Research Article

Design of a Patch Antenna on Different Substrates for Higher Frequencies Applications

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Abstract: The microstrip patch antennas offered in this research exposure was designed and simulated on three different substrate materials to investigate its performance for its employment in future higher frequencies wireless applications in general and 5G cellular applications in particular. In the past, researchers employed different dielectric substrates to analyze microstrip patch antenna in low frequency range. In the presented research work three different dielectric materials were investigated in the higher frequency range starting from 12GHz as the scientists consider these higher frequencies suitable for future wireless mobile applications. Three simple rectangular patch structures were designed on three different insulated substrates including FR-4, Mica and Preperm. The thickness of the Mica was 2.15mm and the thickness of FR-4 was 2mm, while the thickness of the Preperm was reduced to 1.75mm. The parameters of all the three antennas were optimized to demonstrate better results. The results obtained from all the aforementioned structures were compared with one another. Emphasis was made on the bandwidth expansion and improvement on the efficiency. The Patch antenna on Mica substrate demonstrated better results as compared to the antennas on Preperm and FR-4 substrates. Patch antenna on Mica substrate attained huge dual bandwidths of 26.06GHz and 16.16GHz respectively. It attained greater efficiency of 81.88% and a maximum gain of 8.19dBi. Based on the results attained by the antenna on the Mica substrate, it is established that it will be the best antenna for wireless mobile applications at higher frequencies as compared to the remaining two antennas.

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Introduction

Microstrip patch antenna is a charming area for the scientists doing research on the future wireless mobile phones. The antenna for future wireless mobile appliances must encompass a straightforward clear structure that will result in its inexpensive production. The use of higher frequencies for future wireless mobile phones had minimized the volume of these antennas. The scientists are emphasizing on high frequencies band from 12GHz to 80GHz. During the designing process the selection of an appropriate substrate's material plays an important role. The appropriate substrate material not only provides mechanical strength but its electrical characteristics are very important for the size, resonant frequency and the improvement of the antenna's efficiency. This is why the substrate material must fulfill the electrical and mechanical prerequisites of the antenna. The author of (Nor *et al*., 2016) presented an antenna that demonstrated a small bandwidth of 2.1GHz but the Gain of this antenna was very large as compared to the

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proposed antennas of this article. The substrate of the design presented in (Ahmad *et al*., 2018) was made from Preperm L-450 and the bandwidth attained by this antenna was 5.45GHz with the return loss of 62.38dB at the center frequency of 16.93GHz. Preperm of 1.64mm thickness was engaged to achieve the bandwidth of 13.13GHz (Ahmad and Babar, 2019). A gain of 7dBi and efficiency of 0.99 were demonstrated by this patch antenna. The researchers in (Ahmad *et al*., 2018) presented an antenna having a bandwidth of 5.51GHz. The author in (Khan and Rajeesh, 2012) presented five patch antennas on five different substrates for applications in X-band. The performances of all these antennas have been critically analyzed. In light of results comparison, RT Duroid was declared as a good dielectric substrate for the microstrip patch antenna in X-band applications. The results of patch antennas which were designed on various substrate materials were compared in (Amba and Nandita, 2017). Roger RO4003(tm) was declared the best material based on the antenna's efficiency as it attained 92% efficiency. In (Israa and Riydah, 2018) the increase in the relative permittivity of dielectric material resulted in decrease in the bandwidth, directivity and VSWR. On other hand this increase resulted in the improvement of the specific absorption rate (SAR) of the antenna.

It was concluded in (Mohamed, 2017) that the selection of high dielectric constant substrate reduces the size as well as the efficiency. This means that this kind of material can be selected for the size miniaturization of the patch antenna on the expense of efficiency. This small sized antenna will not be efficient. A thick substrate material having low value of relative permittivity attains high efficiency, a wide bandwidth but the size of the antenna will be large (Gurpreet and Sonia, 2016). The future wireless antennas need to have a large bandwidth and high efficiency to cope with the demands of the end users. In this article a simple patch has been designed using three different substrate materials to investigate its performance at higher frequency bands. The substrate giving better results in terms of bandwidth, efficiency and gain will be recommended for future mobile applications. Microstrip line feeding was employed in the proposed antenna as it can be made-up without difficulty.

Antenna design

Three antennas on different substrate materials were designed and analyzed analytically. Design parameters of all these three antennas on different substrate materials have been explained in the subsequent sections. All these three antennas have very simple rectangular structures enabling the manufacturer to fabricate it easily and economically. The thickness of the substrate material of the Preperm antenna was 1.75mm while the thicknesses of the remaining two substrates were increased from 1.75mm to 2mm and 2.15mm for attaining desirable results. The permittivity and thickness of all the three different substrate are exposed in Table 1.

