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High Gain Patch Antenna for Broadband Applications from 10.1 to 14.2 GHz

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Abstract— **This paper reveals a patch antenna with a large bandwidth of 34% and a high gain of 8 dBi in the frequency range from 10.1 to 14.2 GHz. The patch antenna is a four layer design comprising of a superstrate dielectric layer of εr 10.2 on top of a metal layer with six small simply designed parasitic H-shaped elements, which are optimized using CST Microwave Studio. The six H-shaped parasitic elements are centrally located on the metal layer. On the same layer, the antenna is fed through a coupled feedline so as to reduce mutual coupling and the antenna is thus a perfect candidate to preserve its wideband feature in an antenna array. Right underneath the metal layer is the substrate dielectric layer of εr 2.2 with two strategically placed slots underneath the metal layer in order to decrease the back radiation of the H-shaped parasitic elements. The whole design is terminated with a final metal layer to act as a conductor backed antenna to push most radiation out. The final antenna occupies a volume of 25 mm x 25 mm x 2.56 mm. The design has a high gain of 8 dBi in both the φ = 0° plane and the φ = 90° plane with a large beamwidth of 77° in the φ = 0° plane and 83° in the φ = 90° plane in the farfield.**

Index Terms— **Antenna element, patch antenna, H-shaped antenna, X-band, Ku-band, gain, slots, parasitic elements, superstrate layer, bandwidth, linear polarization, farfield, beamwidth, azimuth, elevation, coupled line, feedline**

I. INTRODUCTION

THE microstrip patch antenna is a very popular element and is widely used due to its low profile, simplicity, lightweight, ease of fabrication using the same technology as printed circuits and also its ease of integration with feed network [1]. The microstrip patch antenna is made up of a metal layer on top of a dielectric substrate terminated by a ground plane. The main disadvantage of the microstrip patch antenna, however, is its narrow bandwidth limited to about 5% of the center frequency and its low gain limited to a maximum of 5 dBi [2]. Much effort is being made to develop techniques to enhance its bandwidth and its gain by working in layers [3], modifying its shape [4], adding parasitic elements [5], changing its feedline from single ended microstripline to coplanar or coplanar waveguide [6], increasing the thickness of the dielectric substrate [7], or by adding slots [8].

The H-shaped antenna was first introduced by V. Palanisamy and R. Garg in 1985 when the H-shaped antenna was proposed as an alternative to the rectangular patch antenna to permit improvements over a simple patch antenna element [9]. The H-shaped patch only showed a 1% bandwidth but a large beamwidth of 112° in the φ = 0° plane and 88° in the φ = 90° plane. Further work was done by Thakur *et al* where an H-shaped fractal patch was introduced and fractal geometry and slots were applied in order to obtain an H-shaped antenna with a maximum bandwidth of 9% and a gain of 6.05 dBi at 2.7 GHz [10]. Kushwaha, Srivastava and Saint showed a high gain wideband H-shaped slot-loaded microstrip patch antenna fed with coaxial cable and the authors showed a 19% bandwidth at 2.42 GHz with no mention of the antenna gain [11]. Islam, Shakib and Misran showed a broadband inverted E-H shaped microstrip patch antenna with L-probe feed technique for wireless system with a 30% bandwidth, a maximum gain of 9.37 dBi and beamwidth of 64° in the φ = 0° plane and 51° in the φ = 90° plane at 2.07 GHz [12]. Kumara *et al* showed a concaved H-shaped patch antenna with improved bandwidth of 70% between 2 to 6 GHz but with no mention of the gain or beamwidth of the concave antenna [13]. Tarange *et al* showed a 46% bandwidth at 2GHz using a capacitive scheme consisting of a radiation patch and a feed strip where the design of the antenna incorporates the capacitive feed strip which is fed by a coaxial probe. A slot is used in the radiating patch along the radiating edge to improve the bandwidth using a thick substrate of height 1.56 mm and an air gap of 5.4 mm on Rogers 3003 of εr 3. However the gain is not mentioned [14].

