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Development of a radio telescope for the observation of celestial bodies in the Ku Band

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Abstract. Solar events such as flares or explosions present intense radiation in the KU band (10-12) GHz, the range in which satellite television operates. Subsequently, the development of radio telescopes that make use of elements present in satellite television due to its low cost is evident around the world. The radio telescope in the study is, composed of a reflective mesh antenna, a mount that allows for remote operation, a Low Noise Block, and a satellite search engine. The system is installed in the Astronomical Observatory of the Technological University of Pereira and has a freedom of movement of 360° in azimuth and 180° in altitude, with a resolution of 0.2°. The set-up of the radio telescope was done by observing television satellites and registering the Solar transit. The developed radio telescope is easily scalable thanks to its modular architecture. Additionally, it is stable in adverse weather conditions because of its mesh antenna.

1. Introduction

The Sun is one of the greater intensity sources of radio waves from space perceived from Earth. This radiation is caused by flares or solar explosions that are emitted by ionized particles. When these particles reach Earth, they interact with the magnetic field and affect satellite communications and air navigation, among others [1].

These radio waves caused by solar activity present intense radiation in the SHF band (3 - 30) GHz frequency range that includes satellite television (KU band, Kurz-unten band) [2],[3]. Projects have developed, around the world to make use of elements of satellite television systems, such as reflective antennas, LNB (Low Noise Block) and satellite search engines. One of the biggest advantages of these instruments is their signal-to-noise ratio, as it has improved with television systems advances [4]. Moreover, they are low cost and easily accessible, permitting more people to venture into radio astronomy.

There are projects around the world to develop radio telescopes in the Ku band. They have different configurations according to their application. Variations are found in antenna designs (although for all cases they are parabolic or reflective). Some have solid surface discs [5], [6], [7], often recycled from non-functioning television systems, making these antennas a low-cost option [2], [8]. In other cases, antennas that have a mesh disc are used. Mesh disc decrease the gain of the signal obtained, but they, also decrease the weight of the structure without increasing its cost [9]. This facilitates the tracking of objects. Additionally, mesh antennas allow airflow in



the structure while preventing the accumulation of water, generating less torque to the structure when the system is installed in places with adverse weather conditions.

There are manual and electronic mounts used for the movement of antennas. Manual mounts require permanent manipulation by an operator [2]. Electronic mounts are used to control the movement of the antenna remotely, permitting the manipulation of radio telescopes that are difficult to access [10]. For electronic mounts, it is possible to find mounts with movement resolutions from 1° [11], up to 0.1° [9].

In KU band radio telescopes, the radio waves are directed to the focus of the reflective antenna and received by an LNB. The latter delivers a GHz signal. Considering that this frequency is high, a mixer element is used, which delivers a lower-frequency signal with the same characteristics. In some cases, this task is performed by a satellite search engine [12], an element specifically designed to amplify the signal obtained from the LNB [10]. Celestial objects such as the Sun, Saturn and the center of the Milky Way can be studied with this configuration. The advantages of this configuration include its low cost, easy acquisition, and a bandwidth of 1.1 GHz [2]. In this type of instrumental arrangements, the signal is taken from the terminals of the satellite finder galvanometer [3], whose amplitude is proportional to the signal in the Ku band shown by the LNB. Conversely, the LNB signal can be input to an instrument, whose function is to decrease the frequency [13], allowing its processing. This makes the system work in a reduced frequency range (3 MHz) [2], limiting the number of objects to study while reducing the incidence of noise.

Some radio telescopes are developed for educational purposes, so the visualization of the signal is carried out by means of instruments such as oscilloscopes or multimeters, facilitating interaction of the students [14]. In radio telescopes that are developed for scientific purposes, the signal is entered into a computer to be processed, visualized, and stored. Prior to this step, it is necessary to condition the signal dropped by the receiver. This task is performed with an Arduino-based system [2].

