NanoSatellite Ground Station using Software Defined Radios

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NanoSatellite Ground Station using Software Defined Radio (SDR)

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Abstract

The CubeSat origin lies with Professor Bob Twiggs from Stanford University and was proposed as a vehicle to support hands-on university-level space education and opportunities for low-cost space access. Most recently this kind of project have left to be university level since the scientific, private and federal communities has grown significantly in their interest about the CubeSat, due to its low cost, capability to perform the same scientific task than a larger satellite, short term of design, construction and implementation. An essential part of a Satellite project is the ground station. Most of CubeSats Ground Stations are created using expensive hardware material; radios, modulators, demodulators, etc that increase substantially the project cost (for thousands of dollars) and once designed are only for specific bands and modulations. However implementing a SDR (Software Defined Radio) station reduced significantly the cost of a full operational system without sacrificing final performance and creating a more flexible system for other applications. The SDR is a growing innovation in the wireless communication field and was created to locate the code as close as possible to the antenna to minimize the hardware limitation. This type of Ground Station can be constantly updated and improved, taking into account the development of new devices under this SDR technology. In addition, the application of this kind of hardware is not only CubeSat Ground Station related.

Introduction

Usually there are two basics ways of implementing a fully functional Ground Station for CubeSats, with regular radio hardware or with the implementation of the SDR technology. The problem with the first option is that the hardware to create it normally is expensive and does not offer flexibility since it is application designed. Even though it is a proven method**,** the SDR offers the same results with a much cheaper implementation and a more flexible design. In practice, designers choose one of the two approaches based on a qualitative assessment of the trade-offs. In this paper we put the second option on a firmer basis based on its objectives:

- Develop a Software Define Radio ground station capable of providing coverage on two different Nano-Sat frequencies bands (VHF 144-148 MHz and UHF 430-438 MHz) for receiving the signals from the SWIM CubeSat (which is under construction) and other satellites from the CubeSat community.
- .Auto-compensates the Doppler Effect and provide auto-tracking of the desired satellites.
- Create a Ground Station Graphical User Interface (GUI) using the GNU Radio software under the GPL (GNU Public License). .
- Creation of the DSP (Digital Signal Processing) blocks in GNU Radio for the specific modulation and data format of the SWIM CubeSat, which currently requires a CCSDS (Consultative Committee for Space Data System) as packet format and the digital modulation of the AX.25 signal with the sound-card of the Ground Station computer.
- Use of this platform and related work as a method to train Puerto Rico's work force for developing the local industry, economy and technology.

Results

SDR Ground Station

Even though the SDR offered us a way of getting rid of most of the extensive and low flexibility hardware, there were still some areas in which the design of the subsystems had to rely on it. In this case our subsystem simply used one UHF antenna with a gain of 18.9 dB and a Bean width 21 degree, for the VHF an antenna with a gain of 12.34 dB and a Beam width of 52 degree **Figure 1**. A Yaesu G-5500 rotor **[1]** and a custom made base antenna. In order to be able to receive signal from satellites with an orbital distance of 500 km (what means 2,560 km of distance between the satellite and ground station at the far point of contact, having as reference 10 degree above the horizon) low noise amplifiers were added in the UHF and VHF with respective gain of 16 dB and 24 dB and a noise figure for both of 0.55 dB.. This is essentially the only hardware needed to implement a successful Ground Station. In addition the USRP(Universal Software Radio Peripheral)**[2]** and a computer.

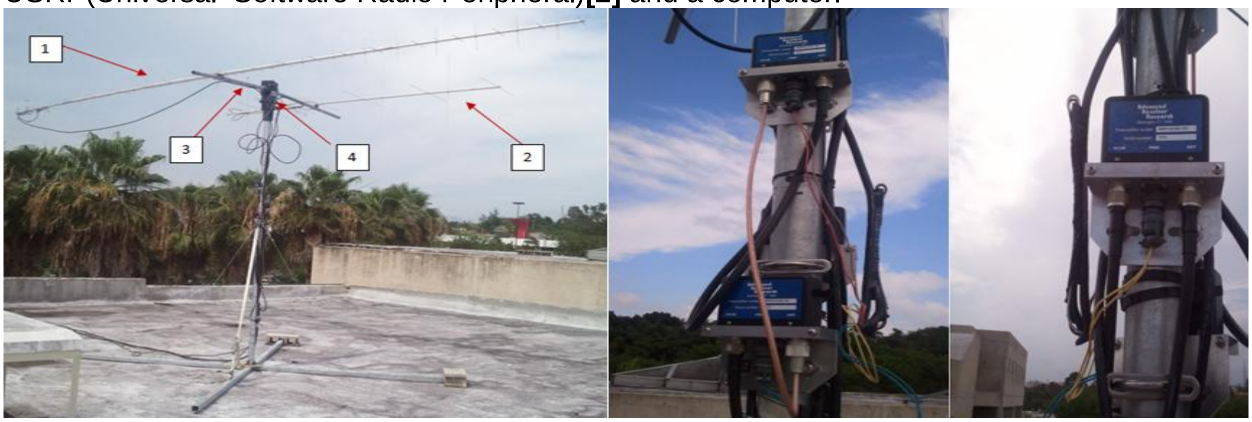

Figure 1 Overview of the hardware used for this Ground Station.