This paper presents a patch antenna where a high

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bandwidth and a high gain with a bonus of a large beamwidth obtained in both the φ = 0° plane and the φ = 90° plane with a simple design tweak of resizing the H-shaped antenna element and lots of structural optimization using CST Microwave Studio 2015. The design is a four-layer one with a superstrate Rogers RT 6010 of εr 10.2 as the top layer added on top of a metal layer. The shape of the patch element is modified by adding six H-shaped parasitic elements fed by coplanar lines in the center of this metal layer. The coplanar lines end in an open-ended coupled stub tuning the design in order to enhance bandwidth. The thickness of the dielectric substrate of Rogers RT5880 of εr 2.2 underneath the metal layer is increased and slots are strategically added on this substrate layer in order to be situated under the H-shaped parasitic elements. The whole element designed has the dimensions of 25 mm x 25 mm x 2.56 mm.

Rogers's substrate and superstrate used in the H-shaped patch element in this paper are a glass microfiber reinforced PTFE composite where the glass reinforcing microfibers are randomly oriented to maximize the benefits of fiber reinforcement. The dielectric constant is uniform from panel to panel and is constant over a wide frequency range. Its low dissipation factor extends the usefulness to the Ku-band and above. Moreover, Roger's laminates are easily cut, sheared and machines to shape. They are resistant to all solvents and reagents, hot or cold, normally used in etching printed circuits or in plating edges and holes. These characteristics are useful as the substrate and superstrate need to allow the antenna element to perform under environmental conditions where temperature or humidity can vary [15], [16].

To the authors' knowledge, the H-shaped antennas documented in the literature are limited to frequencies below 10 GHz. This is because it requires very careful design optimization to obtain a large bandwidth and an appreciable gain at frequencies greater than 10 GHz with an H-shaped element.

Our simple H-shaped four-layer antenna element works in the 10.1 to 14.2 GHz and it is ideal for satellite broadcast television frequencies. The design is terminated with coupled line in order to reduce mutual coupling and is thus an optimum candidate to be integrated in a large antenna array. The antenna element is optimized to obtain a high bandwidth of 34% and a high gain of 8 dBi in both the φ = 0° plane and the φ = 90° plane with a large beamwidth of 77° in the φ = 0° plane and 83° in the φ = 90° plane in the farfield. The importance of the superstrate top layer with substrate of dielectric εr 10.2 is enforced by showing the comparison between the design with and without the top layer and the resulting gain in both the φ = 0° plane and the φ = 90° plane. The addition of a dielectric slab of εr 10.2 on top of the metal layer allows for a constant gain amelioration of about 2 dBi along the whole frequency range from 10.1 to 14.2 GHz. This is because the backlobe radiations of the microstrip antenna are decreased with the introduction of the top dielectric superstrate while causing an increase in the front lobe radiations and thus permitting higher gain as explained through closed form expression by Zhong, Liu and Qasim [17]. However a high dielectric constant substrate also introduces surface waves. These surface waves created by a high dielectric superstrate can be eliminated as described by Alexopoulos and Jackson [18] with the proper choice of dielectric constant and superstrate thickness resulting in the enhancement of the antenna gain in both the φ = 0° plane and the φ = 90° plane.

II. DESIGN METHODOLOGY

The basic antenna element is a strip conductor of length *L* x width *W* on a dielectric substrate of constant εr and thickness *h* backed by a ground plane as shown in Fig.1. When the patch is excited by a feed, a charge distribution is established on the underside of the patch metallization and the ground plane.

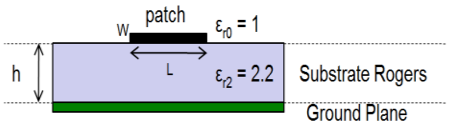

Fig. 1 shows the patch antenna on Rogers with εr 2.2

The repulsive force between the positive charges on the patch pushes some charges towards the edge, resulting in a large charge density, the source of fringing field and radiation. Radiation from the microstrip patch antenna occurs from the fringing fields between the patch and the ground layer as shown in Fig. 2.

