Phased Array Antenna Analysis and Design for LEO Satellite Constellations

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***Abstract*— The main purpose of this work is to analyze and design a phased array system. Specifically, we choose 17.8 to 20.2 GHz frequency range for reception and 27.5 to 30 GHz for transmission. This work has been applied to low orbit satellite communications (LEO), for communications between the earth stations, or gateway and the satellites. This paper describes the workflow, since patch antenna design to array antenna analysis. The goal is to compare different configurations of array. Also, specifications of known satellite constellations will be reached.**

Index Terms – patch antenna, antenna array, Ka-band, Ku-band, K-band

I. Introduction

LEO (Low Earth Orbit) satellite is used to complement 5G communications, giving global coverage [1]. It will allow massive Machine-Type Communications, that bring wide internet applications, such as Internet of Things operating in big areas or trusted communications. It will give 30 ms latency, having 2 ms latency between Earth and constellations [2].

Phased array antenna is a combination of multiple antennas, usually patch antenna. As is shown in Figure 1, beams of radio wave are created to point in different directions without moving the antennas.

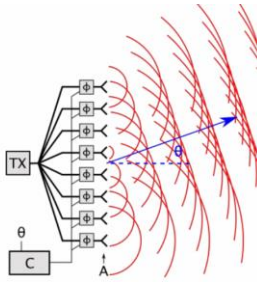


Figure 1. Patch antenna scheme.

Each antenna has a relative phase. There are variated to change the set radiation pattern. Not chosen directions will have weaker radiation. Also, in some cases it could disappear.

After studying the state of art, the conclusion is K-band is used because of ITU's protection for satellite communications [2].

II. Methodology

In order to reach the main objectives of this paper, we are working in three environments: ADS (Advanced Design System) to design the antenna, EMPro to get its gain pattern and SystemVue to model the arrays.

A. Patch antenna design

First, substrate material is chosen. Based on dielectric constant, Taconic TLX-8 is selected for transmission, and Taconic TLY-5 for reception.

Second, we need to calculate patch antenna width (w) and length (L), using equations (1)(2)(3)(4) and (5) [3], basing on effective length (Leff), length extension (ΔL), dielectric constant of the substrate (ε_r), resonance frequency (f), speed of light (c), thickness of the substrate (h) and effective dielectric constant of the substrate (ε_{eff}).

$$w = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

$$L = L_{eff} - 2\Delta L \tag{2}$$

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{eff}}} \tag{3}$$

$$\Delta L = 0{,}412h\frac{(\varepsilon_{eff} + 0{,}3)(\frac{w}{h} + 0{,}264)}{(\varepsilon_{eff} - 0{,}258)(\frac{w}{h} + 0{,}8)} \tag{4}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{w}\right)^{-\frac{1}{2}} \tag{5}$$

Then, we have to get the best feeding point (Xf, Yf), using equations (6) and (7) [3].

$$X_f = \frac{L}{\sqrt{\varepsilon_{eff}}} \tag{6}$$

$$Y_f = \frac{w}{2} \tag{7}$$

Once parameters are determined, the design in ADS is made, and electromagnetic simulations are made. At this time, a 7.5 dBi transmission antenna and 6.1 dBi reception antenna are obtained.

B. *Gain pattern*

At this point, script of ADS patch antenna is got to simulate and get far field file of the antenna element.

C. *Array antenna analysis*

Using the far field file and the Figure 2 schematic, different configurations are proved with the purpose of getting the best performance.

