A systematic approach to the analysis of polarisation-sensitive reflectors

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ABSTRACT

The analysis of a polarisation-sensitive reflector system consisting of two individual reflecting surfaces is described. A procedure is given by which all the predictable scattering effects that will influence the far-field radiation pattern are accounted for. The problem of describing reflection and transmission phenomena from a non-perfectly conducting surface when the incident field is not a plane wave is emphasised, as this is the case when considering scattering between the front and the rear reflector in a dual-gridded reflector system.

Keywords: reflector antennas, gridded reflector, polarisation sensitive reflector, GRASP, physical optics, spacecraft antennas

INTRODUCTION

Spacecraft communications antennas are normally made offset to avoid blockage by the feed system, which will otherwise cause increased sidelobes, poor feed return loss and gain reduction. Unfortunately, the offset geometry inherently introduces cross polarisation when operating in linear polarisation (see Fig. 1).

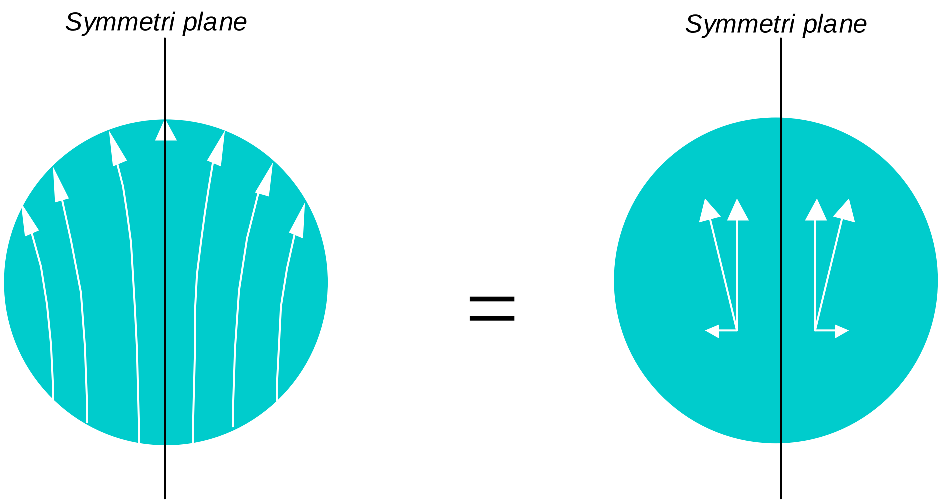

Fig. 1 Current lines on a vertically polarised single offset reflector antenna when viewed from the boresight direction. In the figure to the right, the currents are de-composed into vertical and horizontal elements. The horizontal elements will cancel on-axis but give the typical cross-polar lobe-structure away from boresight.

To make full use of the limited frequency resource, all communications spacecraft implement frequency re-use by means of polarisation separation. This requires isolation between the differently polarised beams of typically more than

33 dB, whereas the numbers that are commonly achievable with a single offset, solid reflector is in the order of 20-25 dB. One of the approaches to overcome this limitation is to employ polarisation sensitive reflector antennas.

Polarisation-sensitive reflector (PSR) antennas have been flown on commercial spacecraft since the seventies, with some of the first examples being RCA Satcom, Comstar 1, and Anik [1]-[3], and is still being studied heavily for space applications [4]. Probably the biggest difference between then and now is that the first PSRs were parabolic reflectors generating either a spot beam or a contoured beam by means of a feed array, whereas today most of the antennas consist of shaped surfaces with one or a few feeds where the beam contouring is generated by the surface shape.

Due to the increased use of gridded reflectors, much effort has been devoted to the detailed analysis of these structures and the available tools have become increasingly better. However, the procedure is complicated and has been the subject of only a few articles in the past, [5]-[6].