Table 1: *Specifications of all the three substrate's materials.*

S. No	Substrate's material	Thickness	Relative permittivity
1	Preperm L680HF	1.75mm	6.8
2	Mica	2.15mm	6
3	FR-4	2.00mm	4.3

Preperm substrate

The thickness of the Preperm material was 1.75mm and its relative permittivity was 6.8. The side view, patch view and ground view are exposed in Figures 1, 2 and 3, respectively. The surface area of the Preperm substrate was 7.99×5.16mm^2, while the surface area of the copper patch was 4.59×2.73mm^2. The thickness of the copper patch as well as copper ground was 0.1mm.

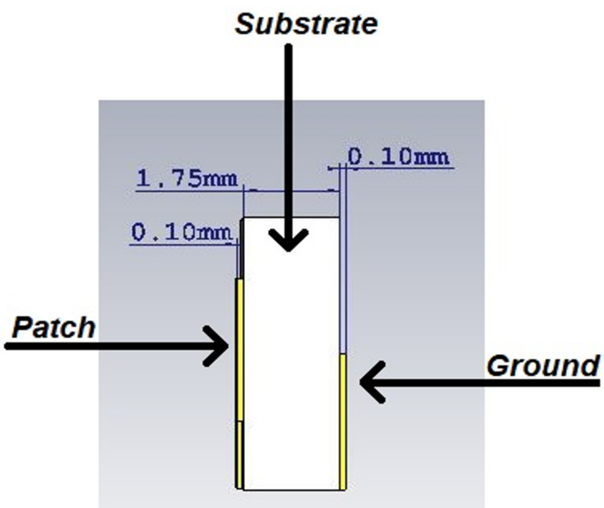

Figure 1: Side view of Preperm antenna.

The transmission feed line was engaged to energize the structure and its surface area was 1.29×0.8mm^2 as depicted in Figure 2.

As evident from Figure 3 the copper ground was reduced by 50% and its surface area was made equal to 7.99×2.58mm^2.

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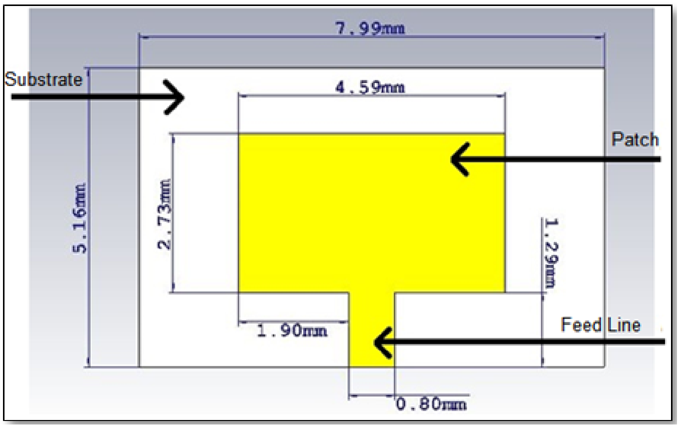

Figure 2: Patch View of the Preperm antenna.

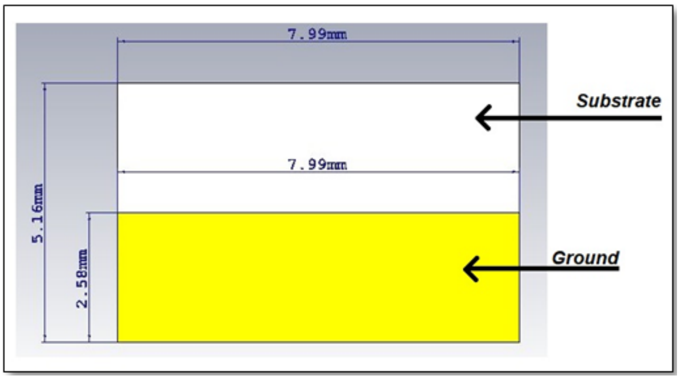

Figure 3: Ground view of Preperm antenna.

This antenna on Preperm substrate can be reproduced using the information in the aforementioned figures as well as Table 2.

Table 2: *Specifications of the Preperm design.*

S. No	Description	Value
1	Surface area of the Substrate	5.16×7.99 mm^2
2	Substrate's thickness	1.75mm
3	Surface area of the Patch	2.73×4.59mm^2
4	Patch's thickness	0.1mm
5	Surface area of the Ground	2.58×7.99mm^2
6	Ground's thickness	0.1mm
7	Surface area of the Feed	1.29×0.80mm^2
8	Feed's thickness	0.1mm

The results of the above mentioned Preperm antenna has been explained in the results and discussion section of this article.

