An Extrapolation Method of Far-Field Bistatic Scattering Cross Section Using Near-Field data

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1 Introduction

The far-field Radar Cross Section (RCS) measurement of a large scatterer is generally difficult due to a limitation of available measurement range. The far-field range R is defined by $R > 2D^2/\lambda$ where D is the largest dimension of the scatterer and λ is an operating wavelength. For example the measurement range must be larger than 600m in the case of D=3m at 10GHz. One way to avoid the above difficulty is to adopt a scale model by the compact range measurement [1]. However, there are some problems in this measurement: it requires labors and expenses to construct the scale model, and the frequency characteristics of the surface impedance of the scatterer may not be reproduced at shorter wavelength measurements [2]. So the real target measurement is necessary to obtain accurate data. There exists the near-field antenna measurement technique [3], however a direct application of this technique for the RCS measurement fails because RCS depends on the locations of both the source and the observation points. Falconer has overcome the above difficulty and successfully estimated the far-field RCS by the near-field RCS measurement [4]. We have also proposed a far-field RCS prediction algorithm which uses cylindrical or planar near-field RCS data [5]. However these algorithms are applicable only for the prediction of monostatic RCS. In this paper a far-field bistatic Scattering Cross Section (SCS) prediction algorithm which uses near-field SCS data is obtained by extending the proposed algorithm. We predict the far-field SCS by using calculated near-field SCS data of the conducting rectangular plate. The validity of our algorithm is examined.

2 Extrapolation Method of Far-Field SCS

2.1 Bistatic Scattered Field and Scattering Coefficient

We derive the relation between bistatic scattered field and scattering coefficient. A scatterer and the coordinate system are shown in Fig.1. Any characters with prime indicate a quantity in terms of source. A source point and an observation point are located at the point P' and P, respectively. Q(=(x,y,z)) is an arbitrary point on the scatterer surface. $\hat{\mathbf{n}}$ is an outward unit vector normal to the surface of the scatterer. At first we approximate incident electric field $\mathbf{E^i}$ and magnetic field $\mathbf{H^i}$

$$\mathbf{E^i} \approx \frac{E_0 \exp(-jkr)}{r}\hat{\mathbf{e}}', \qquad \mathbf{H^i} \approx \frac{\mathbf{E^i} \times \hat{\mathbf{s}'}}{\eta}. \tag{1}$$

where $\hat{\mathbf{s}'}$ is a unit vector from P' to origin, η is the free space wave impedance, E_0 is a constant which determines field strength, and $\hat{\mathbf{e}}'$ is the polarization vector of the incident electric field. According to physical optics, we obtain approximate currents $\mathbf{J^{PO}}$ on the scatterer and related vector potential $\mathbf{A^{PO}}$

$$\mathbf{A^{PO}} = \frac{\mu}{4\pi}\iint \mathbf{J^{PO}}\frac{\exp(-jkr)}{r}dS \qquad \mathbf{J^{PO}} \equiv 2\hat{\mathbf{n}} \times \mathbf{H^i}. \tag{2}$$

The integration must be carried out on the whole lit region of the scatterer. Observed electric field $\mathrm{E^s}$ is obtained using the far-field approximation

$$\begin{aligned}\mathrm{E^s} &\approx j\omega(\mathbf{A^{PO}} \times \hat{\mathbf{s}} \times \hat{\mathbf{s}}) \cdot \hat{\mathbf{e}} \\ &\approx \frac{E_0}{j\lambda RR'}\iint \mathrm{S(x,y,z)}\exp\{-2jk(r+r')\}dS \end{aligned}\tag{3}$$

$$\mathrm{S(x,y,z)} \equiv [\{\hat{\mathbf{n}} \times (\hat{\mathbf{s}'} \times \hat{\mathbf{e}}')\} \times \hat{\mathbf{s}} \times \hat{\mathbf{s}}] \cdot \hat{\mathbf{e}}. \tag{4}$$

where $\hat{\mathbf{e}}$ is a polarization vector of observation and $\hat{\mathbf{s}}$ is a unit vector from origin to P.

This equation shows that bistatic scattered field is obtained by integrating $\mathrm{S(x,y,z)}$ with both phases in terms of source and observation. We define $\mathrm{S(x,y,z)}$ as *scattering coefficient* because the scattered field strength is determined by $\mathrm{S(x,y,z)}$.

