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Radiation Analysis of Satellite Tracking UHF/VHF Yagi Turnstile Array Antenna for APRS Digipeater Ground Station

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Abstract: Research and development have been rapidly advancing in the field of amateur radio in the Low earth orbit (LEO). Amateur radio has become some of the first users of personal communication services provided by LEO satellite systems. Study of design and development of low-cost store-and-forward communication satellites operating in low earth orbit has been a popular area to explore in the satellite communication. A small sized antenna which is compact and effective is preferred than the earlier satellites. For this, Automatic Packet Reporting System (APRS) digipeater was evolved. Accordingly, the design of the antenna also needs to align with the change in the evolution of satellites. This paper focuses on the analysis of the real time Ultra High Frequency (UHF) and Very High Frequency (VHF) antenna array with its parameters like gain, directivity and return loss.

Keywords: Yagi-Uda, Turnstile, Antenna, UHF, VHF, APRS

I. INTRODUCTION

Rapid advancement is taking place with the design and development of store-and-forward communication satellites in low earth orbit. The LEO microsatellites are used for data collection and messaging due to its simple and low-cost construction [1-4]. In recent times, Automatic Packet Reporting System (APRS) digipeater payload is becoming popular for amateur use in global community. APRS is an amateur radio system for real time digital communications for exchanging information among a large number of stations covering a large area. Data can be used for weather monitoring, Global Positioning System (GPS), tracking, text messages and announcements [1]. With the demand of smaller classes of satellite, low weighted satellites such as CubeSats are also carrying APRS-DP which supports more delay tolerant store and forward type of communication. CubeSats have simple designs and lower cost which enables requirement of tight design constraints in terms of power and communication link budget [1, 5]. Handheld radio is connected to the antennas in the ground station to communicate with the satellite. The antennas should be able to rotate in order to track the position of the satellite. The antenna should be able to operate in VHF and UHF range. Yagi-Uda and turnstile antenna is found to be appropriate for this particular application.

APRS Global Internet System (APRS-IS) can be used for global monitoring and end-to-end messaging between two APRS uses interconnected by the internet. APRS digipeater (APRS-DP) acts as a relay node which can be used to cover remote areas which are not easily accessible [6]. Digipeaters are the backbone of the APRS system and uses store and forward technology to retransmit packets. All stations use the same radio channel as packets travels from digipeater to digipeater. Digipeaters can track the packets forwarded which prevents from duplication of packets being retransmitted [1].

A Yagi-Uda antenna is a directional antenna with multiple parallel elements. It is basically constructed using 3 major elements. Driven element which is usually an active folded dipole antenna will be connected to the transmitter of receiver with a transmission line. The power supply is given through the feed line to the active element. The current will induce the voltage in the parasitic elements [7-9]. This causes the emission of radiation towards the directors. Parasitic elements like reflector and director are not connected through the transmission lines. The reflector element is 5% longer than the length of an active element. Active element is 5% longer than the length of the radiator. Directors are used to increase the directivity of the antenna and reflectors are used to reduce the loss and back radiated waves of the antenna radiation. Multiple directors are placed in the arrangement so that each director will provide excitation to the next one [7].

Crossed dipole antenna is also being included in the design of array. Turnstile antenna consist of two identical dipole antennas perpendicular to each other. The current applied to the two dipoles will be out of phase to each other to create circular polarization. The antenna can be used in two modes which are normal mode and axial mode. In normal mode, antenna radiates horizontally perpendicular to its axis. In axial mode, antenna radiates circularly polarized along its axis [10-11].

Satellite antenna concentrates the transmitting power into a designated geographical region on the earth. Since Yagi-Uda antenna being unidirectional antenna, it is mostly used in satellite communication to avoid interference from undesired

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signals transmitted from the outside of the service area. For improving the available margins for communications in satellites, it is important to improve upon the antenna system performance at the ground station used for the establishment of links with the satellite. This can be improved by enhancing the forward gain, front to back ratio, and the directivity of antenna [7].

II. DESIGN OF ANTENNA

Array of Yagi-Uda and turnstile is widely used for satellite ground terrestrial station in VHF and UHF bands. Antenna should have high gain, high directivity and circular polarization. Circular polarization is often preferred in satellite communication as it is not sensitive to the orientation of the satellite antenna in space. Therefore, array of turnstile antenna is opted to construct the crossed dipole configuration. One configuration will form the horizontal array and another will form the vertical array. In order to match the noise temperature of the antenna with the low noise amplifiers, the radiation pattern need to be well-shaped. The VHF range and UHF range chosen were 144-148MHz and 432-440MHz respectively. The feed is folded dipole antenna.

