities versus time are shown in figures 141 to 167, and power density versus angle in figure 168.

VI. Addition of Absorber

The next case was the addition of a 2 inch thick layer of lossy material to the inside and end of the can. The relative dielectric constant and the conductivity were adjusted so the material was one skin depth thick at 1 GHz. The values obtained for the relative dielectric constant and the conductivity, ($\epsilon_r = 1.5$, $\sigma = 0.03$ s/m), are very near those of some commercially available products.

A cut through the finite difference mesh is shown in figure 169. On boresight, only small changes in the late time waveform are observed. There is some small reduction in the amplitude late in the response. Also, a very small reduction is noted in the first positive peak and in the following peaks. The initial negative-going peak remained unchanged.

As the angle is changed from boresight, similar behavior is observed in both the vertical and horizontal planes. The late time response is reduced slightly, but no major changes are seen.

Time histories with the addition of the absorber are shown in figures 170 to 196. Power densities versus time are plotted in figures 197 to 223, and power density versus angle in figure 224.

VIII. Addition of Resistors

For this configuration resistive material was added to connect the end of the antenna to the surrounding cylinder. Small blocks of material were placed at intervals around the antenna to represent individual resistors. They were assigned a conductivity of 0.85 S/m such that the parallel configuration looked like 50 ohms.

Compared to the previous case, very little change is noticed. The latter part of the initial pulse is diminished minimally, as is some of the

late time behavior. The biggest difference appears to be at about 6 ns. after the main pulse. This is considered to be the reflection from the end of the can, and the amplitude reduction seems to be the greatest for this part of the record.

Comparison of the power density plots with those of the previous case shows that the peak power density is slightly reduced by the addition of the resistors. Plots of the field values are given in figures 225 through 251, power densities versus time in figures 252 to 278, and peak power density versus angle in figure 279.

IX. Addition of Flat Plate

At this point, a flat plate was added just above the cylinder. The plate was longer than the cylinder, with a 250 mm overhang at the front. It was also slightly wider than the diameter of the cylinder. Memory considerations limited the width of the plate. Since vertical symmetry was broken, fully one-half of the antenna needed to be modeled, greatly increasing memory requirements. The horizontal PEC symmetry plane was eliminated, leaving only the vertical PMC symmetry plane. Views of the model with the plate are shown in figures 280 and 281.

With the plate installed, a very slight reduction in peak-to-peak amplitude is observed in the main pulse, as seen in figure 282. There is an increase in the amplitude of the ring-down portion, roughly the first nanosecond after the main pulse. The remainder of the time record remains basically unchanged. Diffraction from the front edge of the plate could account for the interference effects noted as changes in the first few nanoseconds.

Similar effects are noted in the time histories off boresight. The main pulse is very slightly diminished, and increased amplitude is seen in the early ring-down, in both the vertical and horizontal planes. The E-field time histories off boresight are plotted in figures 283 through 308. Power densities are shown in figures 309 to 335. The changes due to the plate are slightly easier to observe in the power density plots. A plot of peak power density versus angle is shown in figure 336.

X. Addition of Ferrite Ring

In final configuration we added a ferrite ring to the inside of the cylinder just ahead of the antenna. A dispersive magnetic material algorithm was added to TSAR to model the ferrite. The algorithm

used was the dual of the dispersive electric material model, which was based on the work of Kallman and Hawkins¹. A two-pole model was used, with values from a ferrite simulation given in DeFord, et al².

The addition of ferrite lowers the propagation velocity of electromagnetic waves. This greatly reduces the wavelength in the ferrite, thus requiring much smaller cells to meet the standard 10 cell per wavelength criteria. For an object the size of this antenna and the surrounding structures, this is simply not possible given current computer and memory considerations. Since the ferrite ring presented a relatively small cross-section to the outgoing wave, and since the volume of ferrite is small compared to the problem space, the problem was run using the 5 mm cell size as used in previous simulations. Earlier simulations of simple ferrite blocks indicated that too large a cell size would lead to increased reflections from the surface of the ferrite, but for this model there seemed to be no other option. The code remained stable and produced reasonable results, but they are not precisely the results one would expect from a real ferrite. However, the exact choice of parameters would also affect the results from the code, so for comparison purposes, the current model, even with its limitations, was used.