2.2 Derivation of Extrapolation Algorithm

Fig.2 shows a coordinate system of spherical scanning for an extrapolation of far-field SCS. We take the X axis in the central direction of required bistatic angle:2α. A source point P' is fixed on the line between origin and required far-field source, and the distance from origin is ρ. An observation point P is defined in the same manner. The scanning angles θ and ϕ are defined by the rotational angles of scatterer in YZ and XY plane, respectively. When points P and P' are in the fresnel region, r and r' can be approximated by expanding in a power series of ρ and neglecting the lower order terms than ρ^{-2}[6]. Then we obtain the approximate equation of the distance r+r' under the condition that the scanning angles θ, ϕ and bistatic angle 2α are small enough

$$r + r' \approx 2\rho - 2\cos\alpha x - 2\phi\cos\alpha y - 2\theta\cos\alpha z + \frac{y^2+z^2}{\rho} \tag{5}$$

Substituting (5) into (4), we can obtain the relation expressed by the scanning angles θ and ϕ

$$\begin{aligned}\mathrm{E^s}(\rho,\phi,\theta) &\approx \frac{E_0}{j\lambda}\frac{\exp(-2jk\rho)}{\rho^2}\iint \mathrm{S_e(y,z)}\exp\{-\frac{jk(y^2+z^2)}{\rho}\} \\ &\cdot \exp(2jk\cos\alpha\phi y + 2jk\cos\alpha\theta z)dydz \end{aligned}\tag{6}$$

$$\mathrm{S_e(y,z)} \equiv \mathrm{S(x,y,z)}\exp(2jk\cos\alpha x)/(\hat{\mathbf{n}} \cdot \hat{\mathbf{x}}). \tag{7}$$

We define $\mathrm{S_e(y,z)}$ as *equivalent scattering coefficient* in this paper. $\mathrm{S_e(y,z)}$ depends on the scanning angles θ and ϕ. However it is not so different for small scanning angles. Taking the inverse transform of (6), we can obtain the next approximate equation:

$$\begin{aligned}\mathrm{S_e(y,z)} &\approx \frac{4j\rho^2\cos^2\alpha}{E_0\lambda}\exp\left\{jk\left(2\rho + \frac{y^2+z^2}{\rho}\right)\right\} \\ &\cdot \iint_{\theta_w,\phi_w} \mathrm{E^s}(\rho,\phi,\theta)\exp(-2jk\cos\alpha\phi y - 2jk\cos\alpha\theta z)d\phi d\theta \end{aligned}\tag{8}$$

where θ_w and ϕ_w are the measured range of scanning angle. This equation shows that the equivalent scattering coefficient $\mathrm{S_e(y,z)}$ can be obtained by taking the Fourier transform of the bistatic scattered field data, as weighted with the factor $\exp\left\{jk\left(2\rho+\frac{y^2+z^2}{\rho}\right)\right\}$. We have obtained the fundamental relations between SCS data and $\mathrm{S_e(y,z)}$.

The extrapolation procedures of the far-field SCS are as follows. First we measure the bistatic scattered field data within the ranges of scanning angles θ_w and ϕ_w. The equivalent scattering coefficient $\mathrm{S_e(y,z)}$ can be obtained by taking the weighted Fourier transform of these measured SCS data by using (8). The scattered electric field in the far-field region can be obtained by taking sufficiently large ρ in (6) and $\theta=\phi=0$. The integration of (8) is carried out in a projected region of the scatterer on the YZ plane. We obtain SCS:σ using standard definition

$$\sigma=\frac{4\pi}{\lambda^2}\left|\iint_{y_w,z_w}\mathrm{S_e(y,z)}dydz\right|^2. \tag{9}$$

3 Simulation Results

We examine the algorithm described here by extrapolating far-field SCS using calculated near-field data. The calculation model is a conducting plate shown in Fig.3 and analysis specifications are shown in Table.1. We investigate two kinds of bistatic angles 30°, 90° and these simulation results are shown in Fig.4 and Fig.5. A horizontal axes in these figures indicate an angle between X axis and central direction of bistatic angle. Both near-field and far-field SCS data are calculated by "Separated Equivalent Edge Current Method" [7], which is a kind of equivalent edge current method. The extrapolated far-field SCS for bistatic angle of 30° agree with calculated far-field SCS. However the result for bistatic angle of 90° does not correspond to calculated one. This is caused by the derivation of (5) using small bistatic angle.

4 Conclusion

We have proposed an extrapolation method of far-field bistatic scattering cross section by using near-field bistatic data. We examine the algorithm described here by extrapolating far-field SCS using calculated near-field data. The validity of our algorithm is demonstrated.