Mica substrate

The thickness of the Mica material was 2.15mm and its relative permittivity was 6. The side view, patch view and ground view are exposed in Figures 4, 5 and 6, respectively. The surface area of the Mica substrate was 11.6×16.02mm^2, while the surface area of the copper patch was 5.5×9.81mm^2. The thickness of the copper patch as well as copper ground was 0.1mm. The transmission feed line was engaged to energize the structure and its surface area was 1.69×2.89mm^2 as depicted in Figure 5.

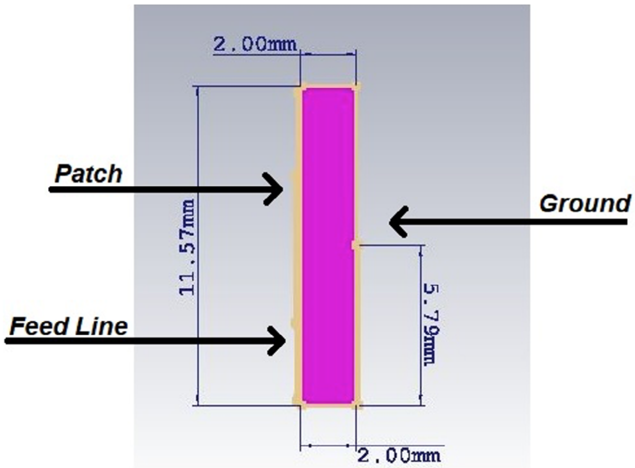

Figure 4: Side view of Mica design.

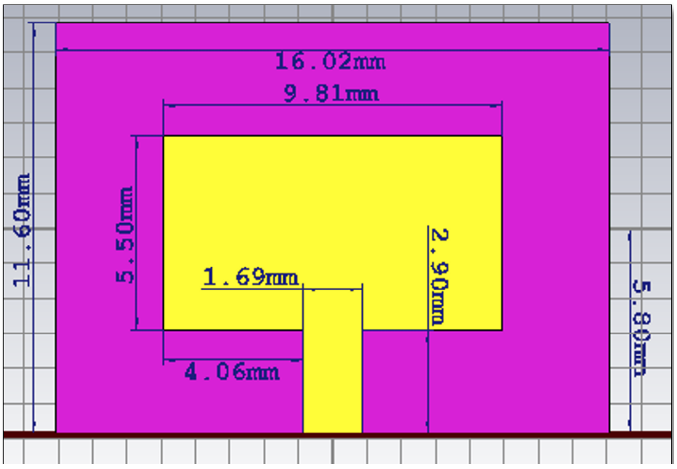

Figure 5: Patch view of Mica antenna.

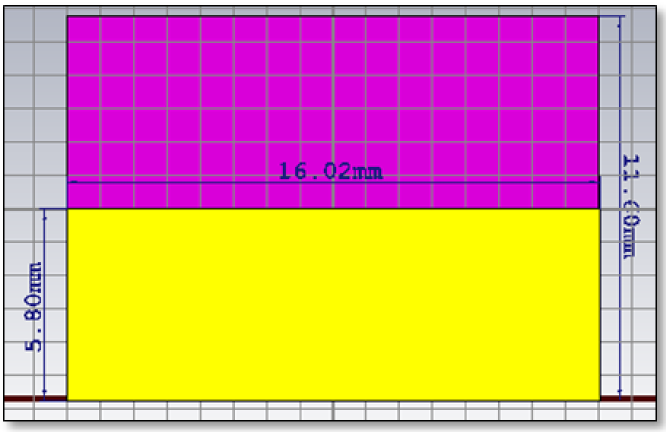

Figure 6: Ground view of Mica antenna.

As evident from Figure 6 the surface area of the copper ground was reduced to make it truncated ground structure and its surface area was made equal to 16.02×5.8mm². This antenna on Mica substrate can be reproduced using the information in the aforementioned relevant figures as well as Table 3.

Table 3: *Specifications of the Mica design.*

S. No	Description	Value
1	Surface area of the substrate	11.6×16.02mm²
2	Substrate's thickness	2.15mm
3	Surface area of the patch	5.5×9.81mm²
4	Patch's thickness	0.1mm
5	Surface area of the ground	5.8×16.02mm²
6	Ground's thickness	0.1mm
7	Surface area of the feed	2.9×1.69mm²
8	Feed's thickness	0.1mm

FR-4 substrate

The thickness of the FR-4 material was 2mm and its relative permittivity was 4.3. The side view, patch view and ground view are exposed in Figures 7, 8 and 9, respectively. The surface area of the FR-4 substrate was 11.51×8.12mm², while the surface area of the copper patch was 6.55×3.81mm². The thickness of the copper patch as well as copper ground was 0.1mm. The transmission feed line was engaged to energize the structure and its surface area was 1.21×2.03mm² as depicted in Figure 8.

