



Recommendation ITU-R SA.1345-1
(01/2010)

**Methods for predicting radiation patterns
of large antennas used for space
research and radio astronomy**

SA Series
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Note: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.

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RECOMMENDATION ITU-R SA.1345-1

Methods for predicting radiation patterns of large antennas used for space research and radio astronomy

(1998-2010)

Scope

This Recommendation describes methods to be used in predicting the radiation patterns of large antennas used for space research and radio astronomy taking into consideration the reflector surface distortion effects in modelling the antenna radiation pattern.

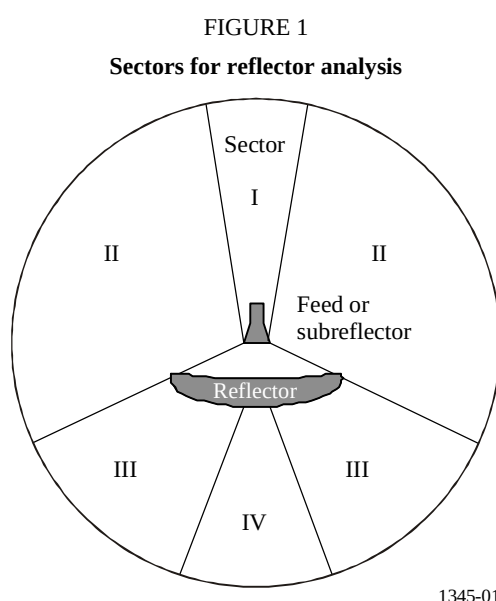
The ITU Radiocommunication Assembly,

considering

- a) that in many cases reflector antennas used by space research and radio astronomy are similar in that they are of large diameter and operate at frequencies up to tens of GHz;
- b) that because of the large distances required to achieve conventional far-field conditions ($2D^2/\lambda$), standard antenna test range or anechoic chamber measurements are inappropriate, however the predictions of radiation patterns for very large antennas can in some instances be validated by calibrated measurements;
- c) that many potential sources of terrestrial based interference to the two services will be in the near-field of the antenna;
- d) that accurate models and associated software are becoming available for the prediction of antenna radiation patterns in both the near-field and the far-field, and also for situations which involve interaction with additional reflectors or undesirable obstacles,

recommends

- 1 that where a choice of the most appropriate modelling technique is required for predicting the gain pattern of large reflector antennas, the methods described in Annex 1 and tabulated below should be used:



Recommended analysis techniques	
Sector I Forward axial sector	Physical optics
Sector II Far sidelobes	Geometrical theory of diffraction/ uniform theory of diffraction and induced field ratio
Sector III Backlobes	Geometrical theory of diffraction/uniform theory of diffraction
Sector IV Rear axial sector	Equivalent edge currents

- 2 that with respect to modelling techniques involving measurement, the description of the methods in Annex 2 should be used as a guide in selecting the most appropriate method;
- 3 that in determination of the significance of the mechanical characteristics of the antenna to be modelled, the following factors should be taken into account:
- a) scattering by the feed support struts in determining the sidelobe levels;
 - b) spill-over of the radiation direct from the feed; and
 - c) surface distortions.

Annex 1

Suitability of various electromagnetic modelling methods to predict the gain and radiation patterns of large antennas

1 Introduction

There are a large number of techniques available for solving electromagnetic problems. Each technique may have advantages for modelling particular problems but may be impracticable for other problems. This annex considers the techniques used for the modelling of reflector antennas and considers their suitability for analysis of the large reflector antennas typically used for space research and radio astronomy.

