Design and Development of High Frequency Antenna Array for High Altitude Platform

Awais Ali [1], Omar Ansari [1], Mohammad Ali Jamshed [1], Moazam Maqsood [1] and Umar Iqbal Bhatti [1]

***Abstract*—Microstrip feed Yagi-Uda antenna is designed for using onboard High-Altitude Platform (HAP). The (31/28 GHz) antenna is designed on both sides of the 0.127mm thick Rogers RT N 6006 with permittivity $\epsilon_r = 6.15$ and loss tangent $\delta = 0.0027$. Thin substrate is used in order to avoid the losses due to skin effect. Antenna element is backed by a reflective ground structure. Six parasitic elements are added for gain enhancement and to make the beam directive. The antenna driven element and the directors are halved to place on both sides of the substrate. The paper presents the unit cell, 4x4, 8x8, 16x16 and 24x24 non-integrated feed array results. Although same antenna design can be used for both 31/28 GHz, results have been presented for 28 GHz only. It can be seen from simulation results that array of 24x24 elements is able to achieve the overall gain of 25.6 dB with 3.9 deg beamwidth.**

***Index Terms*—mm wave antenna, high altitude platform, parasitic elements, integrated feed**

I. Introduction

Printed antennas are frequently used in mobile satellite and mm wave applications. They possess the advantages of low cost and ease of fabrication. Printed antennas also better for their compactness, conformability and considerably low mass. Large-printed antenna arrays are commonly used in a variety of commercial as well as military applications. The antennas are used in MIMO configuration for telephony, as large arrays for communication satellites and as AESA for aircraft.

High Altitude Platforms (HAPs) have mostly been proposed for communication applications for providing both back-haul connectivity as well as direct to user applications. HAPs are usually balloon like structures placed in the stratosphere are and communicating at mm-wave frequencies. Antennas in the HAPs are key to system performance. Light weight and high gain antennas are preferred for such applications considering the HAPs must be deployed for long endurance. Moreover, the overall payload must be lifted using counter-weight mechanism such as Helium (He) gas.

This paper presents the design of a Printed Yagi antenna which is most suitable for using onboard a HAP considering its high gain and ease of fabrication while keeping the overall weight to be low. Antenna array is fed by using corporate fed microstrip line structure [1]. Alhalabi et al. presented a folded dipole feed Yagi antenna with four directors for frequency range of 22-26 GHz with 9-11 dB gain, where parasitic elements are placed on top of substrate with truncated ground plane and balun [2]. However, the frequency dependence of the antenna limits its performance. A Yagi-Uda antenna with truncated ground plane and antenna balun between top and bottom side of substrate was presented in [3]. A planar Yagi-Uda antenna is designed on a thin substrate with concave parabolic reflector and a director operating at frequency of 1.58 GHz [4]. Frequency reconfigurability be achieved using two varactor diodes at the arms of Quasi Dipole Yagi antenna [5].

To minimize the interference frequency reconfigurable antennas are used. Unwanted radiation and interference are suppressed using directional antennas. Multilayer Yagi antenna with a pair of folded dipoles and latticed directors is presented for 2G/3G/LTE applications [6]. Air filled slot loop structure is introduced as a radiator using low cost FR4 substrate for 5G phased array applications [7]. Ten element array is capable to provide 0° to 50° scanning with 13 dB gain. Multilayer broadband antenna with partial superstrate layers is designed by Kandwal, Electromagnetic Band Gap (EBG) and reflector surfaces are made to operate the antenna at high frequency of 140 GHz [8].

In another publication corrugated feed horn design parameters are discussed for Ka band satellite communication and remote sensing [9]. According to FCC and frequency allocation board of Pakistan 28/31 GHz frequency is allocated for communication with HAPs. Proposed Yagi antenna array is designed for 28 GHz is to be mounted at HAP. The purpose of HAP is to provide broadband services over wide range using one node [10]. As per Nauman and Maqsood, gain and beamwidth requirement are 32.6 dB and 5° respectively [10].

In comparison to previous work, this paper presents the design of a printed Yagi antenna array integrated to a feed network. Both antenna and the feed network are designed and printed on the same substrate for ease of fabrication and keeping the overall connecter losses to minimum. Contrary to the previous work, single element gain is enhanced to achieve the desired gain with minimum possible number of elements.

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[1] Institute of Space Technology, Islamabad, Pakistan.

