SIMULATION AND VERIFICATION TWO YAGI-UDI AND S-BAND SATELLITE DISH GROUND STATION ANTENNAS FOR LEO NANOSATELLITES COMMUNICATIONS

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ABSTRACT

Ground station antennas are a part of TTC system, generally, Yagi-Udi antennas and Parabola dish antenna are using in Earth segment to communicate with LEO small satellites, this paper uniquely presents the three huge antennas of a ground station which are communicating with some microsatellites with view window above Beijing, China. The ground station contains two Yagi-Udi antennas for VHF/UHF and an S-band dish antenna for reception of payloads data. For verification feasibility of the antennas, simulations have been accomplished according to the antennas requirements. Eventually, the simulations assisted to recognize the matched commercial ground station antennas based on comparison of the simulations with commercial antennas and the matched ones are chosen for the implementation on the ground station.

KEYWORDS

Amateur radio antenna, Telemetry and Tracking, Yagi-Udi antenna, parabolic dish antenna, ground station antennas

1. INTRODUCTION

Satellites telecommunication are required to utilize antennas at both reception and transmission section, farther, antennas have a key operation in the coupling link of satellite-ground segments based and this function is directly related to antennas gain [1] due to constraints of CubeSats such as power and mass, increasing power in satellite side is critical and in some circumstances impossible, hence TTC engineering prefer to improve power and antennas gain in ground sections. Selection antennas and equipment at satellite ground stations require specific calculation and simulations to prevent malfunctioning and increase expenses. The main goal of this paper is simulation SSS-1 (SSS-1 is 30 kg microsatellite project from APSCO organization which is defined to educate young students from this organization to improve their skills) ground station antennas to realize the matched commercial and physical model of antennas high-directive antennas. Hence TTC system requires establishment sufficient ground segment. The performance of the total system can be highly developed by utilization a high gain directional antenna [2]. Generally, satellite-ground telecommunications have been implemented in VHF/UHF bands where the required equipment (such as antenna pointing accuracy) is not as critical as for higher frequencies. In VHF/UHF bands, a cost-effective ground station could be assembled using commercial off-the-shelf amateur radio hardware and software. Compared to general existing amateur radio VHF/ UHF systems on CubeSats, S-band communication transmits data throughput improvements by a beneficiary of higher bandwidth and higher frequency [3]. In SSS-1 project, S-band is utilized for transmission data of payloads, because its project contains several payloads,

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hence the capacity of data which are monitored are very high, logically the transmission requires higher data rate meanwhile higher gain, this trade-off is only possible with a higher frequency band such as S-band.

2. GROUND STATION ANTENNAS DESIGN

SSS-1's ground station consists of two Yagi-Udi antennas for VHF/UHF frequency band and parabolic dish antenna for S-band frequency band. For VHF, the antenna is 2MPC22 namely with 22 elements,144-148MHz, Gain 14.4dBi, circular polarization and for UHF antenna is 436CP42UG namely, with 42 elements, 430-438MHz, Gain 18.9dBi, beam width 21°, circular polarization and for S-band parabolic dish antenna with 4.2m radius, 2.1-2.4GHz, Gain 37.5, beam with 2.2°,circular polarization. These gigantic antennas are purposed for creating vital links between a nanosatellite and the ground station. CST software has been utilized to verify the ground station antennas polarization specifications and operation.

