A method for designing an offset-parabolic-reflector antenna for a ultra-high throughput satellite

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Resumen: *En este artículo se estudian parámetros y características cuando se calcula un reflector parabólico con alimentación desplazada para un sistema satelital de ultra alto desempeño para múltiples haces spot en las bandas Q/V y Ka. La banda Q/V es usada únicamente para los enlaces de alimentación y la banda Ka para los enlaces de usuario. Hay algunos parámetros que son esenciales en las comunicaciones satelitales debido que toman un importante rol en la configuración del reúso de frecuencia. En este estudio se analizará únicamente para el enlace downlink tanto en el enlace de alimentador como en el de usuario. Es importante mencionar que las polarizaciones cruzadas serán decisivas para el rendimiento y la factibilidad del sistema. Por lo tanto, es necesario analizar varios parámetros que serán introducidos en este estudio para calcular una antena con reflector parabólico con alimentación desplazada que se ajuste a nuestro sistema. Para nosotros, el objetivo más importante es ajustar y reducir los niveles de interferencia y asegurar disponibilidad para todos los enlaces satelitales en un sistema UHTS.*

Palabras clave: Antenas, aperturas en antenas, antenas satelitales, comunicaciones satelitales, ultra-high throughput satellite (UHTS), banda Ka, banda Q.

Abstract: *In this paper it is studied features and parameters when to calculate an offset – fed parabolic reflector antenna for a Ultra High Throughput Satellite (UHTS) system for multiple spot-beams both for Q/V-band and Ka-band. The Q/V-band is only used for the feeder link while the Ka band is used for the user link. There are some parameters that are essentials in satellite communications due to they take an important part of the frequency reuse configuration. In this study it will be analyzed only for the downlink at both feeder and user link. It is important to mention that the cross-polarizations will be decisive for the system performance and feasibility. Therefore, it is necessary to analyze various parameters that will be introduced in this study to calculate a satellite reflector antenna suitable for our system. For us, the most important aim is to adjust and reduce the interference levels and ensure availability for all satellite links for a UHTS system.*

Keywords: Antenna, aperture antennas, satellite antenna, satellite communications, ultra-high throughput satellite (UHTS), Ka-band, Q-band.

1. Introduction

The High Throughput Satellite (HTS) systems have evolved in an exponential manner in the last decade. For instance, Spaceway 3 was launched in 2007, which has a capacity of up to 10 Gb/s, meanwhile in 2017 the HTS satellite Echostar XIX, with a capacity of up to 200 Gb/s, was launched. Those HTS satellites are operating in Ka band and multi beam with 100 beams per satellite at least. Thus, this indicates a significant market for satellite broadband in terms of households that will not be served by terrestrial means.

In order to have both reliability and a high performance of the satellite system, the satellite antennas accomplish an important role within in an HTS system. Such satellite antennas are important for more efficiency in both Earth-space (E-s) and space-Earth (s-E) communications but it must be reduced the interferences produced by the RF links. Therefore, the most suitable design of the reflectors will give us the guidelines so that our proposed system could be feasible. By 2020 the UHTS system will have reached the 1 Tb/s capacity. Techniques like frequency reuse, multiple spot beams and circular polarization are needed in order to achieve such higher capacities desired.

In this work, it will be analyzed all features for increasing the parabolic reflector performance so as to obtain maximum advantage for frequency reuse configurations, multiple beams amount and circular polarization.

Hence, the proposed model will be fundamental to reach the communications system requirements for a UHTS system.

2. Proposed Model

2.1. Design Method

The geometry for the study is show in Figure. 1, whose parameters will be indicated below later in this section. Moving the feed out of the aperture eliminates some of the problems with axisymmetrical reflectors. Blockage losses and diffraction-caused sidelobes and cross-polarization disappear.

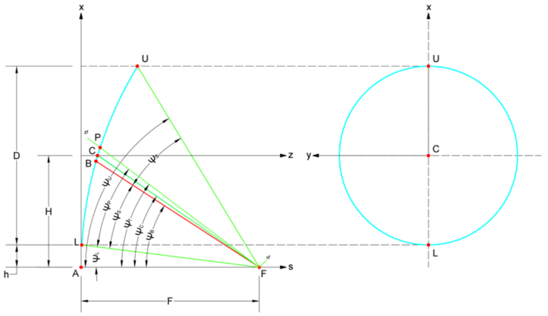

Figure 1: The geometry for the offset-parabolic-reflector antenna, [1].