2 Analytical and numerical methods

2.1 Method of moments

The method of moments is a mathematical technique for solving inhomogeneous linear equations of the type:

$$Lf = g \quad (1)$$

where L is usually a linear integro-differential operator, and the functions f and g are elements of Hilbert spaces. In this equation, g is known and the idea is to invert L to obtain the unknown function $f = L^{-1}g$. The procedure involves a technique that transforms the operator equation (1) to a system of linear algebraic equations. To this end, the unknown function f is expanded in a series of basis functions $\{f_n\}$ with unknown constant coefficients $\{C_n\}$. Substituting this back into equation (1), and taking the inner product of both sides with a set of known testing functions $\{w_m\}$ reduces equation (1) to a simple matrix equation of the form:

$$\mathbf{Ax} = \mathbf{b} \quad (2)$$

where $\mathbf{A}$ and $\mathbf{b}$ are given by the inner products $A_{mn} = \langle w_m, Lf_n \rangle$, $b_m = \langle w_m, g \rangle$, and $\mathbf{x}$ is the vector of unknown coefficients $\{C_n\}$. Equation (2) is easily solved for $\mathbf{x}$ using elementary numerical methods which then yields f .

In order to apply this technique to reflector analysis, it is necessary to formulate the problem in the form of equation (1). This is accomplished by expressing the field scattered by the antenna as an integral of the unknown surface currents on the reflecting surface. Invoking the electromagnetic boundary condition that the tangential component of the total electric field be zero on a perfect conductor yields an equation for the unknown surface current density $\mathbf{J}_S$ in the form of equation (1):

$$\mathbf{u}_n \times \int_S \mathbf{J}_S \cdot (\nabla \nabla + k^2 \tilde{\mathbf{I}}) G dS = -j\omega\epsilon_0 \mathbf{u}_n \times \mathbf{E}^i \quad (3a)$$

which is a Fredholm integral equation of the first kind. Here:

$\mathbf{u}_n$: unit normal to the surface

$\tilde{\mathbf{I}}$: unit dyadic given by $\tilde{\mathbf{I}} = \mathbf{u}_x \mathbf{u}_x + \mathbf{u}_y \mathbf{u}_y + \mathbf{u}_z \mathbf{u}_z$

G : free space scalar Green's function, given by:

$$G = \frac{e^{-jk|r-r'|}}{4\pi|r-r'|}$$

with r' and r distances for the source and observation points respectively

$\mathbf{E}^i$: incident electric field

$k = 2\pi/\lambda_0$: free space wave number.

Equation (3a) can be solved by dividing the surface into small patches over each of which $\mathbf{J}_S$ is expanded as a sum of current components along two orthogonal directions. Alternatively, the reflector may be modelled in the form of a wire grid. This has the advantage that the scattered field can then be expressed as a one dimensional integral of current flowing along the wire. For the case of a thin wire segment along the z -direction defined by the unit vector $\mathbf{u}_z$, the appropriate equation of the form (1) can be given by:

$$j\omega\mu_0 \int [I(z) + (1/k^2)I'(z)(\mathbf{u}_z \cdot \nabla)] G dz = \mathbf{u}_z \cdot \mathbf{E}^i \quad (3b)$$

where the prime denotes the derivative. Equation (3b) is solved for the unknown current distribution by expanding it in a suitable set of basis functions.

In principle, this is the most accurate of all known methods used in electromagnetic scattering analysis. The formulation of the governing equation is exact, and extremely accurate solutions can be obtained by a suitable choice of basis and testing functions. In addition, struts, feed, subreflector and supporting structures can all be integrated into the problem. Well-defined surface irregularities on the reflector can be similarly modelled. The technique essentially fragments the complete structure into tiny linear or planar segments, on each of which a boundary condition directly derived from Maxwell's equations is applied by brute force. This results in a coupled system of equations in which electromagnetic interaction of every segment with every other segment is automatically accounted for. The method is, therefore, capable of predicting the complete antenna pattern at all points in space, taking into account the effect of antenna support and related sub-systems. Herein lies the difficulty: assuming a wire grid solution, if the reflector is modelled with M wire segments, and the current in each is represented by N basis functions, this would, in general, lead to a system of MN linear equations in as many unknowns, requiring the numerical evaluation of $(MN)^2$ integrals to obtain the elements of the coefficient matrix. Typically, 10 to 20 segments per wavelength with 3 basis functions per segment are needed for an accurate representation of the currents, leading to a system with over 650 unknowns per square wavelength of the reflecting surface.

