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Development of Active Detection System Using Leaky-Wave Focusing Antenna

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Abstract Object detection using the previously proposed leaky-wave focusing antenna operating in the frequency range of 20 GHz to 35 GHz is performed and the results presented in this report. In the proposed system, the leaky-wave focusing antenna steers the focusing position by varying the frequency which allows scanning in the one-dimensional spatial domain. Two such focusing antennas are deployed in a quasi-monostatic transmit and receive system with target objects placed at a fixed distance from the system and the scattering characteristics of the objects are used to locate the objects by frequency scanning. Detection of the flat plate and cylinder canonical objects is performed by FDTD and compared with the experimental results.

Keywords Leaky-Wave Antenna, Focusing, Millimeter-Wave, Active, Illumination

1. Introduction

Due to the ever-present need for the prevention of criminal or terrorist incidents, progress has been made in the development of body-scanning technologies. One of these technologies that has received great attention in recent years is Millimeter Wave (MMW) imaging. MMW imaging offers some advantages over other technologies [1] such as accuracy in low-visibility conditions (fog, smoke, etc) and the absence of harmful radiation effects that are inherent in X-ray systems.

At the moment, stationary MMW imaging systems exist [2], [3], however, they suffer from some disadvantages such as requiring bulky equipment and a lack of portability which means some hard to reach areas on a target body may not be scanned. Therefore a handheld system is expected in order to address these problems.

Additionally, stationary systems also require an array of image sensors and a dielectric lens in order to perform imaging. For example, in [4], a combination of a dielectric lens, a flapping metal reflector to scan the object and a one dimensional array of image sensors were used to obtain two dimensional images. An alternative method that would reduce the costs of fabricating the components required in such a system would be to use a leaky-wave antenna (LWA) to scan across an object by frequency scanning [5].

LWAs are traveling wave antennas that have the characteristics such that the radiation direction changes as the frequency changes. If the focusing effect can be realized in the case of the LWA, these characteristics are useful in changing the focusing position without using a dielectric lens or a metal reflector.

Some focusing LWAs have been proposed in previous studies. In [6], focusing was achieved by mechanical curving of the waveguide structure. However, the physical profile of this design makes it unsuitable for handheld operation. In [7], the waveguide slot width is modified to achieve focusing. In [8], focusing is achieved by changing the distance between the focal point and the slots located on the curved substrate integrated waveguide. The resulting designs from these last two proposals are suitable for handheld operation but the fabrication method is relatively complicated. In [9], 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.

Other handheld millimeter wave imaging systems have been previously proposed. In [10], a handheld active millimeter wave camera was reported. The camera had a large field of view of 2500 mm x 1700 mm and an integrated display screen. In [11], a portable millimeter-wave radar system is proposed. These two systems solve the problem

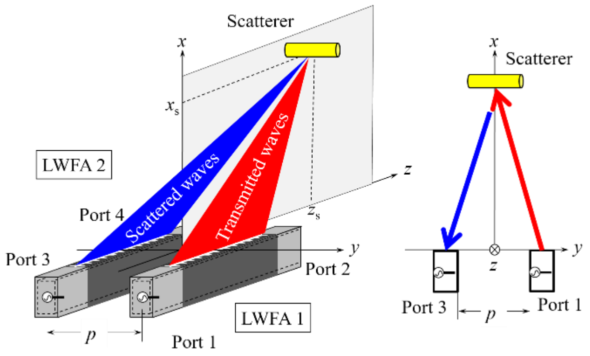


Fig. 1 Active Detection System.

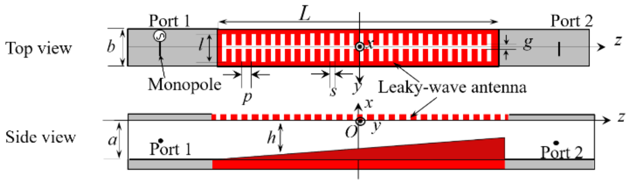


Fig. 2 Leaky-Wave Focusing Antenna (LWFA).

Table 1 Parameters of LWFA.

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

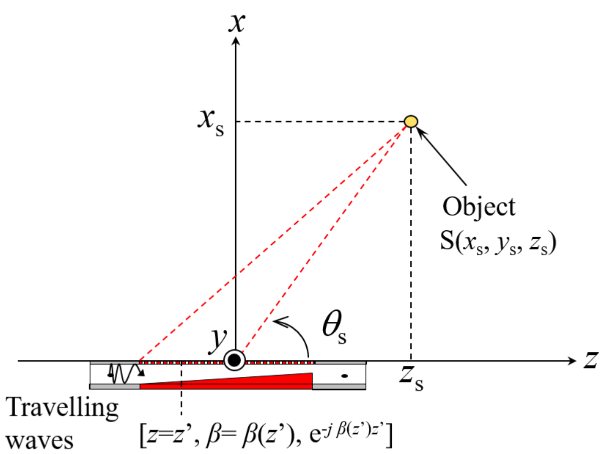


Fig. 3 Principle of focusing effect. As $\beta(z)$ changes, θ_s changes along z to focus upon S.

