Quasi-Monostatic Microwave Imaging Using Multi-Source Illumination

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Abstract

In this paper, the principle and experimental results of quasi-monostatic frequency-swept microwave imaging of conducting objects using multi-source illumination are presented. Images of scattering objects reconstructed from the experimental data measured in the frequency range 7.5GHz-12.5GHz are shown in good agreement with the scattering object geometries.

I. Introduction

The theory of monostatic microwave imaging for perfectly conducting objects based on Bojarski's identity was described in [1-2]. For better image resolution, frequency and angular diversity techniques [3-5] are adopted to enlarge the area of object Fourier-domain data. However, in order to acquire the object scattering information in the angular direction, one has to rotate the scattering object at the corresponded viewing angle and then record the object scattered field in a sequential format. It becomes an unefficient approach when better angular resolution is required. In this paper, the quasi-monostatic microwave imaging using multi-source illumination is exploited to obtain multiple sets of the object Fourier-domain data contributed from multiple sources at the same time. In other words, multi-source illumination is used to reduce the object rotation angle needed. The principle of quasi-monostatic microwave imaging using multi-source illumination is given in Section II. The experimental results in Section III demonstrate the developed microwave imaging system is an efficient approach as compared with that using single-source illumination.

II. Principle

The quasi-monostatic backscattering geometry for multi-source illumination is shown in Fig. 1. The scattering object is illuminated by multiple normally incident TM-polarized plane waves simultaneously. The transmitting and receiving antennas are in the far-field region. The scattered field recorded by the receiving antenna can be represented as

$$U^s = \frac{-jk_0 e^{-jkr}}{|\bar{r}-\bar{r}'|} \sum_{i=1}^{n} E_i \iint O_i(\bar{r}') e^{jk_0(\hat{k}-\hat{k}_i)\cdot\bar{r}'} d^2\bar{r}' \tag{1}$$

where E_i is the amplitude of the i-th illuminating plane wave. $O_i(\bar{r}')$ is the partial microwave image contributed from the i-th source illumination.

By performing the Fourier transformation, (1) can be expressed as

$$U^s = C_R \sum_{i=1}^{n} E_i \widetilde{O}_i(\bar{p}_i) \tag{2}$$

where C_R is the range related term $-jk_0 e^{-jkr}/|\bar{r}-\bar{r}'|$. $\bar{p}_i$ is defined as

$$\begin{aligned} \bar{p}_i &= p_i \hat{p}_i = k_0(\hat{k}-\hat{k}_i), \\ &= k_0 \cos\frac{\theta_i}{2} \hat{p}_i \end{aligned} \tag{3}$$

where θ_i is the angle between i-th source and the receiving antenna.

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The Fourier transformation of $O_i(\bar{r})$ is given as

$$\tilde{O}_i(\bar{p}_i) = \iint O_i(\bar{r}) e^{j\bar{p}_i \cdot \bar{r}} d^2\bar{r} . \tag{4}$$

In order to properly extract each partial microwave image contributed from the corresponding source illumination, a set of n arrangements of (2) with different illuminating amplitude E_i are written as

$$\begin{bmatrix} U_1^s \\ U_2^s \\ \vdots \\ U_n^s \end{bmatrix} = C_R \begin{bmatrix} E_{11} & E_{12} & \cdots & E_{1n} \\ E_{21} & E_{22} & \cdots & E_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ E_{n1} & E_{n2} & \cdots & E_{nn} \end{bmatrix} \begin{bmatrix} \tilde{O}_1 \\ \tilde{O}_2 \\ \vdots \\ \tilde{O}_n \end{bmatrix} . \tag{5}$$

With the use of frequency diversity technique to have k_0 swept from k_1 to k_2, (5) shows that n lines of the Fourier-domain data contributed from n illumination sources can be extracted from the n sets of scattered field recorded at one viewing angle, as the matrix $[E_{ij}]$ is a known non-singular matrix. In other words, an n-fold Fourier-domain data can be obtained by using n-source illumination. This is then equivalent to the Fourier-domain data obtained with single-source illumination at n different object rotation angles. Therefore, by correctly locating the exacted Fourier-domain data one can efficiently acquire the object Fourier-domain information. Figure 2 shows the three-fold Fourier-domain acquired using three-source illumination at the viewing angles indicated by the little black dots.