In this paper we will summarise the procedure once again, and discuss a particular problem that occurs when trying to analyse the PO scattered field from a gridded surface when the incident field is not a plane wave, as required by the PO formulation. We will also suggest a way of overcoming this problem. But first, we will look at the dual-gridded reflector system in general.

DUAL-GRIDDED REFLECTORS: PRINCIPLE OF OPERATION

The Satcom I antenna employed a polarisation screen in the aperture plane of a solid reflector to clean the polarisation of the reflected field. The screen consisted of parallel metal strips orthogonal to the desired polarisation. Hence, only the wanted polarisation could be transmitted through the screen. The approach inherently required two separate antenna apertures, one for horizontal and one for vertical polarisation.

Later, it became possible to interleave the two apertures by depositing the metal strip grid directly on the reflector surface, thereby saving a substantial amount of space on the spacecraft. This is illustrated in Fig. 2.

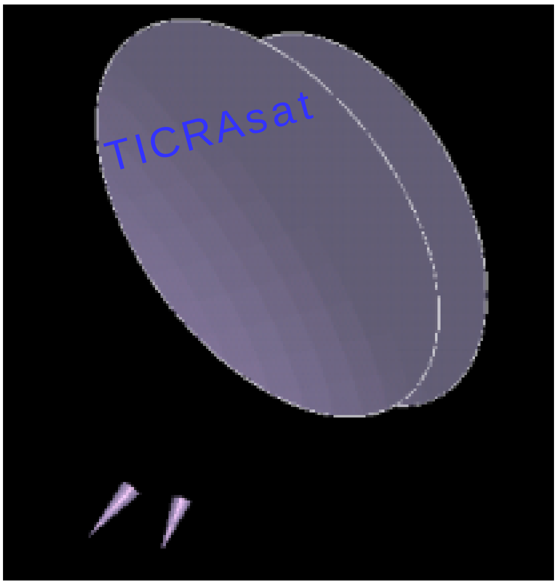

Fig.2 Interleaved reflectors in a dual-gridded system. The front reflector has metal strips deposited on a dielectric support shell, thus reflecting the majority of the field coming from one of the feeds, whereas the other feed field is transmitted through the front and reflected from the rear shell.

The metal strips on the front shell should be deposited in such a way that they are parallel to the wanted direction of linear polarisation when seen from the boresight direction, or, in the case of a highly-shaped contoured-beam antenna, from somewhere inside the wanted coverage.

One of the feeds is aligned such that it's linear polarisation matches to the greatest possible extent the direction of the strips on the front shell. We designate this the front feed. Most of the energy will be reflected by the front shell, but a portion will be transmitted through due to the offset configuration. This small portion will be reflected by the rear shell and re-transmitted through the front shell to eventually show up as cross polarisation in the far-field pattern. It is important to note that the level of this cross polarisation is of the same order as what is normally seen in a solid, single-offset reflector system. However, due to the arrangement of the front and the rear reflectors, the front feed is placed off-focus relative to the rear reflector and hence the cross polarisation will be scanned away from the coverage. One of the challenges for the antenna engineer is to design the geometry such that the cross polarisation is scanned sufficiently far away.

The operation of the other feed, the rear feed, is similar: most of the energy is transmitted through the front reflector to be reflected by the rear. If the rear reflector is solid, the reflected field will contain a generally high cross-polar component due to the offset. However, this field has to pass through the grid on the front reflector once again, and this time it acts as a polarisation filter, allowing only the wanted linear polarisation to be transmitted. A small portion of the feed field will be reflected by the front shell and show up as a fairly high cross-polar component in the far field, but just as before, this component will be scanned away from the coverage due to the alignment of the two reflector systems.

It should be evident by now that the total radiated far field, whether due to the front or the rear feed, strongly depends on the interaction between the front and the rear shell, and it is far from sufficient to analyse the system by considering the two reflectors independently. The systematic approach to the analysis is presented in the next paragraph.