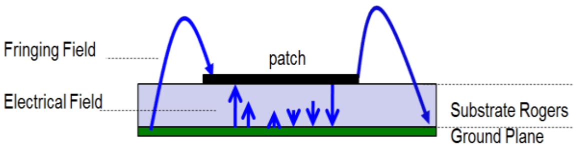

Fig. 2 shows the fringing fields of the patch antenna on Rogers of εr 2.2

The width of the antenna can increase the fringing fields and increase the radiation. The fringing field can also be increased by using a low εr closest to 1 and by increasing the substrate thickness [19]. Rogers

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substrate with εr 2.2, tan δ=0.0009 (@10 GHz is a stable, low loss and low cost material with an excellent chemical resistance at high temperature. When the substrate height *h* of the patch antenna is increased, the design becomes mechanically stronger and the radiating power increases, and the bandwidth increases while the conductor loss decreases. However, the weight of the patch antenna increases as well as the dielectric and surface wave losses. Also, the substrate height *h* cannot be increased indefinitely as the patch antenna stops radiating when $h > 0.11\ \lambda$ where λ is the wavelength. Moreover, as the height increases, surface waves are introduced and these are not desirable as they extract power from the total power available for direct radiation. The surface waves degrade the antenna radiation pattern when it travels through bends and surface discontinuities such as dielectric to dielectric or dielectric to ground transition.

Microstrip patch antenna can be fed by different ways such as microstrip feed, probe feed, aperture coupled and proximity coupled feedline. Using a coupled feedline ensures a decrease in mutual coupling in the antenna element and this is an important consideration when the element is used in an array, as mutual coupling is the main culprit for breaking down a large array of patch antenna elements.

The use of the slots in the substrate layer of εr 2.2 allows for a smaller slot size for efficient electromagnetic energy coupling and thus a reduction in the back radiation of the slot. The larger bandwidth is because the coupling slot is placed at the patch center and has a better electromagnetic energy coupling resulting in good impedance matching over a wider frequency range.

The design of the H-shaped metal layer is shown in Fig. 4. First two centered asymmetrical rectangular patches on each side of the coupled feedline are designed to create two closely spaced resonance frequencies as shown in Fig 4a). Then two slots are added on the substrate layer right underneath the two asymmetrical rectangular patches as shown in Fig. 4 a). The equation shown in Equation (1) to calculate the size of the slot under the patch is given by [20] where λ_0, W and *h* are the resonant wavelength, width and height of the patch respectively.

$$\frac{\lambda_{slot}}{\lambda_0} = 1.05 - 0.04\varepsilon_r + 1.411x10^{-2}(\varepsilon_r - 1.421)$$

$$x \ln\left[\frac{W}{h} - 2.012(1 - 0.146\varepsilon_r)\ \right]$$

$$+ 0.111(1 - 0.366\varepsilon_r)\sqrt{W/\lambda_0}$$

$$+ 0.139(1 + 0.52\varepsilon_r \ln(14.7 - \varepsilon_r))(\frac{h}{\lambda_0})\ln(\frac{h}{\lambda_0})$$

Equation (1)

Next the substrate height is increased as an effort to lower the Q-factor and increase the bandwidth of the antenna element. An optimization of the ideal substrate height is performed and the substrate height is set to 1.23 mm as shown in Fig. 4c). Through further optimization from CST Microwave Studio 2015, the metal layer is modified into six parasitic patches as shown in 4d). Further optimization of the six parasitic patches converts them into six parasitic H-shaped elements centrally located and fed through coupled lines. This is shown in Fig. 4e) and Fig. 4f). This loading effect produced by the parasitic patches also helps to enhance the bandwidth. Thus, by carefully optimizing the distance between the resonance frequencies of each patch, a large bandwidth increase can be obtained.

A zoomed-in of the design from Fig. 4f) is shown in Fig. 5 where the detail of the two slots on the substrate layer right under the middle H-shaped elements is shown in Fig. 6. All the design dimensions are shown in Table 1.

The final design is shown in Fig. 7 with the four layers each separately shown in Fig. 8a) to Fig. 8d). The feedline is thus a coupled line ended in a coupled open circuit stub, which acts as a tuning stub and contributes to an enhanced bandwidth.