The NanoSat Ground Station was implemented using the SDR radio named USRP. This SDR instrument allowed us to locate the code as close as possible to the signal. Even though our team chose the USPR1 (because it is able of manage two transceiver daughter boards (RF Front end) at the same time), there are other reliable and cheaper instruments that can be used and that are also supported on GNU Radio platform. **Figure 2** shows a clear example of the implementation of a SDR Ground Station versus a traditional one, note the significant difference in hardware.

Figure 2 Difference in hardware between the two types of systems

Doppler Effect Compensation and Auto-Tracking

One of the biggest achievements was the auto Doppler Effect compensation. This effect is produced by the CubeSat translation velocity (near to 5Km/s) and affects the carrier frequency by certain amount, depending of the velocity and position of the satellite. This bias needs to be compensated properly to be able to receive data; if this step is missed, the communication link will be affected due to the frequency shifting constantly occurring. To resolve this situation we developed a block in GNU Radio that is feed through TCP/IP protocol with the unlink and downlink frequency data produced by Orbitron **[3](**a free software capable of tracking satellites of all kinds based on its TLE (Two Line Elements)). One of its features is that the software generates several parameters of the satellites such as downlink and uplink frequency, azimuth and elevation angle. We took advantage of this and while keeping the environment simple, established a DDE (Dynamic Data Exchange) link to obtain those streams. The Doppler's frequency related data was sent via a TCP/IP protocol to the custom made GNU Radio block, which processed the information, extracted the values and transferred it to the USRP blocks during the communication link. As a result, the link was never again lost and the values for downlink and uplink were constantly updated, in order to compensate for the Doppler shifting using the Orbitron software.

Additionally the azimuth and elevation data form Orbitron was used to feed the ground station tracking system. These spacecrafts are in constant movement and therefore a problem arises because the ground station has directional antennas that require it to be pointing in the direction of the satellite during its light of sight to receive its signal. For that reason the system required an Azimuth & Rotor controller **[4].** The use of a rotor in the antennas allowed us to provide the system with moving antennas ready to point to the device direction. In order to guarantee a proper movement of the antenna, a microcontroller was used to interact with the G-5500 rotor. This device controlled the rotor movement by processing the azimuth and elevation variation data received from Orbitron via a serial port. The board developed as in **Figure 3** allowed us to point to the desired location of the CubeSat when it was being tracked automatically with an additional feedback information from the rotors to the controlling PC.

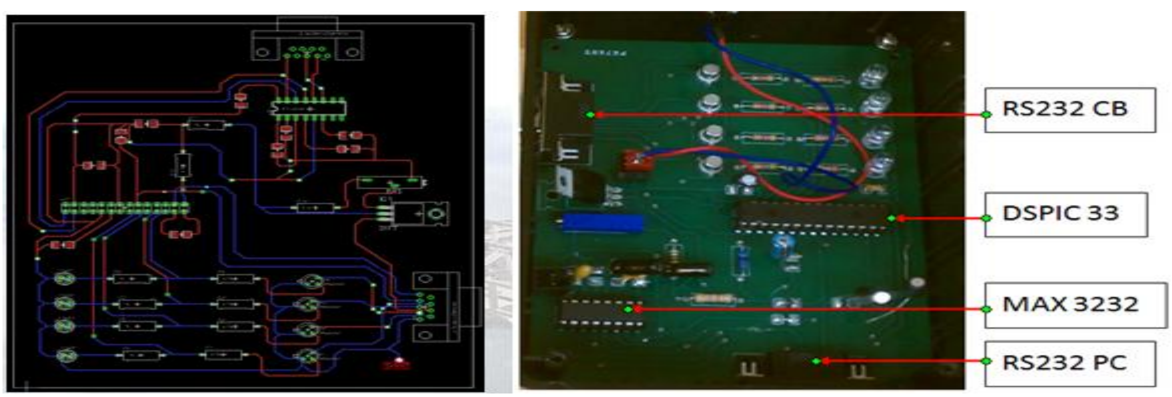

Figure 3 Electrical design and final product of tracking Interface board.

