Design and implementation of a satellite communication ground station

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***Abstract*—In the context of an increasing number of satellites orbiting around the Earth, developing a vast ground stations network becomes very important in order to be able to receive the satellite transmitted data. Consequently, this paper presents the aspects related to the implementation of a ground station for LEO satellites, located in Suceava city. The paper presents a relatively simple and cost efficient ground station solution, and also offers an example of satellite data reception. As the ground station is located within city limits, whereas the antennas are omnidirectional, the paper also analyses the location's radio horizon and radio compatibility.**

I. Introduction

As the number of satellites orbiting around the Earth is significantly increasing [1], so is their application domain. Thus, satellite communications begun to be used in new areas, whereas their educational component becomes more and more important [2], [3]. Nevertheless, as most of the existing satellites are low earth orbiting (LEO) [4], developing a reliable ground station network becomes mandatory, in order to be able to receive as many of the satellite transmitted data. Consequently, an increased number of evenly distributed ground stations should be build, and a ground stations network should be developed [5]-[7].

Within this context, this paper approaches the practical aspects (hardware and software) related to the development of a ground station in Suceava city (Romania). The ground station was envisioned to communicate with university satellites, which generally use the frequency bands allocated to radio amateurs: 145, 436, 1290, 2400, 10500 MHz and which have a low orbit (500-1500 km above Earth). It has a mid-level complexity and is currently communicating using the 145 and 436 MHz bands, whereas two additional antennas, for the 2400 and 10500 MHz bands are envisioned. As the ground station was developed under budget constraints, this paper might come in handy for other developers, stimulating the growth of the ground station network. Besides the support provided for the satellites owners, the ground station is envisioned to be used for educational purposes as well.

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II. Ground Station Architecture and Hardware Implementation

The architecture of the ground station, in its current form is illustrated in Fig. 1. For this version, one of the main goals was to confirm the viability of certain concepts and technologies. However, ongoing efforts are driven to further enhance the ground station's performances.

The antenna is connected to the Low Noise Amplifier (LNA) by using a RG58 cable. At this point, the ground station is able to communicate using the 145 and 436 MHz bands, using a λ/4 ground plane antenna [8] and a ¾λ parasitic circular polarized vertical antenna prototype [9] (Fig. 2). Furthermore, two more antennas for 2400 and 10500 MHz are envisioned. Referring to the RG58 cable, although it is not the best solution, in this case, the relatively short path does not lead to significant signal losses. The LNA provides a 20 dB gain at the cost of introducing a 1.5 dB internal noise. Next, the signal passes through a band pass filter, where part of the external noise is eliminated. As a receiver, we currently use a Software Defined Radio (SDR) RTL2832U equipment, replacing the previous Yaesu FT857 transceiver. The SDR produces a complex baseband signal which is applied to the input of the data processing computer. A second computer is used to determine the satellites trajectories, providing data regarding their position in space (i.e. azimuth and elevation), regarding the uplink and downlink frequencies and also the data required to compensate the Doppler Effect. The two computers are connected to internet, in order to deliver the received satellite data and for clock synchronization. Considering the current trend toward environment-friendly technologies, the ground station is powered by using photovoltaic solar panels.

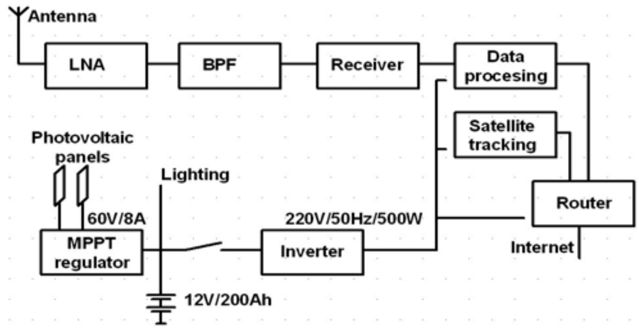

Figure 1. Ground station block diagram.