* Corresponding author email: *moazam.maqsood@ist.edu.pk

II. Antenna Design and Measurement

One of the challenges in designing high frequency antenna array is substrate selection and the array feed design. Thick substrate cannot be used for designing high frequency large antenna array because of the skin effect the current would start flowing at the boundary of the conductor and hence the antenna losses will increase. Considering this, the array is designed on thin substrate of 0.127 mm thickness. Substrate has high permittivity and low loss tangent so that there will be less losses when antenna feed would be designed for the large array.

A. Unit Cell

The microstrip fed Yagi Antenna was designed on RT/Duroid N6006 substrate (ε = 6.15) with a thickness of 0.127 mm with six directors as shown in Fig 1. The antenna structure is backed with a ground wall placed at a distance of $\lambda/4$ to make the omnidirectional pattern of dipole to directional pattern and to minimize the sensitivity of antenna from backward.

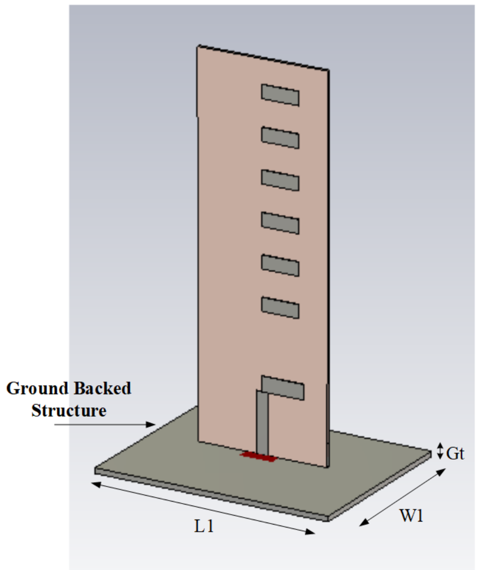

Fig 1: Antenna structure with ground backed

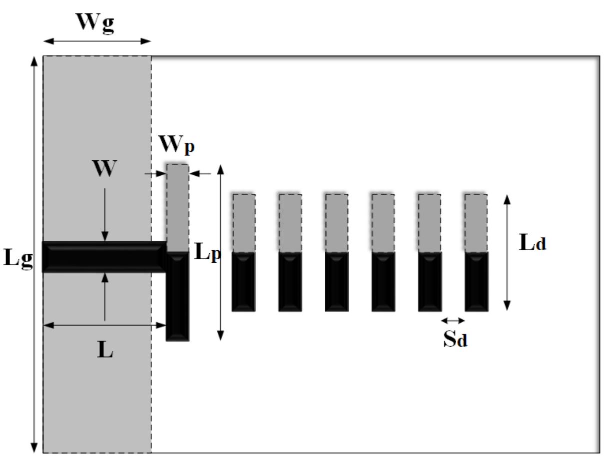

Fig 2: Antenna geometry with variables mentioned.

Dipole and directors are broken into two halves placed on top and bottom of the substrate layer as shown in Fig 2. The initial dimensions of the antenna elements are given in TABLE I. The ground wall is placed at a distance d=0.176 mm. The antenna is designed to have input impedance of 50Ω and is attached to a microstrip line of width W=0.45 mm (Zo=50Ω) and length L=2.25 mm.

TABLE I
Dimensions of single unit for 28 Ghz

Structure Description	Parameter	Value (mm)
Top Layer	L	2.25
	W	0.45
	Wp	0.56
	Lp	1.6*2
	Sd	1
	Ld	1.4*2
Bottom Layer	Lg	5
	Wg	0.8
Ground Backed Structure	L_1	9
	W_1	7
	G_t	0.2

Fig 3 shows S_{11} of the single element antenna simulated in CST. Simulated S_{11}<-10dB from 26.5 GHz to 29.473 GHz. Simulated radiation pattern of the antenna at 28 GHz is shown in Fig 4 with gain value of 10.1 dB and -12 dB side lobe level. The antenna structure is designed in CST microwave studio.