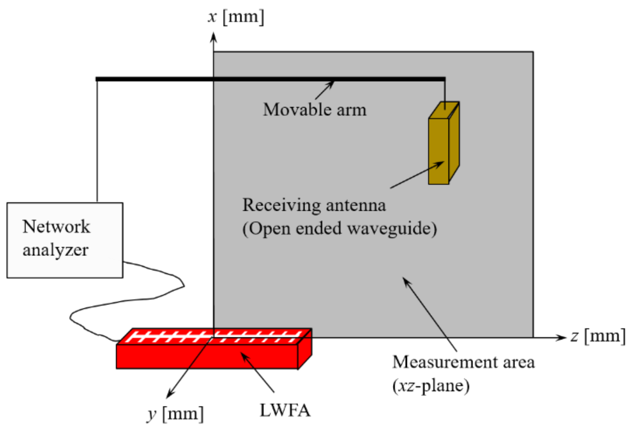


Fig. 4 Experiment setup to measure electric field distribution in xz-plane.

of portability. However, they employ frequency-modulated continuous-wave (FM-CW) radar therefore requiring complex circuit components for their operation

In this report, we propose an active detection system that uses two LWFAs and is relatively simpler in construction. The LWFAs are used in a transmitter-receiver pair and the results of one dimensional detection are determined through numerical analysis and verified by experiment.

2. Active Detection System

The proposed detection system is shown in Fig 1. The transmitting antenna LWFA 1 has Ports 1 and 2. The receiving antenna LWFA 2 has Ports 3 and 4. The pitch between the LWFA 1 and LWFA 2 was set at p=50 mm. Ports 2 and 4 were both terminated by 50 Ω impedances. The object to be detected was placed at the focusing position S.

A monopole located at Port 1 excites TE_{10} mode and LWFA 1 illuminates the object at S. The scattered wave from the object is received at LWFA 2. The scattered wave is observed by measuring the S parameter between Port 1 of LWFA 1 and Port 3 of LWFA 2 denoted as S_{31}. The LWFA used in the proposed system is shown in Fig 2. The parameters of LWFA are shown in Table 1.

One method of achieving focusing in the near field is to change the phase constant β of the traveling wave along the waveguide such that the radiated waves focus upon a desired position. This was achieved in the LWFA by changing the height h of the broadwall along the waveguide as shown in Fig.2. Fig. 3 shows the principle of focusing by changing β as achieved in the LWFA. The design

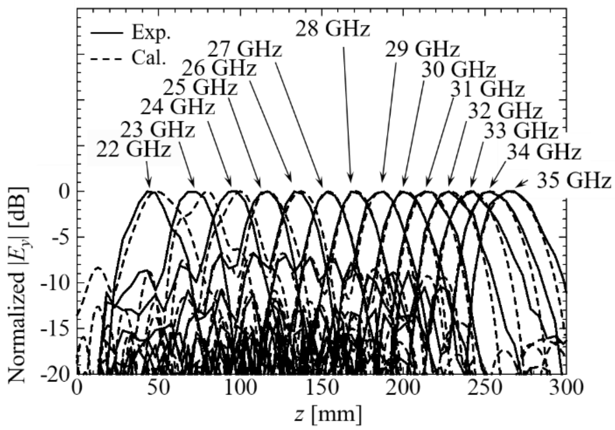


Fig. 5 Peak locations of electric field distribution along z-direction.

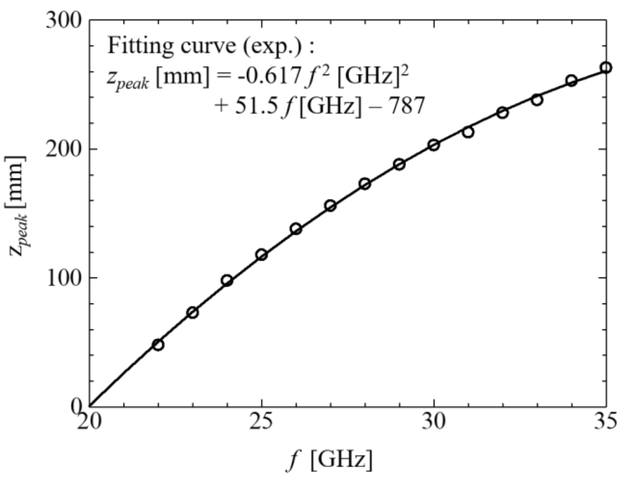
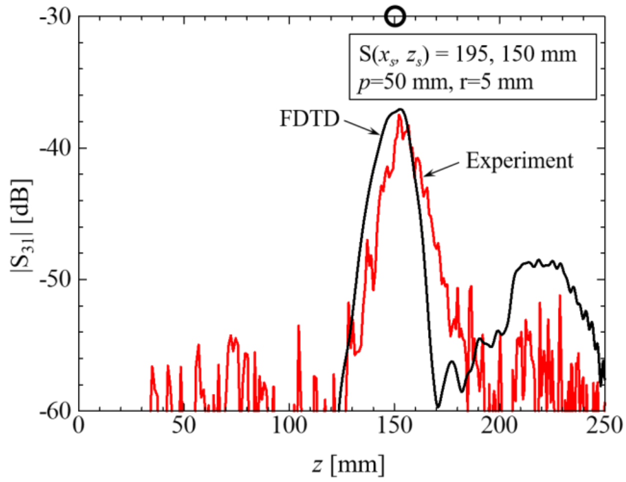
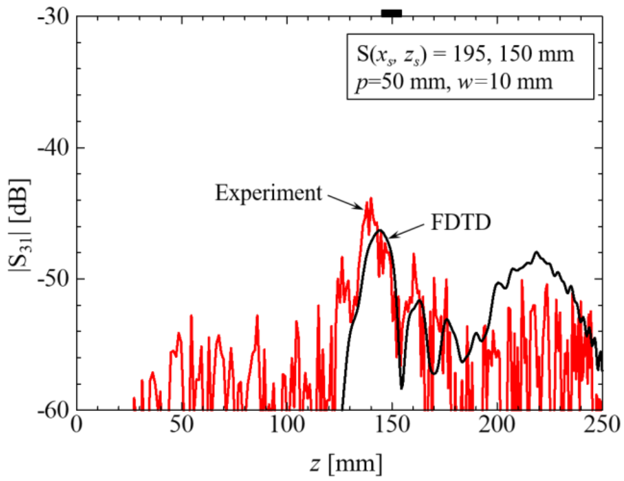


