# Considerations on ground station antennas used for communication with LEO satellites

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*Abstract*—**As the number of satellites orbiting around the Earth is significantly increasing, it is important to extend the ground station network, in order to be able to receive as much of the satellite transmitted data. In this context, this paper addresses the aspects related to the implementation of a ground station for LEO satellites, located in Suceava city, focusing on the analysis of the reference antenna's parameters using probe signals from satellites that are not stabilized in attitude. The ground station currently uses a 145 and a 436 MHz omnidirectional antenna, with two more antennas and a remote control station under development.**

## I. INTRODUCTION

In recent years, the number of satellites orbiting around the Earth is significantly increasing [1]. Furthermore, their field of application is becoming more and more diversified, including fundamental research, testing of new materials and technologies, communications, Earth observation, weather research, education, and so on [2]-[4]. As most of the existing satellites are low earth orbiting (LEO), in order to maximize the amount of received data, there is the need to build as many Earth stations, with close cooperation among themselves [5], [6]. Furthermore, it is also essential to develop ground station networks [7], which in turn can also provide a strong educational component [8]. Within this context, communicating with the satellites or just receiving data from them involves the availability of an increasingly number of ground stations, evenly distributed on the Earth's surface, and capable of communicating using various frequencies and diverse working techniques. A Ground Station is a radio station used for tracking, reception and/or control of communication or research satellites. By extension, the term is used when tracking or controlling other flying objects, as remote controlled planes, quadcopter, or other flying objects.

Both space missions and ground stations have a variety of purposes and configurations. Regardless of the size or purpose of a ground station, its connection to the satellites is only possible by using an antenna. Thus, the antennas are one of the most important elements of the ground station. Depending on the use case scenario, and thus on the required budget, gain power, radiation pattern or on mechanical aspects, almost any existing antenna can be used for space communications, with better or worse results. Thus, selecting the optimum antennas for the ground station involves a tradeoff between the antennas electrical parameters on one hand, and the mechanical characteristics and price on the other hand. Furthermore, the climate characteristics (i.e. rain, wind, salinity) also influence the antenna selection. Table I contains a summary of the antennas used for aerospace communications in ground stations, presenting their main characteristics.

Within this context, this paper presents the aspects regarding the development of a ground station in Suceava city, focusing on the aspects related to the antennas. The mission type has a great influence on the ground station parameters and determines the required equipment. As it is not feasible to build a ground station suitable for all scenarios, the one we are presenting is intended to communicate only with university satellites, which generally use the frequency bands assigned for radio amateurs: 145, 436, 1290, 2400, 10500 MHz and have a low orbit [9]. In this case, the ground station has a mid-level complexity and is able to communicate using the 145 and 436 MHz bands, whereas two more antennas are envisioned, for 2400 and 10500 MHz. The reception of LEO satellites involves the usage of receivers able to automatically perform frequency corrections, because we are dealing with a strong Doppler effect. Concerning the sensitivity, this parameter depends on the satellite. For example, the reception of Cubesat satellites assumes a high sensitivity, whereas for the reception of the International Space Station (ISS) the sensitivity is not crucial parameter.

Due to technological advances in the area of satellite receivers, we considered the usage of omnidirectional antennas. Although their gain is considerably lower (see Table I), the main advantage of these antennas is that they do not require a mechanical system for orientation in space, significantly simplifying the design and thus reducing the implementation and the maintenance costs. Nevertheless, this approach limits its application only to the communication with LEO satellites. Furthermore, it involves an increased sensitivity to adjacent noise sources affecting the SNR level.

