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DESIGN AND ANALYSIS OF FLAME RETARDANT MATERIAL BASED MICROSTRIP PATCH ANTENNA FOR THE DETECTION OF SEMTEX

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Abstract

Microstrip patch antennas are recently used in wireless detection applications due to their low power consumption, low cost, versatility, field excitation, ease of fabrication etc. The microstrip patch antenna suffers with an array elements of antenna and narrow bandwidth. To overcome the above drawbacks, Flame Retardant Material is used as the substrate. Rectangular shape of microstrip patch antenna with FR4 material as the substrate which is more suitable for the explosive detection applications. The proposed microstrip patch antenna was designed with the dimension of 60×60mm^2. FR-4 material has a dielectric constant value of 4.3 with thickness 1.56mm, length and width 60mm and 60mm respectively. One side of the substrate contains the ground plane of dimensions 60×60mm^2 made of copper and the other side of the substrate contains the patch which have dimensions 34 × 29mm^2 and thickness 0.03mm which is also made of copper. RMPA without slot, Vertical slot RMPA, Double horizontal slot RMPA and Centre slot RMPA structures were designed and the performance of the antennas were analysed with various parameters such as gain, directivity, E-field, VSWR and return loss. From the performance analysis, double horizontal slot RMPA antenna provides a better result and it provides maximum gain (8.61dB) and minimum return loss (-33.918dB). Based on the E-field excitation value of the double horizontal slot the SEMTEX explosive material is detected. When the absence SEMTEX material the E-field value is 18.2dBV/m which is reduced in presence of SEMTEX material and it was simulated using CST software.

Keywords:

Gain, Directivity, Return Loss, E-field, H-field

1. INTRODUCTION

Antennas are the essential component of wireless communication. An antenna is a transducer that converts electrical signal into electromagnetic waves and it radiates into the space [1]. Antenna can be designed to transmit and receive radio waves in all horizontal directions equally or preferentially in a particular direction. There are several types of antennas are available namely wire antenna, travelling antenna, reflector antenna, microstrip patch antenna, log periodic antenna, aperture antenna etc., out of these microstrip patch antennas are widely used in communication systems because of their low profile, light weight, low cost, feed-line flexibility, versatility, ease of fabrication[8]. Basically microstrip element consists of an area of metallization support above the ground plane, named as microstrip patch [3]. The supporting element is called substrate material which is placed between the patch and the ground plane. In majority of the cases the performance characteristics of the antenna depends on the substrate material and its physical parameters. The slot is loaded over the patch for improving gain and directivity. So many advantages and applications can be mentioned for microstrip patch antennas over conventional antennas. There are several undesirable features we encountered with conventional antennas like they are bulky, conformability problems and difficult to perform multiband operations so on [11]. Microstrip patch antenna is used in the military applications such as detection of explosive of material in the battle. The explosive material may be SEMTEX, RDX, TNT which are produce a dangerous explosion. It can be detected by using this antennas.

2. LITERATURE REVIEW

Payal et al. [14] proposed microstrip patch antenna for the detection of plastic explosive SEMTEX. In this paper Fr4 material as substrate of thickness 1.62mm with dielectric constant of 4.4 whereas the radiating patch and ground plane are made up of copper material having high conductivity and low resistivity. The reduced ground plane has been used in order to acquire the desired resonant frequency. It has been observed that the proposed antenna has an input impedance of 49.15 which resonates at 4.32THz frequency with return loss of -52.10dB and with a gain of 5.88dB and directivity of 5.75dBi which makes it highly suitable for detection of plastic explosive SEMTEX. The reduced ground plane has been used in order to improve the return loss plot and other antenna parameters like gain, directivity of an antenna.

Kalra et al. [15] proposed microstrip patch antenna using FR4 as substrate for detection of riboflavin. In this paper the design and analysis of terahertz microstrip patch antenna employing flame retardant as substrate material having thickness of 1.6mm and dielectric constant of 4.4 the patch and ground are made up of copper material and rectangular slot has been introduced in patch to improve the antenna parameters such as return loss, directivity, gain and bandwidth. The ground has been reduced to increase the bandwidth and gain of the antenna. The proposed antenna design has been observed that the designed antenna is resonant at 4.17THz. The designed antenna has return loss (S11) magnitude of -39.73dB at resonant frequency of 4.17THz. The antenna has gain of 6.8dB and directivity of 6.4dBi at corresponding resonant frequency of 4.17THz.