Initially, there are some parameters are obtained by geometry and illumination laws for parabolic reflectors. The θ_{3dB} *beamwidth* is the angle subtended by the half power points of the main lobe (Half Power Beamwidth). This parameter is used to characterize the width of the beam.

For reflector antennas, the coefficient depends on the illumination law. A typical value is 70° when the illumination law introduces some tapering at the edge of reflector, which leads to the following expression for an aperture plane diameter D [2]:

$$D = 70 \cdot \frac{\lambda}{\theta_{3dB}} \tag{1}$$

Where θ_{3dB} beamwidth will have a value of 0.2° in Q band [3], while the θ_{3dB} beamwidth in Ka band will have a value less than 0.5° [2]. The λ is the wavelength of the frequency band used in each link.

In this study, for an offset case ($h>0$), to provide a blockage-free region for structures in the focal region. The offset distance was considered [1]:

$$h = \frac{D}{8} \tag{2}$$

Where h is the distance from the axis of symmetry to the lower reflector edge. This expression of h is popular in VSAT applications.

The distance from of symmetry to center of reflector is known as offset of reflector center H [1]:

$$H = \frac{D}{2} + h \tag{3}$$

In our design, one of the most important parameter is to keep the ratio of focal length F to diameter D constant, i.e., the value of ratio is 1 [4]:

$$\frac{F}{D} = 1 \tag{4}$$

Our contribution for this study will be to modify D according to the beamwidth in both Ka and Q/V band.

Hereinafter, we will determine the angles as shown in Fig. 1 which are indicated by Milligan [5]. The half of the angle subtended ψ_S by the reflector as viewed from the focal point which is expressed as:

$$\psi_S = \tan^{-1}\left(\frac{8 \cdot F \cdot D}{16 \cdot F^2 + 4 \cdot H^2 - D^2}\right) \tag{5}$$

The angle which bisects the reflector subtended angle is identified as ψ_B and is defined by:

$$\psi_B = \tan^{-1}\left(\frac{16 \cdot F \cdot H}{16 \cdot F^2 + D^2 - 4 \cdot H^2}\right) \tag{6}$$

The lower angle ψ_L can be graphically expressed as:

$$\psi_L = \psi_B - \psi_S \tag{7}$$

The upper angle ψ_U is determined by the sum of subtended angle and lower angle. ψ_U is expressed as:

$$\psi_U = 2 \cdot \psi_S + \psi_L \tag{8}$$

We direct the feed an angle ψ_f from symmetry axis to the center of the projected diameter (point P). The angle is expressed as:

$$\psi_f = 2 \cdot \tan^{-1}\left(\frac{H}{2 \cdot F}\right) \tag{9}$$

The angle from lower edge of dish to feed pointing direction is defined by:

$$\psi_P = \psi_f - \psi_L \tag{10}$$

For a parabolic reflector, the spherical spreading loss for both upper ψ_U and lower ψ_L edges is given by [1]:

$$\mathrm{SPL}(\psi) = -20 \cdot \log\left[\cos^2\frac{\psi}{2}\right] \tag{11}$$

Edge illuminations have a difference between them which is expressed in dB [1]:

$$\Delta\mathrm{EI} = EI_U - EI_L \tag{12}$$

The negative of the edge illumination is the sum of the feed edge taper FT and the spherical spread loss SPL. It is expressed as [1]:

$$\mathrm{FT}_L + \mathrm{SPL}_L = \mathrm{FT}_U + \mathrm{SPL}_U + \Delta\mathrm{EI} \tag{13}$$

Hence, substituting equation (11) into equation (13) obtains the design equation [1]:

$$\Delta\mathrm{FT} = \mathrm{FT}_L + \mathrm{FT}_U = 40 \cdot \log\left\{\frac{\left[\cos\frac{\psi_L}{2}\right]}{\left[\cos\frac{\psi_U}{2}\right]}\right\} + \Delta\mathrm{EI} \tag{14}$$

Where $\Delta EI = 0$ is used for the case of balanced aperture illumination.

