Estimation of Blockage Effects of Complex Structures on the Performance of the Spacecraft Reflector Antennas by a Hybrid PO/NF-FF Method

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Abstract **—** A hybrid (PO/NF-FF) method is presented in this paper for estimating the blockage effects of complex structures on the performance of the spacecraft mounted reflector antennas. The method estimates the blockage effect based on null-field hypothesis. The main advantage of this method is its ease of implementation for different obstacle geometries. The accuracy and functionality of the method is demonstrated by comparing the results of this method with other methods such as Method of Moments (MoM) and Direct (PO). An alternative definition of beam efficiency is adopted when the radiated power is available only in the forward radiation region. As a case study, the method is used to evaluate the effects of side panels on the performance of a reflector antenna operating at K band. A new parameter is also defined to represent the effects of absorbed power by panels. This parameter may be used to estimate the contribution of absorbed power in increasing system noise temperature.

Index Terms — Blockage effect, FFT, Hybrid methods, near field, Physical Optics, Reflector antennas.

I. INTRODUCTION

Recent technology advances in building large and light reflector antennas with reduced launch mass and stowed volume allows scientists to envision the use of large reflector antennas for spaceborne applications. In many cases, the performance of the reflector can be affected by structures around the antenna which may potentially interfere with its radiated fields. The situation may be even more critical for high-frequency radiometer applications in which the beam efficiency of the antenna can be degraded by any blockage effects. Furthermore, in many applications, the blocking object can have varied signature before and after development on the platform. Therefore an initial assessment of these blockage effects in a reasonably fast fashion is essential for spaceborne platform designs.

In general, several conventional methods have been considered for evaluating the effects of blocking objects on the performance of reflector antennas [1-4]. Using full-wave methods to analyze these effects can give accurate results. However, they are impractical due to very large dimensions of the antenna and blocking obstacles relative to the wavelength. Consequently, various types of approximations have been used to estimate the effect of large blocking objects. Induced field ratio (IFR) hypothesis has been invoked in [1] to study the effect of feed-support struts of symmetric paraboloidal reflectors. This hypothesis assumes that the currents at a point on the struts due to the plane-wave component of focal-region field are the same currents that would flow on an infinite, cylindrical structure of the same cross-section immersed in an infinite, free space plane wave with the same polarization and direction of incidence as the local geometrical ray incident upon that part of the struts as it emerges from the reflector. So this method is effective when the blocking obstacle is in ray-field regions and it is also limited to cylindrical strut structures. Another competitive method is observation-point-dependent shadowing technique which uses the null-field hypothesis [2, 3]. In this method, which is based on the GO approximation of the field, it is assumed that currents do not radiate in observation point directions which are shadowed by objects between the observer and the reflector. Thus, completely “dark” shadows are assumed to be contained within peripheries defined by geometrical rays. However, this method is restricted to some simple geometries and it is difficult to apply it for more complex structures. Another used method is to make the current zero in shadow regions caused by blocking objects [4]. This method is only useful when the blocking object is in front of the reflector and in the GO ray-field region.

Therefore, for the scenarios in which there are several blocking objects with different geometries and locations, the objective is to use a method which is applicable to large structures and can give fairly accurate results for obstacle in arbitrary locations in the forward region of the reflector (not only GO ray-field region). In addition, since the shape of some of the obstacle may change during deployment on the platform, the method should be easily applied for arbitrary geometries.

This paper addresses a hybrid PO/NF-FF method using near-field to far-field transformation combined with null-fill hypothesis to estimate the effect of complex structures on the far-field pattern and beam efficiency of reflector antennas. A preliminary presentation of technique was documented in a recent conference paper [5]. The main advantage of this method is that it can be potentially used for any arbitrary shape of blockages. The accuracy of the method is verified by comparing the results with Method of Moments (MoM). To estimate the blockage effects on the beam efficiency, an alternative definition of beam efficiency will be introduced based on the total forward radiated power in the near-field plane. Finally, the results will be shown for a case study in which the blockage effects of side antenna panels, for an antenna configuration presented in [6], is estimated on the performance of the reflector antenna. A new parameter, "*Power Ratio*", will be also defined to represent the effects of absorbed power by obstacle. This parameter can be used to estimate the contribution of absorbed power in increasing system noise temperature.