ANALYSIS APPROACH

The following steps need to be taken, as a minimum, to adequately analyse the pattern from a dual-gridded antenna (note that the procedure applies to both feeds independently, there is no distinction between the front and the rear feed):

1) Calculate the scattered field from the front shell due to the feed
2) Calculate the scattered field from the rear shell due to the combined illumination from the feed and the scattered field in the front reflector
3) Calculate the scattered field from the front reflector due to the illumination by the scattered field from the rear reflector
4) Add all the far fields from 1)-3) to get the composite pattern

One should be aware of the fact that some of the scattered field obtained in 3) will radiate back towards the rear reflector where it will be reflected and scattered again in the front reflector. This could be continued ad infinitum to account for multiple reflections between the two shells but normally steps 1) through 3) will be adequate.

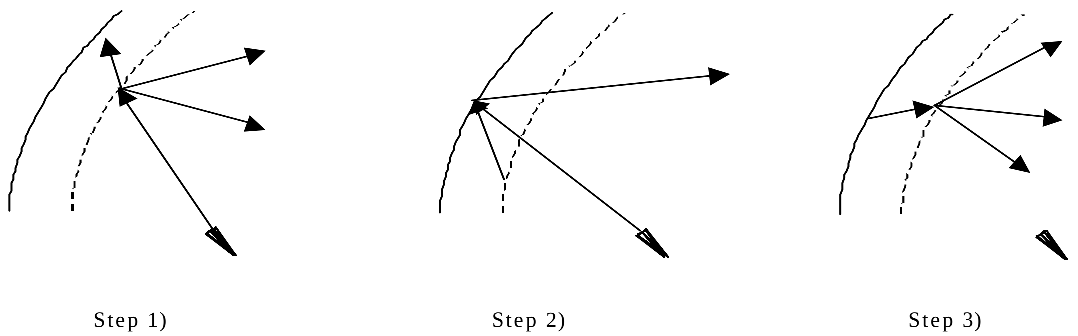

Fig. 3 The three major scattering mechanisms in a dual gridded reflector: 1) scattering of the feed field in the front shell, 2) scattering of the front field and the feed field in the rear shell, 3) scattering of the rear field in the front shell.

The scattering in each of the shells can be conveniently analysed by means of Physical Optics (PO), with a modification of the induced currents at the gridded surface to account for the transmission and reflection properties. Furthermore, it is necessary in general to calculate magnetic as well as electric currents, as described in [5] and in more detail in [7].

The polarisation grid will always be deposited on one or more layers of a dielectric support material, just as there will usually be a sandwich structure in between the front ant the rear reflector. The reflection and transmission characteristics of the front shell will depend upon this, and the composite parameters must be known in order to derive the PO currents. This can for example be done by cascade coupling of the reflection and transmission matrices for the individual materials.

SPECIAL CONSIDERATIONS FOR NON-PLANE-WAVE INCIDENCE

The PO currents on a surface, which is not perfectly conducting, are derived under the assumption that the incident field is locally a plane wave, and make use of the reflection and transmission parameters for an infinite planar structure of the material, illuminated by a plane wave. An important consequence of this is that a direction of incidence must be defined at every point on the surface, where the PO currents are calculated. If we consider the front shell illuminated by the feed then this will cause us no concern, as we simply define the direction of incidence to be the direction to the feed. But when we look at the illumination of the front shell by the rear-reflector scattered field the situation is very different. Here, the incident field is the composite effect of a scattering in the entire rear shell which is located very close to the front. It is far from obvious how to define the direction of incidence.

We have successfully employed two different techniques, a fast and yet very accurate method and a more rigorous approach. The first one is based on the Poynting vector: at each point of PO calculation, the direction of the Poynting vector for the incident field is calculated and taken as an indication of the direction of incidence. Particularly when we are looking at the radiation of the front reflector from the rear this seems to be a justifiable approach.