Saini et al. [21] proposed microstrip patch antenna design employing denim substrate for detection of TNT explosives. In this paper, a textile terahertz reduced ground microstrip patch antenna for detection of trinitrotoluene (TNT) has been proposed. The proposed antenna is employing black denim as substrate having dielectric constant of 1.6. The ground and patch of the proposed antenna has been designed using copper of thickness 0.05mm. It has been analyzed that the proposed antenna has impedance bandwidth of 247GHz with an operating frequency range of 8.0481THz to 8.3321THz with resonant frequency of 8.208THz. It has been observed that the textile terahertz reduced ground microstrip patch antenna has gain of 7.359dB and directivity of 7.002dBi. The proposed antenna has minimal return loss of -65.89dB at resonant frequency of 8.208THz.

Cheng et al. [7] proposed the microstrip patch antenna sensing system for salinity and sugar detection in the water. In this paper describes the design and development of a microstrip patch antenna for salinity and sugar detection. This sensor is operating in the Industrial, Scientific and Medical (ISM) radio band, i.e. 2.45GHz. Dimension and shape of the patch antenna as well as location of feed point is analyzed. There are three types of microstrip patch antennas are developed in this work, i.e. rectangular, circular and square patch microstrip antennas. These microstrip patch antennas were used to measure the salt and sugar content in water. In addition, reflection coefficient and Q-factor were discussed too in this paper. Different amount of salt or sugar that present in water will exhibit different dielectric properties, and in turn change its reflection coefficient and Q-factor.

Devi et al. [18] proposed a pentagon microstrip antenna for radar altimeter application . In this paper comparison between triangular patch antenna of 5.88GHz and annular ring triangular patch antenna is done. Linearly polarized yagi-array antenna used and observed response with different sizes and distance between elements. It is seen that the Return Loss is increased by 57.4% whereas Gain is improved by 37.09% after introducing the annular ring in the Triangular Patch Antenna. Simulated and implemented result is compared and got 6.94% deviation in frequency for the implemented antenna. The frequency deviation is due to the deviation from exact measurement. It is also due to the effect of the permittivity of the substrate. Array of antennas are used which is difficult to handle and more complex to implement and it produced high directivity value.

3. SLOTTED BASED METHOD

The proposed Rectangular shape of microstrip patch antenna designed using a flame retardant material (FR4) having a dielectric constant of 4.3 and this material is used as the substrate which is loaded over the ground plane of copper. The same copper material is used as the patch and feed of antenna. The Fig.1 shows the structure of basic Microstrip Patch Antenna.

