Development of an Active Millimeter Wave Imaging System Using Leaky-Wave Focusing Antenna

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SUMMARY In this paper, an active millimeter wave imaging system using the leaky-wave focusing antenna is proposed. In the imaging system, the leaky-wave focusing antenna steers the focusing position by varying the frequency. Effect of the mutual coupling between transmitting and receiving antennas is eliminated by pre-processing and a clearer image of conducting objects is obtained.
key words: *Leaky-Wave Antenna, Focusing, Active imaging, Millimeter-Wave.*

1. Introduction

Due to the threat of terrorism and criminal activities, surveillance at security checkpoints such as airports is becoming increasingly important. Current personnel scanning technologies have some disadvantages where metal detectors are effective against only metal objects while X-ray has some perceived harmful health effects. In order to address these challenges, Millimeter Wave (MMW) imaging systems have been developed that offer advantages such as accuracy in low visibility conditions, the ability to penetrate clothing and detect dielectrics without harmful health effects [1].
However, current MMW imaging systems suffer from some disadvantages. One disadvantage is they require an array of sensors which increases the cost of fabrication [2]. Another disadvantage is they may require a dielectric lens [3] which increases the size of the overall system and limits portability. To eliminate the need for an array of sensors, an alternative method would be to use a leaky-wave antenna (LWA) to scan across an object by frequency scanning [4]. LWAs are travelling wave antennas where the radiation direction changes as the frequency changes. Additionally, if focusing can be achieved using the LWA and eliminating the need for a dielectric lens or a metal reflector, then the LWA would have potentially useful imaging applications. Therefore, by using a focusing LWA, a lightweight handheld MMW imaging system is expected to address the disadvantages in current systems.
In [5], our group developed a leaky-wave focusing antenna (LWFA) where focusing was achieved in the near field in a relatively simple method by changing the height of the broadwall of the waveguide.
In this paper, we propose an active MMW imaging system that uses two LWFAs. The LWFAs are employed in a quasi-monostatic transmitter-receiver pair and the results of imaging are determined by experiment.

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2. Active Detection System

Fig. 1 shows the proposed imaging system. Transmitting antenna LWFA 1 has Ports 1 and 2 while the receiving LWFA 2 has Ports 3 and 4. Pitch between the LWFAs is p=50 mm. 50 Ω impedances terminated both Ports 2 and 4. A monopole located at Port 1 excites a TE_{10} mode and LWFA 1 illuminates the object at S. The magnitude of the scattered wave due to object was obtained by measuring the S parameter between Ports 1 and 3 denoted as S_{31}.
The LWFA used in the proposed system is shown in Fig. 2. The parameters of the LWFA are shown in Table 1.
One method of achieving focusing in the near field is to change the phase constant β of the travelling wave within the waveguide such that the radiated waves focus upon a desired position. In the LWFA, this was achieved by changing the height of the broadwall h as shown in Fig.2. Fig. 3 shows the principle of focusing by changing β as achieved in the LWFA.
The tapering of the height of the broadwall was designed at 27 GHz. At this frequency, the focusing position was selected to be at S(x_s, y_s, z_s)=(195, 0, 150) mm.

3. Experimental Setup

Fig. 4 shows the experimental setup used to perform imaging. A conducting cylinder of length l=50 mm and radius r=5 mm was used as the target object. The cylinder was positioned at S(x_{obj}, δ_y, z_{obj})=(195, δ_y, 100) mm where δ_y is the distance from the center of the LWFA pair to the center of the object in the y-direction. δ_y was changed in 10 mm intervals in the range -67≤ δ_y ≤-63. S_{31} was recorded for each δ_y. The object position was changed along the y-direction to simulate the physical movement of the antenna pair in y-direction. Scanning in the z-direction was achieved by frequency sweep.