II. PO/NF-FF TRANSFORMATION METHOD

The evaluation of far-field pattern of an antenna from its near-field measurements by means of a near-field to far-field (NF-FF) transformation is well established and widely used [7]. There are several techniques for near-field measurements such as spherical, cylindrical, or planar measurements which have their own particular advantages depending upon the antenna and the measurement requirements. The method introduced in this paper is based on planar-rectangular near-field construction. Fig. 1 shows a schematic algorithm of this method. The field is calculated using Physical Optics (PO) on a finite rectangular plane through which the major portion of energy radiates. The near-field data is then used to construct the far-field pattern of the antenna using a fast Fourier transform FFT algorithm [8]. To evaluate the blockage effect, according to the null-field hypothesis, it is only required to make the field zero at the locations of conductor objects or their effective shadow regions which block the field. This can be done by post processing of the near-field data and use the modified near-field data to construct the affected far-field pattern. The important advantage is that once the near-field data is obtained it can be used for any arbitrary masking object geometry, and it is not necessary to modify algorithms for each case. This is clearly an approximation with reasonably useful results for engineering applications.

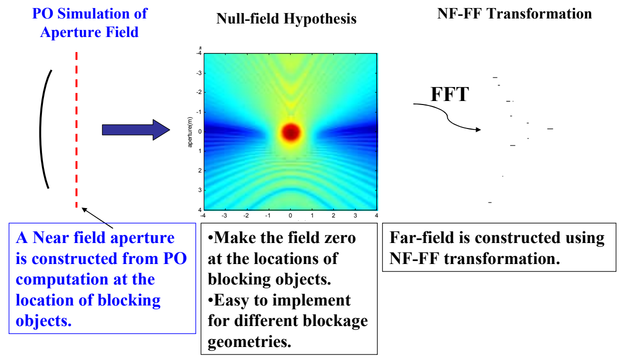


Fig. 1. Schematic algorithm of PO/NF-FF hybrid method to estimate the blockage effect of complex structures on the performance of the reflector antennas.

In general, this method can be used for any arbitrary object in GO field region by finding the projected shadow in the reference plane. For objects outside of GO field region the method is effective for planar structures by calculating the field at the location of the structure. For the cases where the objects are in different distances from the reflector, an iterative procedure can be invoked to estimate the effects of obstacles in different planes as shown in Fig. 2. The fields are nulled at the location of objects in the first plane and far-field is constructed. This far-field data is used to perform Inverse FFT to construct the near-field in the second plane. This near-field constructed data includes the effect of objects in the first plane. By nulling the field for objects in the second plane the far-field can be constructed and this iterative procedure can be performed until the effects of all objects in different planes are considered.

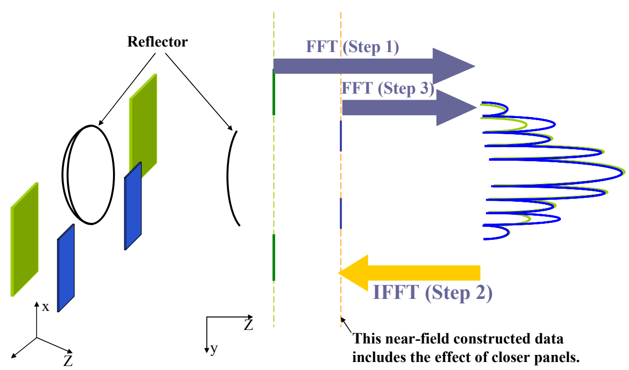


Fig. 2. An iterative procedure to evaluate the blockage effects of objects at different distances.