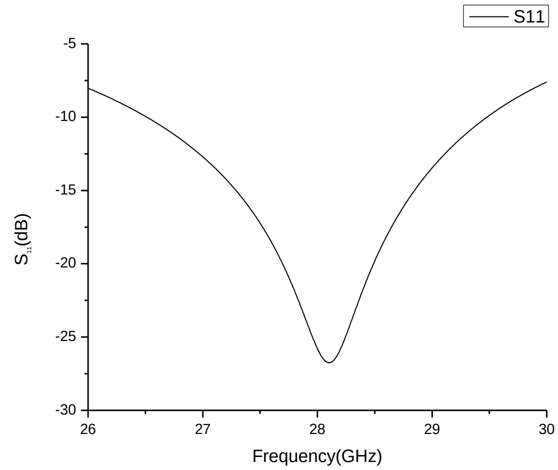

Fig 3: Simulated S_{11} in CST MWS

The driver dipole is built on both sides of the substrate with several directors and a ground wall for gain enhancement. Same design is tuned to operate at 31 GHz. Dimensions of the antenna parameters are modified accordingly to make the antenna resonate at the desired frequency. Thin substrate is chosen for antenna design in order to avoid the skin effect.

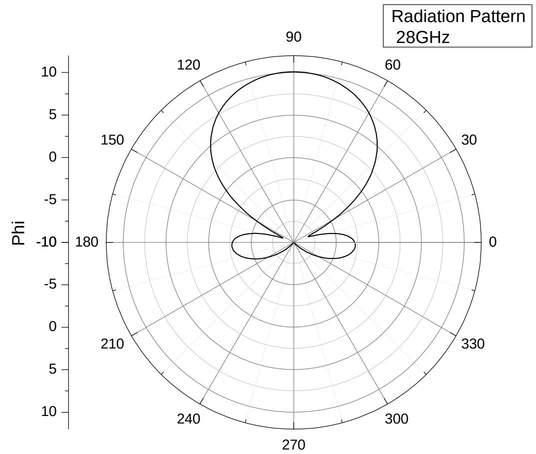

Fig 4: Radiation pattern at 28 GHz

Fig 5 and Fig *6* presents the s-parameters and radiation pattern of the single element designed at 31 GHz frequency, respectively. Length of the feed line L and Lp is reduced to 1.25 mm and 1.45 mm respectively. These figures show a good matching of unit cell designed at 31 GHz, below -10 dB and gain of -11.3 dB.

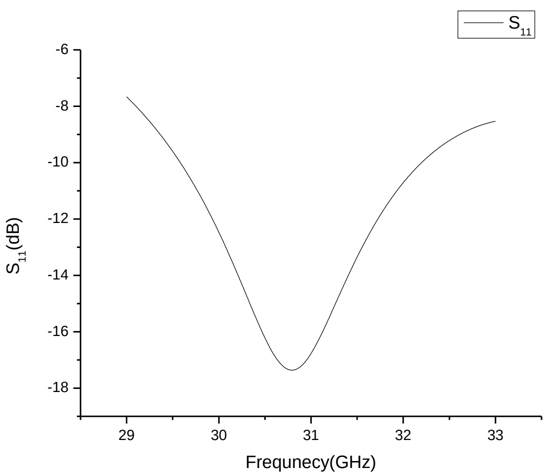

Fig 5: S11 of single element at 31 GHz

B. Feed Network Design

Corporate feed structure is proposed for the array feeding. Array feed structure is designed on the 0.127 mm thick RT N6006 substrate. Input 50 Ω impedance is divided into two 100Ω lines and a quarter wave transformer is used to match 100Ω line to further 50Ω lines.

TABLE II
Feed Network Dimensions

Parameters	Values (mm)
W50 (width of 50Ω line)	0.38
L50 (length of 50Ω line)	1.35
W100 (width of 100Ω line)	0.035
L100 (length of 100Ω line)	4.5
W70.7 (width)	0.092
L70.7 (length)	1