The code run with the ferrite resulted again in a slight reduction of the initial peaks on boresight, about 5% for the negative-going peak and 10% for the positive, as compared to the previous case. A significant reduction, on the order of 50%, is noted in the early ring-down immediately following the main pulses, after which little change is noted for about 1 ns. There is a definite reduction in the late time ringing observed, with the exception of the section at about 11 ns, which has been identified as a reflection from the end of the can. The overall behavior in the late time is improved by the addition of the ferrite.

As the test position is moved off boresight, the reduction in the initial positive and negative pulses is less. The reduction in late time ringing, particularly of the higher frequency components, is observable. This behavior continues in both the horizontal and vertical planes, with the most notable differences in the late time ringing and less difference in the main part of the pulse.

¹Linear Electronic Dispersion and Finite-Difference Time-Domain Calculations: a Simple Approach, R.J. Hawkins and J.S. Kallman, to be published in the IEEE Journal of Lightwave Technology.

²Dispersive Soft Ferrite Models for Time-Domain Simulation and Their Application to Accelerator Component Modeling, J.F. DeFord, G. Kamin, G.D. Craig and L. Walling, accepted for publication in Particle Accelerators.

The power density plots seem to bear this out. Definite reductions are seen in the main peak, within 5 degrees of boresight. Beyond about 5 degrees, reductions in the peak still occur, but they are much less pronounced. The plot of peak power density versus angle, figure 392, is very similar to the previous case with the plate, just slightly reduced in amplitude.

Plots of the E-field versus time are shown in figures 338 to 364, and power density plots versus time are in figures 365 to 391.

Conclusions

The addition of the dielectric lens to the simple antenna model produced the most significant change to the far fields. Any further addition to the model complexity resulted in reduced field levels on boresight. These reductions were cumulative, until the model with canister, absorber, resistors, plate and ferrite produced fields on boresight about 22% lower than with the lens alone.

Except for the lens addition, none of the changes resulted in increased amplitude off boresight. The addition of asymmetry in the form of the plate also did not result in increased side lobe behavior. The coupling between the vertically polarized wave and the horizontally oriented plate was not strong enough to divert the main portion of the beam nor to produce any side lobe increase.

The addition of the can had a significant effect on the late time behavior, producing ringing, as would be expected. Since the can extended beyond the antenna proper and the lens, interference between the direct wave and the diffracted wave from the end of the can reduced the amplitude of the main pulse. The exact distance that the can extends beyond the antenna, as well as the can's diameter, might be adjusted to optimize the amplitude of the main pulse. These values should be considered as part of the overall antenna system design.

The late time ringing was reduced by the addition of absorbing material, as well as by the ferrite ring. Since a linear, non-dispersive model was used for the absorber, reflections from a real absorber may not be as large. Also, the thickness of the absorber and its exact placement should be studied when designing the antenna system. The presence of a large reflection from the back end of the can indicates that more absorber may be necessary there. It might be possible to reduce the amount of absorber on the sides without increasing the amplitude of the ringing significantly. Since the fields,

even in the late time, are mainly on or near boresight, perhaps the absorber could be eliminated entirely, reducing concern for overheating when high power is encountered.

Adding resistors to the front of the cone did not seem to accomplish much in the simulations. However, since a hard drive was used to excite the problem, (E-field nodes were assigned values), one would not see the change in input impedance that might result in a real system. Unless a very good model is developed for the feed region of an antenna, the question of whether or not to include resistors might be best answered experimentally.

The addition of a plate over the antenna and can also did not produce large variation in the far-fields. While computer memory restrictions did not allow a truly large structure to be put in place, still there was enough material present in front and to the side of the antenna to have had some effect, particularly at higher frequencies. It appears that the vertically-polarized wave launched does not couple strongly to the plate as modeled. The reduction in amplitude of the main pulse does suggest that destructive interference occurs between the direct pulse and the diffracted wave from the plate. This suggests another design option, the distance the antenna is mounted behind the front edge of the plate. There may be an optimum location for the antenna/can/plate combination, with the reduction in amplitude on boresight minimized for the proper geometry. Changing the layout and re-running the simulation would tell whether or not the amplitude would be significantly effected.

The ferrite ring seemed to be most useful in damping late-time reflections. If better absorber were used in the can, or if late-time reflections were deemed insignificant, the need for the ferrite would be reduced. Since no apparent gain was made by the addition of the ferrite, it might be best left out in the interest of weight saving. The model used for the ferrite, and the inability to use enough cells, suggests that some further studies or experiments be performed prior to a decision as to whether the ferrite should be included.