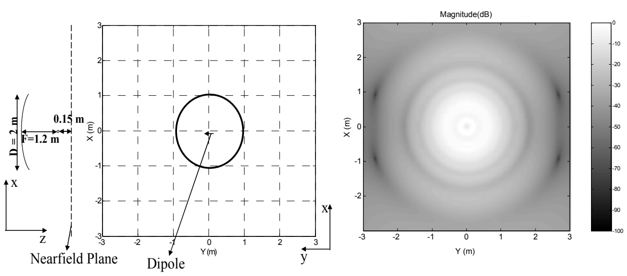
III. PO/NF-FF PERFORMANCE

A. *Accuracy of PO Near-Field Data*

To verify the accuracy of near-field data, the performance of a 2 m reflector fed by a dipole was simulated at 1.5 GHz using three different methods.

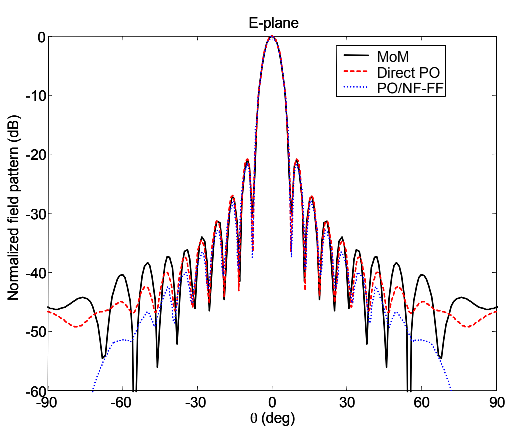
These dimensions allowed the problem to be solved by using Method of Moments. Fig. 3 shows the geometry of the reflector. The problem was first solved using the Method of Moments code [9] and the far-field was calculated from the current on the reflector. Then, a diffraction analysis code [10] was used to calculate the far-field pattern of the reflector. This code uses Physical Optics (PO) approximation of the current on the reflector and calculates the far-field directly from the PO current on the reflector. The third approach is the proposed PO/NF-FF method. The near-field data was simulated on a 30λ x 30λ plane in front of the reflector (Fig. 3b) and far-field pattern was constructed by performing FFT calculation.

Fig. 4 shows the pattern of the reflector calculated by these three methods. A very good agreement is observed between all methods up to 40^o. The discrepancy in sidelobe level after 40^o is mainly due to the finite size of the near-field plane. It has to be also mentioned that for this configuration, the valid angle for the far-field pattern of PO/NF-FF method is 65^o and the pattern cannot be relied on beyond this angle [11].

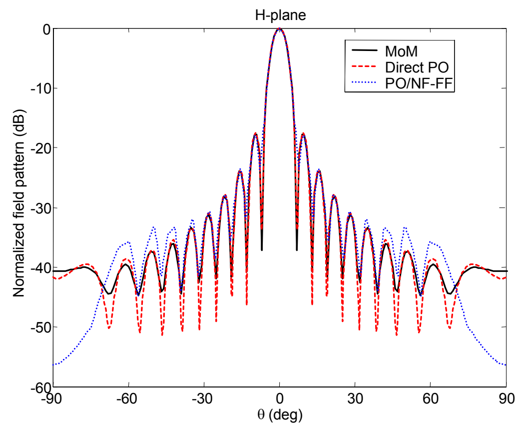


(a) (b)

Fig. 3. (a) Geometry of a 2 m reflector fed by a dipole at 1.5 GHz and constructed near-field plane, (b) Constructed near field data.



(a)

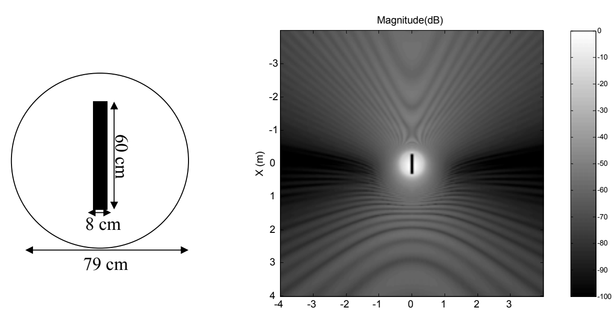


(b)

Fig. 4. Far-field pattern of a 2 m reflector fed by a dipole at 1.5 GHz using three different techniques, (a) E-plane, (b) H-plane.

