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W Band MEMS Detection Arrays

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Abstract— **Microstrip antennas posse's attractive features such as low profile, light weight and low production cost. However, losses in the microstrip feed network form a significant limit to the achievable gain. This paper presents the design and fabrication of a W band microstrip antenna array with high efficiency. Millimeter wave detection arrays may be applied to detect explosive materials and weapons underneath terrorist clothes. The radiation that is reflected or emitted from different materials has different intensity rate. Detection of this radiation may be used to detect explosive materials and weapons. MEMS technology may be used to produce low cost millimeter wave detection arrays. In this paper the development of a MEMS millimeter wave detection array is presented. The detection array may be constructed from 256 to 1024 elements. Each element in the array includes an antenna and a bolometer. The arrays center frequency may be at 100GHz or at 220GHz. Design considerations of the antenna and the bolometer are given in this paper. Optimization of the antenna and bolometer structure allows us to maximize the power rate dissipated on the bolometer to around 25-30%.**

Index Terms— **Microstrip antennas, Antenna array, MEMS technology, Detection array**

I. INTRODUCTION

Microstrip antennas posse's attractive features such as low profile, light weight, small volume and low production cost. In microstrip antenna arrays we may integrate the RF feed network with the radiating elements on the same substrate. Microstrip antennas are widely presented in books and papers in the last decade as referred in [1-7].

This paper presents the design of a W band microstrip antenna array with high efficiency. Gain limitation in microstrip antenna arrays due to losses in the feed network are presented in [3]. Losses in the microstrip feed network are due to conductor loss, radiation loss and dielectric loss. Equations to calculate conductor loss and dielectric loss in microstrip lines are given in [3]. In [8-9] a planar multiport network modeling approach has been used to evaluate radiation loss from microstrip discontinuities. Full-wave analysis has been used [10] to calculate radiation conductance of an open-circuited microstrip line. In [4] detailed analysis of losses in the antennas feed network is presented. In [4] 64 microstrip antenna array with efficiency of 67.6% and a 256 microstrip antenna array with efficiency of 50.47% at Ka band are presented. By minimizing the number of bend discontinuities the gain of the 256 microstrip antenna array has been improved by 1dB. The insertion loss of a flexible cable at 30GHz is 0.039 dB per centimeter. However, the insertion loss at 30GHz of a 50 ohm microstrip line on a 10 mil substrate with εr=2.2 is around 0.2dB per centimeter. By replacing a microstrip line with length of ten centimeters with a coaxial cable, the gain of the 256 patch antenna array has been improved by 1.6 dB. In [2] a planar slotted waveguide array at 76.5GHz with 24 waveguides and 13 slots in each waveguide is presented. The array dimensions are 71.5x64.7mm. The array gain is 33.2dB. The aperture efficiency of the array is around 40%. In [2] a 27x2 comb line microstrip antenna array is presented at 76.5GHz.The array gain is 20.3dB. In [11] a 2x2 94GHz Micro-machined Aperture- Coupled Microstrip Antenna array is presented. The 2x2 94GHz micro-machined microstrip antenna array has efficiency around 58% for a 100μm thick substrate with εre=3. However, the antenna has efficiency around 27% for a 100μm thick substrate with εr=11.7. In [12] the design of 8x8 60GHz microstrip Antenna array is presented. The computed efficiency of the antenna is around 40%. In [13] a reflect array is employed to improve the efficiency of microstrip antenna arrays at Ka band. However, reflect arrays lucks most of the advantages of microstrip antennas. In [13] the efficiency of a 6 inch diameter (f/d=0.44) reflect-array on 10mil Taconic substrate is around 35%. The efficiency of a 6 inch diameter (f/d=0.44) reflect-array on 20mil Duroid substrate is around 54%. Dielectric losses on Duroid substrate are lower by 1.6dB than dielectric losses on a Taconic substrate.