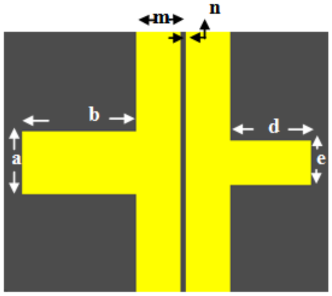

Fig. 4a) shows the centered asymmetrical rectangular patches on each side of the coupled feedline to create two resonance frequencies

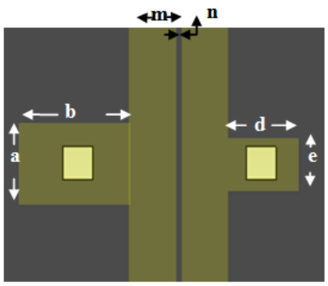

Fig. 4b) shows the two slots in the substrate right underneath the centered asymmetrical rectangular patches

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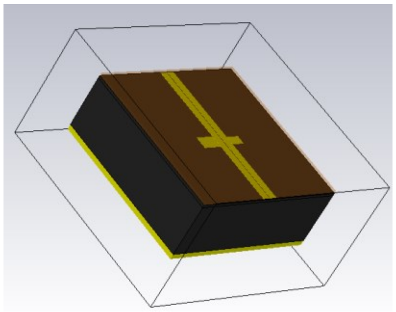

Fig. 4c) shows the optimisation step of the substrate height to 1.23 mm

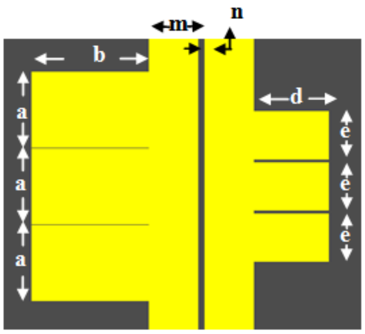

Fig. 4d) shows parasitic elements added on top and below the centrally located asymmetrical rectangular patches

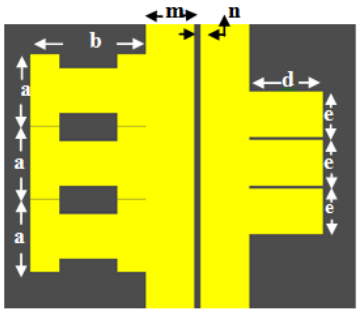

Fig. 4e) shows the inter-optimized H-shaped parasitic elements

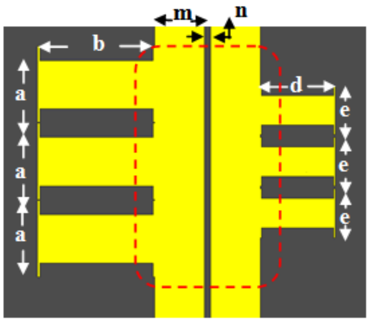

Fig. 4f) shows strongly optimized H-shaped parasitic elements

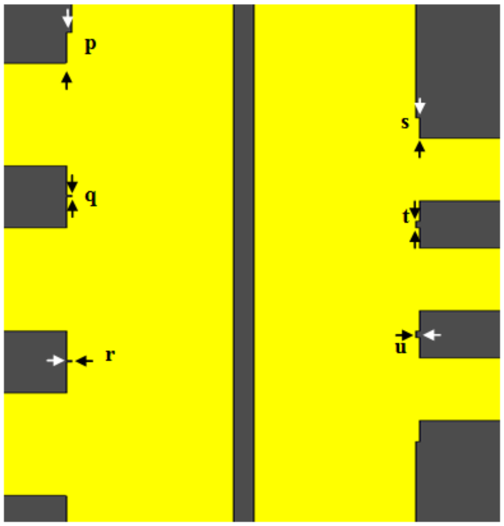

Fig. 5 shows a zoomed-in our Fig. 4f) to show the inter gap dimensions

Label	Dimensions/mm
a	1.91
b	2.89
d	1.84
e	1.21
m	1.21
n	0.15
p	0.36
q	0.02
r	0.06
s	0.24
t	0.07
u	0.04