B. *Evaluation of Blockage Effect*

A test scenario was also designed to evaluate the capability of the PO/NF-FF in predicting the effect of blocking objects. As shown in Fig. 5, a rectangular strip is assumed to block a 79 cm reflector operating at 18.7 GHz. The effect of this blockage is simulated by two methods: In the first method the PO currents in the shadow region of the reflector are made zero and then the far-field pattern is simulated directly from the modified current on the reflector. Since the blockage is in collimated field region of the reflector, the size of the shadowing region on the reflector was chosen to be equal to the actual size of the blockage. Secondly, PO/NF-FF method was used by constructing the near field data in a 8 x 8 meter window and nulling the field in the location of the strip and constructing the far-field from the modified near-field data. One can observe a good agreement between patterns in Fig. 6 and the main features of the patterns are very similar.



(a) (b)

Fig. 5. (a) A 79 cm reflector antenna operating at 18.7 GHz blocked by a rectangular strip, (b) Near field data with blockage effect.

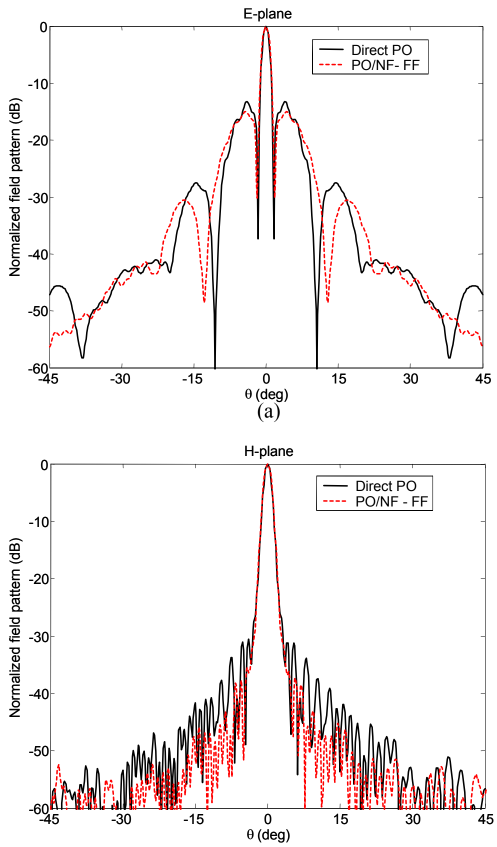


Fig. 6. Far-field pattern of the K band reflector blocked by the rectangular strip, (a) Direct PO method, (b) PO/NF-FF method.

IV. PO/NF-FF EVALUATION PARAMETERS

A. Beam Efficiency

Beam efficiency is one of the important parameters for characterizing the performance of reflector antennas used for radiometer applications. For a given power pattern of a reflector-antenna system the beam efficiency may be defined as [12],

$$BE = \frac{Power\ radiated\ in\ the\ main\ beam}{Total\ radiated\ power}.$$

The total radiated power for a reflector can be calculated from the total power emitted from the feed including scattered field and feed spillover. However, in the NF-FF transformation method, although choosing a large enough near-field plane gives a reasonable accurate result for far-field pattern, the total measurable power is the "total *forward* radiated power" and there is always a fraction of power which is not considered due to plane truncation or back scattering. So, it is necessary to define beam efficiency based on this forward radiated power to have a proper criterion to estimate the effect of blockage. Hence for this method, the beam efficiency is defined as

$$BE_{FFT} = \frac{Power\ \ radiated\ \ in\ the\ \ main\ \ beam}{Total\ \ near\ \ field\ \ power\ \ captured\ \ in\ the\ \ front\ \ plane}.$$

For high edge taper and large enough near-field plane, this number is almost equal to the value calculated based on the original definition. This is verified by numerical examples in the following sections.

