Efficient RCS Measurement Technique by Near-Field Far-Field Transformation Which Utilize 2-D Plane-Wave Expansion

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***Abstract*—A near-field far-field (NF-FF) transformation technique for RCS measurement is proposed. This technique employing two dimensional plane-wave expansion enables us to measure RCS from two dimensional near-field measurement. It cause significant reduction of near-field measurement cost for relatively thin measurement targets. In comparison with other 2-D transformation techniques, this technique promised more accurate transformation by its capability of transmitting and receiving antennas correction or Fast Multipole Method (FMM)-like source decomposition.**

I. Introduction

RCS of vehicles or aircrafts is important information for civil and military applications. For instance, RCS of aircrafts is of interest for instrument landing system (ILS). However, its measurement often met difficulty because of the target's large size (absolute or wavelength relative). For reduction of its large necessity, near-field far-field (NF-FF) transformation is object of many research activities. As a transformation technique, NF-FF transformation technique for antenna measurement [1] can be applied to RCS measurement. In [2], we use a transformation technique employing plane wave expansion [3] and measure RCS of some targets accurately. Although the transformation technique can be used for arbitrary shaped target, it requires bistatic field measurement and cause requirement of large measurement costs (equipment size or time). Bistatic measurement in each incident angles is inefficient especially for the purpose of only monostatic RCS measurement. For monostatic near-field RCS measurement, some transformation techniques have been proposed [4]–[6]. These enable us to estimate far-field monostatic RCS from near-field monostatic measurement only. These techniques use effectively reflectivity approximation used in synthetic aperture radar (SAR). Although the approximation is not valid for some structures such as corner reflectors, these techniques indicate sufficient accuracy for many targets. A transformation technique proposed in [7] is one of these techniques. It employs plane-wave expansion used in Fast Multipole Method (FMM). The transformation technique is characterized by its capability of transmitting/receiving (Tx/Rx) antennas correction or FMM-like target decomposition. The second term is used for reduction of Green's function approximation effect caused in monostatic NF-FF transformation techniques. Through these characteristics, this transformation technique is promised to act more accurate transformation relatively to others. However, plane-wave expansion used in the technique is three dimensional, so it requires near-field measurement on the 3-D scan surface. Toward this problem, we propose a transformation technique employing 2-D plane-wave expansion. Using it, monostatic RCS for relatively thin target is estimated from near-field measurement on 2-D line. Accordingly, our proposed transformation has similar advandage to 3-D plane-wave expansion method and, in addition, it significantly reduce its measurement cost.

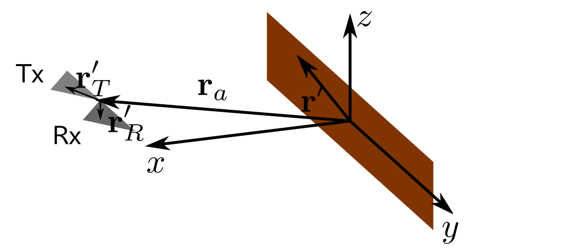

Fig. 1. NF measurement geometry. Tx/Rx antennas located on $\mathbf{r}_a$ on xy plane.

II. Formulation

In this section, we formulate our proposed transformation technique. At first, NF measurement geometry is illustrated in fig. 2. By same formulation as [7], receiving output voltage of Rx antenna is represented as follows,

$$U(\mathbf{r}_a) = \iiint_{V'_R} \iiint_{V'} \iiint_{V'_T} \mathbf{w}_R(\mathbf{r}'_R) \cdot \overline{\mathbf{G}}(\mathbf{r}_a + \mathbf{r}'_R, \mathbf{r}') \cdot \overline{\mathbf{s}}(\mathbf{r}') \cdot \overline{\mathbf{G}}(\mathbf{r}', \mathbf{r}_a + \mathbf{r}'_T) \cdot \mathbf{w}_T(\mathbf{r}'_T) d\mathbf{r}'^3_T d\mathbf{r}'^3 d\mathbf{r}'^3_R \quad (1)$$

where $\mathbf{w}_{R/T}$ is the weighting functions of Rx/Tx antennas and $\overline{\mathbf{s}}$ is reflectivity of the target under test. $\mathbf{r}_a$ equals to location of the Rx/Tx antennas and $\mathbf{r}'_{R/T}$ location in the Rx/Tx's volume. In [7], the Green's functions in (1) are expanded by plane wave expansion used in 3-D FMM. In our transformation technique, in contrast, the 3-D Green's functions in (1) is approximated to 2-D Green's function (Hankel function) and applied plane-wave expansion used in 2-D FMM.

Green's functions in (1) is approximated as follows,

$$\begin{aligned}&\frac{e^{-jk\left|\mathbf{r}_a+\mathbf{r}'_R-\mathbf{r}'\right|}}{\left|\mathbf{r}_a+\mathbf{r}'_R-\mathbf{r}'\right|}\cdot\frac{e^{-jk\left|\mathbf{r}_a+\mathbf{r}'_T-\mathbf{r}'\right|}}{\left|\mathbf{r}_a+\mathbf{r}'_T-\mathbf{r}'\right|}\\ &\approx \frac{e^{-j2k\left|\mathbf{r}_a+\frac{\mathbf{r}'_T+\mathbf{r}'_R}{2}-\mathbf{r}'\right|}}{\left|\mathbf{r}_a+\frac{\mathbf{r}'_T+\mathbf{r}'_R}{2}-\mathbf{r}'\right|^2}\approx\frac{1}{r_a}\frac{e^{-j2k\left|\mathbf{r}_a+\frac{\mathbf{r}'_T+\mathbf{r}'_R}{2}-\mathbf{r}'\right|}}{\left|\mathbf{r}_a+\frac{\mathbf{r}'_T+\mathbf{r}'_R}{2}-\mathbf{r}'\right|}\end{aligned} \quad (2)$$

