Passive Millimeter-Wave Imaging using a Substrate Integrated Waveguide Antenna

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***Abstract*— A Millimeter-wave imaging system for concealed object detection at the frequency of 24 GHz with total power radiometer configuration has been designed and tested. We added to the system a microwave lens to focus the target to the antenna and a nipkow disc to scan the image under surveillance. We also incorporated the Substrate Integrated Waveguide (SIW) technology in the receiver antenna.**

I. Introduction

THE need for a concealed weapons and explosive detection has increased in recent years. Millimeter-wave (MMW) imaging is a possible solution to this problem since millimeter-waves can penetrate thin clothing layers. This is a method of forming images through the detection of millimeter-wave radiation from a scene. This power is a combination of what the scene object is directly emitting and what it is reflecting from its environment. The MMW radiation does not present a health hazard to people under surveillance and this kind of systems has also the ability to see under conditions of low visibility (fog, clouds, smoke, sandstorms, etc.) that would ordinarily blind visible or infrared (IR) sensors [1].

Millimeter-wave imaging can be either active or passive. In Passive Millimeter-Wave (PMMW) imaging, the spectral distribution of natural radiation which is emitted or reflected from a body at environmental temperatures is properly captured and displayed (radiometry).

Various passive mode millimeter-wave imaging systems for target identification have been reported by several authors [1]-[3]. The novelty of this work is the incorporation of the Substrate Integrated Waveguide (SIW) technology in the receiver antenna. SIW technology is synthesized by placing two rows of metallic via-holes in a substrate. The field distribution in a SIW is similar to that in a conventional rectangular waveguide. Hence, it takes the advantages of low cost, lower losses than coplanar and microstrip lines, and it is highly integrable with microwave and millimeter wave integrated circuits [4], [5].

We also propose a technique that uses a nipkow disc to obtain the image under surveillance. The nipkow disc is a mechanical operating image scanning device. The device consist of a mechanically spinning disk of any suitable material (metal, plastic, cardboard, etc.), with a series of equally distanced circular holes of equal diameter drilled in it. These holes are positioned to form a single-turn spiral starting from an external radial point of the disk and proceeding to the center of the disk, much like a gramophone record. When the disk rotates the holes trace circular ring surfaces. Each hole in the spiral takes a horizontal "slice" through the image which is picked up as a pattern of light and dark by a sensor.

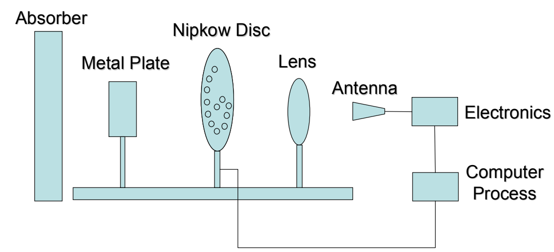

Fig. 1. Passive Millimeter-wave Imaging System block diagram.

II. Passive Millimeter-Wave Imaging System

The experimental arrangement constructed for the passive millimeter wave imaging system is shown in Fig. 1. This system works at the frequency of 24 GHz. For the electronics we used the total power radiometer configuration [6].

To detect the small radiation emitted by the target we use a low noise amplifier which has a bandwidth from 15 to 26 GHz, 2.8 dB NF and 55 dB gain. To downconvert the frequency we use a triple balanced mixer with 9.5 dB NF. The local oscillator used achieves output power from 13 to 16 dBm with phase noise of ~135 dBc/Hz, and a tuning range from 20.641 to 21.7 GHz. The detector used is a square law detector with bandwidth from DC to 40 GHz. To enhance the sensitivity of the system we designed an integrator having integration time of 3 milliseconds.

We designed a SIW horn antenna as proposed in reference [5]. We modified the design of the antenna by introducing exponential flares to have a wide bandwidth as shown in Fig. 2.

We added to the system a microwave lens to focus the target to the antenna and a nipkow disc to scan the image under surveillance. The lens used has a diameter of 24 cm and it is made of teflon material. In order to validate the nipkow disc approach, we performed preliminary measurements at optical frequencies. The detailed explanation of the nipkow disc experimental arrangement at optical frequencies is given by Soto et. al., [7]. The nipkow disc has a spiral of 6 holes which have a diameter of 1.5 mm. Each hole provides one of the 6 scan lines to reconstruct the image under surveillance. The resolution of the image depends only on the number of holes of the nipkow disc.