This is the design method for an offset-parabolic-reflector antenna, in the next section these equations will be applied to simulate and obtain parameters of the parabolic reflector designed.

3. Numerical Results

The equations (1) – (4) are used for determining the feed angle ψ_f which is one of the most important parameter of the parabolic reflector as the well as the rest of parameters that will be calculated for defining the performance of parabolic reflector. In Table 1 are shown the parameters found by the previously equations.

Table 1: Offset-parabolic-reflector antenna parameters.

Parameters	**Q Band**	**Ka Band**				**Unit**
Frequency	40.00	20.00	20.00	20.00	20.00	GHz
Beamwidth	0.20	0.48	0.40	0.32	0.26	deg
Diameter (*D*)	2.63	2.19	2.63	3.28	4.10	m
Offset (*h*)	0.33	0.27	0.33	0.41	0.51	m
Offset (*H*)	1.64	1.37	1.64	2.05	2.56	m
***F/D* ratio**	1.00	1.00	1.00	1.00	1.00	-
Focal (*F*)	2.63	2.19	2.63	3.28	4.10	m
ψ_B	32.93	32.93	32.93	32.93	32.93	deg
ψ_S	25.78	25.78	25.78	25.78	25.78	deg
ψ_L	7.15	7.15	7.15	7.15	7.15	deg
ψ_U	58.72	58.72	58.72	58.72	58.72	deg
ψ_f	34.71	34.71	34.71	34.71	34.71	deg
ψ_P	27.56	27.56	27.56	27.56	27.56	deg

The Q band is used for downlink (in the feeder link) with a frequency band of 40 GHz and a value of 0.20º for the beamwidth while for the 20 GHz band is used for downlink in Ka band. For the downlink in Ka-band, there are four beamwidths as shown in Table 1.

The ratio of focal length F to diameter D is kept constant, $F/D = 1$ [4], it is for this reason that the angle values are constants for all cases as shown in Table 1. The ratio F/D is ambitious but necessary for a UHTS system due to the fact that it is diminished the SPL losses.

In Table 2 is shown the values of the edges illumination levels in both upper and lower. The feed was modeled using a symmetric Gaussian radiation pattern with a 10 dB beamwidth of 70º [1]. Thus, we will have two feed edge taper, $FT_L = 10.0$ dB and $FT_U = 10.0$ dB.

Table 2: Edges illumination levels with symmetric Gaussian radiation pattern.

Parameters	**Q Band**	**Ka Band**				**Unit**
Frequency	40.00	20.00	20.00	20.00	20.00	GHz
Beamwidth	0.20	0.48	0.40	0.32	0.26	deg
FT_U	10.00	10.00	10.00	10.00	10.00	dB
FT_L	10.00	10.00	10.00	10.00	10.00	dB
ΔFT	0.00	00.00	0.00	0.00	0.00	dB
SPL_U	2.39	2.39	2.39	2.39	2.39	dB
SPL_L	0.03	0.03	0.03	0.03	0.03	dB
EI_U	-12.39	-12.39	-12.39	-12.39	-12.39	dB
EI_L	-10.03	-10.03	-10.03	-10.03	-10.03	dB
ΔEI	-2.35	-2.35	-2.35	-2.35	-2.35	dB

The values of EI_U and EI_L are not recommendable, a balanced aperture illumination, i.e. $\Delta EI = 0$, is required so that the feed must be pointed with an angle desirable. Table 3 shows the parameters involved in balanced aperture illumination, $\Delta EI = 0$, when the feed is pointed with an angle ψ_f.

Table 3: Edges illumination levels with a Gaussian radiation pattern which is pointed with an angle $\psi_f = 34.71º$.