III. Measurement system and Results

Figure 3 shows the developed experimental microwave imaging system. It has three horn antennas at about $30°$, $0°$ and $-30°$ for simultaneously transmitting swept-frequency microwave signals with power levels controlled by three attenuators. The receiving horn antenna is at about $0°$ for collecting the object scattered field. All the transmitting and receiving antennas are in the far-field region. A Hughes 8010H TWTA and an Avantek AWT-18676 LNA are connected with an Agilent 8722ES network analyzer to provide proper signal amplification. A personal computer is linked to the measurement system for positioner rotation, instrument control, system calibration, and data recording. In the measurement, the frequency is stepped from 7.5 to 12.5 GHz for 51 frequency points and object scattered field is recorded at a total of 120 viewing angles with $1°$ interval. This then gives a total of $360°$ spanned Fourier-domain data. Therefore, it effectively reduces the object rotation angle by three times for a three-source illumination arrangement as shown in Fig. 1.

Figure 4 shows the measured Fourier-domain data and their reconstructed images for a metallic cylinder with 15 cm radius. The experimental results are shown in good agreement with its geometry. In addition, measured results of the Fourier-domain data and reconstructed image of four thin cylinders are illustrated in Figure 5.

IV. Conclusions

The basic principle and experimental results of quasi-monostatic microwave imaging using multi-source illumination for perfectly conducting objects are presented in this paper. When n illumination sources are properly arranged, one can reduce the viewing angle by a factor of n. Based on the experimental results, it shows that it is an efficient approach as compared with that of single-source illumination arrangement.

Acknowledgement

This work was supported by the National Science Council of Taiwan, R.O.C. under Grant NSC 91-2219-E002-030 and by the Ministry of Education of Taiwan, R.O.C. under Grant 89-E-FA06-2-4-6.

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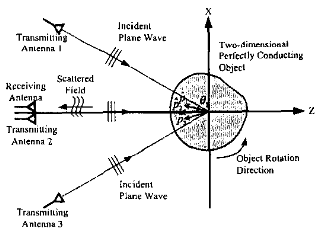

Fig.1. Two-dimensional quasi-monostatic backscattering geometry using three-source illumination.

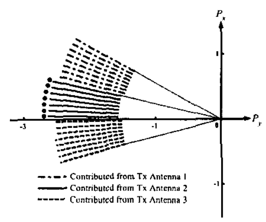

Fig.2. Fourier-domain acquired in the quasi-monostatic backscattering arrangement using three-source illumination.

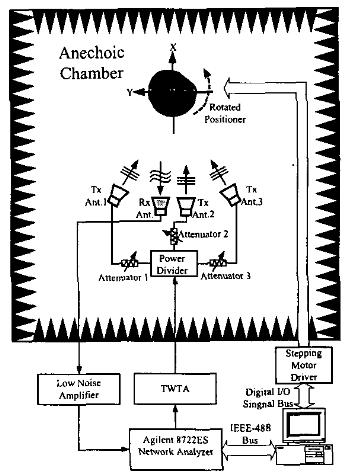

Fig. 3. An automated wide-band quasi-monostatic microwave imaging scattering measurement system using multi-source illumination.

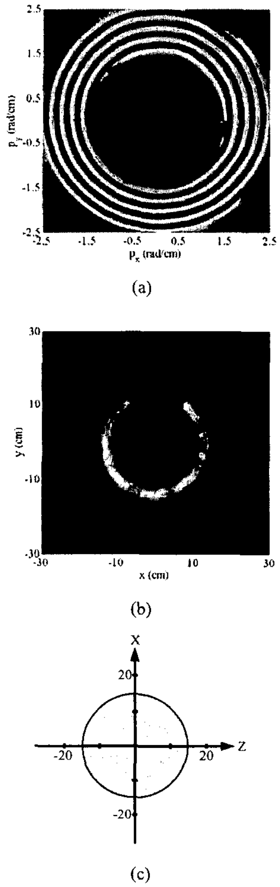

Fig. 4. Measured results of (a) Fourier-domain data and (b) reconstructed images with (c) geometry of a metallic cylinder with 15 cm radius.

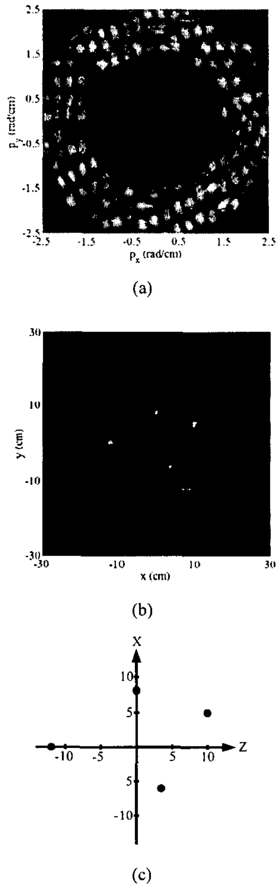

Fig. 5. Measured results of (a) Fourier-domain data and (b) reconstructed image of four thin cylinders with (c) geometries at (-12, 0) cm, (0, 8) cm, (3.5, -6) cm, and (10, 5) cm, respectively.