Array of patch antenna coupled to a bolometer minimize the effect of losses in the array feed network. Several imaging approaches are presented [14-19]. The common approach is based on an array of radiators (antennas) that receives radiation from a specific direction by using a combination of electronic and mechanical scanning. Another approach is based on a steering array of radiation sensors at the focal plane of a lens of reflector. The sensor can be an antenna coupled to a resistor. In this paper we present also the development of millimeter wave radiation detection array. The detection array may consist around 256 to 1024 patch antennas. These patches are coupled to a resistor. Optimization of the antenna structure, feed network dimensions and resistor structure allow us to maximize the power rate dissipated on the resistor. Design considerations of the detection antenna array are given in this paper.

II. W BAND DETECTION ARRAY

Losses in the microstrip feed network are very high in the W band frequency range. A detection array has been designed in W band frequency range. The array concept is based on an antenna coupled to a resistor. A direct antenna-coupling surface to a micro machined micro bridge resistor is used for heating and sensing. Analog CMOS readout circuit may be employed as a sensing channel per pixel. Fig. 1 presents a pixel block diagram. The antenna receives effective mm wave radiation. The radiation power is transmitted to a thermally

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isolated resistor coupled to a Ti resistor. The electrical power raises the structure temperature with a short response time. The same resistor changes its temperature and therefore its electrical resistance. Fig. 2 shows a single array pixel. The pixel consist a patch antenna, a matching network, printed resistor and DC pads. The printed resistor consists of Titanium lines and a Titanium resistor coupled to an isolated resistor. The operating frequency range of 92GHz to 100GHz is the best choice. In the frequency range of 30-150GHz there is a proven contrast between land, sky and high transmittance of clothes. Size and resolution considerations promote higher frequencies above 100GHz. Typical penetration of clothing at 100GHz is 1dB and 5dB to 10dB at 1THz. Characterization and measurement considerations promote lower frequencies. The frequency range of 100 GHz allows sufficient bandwidth when working with illumination. The frequency range of 100GHz is the best compromise. Figure 3 presents the array concept. Several types of printed antennas may be employed as the array element such as bowtie dipole, patch antenna and ring resonant slot. The bowtie dipole is shown in Fig. 4. The patch coupled to a bolometer is shown in Fig. 5. HFSS software has been used to compute mutual coupling effects between pixels in the detection array as shown in Fig. 6.

