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Guard lines conformal slotted antenna array for multiband application

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ABSTRACT

This work investigated a for a miniaturized slotted conformal antenna array for multiband application. Three guard lines are incorporated to the side of main patch and top of main patch to reduce surface current for planner surface and observe the effect of guard line due to which it resonate at three frequencies in X band and Ku band to be useful for multiband. A rectangular slot is etched at center of patches to increase the current path for wide band application. A quarter wave length feeding network is used with good agreement of impedance matching. The main lobe width and direction shows through the radiation pattern which remains stable even it is significantly curved. This structure is wrapped around a cylinder with diameter of 41.4 mm in circumferential direction. It is observed that the planner antenna array operating at 8.4 GHz, 11.2 GHz &18.2 GHz with return loss of -20 dB to -45 dB with fractional BW of 25% at 3rd frequency range and the directivity from 3.4 dBi-6.8 dBi. By doing some alteration in dimensions for the conformal antenna producing fractional BW of 20% and the directivity 5.5 to 9.1 dBi at resonating frequencies of 8.4 GHz, 11.4 GHz and 17.5 GHz. This proposed array is simulated on CST software.

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1. INTRODUCTION

In last one decade researchers paid lot of attention towards antenna for better performance and versatile features. Planner antenna, which we can't use for all purpose, hence conformal antenna was proposed. A modern antenna, which can conforms to any prescribed shape like a high speed train, a space suite, a car, a part of missiles, some part of a media van, an aero-plane, fast moving trains, or other vehicles. The aim is to develop miniaturized conformal antenna so that it could be integrated with the structures with useful applications.

A conformal antenna can be almost in any shape like cylindrical, spherical and conical or in other shapes also, in which the antenna elements are integrated or mounted onto the smoothly curved surface. A 4-elements conformal antenna array investigated for cylindrical surface and analyze the effect of mutual coupling [1], [2]. When MSA printed on curved surface, the radiation characteristics or desired output will be degrade as compared to planer surface. This non-planner surface of MSA may print on the flexible, semi flexible and thin substrate. so that it can be mounted on curve surface, such antenna system can be developed to operated under such conditions, either the antenna parameter of the curved surface is acceptable for the required application or it has to compensate the degrade antenna performance using the compensating circuit/components. Thus, implementation of the microstrip antenna array to the curved surface may be the solution for different application as civil or military air crafts, vehicles, and wearable application. The technique used to analyze microstrip antenna for non planar surface conforming to the parent structure as cylinder has been explained. A flexible miniaturized bowtie antenna proposed at 2.4 GHZ. [3]-[8].

Narrow bandwidth is a major limitation of planar MSA. To resolve it different methods have been developed for bandwidth enhancement of an antenna. They are as: slot loaded patch, modifying the feed, shorting pin, using DGS, parasitic patch and multilayer resonator. To enhance the bandwidth of a patch, cut a slot in the patch of half wavelength long at desired frequency. These slots are in different shapes as E, H, U. There is no analytical approach is developed to compute the exact dimensions of the slot, but a half wavelength long slot provides good agreement to compare the length of slot at desired resonance. A probe feeding, the impedance bandwidth of 2.0-6.3 GHz at resonating frequency of 4.2 GHz has been obtained with the return loss of -30 dB and VSWR of less than 1.07 [9]. The bandwidth of antenna can be improved by use of parasitic elements, by introducing two capacitance technique to excite the parasitic element placed parallel to the radiating edges, creating broadband U,E,T and H shape slot electromagnetic coupling probe feeding technique [10]-[13]. A “MIMO” antenna presented with improved isolation and impedance matching at 6GHz and a Multi band application proposed with a hexagonal complementary split ring resonator. A reconfigurable antenna using PIN diode proposed with harmonic suppression [14]-[16]. An optimal conformal antenna array structure for DOA (direction-of-arrival) estimation on the planar surface and then conforming it on a cylindrical and hemispherical surface studied using the directive elements. Results concluded by adopting different algorithms as CR (Cramer-Rao) lower bound, multiple signal classification, and rms error algorithms to evaluate the estimation accuracy of the conformal antennas [7].