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The signals arriving from satellites are often very weak, requiring high sensitivity for the receiving equipment. Furthermore, the frequency bands adjacent to the ones used for satellite communications are becoming increasingly congested. Consequently, increasing the gain of the receiving equipment without taking appropriate filtering measures may increase the noise level as well. Therefore, by using software simulation tools and laboratory measurements several filters have been implemented. Thus, a bandpass filter based on a coaxial segment is used to eliminate a strong perturbing signal which was found within the 421 - 425 MHz band, close to the 435 – 438 MHz band used for spatial communications. As this filter only delivered 3 – 4 dB attenuation, a second five cells interdigital filter is used, providing 33.85 dB of attenuation on the 425 MHz band. For the 145 MHz satellite communication band, a bandpass filter based on discrete components was implemented (Fig. 3), having an insertion loss of 1.33 dB.

Concerning the receiver unit, the RTL2832U SDR equipment has a noise figure between 8 – 13 dB. To improve its performances, a RF preamplifier is used (Fig. 4). With the help of a Monolithic Microwave Integrated Circuit (MMIC), two preamplifiers have been designed (i.e. one based on SPF5043Z RFMD circuit and one based on PGA103+ from Mini Circuits). The power supply of these units is made based on the LP2985 circuit (low internal noise circuit). Experimental tests have showed a gain of about 20 dB, both for the 145 and the 436 MHz bands, with 1.5 dB internal noise, while the power consumption was of 90 mA at 13.8 V.

III. CONSIDERATIONS ON THE LOCATION INFLUENCE ON THE GROUND STATION PARAMETERS

As the ground station is located within city limits, this section will analyze the location's influence on the ground stations performances, focusing on the radio horizon, and on the radio compatibility.

A. *Ground station's radio horizon*

As the ground station is situated within city limits, its performances will be influenced by the environmental conditions and by the location itself. Considering that high frequencies are envisioned, whereas the satellites may have trajectories covering the entire sky, the station's radio horizon becomes very important.

In this case, the station's radio horizon was analyzed using a compass-clinometer kit, Sunnto type. This kit has a 0.5 degrees measurement resolution for the compass, and a 1.0 degree resolution for the clinometer. The measurements were taken on the antennas platform, and the results are summarized in Fig. 5. The solid line represents the constructions that obstruct radio signals at all frequencies and at any time of year. The dotted line represents the crowns of trees in the area, obstructing higher radio frequency signals (435 MHz band and above), especially during the vegetation season, and in rainy periods. The claims were supported by measurements of the satellite beacon signals experimental FunCube-1 (OSCAR-73) in the 145 MHz band using a Ground Plane antenna.

a. b.

Figure 2. Antennas used for the satellite communication: a) Ground Plane antenna for the 145 MHz band and b) ¾λ parasitic circular polarized vertical antenna.

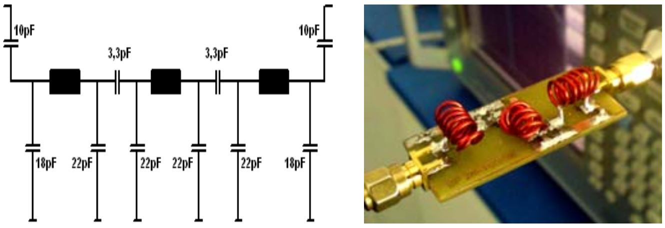

Figure 3. Filter for the 145 MHz band.

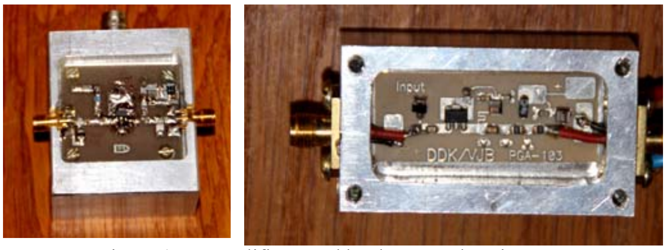

Figure 4. Preamplifiers used by the ground station.