Table 1 shows the dimensions from Fig. 4 and Fig.5

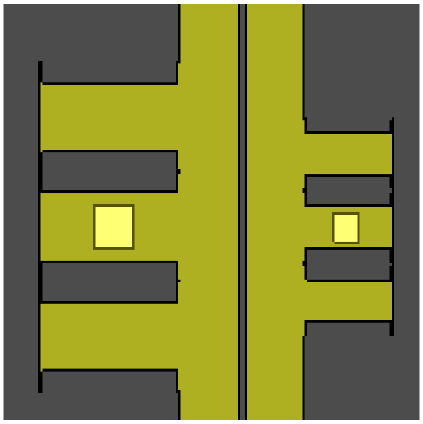

Fig. 6 shows the slots in the substrate layer under the metal layer (the slots do not extend to the metal layer) with the left slot of square dimensions 0.8 mm x 0.8 mm and the right slot of square 0.5 mm x 0.5 mm.

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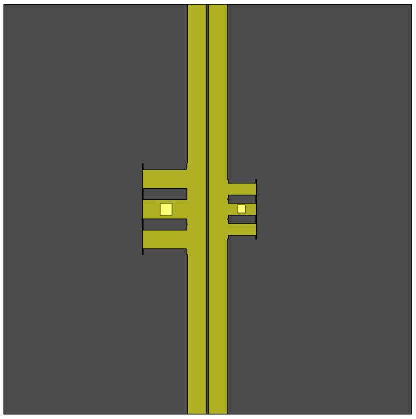

Fig. 7 shows the antenna element design of 25 mm x 25 mm x 2.56 mm

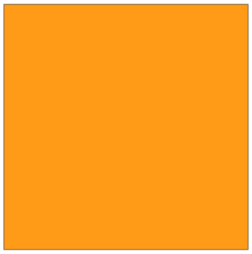

Fig.8a) shows layer 1 with Rogers substrate RT 6010 εr 10.2 of dimensions 25 mm x 25mm x 0.43 mm

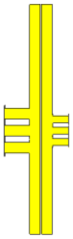

Fig 8b) shows metal layer 2 with a height of 0.43mm

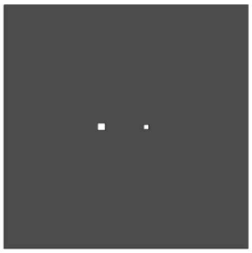

Fig.8c) shows layer 3 with Rogers substrate RT 5880 of εr 2.2 of 25 mm x 25 mm x 1.23 mm

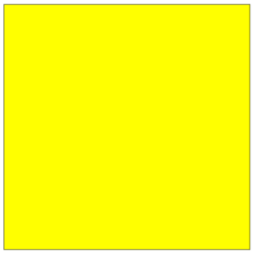

Fig. 8d) shows ground layer 4 of 25 mm x 25 mm x 0.87 mm

III. RESULTS

The port set-up of our antenna element is shown in Fig. 9 where the coupled feedline ends in S+ and S-. The E-fields and the H-fields that flow between the two coupled feedlines are shown in Fig. 10 and Fig. 11 respectively and the zoomed-in of these fields are shown in Fig. 12 and Fig. 13 respectively. Fig 14 to Fig. 17 show the return loss S_{11} (dB) plotted against frequency in GHz. Each S-parameter plot shows the results of the design flow. Thus, Fig. 14 shows the results from Fig. 4a) where an asymmetrical rectangular patch is designed to increase the resonance bandwidth by closely spacing two resonance frequencies together. Fig. 15 shows the optimization runs for the two slots in the substrate layer right underneath the two asymmetrical rectangular patches while Fig. 16 shows the optimization of the substrate height. The final results of the final antenna design are shown in Fig. 17. The bandwidth from this plot is seen to be 34%. The bandwidth of an antenna is defined as the range of frequencies over which the antenna can properly radiate or receive energy. The antenna bandwidth is commonly defined as the frequency range where return loss S_{11} is less than -10 dB, that is, 90% of the antenna power is used for radiation.

It is defined as $(f_u - f_l)/f_c * 100\%$ where f_u is the upper operational frequency in our case is 14.2 GHz and f_l is the lower operation frequency, here, 10.1 GHz and f_c is the center frequency where $f_c = (f_u - f_l)/2$. Here our f_c is 12.1 GHz.