B. Power Ratio

In most practical cases, the field level is considerably low at the location of the blocking objects. Therefore no significant change is observed in far-field patterns. However the power absorbed by these panels can contribute to increase the system noise temperature. Hence, to consider the effect of this absorbed power, a parameter defined as "*Power Ratio*" is introduced,

$$Power\ Ratio = \frac{Near\ field\ power\ at\ the\ location\ of\ blocking\ objects}{Total\ near\ field\ power\ captured\ in\ the\ front\ plane}.$$

It represents the ratio of the near field power at the location of blocking objects versus the total near field power captured in the front plane. It has been suggested that this parameter should signify the black body radiations of the blocked areas in front of the antenna which can potentially contribute to overall system noise temperature. An example of using this parameter will be demonstrated in the following sections.

V. A CASE STUDY: A K-BAND RADIOMETER REFLECTOR

The functionally of PO/NF-FF is demonstrated by calculating the effect of supporting struts and deployed side panels [6] on the performance of an offset parabolic radiometer reflector antenna. The antenna system configuration is shown in Fig. 7. The reflector has a diameter of 79 cm and the antenna operates at 18.7 GHz. The feed is Y polarized. The panels are dual polarized Ku band reflectarray for spaceborne radio altimeter.

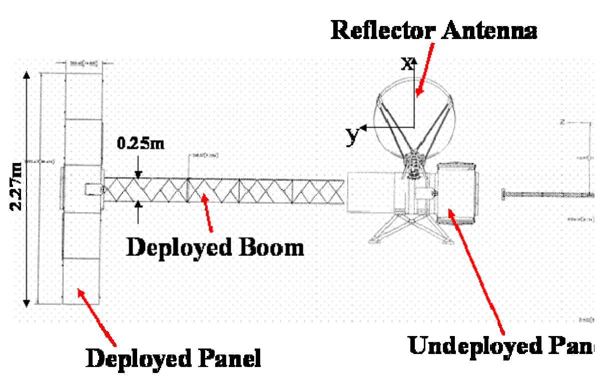
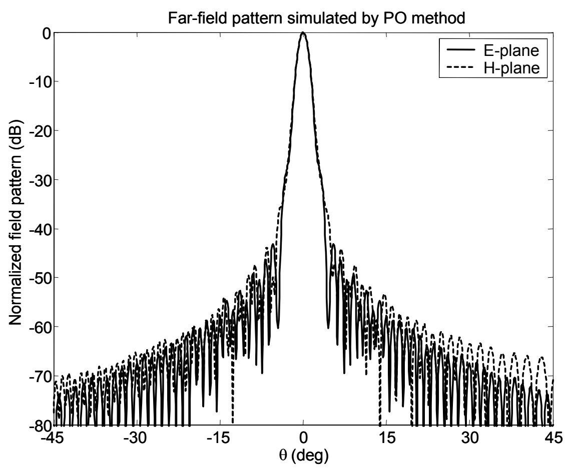
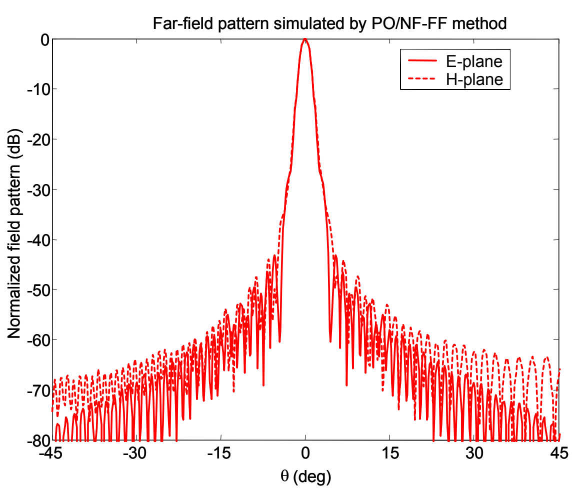


Fig. 7. Complex antenna system configuration operating at 18.7 GHz [6]. The panels are dual polarized Ku band reflectarray for spaceborne radio altimeter.