Table 1 Dimension equations of Yagi-Uda antenna

Director length	(0.4-0.45) λ
Feeder length	(0.47-0.49) λ
Reflector length	(0.5-0.525) λ
Reflector-feeder spacing	(0.2-0.25) λ
Director spacing	(0.3-0.4) λ
Radius of dipole	(0.005) λ

The UHF antenna array designed in this paper have 30 elements with 15 horizontal elements and 15 vertical elements. 13 directors, 1 active element and 1 reflector will make UHF horizontal elements and vertical elements respectively. The VHF antenna array have 22 elements with 11 horizontal and 11 vertical elements. Each horizontal and vertical array will have 9 directors, 1 active element and 1 reflector. Dimensions were calculated as per Table 1 where λ denotes wavelength of the signal. The dimensions of UHF antenna are given in Table 2 and dimensions of VHF antenna are given in Table 3.

Table 2 Dimensions of elements of UHF antenna (432-440 MHz)

Elements	**Element Spacing Length (m)**		**Element Length (m)**	
	Horizontal Element	**Vertical element**	**Horizontal Element**	**Vertical Element**
Reflector	0.05	0.22	0.33	0.33
Driven Element	0.20	0.37	0.32	0.32
Director 1	0.24	0.40	0.31	0.31
Director 2	0.38	0.54	0.30	0.30
Director 3	0.53	0.69	0.29	0.29
Director 4	0.68	0.84	0.29	0.29
Director 5	0.89	1.05	0.29	0.29
Director 6	1.09	1.25	0.28	0.28
Director 7	1.30	1.46	0.28	0.28
Director 8	1.54	1.70	0.28	0.28
Director 9	1.78	1.95	0.27	0.27
Director 10	2.02	2.18	0.27	0.27
Director 11	2.28	2.45	0.27	0.27
Director 12	2.55	2.72	0.27	0.27
Director 13	2.81	2.97	0.29	0.29

Table 3 Dimensions of elements of VHF antenna (144-148 MHz)

Elements	**Element Spacing Length (m)**		**Element Length (m)**	
	Horizontal Element	**Vertical lement**	**Horizontal Element**	**Vertical Element**
Reflector	0.00	0.51	1.02	1.02
Driven Element	0.45	0.94	1.00	1.00
Director 1	0.64	1.13	0.96	0.96
Director 2	0.96	1.45	0.94	0.94
Director 3	1.42	1.91	0.92	0.92

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Director 4	1.92	2.41	0.92	0.92
Director 5	2.52	3.01	0.91	0.91
Director 6	3.11	3.60	0.88	0.88
Director 7	3.75	4.24	0.88	0.88
Director 8	4.49	4.99	0.87	0.87
Director 9	5.14	5.64	0.89	0.89

III. SIMULATION AND RESULTS

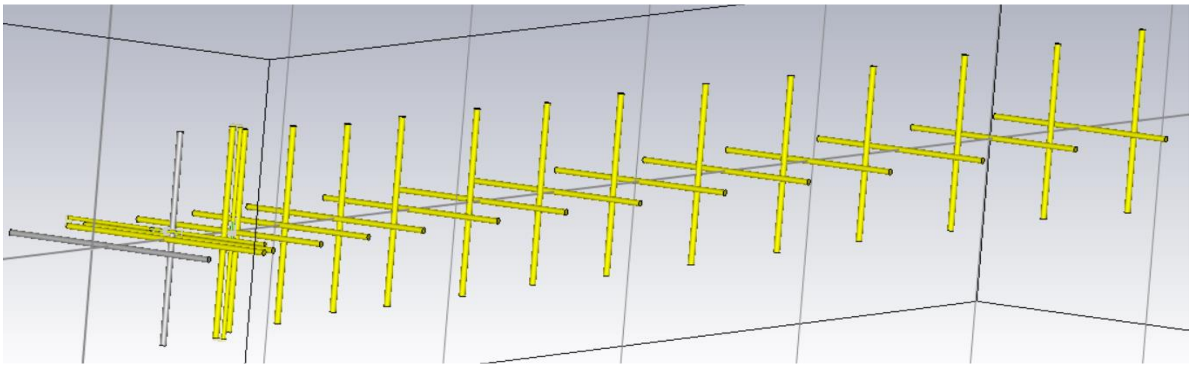

Fig. 1 UHF antenna structure simulation

Simulation was done for the VHF and UHF antenna in CST Studio Suite. The structure can be seen in the figure 1 and 2. The boom length of UHF antenna is 2.97m and that of VFH is 5.64m. There are 30 elements in UHF antenna and 22 elements in VHF antenna as explained in the earlier section. So, there are two feed ports for horizontal array and vertical array respectively.

