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Design, simulation and implementation of low cost microstrip array antenna for KU–band satellite system

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Abstract. This paper present 32 Element microstrip rectangular patch array antenna for KU-Band. The aim of the design is to achieve low cost, low weight and high gain antenna for the transmissions frequency range of KU – Band satellite system. The paper also present 5 designs for array antenna 2, 4,8,16 and 32 elements and the results comparison between them. The substrate material is FR-4 with 1.58 mm thickens. The simulation made by CST Microwave studio 2017. The size of final design is 85×98.81 mm and the bandwidth is 1.489 GHz. The frequency range of design starting from 13.318 GHz to 14.842 GHz with maximum Gain 13.7 dB. The final design of 32 elements array antenna has been fabricated and compared with the simulation results, a good agreements were obtained and the difference between fabrication and measurements results was due to fabrication and measurements tools tolerance. The fabricated design has been measured using Vector network analyzer ROHDE & SCHWARZ ZVB20.

1. Introduction

Satellite communication is one of the most Irreplaceable technology due to its independence of location, boundaries, and infrastructure. The services of the satellite along with a lot of application and industries like oil & gas Fields, marine communication and military have no infrastructure for communications. A great demand for this type of communication and its type of services. The problems of non-proliferation due to some reasons, such as the high price of communications equipment and large volume that is not compatible with many applications especially the antenna and the price of the frequency band.

The aim of this research is to overcome these problems so the design should be low cost and low profile antenna at the same time. Frequency band plays a greeting role based on three factors: satellite coverage, bandwidth, and antenna size. The selection of KU- Band based on the good coverage area compared to KA-Band, bandwidth availability and price compared to C-Band and finally medium antenna size.

The procedure of this design based on two elements antenna and replicates it in array form to achieve high gain and at the same time keep the low profile. This designed simulated with CST MWS 2017[1] using time domain solver tool also 32 element array implemented and S11 measured using



vector network analyzer. The dimensions optimized manually using a parameter sweep tool to get the required bandwidth and the highest gain at the same time.

2. Antenna Design

This section will present two elements and four elements array antenna designs also the final design of 32 element array antenna with fabrication results will be introduced.

2.1 Design two elements antenna

The design of two elements as shown in Figure 1 (a) built on FR4 substrate and based on rectangular patch with dimensions $42\text{mm} \times 27.67\text{mm}$. Table 1 shows all assay antenna dimensions. Two graded feed used to enhance the matching between the feeder and patch. The tapered corners used for the transformation between transmission lines. The achieved bandwidth is 1.556 GHz starting from 13.615 GHz to 15.171 GHz with S_{11} below -35 dB as shown in Figure 1 (b). This design optimized to achieve respectably high gain and high directivity as the gain is 6.39 dBi and directivity is 8.9 dB at 14GHz and Figure 2 shows the gain and directivity along the frequency range. The achieved bandwidth and gain are higher than the other proposed designs for 2 elements array as the highest gain was 5.9 dB with maximum bandwidth 662 MHz [2] [3]. The E-Field in Figure 3 (a) shows the radiation pattern is directive with main lobe magnitude 20.7 dBV/m and main lobe direction 3.0 degree. The H-Field in Figure 3 (b) shows the radiation pattern of the antenna with the main lobe magnitude -38 dBV/m and main lobe direction -2.0 degree.