Fig 6. Fitting curve relating peaks of electric field distribution along z-direction to frequency.



(a) Conducting cylinder.



(b) Conducting plate.

Fig. 7 Magnitude of S_{31} of active detection system converted from frequency domain.

frequency of the antenna was set at 27 GHz. At this frequency, the focal point was selected to be at S(x_s,y_s,z_s)=(195,0,150) mm and h was designed such that the radiated waves focused upon S.

3. Experimental Setup

To convert the results from the frequency domain to the spatial domain, the normalized electric field distribution of one LWFA was obtained in the xz-plane. The location of the magnitude peak of the normalized electric field distribution at each frequency was obtained along the z-direction for fixed x=195 mm and denoted as z=z_{peak}. The relationship between z_{peak} and frequency was then derived by fitting. This relationship was used to map the frequency domain results to the spatial domain.

To measure the electric field distribution in the xz-plane, the experiment setup shown in Fig. 4 was used. The position of the open-ended waveguide (OEWG) was changed along the x and z-directions in 5 mm intervals. The measurement area was 10 mm ≤ x ≤ 300 mm and 0 mm ≤ z ≤ 300 mm and S_{21} between the OEWG and the LWFA was recorded for each position.

For the object detection experiments, the object was positioned with its center at S(x_s,y_s,z_s)=(195, 0, 150) and S_{31} was obtained. Objects used were the flat plate and cylinder canonical structures made of conducting material.

4. Numerical and Experimental Results

Fig. 5 shows the locations of peaks of the normalized electric field distribution along the z-direction corresponding to frequency range of 22 GHz to 35 GHz.

The dashed line indicates the results obtained by FDTD method while the solid line indicates the experimental results. Good agreement was observed in the locations of each peak. Fig. 6 shows the relationship between z_{peak} and frequency derived by fitting from the data in Fig. 5.

Fig. 7 (a) and (b) show the $|S_{31}|$ vs z characteristics of the experiment and FDTD analysis. The cylinder radius was r=5 mm while the width of a flat plate was w=10 mm and 1 mm thickness.

In both the cylinder and the plate cases, a peak in the $|S_{31}|$ was observed which is caused by the scattered wave from the objects. This peak almost corresponds to the object position in the frequency domain. 6 dB lower peak of the flat plate was observed than the peak corresponding to the cylinder. This difference is attributed to the different radar cross section (RCS) patterns of these two structures. The cylinder has a greater back-scattered RCS component than that of the plate structure at the illumination angle at 27 GHz which results in a stronger scattered waves from the cylinder than that from the plate.

The peak positions and heights of the experiment and FDTD were also observed to be aligned in both the cylinder and plate cases. This indicates good agreement in the object position and magnitude of the measured scattered wave between the FDTD and experiment.

A strong signal was observed in the frequency range 29 GHz to 34 GHz. These frequencies correspond to the range 200 mm $\leq z \leq$ 250 mm in the spatial domain. This signal is observed due to the mutual coupling between the two antennas and the broad radiation pattern in the *xy*-plane. A possible solution to this problem that may be investigated in the future would be to increase the p between the LWFAs.

5. Conclusion

An active detection system based on a rectangular waveguide LWA antenna is proposed. The active detection of conducting cylindrical and flat plate canonical structures was performed experimentally and compared with the FDTD numerical analysis. The S-parameter between the input ports of the transmitting antenna and receiving antennas was measured and used to determine the magnitude of the scattered field. This method was used to locate the objects in the frequency domain and then converted to the spatial domain. An agreement was observed between the FDTD and experimental results. Future work would build upon this to perform 2-D imaging where scanning in the second dimension would be achieved by physical movement of the system by hand.

Acknowledgements

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