This paper analyses the opportunity of using the ground plane antenna in a ground station for LEO satellites applications

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TABLE I. ANTENNAS USED IN AEROSPACE COMMUNICATIONS

| Type | Polarization | Gain | Diagram | Observations |
|---|---|---|---|---|
| ***Parabolic*** | Linear / circular | High (up to 30dB) | Directive | Above 1GHz |
| ***Yagi-Uda*** | Linear | Medium to high (3-30dB) | Directive | Circular polarization can be obtained by connecting 2 antennas |
| ***Log periodic*** | Linear | Medium (6-10 dB) | Directive | Broadband |
| ***Helical*** | Circular | Medium to high (11-19 dB) | Directive | Fixed polarization |
| ***Horn*** | Linear | High (6-10 dB) | Directive | Often used as the "Illuminator" in parabolic antennas; broadband |
| ***Patch*** | Linear / circular | Medium to high | Directive | Suitable at high frequencies (generally above 1GHz); ceramic materials |
| ***Turnstile*** | Linear / circular | Low | Omnidirectional | Vertical lobes with circular polarization, and linear polarization towards horizon |
| ***Eggbeater*** | Circular | Low | Omnidirectional | Flat lobes |
| ***Lindenblad*** | Circular | | Omnidirectional | Horizontal lobes |
| ***¾λ with parasitic circular polarizer*** | Circular | | Omnidirectional | Horizontal lobes, simple design |
| ***Discone*** | Linear vertical | Low (~3dB) | Omnidirectional | Broadband (10:1) |

in the 145 MHz band, providing both simulation and experimental results. In the early days, beam pattern antenna measurements were made using source drift scans of known celestial radio sources and anechoic chambers. In 1963, Brueckmann made the first satellite based measurements of antenna beam patterns [10]. Satellite based antenna beam pattern measurements have many clear advantages over astronomical sources. Satellites are preferable mostly because they generate a strong signal and thus they cover the signals coming from other sources [11]. Moreover, they provide a high number of passages enabling an increased number of measurements. Nevertheless, varying antenna pointing or varying plane of polarization (due to Faraday Rotation or simple projection effects) can affect the received signal level. This problem can be addressed with the help of a well-understood reference antenna and power ratio measurements [11]-[14]. The LEO ORCOMM and NOAA satellites that operate in the 137 MHz band were successfully used as well as the MEO GNSS satellite constellation (for higher frequencies). If in the above mentioned examples, the satellites have controlled attitude, in this paper, we perform the reference antenna evaluation using probe signals from satellites that are not stabilized in attitude.

## II. ANALYSES OF THE 145 MHZ GROUND PLANE ANTENNA'S PARAMETERS: SIMULATION RESULTS, EXPERIMENTAL DETERMINATIONS AND DISCUSSIONS

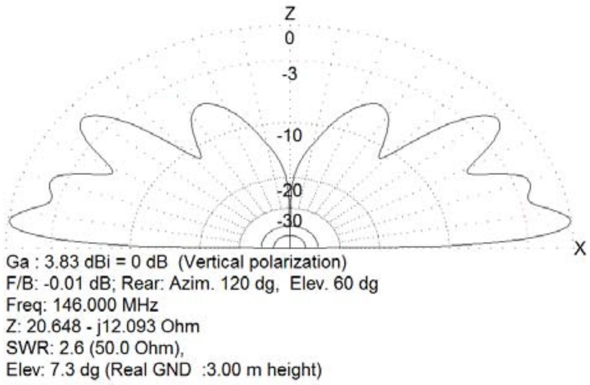
As already mentioned, the ground station this paper presents is able to communicate on the 145 and 436 MHz bands. For this purpose, it uses a ground plane antenna (Fig. 1) and a ¾λ parasitic circular polarised vertical antenna prototototype (Fig. 2). As the parameters of the second antenna were previously presented in [15], this paper will be focused on the 145 MHz Ground Plane antenna.

The Ground Plane antenna is based on an industrial production antenna which was adjusted for the 144-146 MHz frequency band with the help of several extensions made to the central radiator and to the four counterweights It is a vertical polarization antenna, horizontally omnidirectional having the vertical radiation pattern normalized for a maximum gain of

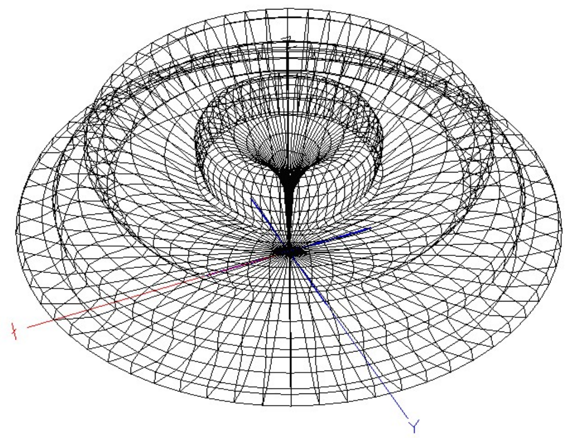
Figure 1. Ground Plane Antenna.