2.1. PARABOLIC DISH ANTENNA DESIGN AND SIMULATION

Reflector antennas have been widely used in radio astronomy, microwave communication, tracking, and telemetry because of their perfect electrical specifications such as high gain, low side lobe level and low cross polarization [4]. the specific properties of a parabola to utilize it as the main feeder dish antennas are considered by two rays particular conditions: 1st, any ray from the focus is mirrored in a direction that will be parallel to the axis of the parabola; and 2nd, the spacing moved by any ray from the focus point to the dish reflector and by reflection to a plane perpendicular to the parabola axis is independent of its path, and therefore such a plane represents a wavefront of uniform phase [5]. A dish antenna operates in the same procedure of an optical telescope. The focus point is an imaginary point which either signals of magnetic waves from different direction arrive on a crescent surface and are reflected a common point, called the focus. When a ray of light reflected from a mirror or flat surface, the angle of the path living (angle of reflection) is the same as the angle of the path, if the mirror is carved, two parallel rays reflect at different angles. If the carve is parabolic 〖y=ax〗^2 then all the reflected rays arrive at the focus. Horn antennas are utilized by themselves in many microwave applications. By utilizing a horn in connection with a parabolic reflector, high gain and directivity can easily be obtained. The energy generated by the horn is sharped at the dish reflector, which centralizes the radiated energy into a narrow beam and sends it toward free space. Because of the unique parabolic shape, the electromagnetic waves are narrowed into an extremely small beam. Beam widths of only a few degrees are typical with parabolic reflectors. Of course, such narrow beam widths also represent extremely high gains [6]. For improvement the Dish antenna's quality factor, another circular reflector which is named the second reflector has been occupied on bottom of the main feeder, this reflector will transmit the rests of electromagnetic fields.

The second reflector is essential due to reflected signals to the feeder. The second reflector causes the total gain of the parabolic antenna to be increased because with the reflection of the reflected signals to the parabola, impacts on the total gain of the antenna. The total gain would be 15 dB without a second reflector and with reflector, the total gain would be 37.8 dB.

Figure 1. BUAA's S-band antenna characterization

For this type of reflector, all reflected rays are parallel to the axis of the paraboloid which illustrates uniquely a single reflected ray parallel to the main axis of the dish without side lobes. The horn antenna releases the magnetic field with a spherical wave front. Reflector causes the signal shifted 180 degrees in phases but the beneficiary is that it makes rays travel in a parallel path, hence logically the required signal must release 180° shifted from the feeder [7].

Table 1. Dish antenna specification

Character	Value
F (frequency)	2.1 GHz
ʎ (Wave length)	143 mm
D (Dish or first reflector dimension)	4200 mm
Dish Thickness	1.8 mm
A (Y=A*t^2, carve factor)	0.00008
Df	700 mm

2.2. CONICAL HORN FEEDER

Conical horn antenna is a shorten part of a right circular conical waveguide and it is generally connected to a circular and rectangular waveguide is slowly transformed to a circular waveguide. It is a basic and popular microwave antenna for many microwave application, and also this sort of antennas is popular for dish parabolic antenna which utilizes conical horn as their main feeder [7]. Horn antennas have a good directional characteristic, which depends on the design. A horn prepares higher directivity if the aperture is big and the angle becomes narrow the gain of a feed horn is proportionate to its length times the aperture [9]. The gain of the conical horn antenna without the main reflector is 18dB and with dish and second reflector is 36.8 dB. Characterizations of S-band antenna includes.

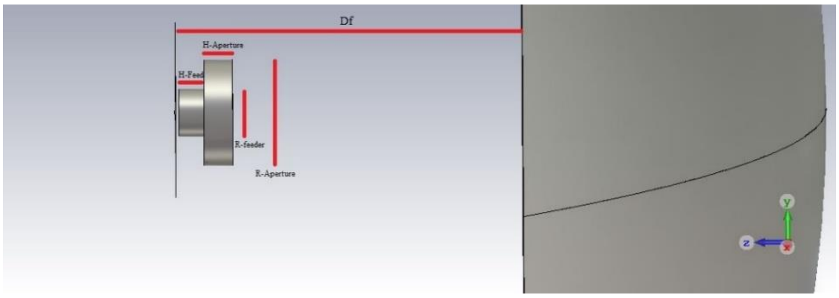

Figure 2. Conical horn feeder specification

The feeder is conical parabola which has a very essential effect on dish antenna gain, the specification at the size and the dimension could change the total gain of dish antenna or even make strong side lobe gain. To achieve proper gain for parabola antennas, it requires to coordinate focus point with wavelength to assure proper radiation of rearward signal from the feeder. Horn antenna operates to produce a uniform phase with a larger aperture than the wavelength, hence more directivity is achieved, and the losses of horn antennas are very negligible hence it's assumed that for horn antennas the gain is equal to the directivity. The waveguide must be larger than the wavelength and it must be flanged at one end.

