RECEPTION ANTENNAS FOR LOW ORBIT EARTH SATELLITES

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ABSTRACT

This paper describes the design and construction of antennas for the detection of low orbit satellites, and in particular NOAA (National Oceanic and Atmospheric Administration) meteorological satellites. Based on an analysis of the requirements needed to detect signals from weather satellites, the design and simulation of antennas is made. The simulations allowed to analyze the electromagnetic processes and evaluate the radiation patterns and polarization characteristics of the designed antennas. Using the commercial software FEKO Suite 6.0 the dimensions of the antennas were optimized and the requirements checked. Selected designs were compared with references of works done on the subject [1 - 8]. In order to validate the design, the antennas were built and measurements were made to verify the design parameters.

1 .- INTRODUCTION

LEO (Low Earth Orbit) or low-orbit satellites, are situated at altitudes between 500 and 1500 km from the earth's surface. In this orbit the satellite can be seen from the ground for about 15 minutes per cycle, with a maximum of 6 passes per day. These passes must be fully exploited for downloading scientific data.

To achieve this goal it is necessary to the earth station to make contact with the satellite just when appearing on the horizon.

On board the satellite, in most cases, the transmitting antenna is fixed pointing to the nadir, having a wide radiation pattern in order to establish communication throughout all the pass.

Due to the spherical expansion of an electromagnetic wave power density ratio drops in function to the square of the distance, therefore, when the satellite hovers above the horizon (elevation theoretically zero) it is in the worst condition of the link. For this reason the transmitting antenna is designed to compensate this.

The radiation pattern of such antennas is known as Isoflux (Figure 1), meaning it achieves the same power density in the entire footprint or coverage area, maximizing the efficiency of the link.

When designing the receiving antenna, the radiation pattern of the transmitting antenna must be taken into account as the link characteristics will depend on both antennas.

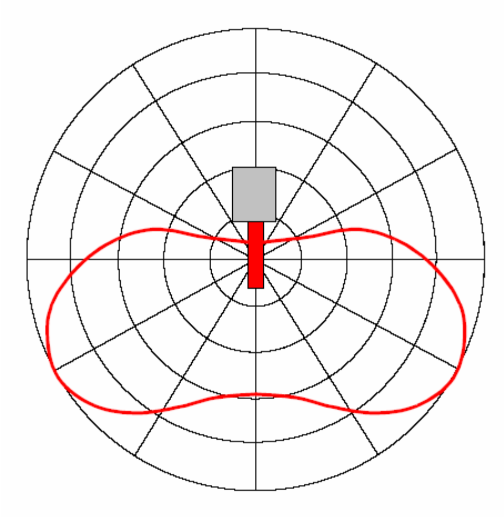

Figure 1-Isoflux radiation pattern.

Another aspect to be taken into account when designing a receiving (receptor) antenna for LEO satellites is polarization. Unlike geostationary satellites, LEO satellites move respect the ground station, therefore a linear polarization vector would rotate. For this reason, circular polarization is used. Furthermore, the circular polarization is more immune to effects of atmospheric depolarization which tend to rotate the electric field vector, causing losses in the linear case. For circular polarization, in the best of cases the two field components rotate without any loss whatsoever and in the worst case one of the components rotates making the polarization become more elliptical but with less loss than in the linear polarization case.

The above characteristics of satellite transmitters of low orbiting satellites are important for the development that follows, consisting in the design and optimization by software of receptor antennas that will receive APT (Automatic Picture Transmission) signals from Weather NOAA (National Oceanic and Atmospheric Administration.) satellites. APT signals carry information from atmospheric and climatic parameters that can be imaged, and are transmitted to earth in the VHF band in a frequency range between 137MHz and 138MHz.

2 .- REQUIREMENTS

In contrast to the transmitter antenna, the receiving antenna can be of a high gain directional type. This kind of antenna can be pointed to the satellite following it along its trajectory during the whole path.

However, it is more convenient to use an antenna mounted in a fixed position. The choice of a fixed antenna establishes the first requirement: the radiation pattern of the antenna must be equally sensitive across the upper hemisphere (the effect of the varying distance between the satellite and earth station is corrected by the transmitting antenna). The gain of these antennas is low, so its pattern should be optimized to ensure the efficiency of the link.

On the other hand it is pretended to minimize the noise reception, which sets another requirement: the sensitivity in the lower hemisphere should be minimized to prevent the antenna to capture the noise from terrestrial radiation.

Bearing in mind that the most important source of noise is artificial noise of human origin, and that this noise reaches the antenna on the horizon, at elevation angles between 0 ° and 10 °, its effect can be minimized by reducing the gain of the antenna in this range. The radiation pattern resulting from these requirements can be seen in Figure 2. In this figure the green line (for satellite elevation angles of 10 °) divides the areas of high and low gain.