Figure 2. 436 MHz ¾λ parasitic circular polarised vertical antenna prototototype.

3.83 dBi, as illustrated in Fig. 3a. The simulation results provided by the MMANA-GAL software [16] (Fig. 3 a and b) show that the antenna has a vertical polarization, whereas the radiation pattern in the horizontal plane is reduced to one point (in practice it is below -20 dBi gain). Although it is not a very efficient antenna, it will be used in ground station as a reference




a.



b.

Figure 3. Simulation showing the Ground Plane Antenna's radiation diagram: a. vertical plane and b. 3D far field plot.

antenna for the 144-146 MHz band, in order to analyze the behavior of the other antennas of the ground station.

Next, by using the generalized Pythagorean Theorem, we can determine the distance between a satellite and a ground station located within its view. Fig. 4 illustrates the distance between the ground station and the ISS, according to eq. 1.

$$D = R\cos(a+90) + \sqrt{R^2\cos^2(a+90) - (R^2 - (R+h)^2)} \qquad (1)$$

where $D$ is the distance between the satellite and the ground station, $R$ is the Earth's radius (about 6400 km), $a$ is the elevation angle, and $h$ is the height at which the satellite is in orbit (400 km in this case).

According to the law of energy conservation, assuming an isotropic radiator emitter and a unit gain antenna receiver, the signal attenuation between the two points is given by eq. 2.

$$A[dB] = 10\lg\left(\frac{P_T}{P_R}\right) = 10\lg\left(\frac{4\pi d}{\lambda}\right)^2 = 92.445 + 20\lg d + 20\lg f \qquad (2)$$

where $A$ is the attenuation propagation, $P_R$ is the received power, $P_T$ is the emitted power, $\lambda$ is the wavelength (m), $d$ is the emitter – receiver distance (km) and $f$ is the frequency (GHz).

Next, by combining the vertical directivity diagram of Ground Plane antenna (Fig. 3a) with the distance variation as a function of the elevation angle (Fig. 4) and taking into account eq. 2, we obtain the attenuation between the ISS and the ground station, illustrated in Fig. 5.

Based on this data one can conclude that the antenna can be used for elevations between 5° and 80° and that the antenna has a signal drop for elevations around 55°. Nevertheless, this should not be considered a serious issue, as the number of crossings at an elevation angle above 50° is quite low, whereas the radio horizon is in many places above 2°. As this antenna is intended mostly for test purposes and as a reference for other antennas, it can be considered that the received signal is not dependent on the satellite's position for most of the passages.

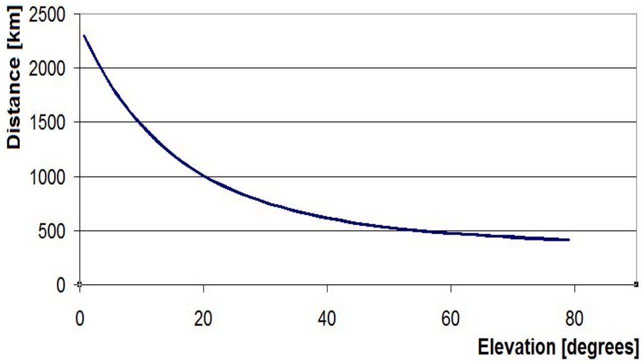



Figure 4. Satellite to ground station distance as a function of the elevation angle.

