FEASIBILITY STUDY FOR THE FOCALISATION OF THE NEW 40m RADIOTELESCOPE OF CENTRO ASTRONÓMICO DE YEBES

E. García[1], L. de Haro [1]*, J. A. López Fernández [2], F. Tercero [2], B. Galocha[1], J. L. Besada[1]

[1]*Grupo de Radiación. Dpto. Señales, Sistemas y Radiocomunicaciones.*

Universidad Politécnica de Madrid. Spain.

[2]*Centro Astronómico de Yebes (CAY). Ministerio de Fomento. Spain.*

Mail address: E.T.S. de Ing. de Telecomunicación. Ciudad Universitaria.

E-28040 Madrid (SPAIN)

Phone: +34 91 549 57 00 ext. 397 Fax: +34 91 543 20 02

e-mail: quique@gr.ssr.upm.es

Abstract: **This paper presents a first study of the focalisation of the new 40m. radiotelescope of Centro Astronómico de Yebes (Spain) which may operate at S, X, K and millimetre bands with a multiband feed system with minor mechanical changes on a classical Cassegrain type radiotelescope. The geometry of this Cassegrain antenna radiotelescope consists of a 40m paraboloidal main reflector with f/D=7.915.**

I. INTRODUCTION

In radioastronomy there are several scientific observation bands of interest, from 2 GHz up to higher than 300 GHz [1], [2]. It is necessary an individualized study of the problem for each observation band [1], [3], in order to design the feeds and the focalization elements such as lenses and conical or plane mirrors [1], [2], [3], [4], [5].This paper is related with the necessity of the focalization of the new 40 m Nasmyth-Cassegrain radiotelescope of the Centro Astronómico de Yebes in Spain with F/D ratio of 7.9 [6]. Our aim is to cover several bands from 120 GHz to 2 GHz. There is a dimension constraint in the receiver cabin for the situation of all the receivers, so it is suitable to share the maximum number of focalization elements for each observation band. In this paper it is verified, such as an example of the method, a possible solution to share an ellipsoidal mirror in three observations bands behind the Nasmyth M3 & M4 mirrors. In *Figure 1* the receiver cabin and the physical dimension available for the situation of the receivers and their focalization elements are represented [6]. It can be seen that the cabin presents two Nasmyth asymmetric sections centered on M4 and M4' mirrors optical axis, that can be selected by means of Nasmyth mirror M3.

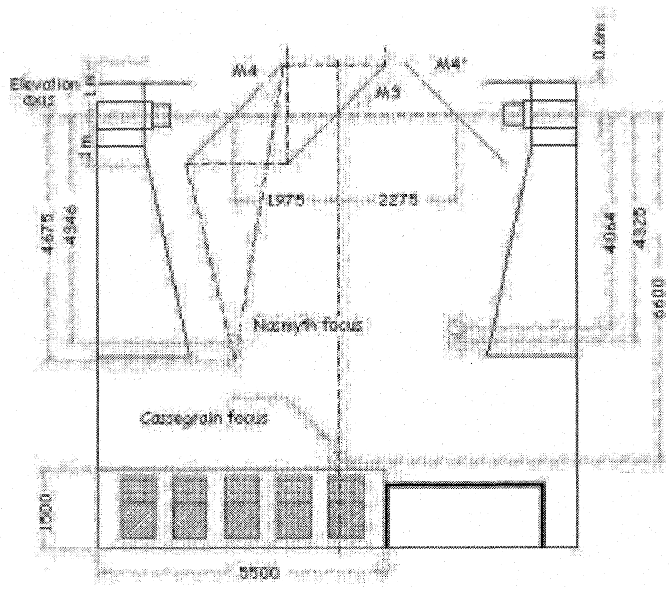

Figure 1: Radiotelescope receiver cabin.