2. SLOTTED CYLINDERICAL CONFORMAL ANTENNA

A wrap around technique introduced antenna placed on cylindrical shape surface and then it provide radial omni pattern with nulls at axis [17]. A folded slot conformal antenna array investigated using two elements with coplanar waveguide [5]. The enhancement in bandwidth and miniaturization of Patch may be achieved by etching the slot in ground and the proper dimensions of patch of Microstrip antenna. The longest slot length provides the minimum change in the resonance frequency whereas maximum change for the minimum slot length. Many literatures have been reported for the slot antenna. Here, that slotted antenna applied for conformal application on cylinder. A comparative performance analysis has been made for these slots shape as: π and half π, U and half U slots design are proposed and reduced area to 50%. [1], [2], [18]-[20]. A conformal structure with truncated corner used for circular polarization. This work presents a slotted conformal antenna by incorporating two slots E shape and U shape which is back-to-back connected to each other and observed the effect of length, width & height on S_{11}, radiation pattern and shifting in frequency. It is fabricated using epoxy FR4 substrate [5], [21], [22].

2.1. Single layer curved surface conformal antennas

The separately bended surface antenna is the least complex type of conformal antenna. The fundamental goal of such antenna is to improve the azimuthally inclusion or acquiring omni-directional coverage at times. The roundabout tube shaped antenna is usually utilized structure in conformal reception apparatuses for various applications. The conical form of antenna is also singly curved surface for particular applications in the cockpit of aircraft or missiles [19], [23], [24]. Here, in this section only cylindrical antennas will be considered because of their simple geometry. The change of the resonant frequency with change in curvature of cylindrical surface taken into account, as show in Figure 1. It is also considered for the full wave analysis. The resonant frequency for a patch for mnth TM mode to be determined analytically as (1) and (2).

$$E_p = E_0 \cos\left[\frac{m\pi}{2\theta}(\varphi - \varphi_1)\right]\cos\left(\frac{n\pi z}{2b}\right) \tag{1}$$

$$f_{mn} = \frac{c}{2\sqrt{\varepsilon_r}}\left[\left\{\frac{m\pi}{2a\theta_1}\right\}^2 + \left\{\frac{n\pi}{2b}\right\}^2\right]^{1/2} \tag{2}$$

For rectangular patch antenna with [R = a] radius cylindrical ground plane, Straight edge length =$2b$, Arc or curved length $= 2(a+h)\theta_1$

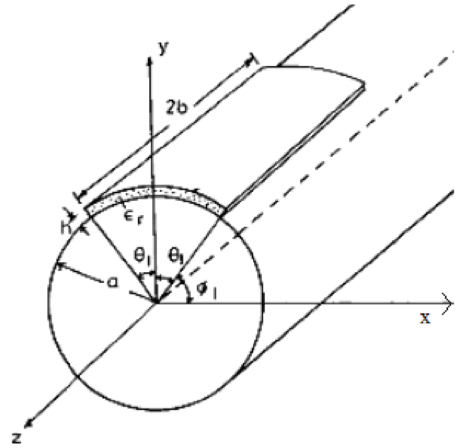

Figure 1. Rectangular microstrip patch on the cylindrical surface

$$f_{mn} = \frac{c}{2\sqrt{\varepsilon_r}}\sqrt{\left(\frac{m}{W}\right)^2 + \left(\frac{n}{L}\right)^2} \quad (3)$$

Where $W = 2R\emptyset_0 + t/\sqrt{\varepsilon_r}$ (4)

Is the effective circumferential length of the patch and

$L = Z_m + t/\sqrt{\varepsilon_r}$ is theeeffective axial length (5)

Z_m is the axial length of the patch

$2R\emptyset_0$and Z_m is the actual dimensions of the patch with 'R' as the radius of cylinder

$\emptyset_0$ is the angle from the center of patch to the straight edge

3. EFFECT OF CURVATURE ON CONFORMAL PATCH

To determine the basic dimension of the patch, section 3.3 reported all the related (6). The single antenna is a printed on the 21mm×51mm patch grounded FR4 dielectric substrate with the dielectric constant of 4.3 and substrate height (h) = 2.5 mm, f_r = in between 10-18 GHz, Radius r_1 =35mm. The dimensions (L & W) of the antenna may calculate using transmission line method. The conductor thickness taken as chosen is 4.7µm. To find the axial length L, determine the angle subtended by measuring two axial lines of patch passing through centre of cylinder to the patch edge shown in Figure 1.

$$L = \frac{\varphi}{180} \text{ x } \pi \text{ x } radius, W = 1_{2_{\varphi mm}} \quad (6)$$

The transmission line method is applicable to infinite ground planes only. For the practical considerations for the line calculation, it is necessary to have a finite ground plane of antenna. The results for infinite and finite ground plane may be optimize if the size of the ground plane is larger than the antenna patch dimensions by approximately six times of the substrate thickness overall.