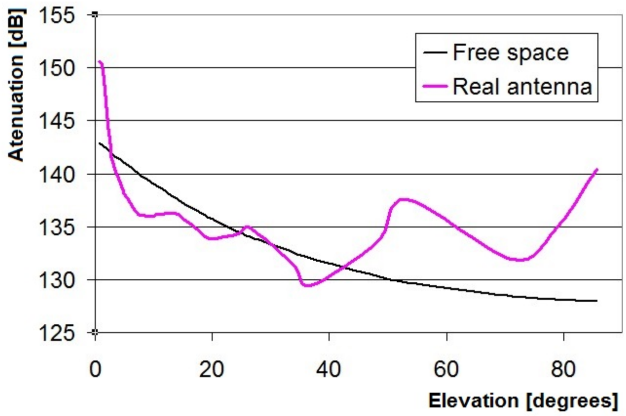



Figure 5. ISS to ground station attenuation for the Ground Plane antenna and in free space.

We should mention here that a X-quad industrial directive antenna was also tested. This antenna has a 10.5 dB gain, with circular polarization and a directivity angle of 47° horizontally and vertically. The results were superior compared to the ones of the omnidirectional antennas: stronger signal (higher gain) and a barely perceptible fading (with circular polarization, linear polarization to the transmitting antenna on the ISS). Nevertheless, in its case, a more complex setup is required, with a mechanical rotor controlling the orientation and the elevation of the antenna. Within this context, in case of budget limitations, the Ground Plane antenna remains suitable.

Next, the ground plane antenna was used in the reception of a real satellite (i.e. Nayif-1) and the experimental results showing the parameters of the received signal were compared with the simulation results. The Nayif-1 satellite has an altitude of 505 km, whereas the elevation angle for this passage was of 86.9º. Thus, Fig. 6 illustrates the λ/4 ground plane antenna's relative gain as a function of the satellite's elevation. The measured values were obtained considering the attenuation between the satellite and the ground station, by using eq. 1 and 2. The graph was obtained by redrawing the diagram in polar coordinates, similar to Fig. 3a, whereas its representation is provided using rectangular coordinates (translated by + 15dB to ensure a better readability of the figure). The experimental measurements are in accordance to the theoretical values, whereas existing differences are caused by the perturbations within the antenna vicinity (i.e. nearby objects can modify the antenna's directivity characteristics).

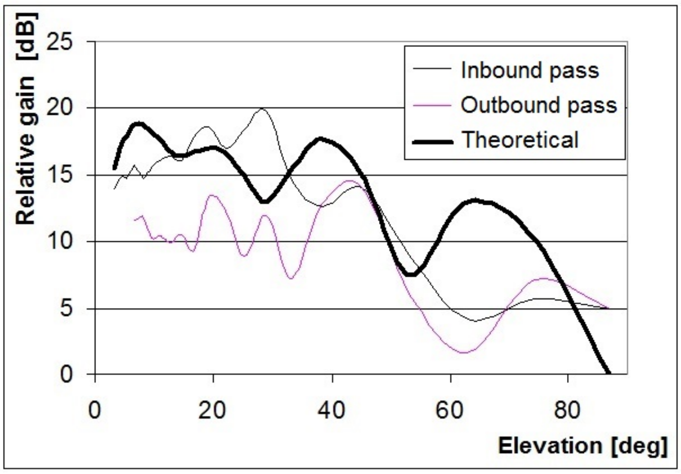



Figure 6. Experimental measurements showing the ground plane antenna's relative gain as a function of the satellite's elevation for satellite approaching and receding from the ground station.

## III. Conclusions

This paper addressed the problem of ground station development, focusing of the parameters of a 145 MHz omnidirectional Ground Plane antenna. The paper analyzed the antenna radiation diagram, its distance as a function of the elevation angle, and determined theoretically and experimentally the attenuation between the antenna and a real satellite (Nayif-1). Although the antenna's parameters enable proper satellite reception, its usage within the ground station is mostly as a reference antenna. In addition to this antenna, the ground station also uses a 435 MHz ¾λ parasitic circular polarised vertical antenna protototype, whereas two additional antennas for 2400 and 10500 MHz are envisioned. Current efforts are driven to develop an additional remote ground station unit which could be used to provide an extra reception node within the ground stations network.

