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A HYBRID METHOD OF ANALYSING REFLECTOR AND FEED ANTENNAS FOR SATELLITE APPLICATIONS

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1. Introduction

We have developed a software package for analysing reflector antennas and finite arrays of horn antennas. Although it is intended for designing on-board satellite antennas for telecommunications, it is suitable for analysing most systems of reflectors and feeds. Satellite manufacturers need accurate analysis software to avoid re-engineering and cut-and-try design, thereby minimising the time to delivery. Our package is drawn from a suite of in-house software for electromagnetic design, and we regard it as part of a continuous process of integration of our software to enable hybrid analyses of complex structures.

A satellite antenna may have a single feed horn or an array of feed horns, a single reflector or multiple reflectors. Interactions with adjacent antennas on the satellite platform or with parts of the platform itself may affect the radiation pattern or input characteristics of an antenna. Therefore, a thorough analysis of an antenna involves interactions between a diverse set of scatterers. Critical to the success of our software is a systematic method for dividing each analysis into distinct steps, each of which involves at most two scatterers, and then performing these steps in the correct sequence.

2. Components of the Analysis

Single rectangular or circular horns and waveguide components are analysed using mode matching. The internal structure of a horn is modelled as a series of uniform waveguide sections that allows smoothly flared or corrugated horns to be treated. Waveguide sections of non-standard cross-section can be included by using a variational technique to calculate mode functions [1]. Mutual coupling in an array of horns is analysed by using a free-space Green's function [2,3]. Diffraction from the flanges of feed horns or arrays is calculated using either the geometrical theory of diffraction (GTD) [4] or an edge-equivalent-current formulation [5]. This allows us to calculate accurately cross-polar radiation, and also wide-angle radiation that may illuminate adjacent scatterers or contribute directly to the antenna's radiation pattern.

Physical optics (PO) is used to calculate radiation from surfaces of scatterers. We model various special surface materials by replacing the PO currents for perfectly conducting surfaces with equivalent currents to represent multiple dielectric coatings [6], gridded or meshed surfaces [7], or carbon-fibre-reinforced-polymer surfaces [8]. The physical theory of diffraction (PTD) is used to enhance the accuracy of PO by better treatment of edge-diffraction effects [9]. This ensures that such effects are modelled accurately as in GTD but allows a greater range of analyses to be performed in a straight-forward manner. We find PTD more convenient to apply to arbitrary edge contours because it uses an integral along the edge instead of requiring stationary-phase ray paths to be located. It also produces continuous radiation patterns and applies at edge-diffraction caustics. GTD can be used in situations where its speed is an advantage.

We calculate coupling between feeds of adjacent antennas using field correlation [10], in which the power transferred from one antenna to another is estimated from a surface integral involving the fields radiated separately by each antenna. The integration surface may be in free space or it may conform to a reflector surface. When the two feeds coincide and field correlation is done on a reflector surface, the reflection coefficient arising at the feed due to the presence of the surface is obtained.

The method of moments (MoM) solves exterior problems without asympototic approximations to Maxwell's equations and so complements mode matching for interior problems. Although a full MoM solution is not efficient for most satellite structures, we have used MoM to verify the accuracy of other techniques [11] and to increase their accuracy, as in a hybrid mode-matching and MoM analysis of single horns or pairs of horns [12].

3. The Hybrid Software Design

We have integrated several Fortran programs by running them under control of a supervising program. Presently the supervising program is written in Fortran and acts via a simple C-shell script. Field and geometrical data are passed between the programs using files. This software design maintains separate programs and thereby avoids substantial rewriting of existing, well-tested code. It also forces the calculations to be divided into steps with clear definitions of input and output, leading to clarity of design and robustness because sharing of data between programs is strictly controlled. The overhead costs associated with running separate programs in the correct sequence and organising data transfer between them is small compared with the time needed for electromagnetic calculations.

The calculations are divided into steps involving the interaction of, at most, two scatterers, and the program calculating each interaction requires only the geometry of the source scatterer, the fields incident on it, and the location of output points on the target scatterer. This is possible because knowledge of the fields incident on a surface or edge, together with its geometry, is sufficient for calculating radiated fields using PO, PTD, or GTD. However, PO and PTD are more convenient than GTD because they do not require a ray representation of the incident field, they apply where ray representations break down as at caustics, and they do not require reflection and diffraction points to be located. Nevertheless, some use of GTD is possible for applications where this is an advantage.

