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Frequency Beam Steering Antenna for Millimeter Wave Checkpoint Scanners

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Abstract— **Millimeter wave scanners are the most prevalent nearfield imaging passenger security systems. The paper describes a planar antenna to replace multiple antennas used in millimeter wave security checkpoints. The antenna is compact in size and capable of frequency scanning over an angle of –50° to +15°. It operates across FCC's frequency range of 24.25 GHz to 30 GHz for full-body airport scanners. The antenna structure, which is based on cheap microstrip technology, is simple to design and fabricate. The proposed antenna consists of a linear array of 1×4 radiating elements. The measured results conforms the antenna exhibits a maximum gain and radiation efficiency measured are 6.75 dBi and 82.34%, respectively, at 27.5 GHz.**

Keywords— Antenna, planar, imaging, checkpoint, beam scanning, millimeter wave antenna, imaging systems

I. INTRODUCTION

Millimeter wave scanner is a whole body imaging device used for detecting objects concealed underneath a person's clothing using a form of electromagnetic radiation [1]-[4]. Typical uses for this technology include detection of items for commercial loss prevention, smuggling and screening at government buildings and airport security checkpoints. Several countries employ the scanners for security screening. A competing technology is backscatter X-ray, which is an ionizing radiation with mutagenic potential.

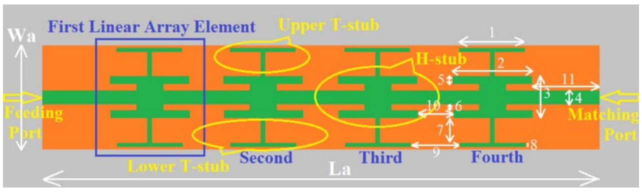
Millimeter wave scanners themselves come in two varieties, i.e. active and passive. Active scanners direct millimeter wave energy at the subject and then interpret the reflected energy. Passive systems create images using only ambient radiation and radiation emitted from the human body or objects. With active scanners, the millimeter wave is transmitted from two antennas simultaneously as they rotate around the body. The wave energy reflected back from the body or other objects on the body is used to construct a three-dimensional image, which is displayed on a remote monitor for analysis. Under a Federal Communications Commission (FCC) waiver full-body airport scanners can use repeated sweeps over the range 24.25-30 GHz to detect objects hidden underneath clothes.

The antenna is a main component in millimeter wave scanners used at airport security checkpoints [1]-[4]. Multiple antennas are employed in the scanner which requires a large booth to accommodate it. In this paper, a compact antenna design is described for operation over 24.25 GHz to 30 GHz with beam steering capability for ultra-wideband imaging of a human body. The proposed antenna should enable the development of small and portable scanners. It is well known and understood that microstrip antennas enable the implementation of miniaturized antennas however the major disadvantage of microstrip antennas are narrow bandwidth and low efficiency performance. To overcome these drawbacks, we have proposed a microstrip antenna implemented using an array configuration. The realized antenna has a frequency bandwidth of 23.10 GHz to 32.50 GHz, which is greater than the desired range. Furthermore, the effective aperture of the array structure is increased resulting in improved antenna gain and radiation efficiency performance.

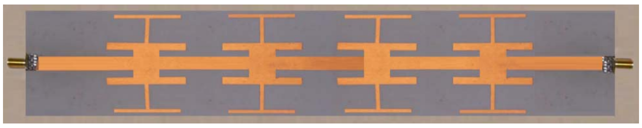
II. THE PROPOSED MILLIMETER WAVE ANTENNA

Configuration of the proposed antenna is shown in Fig. 1. It consists of a linear array consisting of 1×4 radiating elements, comprising H-shaped stub loaded with two T-shaped auxiliary stubs. A common feedline connects the linear array which is terminated with a 50 Ohm load. The antenna design was constructed on Rogers RT/Duroid 5880 substrate with dielectric constant (ε_r) of 2.2, loss tangent (tanδ) of 0.0004, and height (h) of 1.6 mm. The optimized structural parameters of the antenna are listed in Table I.

Physical dimensions of the antenna are $42.2\times7.7\times1.6$ mm^3, which corresponds to an electrical size of $3.25\lambda_0\times0.59\lambda_0\times0.12\lambda_0$, where λ_0 represents free space wavelength at 23.10 GHz. Fig. 2 shows the simulated frequency bandwidth of the optimized antenna is 10.10 GHz (from 22.70 – 32.80 GHz) for a reflection coefficient of $S_{11}\leq$-10dB, which corresponds to a fractional bandwidth of 36.39%. The actual measured bandwidth of the antenna is 9.40 GHz (from 23.10 – 32.50 GHz), which corresponds to a fractional bandwidth of 33.81%. Simulation analysis was done using High Frequency Structure Simulator (HFSS™). There is reasonably good agreement between the simulated and measured results. These results confirm the proposed microstrip antenna covers the frequency range (24.25 GHz to 30.00 GHz) needed for millimeter wave scanners.