II. FOCALIZATION PROBLEM

To deal with the focalization problem of the different radiotelescope bands, the quasi-optics theory (QO) is used in this paper [1], [7], [8], [9], [10]. In order to achieve the proper focalization of the radiotelescope two fundamental requirements are necessary: the first one is that the subreflector (and so the main reflector) has a suitable taper (illumination level in the edge), of 12 dB taper for an optimum aperture efficiency. The second requirement is to exist a perfect focalization, in terms of geometry optics (GO) [3], that feeders are situated in the system foci. In many observatories it is common to make independent focalization systems for each band, only sharing some plane mirrors to redirect the beams [11], [12], [13]. However, in this paper, a novel design procedure is proposed to focalize simultaneously several frequency bands with the minimum possible optic elements [11], [12], [13]. Moreover it has been applied to design Yebes focalization system at 42-48 GHz, 70-90 GHz and 92-120 GHz bands. This solution has a double improvements: a reduction of the number of focalization elements and the total cost of manufacturing and a reduction of the density of optical elements on the receiver cabin allowing more free space for technical maintenance [1], [6] without reducing antenna performance.

Gaussian Beam analysis has been employed to study the behaviour of the fields reflected and subtended in the receiving cabin of the radiotelescope. Different solutions and combinations of ellipsoidal, hyperboloidal, paraboloidal and lenses are used to place the receivers in the limited size of the cabin. First, the main parameters of the fundamental Gaussian Beam Mode are calculated according to the desired horn in each band. Those non optimal solutions because of the sizes of the different focusing elements and the sizes of the feed horns are neglected. By doing so, with the optimal solutions for each band presented in this paper, it has been extensively employed to calculate the electromagnetic behaviour of the fields in the receiving cabin a study of the propagation of the higher order modes.

II. ANALYZED OPTICS

Defocused gaussian beam telescope geometry and its tolerance with the changes in the values of their lenses and focalisation distances are analysed. The gaussian beam telescope is very useful in systems that must operate over broad bandwidths. This device has particularly functional properties in Cassegrain radiotelescope focalisation systems. A pair of focusing elements separated by the sum of their focal lengths is called a gaussian beam telescope [1], [6]. This device has particularly useful properties in radiotelescope focalisation systems that must operate over broad bandwidths. Systems with such a structure are frequency independent. One of the best approaches to study the properties of this geometry, is the Quasi-Optical (QO) theory, which is explained in [1], [6], [9].

However, this frequency independence has several limitations if some quasi-optical parameters are analysed. If a corrugated horn is used as the feed, some dependence of the beam waist with frequency is expected. If it is desired to focalise an observation Cassegrain radiotelescope band [1], [6] with this kind of horn and with the gaussian beam telescope structure in a wide margin, it is necessary to defocus the geometry to achieve the right taper (edge illumination level in the subreflector and therefore in the main reflector) and focalise the beam in the subreflector. In terms of QO, to achieve the right beam radius (w) and the radius of curvature (R) in the subreflector.

This paper deals with the necessity of focalising the new 40 m Cassegrain radiotelescope of the Centro Astronómico de Yebes in Spain. The F/D ratio of this radiotelescope has a value of 7.9 and there will be nine receivers from 10 GHz to 120 GHz bands, including also VLBI measurements in S/X bands. Making use of QO theory, this paper studies the behaviour of the radiotelescope in one observation central frequency (90 GHz) with the defocused gaussian beam telescope configuration geometry. Tolerance results with displacements of the separation distances among the optical elements and with variations in the focal distances of the lenses are considered.

The 90 GHz central frequency is selected to expose some tolerance results of the defocused gaussian beam telescope. The geometry and the parameters notation is shown in *Figure 2*. The selected feedhorn is a corrugated one. In terms of QO, it is possible to define the theoretical main dimensions of this horn knowing the beam waist of the quasi optical beam that it must generate [13] and the phase error over the horn aperture plane. One way to do that involves the use of three parameters. Two of them are related to the Cassegrain radiotelescope and to the beam that has to illuminate it: the F/D ratio and the taper at the angle defined by this F/D ratio. The third parameter is the phase error over the horn aperture plane.

