Moment Method Surface Patch and Wire Grid Accuracy in the Computation of Near Fields

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***Abstract*—The accuracy of surface patch and wire grid moment method models for the computation of near fields is investigated. A sphere and a flat plate with plane wave illumination are examined.**

It is found that wire grids exhibit stronger near field anomalies than surface patches, which have the current more distributed over the surface. Nevertheless, good results can be obtained with a wire grid, provided that a small distance from the wire grid surface is maintained.

The surface patch results are obtained using the *Junction* code. Wire grid results are obtained with both the *MBC* and *NEC* codes. Validation for the sphere is by comparison with an exact solution, and validation for the plate is by comparison with a high frequency UTD solution obtained from the *NECBSC* code.

1 Introduction

The near field close to the surface of a complex shape is of great interest in antennas and electromagnetic compatibility. For example, the radiation characteristics of an aircraft antenna are distorted by the fuselage on which the antennas are mounted. Another example is in the assessment of electromagnetic hazards to personnel and equipment on the deck of a ship, in the presence of strong RF and microwave sources.

The method of moments is a suitable methodology for the calculation of fields scattered by bodies of resonant size and smaller. Numerous codes exist, and assessment of their accuracy for the computation of electromagnetic fields has been a topic of ongoing research for many years. Historically, wire grid models were the first methodology which permitted moment method modeling of scattering by complex shapes. Richmond's *Thin Wire* code [1] was a pioneering effort in this direction. His code was later extended significantly by Tilston and Balmain as the *Multiradius Bridge Current MBC* code [2]. The *Numerical Electromagnetic Code NEC* was developed by Burke et al. [3]. The development of surface patch codes such as *Patch* by Rao et al. [4], *Junction* by Hwu et al. [5], the *Electromagnetic Surface Patch Code ESP*, by Newman [6], and others, have further expanded the applicability of the moment method.

For smooth bodies without sharp edges, surface patches can accurately model the surface current. On the other hand, wire grids can also be useful, as an edge current can be more accurately handled by a wire than a patch. A patch cannot represent the current at the patch edge, so a separate "edge mode" is required. Inclusion of edge modes have been shown to enhance the accuracy [7], though their incorporation into a general purpose code is not straightforward. Another reason for using wires is that if open bodies are modeled with NEC, we must use a wire grid model, as its MFIE based patch model is only appropriate for closed bodies.

Although much work has been done on the validation of wire grids and patches for far field calculations, investigations into the near field are relatively scarce. Ludwig [8] examined a 2-D TM polarized wire grid model of a cylinder and found that though the tangential field is not accurate between the wires, the far field is accurate, provided that the "same surface rule" is met, i.e. that the total surface area of the wires equals the surface area of the true surface being modeled. Later, Paknys [9] extended Ludwig's work and demonstrated that the same surface rule is also optimum for the near field of a 2-D TM cylinder. Other work has examined the use of surface patches in near field computations. Yang et al. [10] examined a 2-D cylinder and demonstrated the equivalence of pulse basis patch currents and filamentary wire currents, provided that the same surface rule is used. Kashyap and Louie [11] compared the surface currents of plates made of either wire grids or patches, and found that the edge wires have to be made thinner to obtain agreement with a patch model. Burton et al. [12] also used a patch model to study near fields. They constructed a sufficiently detailed model that enabled one to examine the leakage through gaps in a door on a closed box. Kemptner [13] computed the near fields of a metallic cube and an airplane, using a patch formulaton. His results for a cube agreed well with the measured surface current and electric field.

This paper is an investigation into the accuracy of near zone tangential and normal electric fields for 3-D bodies, as computed from surface patch and wire grid models. A square plate and a sphere with plane wave illumination are used as test cases. The accuracy of the patch models are compared to a UTD solution for the plate, and an exact solution for the sphere. For the wire grid models, the same surface rule and the extent of near field anomalies are investigated.

Section 2 examines the near fields of the plate. Section 3 examines the near fields of the sphere. Section 4 compares two different moment method wire codes, MBC and NEC. Section 5 contains the conclusions.

2 Near Field of the Plate

The square plate is 1 × 1 m in size and lies in the $x-y$ plane with the origin at the center of the plate. A wire grid model that has a grid size $g = 0.1$ m is shown in Fig. 1. The wire radius is $a_w = 0.0145$ m, in accordance with the same surface rule. The surface patch model is similar, except that each square area is divided into two triangular patches.