B. *Ground station's radio compatibility*

The ground station's location was also checked for possible radio interference (Fig. 6). In this case, parasitic radiation from different electronic equipment and antenna signals were analyzed. For this purpose, we used a RTL-SDR stick and a FT857D transceiver, with and without additional pre-amplification. Thus, perturbing signals coming from high frequency stations, internet and the electricity networks, and also from switching power supplies were identified. The signals from the mobile phone networks (900 MHz) and from the radio WFM broadcasting (88 to 108 MHz) were identified as well. In the case of the FT857D receiver, these frequencies are not disturbing, as the receiver contains input bandpass filters. However, in the case of the RTL-SDR, mixing components are generated covering the data signal. Similar interferences are found when a broadband preamplifier is used, no matter the subsequent receiver.

IV. SOFTWARE DEFINED RADIO EQUIPMENT USAGE

Traditional radio devices based on hardware equipment can be modified only by physical intervention. This leads to a higher production cost and a lower flexibility. On the other hand, SDR tools provide efficient and relatively inexpensive radio equipment suitable for multiple operating modes, whereas architecture improvements can be made by software updating. SDR devices can be classified as hybrid SDR (i.e. part of the signal processing is done based on analog techniques: e.g. the signal is pre-amplified and then it is converted to digital and processed using software techniques) or as SDR with direct sampling (i.e. the signal is sampled directly and then processed digitally).

Currently, a wide range of SDR equipment is available. In this case, a RTLSDR stick based on the chip RTL2832U and R820T(2) tuner was considered. It is a hybrid SDR, englobing an input mixing circuit, an analog-digital converter (ADC) with a sampling frequency of 28.8 MHz, generating two series of 8-bit data in quadrature, providing a 3.2 MHz maximum bandwidth. The data is then transmitted to the computer via a USB link, and it is processed using a software tool. In our case, GNU Radio Companion has been used. The data processing block diagram is shown in Fig. 7. Thus the signal from the SDR receiver passes through a 7 kHz band pass filter to remove the noise. This value was chosen in order maintain the signal within the bandpass even when the Doppler Effect induces frequency deviations. Next, the signal is multiplied by its complex conjugate in order to obtain a signal proportional to the input signal power. Then, a logarithmic function is applied, generating a value proportional to the dB signal value. An averaging function is applied, before storing the final values. The received satellite signals and other additional information are displayed in real time (Fig. 8). Prior to testing, the calibration of the SDR receiver (hardware and software) was performed in laboratory conditions using a radiofrequency generator.

V. EXPERIMENTAL TESTS

In order to demonstrate the viability of the proposed design, Fig. 8 and Fig. 9 illustrate an example of data reception from two satellites passing above Suceava city. In both cases, the satellites communicate within the 145 MHz band, and thus, we used for reception a λ/4 Ground Plane antenna [8], which explains the lack of signal in the zenith point.

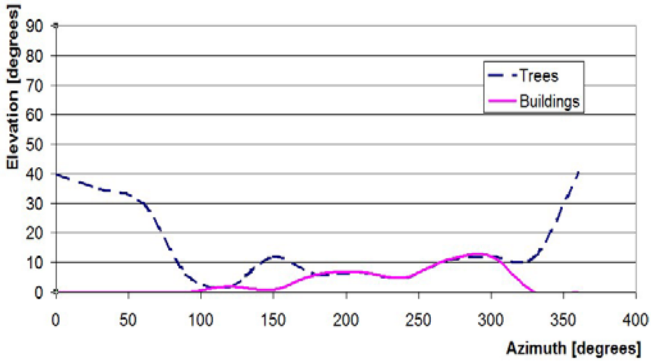

Figure 5. Ground station radio horizon. The measurements were taken on the antennas platform.

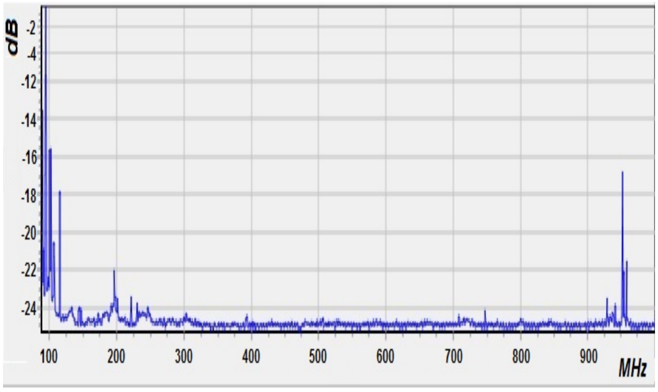

Figure 6. Over the air spectrum analysis: 100 to 1000 MHz.