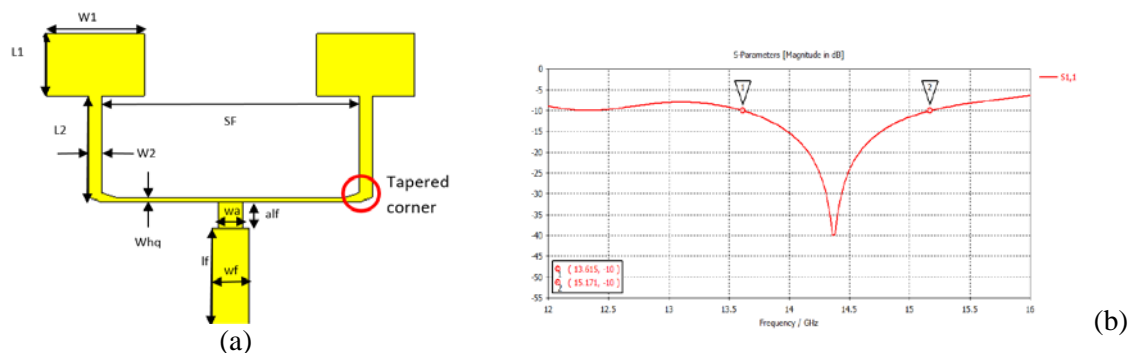


Figure 1. (a) Two elements array antenna (b) Two elements array antenna S_{11}
Table 1. Two elements array antenna parameters dimensions

Parameter name	Dimension (mm)	Parameter name	Dimension (mm)
Ws	42	Ls	27.67
W1	8	L1	5.3
W2	1.1	L2	10.37
whq	0.398	alf	1.4
wa	1.936	H	1.6
wf	2.95	T	.035
SF	21		

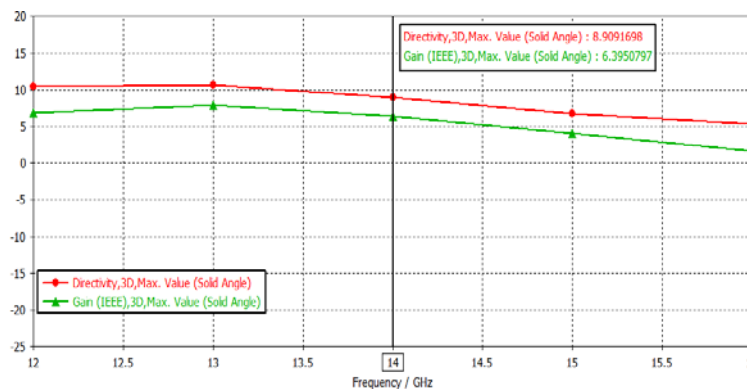


Figure 2. Two elements array antenna Gain and Directivity

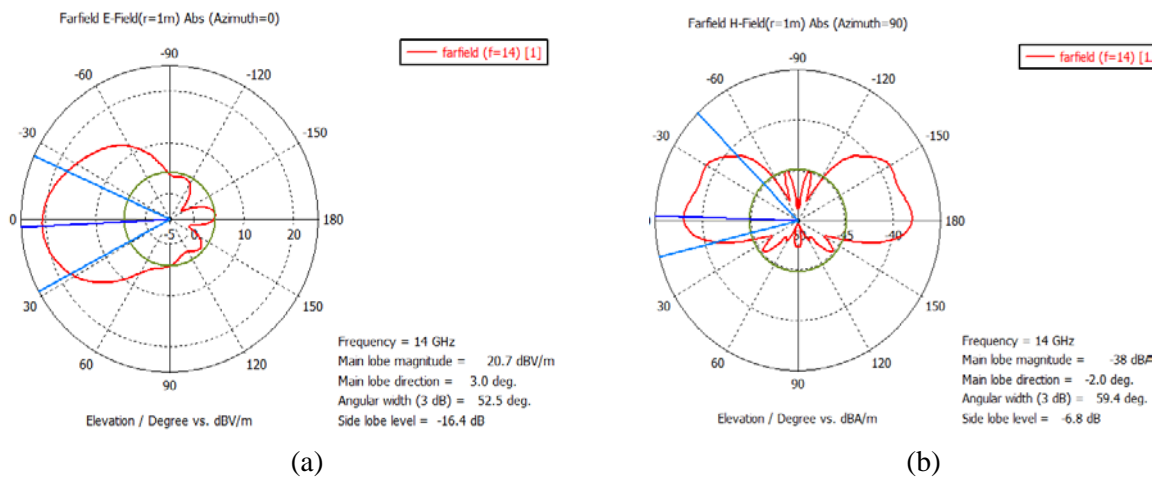


Figure 3. (a)Two element array antenna E-field (b) Two elements array antenna H-Field