Overall, this antenna system seems to be a good, robust choice for directing energy predominantly in the forward direction. The beamwidth is relatively narrow, accomplished with a simply shaped dielectric lens, and is not strongly influenced by the presence of other materials around the antenna. Side lobe levels are low in both horizontal and vertical planes. If only a main pulse is desired, absorbing material can diminish late time ringing, but this is not necessary to contain the energy in the main beam. In the computer model, the cross-polarized component was greater than 100 dB down

from the main peak, indicating cross-polarization effects are not a concern. The general conclusion is that this antenna system would be a good one for keeping the energy where it is desired.

*Work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Figure 1. Cut along centerline of complete FDTD model.

Figure 2. Cut through simple one-quarter antenna model, (with image).

Figure 3. E-field of simple antenna on boresight.

Figure 4. E-field of simple antenna 0.4 degrees vertically off boresight.

Figure 6. E-field of simple antenna 5.2 degrees vertically off boresight.

Figure 7. E-field of simple antenna 7.7 degrees vertically off boresight.

Figure 8. E-field of simple antenna 10 degrees vertically off boresight.

Figure 9. E-field of simple antenna 20 degrees vertically off boresight.

Figure 10. E-field of simple antenna 30 degrees vertically off boresight.

Figure 11. E-field of simple antenna 40 degrees vertically off boresight

Figure 12. E-field of simple antenna 50 degrees vertically off boresight.

Figure 15. E-field of simple antenna 80 degrees vertically off boresight.

Figure 16. E-field of simple antenna 90 degrees vertically off boresight.

Figure 17. E-field of simple antenna 2.3 degrees horizontally off boresight.

Figure 18. E-field of simple antenna 4.7 degrees horizontally off boresight.

Figure 19. E-field of simple antenna 7 degrees horizontally off boresight.

Figure 20. E-field of simple antenna 9.4 degrees horizontally off boresight.

Figure 21. E-field of simple antenna 10 degrees horizontally off boresight.

Figure 22. E-field of simple antenna 20 degrees horizontally off boresight.

Figure 23. E-field of simple antenna 30 degrees horizontally off boresight.

Figure 24. E-field of simple antenna 40 degrees horizontally off boresight.

Figure 25 E-field of simple antenna 50 degrees horizontally off boresight.

Figure 26. E-field of simple antenna 60 degrees horizontally off boresight.

Figure 27. E-field of simple antenna 70 degrees horizontally off boresight.

Figure 28. E-field of simple antenna 80 degrees horizontally off boresight.

Figure 29. E-field of simple antenna 90 degrees horizontally off boresight.

Figure 30. Power density of simple antenna on boresight.

Figure 31. Power density of simple antenna 0.4 degrees vertically off boresight.

Figure 32. Power density of simple antenna 3 degrees vertically off boresight.

Figure 33. Power density of simple antenna 5.2 degrees vertically off boresight.

Figure 34. Power density of simple antenna 7.7 degrees vertically off boresight.

Figure 35. Power density of simple antenna 10 degrees vertically off boresight.

Figure 36. Power density of simple antenna 20 degrees vertically off boresight.

Figure 37. Power density of simple antenna 30 degrees vertically off boresight.

Figure 38. Power density of simple antenna 40 degrees vertically off boresight.

Figure 39. Power density of simple antenna 50 degrees vertically off boresight.

Figure 40. Power density of simple antenna 60 degrees vertically off boresight.

Figure 41. Power density of simple antenna 70 degrees vertically off boresight.

Figure 42. Power density of simple antenna 80 degrees vertically off boresight.

Figure 43. Power density of simple antenna 90 degrees vertically off boresight.

Figure 44. Power density of simple antenna 2.3 degrees horizontally off boresight.

Figure 45. Power density of simple antenna 2.3 degrees horizontally off boresight.

Figure 46. Power density of simple antenna 7 degrees horizontally off boresight.

Figure 47. Power density of simple antenna 9.4 degrees horizontally off boresight.

Figure 48. Power density of simple antenna 10 degrees horizontally off boresight.

Figure 49. Power density of simple antenna 20 degrees horizontally off boresight.