With regard to polarization, NOAA satellites transmit their APT signals using right hand circular polarization (Right Hand Circular Polarization, RHCP), showing good rejection in left hand circular polarization (Left Hand Circular Polarization, LHCP).

When circularly polarized electromagnetic waves are reflected they do it reversing the direction of their polarization, thus, if the receiving antenna is sensitive only to fields with RHCP polarization, it becomes insensitive to the reflections.

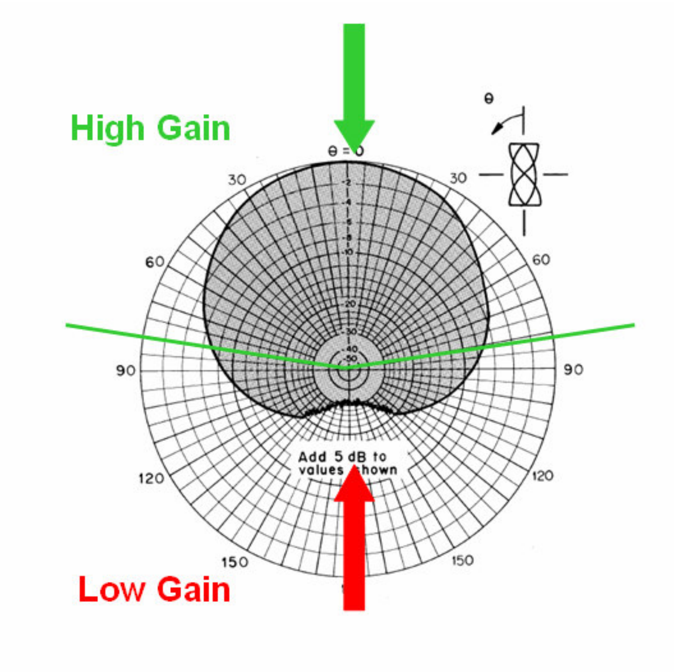

Figure 2-Requirements of the receiving antenna.

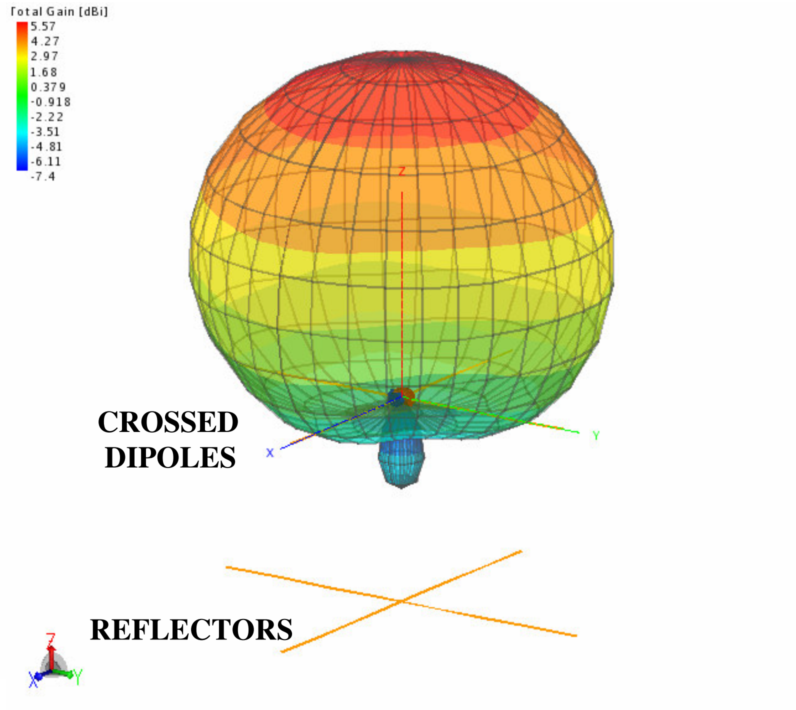

Figure 3-Crossed Dipole Antenna and simulation of its radiation pattern.

3 .- DESIGN

Two antennas that cover the raised requirements are Turnstile Antenna or Crossed Dipoles [1-2] and Quadrifilar Helix antenna [3-8]. In both the radiation pattern can be adjusted by varying its dimensions. To design the antennas they were sized based on the references [1-8], then ran simulations using the commercial software FEKO Suite 6.0 [9] and their dimensions were adjusted to obtain the optimum radiation pattern.