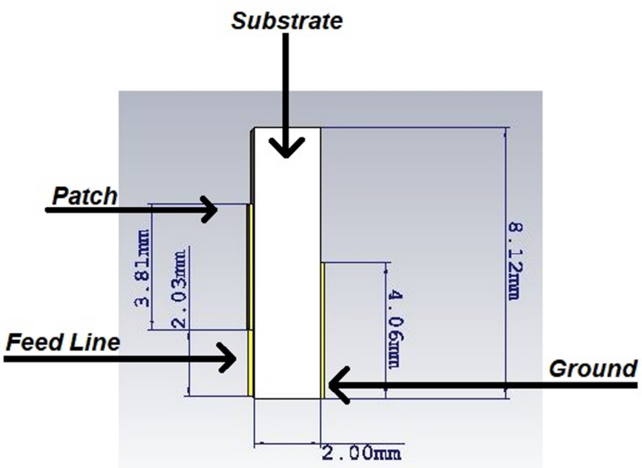

Figure 7: Side view of the FR-4 antenna.

As evident from Figure 9 the surface area of the copper ground was reduced by half to make it truncated ground structure and its surface area was made equal to 11.51X4.06mm². The thickness of the copper ground was kept the same but the thickness of the copper patch as well as copper feed line was increased from 0.1mm to 0.12mm. This antenna on FR-4 substrate can be reproduced using the information in the aforementioned relevant figures as well as Table 4.

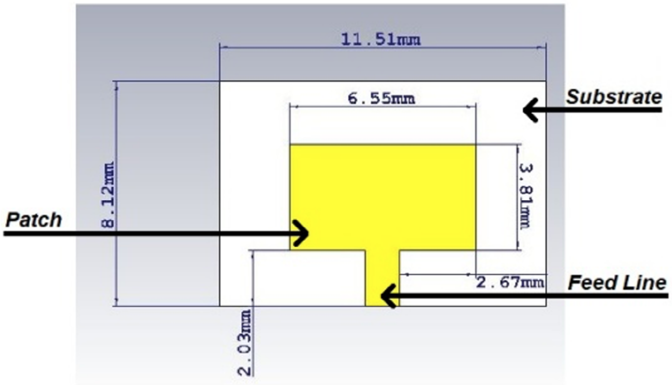

Figure 8: Patch view of the FR-4 antenna.

Table 4: *Specifications of the FR-4 design.*

S. No	Description	Value
1	Surface area of the substrate	11.51×8.12mm²
2	Substrate's thickness	2.00mm
3	Surface area of the patch	6.55×3.81mm²
4	Patch's thickness	0.12mm
5	Surface area of the ground	4.06×11.51mm²
6	Ground's thickness	0.1mm
7	Surface area of the feed	2.03×1.21mm²
8	Feed's thickness	0.12mm

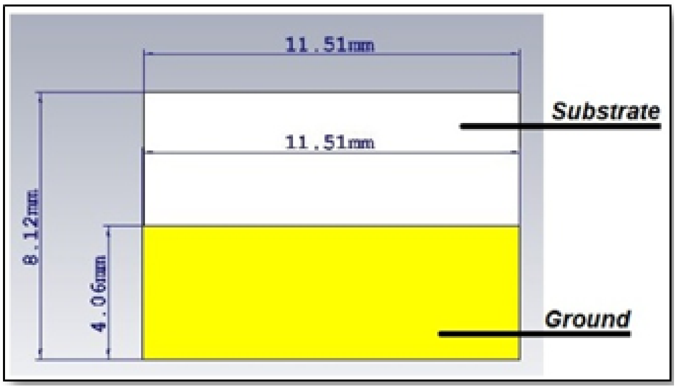

Figure 9: Ground View of the FR-4 Antenna

Results and Discussion

Various results of all the three designs are analyzed critically in the following sections of this article.

Results of preperm design

Preperm is a dielectric material and the relative permittivity of the Preperm material used as a substrate of this antenna was 6.8. The antenna on Preperm attained two functional bands as plotted in Figure 10. The first band was from 19.24GHz to 27.15GHz giving an impedance bandwidth of 7.9GHz. The second band was from 43.66GHz to 66.61GHz giving a huge impedance bandwidth of 22.94GHz.