The feeder for this project is contained special kind of conical horn antenna which it has made from two spherical bodies, spherical of the feeder and spherical of aperture. Waveguide aperture is designed based on WR-430 standard, this standard is giving $R_{Aperture} = 71.5\,mm$, R_{Feeder} =35.75 mm and heights of the spherical are estimated with $H_{Feeder} = 28.5\,mm$, $H_{Aperture}$=335.35 mm. Horn designed in this shape could reduce the power radiated outside of the interesting region that it can improve total gain of the conical parabola.

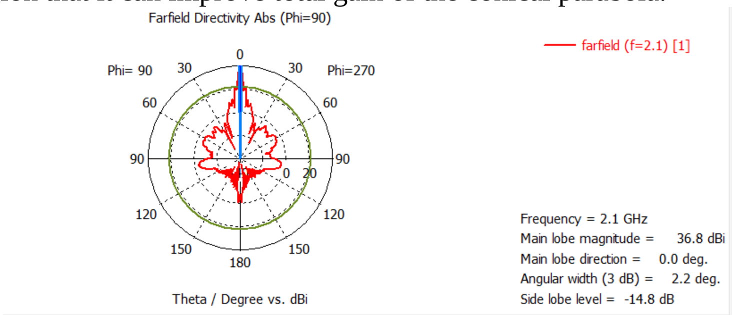

Figure 3. S-band dish antenna simulation result

Table 1 is provided for compression and verification of the simulated antenna with the commercial antenna. As it is visible there is a sufficient match between the commercial antenna and the simulated antenna. This ground station is implemented at international school of BUAA university, China, to communicate with Student Small Satellite project command data and also receiving data of its payloads.

Table 2. Comparison between the simulated antenna and the commercial model

Character	**The physical model**	**The simulated antenna**
Gain	**37.6**	**36.8**
Beam width	**2.2**	**2.2**
Side lobs gain	**-14**	**-14.8**

3. VHF/UHF Yagi-Udi Antennas

Antennas array pursues rules, they contain several elements but the concepts is generally dipole antenna. VHF/UHF array antenna usually utilize Yagi-Udi antennas and those kind of antennas operate at various applications such as atmospheric radar, amateur radio ground station antenna. Yagi-Udi antenna basically follows wavelength rules, nearly ʎ/2 elements which are ordered to be the center of a boom, in circular polarization Yagi antennas, another group of elements with 90◦ different phase and 90◦ in physical with a little distance would be occupied [11], by this layout the a dipole antenna is transferred to high-gain and directive antenna, which made it specialized for LEO small satellite ground stations.

Yagi-Udi antennas are usually utilized at HF/VHF/UHF frequency bands, generally elements are active element, director and reflector. Active elements length range is [0.45ʎ-0.49ʎ], reflector mostly 5% more than active element, reflectors are located behind of actives elements with 0.25ʎ distance. Directors have effective efficiency at directivity and antenna gain, a detector ranges is [0.4ʎ-0.45ʎ]. Increase in numbers of detectors increase the total gain and every detector is located in front of an active element, every detector has been spaced at [0.35ʎ-0.4ʎ] with pervious detector [12]. Boom is the important part of antenna support assembly but it is also an unintended radiating part of antenna.

3.1. VHF ANTENNA

The VHF antenna is totally occupied by 22 elements with reflector/Driven/director elements altogether, the antenna is Circular Polarization at frequency range [140-148] MHz, and the total gain would be 13 dB, VSWR 1.4:1, front-to-rear ratio 25dB.VHF Yagi cross-polarized antenna is selected as an uplink for a nanosatellite with 500 Km altitude, based on the link budget antenna gain can provide an adequate safety margin for communication by a nanosatellite with 500 Km altitude. According to table 3, the distance between elements is increased with the number of each element, the reason for this layout is accomplished by estimation, for example, if the distances don't change by the number of the element, the antenna couldn't give adequate gain and polarization, in some cases the antenna displays circular polarization average gain 2~3 dB meanwhile the pattern must be directive polarization. 1 mm is considered for the diameter of elements and simulations are based on this.