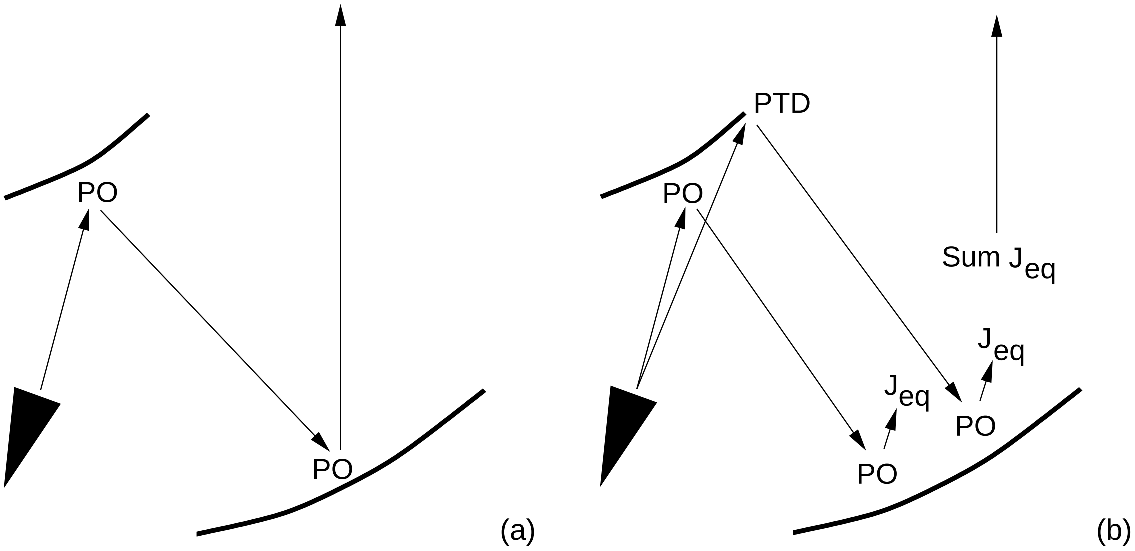

Figure 1: Analysis steps for a dual-reflector antenna using (a) simple PO on both reflectors and (b) PTD on the subreflector and equivalent currents on the main reflector.

Each step calculates the illumination of one scatterer by another or performs a special function, such as calculating equivalent currents on a surface, superposing fields or currents, or calculating a field-correlation integral. A standard PO analysis of a dual-reflector antenna is shown in Figure 1(a) and has three steps. Calculating edge diffraction from the subreflector and equivalent currents for a special main-reflector surface material requires the extra steps shown in Figure 1(b).

Including other interactions, such as the feed illuminating the main reflector or direct subreflector radiation, or including scatterers from adjacent antennas and the antenna platform requires a multitude of steps to be performed in a sensible order. There is some flexibility in ordering the steps, but all steps illuminating a scatterer must be calculated, and the resulting equivalent currents superposed, before that scatterer can illuminate another. Based on this requirement we have developed an algorithm for planning an analysis and choosing the correct input files of field data for each step.

4. Examples

Some capabilities of our software are demonstrated through two example calculations. In the first example, a C-band feed system illuminates a splash plate that is close to the horn aperture and has a central knob to minimise reflection back into the horn; see Figure 2(a). The calculated secondary radiation pattern, G/T, and return loss are shown in Figures 2(b) and 2(c). The return loss includes the interaction between the horn and splash plate calculated using field correlation. In the second example, the Ka-band horn [13] in Figure 3(a) is modelled using mode matching for the interior and aperture and MoM for the exterior wall currents, resulting in superb agreement with measurements in Figure 3(b). This design uses transitions and a polariser with non-standard waveguide cross-sections [1] the dimensions of which were optimised by a gradient search method. Further examples can be found in [14]. We are grateful to our colleagues Stephen Barker, John Barron, Ross Forsyth, Jerry Oprzedek, Ken Smart, and Mark Sprey for assistance in the design, manufacture, and measurement of these antennas to verify our numerical methods.