To verify the accuracy of the method, the far-field pattern is simulated using two methods. First, it was calculated directly using Physical Optics (PO) and second, it was calculated by simulating near-field data by Physical Optics and this data was then used to construct the far-field pattern (PO/NF-FF). In NF-FF transformation, to construct the far-field, near-field data was calculated in a rectangular aperture with dimensions of 500λ x 500λ. The aperture lies in the same plane as the deployable side panels. Shown in Fig. 8, the patterns are very similar in terms of directivity and side lobe profile. The beam efficiency values are calculated for both cases and as expected the values are similar. BE_{FFT} is 97.3% and it is slightly higher than BE (96.1%) due to the radiated field not captured in the near-field window and cause the total radiated power captured in the front window to be less than true total radiated power.



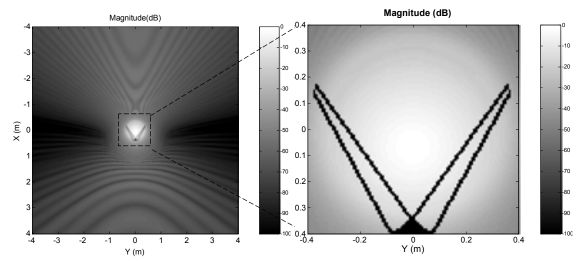
Directivity=41.2 dB
BE_{PO}=96.1 %
(a)



Directivity=41.3 dB
BE_{FFT}=97.3 %
(b)

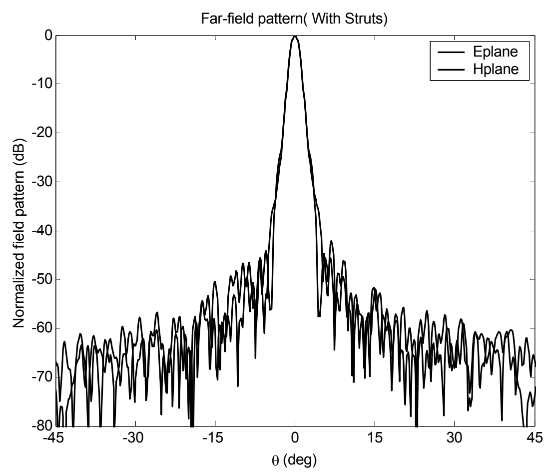
Fig. 8. (Far-field pattern of the reflector (without struts effect) (a) PO method, (b) PO/NF-FF method.

Next, the field is made zero at the location of supporting struts. The modified near-field pattern is shown in Fig. 9. The constructed far-field pattern from this near-field is now compared with measured far-field pattern in Fig. 10. The beam efficiency values are almost equal (94%) and the measured results confirm the performance of this method.

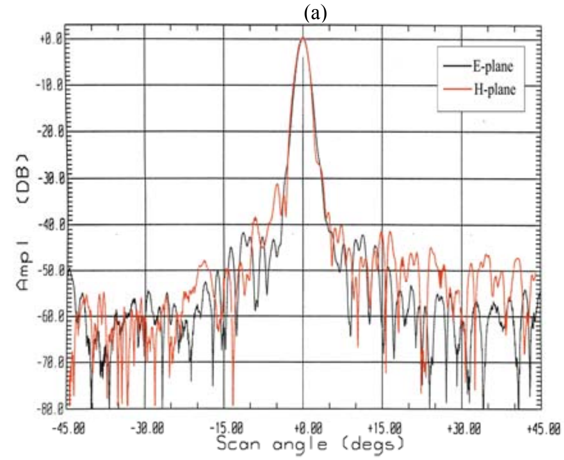


(a) (b)

Fig. 9. (a) Near-field pattern of the reflector with strut blockage effect, (b) Enlarged center area.



BE_{FFT}=94.1 %
(a)



Measured BE=94 %
(b)

Fig. 10. Far-field pattern of the reflector with struts effect, (a) simulation results using PO/NF-FF method, (b) measured far-field result from an early JPL measurement.

The effect of undeployed and deployed booms and reflectarray panels were investigated. Fig. 11 shows the geometry of the deployed panels while Fig. 12 shows the modified near-field pattern and far-field pattern of the antenna. It should be noted that the near-field data with strut blockage effect were used for all these cases and it was modified for different blocking geometries.

