Simulation of secondary radiation pattern of MSMR antenna

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Received 2 January 1998; revised received 11 September 1998; accepted 13 October 1998

Simulation of secondary radiation pattern of the multifrequency scanning microwave radiometer (MSMR) has been presented in this paper. Simulated patterns are used, as many practical difficulties have been encountered during measurements. Aperture integration in conjunction with geometric theory of diffraction has been used for simulation of secondary pattern of offset parabolic reflector. The simulated and measured results are presented and fairly good agreement has been observed between them.

1 Introduction

The multifrequency scanning microwave radiometer (MSMR) to be launched on board IRS-P4 satellite will find its application in estimation and monitoring of a number of geophysical parameters related to the land, ocean and atmosphere. The antenna forms the most critical part of this radiometer. The MSMR antenna system is required to receive thermal microwave radiation emissions from earth at four frequency bands, viz. 6.6 GHz, 10.65 GHz, 18.0 GHz and 21.0 GHz. These four frequencies are received in two ports each for measuring horizontally and vertically polarized energy. A high degree of cross-polar isolation is required at each port. A high beam efficiency is also required for this antenna and the beam is required to scan about the yaw axis (axis of the feed). In order to meet these requirements an offset parabolic reflector having a large focus-to-diameter ratio (f/d) with a common feed for all the eight ports and having scanning mechanism about the feed axis has been designed.

A brightness temperature accuracy of 1 K is required to estimate the various geophysical parameters. In order to get brightness temperature of this accuracy the radiation pattern has to be measured in a very small interval at the boresight at each frequency and polarization and for a number of scan angles. However, such measurements at high frequency and for an antenna having a large aperture diameter in open test range are not possible, as it involves making measurements at a large distance in order to avoid phase errors associated with near-field measurements. No test range, in this country, has the capability for making far field measurements at such high frequency and for such large diameter antennas. Compact range measurements are also not possible because of large size and weight of this antenna and its support structure. Keeping up with the trend of shifting the reliance on numerical methods from expensive, time consuming and inaccurate measurements, it was decided to explore the possibility of simulation of secondary radiation pattern.

In the present work the secondary radiation pattern has been computed from measured primary radiation pattern using the aperture integration method for finding the pattern at main lobe and first few sidelobes, and geometric theory of diffraction has been used to find pattern at far sidelobes. The measured results at 30 m range has been compared with the simulated pattern at 30 m distance and was found to have a good agreement up to 20 dB level.

2 Description of MSMR antenna configuration

The geometry of MSMR antenna is shown in Fig.1. The MSMR antenna consists of an offset paraboloidal reflector having a projected aperture diameter of 800 mm and having an offset angle of 43.32°. A large value of f/d has been chosen in order to get a low cross-polarization. The feed consists of a corrugated horn with eight ports operating at four frequency bands. Each frequency band has two ports, namely, vertical and horizontal ports, for receiving radiation of only that particular polarization. Hence, a very high value of cross-polarization isolation (<=23 dB) is necessary.
3 Computation of secondary radiation pattern

A brief description of the analysis involved in aperture integration method for simulating the secondary pattern near the main lobe and first few side lobes, and the technique used for finding the diffracted fields from the rim of the reflector using geometrical theory of diffraction are given as follows.

3.1 Aperture integration method

A parabollic reflector antenna has the property that all path lengths from the focal point to the reflector and on to the aperture plane are the same.

The copolar primary radiation pattern of the feed is given by

$$E_r = e^{j\alpha} / r \{ e(j\theta_0 \phi_0)(a_{\phi_0} \sin \phi_0 + a_{\theta_0} \cos \phi_0) \}$$

where, $e(\theta_0, \phi_0)$ is the measured copolar primary pattern, $r$ the distance from the phase centre to the observation point, $k_0$ the wave number, and $\theta_0$, $\phi_0$ are, respectively, the elevation and the azimuth angles of the feed and $a_{\theta_0}$, $a_{\phi_0}$ are the unit vectors in the spherical co-ordinate system.

The reflected field from the reflector surface is given by

$$E_r = -E_r + 2(n.E_r)n$$

where, $n$ is the outward normal of the reflecting surface.

The electric field on the aperture of the reflector can thus be found following the methods illustrated by Collin. Any small displacement of the phase centre from the focus will result in a small change in phase of aperture field due to small path length perturbation.

From the equivalence principle the magnetic surface currents at the aperture plane can be found and the far field copolar radiation pattern can be computed.