Figure 50. Power density of simple antenna 30 degrees horizontally off boresight.

Figure 51. Power density of simple antenna 40 degrees horizontally off boresight.

Figure 52. Power density of simple antenna 50 degrees horizontally off boresight.

Figure 53. Power density of simple antenna 60 degrees horizontally off boresight.

Figure 54. Power density of simple antenna 70 degrees horizontally off boresight.

Figure 55. Power density of simple antenna 80 degrees horizontally off boresight.

Figure 56. Power density of simple antenna 90 degrees horizontally off boresight.

NO_LENS: Peak power density relative
to the lens case (dB)

Theta

Phi

Figure 57. Power density of simple antenna versus angle.

Figure 58. Cut through FDTD mesh with lens.

Figure 59. E-field with lens on boresight

Figure 60. E-field with lens 0.4 degrees vertically off boresight

Figure 61. E-field with lens 1 degree vertically off boresight

Figure 62. E-field with lens 5.2 degrees vertically off boresight

Figure 63 E-field with lens 7 degrees vertically off boresight

Figure 64 E-field with lens 10 degrees vertically off boresight

Figure 65 E-field with lens 20 degrees vertically off boresight

Figure 66 E-field with lens 30 degrees vertically off boresight

Figure 67 E-field with lens 40 degrees vertically off boresight

Figure 68 E-field with lens 50 degrees vertically off boresight

Figure 69 E-field with lens 60 degrees vertically off boresight

Figure 70 E field with lens 70 degrees vertically off boresight

Figure 71 E-field with lens 80 degrees vertically off borelight

Figure 72 E-field with lens 90 degrees vertically off borelight

Figure 75 E-field with lens 7 degrees horizontally off boresight

Figure 76 E-field with lens 9.4 degrees horizontally off boresight

Figure 77 E-field with lens 10 degrees horizontally off boresight

Figure 78 E-field with lens 20 degrees horizontally off boresight

Figure 79. E-field with lens 30 degrees horizontally off boresight

Figure 80. E-field with lens 40 degrees horizontally off boresight

Figure 81. E-field with lens 50 degrees horizontally off boresight

Figure 82. E-field with lens 60 degrees horizontally off boresight

Figure 83. E-field with lens 70 degrees horizontally off boresight

Figure 84. E-field with lens 80 degrees horizontally off boresight

Figure 86. Power density with lens on boresight

Figure 87. Power density with lens 0.4 degrees vertically off boresight

Figure 88. Power density with lens 3 degrees vertically off boresight

Figure 90. Power density with lens 7.7 degrees vertically off boresight

Figure 91. Power density with lens 10 degrees vertically off boresight

Figure 92. Power density with lens 20 degrees vertically off boresight

Figure 93. Power density with lens 30 degrees vertically off boresight

Figure 94. Power density with lens 40 degrees vertically off boresight

Figure 95. Power density with lens 50 degrees vertically off boresight

Figure 96. Power density with lens 60 degrees vertically off boresight

70 degrees vertically off boresight

Figure 98. Power density with lens 80 degrees vertically off boresight

Figure 99 Power density with lens 90 degrees vertically off boresight

Figure 100. Power density with lens 2 3 degrees horizontally off boresight.

Figure 101 Power density with lens 2 3 degrees horizontally off boresight

Figure 102 Power density with lens 7 degrees horizontally off boresight

Figure 103. Power density with lens 9 4 degrees horizontally off boresight.

Figure 104. Power density with lens 10 degrees horizontally off boresight.

Figure 105. Power density with lens 20 degrees horizontally off boresight.

Figure 106. Power density with lens 30 degrees horizontally off boresight.

Figure 107. Power density with lens 40 degrees horizontally off boresight

Figure 108. Power density with lens 50 degrees horizontally off boresight

Figure 109. Power density with lens 60 degrees horizontally off boresight

Figure 110. Power density with lens 70 degrees horizontally off boresight

Figure 111 Power density with lens 80 degrees horizontally off boresight

Figure 112 Power density with lens 90 degrees horizontally off boresight

LENS: Peak power density relative to the lens case (dB)

Theta

Phi

Figure 112b Power density with lens versus angle.

Figure 113. Cut through FDTD mesh with canister.

Figure 114. E-field with can on boresight.

Figure 115. E-field with can 0.4 degrees vertically off boresight.