Figure 3 shows the Crossed Dipoles antenna with its simulated gain pattern obtained by the FEKO Suite 6.0 software. This antenna consists of two half lengthwave dipoles, mounted at right angles, and fed with a phase difference of 90 °. Below the active dipoles lies a reflector consisting of two other dipoles with a length 10% greater than the former.

The radiation pattern of this antenna is highly dependent on the separation between the active dipoles and the reflector.

An optimized diagram for a separation of a quarter wavelength was obtained according to the set of requirements. The polarization of the field generated by this antenna is circular in the direction of maximum gain, being able to achieve right hand circular polarization (RHCP) or left hand circular polarization (LHCP) depending on which of the dipoles are fed with phase lag of 90 °.

Figure 4 shows the Quadrifilar Helix antenna with the corresponding simulation gain diagram. This antenna consists of two bifilar helical loops, orthogonal to each other, on a single axis, surrounding a common volume. The power in the two arms of the antenna is supplied in phase quadrature.

The Quadrifilar Helix antenna was developed by Dr. C. C. Kilgus between 1968 and 1975 [5-8]. The helix antenna has unique and versatile properties.

The radiation generated by this antenna provides circular polarization with the same sense in the whole field of radiation.

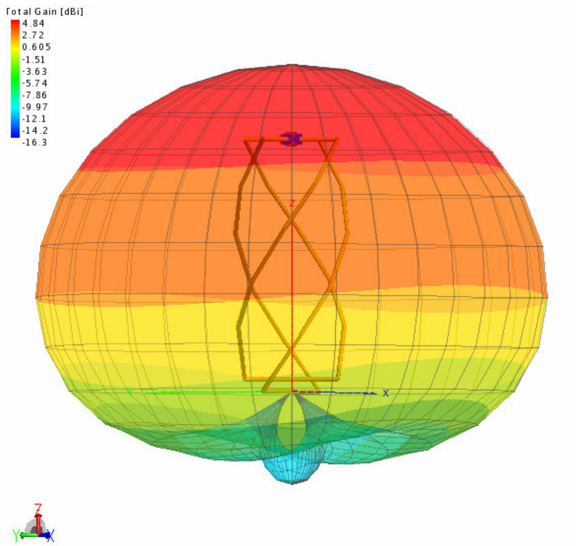

Figure 4-Quadrifilar Helix Antenna and simulation of its radiation pattern.

Through the proper configuration of the loops, a wide variety of radiation patterns can be achieved. Figure 5 shows one of the possible antenna configurations [7].

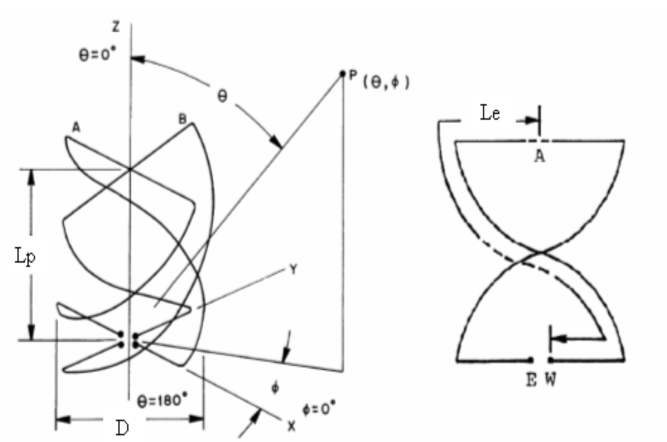

Figure 5-Diagram of a half turn Quadrifilar Helix Antenna.

Characteristic parameters of the antenna are:

T: number of turns of the helix.
D: diameter of the imaginary cylinder surrounding the antenna.
Lp: axial length
Le: half the helix length of each bifilar (total length of each link between terminals is 2xLe).

An additional parameter relating the diameter with the axial length of the antenna is defined:

$$R = \frac{D}{Lp}$$

R is a design parameter that determines the shape of the radiation pattern of the antenna.

The polarization of the field generated by this antenna is circular, and its opposite to the direction of the thread of the antenna. Sensitivity can be achieved in the upper hemisphere or lower hemisphere depending on which of the loops is fed with phase lag of 90°.

To size the antenna articles published by Kilgus [5-8] in which the author shows the results of experimental measurements of ¼, ½, 1, 2, 3 and 5 laps. quadrifilar helix antennas were analyzed The antennas mentioned in these articles were designed to be sensitive to LHCP polarization, contrary to what was required. In the article by R. W. Hollander [3], based on the work of Kilgus, the author proposes a design for reception of APT signals from weather satellites.

It was decided to use the Hollander design consisting of a helix half turn and a half wavelength (Le = λ / 2), with a ratio between the diameter and the axial length of the antenna R = 0.44.