3.2 Computation of secondary pattern using GTD

Aperture integration (AI) method fails to yield satisfactory results after main lobe and a first few side lobes. Therefore, geometric theory of diffraction (GTD) has been used to predict secondary pattern in the region where AI cannot be used. The switch-over from AI to GTD is done when $\theta > 1/AW$, where $AW$ is the aperture width of the reflector in terms of $\lambda$, as at this value of $\theta$, the value of the field obtained by AI and GTD are found to be the same. The value of a field in a diffracted ray is determined from the incident field with the aid of appropriate diffraction coefficients, that is, a dyadic for electromagnetic fields. The diffraction and attenuation coefficients are usually determined from the asymptotic solutions of the simplest boundary value problems, which have the same local geometry at the points of diffraction as the object at the point of interest. The primary objective of using GTD is to resolve each problem into smaller components, each representing a canonical geometry of a known solution.

The GTD analysis of the reflector is similar to that of diffraction by a flat plate in which each segment is treated as an edge of a flat plate which is tangential to reflector surface. Uniform GTD techniques are used to calculate the edge-diffracted and slope-diffracted fields. The reflector rim is treated as a piecewise linear segments.

The slope-diffracted fields are calculated in a similar way except that the slope-diffraction coefficients $\partial D_s / \partial \phi'$ and $\partial D_s / \partial \psi'$ and the slope-diffraction coefficients $\partial E / \partial n$ of the incident field at the edge are used.

Since each rim segment is small, the diffractions from its two end-points are significant. These diffractions are calculated by using the corner diffraction analysis. The corner diffraction
compensates for the discontinuity which occurs when the diffraction point moves off to the rim segment.

4 Numerical results and conclusions

The various input parameters given to simulate the secondary pattern like focus, diameter of the reflector, etc. were as per the physical dimension of the antenna system. The primary radiation pattern was measured at various $\phi$ cuts and were given as input to the programme. Since a common feed has been used for four different frequency bands the phase centre at each frequency band was measured in the anechoic chamber and the displacement of the phase centre from the focus was also given as input to the code.

The simulated secondary patterns for a near field distance of 30 m [Space Applications Centre (SAC) test range distance] was compared with the measured patterns carried out at SAC test range at various frequencies and different $\phi$ cuts. The simulated and experimental results show good agreement as shown in Figs 2-9, thereby validating the software used. Figures 10 and 11 show the $E$-plane and $H$-plane patterns at 18.0 GHz having both slope and corner diffractions. Figures 12 and 13 show the $E$-plane and $H$-plane patterns at 18.0 GHz without taking into account the slope diffraction and Figs 14 and 15 show the $E$-plane and $H$-plane patterns without taking corner diffraction.

Table 1 shows the comparison between measured and simulated patterns in terms of $-10.0$ dB beam efficiency.

Since the scan of reflector about yaw axis is equivalent to rotation of the feed around its own axis, this can be used to predict the secondary radiation pattern for various scan angles by just simulating the rotation of the feed. This software can be used to predict the performance of any offset reflector antenna by just characterizing its primary radiation pattern.

Therefore, from Table 1 and Figs 2-15 it can be concluded that simulated far field secondary patterns can be used for characterizing MSMR antenna, and measurements which are error prone and time consuming can be avoided.

![Figure 2](image-url)

*Fig. 2—Curves showing the $E$-plane pattern at 6.6 GHz*
Fig. 3—Curves showing the H-plane pattern at 6.6 GHz

Fig. 4—Curves showing the E-plane pattern at 10.65 GHz
Fig. 5—Curves showing the $H$-plane pattern at 10.65 GHz

Fig. 6—Curves showing the $E$-plane pattern at 18.0 GHz
Fig. 7—Curves showing the $H$-plane pattern at 18.0 GHz

Fig. 8—Curves showing the $E$-plane pattern at 21.0 GHz
Fig. 9—Curves showing the H-plane pattern at 21.0 GHz

Fig. 10—Curves showing the E-plane pattern at 18.0 GHz
Fig. 11—Curves showing the $H$-plane pattern at 18.0 GHz

Fig. 12—$E$-plane pattern at 18 GHz without slope diffraction
Fig. 13—H-plane pattern at 18 GHz without slope diffraction

Fig. 14—E-plane pattern at 18 GHz without corner diffraction
Table 1—Comparison of measured and simulated -10 dB beam efficiency

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<tr>
<th>Frequency (GHz)</th>
<th>Measured efficiency (%)</th>
<th>Simulated efficiency (%)</th>
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<tbody>
<tr>
<td>6.6</td>
<td>87.35</td>
<td>87.17</td>
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<tr>
<td>10.65</td>
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<td>90.66</td>
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<td>18.0</td>
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<td>21.0</td>
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</table>

Fig. 15—H-plane pattern at 18 GHz without corner diffraction

Acknowledgements

The authors wish to thank the Director, SAC, Ahmedabad, for providing them an opportunity to work with Prof. N Balakrishnan at IISe, Bangalore, and for his encouragement and support. The authors also thank Prof. N Balakrishnan, Chairman, SERC, IISe, Bangalore, for agreeing to collaborate with SAC for development of software for reflector antenna in spite of his heavy schedule. The authors are also thankful to their colleagues in SAFG, for various help given in carrying out this exercise.

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