Figure 116. E-field with can 3 degrees vertically off boresight.

Figure 117. E-field with can 5.2 degrees vertically off boresight.

Figure 118 E-field with can 7.7 degrees vertically off bore sight

Figure 119 E-field with can 10 degrees vertically off bore sight

Figure 120 E-field with can 20 degrees vertically off bore sight

Figure 121 E-field with can 30 degrees vertically off bore sight

Figure 122 E-field with can 40 degrees vertically off boresight

Figure 123 E-field with can 50 degrees vertically off boresight

Figure 124 E-field with can 60 degrees vertically off boresight

Figure 125 E-field with can 70 degrees vertically off boresight

Figure 126 E-field with can 90 degrees vertically off bore sight

Figure 127 E-field with can 90 degrees vertically off bore sight

Figure 128 E-field with can 47 degrees horizontally off bore sight

Figure 129 E-field with can 47 degrees horizontally off bore sight

Figure 130. E-field with can 7 degrees horizontally off boresight

Figure 131. E-field with can 9 4 degrees horizontally off boresight

Figure 132. E-field with can 10 degrees horizontally off boresight

Figure 133. E-field with can 20 degrees horizontally off boresight

Figure 134. E-field with can 30 degrees horizontally off boresight

Figure 135. E-field with can 40 degrees horizontally off boresight

Figure 137. E-field with can 60 degrees horizontally off boresight

Figure 138. E-field with can 70 degrees horizontally off boresight.

Figure 139. E-field with can 80 degrees horizontally off boresight.

Figure 140 E-field with can 90 degrees horizontally off boresight

Figure 141. Power density with can on boresight

Figure 142. Power density with can 0.4 degrees vertically off boresight.

Figure 143. Power density with can 3 degrees vertically off boresight.

Figure 146. Power density with can 10 degrees vertically off boresight.

Figure 147. Power density with can 20 degrees vertically off boresight.

Figure 148. Power density with can 30 degrees vertically off boresight.

Figure 149. Power density with can 40 degrees vertically off boresight.

Figure 150. Power density with can 50 degrees vertically off boresight.

Figure 151. Power density with can 60 degrees vertically off boresight.

Figure 152. Power density with can 70 degrees vertically off boresight.

Figure 153. Power density with can 80 degrees vertically off boresight.

Figure 154. Power density with can 90 degrees vertically off boresight.

Figure 155. Power density with can 2.3 degrees horizontally off boresight

Figure 158. Power density with can 9.4 degrees horizontally off boresight

Figure 159. Power density with can 10 degrees horizontally off boresight

Figure 161. Power density with can 10 degrees horizontally off boresight

Figure 162. Power density with can 40 degrees horizontally off boresight.

Figure 163. Power density with can 50 degrees horizontally off boresight.

Figure 165. Power density with can 70 degrees horizontally off boresight.

Figure 167. Power density with can 90 degrees horizontally off bore sight

Figure 166. Power density with can 80 degrees horizontally off bore sight

NO_ABS: Peak power density relative to the lens case (dB)

Theta

Phi

Figure 168. Power density with can versus angle.

Figure 169. Cut through FDTD mesh with absorber.

Figure 170. E-field with absorber on bore-sight

Figure 171. E-field with absorber 0.4 degrees vertically off bore-sight

Figure 173. E-field with absorber 5.2 degrees vertically off bore-sight

Figure 174. E-field with absorber 7.7 degrees vertically off bore sight

Figure 175. E-field with absorber 10 degrees vertically off bore sight

Figure 178. E-field with absorber 40 degrees vertically off bore sight

DS 011 For field Elveta at R = 5.00E+00, Theta = 3.00E+01 Phi = 1.00E+02

Figure 179. E-field with absorber 50 degrees vertically off bore sight

Figure 181. E-field with absorber 70 degrees vertically off bore sight

Figure 102. E-field with absorber 80 degrees vertically off bore sight

Figure 105. E-field with absorber 67 degrees horizontally off bore sight

Figure 103. E-field with absorber 90 degrees vertically off bore sight

Figure 186. E-field with absorber 7 degrees horizontally off boresight.

Figure 187. E-field with absorber 9.4 degrees horizontally off boresight.

Figure 188. E-field with absorber 10 degrees horizontally off boresight.