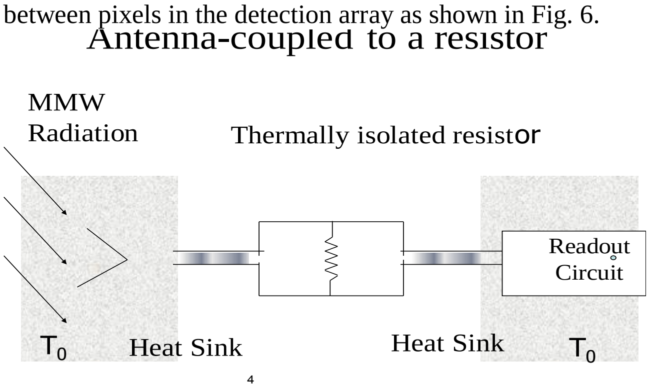

Fig. 1 Antenna coupled to a resistor

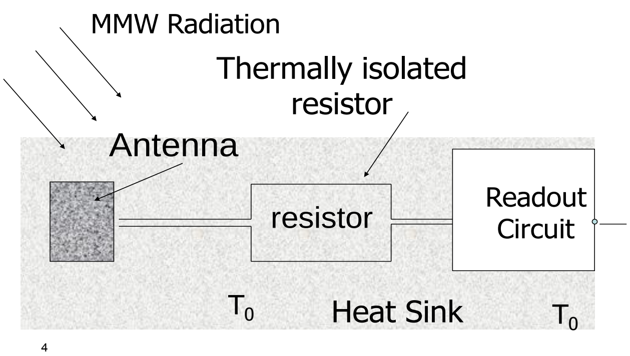

Fig. 2 A single array pixel

Computation results indicate that the power dissipated on the centered pixels in the array is higher by 1% to 2% than the pixels located at the corners of the array. The detection array may be constructed from 256 to 1024 elements. The bowtie dipole and a patch antenna have been considered as the array element. Computed results shows that the directivity of the bowtie dipole is around 5.3dBi and the directivity of a patch antenna is around 4.8dBi. However the length of the bowtie dipole is around 1.5mm the size of the patch antenna is around 620x620µm. We used a quartz substrate with thickness of 250µm. The bandwidth of the bowtie dipole is wider than that of a patch antenna. However, the patch antenna bandwidth meets the detection array electrical specifications. We chose the patch antenna as the array element since the patch size is significantly smaller than that of the bowtie dipole. This feature allows us to design an array with a higher number of radiating elements. The resolution of detection array with a higher number of radiating elements is better. We also realized that the matching network between the antenna and the resistor has smaller size for a patch antenna than that for a bowtie dipole. The matching network between the antenna and the resistor consist of microstrip open stubs.