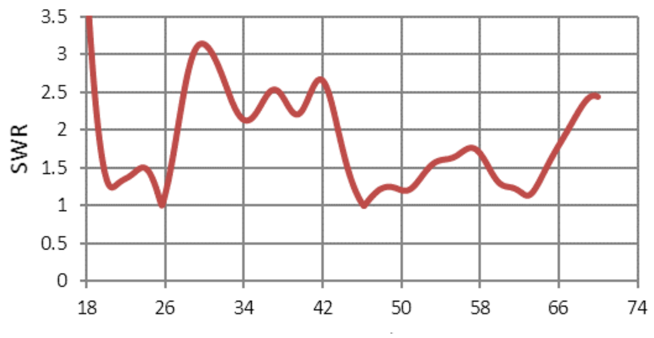

Figure 10: Return loss of Preperm substrate.

The smallest value of the reflection coefficient in the first functional bandwidth was -42.6dB while the smallest value of the reflection coefficient in the 2nd bandwidth was -48.88dB thus demonstrating excellent impedance matching. VSWR was justified in both the bands. Its minimum values in the first and second band were 1.02 and 1.007 which can be confirmed from Figure 11.

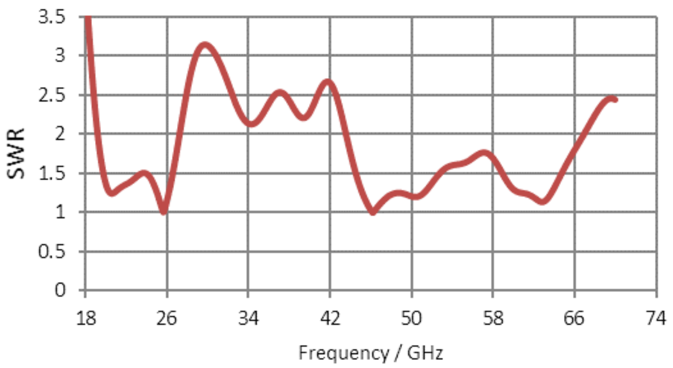

Figure 11: SWR of the PREPERM antenna.

This antenna demonstrated the maximum efficiency in the 2nd band. This maximum value was 77.88% that occurred at the frequency of 55.5GHz. These values can be confirmed from Figure 12.

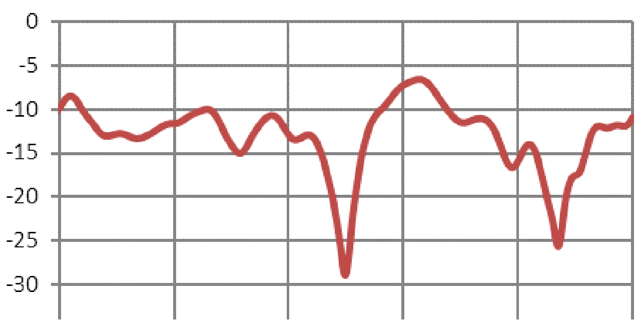

Figure 12: efficiency of PREPERM antenna.

Two values of Gain were recorded at the frequencies of 25.6 and 46.1GHz in Figure 13 and these values were 3.43dBi and 4.44dBi, respectively.

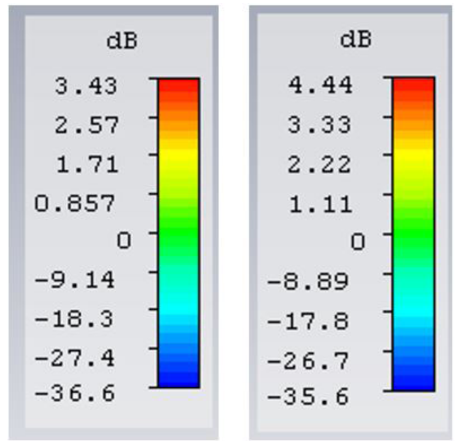

Figure 13: Gain at 25.6GHz and 46.1GHz.

The important results such as impedance bandwidth, minimum values of reflection coefficient, Minimum values of VSWR, maximum value of efficiency and the Gain values at the center frequencies of the aforementioned design were summarized in Table 5.

Table 5: *Summary of results of Preperm antenna.*

Description	Values
Impedance Bandwidth of the 1st band	7.9GHz
Impedance Bandwidth of the 2nd band	22.94GHz
Minimum Value of VSWR of the 1st band	1.02
Minimum Value of VSWR of the 2nd band	1.007
Maximum value of the efficiency	77.88%
Gain at the central frequency of the 1st bandwidth	3.43dBi
Gain at the central frequency of the 2nd bandwidth	4.44dBi

Results of mica design

Mica is a dielectric material and the relative permittivity of this material, used as a substrate of the antenna, was 6. The antenna on Mica attained two functional bands as plotted in Figure 14. The first band was from 20.04GHz to 46.06GHz giving a huge impedance bandwidth of 26.02GHz. The second band was from 51.84GHz to 68GHz giving an impedance bandwidth of 16.15GHz.