(a) Layout of the proposed antenna



(b) Fabricated prototype antenna

Fig. 1. Geometry of the proposed antenna.

TABLE I. ANTENNA STRUCTURAL DIMENSIONS DEFINED IN FIG. 1a (IN MILLIMETERS)

Number (#)	#1	#2	#3	#4	#5	#6	#7
Dimensions	5	6	3.3	1.25	0.6	0.4	2.2

Number (#)	#8	#9	#10	#11	*#La*	*#Wa*	*#h*
Dimensions	0.4	3.6	2.6	5.2	42.2	7.7	1.6

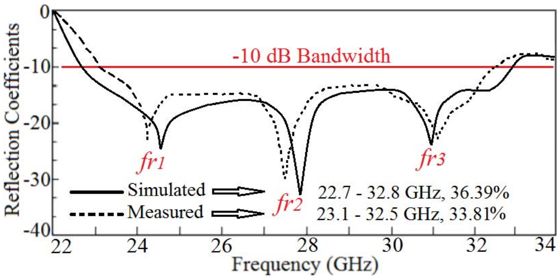


Fig. 2. Simulated and measured reflection coefficient response (S_{11}<-10dB).

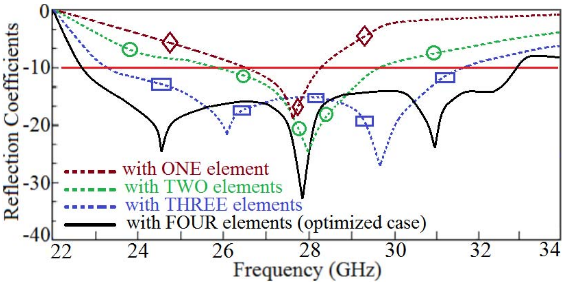


Fig. 3. Parametric study showing how the number of array elements affects the antenna's bandwidth performance.

Results of the parametric study on the antenna bandwidth are shown in Fig. 3. It is evident from this study that the larger the number of elements in the array the greater the frequency bandwidth of the antenna. The array elements essentially introduce resonance frequencies thereby enhancing the antenna's operational bandwidth and matching impedance.

In addition to meeting the goals of miniaturized dimensions and frequency bandwidth, the radiation characteristics of the antenna is important. The antenna's gain and radiation efficiency response are shown in Fig. 4. The results show the simulated gain and efficiency vary from 3.50 dBi to 7 dBi and 45.5% to 85.1%, respectively, within the frequency range of 22.7 GHz to 32.8 GHz. The measured gain and efficiency vary from 3.35 dBi to 6.75 dBi and 40.85% to 82.34%, respectively, in the frequency range of 23.1 GHz to 32.5 GHz. The maximum measured gain and radiation efficiency are 6.75 dBi and 82.34%, respectively, at 27.5 GHz.

Fig. 5 shows the parametric study on how the antenna's gain and radiation efficiency are affected by the number of array elements. By increasing the number of array elements in the linear configuration, shown in Fig. 1, the antenna's physical dimensions will inevitably increase. By doing this the effective aperture of the antenna also increases too thus enhancing the antenna's radiation characteristics, as shown in Fig. 5. The final antenna design consists of an array with 4 elements to satisfy the scanners bandwidth requirements (24.25 GHz to 30 GHz).

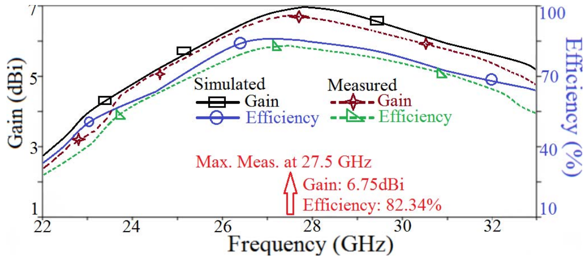


Fig. 4. The proposed antenna's gain and radiation efficiency response.