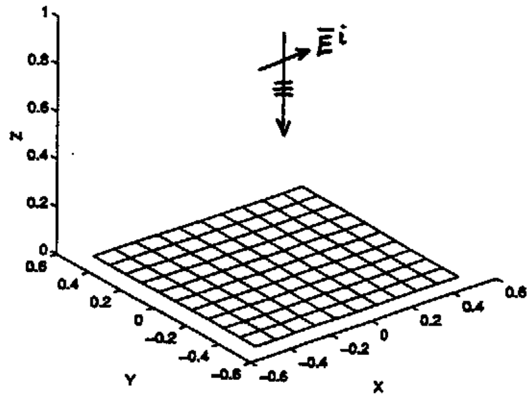


Figure 1: Wire grid model for the 1 × 1 m plate. An $\hat{x}$ polarized plane wave of 1 V/m is normally incident from above. The field point is in the $y = 0$ plane.

The incident field on the plate is a plane wave with an amplitude of 1 V/m, polarized in the $\hat{x}$ direction and traveling in the $-z$ direction, i.e. $\vec{E}^{inc} = \hat{x}e^{jkz}$. The field point is in the $y = 0$ plane. The near field was calculated for several cases, and the total field $\vec{E} = \vec{E}^{inc} + \vec{E}^{scatt}$ was plotted, using a reference level of 0 dB = 1 V/m. Unless otherwise specified, the frequency is 300 MHz so that $g = 0.1\lambda$.

A. Junction and UTD Models for the Plate

The scattering by a plate does not have an exact solution, so results from the UTD based BSC code [14] were compared with the Junction MM patch code, to establish confidence in the patch model. Fig. 2 shows the tangential field E_x and the normal field E_z at $z/g = \pm 0.04$.[1] The agreement is within 1.2 dB for E_x for all values of x along the plate. The agreement is also within 1.2 dB for E_z near the plate, but gets worse beyond the plate edges where $|x| \geq 0.5$. The reason for this is unknown, but it is speculated that further improvements could be obtained by the inclusion of multiple diffraction effects in the UTD

[1] $|E_z|$ is the same on both sides of the plate so $z \leq 0$ is not shown.