The smallest value of the reflection coefficient in the first functional band was -28.87.6dB while the lowest value of the reflection coefficient in the second band was -25.49dB thus demonstrating good impedance matching. VSWR was justified in both the bands. Its minimum values in the first and second band were

1.07 and 1.11 which can be confirmed from Figure 15.

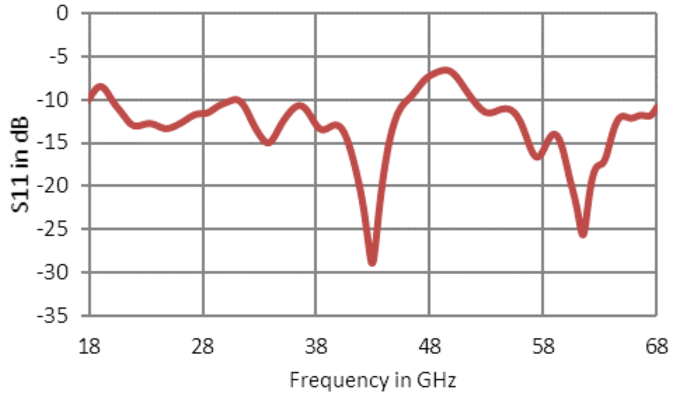

Figure 14: Return loss of mica substrate.

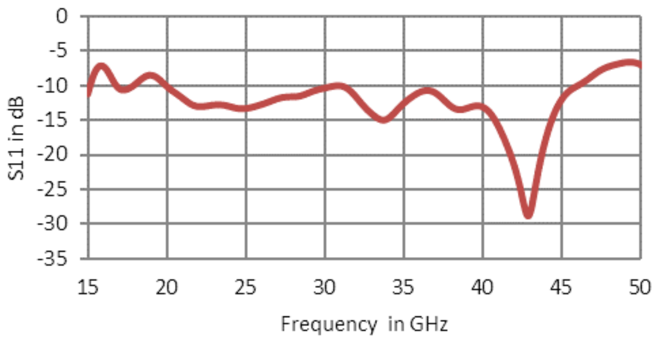

Figure 15: SWR of the MICA antenna.

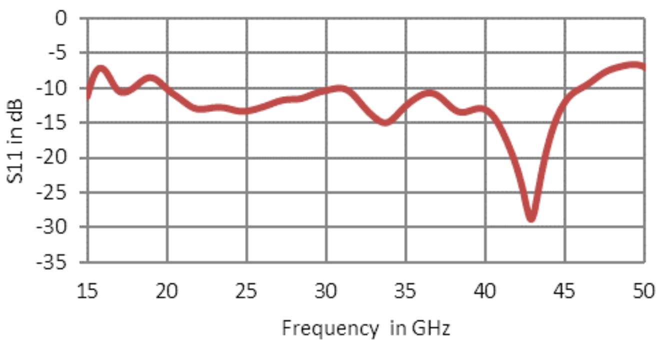

Figure 16: Efficiency of the MICA antenna.

This antenna demonstrated the maximum efficiency in the 1st band. This maximum value was 81.88% that occurred at the frequency of 29.1GHz. These values can be confirmed from Figure 16.

Two values of Gain were recorded at the frequencies of 43GHz and 62GHz in Figure 17 and these values were recorded as 8.19dBi and 10.2dBi respectively.

The important results such as impedance bandwidth, minimum values of reflection coefficient, minimum values of VSWR, maximum value of efficiency and the Gain values at the center frequencies of the aforementioned design were summarized in Table 6. The values were compared with the values of the previous design on Preperm Substrate as well.

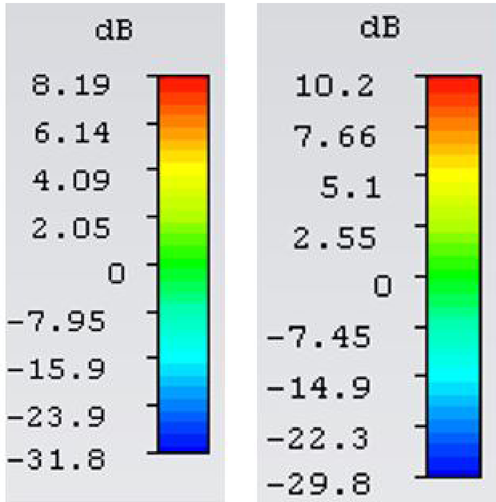

Figure 17: Gain at 43GHz and 62GHz.

