Tradeoff Study of Microwave Imaging Based on Frequency Considerations

Dau-Chyrh Chang[1], **Yau-Jyun Tsai**[1], **Chih-Hung Lee**[2,3], **and Chang-Hsuan Kao**[1]

[1]Oriental Institute of Technology, CRC, OIT, Taiwan
[2]Yuan Ze University, Taiwan
[3]Electronics Testing Center, Taiwan

Abstract— The quality of image includes the resolution of pixel and contrast of the pixel. The better the quality of microwave image is with higher the resolution of image pixel and larger the image contrast. The contrast depends on the signal to noise ratio of the radar receiver. The resolution of pixel depends on the radar frequency. The higher the frequency the better the resolution of pixel will be. Unfortunately, the higher the frequency the smaller the signal to noise ratio will be. The phenomenon will cause the lower image contrast. In this paper, the formulation of microwave imaging, quality of radar image with various frequencies and number of transceivers are detail discussed. In order to obtain the better quality of image, a new technique with multiple frequencies is developed. The results of microwave image with better resolution and higher contrast by both simulation and measurement are agreed.

1. INTRODUCTION

Images are very useful for nowadays applications in medical and industries. The quality of images should include the image resolution, image contrast, and less false alarm image. The sensors of image include x-ray, acoustic, MRI, and microwave. The advantages and disadvantages of these sensors with image quality are discussed in many literatures. Traditional microwave image will have lower resolution, lower contrast, and many false alarm images with higher contrast. In the paper microwave image with higher image resolution and higher contrast with lower false alarm images will be discussed.

2. FORMULATION OF MICROWAVE IMAGING

All the formulation of coordination in the following is rectangular coordination. If the target image with rotation center at $(0, 0, 0)$ and image region $X_m/2 \geq x \geq -X_m/2$, $Y_m/2 \geq y \geq -Y_m/2$, $Z_m/2 \geq z \geq -Z_m/2$ is interested. The microwave image region is consisted of infinite scatter points $\sigma(x, y, z)$ with RCS (radar cross section area) magnitude σ at pixel (x, y, z). In order to reduce the coupling between transmitter and receiver, the location of bistatic transmitter and receiver are $T_x(x_t, y_t, z_t)$ and $R_x(x_r, y_r, z_r)$ respectively. The detail geometry is shown in Fig. 1.

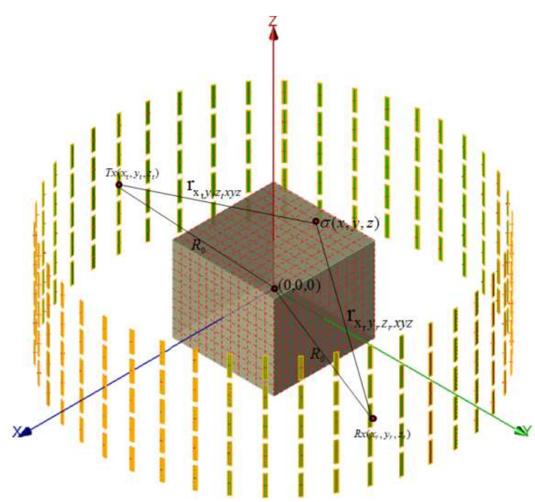

Figure 1: Geometry of microwave imaging.

2.1. Preliminary Image Construction

The geometry of image pixel $\sigma(x, y, z)$, transmitter and receiver will be formulated in this section.

The distance between transmitter and $\sigma(x, y, z)$ is as shown in Eq. (1),

$$r_{x_t y_t z_t xyz} = \sqrt{[(x_t - x)^2 + (y_t - y)^2 + (z_t - z)^2]} \tag{1}$$

The distance between receiver and $\sigma(x, y, z)$ is as shown in Eq. (2),

$$r_{x_r y_r z_r xyz} = \sqrt{[(x_r - x)^2 + (y_r - y)^2 + (z_r - z)^2]} \tag{2}$$