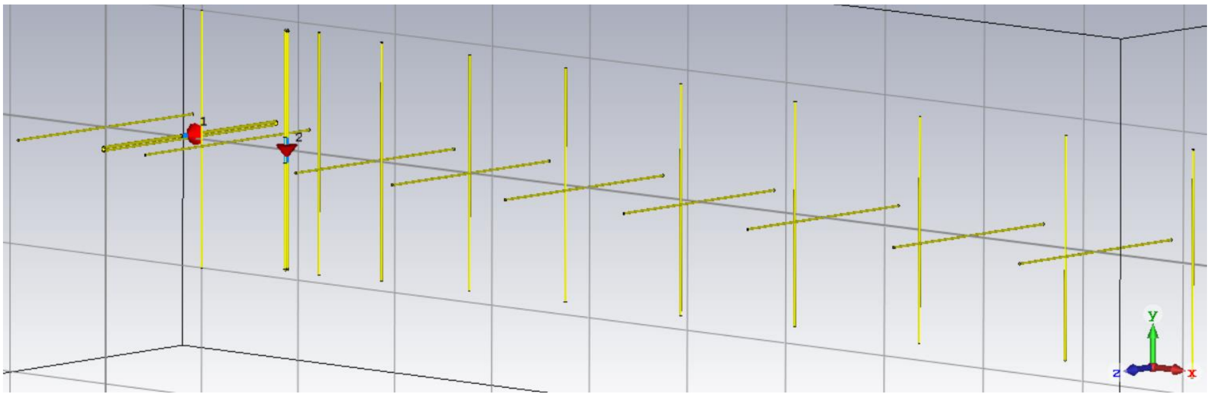

Fig. 2 VHF antenna structure simulation

Gain, directivity, return loss and radiation efficiency was analyzed from the simulation. The gain and directivity are higher for 144 MHz and 432 MHz antennas. The radiation plot is in figure 3 and 4. This can be true because the radiation efficiency is also higher or acceptable for these two antennas. The simulation results can be seen in the table 4 and 5.

Table 4 Simulation results of VHF antenna

Frequency	**144 MHz**		**146 MHz**		**148 MHz**	
	Horizontal port	**Vertical port**	**Horizontal port**	**Vertical port**	**Horizontal port**	**Vertical port**
Gain	13.3 dBi	13.9 dBi	11.7 dBi	13.2 dBi	4.83 dBi	8.98 dBi
Directivity	13.3 dBi	13.9dBi	12.1 dBi	13.3 dBi	6.08 dBi	9.81 dBi
HPBW	33.9 deg.	33.5 deg.	47.7 deg.	35.3 deg.	79.4 deg.	29.4 deg.
Return Loss	-0.74 dB	-0.34 dB	-0.043 dB	-1.82 dB	-0.02 dB	-9.2 dB
Radiation Efficiency	-0.008 dB	-0.06 dB	-0.411 dB	-0.113 dB	-1.25 dB	-0.84 dB

Table 5 Simulation results of UHF antenna

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Frequency	432 MHz		436 MHz		440 MHz	
	Horizontal port	Vertical port	Horizontal port	Vertical port	Horizontal port	Vertical port
Gain	13.8 dBi	13.8 dBi	13.7 dBi	13.7 dBi	10.8 dBi	11.3 dBi
Directivity	14.1 dBi	14.2 dBi	13.9 dBi	13.9 dBi	11.3 dBi	11.8 dBi
HPBW	24.1 deg.	25.3 deg.	26.6 deg.	28.3 deg.	32.3 deg.	34.5 deg.
Return Loss	-0.1 dB	-0.09 dB	-0.19 dB	-0.16 dB	-0.74 dB	-0.4 dB
Radiation Efficiency	-0.327 dB	-0.394 dB	-0.234 dB	-0.245 dB	-0.51 dB	-0.49 dB

The values are simulated without any optimization and impedance matching techniques in order to analyze the radiation of antenna. From the reading, it shows that much of impedance mismatching persist since return loss is high. Return loss was calculated from S11 and S22 graph shown in figure 7 and 8. S11 is used to plot the return loss of horizontal port 1 and S22 vertical port 2.