## References

[1] J. Alvarez and B. Walls, "Constellations, clusters, and communication technology: Expanding small satellite access to space," *2016 IEEE Aerospace Conference*, Big Sky, MT, 2016, pp. 1-11.

[2] A. C. Kelly, S. M. Volz, C. L. Yuhas and W. F. Case, "Constellations: A new paradigm for earth observations," *2009 IEEE International Geoscience and Remote Sensing Symposium*, Cape Town, 2009, pp. III-73-III-76.

[3] P. A. Bernhardt, C. L. Siefring, J. D. Huba, J. Abrams, S. Miller and N. Voronka, "The tandem instrumented CubeSats experiment (TICE) in low earth orbit for continuous occultation observations of the ionosphere," *2011 XXXth URSI General Assembly and Scientific Symposium*, Istanbul, 2011, pp. 1-2.

[4] J. Laviada, C. Vázquez-Antuña, R. Camblor, M. Fernandez-García, A. Arboleya-Arboleya and F. Las-Heras, "Antenna Manufacturing at VHF Frequencies Applied to Weather-Satellite Data Reception [Education Column]," in *IEEE Antennas and Propagation Magazine*, vol. 55, no. 3, pp. 201-211, June 2013.

[5] C. Fuchs and F. Moll, "Ground station network optimization for space-to-ground optical communication links," in *IEEE/OSA Journal of Optical Communications and Networking*, vol. 7, no. 12, pp. 1148-1159, Dec. 2015.

[6] F. Riffel and R. Gould, "Satellite ground station virtualization: Secure sharing of ground stations using software defined networking," *2016 Annual IEEE Systems Conference (SysCon)*, Orlando, FL, 2016, pp. 1-8.

[7] J. Li, G. q. Ye, J. Zhang, T. j. Zhang and L. j. Ke, "A routing algorithm satisfied ground station distribution constraint for satellite constellation network," *2015 Science and Information Conference (SAI)*, London, 2015, pp. 997-1002.

[8] T. M. Bumbary and J. Maybury, "Design of luminosity sensor experiment on a CubeSat satellite for middle and high school students," *2016 IEEE Integrated STEM Education Conference (ISEC)*, Princeton, NJ, 2016, pp. 94-95.

[9] J. E. Oros, J. Trejo and A. Salcedo, "Identification, Location, and Reception of Low Earth Orbit Satellites (LEO) Signals," *2015 International Conference on Mechatronics, Electronics and Automotive Engineering (ICMEAE)*, Prague, 2015, pp. 246-250.

[10] H. Brueckmann, "Antenna pattern measurement by satellite," in *IEEE Transactions on Antennas and Propagation*, vol. 11, no. 2, pp. 143-147, Mar 1963.

[11] A. R. Neben *et al*., "Measuring phased-array antenna beampatterns with high dynamic range for the murchison widefield array using 137 MHz ORBCOMM satellites," in *Radio Science*, vol. 50, no. 7, pp. 614-629, July 2015.

[12] D. C. Law, J. R. Khorrami, W. B. Sessions and M. K. Shanahan, "Radiation patterns of a large UHF phased-array antenna: a comparison of measurements using satellite repeaters and patterns derived from measurements of antenna current distributions," in *IEEE Antennas and Propagation Magazine*, vol. 39, no. 5, pp. 88-93, Oct 1997.

[13] M. Hurtado, H. Lorente and C. Muravchik, "An in-situ method to measure the radiation pattern of a GPS receiving antenna," in *IEEE Transactions on Instrumentation and Measurement*, vol. 50, no. 3, pp. 846-849, Jun 2001.

[14] B. Butler, "Options for VLBA antennan surface measurement", Tech. rep., National Radio Astronomy Observatory, VLBA Test Memo. No. 57, 1998.

[15] C. E. Lesanu and A. Done, "Parasitic circular polarized vertical antennas," *2016 International Conference on Development and Application Systems (DAS)*, Suceava, 2016, pp. 143-149.

[16] M. Mori, MMANA-GAL antenna analyzer software http://hamsoft.ca.