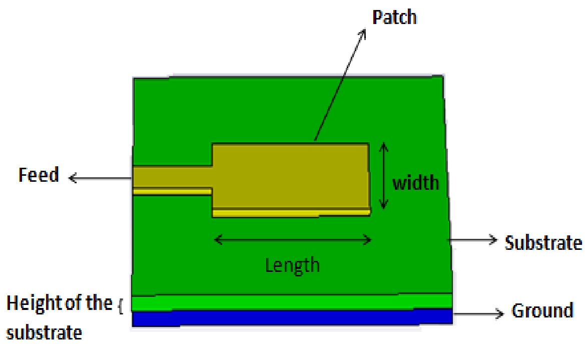


Fig.1. Basic Microstrip patch antenna

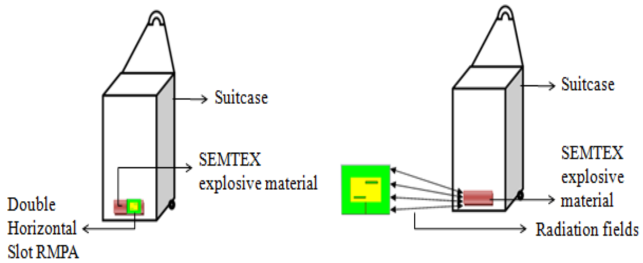


Fig.2. Proposed design to detect the SEMTEX material

3.1 DESIGN OF RMPA WITHOUT SLOT

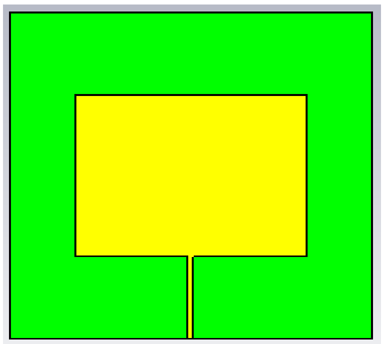


Fig.3. Design of RMPA without slot

The Fig.3 shows the Rectangular Microstrip patch antenna has a substrate made of FR-4 which has a dielectric constant of 4.3. The ground plane is made up of copper with pure metal which is placed one side of the substrate. The other side of the substrate contains the patch that is made up of copper with pure metal. The proposed antenna is fed with microstrip line feed. The Table.1 shows the specifications of rectangular microstrip patch antenna without Slot.

Table.1. Design specifications of RMPA without Slot

Antenna Specifications	Dimension
Thickness of the Ground	0.03mm
Width of the Ground	60mm
Height of the Ground	60mm
Thickness of the Substrate	1.56mm
Width of the Substrate	60mm
Height of the Substrate	60mm
Thickness of the Patch	0.03mm
Width of the Patch	29.8mm
Height of the Patch	38.4mm
Thickness of the Feed	0.03mm
Width of the Feed	1mm
Height of the Feed	15mm
Operating frequency	4 to 5GHz

3.2 DESIGN OF SINGLE VERTICAL SLOT RMPA

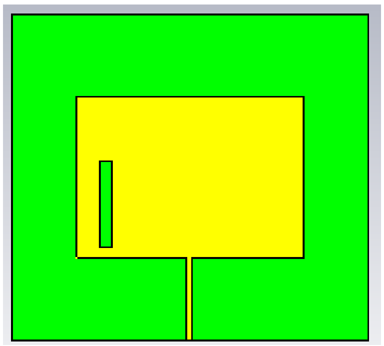


Fig.4. Design of single vertical slot RMPA

The Fig.4 shows the single vertical slot Microstrip patch antenna it uses the same Ground, Substrate, Patch and Feed dimensions of the Microstrip patch antenna without slot along with single vertical slot is created. The Table.2 shows the specifications of single vertical slot RMPA.

Table.2. Design specifications of single vertical slot RMPA

Antenna Specifications	Dimension
Thickness of the Ground	0.03mm
Width of the Ground	60mm
Height of the Ground	60mm
Thickness of the Substrate	1.56mm
Width of the Substrate	60mm
Height of the Substrate	60mm
Thickness of the Patch	0.03mm
Width of the Patch	29.8mm
Height of the Patch	38.4mm
Thickness of the Feed	0.03mm
Width of the Feed	1mm
Height of the Feed	15mm
Thickness of the Slot	0.03mm
Width of the Slot	10mm
Height of the slot	2mm
Operating frequency	4 to 5GHz

3.3 DESIGN OF DOUBLE HORIZONTAL SLOT RMPA

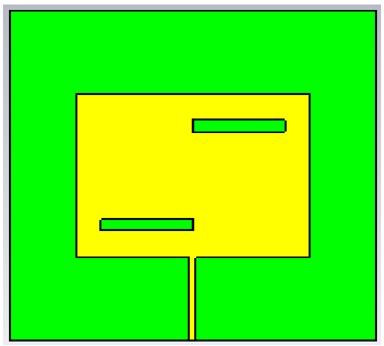


Fig.5. Design of double horizontal slot RMPA

The Fig.5 shows the double horizontal slot RMPA it uses the same Ground, Substrate, Patch and Feed dimensions of the rectangular microstrip patch antenna without slot along with double horizontal slot is created on the patch. The Table.3 shows the specifications of double horizontal slot RMPA.