For the isotropic antenna radiation pattern, the spherical wave incident at $\sigma(x, y, z)$ and reflected by $\sigma(x, y, z)$ is shown in Eq. (3),

$$S = \frac{\sqrt{\sigma} e^{-jkr_{x_t y_t z_t xyz}}}{r_{x_t y_t z_t xyz}} \tag{3}$$

where the propagation constant, k, is function of guide wavelength λ_g, guide velocity v_g, and frequency. The propagation constant k is expressed as in Eq. (4),

$$k = 2\pi/\lambda_g = \omega/v_g \tag{4}$$

The signal received at the microwave receiver (ϕ_r, z_r) or (x_r, y_r, z_r) with isotropic antenna pattern for giving propagation constant k is shown in Eq. (5),

$$V_{\phi_b z_b} = \sum_{x=-X_m/2}^{x=+X_m/2} \sum_{y=-Y_m/2}^{y=+Y_m/2} \sum_{z=-Z_m/2}^{z=+Z_m/2} \frac{\sqrt{\sigma_{xyz}}}{(r_{x_t y_t z_t xyz})(r_{x_r y_r z_r xyz})} e^{-jk(r_{x_t y_t z_t xyz} + r_{x_r y_r z_r xyz})} \tag{5}$$

Then the target image $\sigma(x, y, z)$ can be constructed for giving simulated or measured data $V_{\phi_b z_b}$ in cylindrical coordination $2\pi \geq \phi_b \geq 0$ and $z_m \geq z_b \geq -z_m$. The number of received signal in ϕ and z are M and N respectively. The constructed of image from the M by N received data points for given propagation constant k or frequency f is given by Eq. (6),

$$\sigma_{xyzf} = \left| \frac{1}{MN} \sum_{z=z_i}^{z=z_f} \sum_{\phi=\phi_i}^{\phi=\phi_f} a_{\phi_b z_b} (r_{x_t y_t z_t xyz})(r_{x_b y_b z_b xyz}) \; V_{\phi_b z_b} e^{-jk(r_{x_b y_b z_b xyz} + r_{x_t y_t z_t xyz})} \right|^2 \tag{6}$$

The three dimensional image for $X_m/2 \geq x \geq -X_m/2$, $Y_m/2 \geq y \geq -Y_m/2$, $Z_m/2 \geq z \geq -Z_m/2$ can be constructed by Eq. (6) for fixed frequency f. The mutual coupling between transmitter and receiver will degrade the small signal detection. In order to reduce the mutual coupling between transmitter and receiver, the bistatcic angle α for the same z value is included during measurement.

2.2. Fine Image Construction

The quality of image will be degraded from the low resolution pixel which due to the longer wavelength at lower frequency, lower image contrast due to the higher propagation loss at higher frequency, and false alarm image pixels due to the diffraction and reflection of wave propagation. By using the multiple frequencies or frequency agility technique, the final value of image is the average of image for total frequency points L and frequency increment Δf as shown in Eqs. (7) & (8),

$$\sigma_{xyz} = \frac{1}{L} \sum_{f_{lower}}^{f_{higher}} \sigma_{xyzf} \tag{7}$$

$$\Delta f = (f_{higher} - f_{lower})/L \tag{8}$$

3. RESULTS OF MEASUREMENT

In order to verify the proposed algorithm, two identical spherical metal targets $\sigma_1(x_1, y_y, 0)$ and $\sigma_2(x_2, y_2, 0)$ with radius 2.7 cm are arranged in Fig. 2. The RCS value of the metal sphere is -26.4 dBsm. In order to reduce the mutual coupling between transmitter at $(-129.2, 28.6, 0)$ and receiver $(-129.2, -28.6, 0)$, the bistatic angle is 25° which is corresponding the distance between

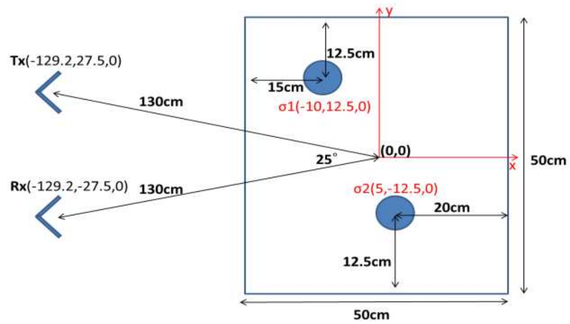

Figure 2: Geometry of arrangement.