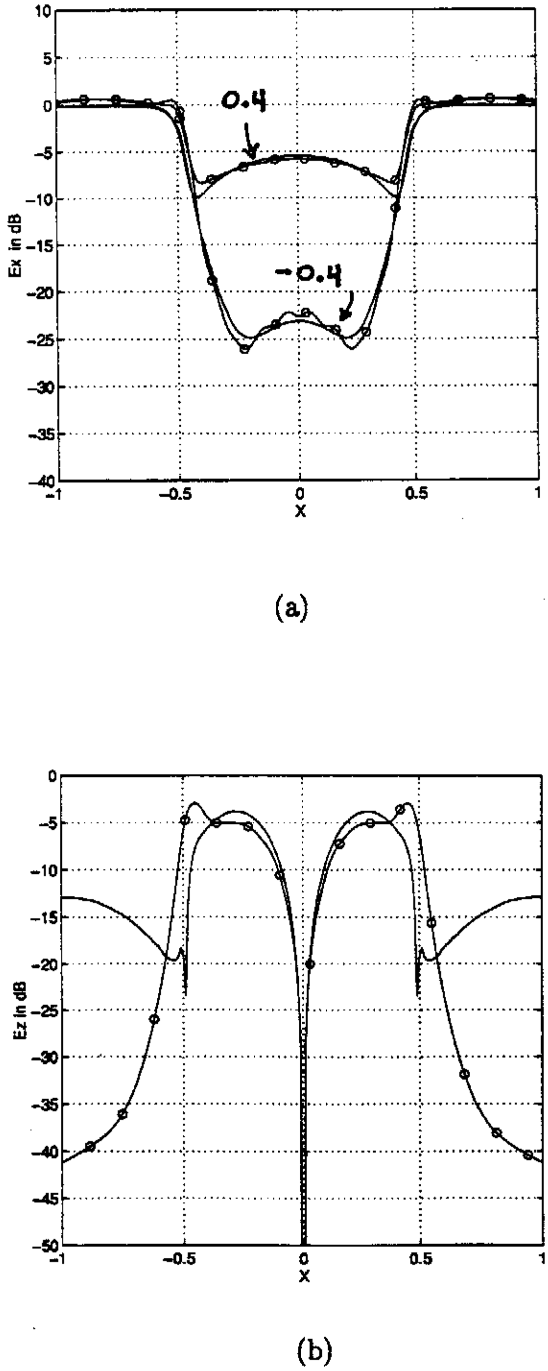


Figure 2: Comparison of UTD (—) and Junction (ooo) for the plate, with patch size $g = 0.1\lambda$. (a) E_x, $z/g = \pm 0.4$ (b) E_z, $z/g = 0.4$. The field point is in the $y = 0$ plane.

model, and possibly reduced patch size in the patch model. We chose Junction for the subsequent plate model validations.

B. Extent of the Near Field Anomalies

The near field of the wire grid plate was calculated with NEC and compared to Junction. A frequency of 300 MHz and $g = 0.1\lambda$ was used. Fig. 3 shows the near field at a distance of $z/g = \pm 0.4$ and $z/g = \pm 0.8$. At $z/g = 0.4$, the anomalies in E_x and E_z are of comparable magnitude. For E_x, the onset of anomalies occurs at about $z/g = 0.4$ on the lit side, and $z/g = -0.8$ on the shadow side. An increased grid size of $g = 0.25$ m at 300 MHz was also tried, and anomalies of comparable magnitude were obtained at $z/g = 0.1$ on the lit side and $z/g = -0.2$ on the shadow side. This suggests that the onset of anomalies for flat plate structures occurs when $z/g \approx 0.4$ on the lit side, and $|z|/g \approx 0.8$ on the shadow side.

The results in Fig. 3 show that for a given observer height, the wire grid results are not as smooth as those obtained in Fig. 2 using Junction. It was found that anomalies of comparable magnitude could also be observed using Junction, but only for field points much closer to the surface.

C. Test of the Same Surface Rule

It is widely accepted that the same surface rule gives the best result for the field radiated by a wire grid model. To test this assertion, NEC was used to compute the near field for several wire radii, and compared to Junction. The frequency was 300 MHz with $g = 0.1\lambda$. The field points were chosen as close as possible to the plate, but not so close that the anomalies might obscure the results.

Figs. 4a, b show the tangential field E_x at $z/g = \pm 0.8$ and Fig. 4c the normal field E_z at $z/g = 0.8$. It is interesting to note that the same surface rule gives the best result for E_x but not for E_z. Hence, it is not possible to choose a wire radius that is simultaneously optimum for both the tangential and normal field components. It is also noted that E_x is more sensitive to the wire radius than E_z.

Fig. 4 also shows that E_x on the shadow side is more sensitive to wire radius changes than on the