Ground Station Graphical User Interface

Another important element in the ground station is the software that will receive and process the scientific and housekeeping data that will send the satellite. This software will help the ground station's operator to know the status of the payload and the different subsystem on the satellite. Normally CubeSats will be exchanging information, such as data, commands and status log. For this reason the operator needs a method to interact with the spacecraft. These steps involve a complex link with the Command and Data Handling subsystem of the spacecraft, which are customized by each project. In order to offer a more reliable system to the users a GUI was generated using GNU Radio utilities. The GUI required programming the interfaces using Python and QT on the Linux platform, but at the end offered a more user friendly way to allow the operator to handle the Ground Station. As a result of the GUI created the operator was able to generate graphs of the Housekeeping data of the space vehicle, plotting the values received and getting a better idea of the satellite performance as shows in **Figure 4**. This part of the project is not completely tested until the SWIM project get into further steps of its creation, however the platform is there to add the modifications needed when the opportunity comes.

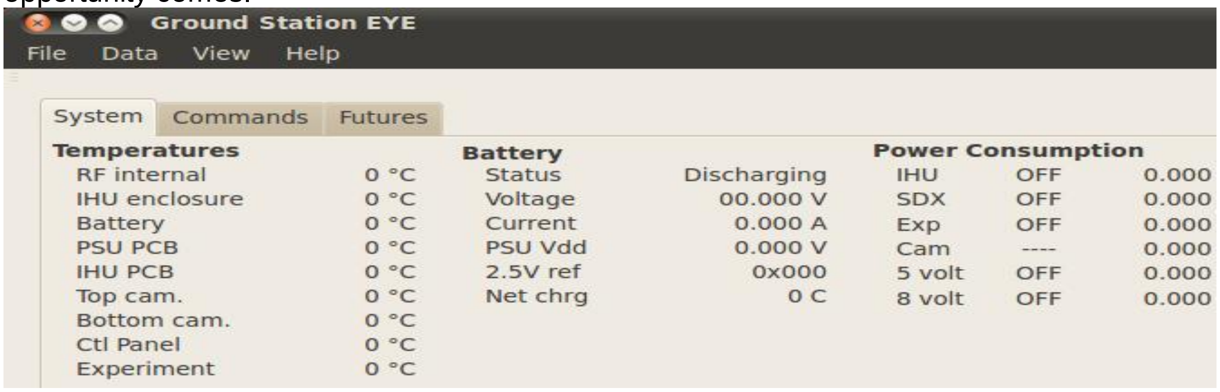

Figure 4 Basic Layout of the GUI development. Housekeeping plotted data.

Digital Signal Processing Blocks

The entire DSP signal block created for the Ground Station was developed as an out-of-tree module in GNU Radio. This is a component that does not live within the GNU Radio source tree. Typically, if you want to extend GNU Radio with your own functions and blocks, the programming should be headed through this direction. This allowed us to maintain the code for ourselves and have additional functionality alongside the main code **[5].** The new blocks created are listed as follows:

DSP Block Name	**Description**
SWIM CCSDS Encoder	The block takes the input bytes commands for uplink, format it into a CCSDS packet format. It is later advanced to the ax25 encoder
SWIM AX25 Encoder	The block take the CCSDS stream and format it into an unnumbered information ax25 packet format
SWIM AX25 Modulator	The modulator transforms the ax.25 packet into audio signals just by generating sine and cosine waves according to the bit order.
SWIM CCSDS Decoder	The block processes the incoming data and stores the information field into a file for GUI processing later on.
SWIM AX25 Decoder	The block decodes the received sample and extracts it into an ax25 packet format, and then it advances the information fields into the CCSDS decoder.
SWIM AX25 Demodulator	The block receives the sample and extracts its content with several steps that involve band pass filters, correlations calculations,etc **[6]**

Table 1 List of main blocks developed for the signal processing of the SWIM Ground Station.

Discussion

The implementation of this Ground Station will provide the CubeSat community with a secure and reliable spot for downlink communications in the Caribbean region, which has been unavailable for the downlink of data for most of the CubeSats built so far. This is a very significant aspect because the contact time for CubeSats normally is short (7-15 minutes between 4-6 times daily), and most of the time with only a single Ground Station is not enough to download all the data that could be generated by CubeSats. However with this kind of facilities the CubeSat fleet will have more frames for downlink and as a result more scientific data for the mission in question. In addition, compare to the traditional system, the SDR Ground Station offers a low cost platform, capable of receiving a frequency range normally not available with traditional hardware. The flexibility of SDR Ground Station can be improved with the addition of not so expensive daughter boards (RF Front-ends), for example with the WBX from Ettus Research the SDR could be used for a range between 50 MHz to 2.2 GHz (following the FCC regulations). This kind of Ground Station was implemented with a total budget of less than $3000.00, amount affordable for most universities budgets. In addition once obtained the SDR can be used with other projects, which involve the same low cost hardware as for example projects involving the creation of a GNSS (Global Navigation Satellite System) receiver, DRM (Digital Radio Mondiale) receiver used for digital HF broadcasting, Spectrum Analyzer for cell phones bands, among other. All these features make the SDR, a multifunction device that have no limit on the type of application in which can be used.

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