Results of FR-4 design

FR-4 is a dielectric material and the relative permittivity of this material, used as a substrate of the antenna, was 4.3. The antenna on FR-4 attained a single band as plotted in Figure 18. This single band was from 20.43GHz to 45.27GHz giving a huge impedance bandwidth of 24.85GHz.

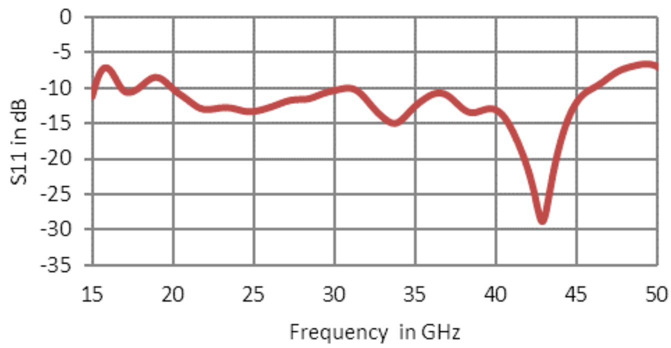

Figure 18: Return loss of FR-4 substrate.

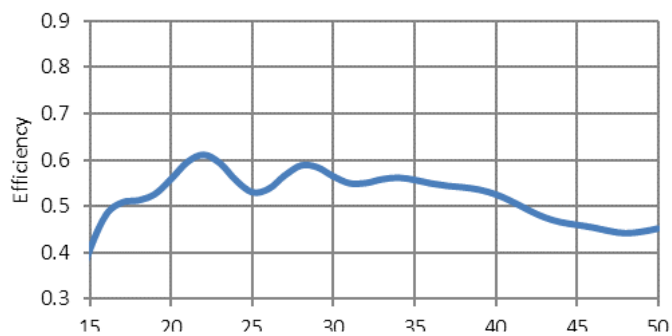

Figure 19: SWR of the FR-4 antenna.

The first lowest value of the reflection coefficient was -41.27dB that occurred at 24.28GHz while the second lowest value of the reflection coefficient was -34.46dB that took place at the frequency of 31.05GHz. VSWR was justified in the mentioned functional band. Two minimum values were recorded as 1.03 and 1.01 which can be confirmed from Figure 19.

This antenna demonstrated the maximum value of efficiency at the frequency of 22GHz. This maximum value was 61.08% and the minimum value was recorded as 45.27%. These values can be confirmed from Figure 20.

The important results such as impedance bandwidth, minimum values of reflection coefficient, minimum values of VSWR, maximum value of efficiency and the Gain values at the center frequencies of the aforementioned design were summarized in Table 7. The values were compared with the values of the previous design on Mica Substrate as well.

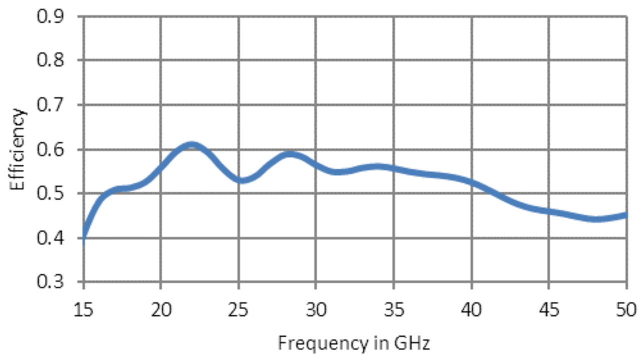

Figure 20: Efficiency of the FR-4 antenna.

Two values of Gain were recorded at the frequencies of 43GHz and 62GHz in Figure 21 and these values were recorded as 4.19dBi and 3.02dBi, respectively.

Table 6: *Summary of results of Mica antenna.*

Description	Values	Comparison with Preperm Design
Impedance Bandwidth of the 1st band	26.06GHz	It has attained a larger bandwidth
Impedance Bandwidth of the 2nd band	16.15GHz	It has attained a smaller bandwidth
Minimum Value of VSWR of the 1st band	1.07	Almost the same SWR
Minimum Value of VSWR of the 2nd band	1.1	This value is greater than the preperm one
Maximum value of the efficiency	81.88%	It has attained greater efficiency
Gain at a frequency of the 1st band	8.19dBi	It has attained a larger gain
Gain at a frequency of the 2nd band	10.2dBi	It has attained a larger gain