A more rigorous way is to consider the incident field as coming from a number of point sources rather than looking at the composite field from the reflector. If we again use the front reflector illuminated by the rear as an example, then the incident field on the front would normally be calculated by integrating the PO currents on the rear. Instead of carrying out the integration and then calculating the PO currents on the front, we could consider each of the current elements on the rear as a source on its own, and calculate it’s contribution to the induced currents on the front. Since the radiation in this case comes from a point source there is no discussion about the direction of incidence. The approach can take significantly longer time, but will in general give results that are more accurate.

Direction of the Poynting vector after integration of currents on the rear reflector. Only one current element is calculated at the point of interest on the front reflector.

The current on the front is calculated as a sum of current elements, each one caused by a current element on the rear reflector.

Fig. 4 The two different methods for calculating the induced currents on a surface that is not a perfect conductor.

It should be noted that in the example to be presented below, we have analysed the radiation pattern in both ways and found a difference of less than 0.5 dB in the peak cross-polar level while the structure of the cross-polar field remained the same.

AN EXAMPLE

The analysis procedure has been applied to a design of a contoured beam antenna to cover Australia from an orbital location of 150º East longitude. The front and the rear antenna are both 1 meter in diameter, with focal lengths of 0.6 and 0.65 meter, respectively. The two reflectors are rotated +/-3.5º relative to each other to ensure that the cross polarisation is scanned outside the coverage. A metallic grid has been applied to the front reflector, with a grid spacing, s, of 1/20 wavelength, and a width, w, of 1/5 of s, following the guidelines in [7].

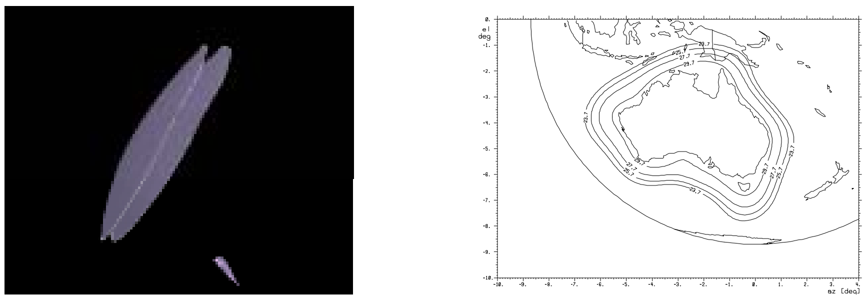

Fig.5 Dual-gridded shaped reflector system for coverage of Australia and the copolar beam from the front reflector.

To illustrate the importance of the thorough analysis of such system we have performed three different sets of analyses:

1) Both reflectors are solid, and both are analysed as if the other reflector was not there
2) As in 1) but both reflectors are gridded
3) Gridded front and solid rear, thorough analysis

The cross-polar pattern is shown for the two first cases in Fig. 6 and for the thorough analysis in Fig. 7.