This study presents the development of a radio telescope for the observation of the Sun in the Ku band, making use of typical satellite television elements. A mesh antenna of 1.2 m (grid of 2.8 mm) is used for the reception of the signal. Its architecture facilitates the tracking of celestial bodies and offers greater stability to the structure to withstand gusts of wind characteristic of the region. The radio waves are concentrated in the focus of the reflective antenna, then are registered by an LNB, and finally sent to a satellite search engine. A conditioning circuit was built in order to amplify and filter the signal. This signal is entered into a computer through a myDAQ acquisition card.

2. Methodology

Figure 1 shows the block diagram that forms the radio telescope developed for the observation of celestial bodies in the Ku band in the Astronomical Observatory of the Technological University of Pereira. The antenna and its control devices, the radio receiver, and the software for viewing and storing the received signals are identified.

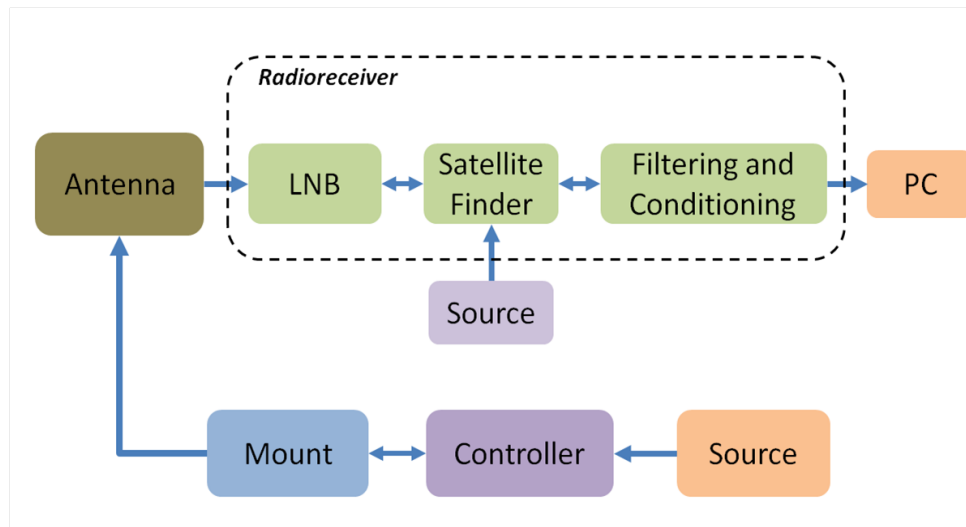


Figure 1. General diagram of the developed radio telescope in the Ku band.

2.1. Antenna

A reflective antenna was built from a circular metal mesh 1.2 m in diameter with a 2.8 mm grid for capturing the signals under study. For the support of the antenna, a structure of aluminum bars was built, which generate the concavity (see Figure 2). The antenna has a focal length of 0.72 m ($f/D = 0.6$). With this configuration it is possible to obtain a maximum gain of 31.9 dBd at 11 GHz. This frequency is located in the intermediate zone of the 10-12 GHz range, the operating range of the Ku-band LNB. The software *4nec2* was used to simulate the radiation pattern and frequency response of the antenna (see Figure 3).



Figure 2. Build antenna.

The antenna is installed on the SPX-01/HR mount of the RF Hamdesign brand. The movement of the antenna-mount arrangement is controlled through the MD-02 controller of