4 .- SIMULATION

The simulations of the antennas under study were performed with FEKO Suite 6.0, in a frequency of 137.5MHz, which is the central frequency of the APT transmission band of NOAA satellites.

Figure 6 shows the radiation pattern of the crossed dipoles antenna gain, which refers to the radiator isotopic radiator expressed in decibels, (in function) depending on the angle θ shown in Figure 5, obtained from the simulations.

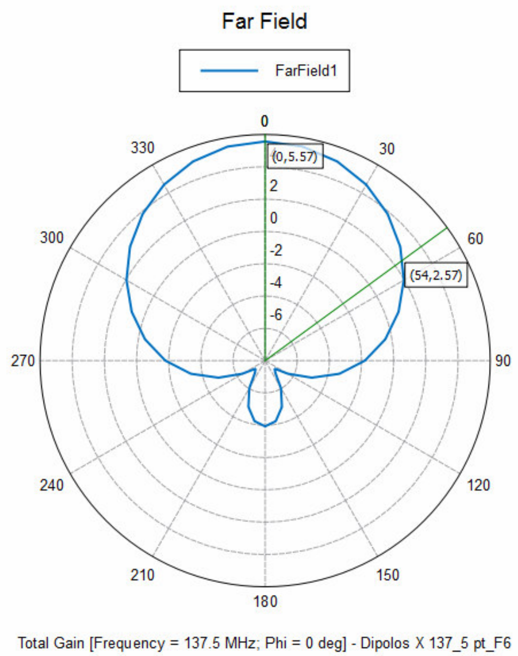

Figure 6 - Diagram of radiation of the crossed dipoles antenna obtained from the simulation.

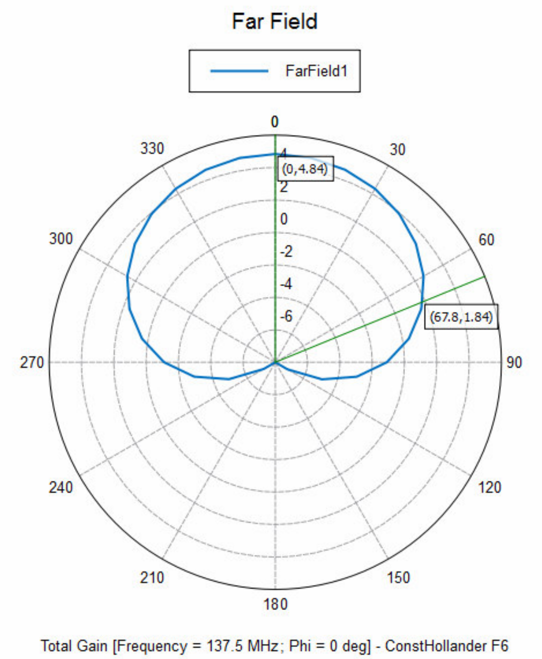

Figure 7 - radiation pattern of Quadrifilar helix antenna obtained from simulation.

You can see that the most profitable area of the diagram is located in the upper hemisphere with a value of 5.57dB in the direction of maximum radiation. The half-power angle of the diagram is 108°. For the angle θ = ± 90° in the diagram, the gain falls 7.5dB with respect to the direction of maximum radiation and for an angle of 130° the difference is 13dB.

Figure 7 shows the equivalent diagram for a Cuadifilar Helix antenna. In this case, the most profitable area of the chart also is also located in the upper hemisphere with a value of 4.84dB in the direction of maximum radiation. The half-power angle is 135.6°. For the angle θ = ± 90° of the diagram the profit falls 6dB in respect to the direction of maximum radiation and continues to fall towards the lower hemisphere of the diagram.

For an angle of 120° the difference is 15dB. Figure 8 shows a Cartesian graph of a crossed dipoles antenna where polarization components RHCP and LHCP stand, and in Figure 10 the graph of the axial ratio for the same antenna for the frequency of 137, 5MHz.

For an angle θ = 0° the right hand circular polarization component is 57dB above the left hand circular component. For the value of θ corresponding to half-power angle (θ = 55°) the difference between polarization is 10.5dB and for an angle of θ = ± 90° both components are equal.

The axial ratio (Figure 10 and 11) indicates the degree of purity of circular polarization. Low values indicate pure circular polarization, medium values indicate elliptical polarization and high values indicate linear polarization.

Analyzing Figure 10, can be seen that the Crossed Dipole antenna has linear polarization for values of θ = ± 90°, pure circular polarization in angles θ = 0° and θ = 180°, and elliptical polarization at intermediate angles.

In Figures 9 and 11 diagrams of polarization and axial ratio were simulated for a Quadrifilar Helix antenna, under the same conditions as on the Crossed Dipole antenna.