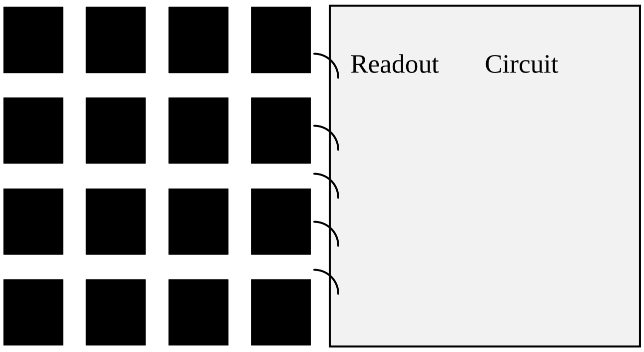

Fig. 3 Detection Array concept

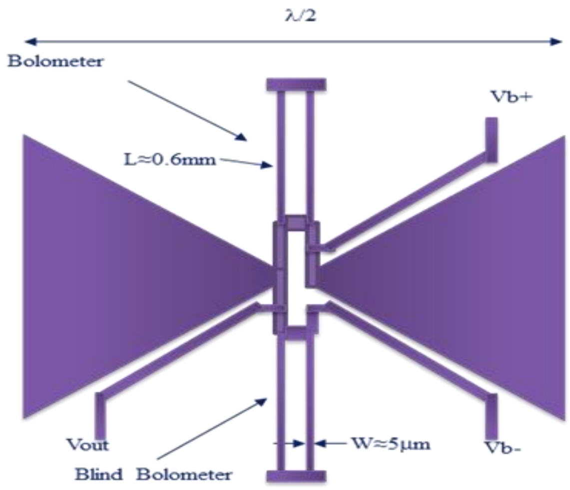

Fig. 4 Bowtie dipole coupled to bolometer

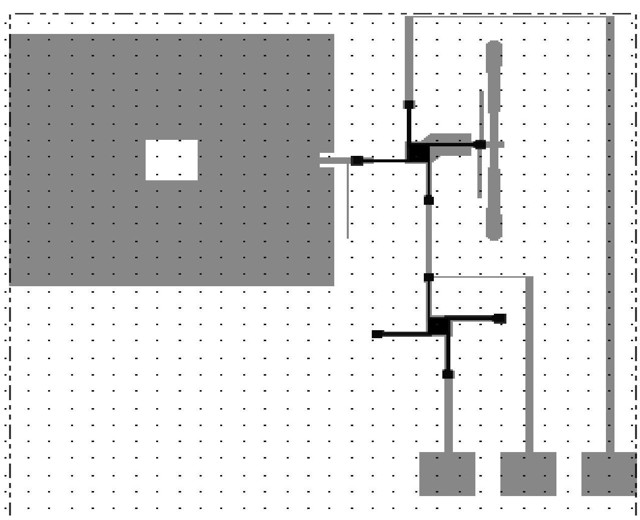

Fig. 5 Patch antenna coupled to bolometer

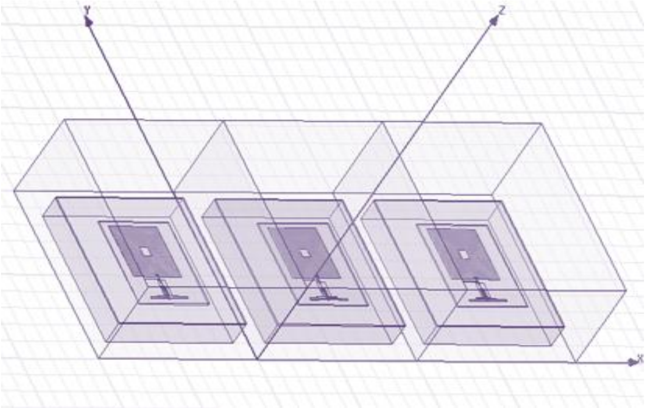

Fig. 6 Mutual coupling computation model

The feed network determines the antenna efficiency. The insertion loss of a gold microstrip line with width of 1µm and 188µm length is 4.4dB at 95GHz. The insertion loss of a gold microstrip line with width of 10µm and 188µm length is 3.6dB at 95GHz. The insertion loss of a gold microstrip line with width of 20µm and 188µm length is 3.2dB at 95GHz. To minimize losses the feed line dimensions was selected as 60x10x1µm. A taper connects the 10µm width patch feed line to the 1µm width Titanium resistor line. The resistor is thermally isolated from the patch antenna by using a 3µm sacrificial layer. The patch is matched to the10µm width patch feed line by employing open circuited stubs. Fig. 7 presents S11 parameter of the patch antenna. The patch antenna V.S.W.R is better than 2:1 in the frequency range of 92GHz to 99GHz. Fig. 8 shows the 3D radiation pattern of the Bowtie dipole. Fig. 9 shows the 3D radiation pattern of the patch.