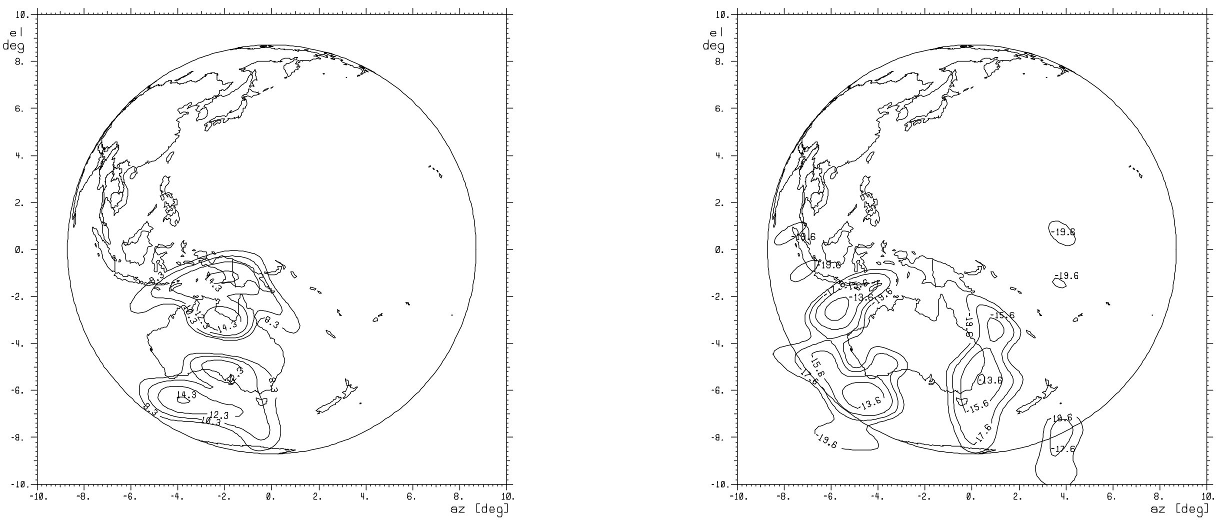

Fig. 6 Cross-polar pattern for the front reflector analysed as a solid (left, peak = 16.3 dBi), and gridded without taking the rear into account (right, peak = -11.5 dBi)

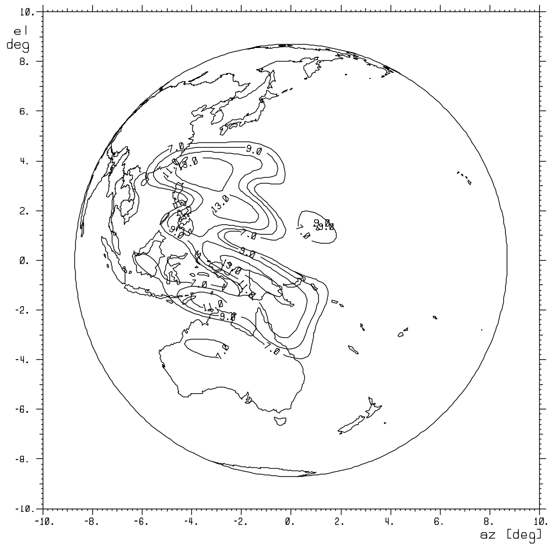

Fig. 7 Cross-polar pattern for the front reflector after a thorough analysis, taking into account the scattering from the rear reflector. Peak = 15 dBi.

It is seen that the grid makes a dramatic improvement in the cross polar performance, illustrated by the reduction of the peak from 16.3 dBi to –11.5 dBi in Fig. 6. But when the rear reflector effect is accounted for, the cross-polar peak increases to almost the same level as for the solid reflector, but occurs outside the coverage region due to the geometry. In fact, the performance of the present design could be improved by a further displacement of the two foci for the front and the rear reflector, but this is a trade-off between mechanical and electrical constraints, as discussed in [4].

CONCLUSIONS

A straightforward and systematic analysis procedure for dual-gridded reflector antennas has been presented. It takes into account the first-order scattering from the front and the rear reflector, but if multiple bounces between the two shells are of concern, the procedure can easily be expanded to also consider this.

The issue of analysing scattering from a gridded surface when the incident field is not locally a plane wave was discussed, and a method in which the radiation from the rear shell towards the front is calculated by looking at each individual PO current element rather than the composite integrated effect, is proposed. In most practical cases, the faster method based on the direction of the Poynting vector provides very reliable results.

It is possible to account for not only the grid but also the homogeneous support dielectric or layers of dielectric. What is not considered here are the un-wanted effects coming from structures that are necessary for mechanical reasons, such as stubs or intercostals between the front and the rear shell, and possibly a skin around the edge to bond the two reflectors together. Ideally, these mechanically required objects should not influence the radiation pattern too much, but the effects are difficult to analyse in general terms and require a careful investigation for each individual configuration.

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