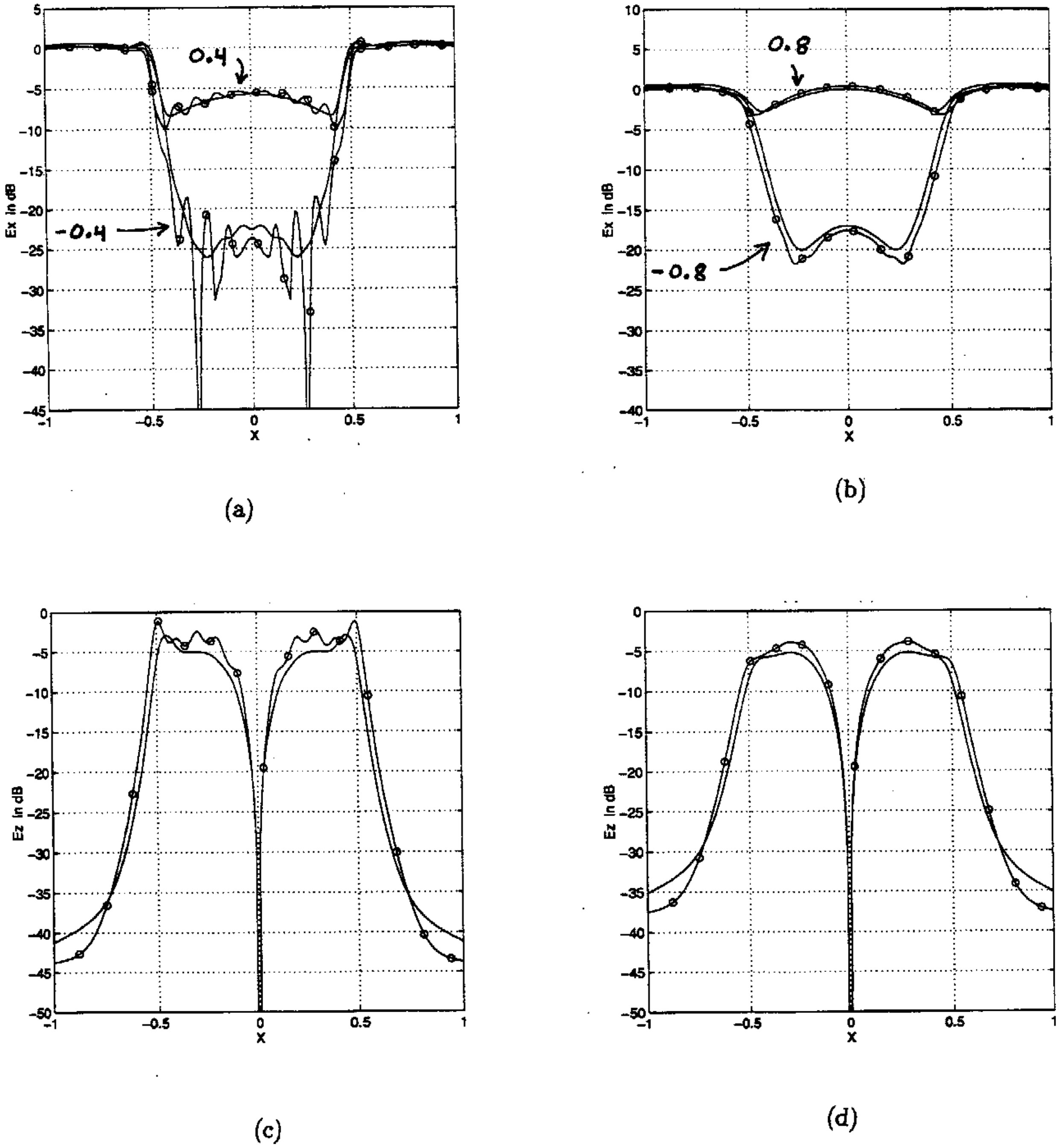
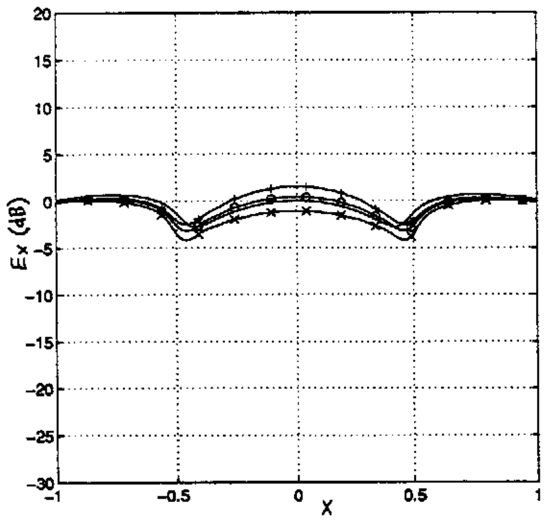


Figure 3: Near field of the plate with grid size $g = 0.1\lambda$. Comparison of NEC wire grid (ooo) and Junction surface patches (—). (a) E_x, $z/g = \pm 0.4$ (b) E_x, $z/g = \pm 0.8$ (c) E_z, $z/g = 0.4$ (d) E_z, $z/g = 0.8$. The field point is in the $y = 0$ plane.