2.2 Design four elements array antenna

This design overall dimension 85×26.81mm. The previous technique for a transformation from high to low impedance also used here as shown in Figure 4. The spacing between elements is equal. To achieve the same bandwidth with high gain, many parameters had to be optimized using manual parameter sweep tool as shown in Figure 5 the new bandwidth is 1.599 GHz stating from 13.276 GHz to 14.875 GHz and the gain is 11.11 dBi as shown at Figure 6 also the directivity is 13.94 dB at 14.0 GHz. According to the previous literature review in 2017 paper proposed with 10 dB gain and 300 MHz bandwidth [4] on the other hand in 2018 maximum achieved gain was 12.69 dB but with low bandwidth 550 MHz [5].

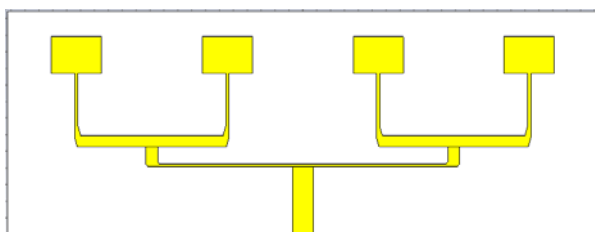


Figure 4. Four elements antenna

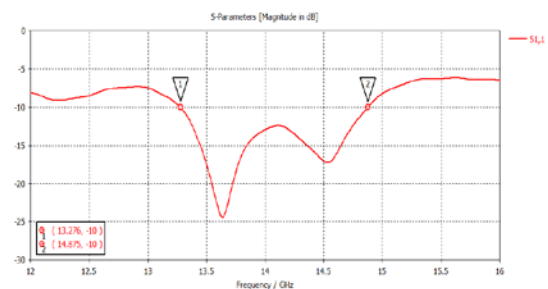


Figure 5. Four elements antenna S11

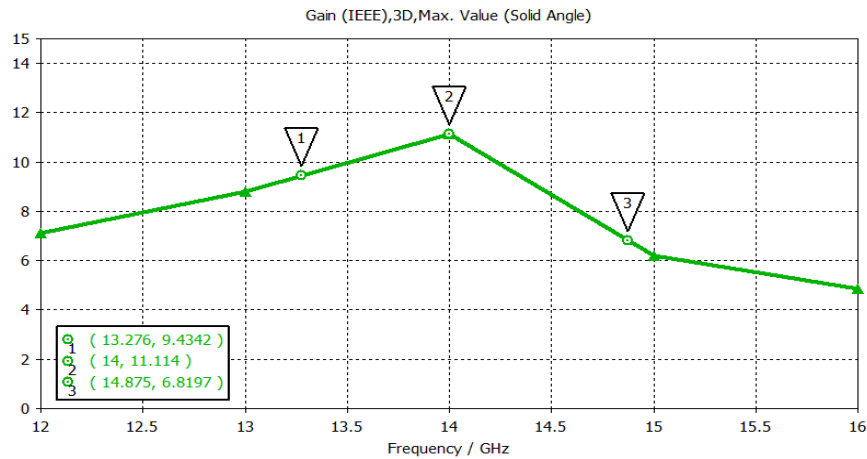


Figure 6. Four Elements Gain VS Frequency

2.3 The final design

The final design consists of 32 elements the vertical space between elements is equal. The dimension of the substrate is 85×98.81mm as shown in Figure 7 which is less than 9cm×10cm with 13.7dB gain and 16.56dB directivity at 14 GHz. The final bandwidth is 1.578 GHz starting from 13.371 GHz to 14.949 GHz as shown in Figure 8. The gain of antenna changes along the bandwidth as shown in Figure 9 starting from 12.25dB to 8.6dB at the end of bandwidth and recording the highest value at 14 GHz which is 13.7 dB. This is design also implemented as shown in Figure 10 and also comparison were made between the measured and simulated S11 as shown on figure 11. The measuring made using Rohde & Schwarz Vector network analyzer ZVB 20 as shown in Figure 12[6] for more accuracy calibration were made using the below calibration kit as shown in Figure 13. The E-Field in Figure 14(a) shows the radiation pattern is broadside with main lobe magnitude 28 dBV/M, main lobe direction -9.0 degree and side lobe level -4.8 dB. The H-Field in Figure 14(b) shows the radiation pattern is broadside with main lobe magnitude -32.8 dBV/ M, main lobe direction 90 degree and side lobe level -3.7 dB. The maximum current distribution of the array was 61.82 A/m as shown in Figure 15.

