Imaging of Object in Front of Human Body Phantom Using Leaky-Wave Focusing Antenna

Kevin Kipruto Mutai[1*], Hiroyasu Sato[1], and Qiang Chen[3]

[1] Department of Communications Engineering, Tohoku University, Japan

[*]email: mutai-k@ecei.tohoku.ac.jp

***Abstract* – In this paper, millimeter-wave imaging using two rectangular waveguide leaky-wave focusing antennas in a quasi-monostatic arrangement was performed. One-dimensional detection of a conducting and dielectric cylinders positioned in front of a human body phantom representing the human body was performed by experiment to confirm the imaging capability of the proposed system. Two-dimensional imaging of a conducting cylinder positioned front of the phantom was finally performed.**

***Keywords* — Millimeter wave imaging, Millimeter wave radar, Leaky wave antennas (LWAs).**

I. INTRODUCTION

Millimeter wave imaging (MMWI) technology has been developed in recent years in response to the threat of subversive actions at airports and seaports [1]-[2]. However, current MMWI systems have some disadvantages such as requiring an array of sensors [3] which increases fabrication costs. In other cases, a dielectric lens is required which increases the overall size of the systems [4]. To address these problems, we propose an active MMWI system using the leaky wave focusing antenna (LWFA) shown in Fig. 1 that is small enough to be held by hand.

The LWFA was first proposed by our group in [5]. One direction is scanned by frequency sweep, removing the need for an array of sensors whereas focusing is achieved by appropriate variation of the rectangular waveguide broadwall height, $h(z')$, in the LWFA structure thereby also removing the need for a dielectric lens or reconstruction algorithms. Additionally, the inclined radiation direction from the LWFAs ensures that only scattering from an object is detected if the object is positioned in front of a relatively flat conducting surface such as the human body because the flat surface would reflect the incident field away from the direction of the antenna pair.

II. IMAGING SYSTEM

Because the imaging system uses the frequency scanning characteristic of the LWFA, the data collected will be in the frequency domain. To determine the object position and size from the image, conversion form the frequency domain to the spatial domain is required. To accomplish this, the electric field distribution was measured in the z-direction in the range 0 mm ≤ z ≤ 300 mm at $x = x_s = 195$ mm for different frequencies. An open-ended waveguide (OEWG) was moved along the z-direction at $x = x_s = 195$ mm in 5 mm

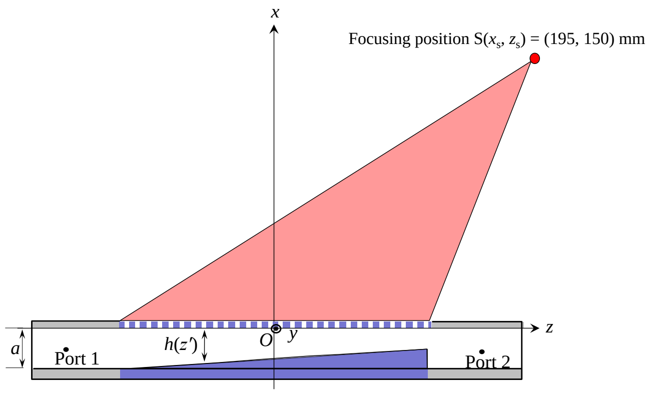

Fig. 1. Leaky-wave focusing antenna (LWFA) used in proposed system.

increments and the S-parameter between the OEWG and the LWFA was measured at each position by vector network analyzer (VNA). The peaks at each frequency were obtained and the peak positions along the z-direction at each frequency f were then denoted as z_{peak}. The relationship between z_{peak} in mm and f in GHz was then obtained by a fitted curve as

$$z_{peak}[\mathrm{mm}] = -0.617 f^2[\mathrm{GHz}] + 51.5 f[\mathrm{GHz}] - 787. \quad (1)$$

By using (1), the measured data can be converted to the spatial z domain.

To improve the clarity of the final image and remove the effect of mutual coupling and scattering from the surroundings, the scattered field can be obtained. To obtain the scattered field by experiment, the S-parameters measured in the incident field case can be subtracted from the total field case by

$$S_{ji}^{scat} = S_{ji}^{tot} - S_{ji}^{inc} \quad (2)$$

where S_{ji}^{tot} is measured with the scattering object present and S_{ji}^{inc} is measured without the object present.