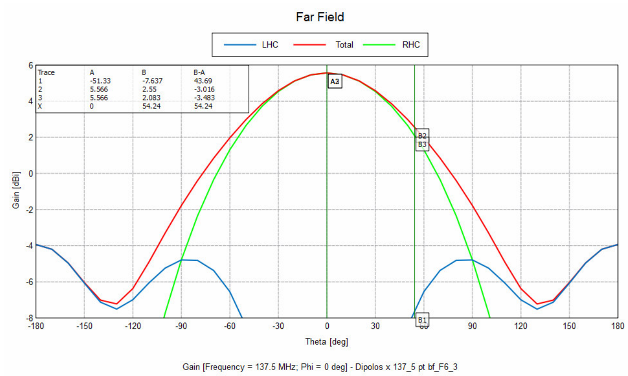

Figure 8 - Polarization Components of Crossed Dipole antenna obtained from simulation.

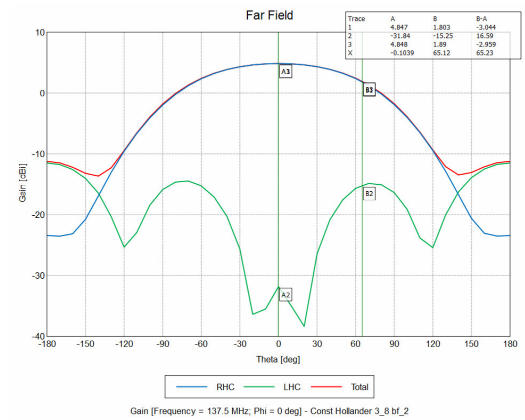

Figure 9 – Polarization Components of a Quadrifilar Helix antenna obtained from simulation.

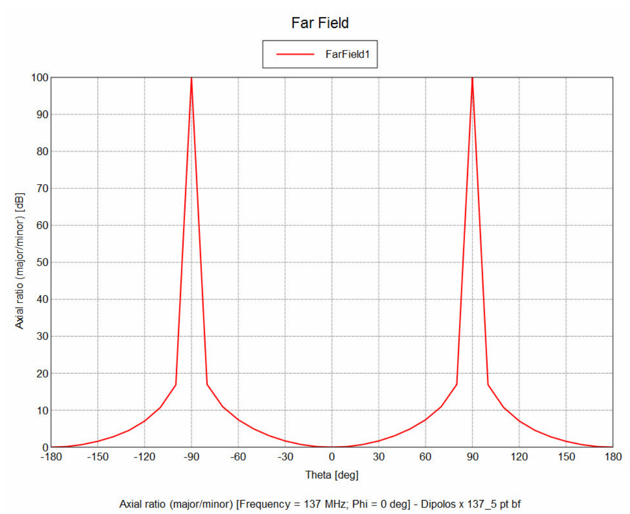

Figure 10 - Axial Ratio of a Crossed Dipole antenna obtained from simulation.

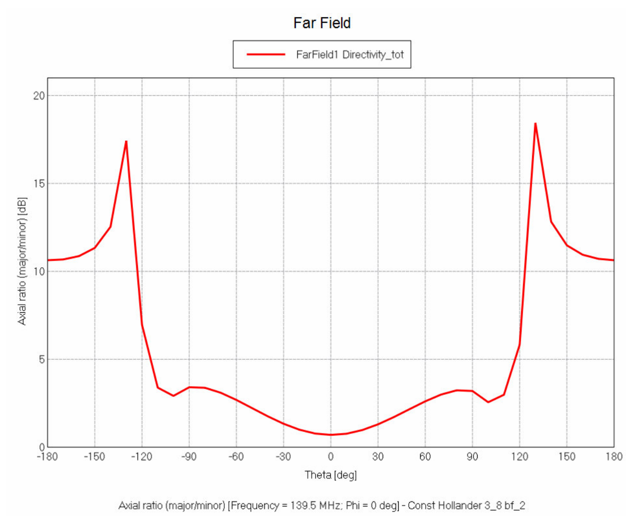

Figure 11 - Axial Ratio of a Quadrifilar Helix antenna obtained from simulation.

In QFH for angle values ranging from ± 140°, the right hand circular polarization component is higher than the left hand circular component. It can be seen that for an angle θ = 0° the right hand circular polarization component is 37dB higher than the left hand. For values of θ corresponding to half-power angle (θ = 65°) the difference is 17dB and at angles of θ = ± 90 ° the difference is 7dB.

The value of the axial ratio for the Helix antenna is maintained below 17dB in the whole diagram. The values shown in figure 11 indicate that this antenna has right hand circular polarization with a high degree of purity in all its radiation pattern. Therefore it has better rejection of reflections on the horizon and better satellite reception than the Crossed Dipole Antenna.