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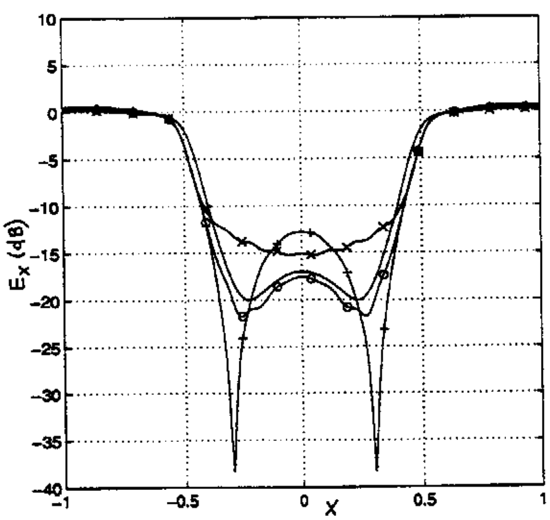

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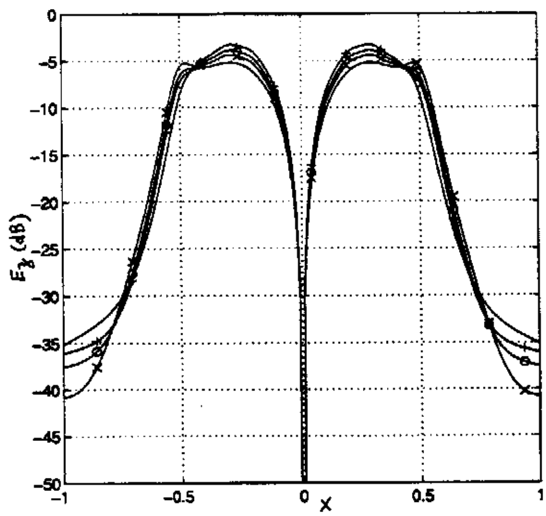


(c)

Figure 4: Effect of wire radius on the near field of the plate, with grid size $g = 0.1\lambda$. The wire radius that satisfies the same surface rule is a_w=0.0145 m. Using NEC, with a_w (ooo), $a_w/2$ (+++), $2a_w$ (xxx). Comparison is with Junction (—). (a) E_x, $z/g = 0.8$ (b) E_x, $z/g = -0.8$ (c) E_z, $z/g = 0.8$. The field point is in the $y = 0$ plane.

lit side. This is probably because the accuracy of E^{scatt} on the shadow side is more critical, as E^{scatt} must cancel E^{inc} in order to accurately predict the low field level on the shadow side of the plate. E^{scatt} was examined separately, and was found to be much less sensitive to wire radius changes than the total field $E^{inc} + E^{scatt}$.

A higher frequency of 750 MHz was also tried. The corresponding grid size in this case is 0.25λ. The results were still good, with typical errors of 2 dB or less. The sensitivity with respect to wire radius was increased for E_x, in the shadow. The sensitivity of E_z remained relatively weak.

D. Field Between the Wires

The previous results were taken along $y = 0$, which happens to be above a wire. To see what happens in other situations, a contour plot in the $x-y$ plane was generated, from which some qualitative observations could be made. Also, to obtain a quantitative comparison, a cut along $y = g/2$, which is in between the wires, was used. The heights used were the same as before, i.e. $z/g = \pm 0.4$ and $z/g = \pm 0.8$.

It was found that very little changed with respect to the peak to peak amplitude of the near field anomalies. The average field level changed only slightly. By comparing the $y = 0$ and $y = g/2$ cases it was found that with $y = g/2$, E_x increased by 0.7 dB, and E_z decreased by 1.3 dB. This seems correct, as the wire tends to short out E_x and support the surface charge that is associated with E_z.

3 Near Field of the Sphere

The wire grid sphere is shown in Fig. 5. The surface patch model is similar, except that each quadrilateral area is divided into two triangular patches. The sphere is centered at the origin, and its radius is $a = 15$ m. The wire spacing is $\Delta\theta = \Delta\phi = \pi/8$. At the equator the grid size is $g = 5.853$ m and the wire radius is $a_w = 0.9128$ m. Near the poles the grid size is smaller and the wire radii are adjusted in accordance with the same surface rule.