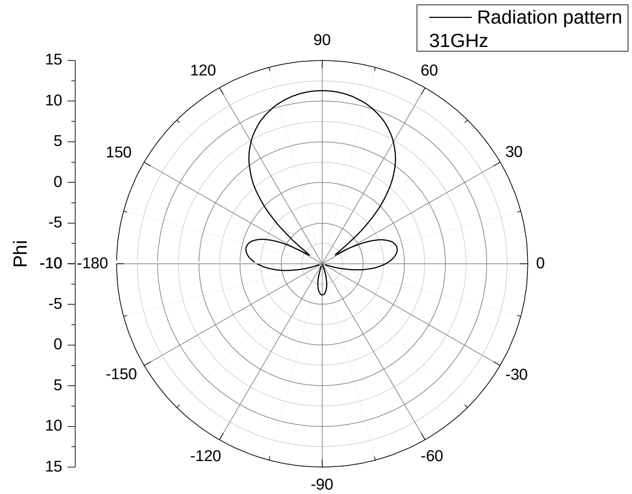

Fig 6: Radiation pattern at 31 GHz

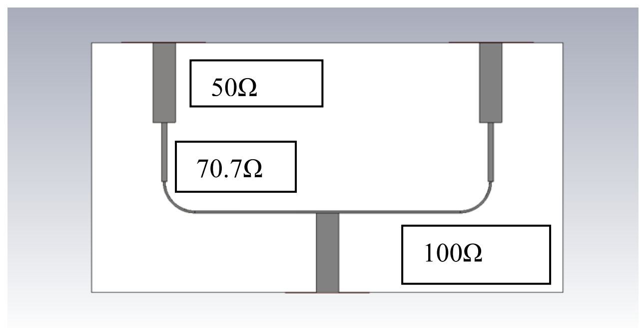

Fig 7: Power divider

C. 4x4 Array with separate feeds

Antenna array is designed with 4 separate feeds in order to view the results of the array without connector and substrate losses:

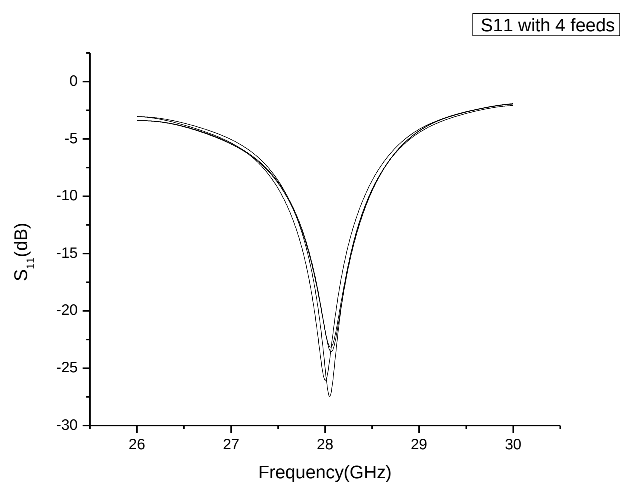

Fig 8: S11 of 4x4 array with four feeds

Structure of the array remains the same as shown in Fig 15, extra feed-structure is not added. Array is matched at 28 GHz with gain of 18.3 dB and 22° beamwidth as shown in Fig 9 and Fig 10.

A. 8x8 Array with separate feeds

Now for the second simulation array size is increased to 8x8 elements with no extra feed-structure integrated to the array. Fig 11 and Fig 12 shows the s-parameters and combined radiation pattern of the array.