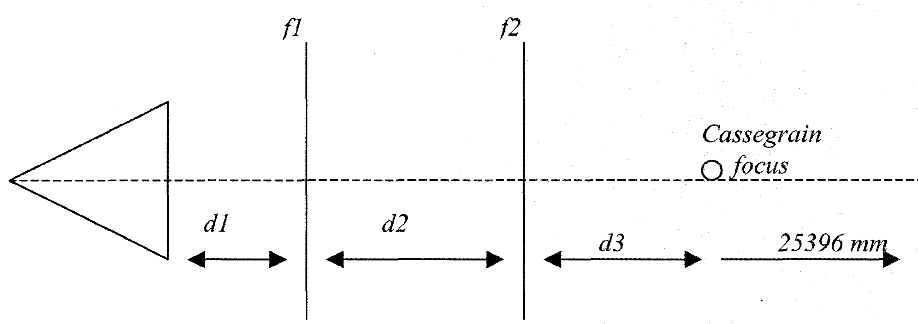

Figure 2: Defocused gaussian beam telescope geometry.

In this paper a F/D ratio of 1.5, a 12 dB taper and a phase error aperture of 0.24 are used. With these characteristics the physical implementation of the horn is guaranteed. The theoretical horn radius and slant length are equal to 6.85 mm and 29.37 mm, respectively.

This horn produces a beam waist of 3.74 mm, which is entirely inside of the paraxial approximation. To show the functional properties of the defocused gaussian beam telescope, the band from 70 to 110 GHz is studied.

The geometry formed by horn + ideal lens + ideal lens is used, but without preserving the values of the distances between the optical elements which would form the focused gaussian beam telescope. Some restrictions are imposed to the focalisation problem due to the design requirements of the Yebes radiotelescope. For a subreflector radius ($R_{subreflector}$) of 1640 mm and an edge taper (T) of 12 dB, it follows:

$$w_{subreflector} = R_{subreflector} \cdot \sqrt{\frac{20}{T \cdot ln(10)}} \quad (1)$$

Therefore the beam radius in the subreflector must take a value of 1395.3 mm. If the focalisation of the system is also required, the radius of curvature must be equal to the distance of the Cassegrain focus, f_s = 25396 mm in the radioastronomical observation band. Furthermore other important requirement has been included in the synthesis of the gaussian beam telescope. As the feed system will be a part of a radioastronomical receiver, a low noise level is essential. Noise level can be reduced cooling the optical system inside a cryostat. Only the horn and the first lens can be cooled due to physical considerations. In order to achieve that, several restrictions on the dimensions of the intermediate beam waist on the cryostat window are introduced. As the diameter of the cryostat window is 140 mm, the intermediate beam waist should be smaller than 35 mm. Finally, the beams in all the band are truncated to a 4w diameter [6], [9], so an accurate analysis in terms of QO theory is again guaranteed. The percentage error allowed to the beam radius and to the radius of curvature in the subreflector in all the band is 1% and 0.05%, respectively.

III. RESULTS

Quasioptical theory has been applied to design a defocused gaussian beam telescope. Geometry is optimised using the conjugate gradient method to achieve all the requirements exposed. Results are presented in *Figure 3 - Figure 14*. The optimal value of the parameters are d1=79.57 mm, d2=86.56 mm, d3=268.00 mm, f1=86.08 mm and f2=908.66 mm. Taper in all the band is between 12.25 and 12.3 dB, and defocusing is $\pm 3\lambda$, which are entirely suitable for Cassegrain systems. The two lenses are perfectly feasible [1], [9]. A tolerance study on the different physical dimensions of the gaussian beam telescope has been done. The aim of this study is to simulate the effects of little displacements between the components and errors on the manufacture of the lenses. The allowed tolerance is 5 mm for each physical dimensions. It has been found that the critical parameters for a designed system are the focal distance of the first lens and the distance between this lens and the aperture of the horn. In *Figure 5 - Figure 6*, little variations of f1, due to contraction of the dielectric material of the lens inside the cryostat, for example, imply a strong variation of the beam radius on the subreflector. The radius of curvature varies too, but no so rapidly. Defocusing presented in radius of curvature figures, have two limits, one for $\pm 3\lambda$ and other for $\pm 10\lambda$, which is still completely suitable in Cassegrain radiotelescopes with high F/D ratio. The same considerations can be applied to the tolerance study for d1, as it is shown in *Figure 9 - Figure 10*. Finally, tolerance study on d2, d3 and f2, shows that both, beam radius and radius of curvature, are more robust with little variations of the parameters.