The incident field is a plane wave with an amplitude of 1 V/m, polarized in the $\hat{y}$ direction and traveling in the $+x$ direction. It is given by $\vec{E}^{inc} = \hat{y}e^{-jkx}$. In all cases the total field $\vec{E} = \vec{E}^{inc} + \vec{E}^{scatt}$

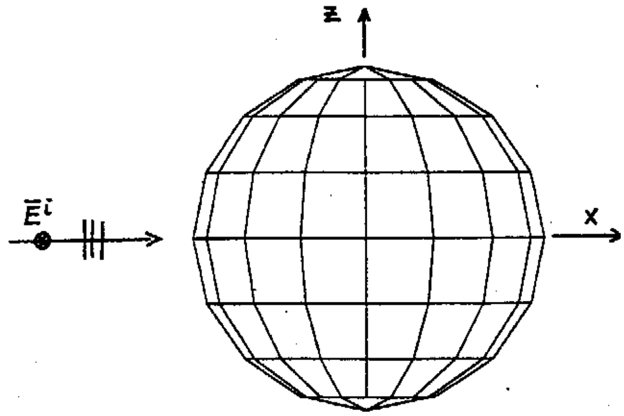


Figure 5: Wire grid model for the sphere. The radius is 15 m. A $\hat{y}$ polarized plane wave of 1 V/m is incident, travelling along +x. The field point is at a height h above the surface, at the equator where $\theta = 90°$ and $0 \leq \phi \leq 360°$.

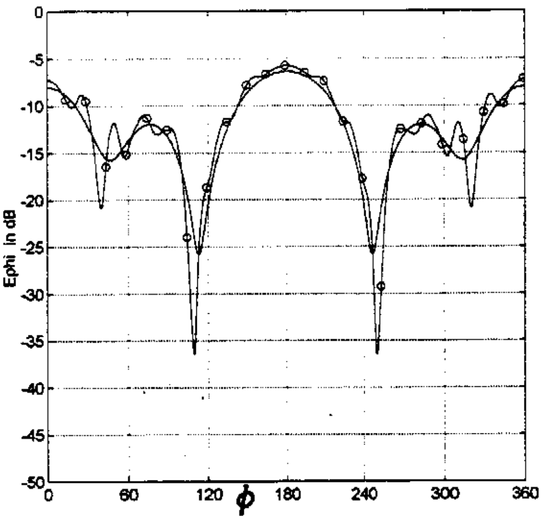
is plotted, using a reference of 0 dB = 1 V/m. The field point is at a height h above the surface, at the equator where $\theta = 90°$ and $0 \leq \phi \leq 360°$. The frequency was chosen as 12.8 MHz so that ka =1.6 and $g = 0.1\lambda$.

A. Junction and Exact Solution for the Sphere

The Junction surface patch model of the sphere was evaluated by comparison with an exact solution obtained from an eigenfunction series [15]. The field was calculated at a height of $h = 2.34$ m off the surface, so that $h/g = 0.4$. The agreement was so close as to be almost indistinguishable, suggesting that Junction is highly suitable for the computation of the near field of a smooth body. As a reference solution, the eigenfunction series was used in the subsequent validations.

B. Extent of the Near Field Anomalies

The field was calculated with NEC, at heights of $h = 2.34$ m and 4.68 m off the surface, so that $h/g = 0.4$ and 0.8, respectively. Fig. 6 shows that for $h/g = 0.4$, on the lit side, the anomalies in E_ϕ



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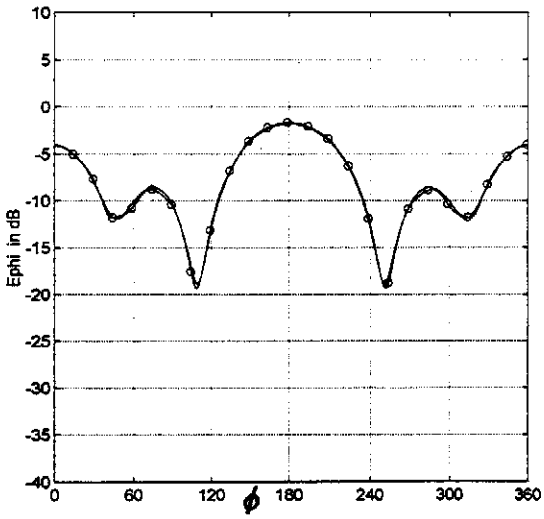

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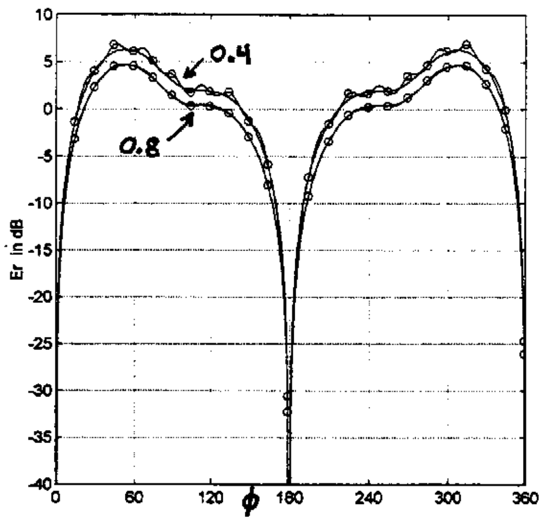