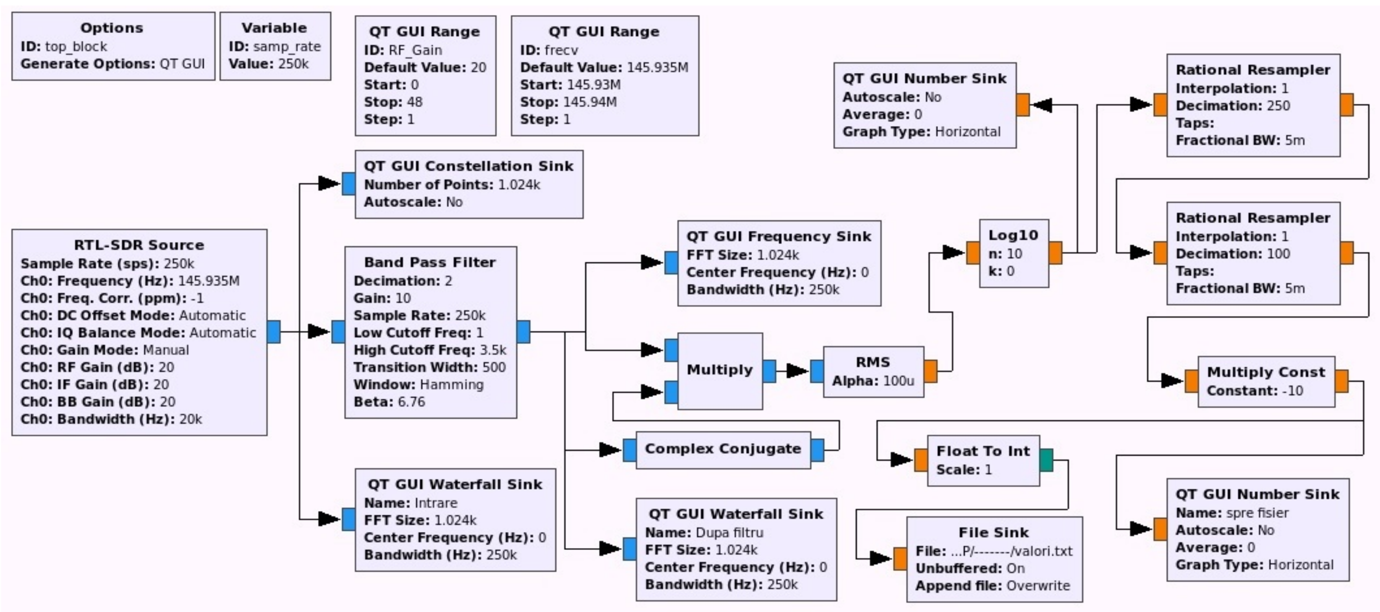

Figure 7. Data processing block diagram implemented in the GNU Radio Companion software.