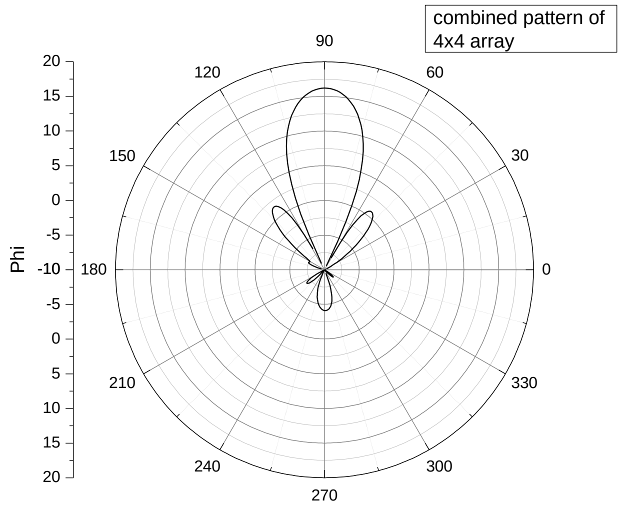

Fig 9: Combined pattern of 4x4 array with 4 separate feeds

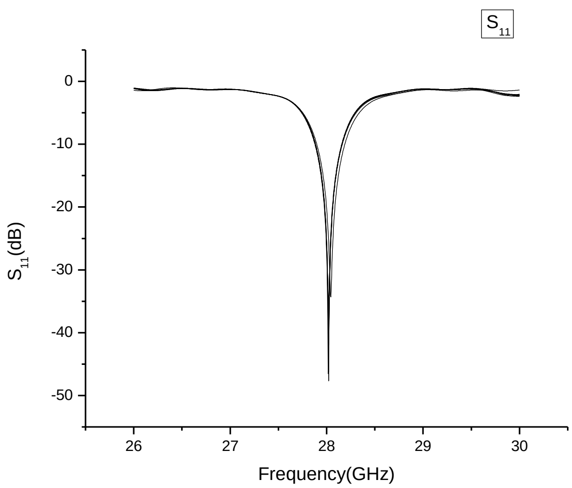

Fig 10: S parameters of array with separate feeds

All the feed structures are matched at desired frequency. Array structure with such feed mechanism gives gain of 22.6 dB with 11.8° beamwidth.

B. 16x16 Array with integrated feed network

Array of 16x16 elements is simulated in CST which shows good agreement of matching in terms of power transfer and acceptance at the desired frequency. Results shows gain of approximately 23 dB is achieved. Fig 12 shows radiation pattern of the array.

C. 24x24 Array with integrated feed network

Final array of 24x24 elements is simulated for the completion of the analysis in CST. Array results in gain of 28.6 dB with 4° beamwidth and side lobe level of -13.5 dB. Radiation pattern of the 24x24 array with non-integrated feed network is presented in Fig 13.

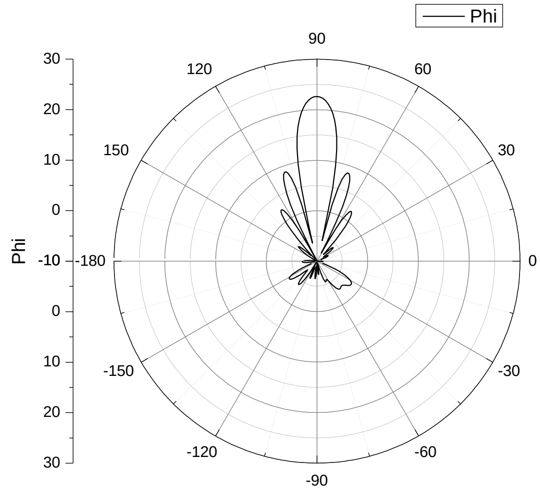

Fig 11: Radiation pattern of 8x8 array with separate feeds

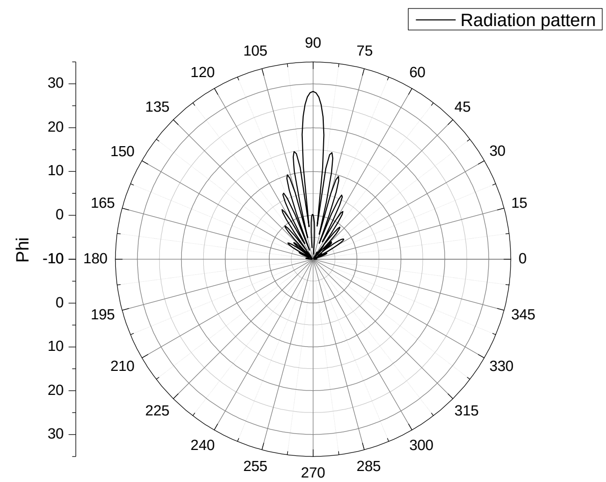

Fig 12: Radiation pattern of non-integrated 16x16 array

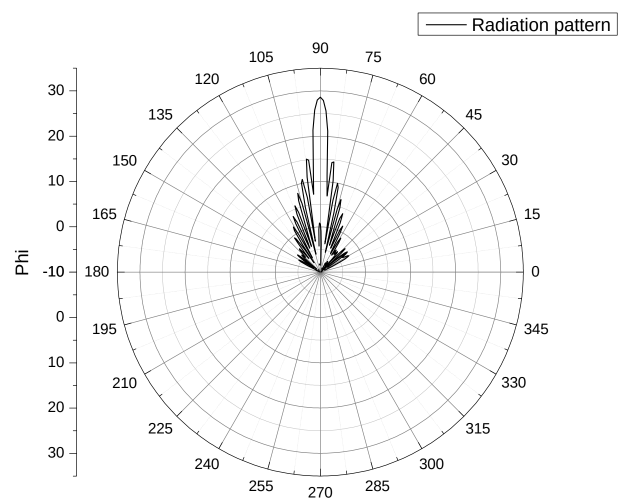

Fig 13: Radiation pattern of 24x24 array with non-integrated feed network.