IV. CONCLUSIONS

Defocused gaussian beam telescope has been analysed with Quasi-optics theory. Variation tolerance in all the parameters of the geometry has been presented in several figures for the central band observation frequency of 90 GHz. Allowing a minimum percentage error of beam radius and radius of curvature over the subreflector, it is possible to achieve a right focalisation in a wide band with the defocused gaussian beam telescope geometry, which is demonstrated by the large band study realised from 70 to 110 GHz centred in 90 GHz. From the figures presented it follows that the radius of curvature tolerates the changes in the value of the telescope parameters better than the beam radius does. Therefore, the defocused gaussian beam telescope is more robust in focalisation than in taper (illumination) when there are variations in the geometry parameters.

V. ACKNOWLEDGEMENT

This work have been realized in the Grupo de Radiación of the Universidad Politécnica de Madrid (Spain) and in the Centro Astronómico de Yebes (Spain), as part of a contract for the electromagnetic design of the new 40 m radiotelescope of this Observatory.

VI. REFERECNCES

[1] P.F.Goldsmith, "*Quasioptical Systems,*" IEEE Press/Chapman & Hall Publishers Series on Microwave Technology and RF. New York 1997.

[2] Rohlfs K., Wilson T. L., "T*ools of Radio Astronomy*", *Springer, Third Edition, Astronomy & Astrophysics Library, 1999.*

[3] G. A. Deschamps, "*Ray tehcniques in electromagnetics*" *Proceeedings of the IEEE, Vol 60, No 9, Sep. 197, pp 1022-135.*

[4] Kraus J.D., *Radio Astronomy,* "2nd Edition, Cygnus Quasar Books, 1986.

[5] Burke F. B., Graham-Smith F., "An Introduction to *Radio Astronomy*", Cambridge University Press, 2000.

[6] López Fernández J. A. et al., "*Configuración óptica del radiotelescopio de 40 m del CAY*", Technical repport of OAN, 2001.

[7] J. Tuovinen, "*Accuracy of a gaussian beam*" *IEEE Transanctions on antennas and propagation, Vol 40, No 4, Apt. 1992, pp 391-398.*

[8] L. Empacher, W. Kasparek, "*Analysis of a multiple-beam waveguide for free-space transmission of microwaves*" *IEEE Transanctions on antennas and propagation, Vol 49, No 3, March 2001.*

[9] P.F.Goldsmith, "*Quasi-optical techniques*" *Proceeedings of the IEEE, Vol 80, No 11, Nov 1992,pp. 1729-1747.*

[10] R.J. Wylde, "*Millimetre-wave gaussian beam-mode optics and corrugated feed horns*" *IEEE Proceedings, Vol 131, Pt H, No 4,Aug. 1984, pp 258-262.*

[11] J.A.Murphy, "*Distorsions of a simple gaussian beam on reflection from off-axis ellipsoidal mirrors*", *International Journal of Infrared and Millimetre Waves, vol 8, pp 1165-1187, 1987.*

[12] A. Azeez, A. Rashed, B. Saleh,"*Decentered gaussian beam*", *Applied Optics, Vol 34, No 30, Oct 1995.*

[13] James W Lamb, "*Quasioptical coupling of gaussian beam systems to large Cassegrain antennas*", *International Journal of Infrared and Millimetre Waves, vol 7, No 10, 1986, pp. 1511-1536.*