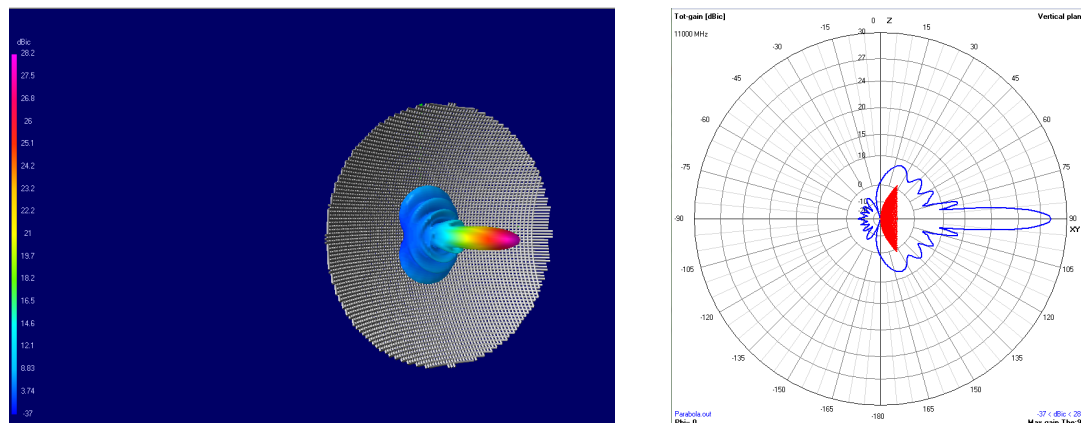


Figure 3. *4nec2* simulate the radiation pattern.

the same brand. The mount is completely maintenance-free. It has a resolution of 0.2° and can support a vertical load of up to 50 *Kg*.

2.2. Radio receiver

The reception of the signal, as shown in Figure 1, occurs in three stages: LNB, a satellite search, and a conditioning and filtering system. The reference of the LNB is the DMS International brand PLL321S-2, designed to operate in satellite TV systems in the Ku band. The LNB is easy to acquire and it costs approximately 20 USD. This device has a reception frequency range of 10.70 to 12.75 GHz, an output frequency range of 950 to 2150 MHz, a f/D ratio of 0.5 to 0.7 and a gain of 60 dB. It is possible to observe bodies like the Sun and Moon given the bandwidth in which the LNB operates [2]. Additionally, this LNB can operate in temperatures from -40°C to $+60^\circ\text{C}$ and is 100% resistant to humidity, a characteristic that is ideal for the climatological conditions of the region in which the radio telescope was installed (Pereira, Colombia).

The signal received by the LNB is entered into a satellite search engine, an element commonly used in satellite television, and used to correctly direct the reflective antennas. In this investigation, the SF99 satellite search engine of the WS International brand was used, which costs approximately 60 USD. This instrument has a galvanometer that visually indicates the correct pointing of satellite antennas. This galvanometer is powered by a signal whose intensity is proportional to that received by the LNB. Therefore, in the developed radio telescope, the signal of interest is taken directly from the galvanometer to proceed with its subsequent conditioning. As a result, the signal taken from the galvanometer of the satellite finder will register an intensity proportional to the signal emitted by the object of study.

The signal obtained by the galvanometer of the satellite finder goes to the third and last stage of radio reception. This stage consists of a signal filtering and conditioning system based on a second-order active filter in the Sallen-Key configuration [15], [16] (see filter Figure 4). This filter was configured for a cutoff frequency of 500 Hz and gain of 3.86 dB. The signal delivered by the radio receiver is entered to the computer through a myDAQ acquisition card. The visualization and storage of the received data is done through the Matlab software. These two elements produce a graph corresponding to the energy of the received signal for its subsequent analysis.

3. Results

Figure 3 shows the radiation pattern and frequency response of the developed antenna. These parameters were obtained from the simulation of the antenna, performed in the software *4nec2*.