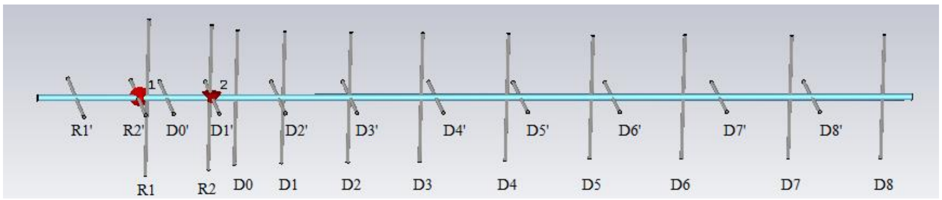

Figure 4. VHF antenna characteristics

The simulation of the VHF antenna is accomplished according to specification in table 3. R1 and R2 are the two active elements, the signal enters with 90° phase difference into them and active elements are perpendicular in each other, hence this layout creates circular polarization for VHF Yagi-Udi antenna. R1' and R2' are Yagi reflectors which they are bigger than the active elements in size, they influence to direct the circular polarization of active elements to directive polarization and the directors increase the total gain and form the pattern into narrow beam width.

Table 3. VHF antenna elements location

Element	Length mm	Element LOCATION X	Element LOCATION X'
R1,R1'	40	20	0.50
R2,R2'	39.5	37.1875	17.562
D0,D0'	37.625	44.313	25.313
D1,D1'	36.937	57.25	37.812
D2,D2'	36.375	75.375	55.875
D3,D3'	36.062	95.062	75.562
D4,D4'	35.688	118.625	99.125
D5,D5'	34.5	141.813	122.313
D6,D6'	34.75	167.062	147.562
D7,D7'	34.473	196.437	176.937
D8,D8'	34.875	221.937	202.437

The simulation of VHF antenna shows up that the antenna has 13dB gain, 34.4° Angular width, and those characteristics could verify the requirements for LEO small satellites based on former flight models and that could provide effective communication window.

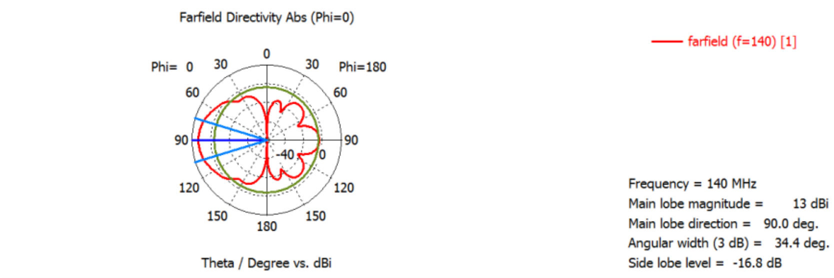

Figure 5. VHF Yagi-Udi antenna 2D patterns

The simulated antenna could be compared with a commercial Yagi-Udi antenna model 2MCP22, this model is implemented for functioning with amateur small satellites, and the simulations have been approached to 2MCP22 and confirm the feasibility of the selected antenna for the ground station.

Table 4. Comparison between the simulated antenna and the commercial model

Character	VHF document	CST software
Gain	14.39 dBic	13 dBic
Beamwidth	38	34.4

3.2. UHF ANTENNA

UHF Yagi-Udi high gain antenna is occupied with 42 elements, 18 dB gain, circular polarization, 430-438 MHz frequency operation and with front-to-rear ratio 25dB. Those requirements could be utilized for transmission commands from earth to nanosatellite with 500 Km altitude, this antenna could be implemented beside the VHF Yagi antenna and S-band parabola antenna, and this integration would have general requirements for a small satellite ground station.

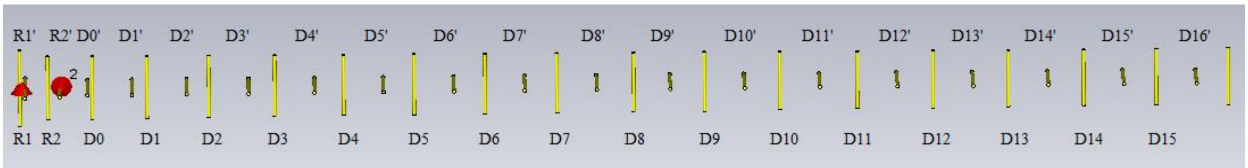

Figure 6. UHF antenna characteristics

R2 and R2’ are active elements with 90° phase difference, active elements are perpendicular with each other, in this way a circularly polarized UHF antenna is created. R1 and R1’ are the reflectors which influence in the Yagi antenna gain and polarization and this antenna consists of 42 directors for improvements the total gain.