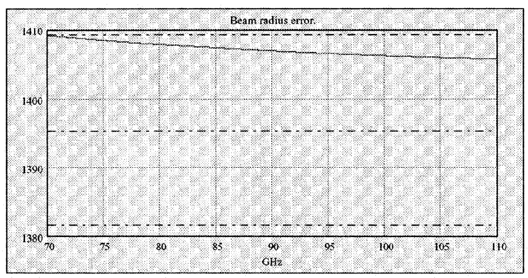

Figure 3: Beam radius in the observation band for optimised parameters

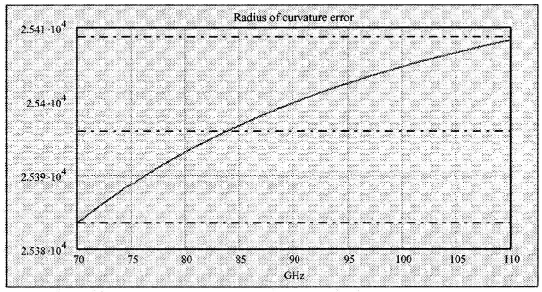

Figure 4: Radius of curvature in the observation band for optimised parameters.

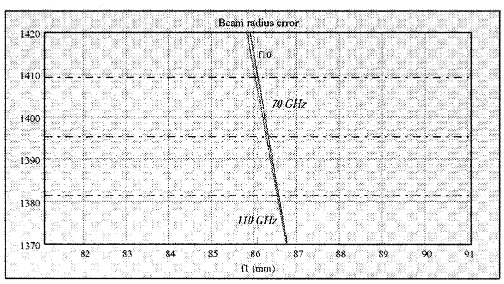

Figure 5: Beam radius for upper and lower frequencies of the band in function of the variation of f1. f10 is the optimised parameter.

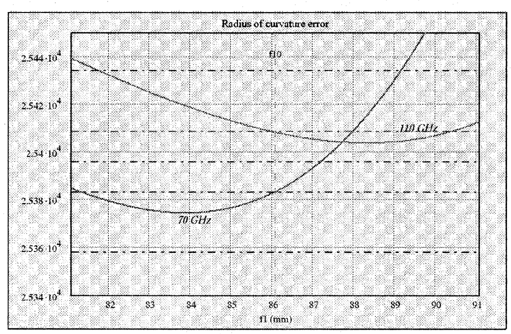

Figure 6: Radius of curvature for upper and lower frequencies of the band in function of the variation of f1. f10 is the optimised parameter.

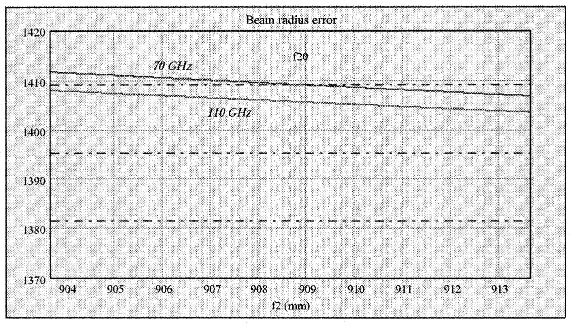

Figure 7: Beam radius for upper and lower frequencies of the band in function of the variation of f2. f20 is the optimised parameter.

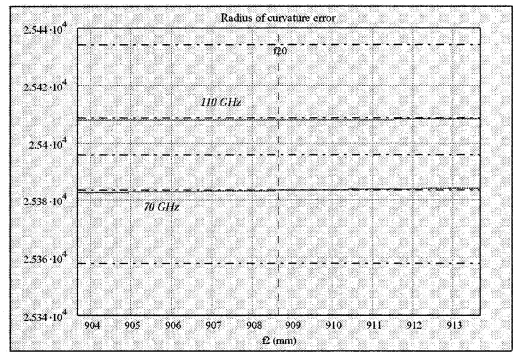

Figure 8: Radius of curvature for upper and lower frequencies of the band in function of the variation of f2. f20 is the optimised parameter.