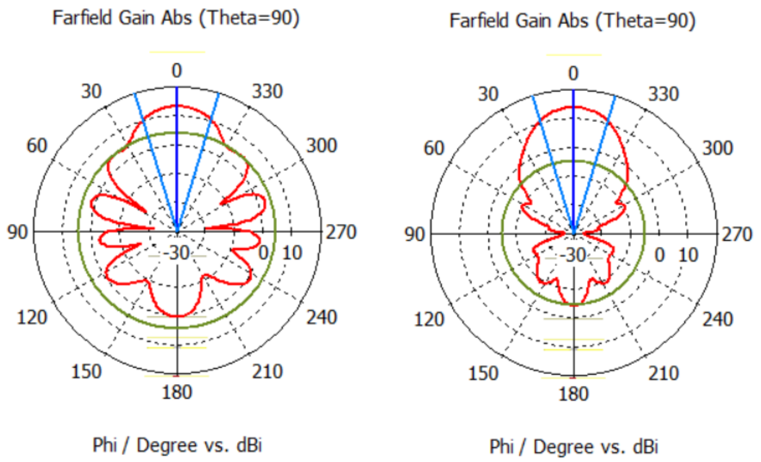

Fig. 3 Horizontal array and vertical array radiation plots of VHF antenna at 144 MHz

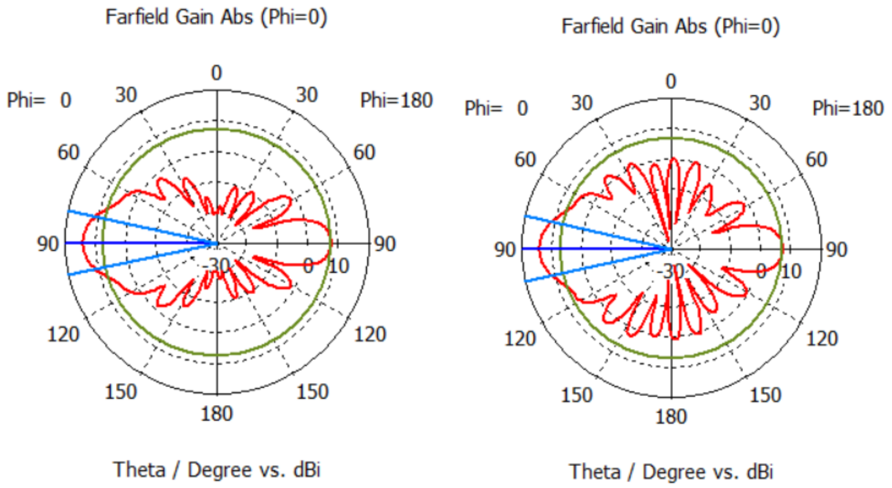

Fig. 4 Horizontal array and vertical array radiation plots of UHF antenna at 432 MHz

In the figure 5, radiation plot of VHF antenna has clearly more directivity at 146 MHz. Similarly, in the figure 6, radiation plot of UHF antenna has clearly more directivity at 436 MHz.

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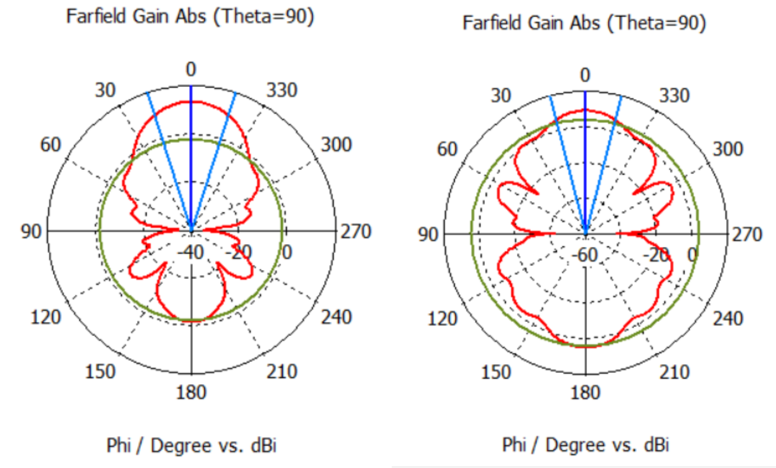