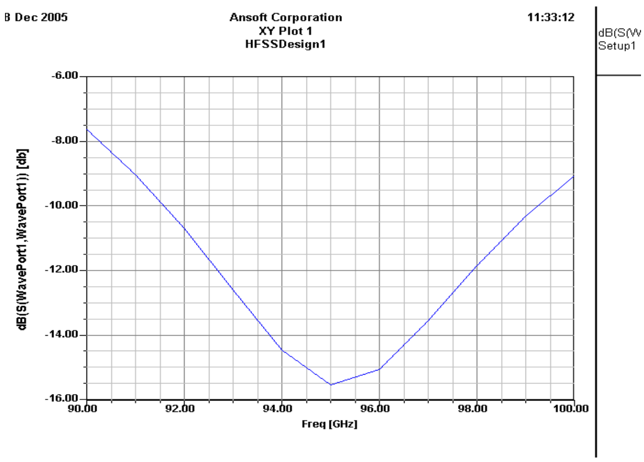

Fig. 7 Patch S11 computed results

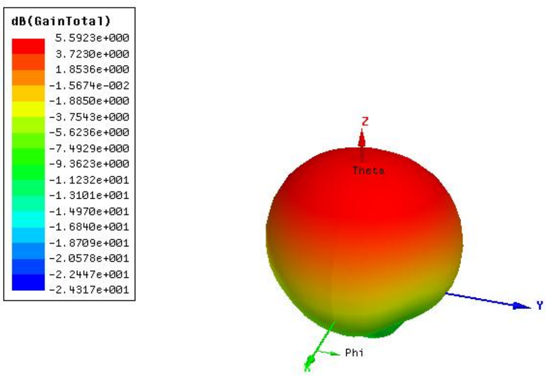

Fig. 8 3D radiation pattern of the Dipole

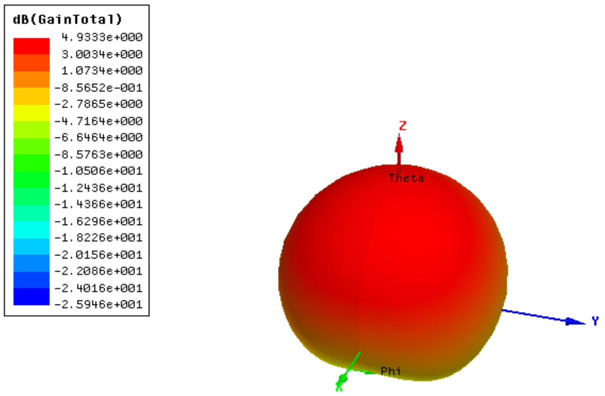

Fig. 9 3D radiation pattern of the Patch

III. Array Design and Fabrication

As described by (M.M. Milkov, 2000) [14], the resistor is thermally isolated from the patch antenna by using a sacrificial layer. Optimizations of the resistor structure maximize the power rate dissipated on the resistor. Material properties are given in Table III. Ansoft HFSS software is employed to optimize the height of the sacrificial layer, the transmission line width and length. The rate of the dissipated power on the Titanium resistor is around 25% to 30%. Dissipated power on Titanium resistor is higher than the dissipated power on Platinum resistor. The rate of the dissipated power on the Platinum resistor is around 4%. The sacrificial layer thickness may be 2µm to 3µm. Fig. 10 shows the resistor configuration. Fig. 11 presents the resistor layout. Nine masks are used to fabricate the detection array. Masks Process and layer thickness is listed in Table II. Layer thickness has been determined as the best compromise between technology limits and design consideration. Dimensions of detection array elements have been measured in several array pixels as part of visual test of the array after fabrication of the array. Measured results are listed in Table III. From results listed in Table III we may conclude that the fabrication process is very accurate.

Table I. Material properties

Property	siNi	Ti	SiO_2	Ni	VO_x
Conductivity W/m/K	1.6	7	1.4	26	3.6
Capacity [C] J/Kg/K	770	520	730	444	540
Density [ρ] Gr/cm^3	2.85	4.5	2.6	8.9	5.9
Resistance Ω/□	>1e8	90	>1e8	20	8-15 e4
Thickness µm	0.1	0.1	250	0.1	0.1

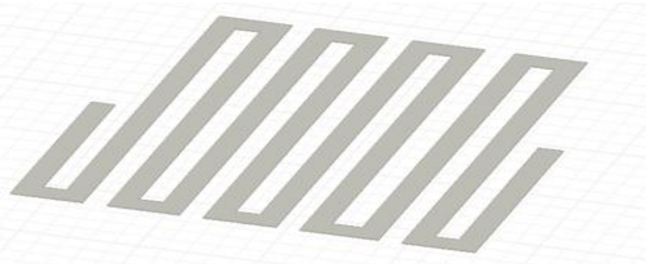

Fig. 10 Resistor Configuration

There is a good agreement between computed and measured results.

IV. 220GHz MICROSTRIP PATCH ANTENNA

HFSS software has been used to design a patch antenna at 200GHz. Quartz substrate with thickness of 50µm to 100µm may be considered to fabricate microstrip antennas at frequencies higher than 200GHz. The size of the patch antenna is around 300x300µm.

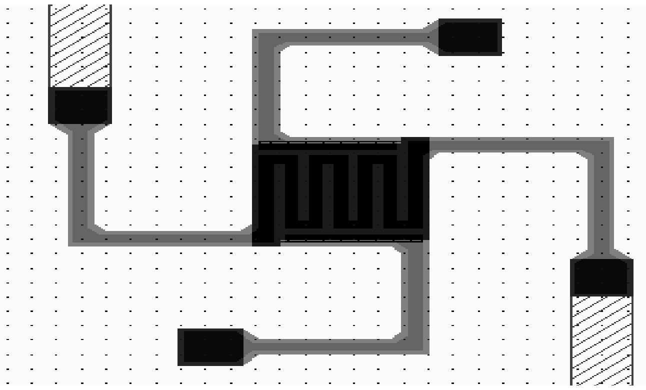

Fig. 11 Resistor Layout

Fig. 12 presents S11 parameter of the patch antenna. The patch antenna V.SW.R is better than 2:1 at the frequency range of 200GHz to 236GHz.