III. Results

To demonstrate the sensitivity of our system, several tests have been performed with concealed objects of different materials such as plastics, ceramics, cardboard and aluminum. The results are shown in Table 1. The initial output voltage at the detector of our system having microwave absorbing background foam placed 1m away from the antenna was 81

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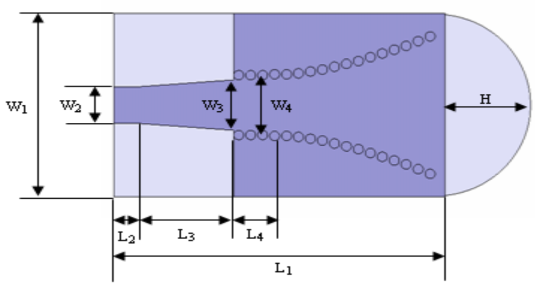

Fig. 2. Geometry of the SIW exponential flare horn antenna. The dimensions of the microstrip line are W_2=3.8mm, and L_2=2mm. The transition dimensions are L_3 =10mm, and W_3 =5.32mm. The SIW dimensions are W_4 =6.312mm, L_4 =3.4mm, cylinder radius r =0.5mm, and cylinder separation p =1.2mm. The substrate thickness is h =2mm, and dielectric constant of ε_r =10.2. The overall dimensions of the horn antenna are 41.775 x 19.4 x 2 mm^3.

mV. Then different objects have been sensed by placing them between the microwave foam and the receiver antenna. The metal plate showed a difference of approximately 30 mV with the initial value, while the cardboard plate did not provide any change. These findings are consistent with the theory, since the metal plate has an emissivity near to zero [3] and the cardboard is invisible to the millimeter waves [2].

The antenna was simulated using a commercial finite element method package [8] and the data is shown in Fig. 3, its bandwidth is from 18 to 40 GHz, having a good response of the return loss S_{11} in this desired bandwidth (under -10 dB approximately). The arc lens placed in the substrate improves the directivity of the SIW antenna. The radiation pattern is illustrated in Fig. 4.

The image obtained using the nipkow disc at optical frequencies is shown in Fig. 5. The image projected on the scanning area was given the shape of a letter C, measuring 19.5mm high and 22.5mm wide. It has 30 data points obtained from the 6 holes in the nipkow disc taking 5 samples of each hole. No corrections were made for shape or intensity distortions in the reconstructed image.

IV. Conclusions

A passive millimeter-wave imaging system using a SIW technology has been shown, different materials such as plastics, ceramics, cardboard and aluminum have been successfully detected. The SIW exponential flare horn antenna was simulated obtaining good return loss in a wide bandwidth (18-40 GHz) and high directivity. The image (letter C) obtained using the nipkow disc at optical frequencies is presented. The demonstration of the nipkow disc principle is made in the optical region in order to validate the approach at microwave frequencies.

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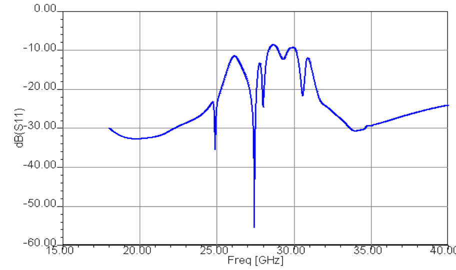


Fig.3. Return Loss S_{11} of the SIW exponential flare horn antenna.

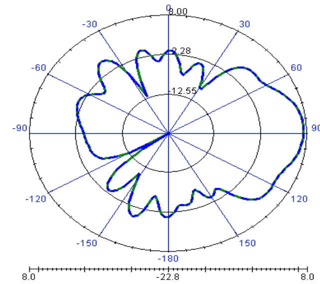
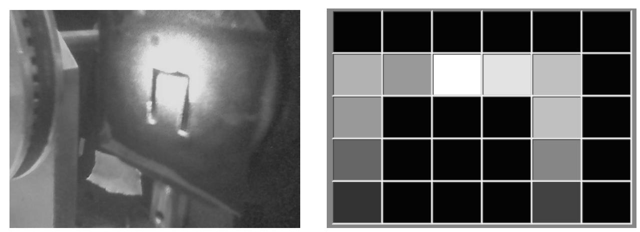


Fig. 4. Radiation patterns of the SIW exponential flare horn antenna.



a b

Fig. 5. a. Object under surveillance. b. Computer image result

Object	Voltage (mV)
Initial Voltage	81
Aluminum Plate	110
Plastic Plate	79
Plastic Mousepath	78
Plastic Bucket	77
Plastic Mobile	79
Ceramic Plate	70
Cardboard Plate	81

Table 1. Output voltage of different materials under surveillance.

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