Figure 190. E-field with absorber 30 degrees horizontally off boresight

Figure 191. E-field with absorber 40 degrees horizontally off boresight

Figure 192. E-field with absorber 60 degrees horizontally off boresight

Figure 194. E-field with absorber 70 degrees horizontally off boresight.

Figure 195. E-field with absorber 80 degrees horizontally off boresight.

Figure 196. E-field with absorber 90 degrees horizontally off boresight.

Figure 197. Power density with absorber on boresight.

Figure 198. Power density with absorber 0.4 degrees vertically off boresight.

Figure 199. Power density with absorber 3 degrees vertically off boresight.

Figure 200. Power density with absorber 5.2 degrees vertically off boresight.

Figure 201. Power density with absorber 7.7 degrees vertically off boresight.

Figure 202. Power density with absorber 10 degrees vertically off boresight.

Figure 203. Power density with absorber 20 degrees vertically off boresight.

Figure 206. Power density with absorber 50 degrees vertically off boresight.

Figure 207. Power density with absorber 60 degrees vertically off boresight.

Figure 208. Power density with absorber 70 degrees vertically off boresight.

Figure 209. Power density with absorber 80 degrees vertically off boresight.

Figure 210. Power density with absorber 90 degrees vertically off boresight.

Figure 211. Power density with absorber 2.3 degrees horizontally off boresight

Figure 212. Power density with absorber 4.7 degrees horizontally off boresight.

Figure 213. Power density with absorber 7 degrees horizontally off boresight.

Figure 214. Power density with absorber 9.4 degrees horizontally off boresight.

Figure 215. Power density with absorber 10 degrees horizontally off boresight.

Figure 217. Power density with absorber 30 degrees horizontally off boresight.

Figure 218. Power density with absorber 40 degrees horizontally off bore sight.

Figure 219. Power density with absorber 50 degrees horizontally off bore sight.

Figure 221. Power density with absorber 70 degrees horizontally off bore sight.

Figure 223. Power density with absorber 90 degrees horizontally off bore sight.

Figure 222. Power density with absorber 80 degrees horizontally off bore sight.

ABS: Peak power density relative to the lens case (dB)

Theta

Phi

Figure 224. Power density with absorber versus angle.

Figure 225. E-field with resistors on boresight.

Figure 226. E-field with resistors 0.4 degrees vertically off boresight.

Figure 227. E-field with resistors 1 degrees vertically off boresight.

Figure 228. E-field with resistors 5.2 degrees vertically off boresight.

Figure 229. E-field with resistors 7.7 degrees vertically off boresight.

Figure 230. E-field with resistors 10 degrees vertically off boresight.

Figure 231. E-field with resistors 13.3 degrees vertically off boresight.

Figure 232. E-field with resistors 16.7 degrees vertically off boresight.

Figure 233. E-field with resistors 60 degrees vertically off borelight

Figure 235. E-field with resistors 60 degrees vertically off borelight

Figure 234. E-field with resistors 30 degrees vertically off borelight

Figure 236. E-field with resistors 30 degrees vertically off borelight

Figure 237. E-field with resistors 80 degrees vertically off borelight.

Figure 238. E-field with resistors 90 degrees vertically off borelight.

Figure 240. E-field with resistors 4.7 degrees horizontally off borelight.

Figure 241. E-field with resistors 7 degrees horizontally off boresight.

Figure 242. E-field with resistors 9.4 degrees horizontally off boresight.

Figure 243. E-field with resistors 20 degrees horizontally off boresight.

Figure 245. E-field with resistors 30 degrees horizontally off boresight.

Figure 246. E-field with resistors 40 degrees horizontally off boresight.

Figure 248. E-field with resistors 60 degrees horizontally off boresight.

Figure 249. E-field with resistors 70 degrees horizontally off boresight.

Figure 250. E-field with resistors 80 degrees horizontally off boresight.

Figure 252. Power density with resistors on boresight.

Figure 253. Power density with resistors 0.4 degrees vertically off boresight.

Figure 254. Power density with resistors 3 degrees vertically off boresight.

Figure 255. Power density with resistors 4.0 degrees vertically off boresight.

Figure 256. Power density with resistors 7.7 degrees vertically off boresight.

Figure 257. Power density with resistors 10 degrees vertically off boresight.

Figure 258. Power density with resistors 20 degrees vertically off boresight.