4. DIMENSIONS OF SLOTTED PLANNER AND CONFORMAL ANTENNA ARRAY

Antenna model dimension in mm as shown in Table 1. The factors affecting the bandwidth of a MSA are shape of the radiator, the substrate, the feeding scheme and the arrangements of slot, radiating and parasitic elements. A wide bandwidth of a MSA may be attributed to its low Quality factor and simultaneously provides well excited multiple resonances. Bandwidth enhancement using slot loading technique, a quarter wave length with width of 0.12mm slot is created on the radiating patch of antenna which leads to wide bandwidth due to double resonant effect while keeping the size small [18]. The slot in the patch increases the current path length and thus increases bandwidth.

The guard line dimensions are: Lg_{L1}=Lg_{L2}=6.2 mm, Lg_{L3} = 8.4 mm, Wg_{L}=1.2 mm.

Table 1. Antenna model dimension in mm

Patch Dimensions		Corporate feed Dimensions		Quarter wave transformer	
Length	Patch width	Length in mm	width in mm	Length in mm	Patch width in mm
L_p =7.2 mm	W_p=9.9mm	50 Ω line L_{50}= 4.1	50 Ω line W_{50}=3.1	Lt=4.1	Wt=3.1
Ground plan Dimensions		70 Ω line L_{70} =3.5	70 Ω line W_{70} =1.6	Total array length width in mm	
Lg=21.5mm	Wg=24mm	line L_{100} = 8.3	W_{100}= 0.7	112	39.5
Theoretical value- radius =20.7mm			Total array length=2πr =129mm		

A slotted array for above structure resonating at X and Ku band is given in Figure 2. A single element slot antenna presented with centre slot in Order to achieve greater bandwidth with the suitable gain as the gain and bandwidth product is constant. The scattering result of single element resonating at four frequency at 7.3Ghz, 11.5Ghz,14.5GHz and 19.16Ghz with the return losses of -11.3dB, -11.57dB, -15.68 and -23.7dB respectively and producing – 10dB bandwidth of 2.44GHz. But the gain of this single element antenna is little bit low about 1.8-4.2dB at above frequencies. In order to increase the gain of antenna, a four element has introduced here.

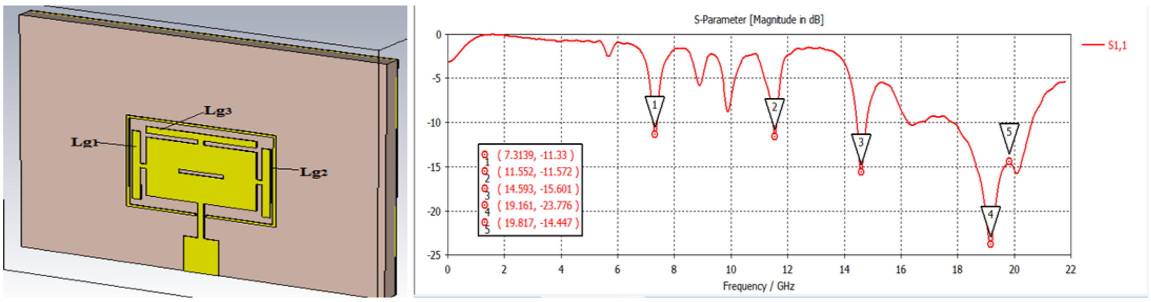

Figure 2. Model and S_{11} in dB for centre slot single element antenna

5. RESULT ANALYSIS - PROPOSED PLANAR AND CONFORMAL SLOTTED ANTENNA

This antenna array makes a tradeoff between gain and resonating frequencies. My previous work done and above analysis prove that the antenna array characteristics parameters as direction of radiation pattern, gain, directivity, shifting in frequency, bandwidth and angular width are affected after conforming the same planar structure[1]-[3] as show in Figure 3. It observed from this analysis that radiation characteristic degrades and with increase in radius, frequency and return loss decreases [1], [2]. In the conformal structure, resonating frequencies has been shifted slightly due to the change in length of curve surface. As conforming the surface gain get reduces.