(c)

Figure 6: Near field of the sphere, grid size $g = 0.1\lambda$. Comparison of NEC wire grid (ooo) and exact solution (—). (a) E_ϕ, $h/g = 0.4$ (b) E_ϕ, $h/g = 0.8$ (c) E_r, $h/g = 0.4$ and 0.8.

and E_r are of comparable magnitude. For E_ϕ, the onset of anomalies occurs at about $h/g = 0.4$ on the lit side, and $h/g = -0.8$ on the shadow side. Similar behavior was noted for the plate, so these aspects appear to be independent of the precise shape of the scattering body.

A higher frequency was also tried. Using $ka = 4$ and $g = 0.25\lambda$, excellent agreement with the exact solution was observed, and we found that $h/g \geq 0.8$ was still a good criterion for avoiding anomalies.

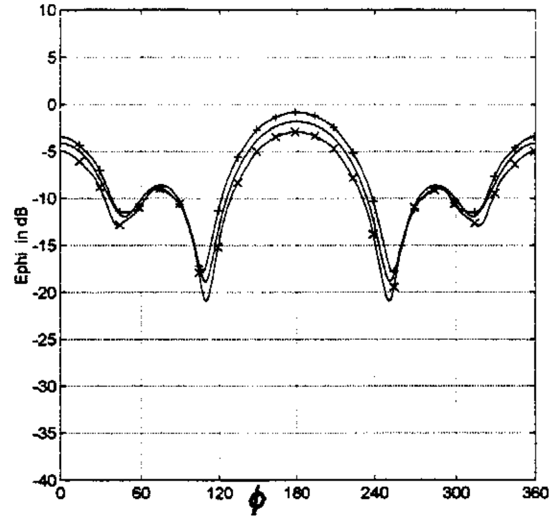
C. Test of the Same Surface Rule

The field was calculated with NEC at a height of $h = 4.68$ m off the surface, so that $h/g = 0.8$. In Fig. 7 we see that the same surface rule gives the best result for both E_ϕ and E_r. The cases of too thick wires ($2a_w$) and too thin wires ($a_w/2$) straddle the exact result. (The case using the same surface rule was not plotted, as it is indistinguishable from the exact solution.) This is unlike the plate, where the same surface rule worked for the tangential field, but not for the normal field.

The tangential E for the sphere was much less sensitive to wire radius changes than the plate. This is not because of the shape, but because the field in the shadow of the plate is much lower. As already mentioned in Section 2 C, errors in the scattered field are more evident when the incident and scattered fields are supposed to be cancelling.

The internal field of a closed body is known to be a sensitive indicator of the quality of a moment method solution, as cancellation of the incident field must take place inside the scatterer. This was not explored here, as there is no corresponding test that can be used for the plate.

A higher frequency using $ka = 4$ and $g = 0.25\lambda$ was also tried. It was found that the sensitivity with respect to wire radius of E_ϕ was increased on the shadow side, and hardly affected on the lit side. The sensitivity of E_r remained relatively weak. Even at this higher frequency, the results remained good, with errors on the order of 1 dB or less when the same surface rule was obeyed.



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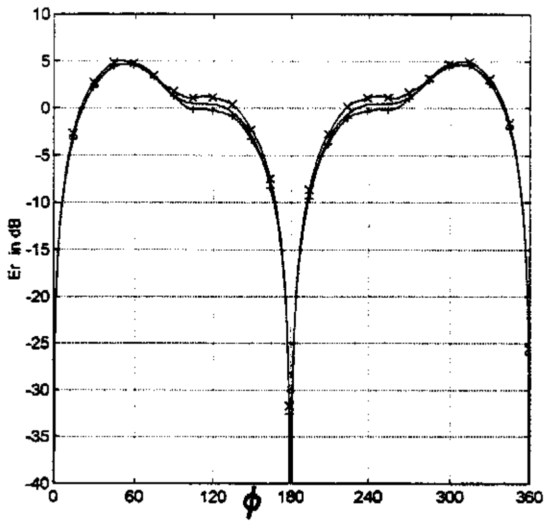


(b)

Figure 7: Effect of wire radius on the near field of the sphere, with grid size $g = 0.1\lambda$ and $h/g = 0.8$. The wire radius that satisfies the same surface rule is a_w=0.9128 m. Using NEC with $a_w/2$ (+++), $2a_w$ (xxx). Comparison is with exact solution (—). (a) E_ϕ (b) E_r.