Table 7: *Summary of results of FR-4 antenna.*

Description	Values	Comparison with preperm design
Impedance Bandwidth	24.28GHz	It has attained a large bandwidth as well
Minimum Value of VSWR	1.01	SWR Value is greater
Maximum value of the efficiency	61.08%	It has attained greater efficiency
Gain at a frequency of 31GHz	3.02dBi	It has attained smaller gain
Gain at a frequency of 43GHz	4.2dBi	It has attained smaller gain

Table 8: *Comparison of the results of all the three antennas.*

Description of the characteristics	Values for preperm antenna	Values for FR-4 antenna	Values for Mica antenna
Impedance Bandwidth of the 1st band	7.9GHz	24.28GHz Single Band	26.06GHz
Impedance Bandwidth of the 2nd band	22.94GHz		16.15GHz
Minimum Value of VSWR of the 1st band	1.02	1.01	1.07
Minimum Value of VSWR of the 2nd band	1.007		1.1
Maximum value of the efficiency	77.88%	61.08%	81.88%
Gain at the central frequency of the 1st bandwidth	3.43dBi	3.02dBi at 31GHz	8.19dBi
Gain at the central frequency of the 2nd bandwidth	4.44dBi	4.2dBi at 43GHz	10.2dBi

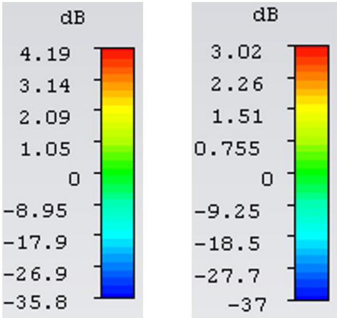

Figure 21: Gain at 43GHz and 31GHz.

All the three antennas have achieved good results. The comparison of the results of all these antennas is given in Table 8. All these three antennas have achieved good results and can be employed in a wireless communication system having a large bandwidth requirement. The antenna made on the substrate of Mica has attained better results.

This design was compared with some previous designs in Table 9 and the comparison shows that the recommended dual band antenna of this article has attained huge bandwidths of 26GHz and 16GHz.

Table 9: *Comparison with previous designs.*

(Jajere *et al.*, 2017)	4.5GHz
(Johary *et al.*, 2018)	0.4GHz
(El-Mashade *et al.*, 2018)	12GHz
(Sekar *et al.*, 2018)	1.02GHz
The recommended antenna of this work	26GHz and 16GHz

Conclusions and Recommendations

Three simple rectangular designs on Preperm substrate, Mica substrate and FR-4 substrate were presented in this article. The antenna on FR-4 attained a single band from 20.43GHz to 45.27GHz giving a huge impedance bandwidth of 24.85GHz. The maximum value of its efficiency was 61.08% and the minimum value was 45.27%. The antenna on Preperm attained two functional bands from 19.24GHz to 27.15GHz giving an impedance bandwidth of 7.9GHz and from 43.66GHz to 66.61GHz giving a huge impedance bandwidth of 22.94GHz. The maximum value of its total efficiency was 77.88%. Keeping in view their bandwidths and efficiency, it is concluded that all these three designs can be engaged in future for mobile wireless communication. But the antenna on the mica substrate demonstrated better results as compared to the remaining two antennas. It attained huge bandwidths of 26.06GHz and 16.15GHz in the 1st and the 2nd band respectively. The total efficiency of the antenna on Mica substrate was 81.88%. The gain at a frequency randomly selected from the 1st bad was 8.19dBi, while the gain at a frequency selected from the 2nd band was 10.2dBi. Surface area of the recommended Mica substrate was 11.6×16.02mm^2. Its thickness was 2.15mm. Surface area of the Patch was 5.5×9.81 mm^2. Surface area of the Ground was 5.8×16.02mm^2. Surface area of the feed was 2.9×1.69 mm^2. The thickness of the copper used in the ground as well as patch was 0.1mm. Based on the results attained from the simulator, it is established that the antenna on the Mica substrate will be the best antenna for future wireless mobile applications as compared to the remaining two antennas.

Novelty Statement

Three simple rectangular patch structures were designed on three different insulated substrates including FR-4, Mica and Preperm. The parametric optimization of these antennas attained huge dual bandwidths of 26.06GHz and 16.16GHz respectively. It attained an efficiency of 81.88% and a maximum gain of 8.19dBi that has never been attained with such a simple design.

Author's Contribution

All the authors designed the structures using CST Simulation software and carried out the parametric optimization of all the three designs for attaining better results at higher frequency bands for future wireless mobile applications.

Conflict of interest

The authors have declared no conflict of interest.

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