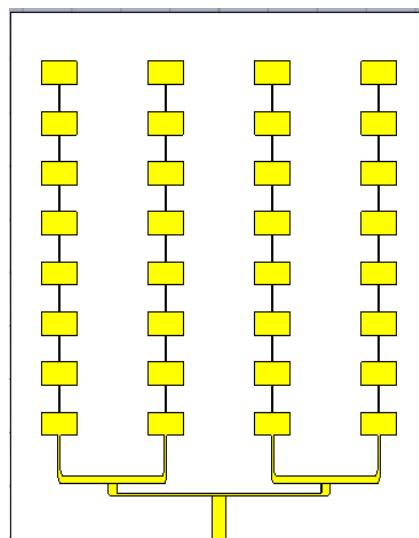


Figure 7. 32 Elements antenna

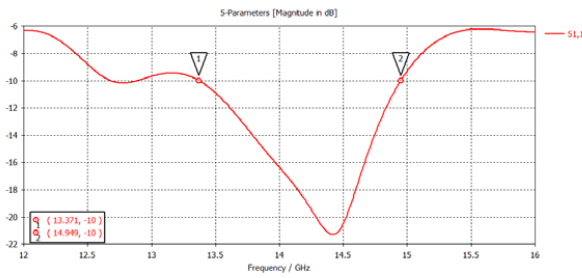


Figure 8. 32 Elements antenna S_{11}

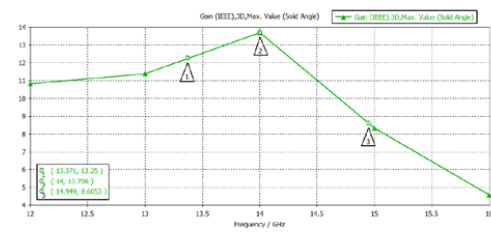
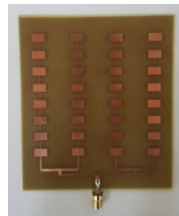


Figure 9. 32 Elements antenna Gain over frequency



(a)



(b)