Fig. 5 Radiation plot of VHF antenna at 146 MHz and 148 MHz

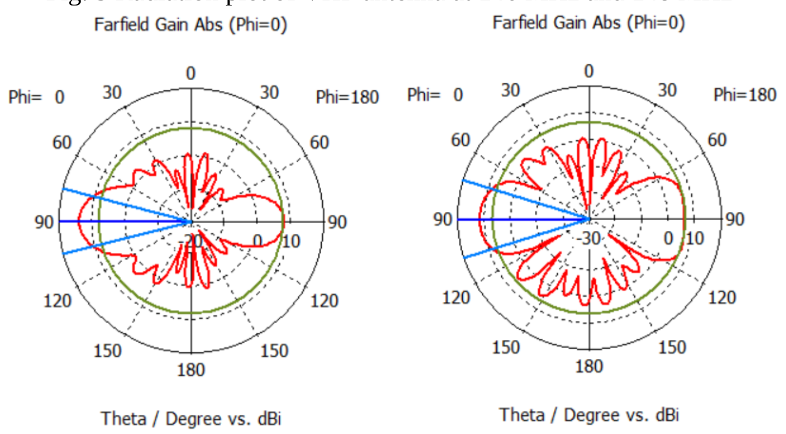

Fig. 6 Radiation plot of VHF antenna at 436 MHz and 440 MHz

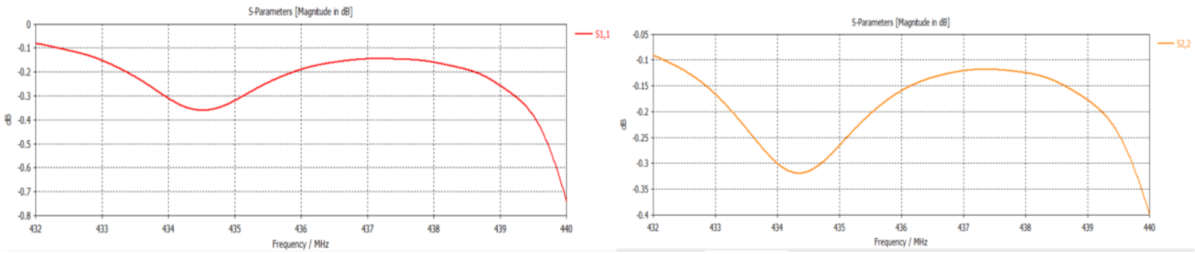

Fig. 7 S11 and S22 parameter plot indicating the return loss of UHF antenna

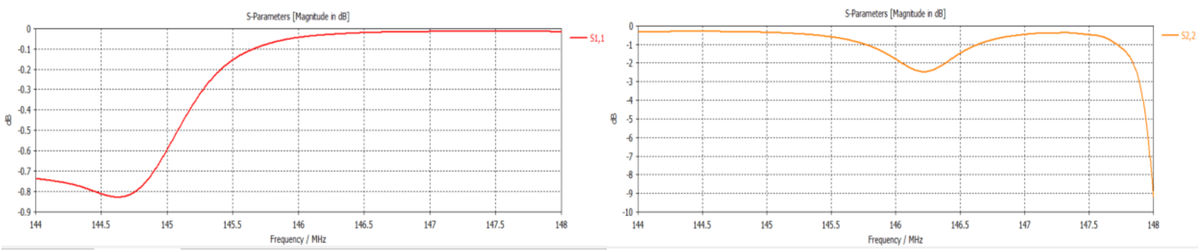

Fig. 8 S11 and S22 parameter plot indicating the return loss of VHF antenna

IV. CONCLUSION

The simulation was done for the practical sized Yagi Turnstile array antenna mainly to analyze the radiation of the antenna. With the help of the reading, further tuning of optimization and impedance matching can be done on this antenna in order to enhance the efficiency of the antenna. Crossed dipole construction was opted to obtain the circular polarization.

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This antenna is intended to communicate with APRS satellite. This antenna would be ideal for satellite communication and terrestrial uses like repeater operation and long-haul communication.

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