Table 5. UHF antenna elements position

Element	**Length mm**	**Element LOCATION X mm**	**Element LOCATION X’ mm**
R1,R1’	**13.25**	**0.500**	**7.125**
R2,R2’	**12**	**6.250**	**12.875**
D0,D0’	**12.5**	**10.875**	**17.500**
D1,D1’	**11.937**	**18.312**	**24.938**
D2,D2’	**11.688**	**27.438**	**34.062**
D3,D3’	**11.625**	**48.750**	**44.375**
D4,D4’	**11.437**	**60.250**	**55.375**
D5,D5’	**11.375**	**72.000**	**66.875**
D6,D6’	**11.375**	**83.813**	**78.625**
D7,D7’	**11.313**	**95.813**	**90.437**
D8,D8’	**11.188**	**108.062**	**102.437**
D9,D9’	**11.125**	**120.437**	**114.688**
D10,D10’	**10.937**	**133.000**	**127.063**
D11,D11’	**10.813**	**145.938**	**139.625**
D12,D12’	**10.750**	**158.563**	**152.583**
D13,D13’	**10.750**	**171.125**	**165.187**
D14,D14’	**10.625**	**183.688**	**177.750**
D15,D15’	**10.562**	**190.313**	**190.313**
D16,D16’	**10.688**	**202.437**	**202.437**
D17,D17’	**10.813**	**214.437**	**214.437**
D18,D18’	**11.125**	**225.5**	**225.5**

UHF antenna simulations show that the antenna has 18.3 dB gain,20.3° angular width at center frequency 135 MHZ. These characteristics can pass the requirements for UHF ground segment antennas, adequate for investigation the existed commercial Yagi-Udi antennas to detect the best products for this project.

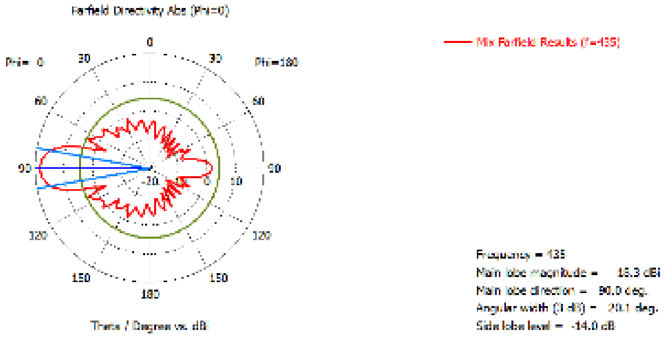

Figure 7. UHF Yagi-Udi antenna patterns

According to characteristics, the model with commercial ID 436CP42UG could be matched. In fact, the simulation could confirm the feasibility of the physical model and gives this confidence that the UHF antenna operates in the required specifications.

Table 6. Comparison between the simulated antenna and the commercial antenna model

Character	**UHF document**	**CST software**
Gain	**18.9**	**18.3**
Beam width	**21 degree**	**20.1 degree**

4. CONCLUSION

Nanosatellite subsystems would be either selected or implemented, the implementation is related to the access technology levels, which in this investigation, the GS antennas have been selected based on the simulations and the requirements. Based on the simulation the nearest equipment would be chosen and used.

Parabolic dish antenna has consisted of 3 main sections, feeder, dish reflector, second reflector. Dish antenna has a reflected signal which reflects from the reflector to the feeder, those reflected signals should be reflected by a second reflector to improve a dish antenna operations.

Dish antennas have a narrow beam, low losses, high-speed data transformation, and very high gain, hence dish antennas mostly utilize as payloads frequency.

The total gain of Yagi antennas would be increased by the number of directors.

For implementation a Circular Polarized Yagi antennas, two Perpendicular layouts must be arranged, and the active element of each layout must feed with the suitable frequency and amplitude but with 90° phase difference.

Either Left Circular polarization or Right Circular polarization would be created within the selection of which active element either vertical or horizontal would have 0°phase and another 90° phase difference. Yagi antennas generally utilize for tracking and telemetry.

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