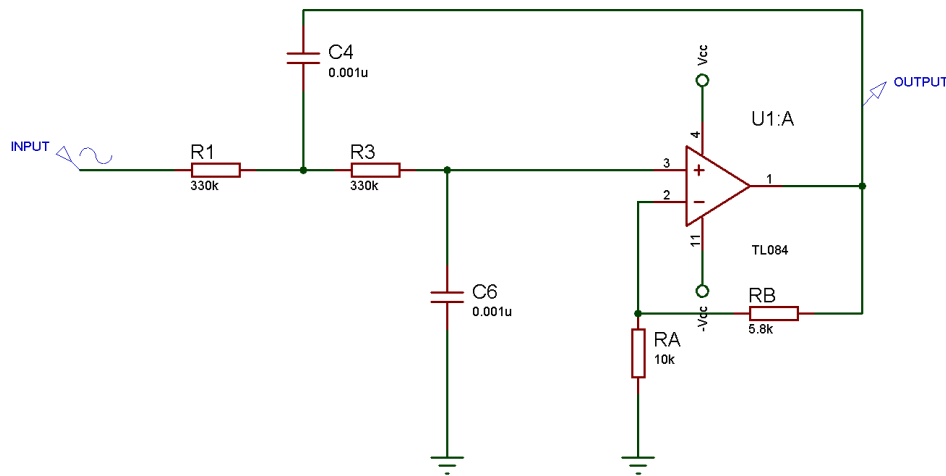


Figure 4. Second order active analog filter.

A highly directive radiation pattern is observed which is a characteristic of reflective antennas. A frequency response centered on the KU band is also observed.

Figure 5 shows an image of the radio telescope developed and installed on the terrace of the Astronomical Observatory of the Technological University of Pereira.

The system was mounted on a metal base 1 m high. The movement of the antenna is 360° in azimuth and 180° in elevation, with a resolution of 0.2° . Once the antenna was assembled, a focal length of 72 cm was obtained, which determined the location of the LNB to obtain maximum gain. The final assembly was tested with the observation of different television signal satellites located in stationary orbit. The received signal from these satellites was also used to calibrate the azimuth and height sensors of the mount, achieving an uncertainty of $\pm 1^\circ$.



Figure 5. Developed radio telescope.

Figure 6 shows the signal registered by the Matlab software when using the radio telescope developed to observe a solar transit. To achieve this, the radio telescope was directed at the intersection of the ecliptic with the meridian in the celestial vault, a few minutes before noon. The signal started with a low level that increased as the Sun approached the region of the sky

where the antenna faced. When the Sun was in this location, the radio telescope registered a signal of maximum intensity, which decreased as the Sun moved away from this point.

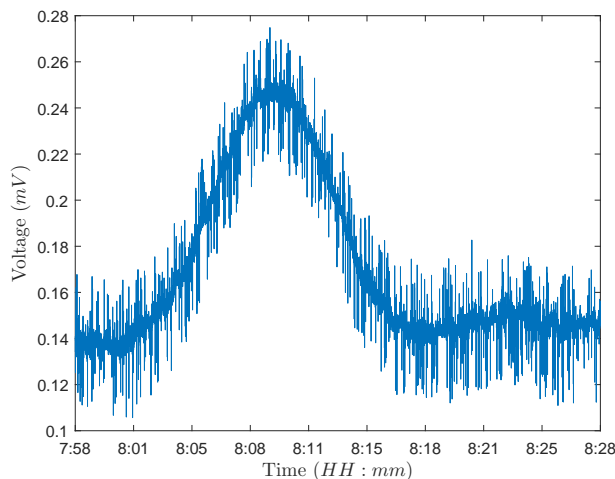


Figure 6. Registered signal of the solar transit on day 2018-11-02. Time is at -5 UTC.

4. Conclusion

The developed radio telescope in the Ku-band takes advantage of the low cost and ease of access to elements of satellite television such as LNB's and satellite search engines. Likewise, the developed antenna was lighter than antennas commonly used in satellite television due to the choice of a mesh disk for its construction. This also created a collector area greater than the standard value of these antennas. The construction did not require a more robust mount or a significant decrease of antenna gain. In addition, the mesh antenna allows the radio telescope to maintain its stability despite adverse weather conditions.

Moreover, the constructed radio telescope is easily scalable, since it is possible to replace the LNB in order to perform observations in other frequency bands within the microwave spectrum. It is also possible to replace the receiver (satellite finder and filtering and signal conditioning circuit) with a radio receiver of commercial use (its cost is much higher than elements used in satellite television). This allows for direct observation as opposed to the low frequency signal that feeds the galvanometer signal of the satellite finder.

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