Table.3. Design specifications of double horizontal slot RMPA

Antenna Specifications	Dimension
Thickness of the Ground	0.03mm
Width of the Ground	60mm
Height of the Ground	60mm
Thickness of the Substrate	1.56mm
Width of the Substrate	60mm
Height of the Substrate	60mm
Thickness of the Patch	0.03mm
Width of the Patch	29.8mm
Height of the Patch	38.4mm
Thickness of the Feed	0.03mm
Width of the Feed	1mm
Height of the Feed	15mm
Thickness of the lower Slot	0.03mm
Width of the lower Slot	10mm
Height of the lower slot	2mm
Thickness of the upper slot	0.03mm
Width of the upper slot	10mm
Height of the upper slot	3mm
Operating frequency	4 to 5GHz

3.4 DESIGN OF CENTRE SLOT RMPA

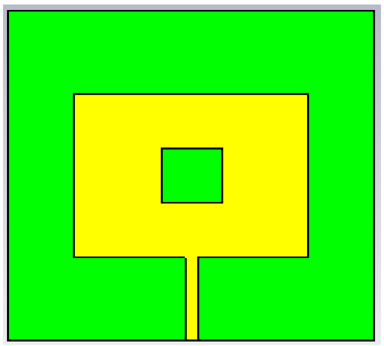


Fig.6. Design of center slot RMPA

The Fig.6 shows the centre slot RMPA it uses the same Ground, Substrate and Patch of the rectangular microstrip patch antenna without slot along with single centre slot is created on the patch. The Table.4 shows the specifications of centre slot RMPA.

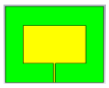
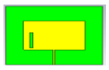
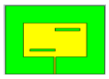
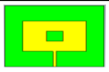
Table.4. Design specifications of centre slot RMPA

Antenna Specifications	**Dimension**
Thickness of the Ground	0.03mm
Width of the Ground	60mm
Height of the Ground	60mm
Thickness of the Substrate	1.56mm
Width of the Substrate	60mm
Height of the Substrate	60mm
Thickness of the Patch	0.03mm
Width of the Patch	29.8mm
Height of the Patch	38.4mm
Thickness of the Feed	0.03mm
Width of the Feed	2mm
Height of the Feed	15mm
Thickness of the center slot	0.03mm
Width of the center slot	5mm
Height of the center slot	5mm
Operating frequency	4 to 5GHz

4. RESULTS AND DISCUSSIONS

The performance of the different Rectangular microstrip patch antenna with and without slots are evaluated by calculating Return loss, VSWR, Directivity, Gain. The performance of the proposed method is compared with the existing method. The Table.5 Performance parameter comparison of RMPA.

Table.5. Performance comparison of Microstrip patch antenna

Antenna Type		**Return Loss**	**VSWR**
Rectangular MPA without slot		-25.924dB	1.077
Single vertical slot RMPA		-21.179dB	1.925
Double horizontal slot RMPA		-33.918dB	1.0451
Centre slot RMPA		-16.364dB	1.3591

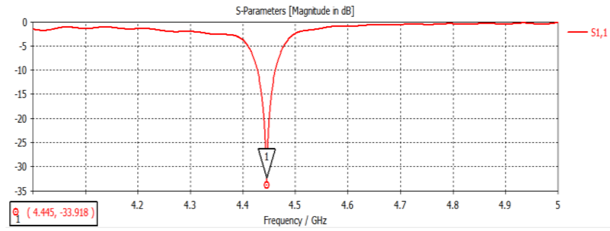


Fig.7. Return loss of double horizontal slot RMPA

The Fig.7 shows the return loss (s_{11}) curve of the proposed antenna obtained by CST simulator. It produce the return loss value of -33.918dB resonate at the frequency of 4.445GHz.