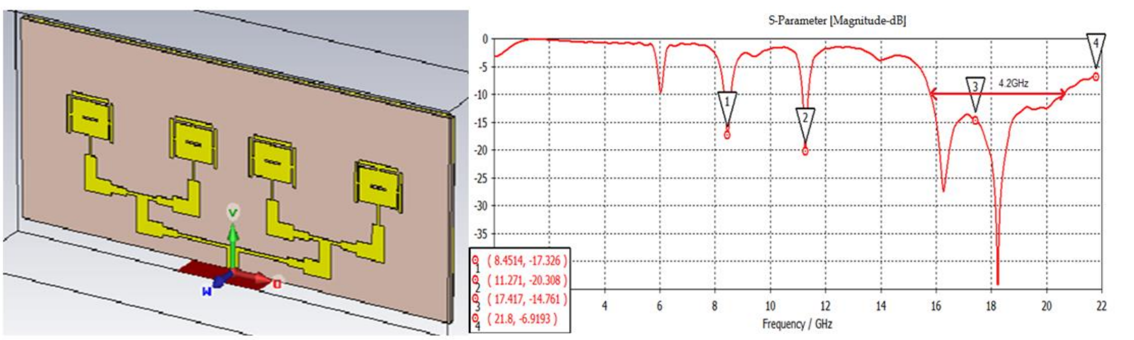

Figure 3. Model and S11-parameter centre slot four element planar array on CST plate form

Return losses for planar array is -45 dB at 18.1GHz and -10 dB bandwidth is 4.35GHz and fractional bandwidth is given $f_c=(f_1+f_2)/2= 18.2$. A wide band application have 20% or greater BW and >50% for ultra wide band.

$$(f_2-f_1)/fc \times 100= (20.5-15.9)/18.2\times100= 25.2\%$$

Some iteration has been done in order to maintain the similar result as achieved in planar configuration. By reducing the side guard line length from 8.4mm to 8.1mm and increased the height of substrate, frequency shifted ahead whereas frequencies will be shifted before for the conformal array antenna. So that similar resonating frequencies may be maintained. This shifting is caused by the change in length of curve surface. By which length will increases and frequencies shifted before the previous one. Optimization techniques used to achieve good agreement of results. As a result overall performances have been improved with the tradeoff of gain and bandwidth shown in Figure 4.

In the previous work already proposed, radiation pattern get shifted in another direction with different angular width 10^0-90^0 for the cylindrical application [1[, [2], [5], [6], [18], [20], [22], [25]. This shifting of beam or radiation pattern may get back to its original position by phase shifting networks in the conformal structure. In the given proposed conformal antenna radiation pattern also get shifted by 30^0-45^0. That may overcome using meandering in the feeding network and diode as phase shifter.

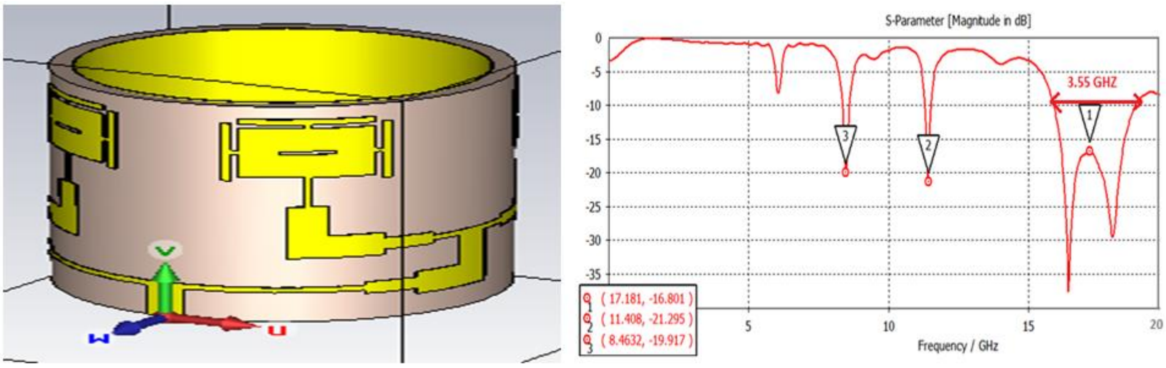

Figure 4. Model and S11-parameter conformal centre slotted antenna array

Return losses for conformal array is -38 dB at 3rd frequency. In this configuration gain/directivity improved with BW compromises. The simulated -10 dB bandwidth is 3.55GHz and fractional bandwidth of 20%.