D. 4x4 Array with integrated feed network

Configuration of the antenna array and its complementary structure are illustrated in Fig 15. One of the important parameters of designing an antenna array is the distance between the adjacent elements. Increasing and decreasing the inter-element distance can cause distortion and interference.

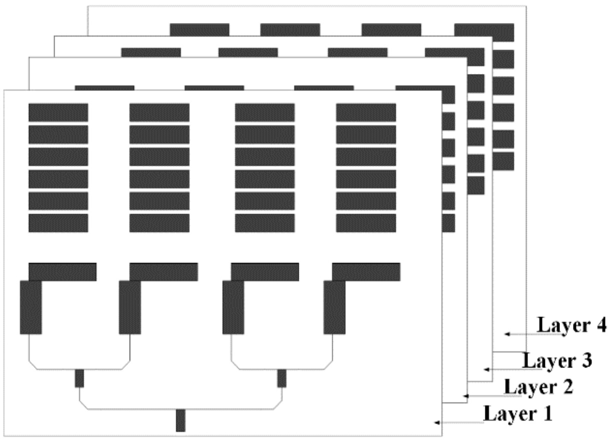

Fig 14: 4x4 antenna array Perspective view

Spacing between the elements and the layers of the antenna array are same i.e., S = 5.5 mm. Antenna array is backed by a structure at a distance of 0.176 mm from antenna feeding point. Back of the antenna is exactly same as front side though parasitic elements are broken into half and with truncated ground plane. Fig 15 shows good agreement of matching of the 4x4 array simulated in CST.

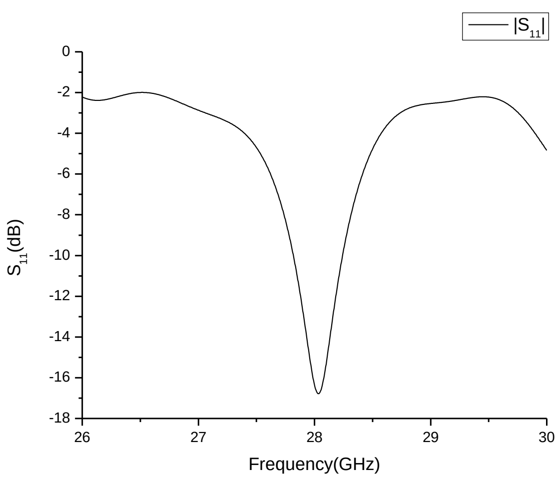

Fig 15: Simulated results of 4x4 array in CST

In addition, Fig 16 shows the polar radiation pattern of the antenna array. Antenna array has a good radiation pattern with realized gain 16.1 dB at 28 GHz.

E. 24x24 Array with integrated feed network

Antenna array is increased in size exactly as per the elements spacing mentioned for the 4x4 array. Fig 17, Fig 18 and Fig 19 show different results for the array with integrated feedback, the front, perspective, and feed of the large array are sketched in these figures respectively.

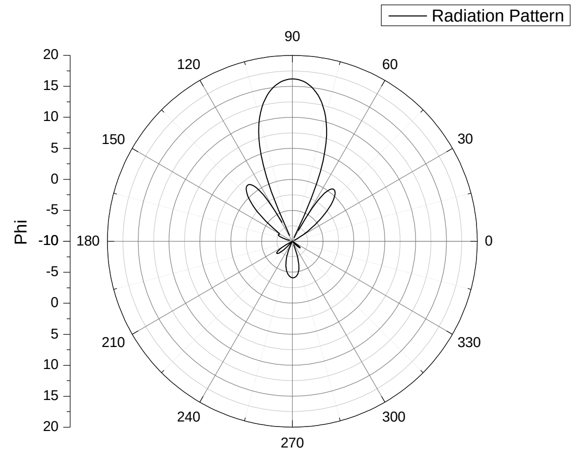

Fig 16: Simulated radiation pattern of the 4x4 antenna array at 28GHz

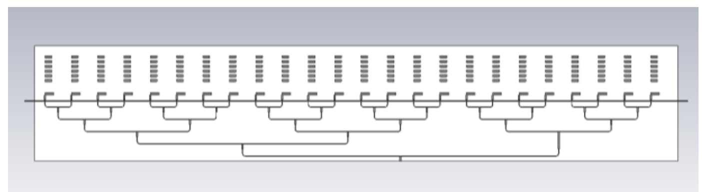

Fig 17: Front view of 24x24 proposed array for uplink to High Altitude Platform

Inter-element spacing is the same as discussed in previous section, so the S is kept as 5.5 mm. The array is further attached to a 1x24 feed network. Fig 20 shows the S parameters of the proposed array.