Figure 259 Power density with resistors 30 degrees vertically off boresight

Figure 260 Power density with resistors 40 degrees vertically off boresight

Figure 261. Power density with resistors 50 degrees vertically off boresight

Figure 262. Power density with resistors 60 degrees vertically off boresight

Figure 263. Power density with resistors 70 degrees vertically off boresight

Figure 264. Power density with resistors 80 degrees vertically off boresight

Figure 265. Power density with resistors 90 degrees vertically off boresight.

Figure 266. Power density with resistors 2.3 degrees horizontally off boresight.

Figure 267. Power density with resistors 4.7 degrees horizontally off boresight.

Figure 268. Power density with resistors 7 degrees horizontally off boresight.

Figure 269. Power density with resistors 9.4 degrees horizontally off boresight.

Figure 270. Power density with resistors 10 degrees horizontally off boresight.

Figure 271. Power density with resistors 20 degrees horizontally off boresight.

Figure 272. Power density with resistors 30 degrees horizontally off boresight.

Figure 273. Power density with resistors 40 degrees horizontally off boresight

Figure 274. Power density with resistors 50 degrees horizontally off boresight

Figure 275. Power density with resistors 60 degrees horizontally off boresight

Figure 276. Power density with resistors 70 degrees horizontally off boresight

Figure 277. Power density with resistors 80 degrees horizontally off boresight.

Figure 278. Power density with resistors 90 degrees horizontally off boresight.

ABS_RES: Peak power density relative
to the lens case (dB)

Theta

Phi

Figure 279. Power density with resistors versys angle.

Figure 280. Cross-section of FDTD mesh with plate.

Figure 281. Front view of FDTD mesh with plate.

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Figure 282. E-field with plate on boresight.

Figure 283. E-field with plate 0.4 degrees vertically off boresight.

Figure 285. E-field with plate 5.2 degrees vertically off boresight.

Figure 286. E-field with plate 7.7 degrees vertically off boresight

Figure 287. E-field with plate 10 degrees vertically off boresight

Figure 288. E-field with plate 20 degrees vertically off boresight

Figure 289. E-field with plate 30 degrees vertically off boresight

Figure 290. E-field with plate 40 degrees vertically off boresight.

Figure 291. E-field with plate 50 degrees vertically off boresight.

Figure 293. E-field with plate 70 degrees vertically off boresight.

Figure 294. E-field with plate 80 degrees vertically off boresight

Figure 295. E-field with plate 90 degrees vertically off boresight

Figure 296. E-field with plate 2.3 degrees horizontally off boresight

Figure 297. E-field with plate 4.7 degrees horizontally off boresight

Figure 298. E-field with plate 7 degrees horizontally off boresight

Figure 299. E-field with plate 9.4 degrees horizontally off boresight

Figure 300. E-field with plate 10 degrees horizontally off boresight

Figure 301. E-field with plate 20 degrees horizontally off boresight

Figure 302. E-field with plate 30 degrees horizontally off boresight.

Figure 303. E-field with plate 40 degrees horizontally off boresight.

Figure 304. E-field with plate 40 degrees horizontally off boresight.

Figure 306. E-field with plate 70 degrees horizontally off boresight.

Figure 307. E-field with plate 80 degrees horizontally off boresight.

Figure 308. E-field with plate 90 degrees horizontally off boresight.

Figure 309. Power density with plate on boresight.

Figure 310. Power density with plate 0.4 degrees vertically off boresight.

Figure 311. Power density with plate 3 degrees vertically off boresight.

Figure 312. Power density with plate 5.2 degrees vertically off boresight.

Figure 313. Power density with plate 7.7 degrees vertically off boresight.

Figure 314. Power density with plate 10 degrees vertically off boresight

Figure 315. Power density with plate 20 degrees vertically off boresight

Figure 317. Power density with plate 40 degrees vertically off boresight

Figure 318. Power density with plate 50 degrees vertically off boresight

Figure 319. Power density with plate 60 degrees vertically off boresight.

Figure 321. Power density with plate 80 degrees vertically off boresight

Figure 322: Power density with plate 90 degrees vertically off boresight

Figure 323: Power density with plate 2.3 degrees horizontally off boresight

Figure 325: Power density with plate 2.4 degrees horizontally off boresight

Figure 326. Power density with plate 9.4 degrees horizontally off boresight.

Figure 327. Power density with plate 10 degrees horizontally off boresight.