and as follows,

$$\begin{aligned}&\frac{1}{r_a}\frac{e^{-j2k\left|\mathbf{r}_a+\frac{\mathbf{r}'_T+\mathbf{r}'_R}{2}-\mathbf{r}'\right|}}{\left|\mathbf{r}_a+\frac{\mathbf{r}'_T+\mathbf{r}'_R}{2}-\mathbf{r}'\right|}\\ &\quad\approx\sqrt{\frac{\pi k}{r_a^3}}e^{j\frac{\pi}{4}}H_0^{(2)}\left(2k\left|\mathbf{r}_a+\frac{\mathbf{r}'_T+\mathbf{r}'_R}{2}-\mathbf{r}'\right|\right).\end{aligned} \quad (3)$$

In (2) and (3), 3-D green function is approximated to 2-D green function. Using 2-D plane-wave expansion [8], here, Hankel function in (3) is expand as

$$\begin{aligned}&H_0^{(2)}\left(2k\left|\mathbf{r}_a+\frac{\mathbf{r}'_T+\mathbf{r}'_R}{2}-\mathbf{r}'\right|\right)\\ &\quad=\frac{1}{2\pi}\int_0^{2\pi}T_N(\beta,k\mathbf{r}_a)e^{-jk\hat{\mathbf{k}}\cdot\mathbf{r}'_T}e^{-jk\hat{\mathbf{k}}\cdot\mathbf{r}'_R}e^{jk\hat{\mathbf{k}}\cdot\mathbf{r}'}d\beta\end{aligned} \quad (4)$$

where $\hat{\mathbf{k}}=\cos\beta\hat{\mathbf{x}}+\sin\beta\hat{\mathbf{y}}$ and T_N is called translation operator in 2-D FMM applications. Here, it should be noted that the target is assumed to be sufficiently thin in $\hat{\mathbf{z}}$ direction. Specifically, it need to be so thin that the measurement distance can be thought as sufficiently "far" (usually detected by the criterion $2d^2/\lambda$) so that 2-D plane-wave expansion in (4) is performed. Using (2)–(4) results in following equation,

$$\begin{aligned}U(\mathbf{r}_a)=\frac{k^2Z_F^2}{4^2\pi^2}\sqrt{\frac{k}{4\pi r_a^3}}\int_0^{2\pi}&T_N(\beta,k\mathbf{r}_a)\\ &\tilde{\mathbf{W}}_R(\mathbf{k})\cdot\left(\bar{\mathbf{I}}-\hat{\mathbf{k}}\hat{\mathbf{k}}\right)\cdot\bar{\mathbf{S}}(\mathbf{k})\cdot\tilde{\mathbf{W}}_T(\mathbf{k})d\beta\end{aligned} \quad (5)$$

where Z_F indicates characteristic impedance and $\tilde{\mathbf{W}}_{R/T}$ correspond to Rx/Tx antenna's directivity. In above equation, reflectivity $\left(\bar{\mathbf{I}}-\hat{\mathbf{k}}\hat{\mathbf{k}}\right)\cdot\bar{\mathbf{S}}(\mathbf{k})$ corresponds to FF RCS and in our transformation technique and is estimated by solving integral equation (5). The integral equation is discretized and solved by means of linear equation solver, such as conjugate gradient (CG) algorithm or singular value decomposition (SVD). In our implementation, the integral equation is discretized by the trapezoidal rule and resulted non-square matrix equation is solved by CG on the normal equation (CGNR) algorithm [9].

III. Measurement Result

In this section, we verify the transformation technique formulated in previous section. The geometry is illustrated in fig. 2. An aluminum made $24\lambda \times 4\lambda$ rectangular plate is chosen as the target under test. Observed frequency is 12GHz. NF measurement is act on circular line whose radius is 271λ and sampling interval $\Delta\phi = 0.2°$. Fig. 3 shows the results. Results observed by the transformation technique shows good agreement with reference value simulated using the electromagnetic field simulator HFSS.

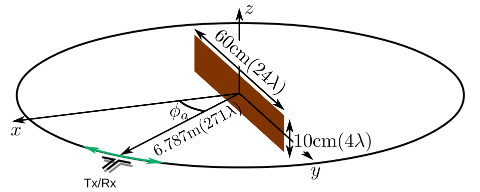

Fig. 2. Measurement on circular line.

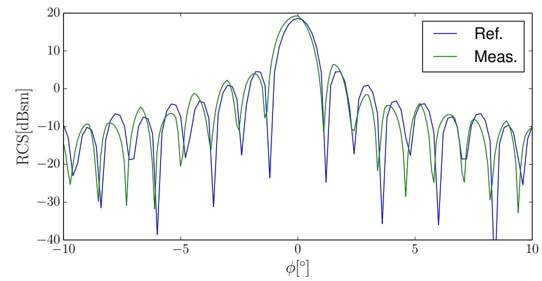

Fig. 3. RCS measurement result on $\theta = 90°$ plane. The reference values are calculated by HFSS.

IV. Conclusion

In this paper, we proposed an NF-FF transformation technique which have the advantage similar to 3-D plane wave expansion method [7]. The difference from 3-D method is, our usage of 2-D plane wave expansion and capability of 2-D on-line NF measurement. It significantly reduce the measurement cost for relatively thin measurement target. Effectiveness of our transformation technique is shown in a measurement result.

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