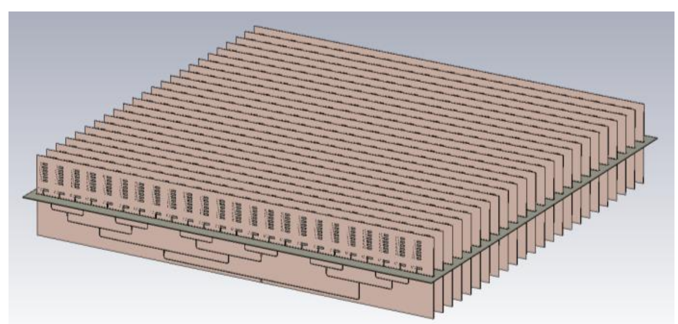

Fig 18: Proposed array of 24x24 elements

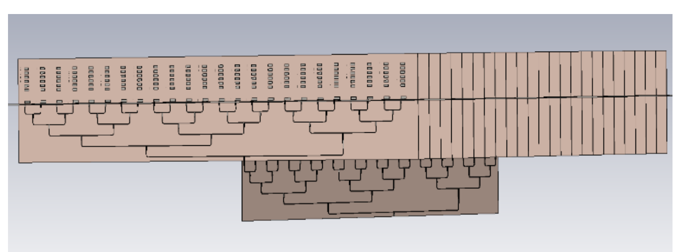

Fig 19: Proposed array with feed structure

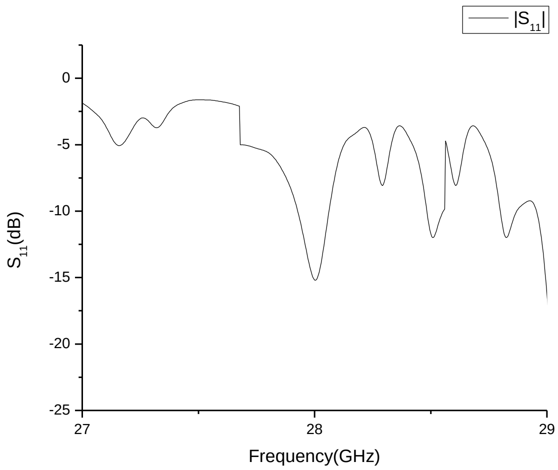

Fig 20: Reflection coefficient of the proposed array

Antenna array has a good radiation pattern with gain of 25.6 dB and -12.3 dB side lobe level.

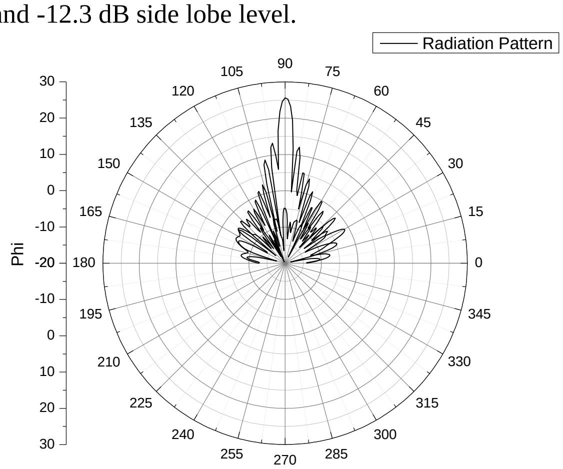

Fig 21: Radiation pattern of the 24x24 array

III. Conclusion

This paper presents printed Yagi-Uda antenna array with dipole as driven element for mm-wave applications. Paper further presents unit cell of antenna elements designed for both 28 and 31 GHz. The analysis in this paper comprises 4X4 and 8X8 array with separate feeds. However, array size 16X16 is simulated which is further extended to 24x24 elements with integrated feed network having 25.6 dB gain and 3.9° HPBW. Array structure of 4X4 with separate feeds and integrated feeds remain same as shown in Fig 15. Array structures are presented and analyzed with and without feed integration in order to elaborate proof of concept.

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