While this antenna was designed for an 11.7 GHz center frequency, the center frequency here is in fact 12.1 GHz. The center frequency is shifted as explained in [18] because the fringing fields are produced by asymmetrical H-shaped parasitic elements designed on each side of the centrally fed patch antenna element in order to produce maximum resonances in an effort to enhance the antenna bandwidth. The εr is also modified with the superstrate εr 10.2 layer and this also modifies the fringing fields and thus the center frequency.

The impedance of 56 Ω across frequency for the final antenna element design is shown in Fig. 18.

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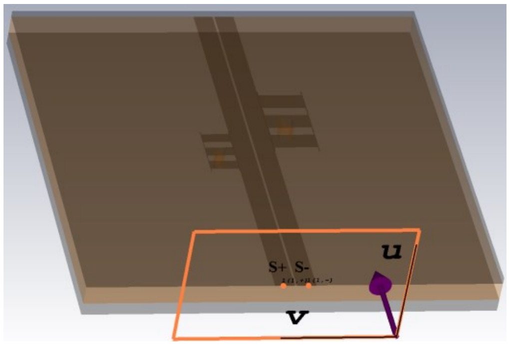

Fig. 9 shows the port set up at the end of the centrally located coplanar S+S- feedline

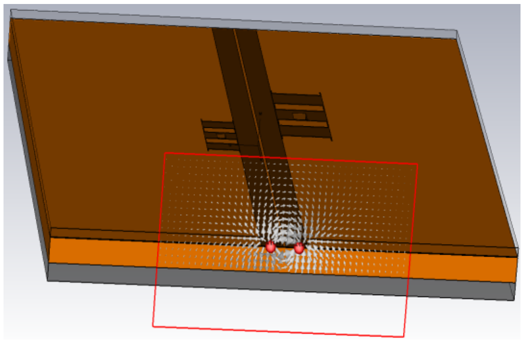

Fig. 10 shows the E-fields at the port of the S+S- feedline

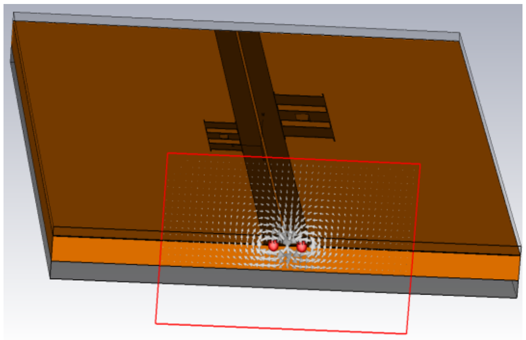

Fig. 11 shows the H-fields at the port of the S+S- feedline

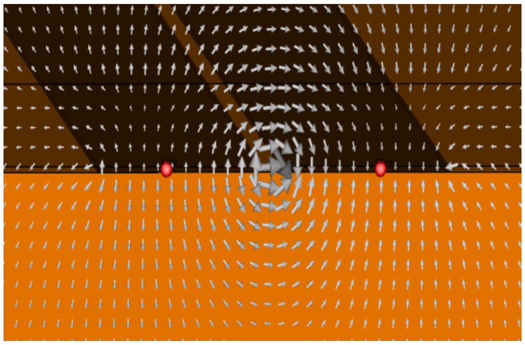

Fig. 12 shows a zoomed-in of the E-fields to show how the voltage flows from S+ to S-

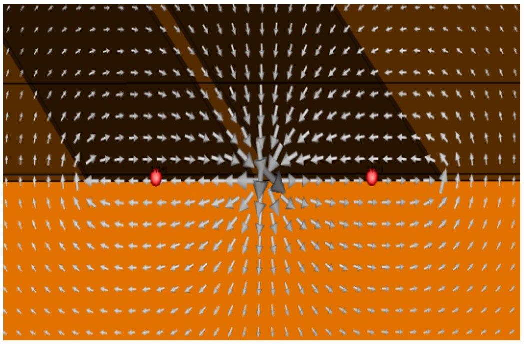

Fig. 13 shows a zoomed-in of the H-fields to show how the current flows from S+ to S-