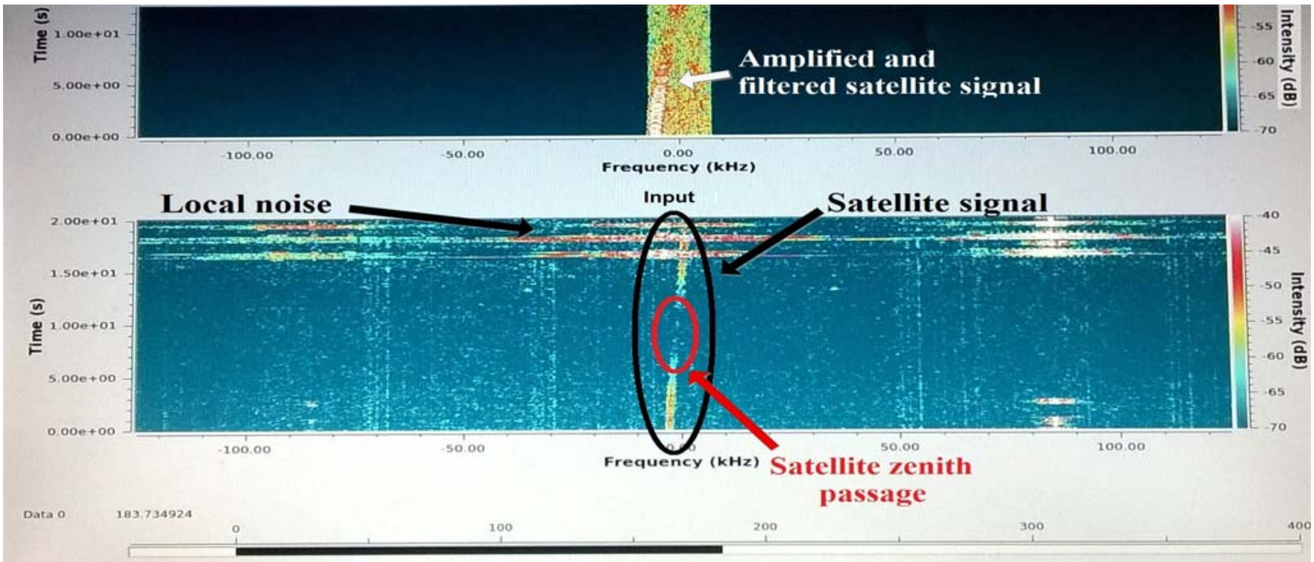

Figure 8. Display showing a passage of the Nayif-1 satellite. The satellite communicates with the ground station using the 145 MHz band. The absence of the signal for the satellite zenith passage is due to the Ground Plane antenna directivity characteristic (see [8]).

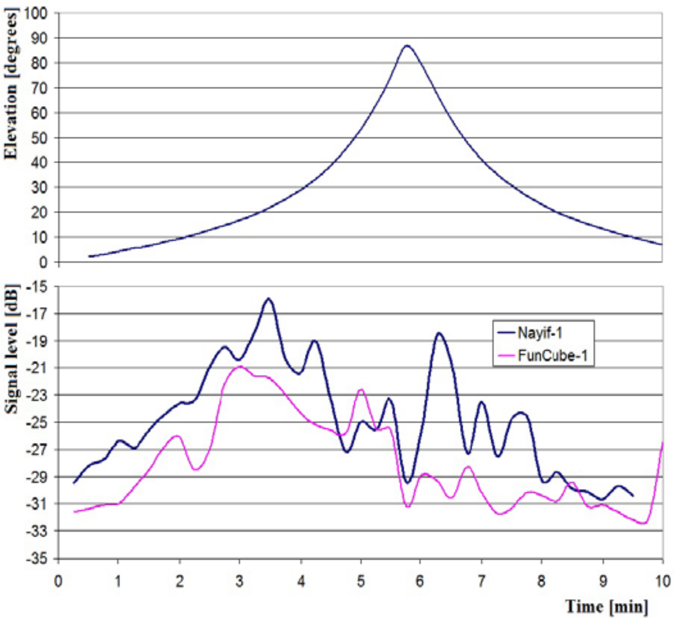

Figure 9. Variation of the received satellite signal correlated with the satellite's elevation angle, as a function of time. The measurements were taken for the Nayif-1 and the FunCube-1 satellites.

VI. Conclusions

This paper presents the practical aspects regarding the implementation of a satellite communication ground station in Suceava city. The provided solution was designed focusing on a fair tradeoff between communication performances and cost restrains. This paper might come in handy for others who consider implementing a ground station with the purpose of developing and enhancing a worldwide ground station network used for satellite communications.

The paper presented the selected hardware and software solutions, analyzed the ground station's radio horizon and radio compatibility, and showed an example of satellite data reception. Currently, we are working on expending the communication band towards higher frequencies and on implementing an additional remote ground station unit which could be used to provide an extra reception node within the ground stations network.

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