Calculations of radiation characteristics of reflector antennas with surface deformation and perforation

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\textbf{ABSTRACT}

To investigate the radiation characteristics of reflector antennas with surface deformation and perforation, the physical optics (PO) method and physical theory of diffraction (PTD) technique are used to calculate the far field and the diffraction of the reflector edge. The computational method is verified reliably by comparing the calculation curve with the experimental curve. As a consequence, the radiation patterns for different deformation properties and different perforation densities are computed. The results show that the deformation of the reflector surface greatly affects the radiation pattern. But in the calculated density range of holes, perforation affects the radiation characteristics less.

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1. Introduction

Radar is the modern core of operational command systems, underpinning alerts, target tracking and missile guidance; once the radar is lost, a defense system goes down. So in the information battlefield, radar is the primary focus of the attack by the various anti-radiation weapons. A reflector antenna is the most common type of radar antenna, which is widely used in guidance, searching, and warning radar. Studies on the reflector antenna have been mainly concentrated on the analysis and synthesis theory, including the effect of random surface error and small distortion [1–5], but the random error method cannot be used to calculate radiation characteristics of a reflector antenna with large deformation and perforation. However, in the battlefield, reflector antennas could be deformed and perforated by shock waves and fragments produced by warheads. These large deformations and perforations will greatly affect the radiation characteristics of the reflector antenna. Therefore, it is necessary to investigate the radiation effects of a reflector with deformation and perforation. Research on reflectors with large deformation and perforation has rarely been reported in the literature. In this paper, the physical optics (PO) method and physical theory of diffraction (PTD) technique are used to calculate the radiation characteristics of reflector antennas with deformation and perforation. An efficient computational method is presented for setting up the relationships of structural deformation/perforation and electrical properties of the reflector antennas.

2. The computational method

According to the physical optics (PO) method, the electric far field can be expressed as

\[ E_{PO} = B \int_{s} \frac{E_i}{r} \left[ \hat{n} \times (\hat{r} \times \hat{e}_i) \right] e^{-j\mu r (1-\hat{r})} ds, \]

(1)

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with the coefficient
\[
B = -\frac{j\nu \mu}{2\pi} \left[ \left( \frac{\varepsilon}{\mu} \right) \frac{P}{2\pi} \right]^{\frac{1}{2}} \frac{e^{jR}}{R},
\]
where \( P \) and \( E_i \) are the radiation power and the incident electric field of the feed, respectively; \( s \) is the area of the reflector surface; \( \mathbf{r} \) is the vector from the focal point to the arbitrary point of the reflector; \( \mathbf{R} \) is the vector from the origin to the observation point; \( r \) and \( R \) are the absolute values of \( \mathbf{r} \) and \( \mathbf{R} \), respectively; \( \hat{\mathbf{r}} \) and \( \hat{\mathbf{R}} \) are the unit vectors of \( \mathbf{r} \) and \( \mathbf{R} \), respectively; \( \hat{\mathbf{n}} \) is the unit normal vector of the reflector surface, and \( \hat{\mathbf{e}} \) is the unit polarized vector of the incident field.

The diffraction effects of the reflector edge are calculated by the PTD technique. According to the method of equivalent currents, the far diffraction field of the reflector edge can be expressed as
\[
E_{PTD} = jk_0 \frac{e^{-jk_0 r}}{4\pi R} \int \left[ \frac{\eta_0 I(\mathbf{r}') \hat{\mathbf{k}}_s \times (\hat{\mathbf{k}}_s \times \hat{\mathbf{t}}) + M(\mathbf{r}') (\hat{\mathbf{k}}_s \times \hat{\mathbf{t}})}{R} \right] e^{j\mathbf{r}' \cdot \hat{\mathbf{t}}} d\mathbf{l},
\]
where \( I(\mathbf{r}') \) and \( M(\mathbf{r}') \) are the equivalent current and magnetic current, respectively; \( \eta_0 \) is the wave impedance of free space; \( \mathbf{r}' \) is the vector of any point of the reflector edge. \( \hat{\mathbf{k}}_s \) is the vector of the scattering wave and \( \hat{\mathbf{t}} \) is the unit tangential vector of the split edge.

So the total radiation field can be written as
\[
E = E_{PO} + E_{PTD}.
\]

In order to verify the computational method, the radiation characteristic of a normal reflector is calculated. The selected reflector antenna is a kind of shaped antenna which is used for low altitude surveillance. The feed of the reflector antenna is a dual-mode (TE11 and TM11) horn. The polarization is vertical. The comparisons of the calculated field and the measured field obtained by Liu [6] are shown in Fig. 1. The calculated results are in good agreement with the experimental curve. Therefore, the computational method is reliable for the calculation of radiation characteristics.

### 3. Numerical results for radiation characteristics

Shock waves and fragments are mainly damage elements for destroying the reflector antennas. Typically, the shock waves will deform the surface of reflector antennas and fragments will perforate them. In this paper, the deformation and perforation of reflector antennas are considered. The reflector antenna is shown in Fig. 2; the caliber is 2.5 m. The feed of the reflector antenna is a dual-mode horn.

#### 3.1. Deformation of the reflector surface

The deformation of the reflector antennas is caused by the explosion of explosives, which are located at different positions. The explosive is TNT, which has a weight of 1.68 kg. The shock waves produced by TNT explosion frontally act on the antenna surface. The deformation area of the reflector surface is simulated by LSDYNA software [7]. The radiation patterns under different loadings of shock waves are shown in Fig. 3.

From Fig. 3, we can see that the deformation of reflector surfaces greatly affects radiation patterns. The peak side-lobe levels of radiation patterns increased rapidly with the distances of the reflector and explosive decreasing. Because the distance of the reflector and explosive is smaller, the deformation of the reflector surface is more serious. The pattern, deviated from the center of the main lobe, becomes disordered and shows divergence, which has little “bunching” capability.
3.2. Perforation of the reflector surface

Fragments with high velocity can easily perforate the reflector surface. According to the experiments, the fragment distributions can be classified into two kinds: uniform distributions and normal distributions. To simplify the calculation, a uniform distribution of holes was considered. The holes on the reflector antenna are assumed as circles, with diameter 2.3 cm.
According to the PO method, the surface current $\mathbf{J}_s$ can be assumed as

$$\mathbf{J}_s = \begin{cases} 2\hat{n} \times \mathbf{H}_i & \text{if the area without hole} \\ 0 & \text{if the area with hole} \end{cases}$$

where $\hat{n}$ is the unit normal vector of the reflector surface; $\mathbf{H}_i$ is the incident magnetic field.

The patterns are illustrated in Fig. 4. We can see that the main lobes of the patterns are almost identical in the two cases, with and without holes. The peak side-lobe level in the case with holes is higher than that in the case without holes, but in the calculated density range of holes (60–100 holes/$m^2$), perforation affects the radiation characteristics less. Due to the reflector having holes on the surface, some of the power will lose, so the side-lobe level rises.

4. Summary

In this paper, a combination of the PO method and the PTD technique is utilized to calculate the radiation characteristics of deformed and perforated reflector antennas. In this computational method, the electric far field is calculated by the PO method and the diffraction of the reflector edge is computed by the PTD technique. The computational method is verified reliably by comparing the calculation results with the experimental curve. The radiation patterns for different deformation areas and different perforation densities of reflector antennas are presented using the computational method, which is an efficient computational method for calculating the radiation characteristics of reflector antennas. The results calculated are very helpful for the structural design of reflector antennas and the operational use of anti-radiation weapons.

References