The versatility of FEKO Suite 6.0 software allows making three-dimensional graphics that makes easier to observe the polarization characteristics and axial ratio of the antenna throughout its radiation area.

Figure 12 shows a three-dimensional graphic of the Crossed Dipole Antenna axial ratio and in Figure 13 the analog graphic of the Quadrifilar Helix Antenna can be seen.

These three-dimensional graphics let us see more clearly the polarization characteristics of antennas, confirming the information obtained from 2D diagrams (Figures 8 and 9).

The crossed dipole antenna has linear polarization in the horizontal plane, RHCP polarization in the upper hemisphere and LHCP polarization in the lower hemisphere.

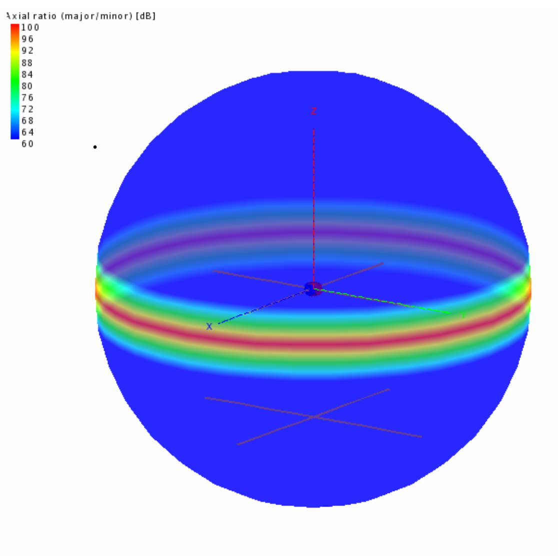

Figure 12 - Axial ratio of the dipole Crusaders observed over the entire radiation sphere.

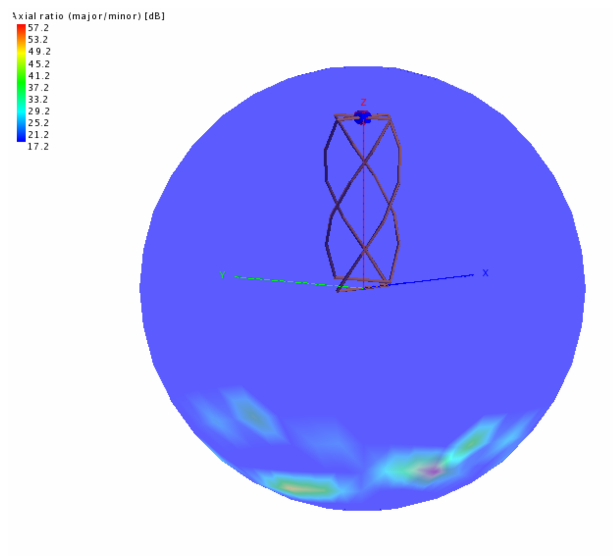

Figure 13 – Quadrifilar Helix Antenna Axial Ratio observed over the (whole) entire radiation sphere.

Red indicates high values of axial ratio, medium values of this parameter are shown in green and low values in blue.

Comparing both figures, the great contrast that exists in the performance of the antennas for satellite elevation angles of 0° (horizontal) can be appreciated.

In Figures 14 and 15 observe the polarization characteristics on the entire sphere of radiation for both antennas.

RHCP polarization is depicted in red, LHCP polarization in blue and linear polarization is shown in green.

On the other hand, the Helix quadrifilar antenna presents RHCP polarization practically in the entire field of radiation, except for a small fraction of the lower hemisphere in which presents LHCP polarization.

5 .- RESULTS

The results of the simulations were considered satisfactory. Based on the dimensions of the antenna resulting from the analysis carried out with the software FEKO Suite 6.0, experimental models were constructed from both antennas to support its features.

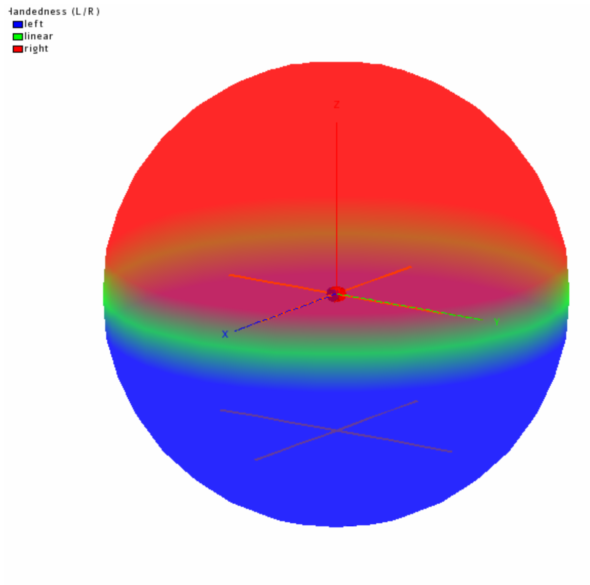

Figure 14 – Polarization Components of Crossed Dipole Antenna obtained from simulation.