4 Comparison of NEC and MBC

The NEC and MBC wire codes were used to compute the near field of the sphere at $h/g = 0.4$. Fig. 8 shows that the positions and amplitudes of the anomalies are very similar. This is noteworthy, as the two codes are quite different, i.e. NEC uses sine and cosine basis functions with point matching, whereas MBC uses piecewise sinusoids and Galerkin's method. Other tests using MBC revealed that the extent of near field anomalies and the dependence on wire radius were very similar to NEC. Hence, the comments made in previous sections with regard to the NEC wire grid models would seem to apply to MBC as well. The square plate was also tried, and similar near field behavior was found using both codes.

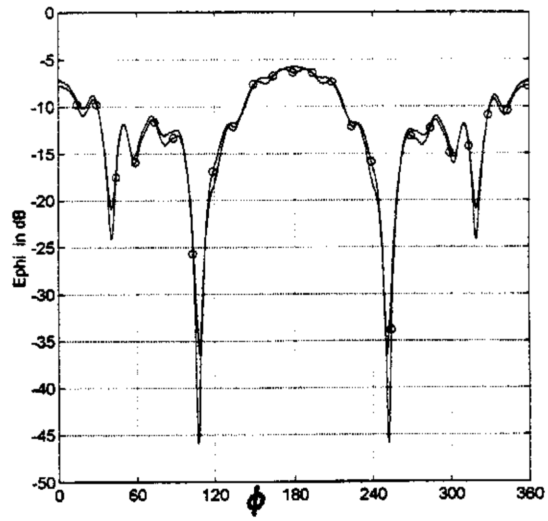
5 Conclusion

The near field of a surface patch model is smoother than for a wire grid with the same segmentation size. Nevertheless, a wire grid was found to give good results when the observer is a small distance h off the surface, provided that $h/g \geq 0.4$ on the lit side, and $h/g \geq 0.8$ on the shadow side. This was found to be true for both the plate and the sphere, and was tested for several grid sizes and frequencies.

Use of the same surface rule gives the best result for the near fields most of the time but not all of the time. It worked for the tangential E for the plate and sphere, for the normal E on the sphere, but not for the normal E on the plate.

The tangential E was more sensitive than the normal E with respect to wire radius, and the greatest errors occured in the tangential component when the same surface rule was violated. The greatest sensitivity occured with the field point in the deep shadow, where the incident and scattered fields are supposed to cancel. On the lit side, the effect of changing the wire radius was much smaller.

The type of MM formulation used in the wire codes was not a major factor, as similar results were obtained from the NEC code and MBC code.



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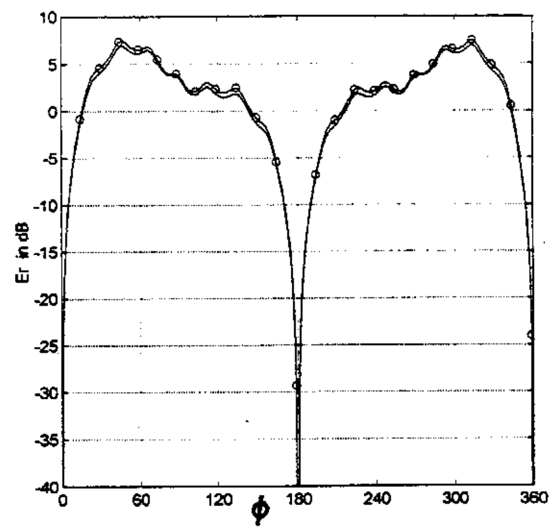

(b)

Figure 8: Comparison of NEC (—) and MBC (ooo) for the sphere, with grid size $g = 0.1\lambda$ and $h/g = 0.4$. (a) E_ϕ (b) E_r.

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