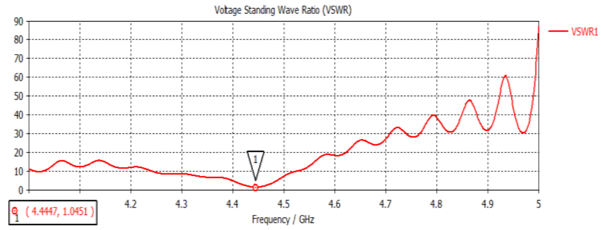


Fig.8. VSWR of double horizontal slot RMPA

The Fig.8 shows the VSWR curve of the proposed antenna obtained by CST simulator. It produce the VSWR value of 1.0451 resonate at the frequency of 4.444GHz. From Table.6, the performance comparison table of Microstrip Patch Antenna, it was observed that the Double horizontal slot RMPA provides high Gain and directivity.

Table.6. Performance parameter comparison of RMPA

Antenna types	**Resonant Frequency (GHz)**	**Directivity (dBi)**	**Gain (dB)**	**E-Field (dBV/m)**
Rectangular MPA without slot	4	4.56	1.36	8.73
	4.5	8.26	8.55	22.2
	5	7.39	6.8	13.5
Single vertical slot RMPA	4	4.82	1.86	9.25
	4.5	7.85	8.16	22.2
	5	5.96	5.25	14.6
	4	6.74	7.3	16.9

Double horizontal slot RMPA	4.5	6.48	7.13	18.2
	5	5.82	8.61	9.9
Centre slot RMPA	4	6.65	8.95	15.6
	4.5	5.98	5.75	17.3
	5	7.87	8.27	15.3

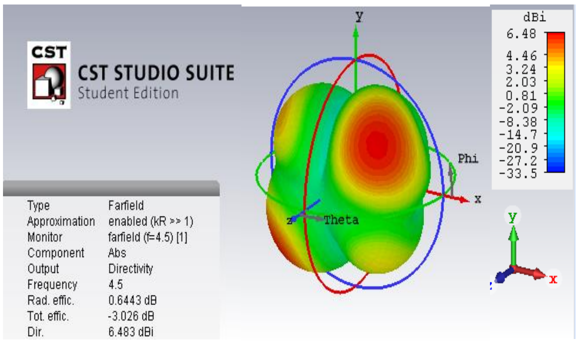


Fig.9. Directivity of double horizontal slot RMPA at 4.5GHz

The Fig.9 shows the directivity of the proposed antenna obtained by CST simulator. It produce the directivity value of 6.48dBi at the frequency of 4.5GHz.

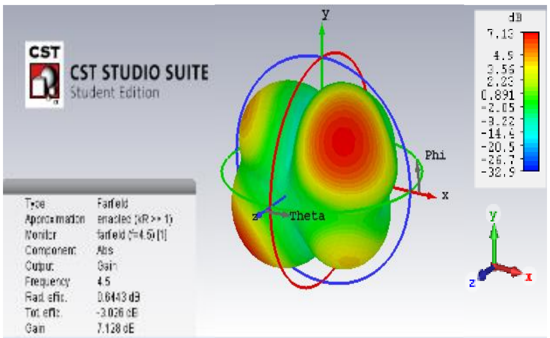


Fig.10. Gain of double horizontal slot RMPA at 4.5GHz

The Fig.10 shows the gain of the proposed antenna obtained by CST simulator. It produce the gain value of 7.13dB at the frequency of 4.5GHz.

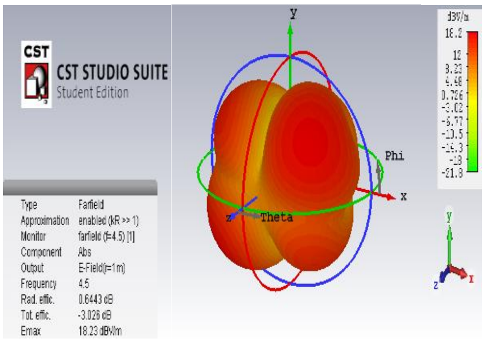


Fig.11. E-field of double horizontal slot RMPA at 4.5GHz

The Fig.11 shows E-field of the proposed antenna obtained by CST simulator. It produce the E-field of 18.2dBV/m at the frequency of 4.5GHz.