In practice, however, some simplifications can be effected. In the case of focus-fed axi-symmetric reflectors, circular symmetry can be exploited to significantly reduce the number of unknown coefficients. In addition, Kirchoff's current law can be invoked at wire junctions to relate some of the unknown constants. In numerical electromagnetics code (NEC), a well-known commercially available suite of moment method software that uses equation (3b), the current $I(z)$ in each segment is represented as the sum of three terms – a constant, a sine and a cosine. Of the three coefficients, two are eliminated by the conditions that charge and current be continuous at wire junctions leaving only one constant, which determines the current amplitude, to be determined by matrix methods. For this representation to be adequate, the length of each wire segment needs to be less than $\lambda/10$, producing over 220 segments per square wavelength of the reflecting surface.

For a 100λ diameter reflector, in the absence of symmetry, this method would require determination of about 1.8 million elements in the coefficient matrix $\mathbf{A}$, followed by the inversion of a $1\,340 \times 1\,340$ complex matrix. If the sub-systems and support structures are also modelled, it would result in a significantly larger system of equations. Apart from CPU time, computer memory resources also increase rapidly with reflector size. The method is, therefore, computationally intensive, and is not a viable technique for electrically large reflectors. Typical maximum size for which the method of moments can be successfully applied is 10λ . If circular symmetry is exploited, reflectors as large as 25λ may be analysed. These limits are continuously extended with powerful computer machines becoming available but it is doubtful whether they can be applied to large reflector antennas, at least in the near future.

2.2 Aperture field method

The aperture field method is based on a theorem which states that if S is a closed surface enclosing a finite collection of sources Σ , then the field due to Σ at any arbitrary point exterior to S can be expressed in terms of integrals of field vectors $\mathbf{E}_a$ and $\mathbf{H}_a$ over S , where the subscript a refers to the tangential component. Thus, if S is chosen to be a sphere enclosing the antenna, then a spherical near-field scanning set-up can be used to measure the magnitude and phase of $\mathbf{E}_a$ and $\mathbf{H}_a$ over S , and from this the field of the antenna at every point in space outside S can be computed. However, measuring the near-field over a complete spherical surface surrounding a large reflector is very difficult, if not impossible, to carry out in practice. An alternative is to determine the fields over S by analytical techniques, but with complex sub-systems this is often an intractable problem and various approximations need to be invoked.

One such approximation, called the aperture field method (see Fig. 2a), is based on the assumption that $\mathbf{E}_a$ and $\mathbf{H}_a$ are non-zero over only a finite sector of S . This is justified in the case of a large class of focus-fed convex reflectors where there exists a finite closed contour Γ_A which circumscribes the family of all specularly reflected rays from the illuminated side of the reflector. The projection along the reflected ray paths on S defines a sector $A \in S$, bounded by Γ_A , over which $\mathbf{E}_a$ and $\mathbf{H}_a$ are computed using the laws of geometrical optics, with $\mathbf{E}_a = 0$ and $\mathbf{H}_a = 0$ over $S - A$. This prescription specifies a sharp discontinuity along Γ_A which is inconsistent with Maxwell's equations.

To overcome this difficulty, electric and magnetic charge densities are postulated along Γ_A in accordance with the equation of continuity. With this, the field scattered by the reflector is given by the expression:

$$\mathbf{E}_s = \int_A \left[-j\omega\mu(\mathbf{u}_n \times \mathbf{H}_a) - j(\omega\epsilon)^{-1}(\mathbf{u}_n \times \mathbf{H}_a) \cdot \nabla\nabla + (\mathbf{u}_n \times \mathbf{E}_a) \times \nabla \right] G \, dS \quad (4)$$