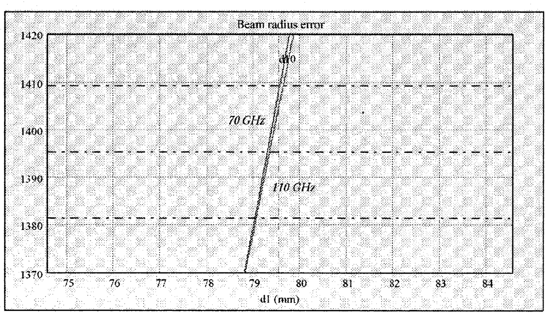

Figure 9: Beam radius for upper and lower frequencies of the band in function of the variation of d1. d10 is the optimised parameter.

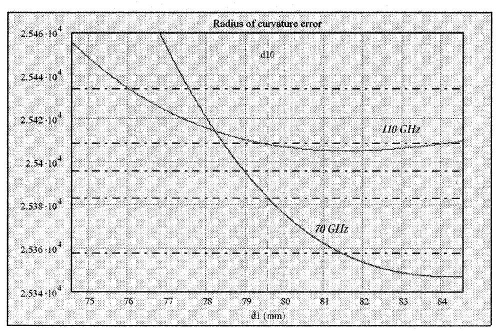

Figure 10: Radius of curvature for upper and lower frequencies of the band in function of the variation of d1. d10 is the optimised parameter.

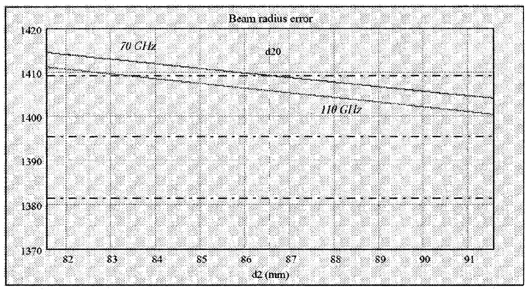

Figure 11 Beam radius for upper and lower frequencies of the band in function of the variation of d2. d20 is the optimised parameter.

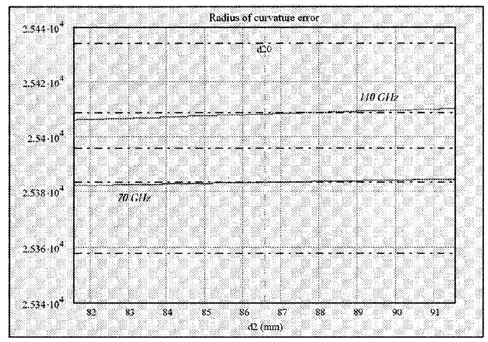

Figure 12: Radius of curvature for upper and lower frequencies of the band in function of the variation of d2. d20 is the optimised parameter.

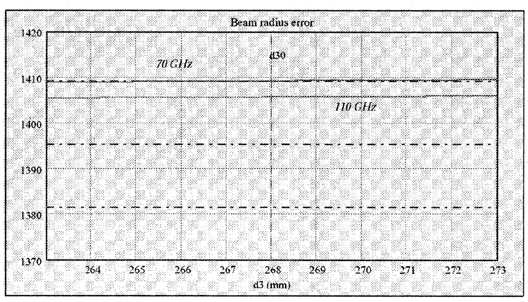

Figure 13: Beam radius for upper and lower frequencies of the band in function of the variation of d3. d30 is the optimised parameter.

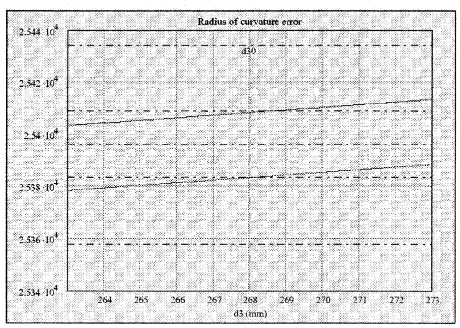

Figure 14: Radius of curvature for upper and lower frequencies of the band in function of the variation of d3. d30 is the optimised parameter.