Table.7. SEMTEX material size is 5×5cm

Distance (m)	Resonant frequency (GHz)	E-field (dBV/m)	H-field (dBA/m)
0.1	4	6.07	-45.4
	4.5	12.7	-38.8
	5	7.35	-44.2
0.2	4	5.25	-46.3
	4.5	12.1	-39.4
	5	12.8	-38.8
0.3	4	5.06	-46.5
	4.5	12.1	-39.5
	5	14.1	-37.4
0.4	4	19.8	-31.8
	4.5	17	-34.6
	5	16.3	-35.2
0.5	4	6.74	-44.8
	4.5	3.94	-47.6
	5	15.5	-36

The Table.7 shows the E-field radiated by the antenna in presence of SEMTEX material with size 5cm.

Table.8. SEMTEX material size is 4×4cm

Distance (m)	Resonant frequency (GHz)	E-field (dBV/m)	H-field (dBA/m)
0.1	4	5.71	-45.8
	4.5	12.6	-38.9
	5	7.38	-44.1
0.2	4	5.32	-46.3
	4.5	12	-39.5
	5	10.7	-40.8
0.3	4	4.94	-46.6
	4.5	12	-39.6
	5	11.9	-39.6
0.4	4	5.27	-46.2
	4.5	12	-39.5
	5	11	-40.5
0.5	4	5.19	-46.3
	4.5	12	-39.5
	5	11.7	-39.8

The Table.8 shows the E-field radiated by the antenna in presence of SEMTEX material with size 4cm. The E-field value gets reduced when the SEMTEX material is present due to the destruction of radiation.

Table.9. SEMTEX material size 3×3cm

Distance (m)	Resonant frequency (GHz)	E-field (dBV/m)	H-field (dBA/m)
0.1	4	5.5	-44.8
	4.5	12.3	-38.3
	5	7.28	-43.5
0.2	4	5.35	-45.2
	4.5	11.8	-39.3
	5	10.5	-41.8
0.3	4	4.74	-46.3
	4.5	12	-40.1
	5	11.5	-39.3
0.4	4	5.23	-46.2
	4.5	11.7	-39.2
	5	11.3	-40.5
0.5	4	5.1	-46.1
	4.5	11	-39.2
	5	11.3	-39.4

The Table.9 shows the E-field radiated by the antenna in presence of SEMTEX material with size 3cm. The E-field value gets reduced when the SEMTEX material is present due to the destruction of radiation.

Table.10. SEMTEX material size 2×2cm

Distance (m)	Resonant frequency (GHz)	E-field (dBV/m)	H-field (dBA/m)
0.1	4	5.53	-43.2
	4.5	12	-38.1
	5	7.16	-43.2
0.2	4	5.27	-45.4
	4.5	11.5	-38.2
	5	9.41	-40.2
0.3	4	4.39	-45.2
	4.5	11	-38.4
	5	11.3	-39.2
0.4	4	5.19	-45.2
	4.5	11.2	-39.1
	5	11.1	-41.3
0.5	4	4.82	-46
	4.5	11	-38.7
	5	11.1	-38.2

The Table.10 shows the E-field radiated by the antenna in presence of SEMTEX material with size 2cm. The E-field value gets reduced when the SEMTEX material is present due to the destruction of radiation.

5. CONCLUSION

Different Rectangular Microstrip patch antennas using FR4 material were designed and performance of those antennas were analyzed with various parameters such as gain, directivity, VSWR and return loss. Various structures like RMPA without slots, vertical slot, double horizontal slot and centre slot were proposed. From the performance analysis, Double horizontal slot provides maximum gain (8.61dB), maximum directivity (5.82dBi), minimum VSWR (1.0451) and minimum return loss (-33.918dB). Thus the double horizontal slot antenna produce the better result than the other antennas. Based on the E-field of RMPA the SEMTEX explosive material is detected. When the absence SEMTEX material E-field value is 18.2dBV/m which is reduced in presence of SEMTEX material. In future work, the proposed antenna will be further developed for the same explosive detection application.

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