Parameters	**Q Band**	**Ka Band**				**Unit**
Frequency	40.00	20.00	20.00	20.00	20.00	GHz
Beamwidth	0.20	0.48	0.40	0.32	0.26	deg
FT_U	10.00	10.00	10.00	10.00	10.00	dB
FT_L	12.35	12.35	12.35	12.35	12.35	dB
ΔFT	2.35	2.35	2.35	2.35	2.35	dB
SPL_U	2.39	2.39	2.39	2.39	2.39	dB
SPL_L	0.03	0.03	0.03	0.03	0.03	dB
EI_U	-12.39	-12.39	-12.39	-12.39	-12.39	dB
EI_L	-12.39	-12.39	-12.39	-12.39	-12.39	dB
ΔEI	0.00	0.00	0.00	0.00	0.00	dB

The feed angle is reduced until desirable cross-polarization performance is achieved. It turns out that this operating point produces a balanced aperture illumination. Therefore, for a feed's angle $\psi_f = 34.71º$ the edge illumination levels in the aperture are equal in the plane of offset [1] as shown in Table 3.

To simulate the offset-parabolic-reflector antenna, we have used a computational tool known as *GRASP®* by *TICRA®* [6] which is useful for obtaining the radiation pattern that will determine the isolation level of cross-polarization, X_{pol}. In Figure 2 is illustrated a radiation-pattern diagram for offset-parabolic-reflector antenna in Q-band, i.e. for the downlink (s-E).

The offset-parabolic-reflector antenna is configured to operate in circular polarization, i.e. the antenna has dual polarization both LHCP (Left Hand Circular Polarization) and RHCP (Right Hand Circular Polarization).

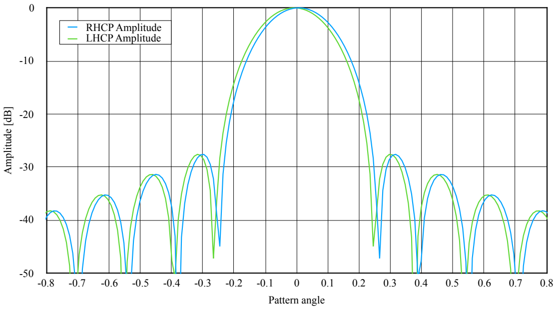

Figure 2: Normalized pattern of the offset-parabolic-reflector antenna with circularly polarization.

Results obtained from various numerical simulations, indicated that the pointing of the feed toughly influences cross polarization. In this case, the value obtained for cross polarization is $X_{pol} = 27.78$ dB, this value is within a suggested range of 20 – 40 dB. In Q-band is recommended that the cross-polarization value is $X_{pol} = 25$ dB [3]. Thus, the X_{pol} value, that was obtained by simulation, is totally viable.

Consequently, the feeder link will be able to operate efficiently with dual-polarization configuration for the downlink (s-E). This link must have robustness for communicating with Earth Stations and to avoid interferences each other.

In addition, simulations were run for the downlink in Ka band (s-E), using *GRASP*, similar to simulations in Q band. The simulation results are shown in Table 4.

Table 4: Cross-polarization X_{pol} values for the downlink (s-E) in Ka band.

Frequency	**20.00**				GHz
Beamwidth	0.48	0.40	0.32	0.26	deg
X_{pol}	27.39	27.33	27.25	27.16	dB

As shown in Tab. 4, X_{pol} values are within recommended range of 20 – 40 dB so that these values can be used with dual polarization for increasing the capacity on the downlink without impacting both RHCP and LHCP polarizations. All calculations in this paper are performed on an Intel Core i5 2.70 GHz machine with 16 GB RAM.

4. Conclusions and Future Work

In this paper we have analyzed and calculated an offset-parabolic-reflector antenna capable of operating at a Ultra-High Throughput Satellite system. The first results were obtained by the GRASP software, which was useful for determining the cross-polarization levels for both bands, Q and Ka respectively, and their different beamwidths. The cross-polarization levels are in an allowed range of 20 – 40 dB in all cases. The edges illumination levels were equalized for operating in a high performance in our system. Thus, this antenna design will be able to manage all the spot-beams required in a UHTS environment.

Finally, in a future work, we are going to evaluate the interferences generated due to the frequency reuse. The *C/I* evaluation will be the most important part to understand the behavior of the spot-beams projected on the Ground Segment within a frequency reuse environment. The *C/I* level will indicate if the design of this antenna will be feasible.

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