References

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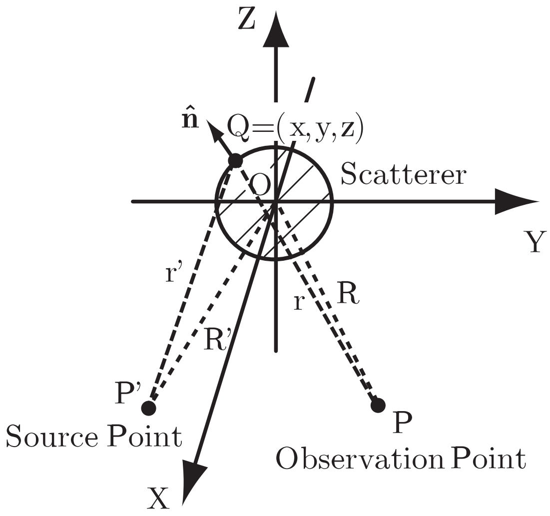

Figure 1: Coordinate System for Scattered Field Calculation.

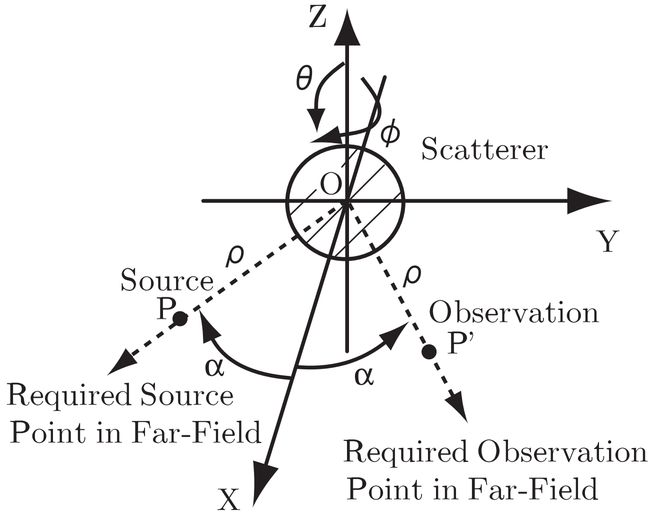

Figure 2: Coordinate System for Spherical Scanning.

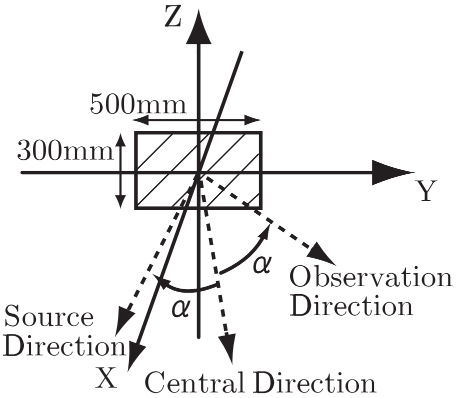

Figure 3: Calculation Model.

Table 1: Analysis Specifications.

Frequency	10GHz
Calculated Range from Scatterer:ρ	5m
Range of Scanning Angle :θ_w	10°(±5°)
Range of Scanning Angle :ϕ_w	10°(±5°)

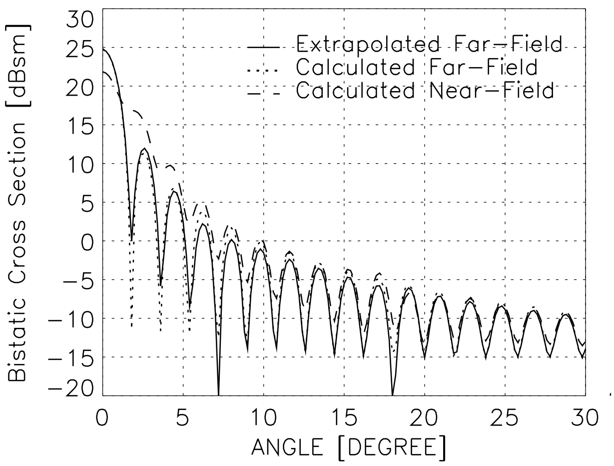

Figure 4: Extrapolated Far-Field SCS of Bistatic angle:30°.

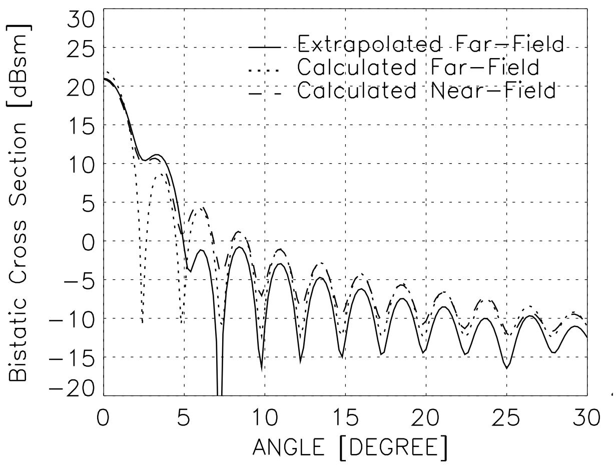

Figure 5: Extrapolated Far-Field SCS of Bistatic angle:90°.