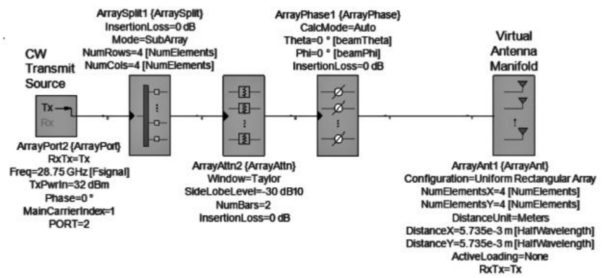


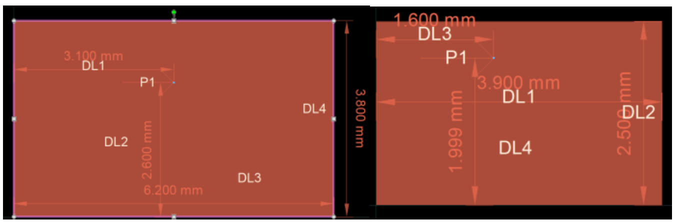
Figure 2. Array antenna schematic.

Operative satellite specifications were attempted to obtain, based of data of [4].

III. RESULTS

A. *Patch antenna*

First, in Figure 3, patch antenna found are shown. The point P1 is the feeding point.



(a) (b)

Figure 3. (a) Transmission patch antenna. (b) Reception patch antenna.

B. *Array configurations*

Three different configurations were tried to work with the array, getting the curves shown in Figure 4 and Figure 5.

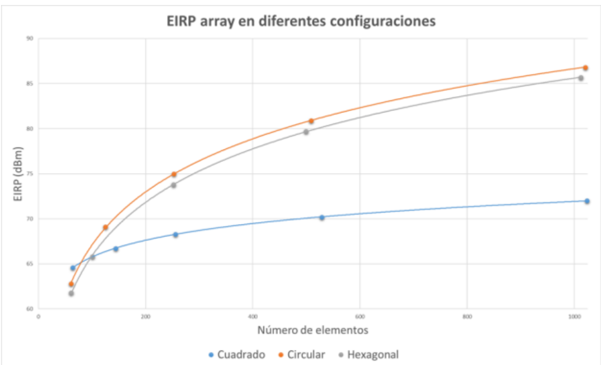


Figure 4. Transmission EIRP.

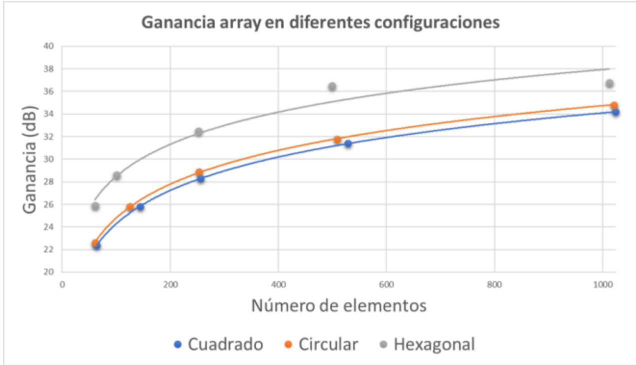


Figure 5. Reception gain.

C. *Operative satellite specifications*

Finally, operative satellite specifications are obtained, using our patch antenna. The results are summarized in Table I. Square arrays were used to get these values. Parameters such as free space path loss, atmospheric loss or path distance are got from [4].

TABLE I. OPERATIVE SATELLITE SPECIFICATIONS

Satellite Constellation	Reception			Transmission	
	Sensitivity (dBm)	***Gain (dBi)***	***Number of Elements***	***EIRP (dBW)***	***Number of Elements***
SpaceX	-112.2	40.9	4900	68.4	4500
OneWeb	-109.5	37.8	2401	63.2	1900
Telesat	-113.6	31.8	625	75.9	18500

IV. CONCLUSIONS

This paper investigates the performance of K-band patch antenna and arrays. Three configurations were proved: square, circular, and hexagonal, designed at uplink and downlink frequencies. The best performance is not for square array configuration, but it is the best way to manufacture because of the shape.

Specifications of operative satellite specifications were found, based on [4]. Patch antenna and square configuration were used to compare results.

In conclusion, the results shown throughout this paper are considered good. To get better results on terms of bandwidth, parasite patch array can be placed on the top of the main array.

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