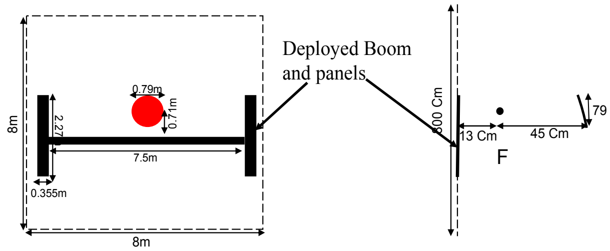
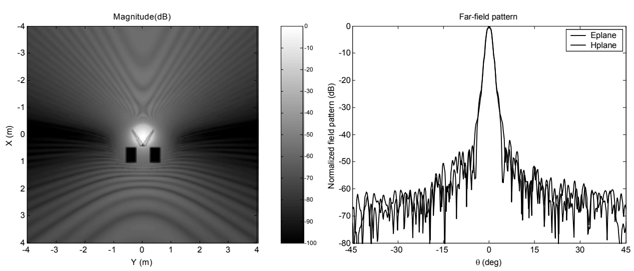
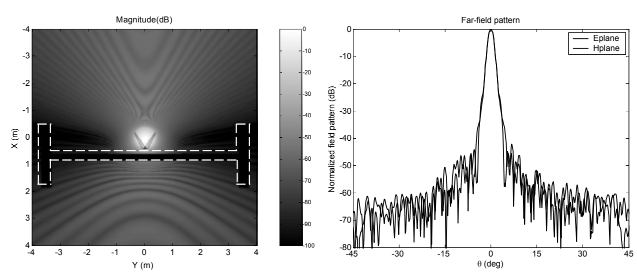


Fig. 11. Geometry of the deployed boom and panels on both sides of the reflector [6].



(a)



(b)

Fig. 12. Near-field and far-field simulated patterns of the reflector incorporating the effects of (a) Undeployed booms, (b) Deployed booms and panels.

No noticeable change is observed in far-field patterns due to blockage effects since the field level is very low at the location of blocking objects. This resulted to define the power ratio parameter, as discussed earlier, to indicate the contribution of absorbed power by blocking objects to overall system noise temperature. For this application, the power ratio was calculated with respect to the total power in (8 x 8) meter near field plane. The values for different cases are given in Table 1. For a given antenna system configuration it would be the user's responsibility to determine what the accepted value for the power ratio should be in order to consider the blocking effects insignificant.

Table 1. Power Ratio for different blockage cases.

Case	Power Ratio
Undeployed Boom	4.1711e-5
Deployed Boom	3.8546e-5
Panels	3.4332e-8
Deployed Boom + Panels	3.8580e-5

VI. CONCLUSIONS

A Hybrid PO/NF-FF transformation method was utilized in this paper to provide an initial estimate of the effects of complex blockage structure on performance of reflector antennas. The method estimates the blockage effect based on the null-field hypothesis. The radiated near-field data of the reflector was simulated under PO approximation and the fields were made to zero in the location of blocking objects. An FFT routine was then used to construct the far-field from the modified near-field data. The advantage is that once the near-field data is constructed, the data can be post processed for any arbitrary shape blockage object. For obstacles in different distances, an iterative procedure can be used to incorporate the effect of all of them on the radiation performance. The accuracy of the PO near field data was verified when the far-field pattern constructed by this method was compared with the results from Method of Moments and direct Physical Optics method. An alternative definition of beam efficiency was adopted when the radiated power was available only in the forward region. To evaluate the functionality of the method, the effect of blocking of a strip in the center of the reflector was simulated by using PO/NF-FF and direct PO method. The result showed a very good agreement in main features.

Lastly, as a case study, the effects of deployed and undeployed reflectarray panels and booms on performance of an 80-cm reflector antenna were investigated. Since the panels were located in the low intensity field region, no significant changes were observed in the far-field. Therefore, a parameter called "power ratio" was defined to signify the effects of the blocking objects in front of the antenna on the overall system parameters. This parameter gives the ratio of the power absorbed in the location of blocking panels versus the total captured power in the front plane. This power may potentially contribute to increase the noise temperature of the antenna system.