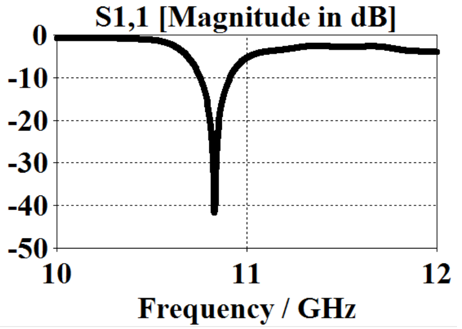

Fig 14 shows S_{11} (dB) versus frequency/ GHz for the closed spaced asymmetrically rectangular patches shown in Fig. 4a)

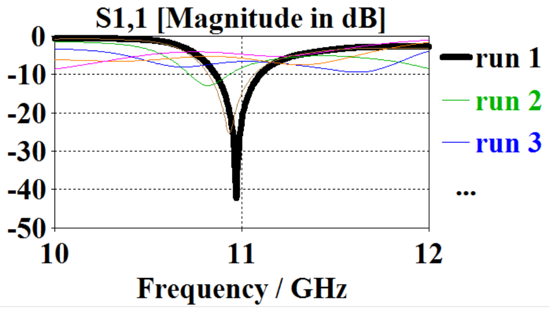

Fig 15 shows S_{11} (dB) versus frequency/ GHz for the two slots in the substrate right underneath the two asymmetrical rectangular patches shown in Fig. 4b)

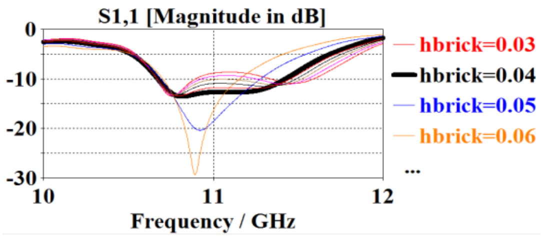

Fig 16 shows S_{11} (dB) versus frequency/ GHz for optimisation of the substrate height shown in Fig.4c)

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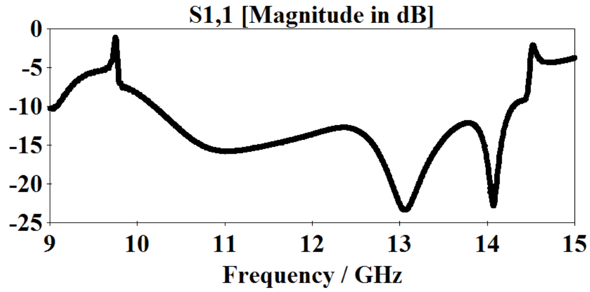


Fig. 17 shows S_{11} (dB) versus frequency/ GHz for the final optimized antenna element showing a bandwidth of 34%

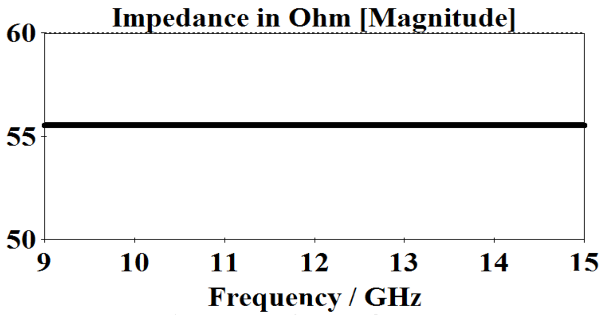


Fig. 18 shows the impedance of 56 Ω across frequency/GHz for the final optimized antenna element

Other important antenna results are shown in Fig. 19 where the 3D radiation patterns at 11.7 GHz are shown. Fig 20 show the high gain of 8 dBi and the wide beamwidth obtained at in the φ = 0° plane and in the φ = 90° plane.

The gain of an antenna is its directivity multiplied by its electrical efficiency where the directivity is the ratio of the radiation intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna was radiated isotopically or equally in all direction.