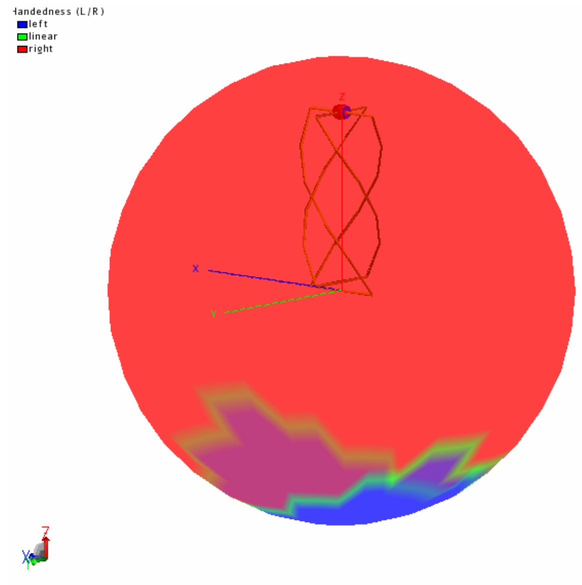

Figure 15 – Polarization Components of the Quadrfilar Helix Antenna obtained from simulation.

The models were designed and built for the frequency of 137.5 MHz, which is the central frequency of the band used by NOAA satellites to transmit their APT signals.

In Figure 16 the built model for the Crossed Dipole Antenna can be seen.

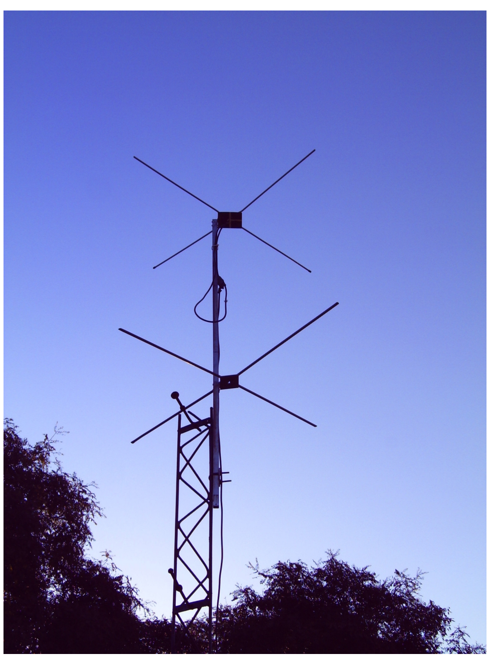

Figure 16 – Built Model of the Crossed Dipole Antenna.

A measurement of the Stationary Wave Ratio (SWR) was made for this model, giving a value of less than 1.3 for the frequency band of interest. The bandwidth obtained was 18%.

Experimental trials were conducted with the Crossed Dipole Antenna model receiving satellite images with good performance, however, the signal to noise ratio of the received signal is acceptable when the satellite reaches 25° elevation angle.

Figure 17 shows a graph of the radiation pattern of an experimental model of a Quadrifilar Helix Antenna, built by R. W. Hollander [3] (plotted in black). Blue shows the results of the simulation carried out with FEKO Suite 6.0. Notice the great similarity between both diagrams.

The Stationary Wave Ratio SWR measured in the experimental model of the Quadrifilar Helix Antenna gave a SWR below 1.6 in the bandwidth of interest. For this antenna the bandwidth is 10%.

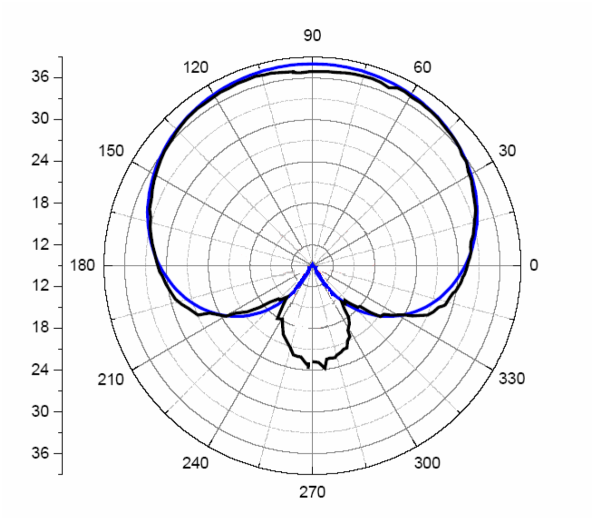

Figure 17 - Comparison of radiation patterns obtained from the simulation (blue) and measurements made by Hollander [3] (black) of a Quadrifilar Helix Antenna.