III. EXPERIMENT

One-dimensional detection of both conducting and dielectric cylinders was performed using the experiment setup shown in Fig. 2. The pitch between the LWFA pair is p = 50 mm and 50 Ω impedances terminated both Ports 2 and 4 whereas Ports 1 and 3 were connected to a VNA. The cylinders were of radius r = 5 mm and length l = 50 mm. The cylinders were positioned at $T(x_{obj}, z_{obj})$ = (195, 150) mm which coincides with the designed focusing position of the LWFAs. The S_{31} was measured in the experiment by VNA and the results are shown in Fig. 3. Peaks caused by

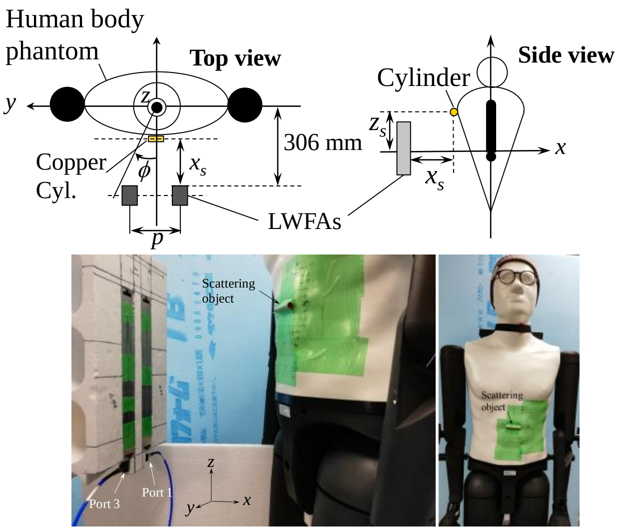

Fig. 2. Experiment setup with body phantom.

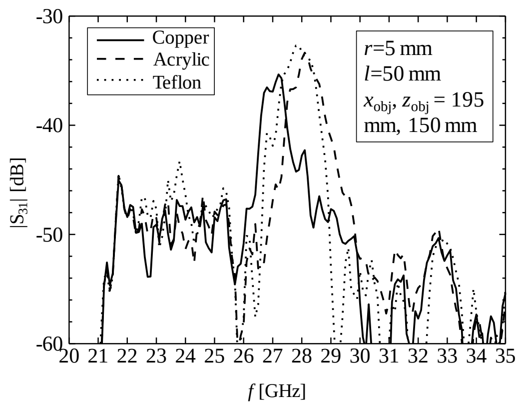

Fig. 3. One-dimensional detection of conducting and dielectric cylinders positioned in front of body phantom.

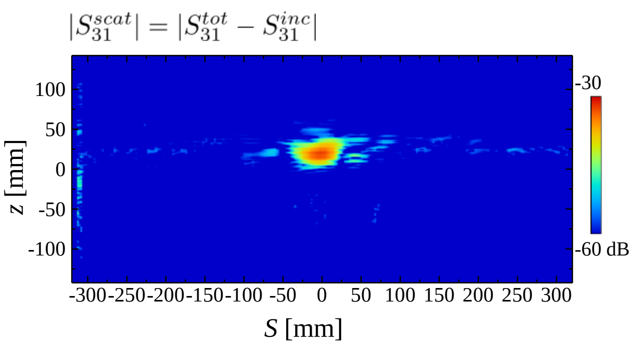

Fig. 4. Two-dimensional imaging of a copper cylinder positioned in front of body phantom before and after subtraction of incident field.

scattering from the objects could be observed in all cases which validates the ability of the LWFA to detect objects positioned in front of the phantom.

The peak in the case of the Teflon cylinder was observed to be the highest compared to the other two materials. This is because Teflon, having the lowest ε_r amongst all the materials, also has a higher transmission factor. Therefore, a greater proportion of the incident field is allowed through the material and is again scattered back through the material leading to the observed phenomenon. Similarly, the peak in the case of Acrylic is higher than in the case of copper but lower than Teflon by the same logic.

The next step was to create two-dimensional images of the objects. This process was performed using the setup in Fig. 2. In this case, the body phantom was rotated in the range $-60 \leq \phi \leq 60$ degrees in steps of 1 degree and the S_{31} was recorded for each position. The angle ϕ was then converted to the arc length S to determine the size of the object from observing the generated image. Equations (1) and (3) were applied in this case to convert the data to the spatial domain and to obtain the scattered field, respectively. The resulting image is shown in Fig. 4 from which the size and position of the image are about the same as the size and position of the actual object.

IV. CONCLUSION

An active millimeter wave imaging system using two LWFAs was proposed. One-dimensional detection of conducting and dielectric cylinders positioned in front of a body phantom with dielectric properties like human tissue was performed by experiment. Finally, a two-dimensional image of a copper cylinder positioned in front of the body phantom was generated from the scattered field.

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