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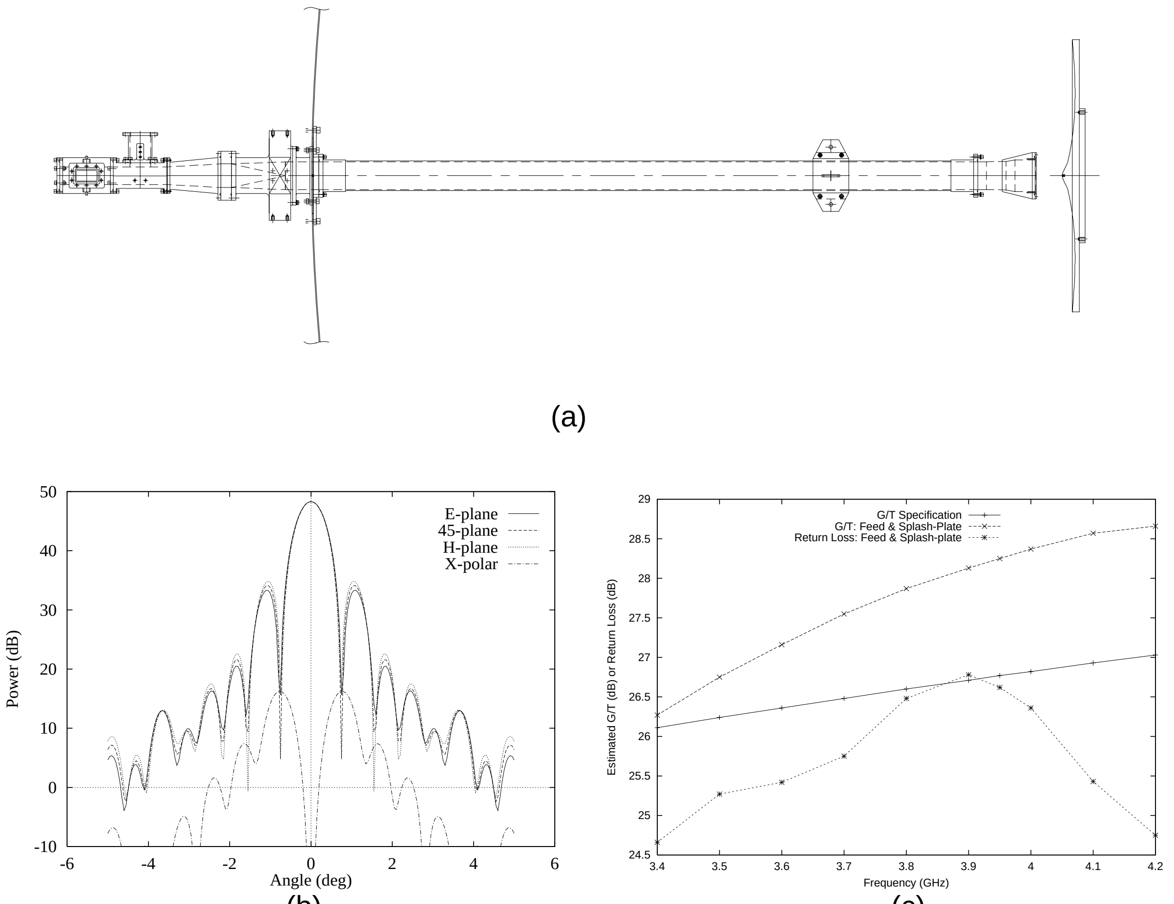
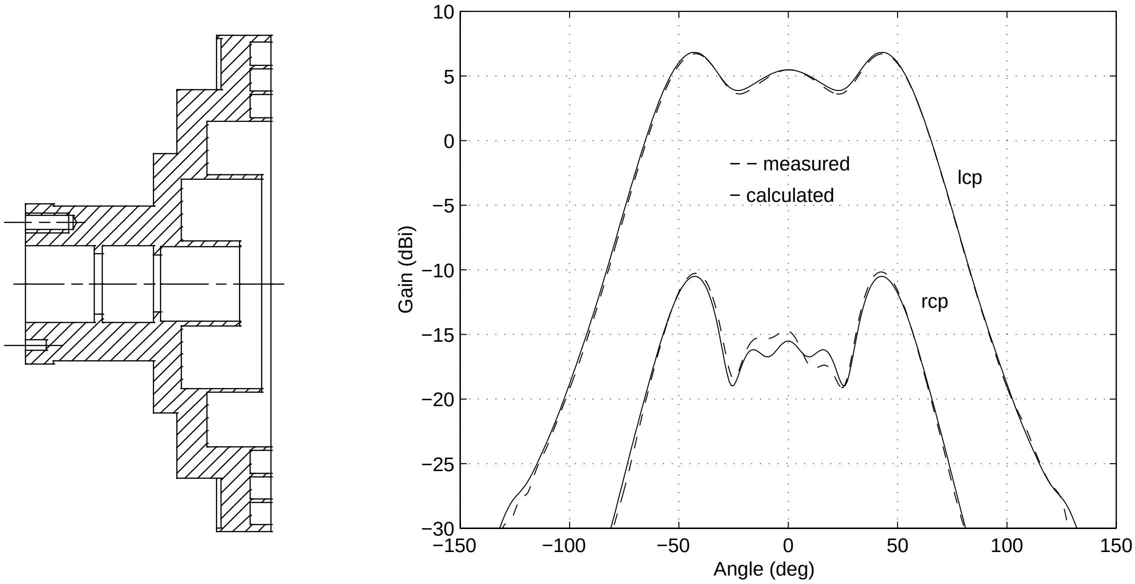


(a)

(b)

(c)

Figure 2: The feed system and splash plate shown in (a) illuminates a main reflector, which is partly shown, and we calculate (b) the secondary radiation pattern and (c) the system G/T and return loss.



(a)

(b)

Figure 3: We calculate the radiation pattern for the Ka-band earth-coverage horn shown in (a) using mode matching and MoM and compare with measured results in (b).