$$(f_2-f_1)/f_0 \times 100= (19.3-15.75)/17.5\times100= 20.2\ \%$$

The radiation characteristics offered directivity of 4.3 dB to 6.8 dB of the above said frequencies in planar slotted configuration. Radiation patterns are investigated with 2-D and 3-D at 8.4 GHz, 11.4 GHz and 17.1 GHz are illustrated in Figure 5 to Figure 6 for conformal antenna array using CST software. This software is best suitable for conformal application. These radiation patterns described the main lobe magnitude, main lobe direction, angular width, radiation efficiency, total efficiency and directivity of the conformal slotted antenna array with the maximum radiation efficiency and maximum directivity of 8.2 db and 8.5 dB respectively. The entire result summary is given in Table 2.

Summary of the Simulated Result- A tabular form has been made for better understanding for scattering and Radiation characteristics as show in Table 2. With reference to Figure 2 & Figure 3, this proposed antenna is suitable for X-and Ku band application.

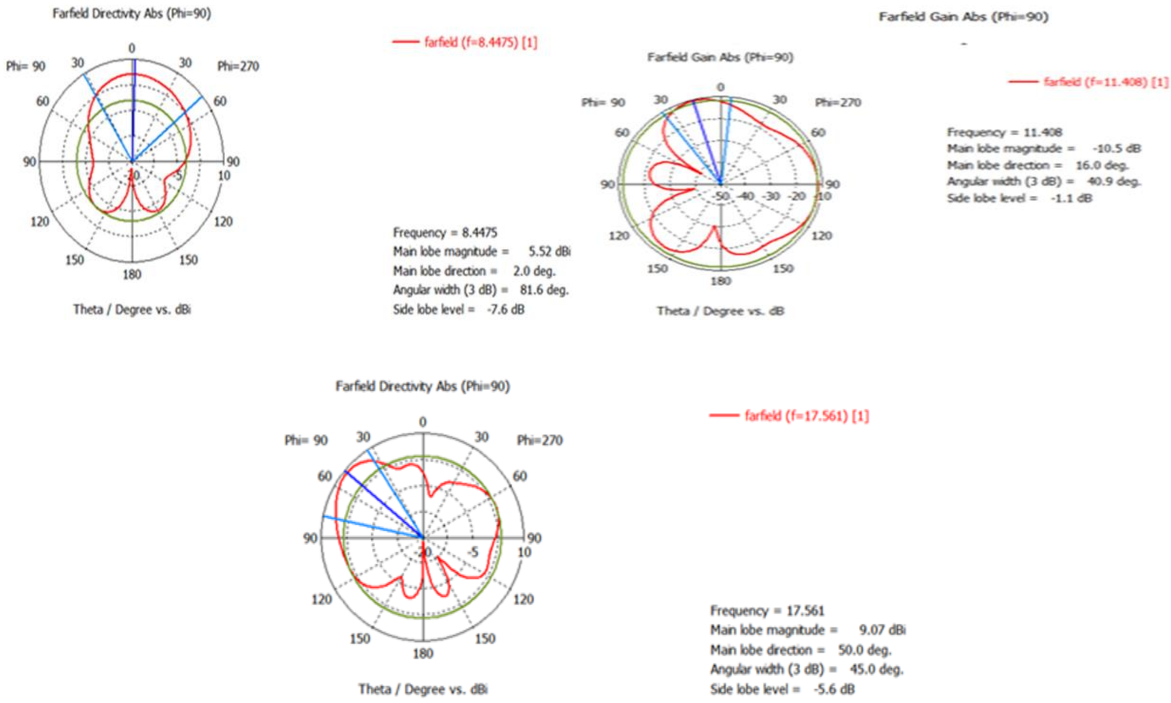

Figure 5. 2-D radiation plots for slotted conformal array at 8.4GHz, 11.4GHz and17.5GHz