This case study showed the capability and usefulness of this hybrid PO/NF-FF method in predicting the blockage effects of arbitrary geometries, on the performance of reflector antennas with a fair accuracy and in a reasonably fast fashion. The method can be a viable tool in the initial design of spaceborne platforms for supporting reflector antennas. Preliminary results obtained using this method could then be verified using more sophisticated approaches.

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He has been editor and guest editor of numerous technical journals and books. He has authored and coauthored over 660 technical journal and conference papers and has written 20 book chapters. He coauthored *Implanted Antennas in Medical Wireless Communications*, (Morgan & Claypool Publishers, 2006), *Electromagnetic Optimization by Genetic Algorithms (New York: Wiley, 1999) and Impedance Boundary Conditions in Electromagnetics* (New York: Taylor & Francis, 1995). He also holds several patents. He has had pioneering research contributions in diverse areas of electromagnetics, antennas, measurement and diagnostics techniques, numerical and asymptotic methods, satellite and personal communications, human/antenna interactions, frequency selective surfaces, electromagnetic band-gap structures, applications of the genetic algorithms and particle swarm optimization, etc., (visit http://www.ee.ucla.edu/antlab). On several occasions, his research has made the cover of magazines and has been featured on several TV News casts. He is listed in Who's Who in America, Who's Who in Frontiers of Science and Technology and Who's Who in Engineering. Professor Rahmat-Samii is the designer of the IEEE Antennas and Propagation Society (IEEE AP-S) logo, which is displayed on all IEEE-AP-S publications.

Dr. Rahmat-Samii is a member of Commissions A, B, J and K of USNC/URSI, Antenna Measurement Techniques Association (AMTA), Sigma Xi, Eta Kappa Nu and the Electromagnetics Academy. He was elected vice-president and president of the IEEE Antennas and Propagation Society in 1994 and 1995, respectively. He was appointed an IEEE AP-S Distinguished Lecturer and presented lectures internationally. He was elected a Fellow of IEEE in 1985 and a Fellow of Institute of Advances in Engineering (IAE) in 1986. He was also a member of the Strategic Planning and Review Committee (SPARC) of the IEEE. He was the IEEE AP-S Los Angeles Chapter Chairman (1987-1989); his chapter won the best chapter awards in two consecutive years. He has been the plenary and millennium session speaker at numerous national and international symposia. He has been the organizer and presenter of many successful short courses worldwide. He was one of the directors and vice president of the Antennas Measurement AMTA for three years. He has also served as chairman and co-chairman of several national and international symposia. He was also a member of the University of California at Los Angeles (UCLA) Graduate council for three years.

For his contributions, Dr. Rahmat-Samii has received numerous NASA and JPL Certificates of Recognition. In 1984, Prof. Rahmat-Samii was the recipient of the coveted Henry Booker Award of International Union of Radio Science (URSI), which is given triennially to the most outstanding young radio scientist in North America. Since 1987, he has been designated every three years as one of the Academy of Science's Research Council Representatives to the URSI General Assemblies held in various parts of the world. He was also invited speaker to address the URSI 75th anniversary in Belgium. In 1992 and 1995, he was the recipient of the Best Application Paper Prize Award (Wheeler Award) for papers published in 1991 and 1993 IEEE AP-S Transactions. From 1993 to 95, three of his Ph.D. students were named the Most Outstanding Ph.D. Students at the School of Engineering and Applied Science, UCLA. Ten others received various Student Paper Awards at the 1993-2004 IEEE AP-S/URSI Symposia. In 1999, he was the recipient of the University of Illinois ECE Distinguished Alumni Award. In 2000, Prof. Rahmat-Samii was the recipient of IEEE Third Millennium Medal and the AMTA Distinguished Achievement Award. In 2001, Rahmat-Samii was the recipient of the Honorary Doctorate in physics from the University of Santiago de Compostela, Spain. In 2001, he was elected as a Foreign Member of the Royal Flemish Academy of Belgium for Science and the Arts. In 2002, he received the Technical Excellence Award from JPL. He is the winner of the 2005 URSI Booker Gold Medal presented at the URSI General Assembly.