Figure 329. Power density with plate 30 degrees horizontally off boresight.

Figure 330. Power density with plate 40 degrees horizontally off boresight.

Figure 331. Power density with plate 50 degrees horizontally off boresight.

Figure 334. Power density with plate 80 degrees horizontally off boresight

Figure 335. Power density with plate 90 degrees horizontally off boresight.

PLATE: Peak power density relative to the lens case (dB)

Figure 336. Power density with plate versus angle.

Figure 337. Cross-section through FDTD mesh with ferrite.

Figure 338. E-field with ferrite on boresight.

Figure 339. E-field with ferrite 0.4 degrees vertically off boresight.

Figure 340. E-field with ferrite 0.7 degrees vertically off boresight.

Figure 341. E-field with ferrite 1.2 degrees vertically off boresight.

Figure 342 E-field with ferrite 7.7 degrees vertically off boresight

Figure 343 E-field with ferrite 10 degrees vertically off boresight

Figure 344 E-field with ferrite 20 degrees vertically off boresight

Figure 345 E-field with ferrite 30 degrees vertically off boresight

Figure 346. E-field with ferrite 40 degrees vertically off boresight

Figure 347. E-field with ferrite 50 degrees vertically off boresight.

Figure 348. E-field with ferrite 60 degrees vertically off boresight

Figure 349. E-field with ferrite 70 degrees vertically off boresight

Figure 350. E-field with ferrite 80 degrees vertically off boresight

Figure 351. E-field with ferrite 90 degrees vertically off boresight

Figure 352. E-field with ferrite 2.3 degrees horizontally off boresight

Figure 353. E-field with ferrite 4.7 degrees horizontally off boresight

Figure 354. E-field with ferrite 7 degrees horizontally off boresight

Figure 355. E-field with ferrite 9.4 degrees horizontally off boresight.

Figure 356. E-field with ferrite 10 degrees horizontally off boresight.

Figure 357. E-field with ferrite 20 degrees horizontally off boresight.

Figure 358. E-field with ferrite 30 degrees horizontally off boresight

Figure 359. E-field with ferrite 40 degrees horizontally off boresight

Figure 360. E-field with ferrite 50 degrees horizontally off boresight

Figure 361. E-field with ferrite 60 degrees horizontally off boresight

Figure 362. E-field with ferrite 70 degrees horizontally off boresight.

Figure 363. E-field with ferrite 80 degrees horizontally off boresight.

Figure 364. E-field with ferrite 90 degrees horizontally off boresight.

Figure 365. Power density with ferrite on boresight.

Figure 366. Power density with ferrite 0.4 degrees vertically off boresight

Figure 367. Power density with ferrite 3 degrees vertically off boresight.

Figure 368. Power density with ferrite 7.7 degrees vertically off boresight

Figure 370. Power density with ferrite 10 degrees vertically off boresight

Figure 371. Power density with ferrite 20 degrees vertically off boresight

Figure 373. Power density with ferrite 40 degrees vertically off boresight

Figure 374. Power density with ferrite 50 degrees vertically off bore sight.

Figure 375. Power density with ferrite 60 degrees vertically off bore sight.

Figure 376. Power density with ferrite 70 degrees vertically off bore sight.

Figure 378. Power density with ferrite 90 degrees vertically off boresight.

Figure 379. Power density with ferrite 2.3 degrees horizontally off boresight.

Figure 380. Power density with ferrite 4.7 degrees horizontally off boresight.

Figure 381. Power density with ferrite 7 degrees horizontally off boresight.

Figure 382. Power density with ferrite 9.4 degrees horizontally off boresight.

Figure 383. Power density with ferrite 10 degrees horizontally off boresight.

Figure 384. Power density with ferrite 20 degrees horizontally off boresight.

Figure 385. Power density with ferrite 30 degrees horizontally off boresight.

Figure 386. Power density with ferrite 40 degrees horizontally off boresight

Figure 387. Power density with ferrite 50 degrees horizontally off boresight

Figure 389. Power density with ferrite 70 degrees horizontally off boresight

Figure 390. Power density with ferrite 80 degrees horizontally off boresight

Figure 391. Power density with ferrite 90 degrees horizontally off boresight

FERRITE: Peak power density relative to the lens case (dB)

Theta

Phi

Figure 392. Power density with ferrite versus angle.

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