4. Experimental Results

Fig. 5 shows the 1-D results for three values of δ_y. As δ_y reduces, it was observed that the peak of the $|S_{31}|$ increased. This is because when the δ_y reduces, more of the surface of

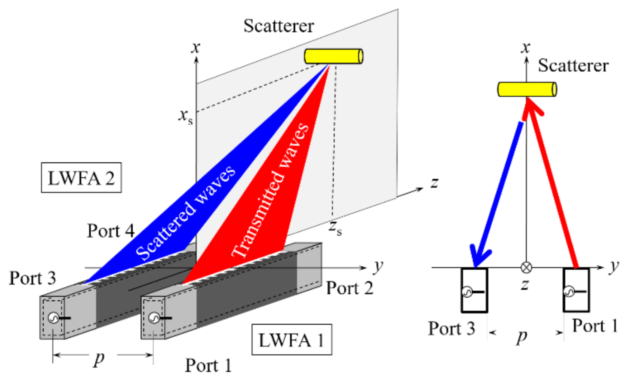


Fig. 1 Proposed Active Imaging System.

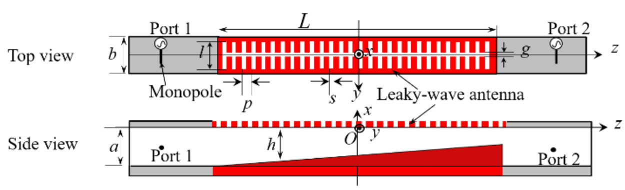


Fig. 2 Leaky-Wave Focusing Antenna (LWFA).

Table 1 LWFA Parameters.

Design freq.	f	27 GHz
Length of antenna	L	200 mm
Width of broad wall	a	8.5 mm
Height of broad wall	h	Inhomogeneous
Width of narrow wall	b	4 mm
Pitch of slot	p	3 mm
Length of slot	l	4 mm
Width of slot	s	1 mm
Width of slit	g	1 mm

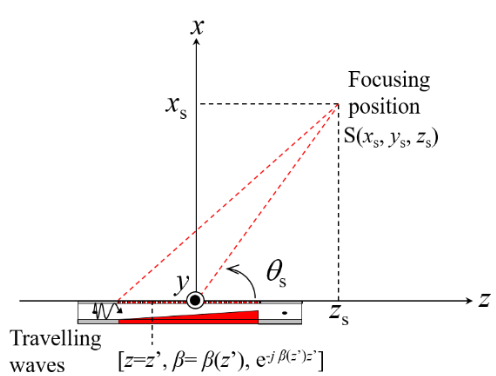


Fig. 3 Focusing effect. As $\beta(z)$ changes, θ_s changes along z to focus upon S.

the cylinder is exposed to the illuminating wave in the *xy*-plane from LWFA 1 and the radar cross section (RCS) increases The magnitude of the scattered wave therefore increases which translates to a higher peak of $|S_{31}|$.

It was also observed that the peaks at high δ_y were difficult to distinguish from one another due to mutual coupling between the LWFAs and this would affect the clarity of the

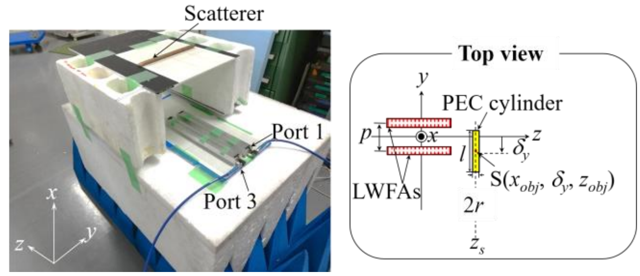


Fig. 4 Imaging experiment setup.

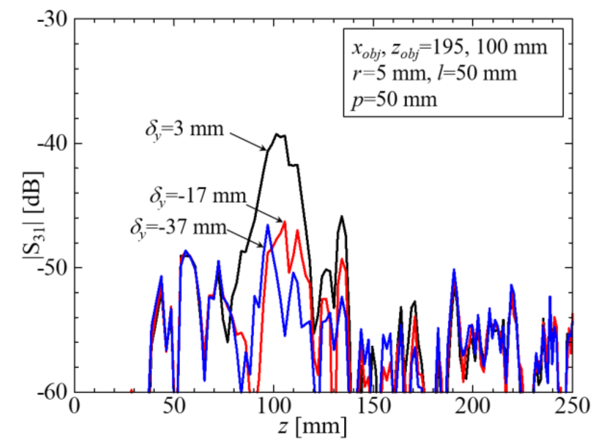


Fig. 5 Magnitude of S_{31} for different δ_y.