Table II. **Masks** process

Masks	Layer	Process	Layer thickness
1	L1 Lift or Etch	Gold reflector Au	1µm
2	L2 Etch	streets open S.L.	3µm
3	L3 Etch	S.L. Contacts	
4	L4 Etch	SiN + Contacts	0.1µm
5	L5 Etch	Ti_1	0.1µm
		SiN	0.15µm
6	L6 Etch	VOx	0.1µm
7	L7 Etch	Contacts for Ti_2	0.1µm
	L 3 Lift	Metal Cap	0.1-0.5µm
8	L8 Etch	Ti_2	
9	L9 Etch	Membrane Definition	

Table III. Comparison of design and Fabricated array dimensions

Element	Design (µm)	Pixel 1 (µm)	Pixel 2 (µm)
Patch width	600	599.5	600.5
Patch length	600	600.3	600.5
Hole width	100	99.8	100
Hole length	100	100	99.8
Feed line	10	10	10
Feed line	10	9.8	10
Stub width	2	2	1.8
Tapered line	15	15.2	14.8
Stub width	2	1.8	2
Taper	25	25.3	25.2

Fig. 13 shows the 3D radiation pattern of the patch antenna.

Results presented in this paper show that microsrip patch antenna may be used as the array element at 200GHz. Fabrication of microstrip detection arrays at 200GHz may have several advantages. Penetration of clothing at 220GHz is better than penetration of clothing at 100GHz. At 220GHz we may design an array with a higher number of radiating elements. The resolution of detection array with a higher number of radiating elements is better.

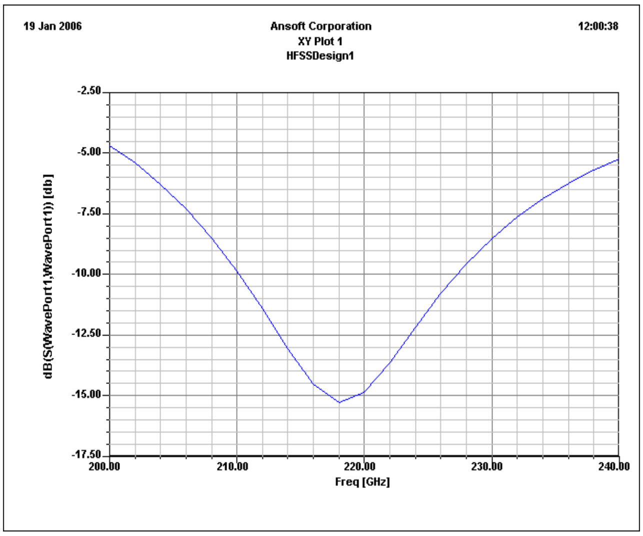

Fig. 12 220GHz Patch results a. S11 results

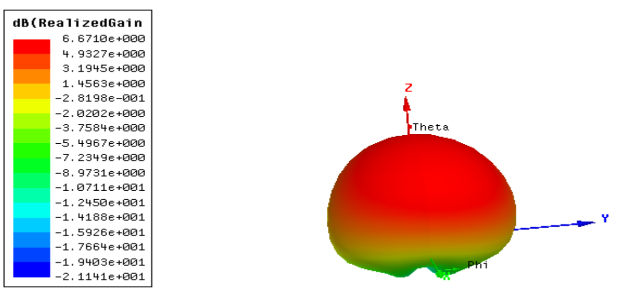

Fig. 13 220GHz Patch 3D radiation pattern

V. Concluding Remarks

Losses in the microstrip feed network form a significant limit on the possible applications of microstrip antenna arrays in mm wave frequencies.

Array of patch antenna coupled to a bolometer decrease the effect of losses in the array feed network. The array may be constructed from 256 to 1024 elements at 94GHz or at 220GHz. Design considerations of the antenna and the feed network are given in this paper. Optimization of the antenna structure and feed network allows us to design and fabricate microstrip antenna arrays with high efficiency. Millimeter wave detection arrays may be applied to detect explosive materials and weapons underneath terrorist clothes. MEMS technology has been applied to produce low cost millimeter wave detection arrays.

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In 1976 he joined the armament development authority RAFAEL in Israel. In RAFAEL he worked as a senior researcher, group leader and project leader in the electromagnetic department till 2007. In 2007 he retired from RAFAEL. From 2008 to 2010 he worked as an RF Specialist and project leader in Hi-tech companies. From 2010 to date he is a senior lecturer and researcher in Ort Braude College in Israel in the electrical engineering department