The antenna beamwidth is measured in degrees between the half power points (3 dB) of the major lobe of the antenna. Beamwidth can be expressed in terms of elevation (vertical plane or the φ = 90° plane) and azimuth (horizontal plane or the φ = 0° plane).

Through careful optimization, the simple four layer antenna element has been thus designed to obtain a high bandwidth, high gain and high beamwidth.

Next, the effect of the superstrate layer 1 on dielectric substrate Rogers 6010 of εr 10.2 examined. Fig. 21 shows gain in dBi versus frequency in GHz of the antenna element when the superstrate layer 1 is included (with superstrate) or removed (no superstrate) As seen in the plot from Fig. 21, the effect of the superstrate is significant with a much higher gain over the frequency range from 9 to 15 GHz for both the φ = 0° plane and the φ = 90° plane.

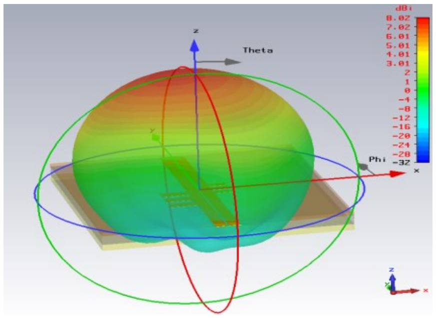
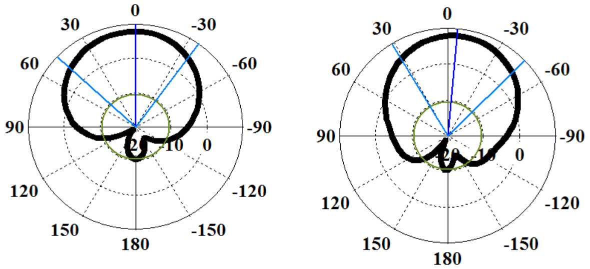


Fig. 19 shows the 3D radiation patterns at 11.7 GHz



a) Gain of 8 dBi and beamwidth of 77° in the φ = 0° plane at 11.7 GHz

b) Gain of 8 dBi and beamwidth of 83° in the φ = 90° plane at 11.7 GHz

Fig.20a)-b) show the beamwidth in the φ = 0° plane and the φ = 90° plane at 11.7 GHz

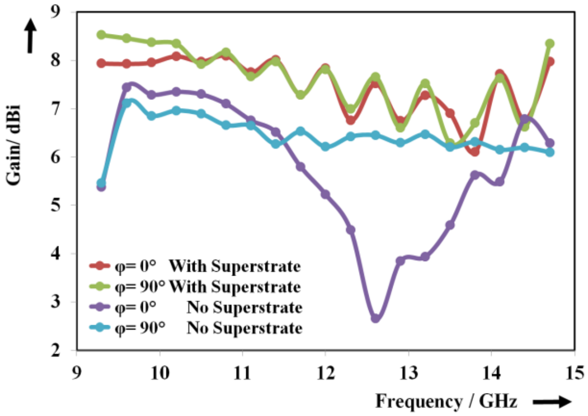


Fig. 21 shows a plot of the gain in dBi of the antenna element in the farfield against frequencies for a frequency range from 9 to 15 GHz. The plot shows the gain obtained in the φ = 0° plane and the φ = 90° plane, with and without the superstrate layer, that is, when the top layer 1 is present or absent.

IV. CONCLUSION

A simple patch antenna is optimized using CST Microwave studio 2015 in order to design a high gain and high bandwidth patch antenna element covering the frequency band from 10.1 GHz to 14.2 GHz. The four-

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layer design, with the dimensions of 25 mm by 25 mm by 2.56 mm, comprises of a superstrate layer of εr 10.2 on top of a metal layer centrally fed with coplanar lines. The metal layer comprises of six parasitic H-shaped elements on top of strategically placed slots in the substrate layer of εr 2.2 underneath. The final layer is the ground layer. The design has a 34% bandwidth between 10.1 to 14.2 GHz and high gain of 8 dBi in both φ = 0° and φ = 90° and with a beamwidth of 77° in the φ = 0° plane and 83° in the φ = 90° plane in the farfield.

V. ACKNOWLEDGMENTS

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