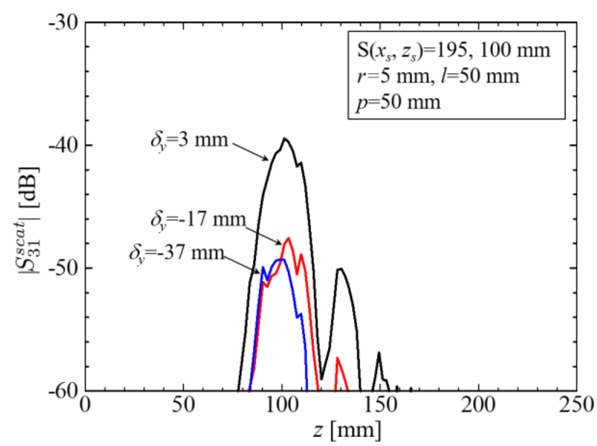
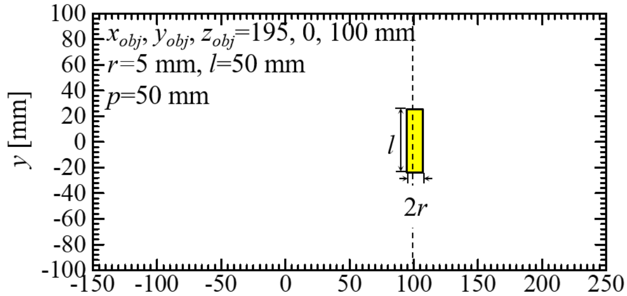


Fig. 6 Magnitude of S_{31}^{scat} for different δ_y.

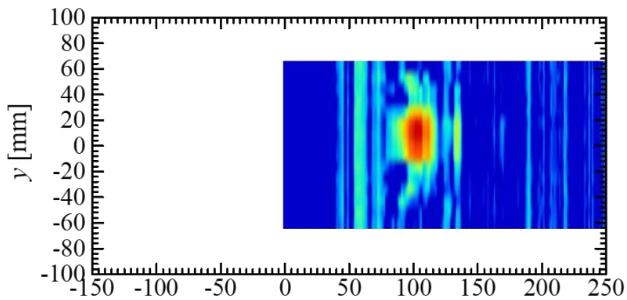
eventual 2-D image. To generate the 2-D image, the 1-D data was collected and ordered into a 2-D array and the image was generated from this array and is shown in Fig. 7 (b).

To improve the quality of the image, S_{31} was measured without the object present and denoted as S_{31}^{inc}. The signal due to only the scattered wave denoted as S_{31}^{scat} was then obtained by equation (1) where S_{31}^{tot} is the S_{31} measured with the conducting cylinder present.

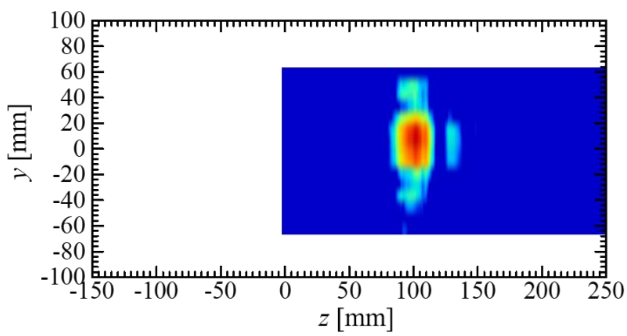
$$S_{31}^{scat} = S_{31}^{tot} - S_{31}^{inc} \quad (1)$$



(a) Actual object position and size in *yz*-plane.



(b) Before pre-processing.



(c) After pre-processing.

Fig. 7 2-D image of cylinder object.

Fig. 6 shows the result of the operation in (1) and it was observed that the peaks were clearer at the high δ_y. From the image in Fig. 7 (c) which is generated from the S_{31}^{scat} array, it was observed the image was clearer compared to the original case. The image of the object was observed to be of similar size and at a similar position as the actual object.

4. Conclusion

An active MMW imaging system based on a rectangular waveguide LWA antenna was proposed. The active imaging of a conducting cylindrical canonical object was performed experimentally. The S-parameter between the input ports of the transmitting and receiving antennas was used to determine the magnitude of the scattered field. This method was used to locate the object in one dimension. The 1-D data was combined into a 2-D array which was used to generate the 2-D image of the object. 1-D data without the object present was subtracted from 1-D data with the object present to improve image quality. Similar position and size between the image and the actual object was observed.

Acknowledgments

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