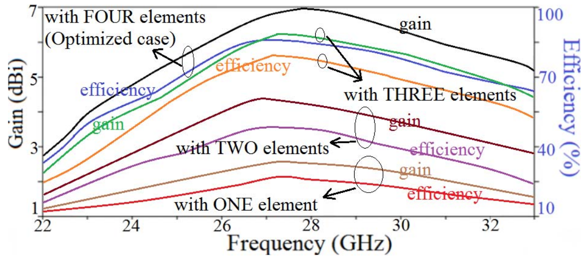


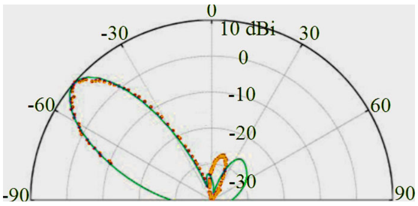
Fig. 5. Parametric study showing the effect of number of array elements on the antenna's gain and efficiency performance.

The antenna radiation patterns are shown in Fig. 6. Clearly, the antenna is capable of scanning from -50^{o} to $+15^{o}$ over its operational frequency bandwidth. The antenna's backfire, broadside and endfire radiations occur at f_{r_1}= 24.25 GHz, f_{r_2}= 27.50 GHz, and f_{r_3}= 31.10 GHz, respectively. The sidebands associated with the antenna are less than -20 dB.

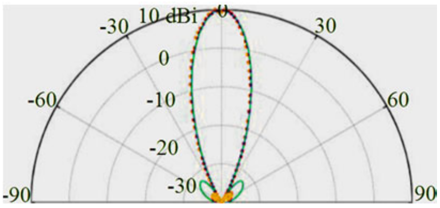
Simulated and measured performance parameters of the antenna are given in Table II. There is generally good agreement between the simulated and measured results. The proposed antenna is compact in size, operates over the frequency band from 23.1 GHz to 32.5 GHz, and is capable of scanning over a wide angle from -50^{o} to $+15^{o}$.

TABLE II. ANTENNA'S PERFORMANCE PARAMETERS

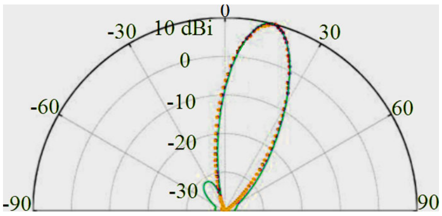
Dimensions	$42.2 \times 7.7 \times 1.6$ mm^3 and $3.25\lambda_0 \times 0.59\lambda_0 \times 0.12\lambda_0$ where λ_0 is free space wavelength at 23.10 GHz					
Bandwidth	Simulated: 10.10 GHz (from 22.70 – 32.80 GHz) / fractional bandwidth = 36.39%					
	Measured: 9.40 GHz (from 23.10 – 32.50 GHz) / fractional bandwidth = 33.81%					
Gain (dBi)	**Simulated**	3.50	5.12	7.00	5.95	5.22
		@22.7 GHz	@24.50 GHz	@27.8 GHz	@30.95 GHz	@32.8 GHz
	Measured	3.35	5.00	6.75	5.73	5.10
		@23.10 GHz	@24.25 GHz	@27.5 GHz	@31.10 GHz	@32.50 GHz
Efficiency (%)	**Simulated**	45.50	63.40	85.10	72.81	65.47
		@22.7 GHz	@24.50 GHz	@27.8 GHz	@30.95 GHz	@32.8 GHz
	Measured	40.85	60.01	82.34	70.10	61.70
		@23.10 GHz	@24.25 GHz	@27.5 GHz	@31.10 GHz	@32.50 GHz



(a) f_{r_1}= 24.25 GHz



(b) f_{r_2}= 27.50 GHz



(c) f_{r_3}= 31.10 GHz

Fig. 6. Antenna's simulated and measured radiation patterns: (a) backfire radiation patterns at f_{r_1}= 24.25 GHz, (b) broadside radiation pattern at f_{r_2}= 27.50 GHz, and (c) endfire radiation pattern f_{r_3}= 31.10 GHz. Dashed lines and solid lines present the simulated and measured patterns, respectively.

III. CONCLUSION

A novel millimeter wave antenna has been demonstrated to exhibit beam scanning over an angle of -50° to $+15^{\circ}$, and it operates over a frequency range of 23.10 GHz to 32.50 GHz. The planar antenna design consists of a linear array consisting of 1×4 radiating elements. The parametric study showed the antenna's characterizing parameters (impedance bandwidth, gain and radiation efficiency) are significantly enhanced by simply increasing the number elements in the array. The measured results conforms the antenna exhibits a maximum gain and radiation efficiency measured are 6.75 dBi and 82.34%, respectively, at 27.5 GHz. The singular antenna can be adapted to replace multiple antennas employed in airport security checkpoint scanners. This should result in a portable scanner system.

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