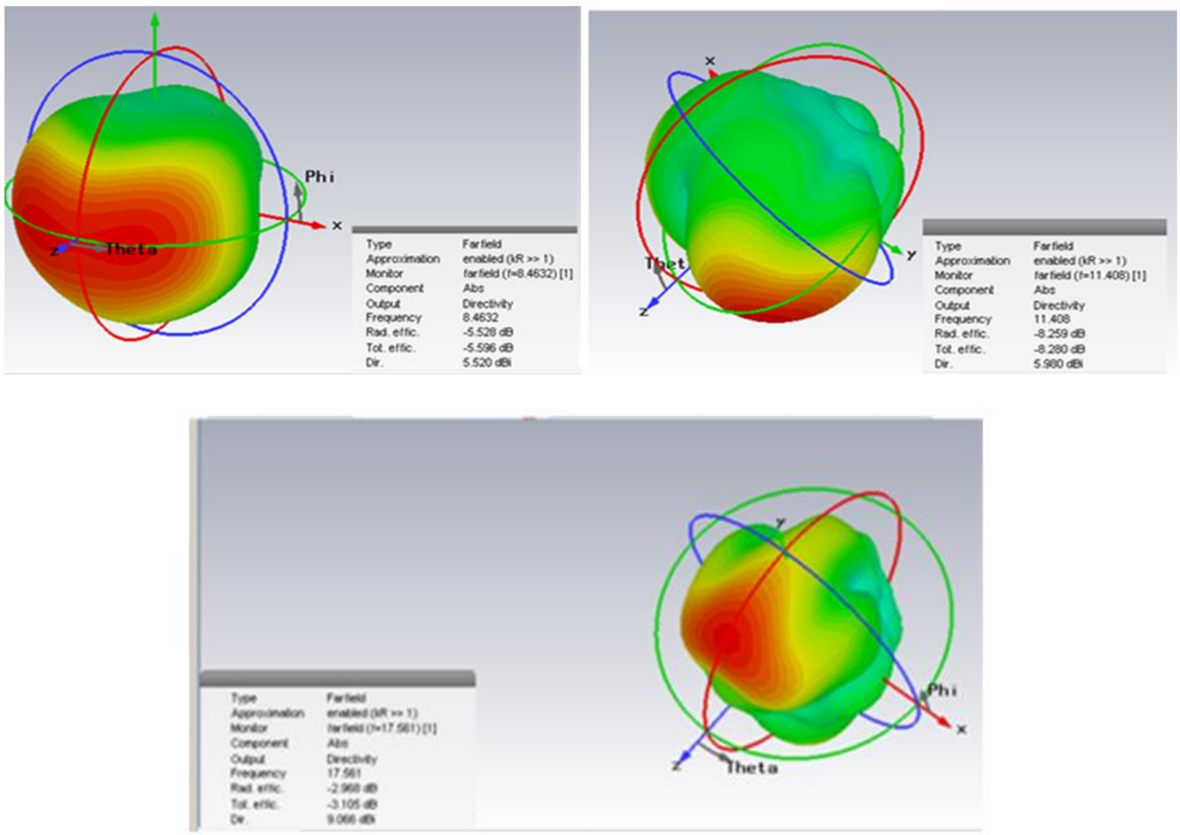

Figure 6. 3-D radiation plots for slotted conformal array at 8.4GHz,11.4 GHz and17.5GHz

Table 2. Summary of the Simulated

SN	Freq. (GHz)	S_{11} (dB)	Main lobe Magnitude(dB) & Direction(deg.)	Angular width (deg.)	Directivity (dBi)
1	8.4	-20	5.5 & 2	81.6	5.5
2	11.4	-21	10.5 & 16	40.9	5.9
3	**17.18**	**-17**	**9.1 & 50**	**45**	**9.2**

6. CONCLUSION

In this paper, an approach has been established to get the performance of conformal antenna array near to planar antenna by doing some alteration in dimensions. Fundamentally, the application of conformal antennas is suggested where good agreement has been achieved in bandwidth and the three resonating frequencies in X and a Ku band with respect to planar configuration as the performance is degrades for the curved structure. Especially on 3rd frequency range at 15.75-19.3GHz with S11 is -17dB to-38dB, -10 db BW 3.55 GHz, Main lobe Magnitude 9.1dB, Main lobe Direction 50^0, angular width 45^0 and directivity of 8.1dBi has been achieved. The main effect of the conformal surface is to increase the amplitude of cross polarization component. In order to analyze the simulation of above planar and conformal antenna array on the bases of scattering parameter, VSWR vs resonating frequencies and radiation patterns in Figures 1-6. Furthermore, a flexible substrate as RT duriode 5880 will be chosen for the fabrication purpose.

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