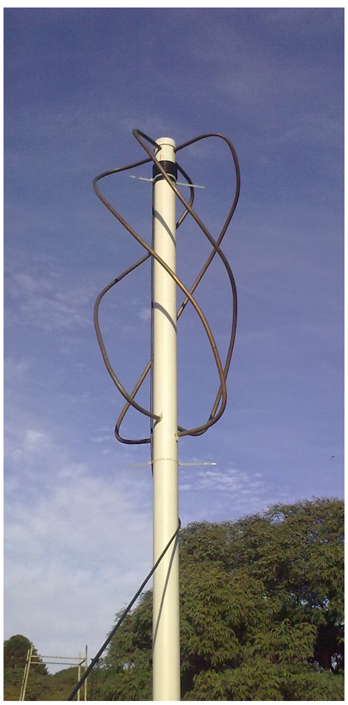

Figure 18 – Built Model Quadrifilar Helix Antenna.

With the experimental model of this antenna NOAA satellite images of very good quality were recieved (Figure 19). The signal to noise ratio is satisfactory when the satellite reaches 15 degrees in elevation, showing a better performance than the Crossed Dipole Antenna.

6 .- CONCLUSIONS

Two antennas suitable for reception of weather satellites but adaptable to receive signals from other satellites in low orbit were developed. Both antennas meet the requirements raised, but have different characteristics, mainly in its polarization properties. Comparing the axial ratio for the Crossed Dipole and the Quadrifilar Helix Antennas (Figure 10 and 11), it was observed that the rejection of polarization is greater in the central region of the Crossed Dipole, however, analyzing the axial ratio on 360° polarization rejection is better in the Quadrifilar Helix Antenna presenting also better global characteristics.

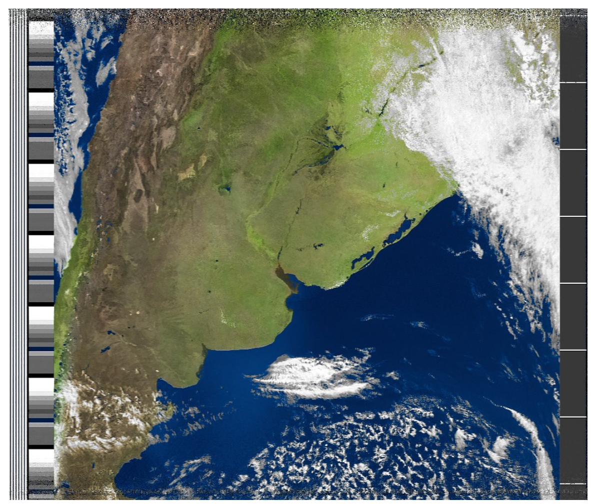

Figure 19 – Received image with the experimental model Quadrfilar Helix Antenna.

REFERENCES

[1] Kirk T. McDonald (2008). Radiation of Turnstile Antennas Above a Conducting

Ground Plane. Joseph Henry Laboratories, Princeton University, Princeton, NJ.

[2] R. Timothy Holzheimer (1991). Typical mountings for Performance Investigations of a Crossed Dipole and Quadra-helix. E - Systems inc., Greenville Texas, IEEE Trans.

[3] Hollander R.W. (2004). Quadrafilar Resonant Helical Antenna. Satellites Working Group, Tech Note.

[4] AT Adams, RK Greenough, RF WALLENBERG, MENDELOVIVICZ A., C. LUMJIAK (1974). The Quadra-Helical Antenna. IEEE Trans. AP-22, Mar. 1974, p.173-179.

[5] KILGUS S.C. (1975). Shaped Conical Radiation Pattern Performance of Quadra Backfire Helix Antenna. IEEE Trans. AP-23, May 1975, p. 392-397.

[6] KILGUS S.C. (1970). Resonant Quadra Helix Design. The Microwave Journal, Dec. 1970, p. 49-54.

[7] KILGUS S.C. (1969). Resonant Quadra-helix. IEEE Trans. AP-17, May 1969, p. 349-351.

[8] KILGUS S.C. (1968). Multi-element, Fractional Turn Helices. IEEE Trans. AP-16, Jul. 1968, p. 499-500.

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