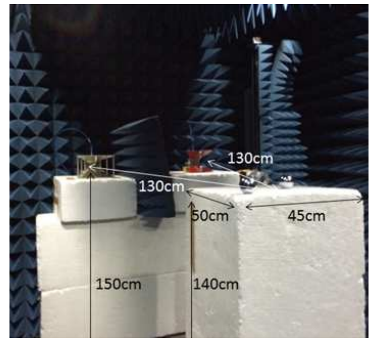

Figure 3: Measurement in anechoic chamber.

transmitter and receiver is 56 cm. The radius of transmitter (receiver) to the rotation center of target is about 130 cm. The antenna for both transmitter and receiver is wideband double ridge horn with bandwidth 700 MHz $\sim$ 18 GHz. In order to simply the structure of data acquisition, targets are rotate along the rotation center. This is similar to that of the bistatic radar with movement along the locus of radius 130 cm. In order to consider the quality of image at highest frequency, there are 501 data points received from 360°.

There are 15 images for frequency from 1 GHz to 15 GHz with frequency interval 1 GHz. Figs. 4 $\sim$ 6 are the examples of images at 1 GHz, 5 GHz, 10 GHz. From these figures, the lower the frequency is the lower the resolution will be. Except for the lower resolution at lower frequency, many false alarm targets are generated. For higher frequency, the signal to noise ratio will be lower due to the RF cable loss for VNA to transmitter and receiver and propagation loss. Although the resolution of image will be better for higher frequency, the contrast of image pixel will be lower. In order to compromise the resolution and contrast, Fig. 7 is the average summation of the image for frequency from 1 GHz to 15 GHz with frequency interval 1 GHz. The image of two metal spheres are clear with higher contrast and better resolution.

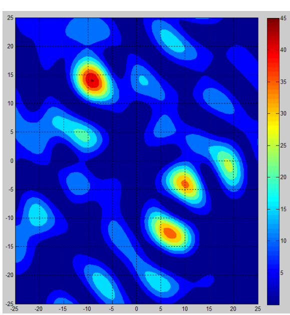

Figure 4: Image at 1 GHz.

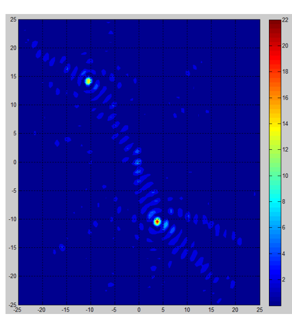

Figure 5: Image at 5 GHz.

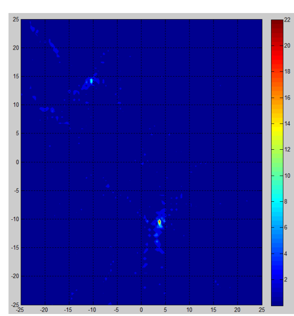

Figure 6: Image at 10 GHz.

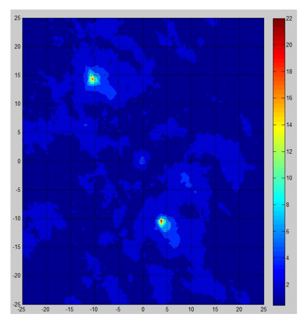

Figure 7: Final image with 15 frequencies.

4. CONCLUSION

The resolution of image will be lower for lower frequency and higher for higher frequency. Unfortunately, the contrast of image will be higher for lower frequency and lower for higher frequency. Except for the resolution and contrast of image quality, false alarm pixel may happen inside image in frequency domain. The formulation of radar image with compromise resolution and contrast is developed in this paper. The measurement results show that this technique is another approach for high quality radar image.

REFERENCES

1. Chang, D.-C. and H.-C. Lee, "Radar image of corner reflector," *IEEE AP-S International Symposium and USNC/CNC/URSI National Radio Science Meeting*, 2003.
2. Qi, Y. L., X. L. Yang, W. X. Tan, Y. P. Wang, and W. Hong, "Research on the microwave snapshot imaging radar based on antenna array," *IET International Radar Conference*, 2013.