Figure 10. 32 Element implemented array antenna

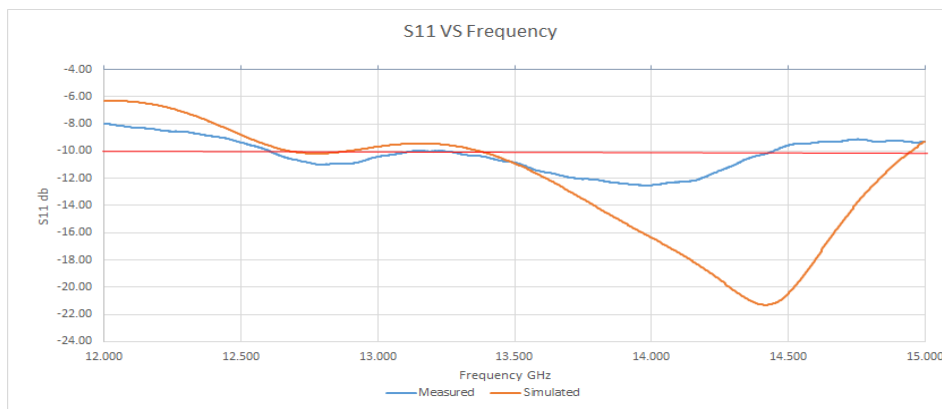


Figure 11. S_{11} for 32 array antenna simulated & measured



Figure 12. R&S@ZVB Vector Network Analyzer



Figure 13. R&S@ Calibration kit

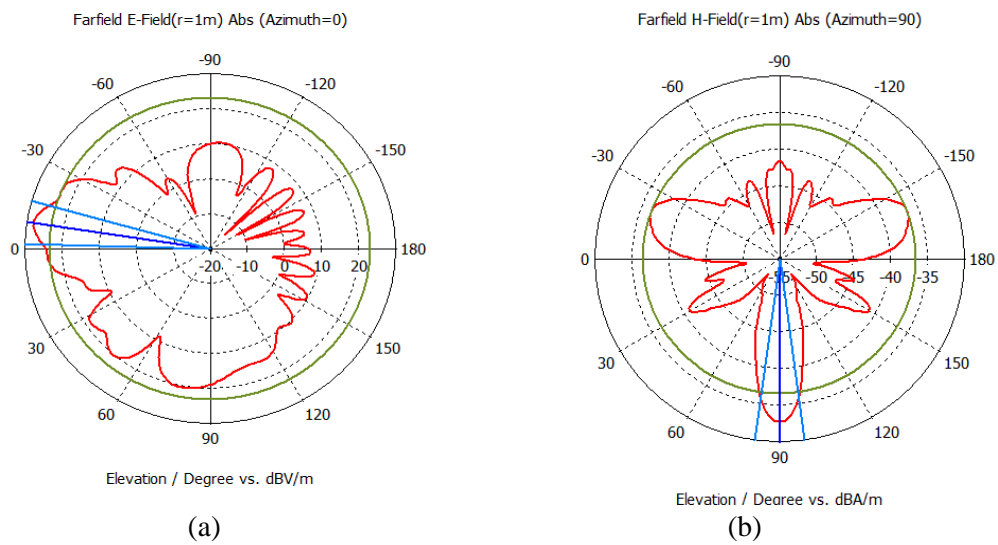


Figure 14. (a)32 elements antenna E-Field (b) 32 elements antenna H-Field

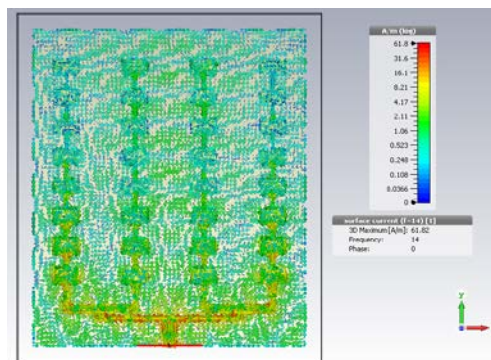


Figure 15. 32 elements antenna Current distribution

3. Results and comparison

This section shows the comparison between five arrays designs 2,4,8,16,32 elements. Every design optimized to achieve the highest gain over bandwidth. As shown at the table below the difference in gain between two elements arrays and four elements arrays is significant unlike the difference in gain between four elements arrays and eight elements arrays was not significant. The last two arrays result compression was good as the value of gain increased by 0.22dB.

Table 2. Results compressions

Design Specifications	Design				
	2 Elements	4 Elements	8 Elements	16 Elements	32 Elements
Dimension	42×27.67m	85×26.81m	85×39.01m	85×63.41m	85×98.81
	m	m	m	m	mm
Bandwidth	1.556 GHz	1.599 GHz	1.383 GHz	1.503 GHz	1.578 GHz
Bandwidth range	13.615 GHz - 15.171 GHz	13.276 GHz - 14.875 GHz	13.364 GHz - 14.747 GHz	13.275 GHz - 14.778 GHz	13.371 GHz - 14.949 GHz
Gain	6.39 dB	11.11 dB	11.16 dB	13.38 dB	13.7 dB
Directivity	8.9 dB	13.94 dB	14.01 dB	16.31 dB	16.5 dB

4. CONCLUSION

The proposed design for 32 Element array antennas with a low profile less than $9\text{cm} \times 10\text{cm}$ and low cost can achieve 13.6dB gain and 16.52 dB directivity. The design based on rectangle patch with series feed and tapered on transmutation lines to enhance the matching. The bandwidth starting from 13.263 GHz to 14.752 GHz designed to operate on the uplink range of KU- Band for the ground terminal. The reflection coefficient is lower than -18dB. The next milestone will be developing this design to achieve more gain and enhance the radiation pattern.

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