New antenna designs for the holography system of the 40m radio telescope

Ó. García-Pérez, J. M. Serna, F. Tercero, J. A. López-Pérez

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Observatorio de Yebes
19080, Guadalajara (Spain)
E-mail: ogarcia@oan.es

Abstract– In order to improve the performance of the coherent holography system of the Yebes 40-m radio telescope, the radiating elements of both test and reference channels have been redefined. On the one hand, a new prime-focus feed horn with wider beamwidth is necessary to get better repeatability with the outer panels of the parabola. On the other hand, a new reference antenna with increased gain allows improving the quality of the reference signal. This report presents the design and experimental characterization of both antenna designs. With these modifications, we expect to improve the random surface errors at the parabola down to 150 µm rms.

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Contents

1 Introduction

Microwave holography is a technique that allows determining the surface errors in large reflector antennas using radiation pattern measurements. This is performed by analyzing the aperture field distribution, which can be in turn computed from measured radiation patterns (in magnitude and phase) of the antenna. In practice, this information is used to adjust the position of the reflector panels in order to reduce the *rms* of the random surface errors [1].

In the case of the Yebes 40-m radio telescope, a coherent holography system based on a dual channel Ku-band receiver, for prime focus operation and at room temperature, is integrated in the antenna [2]. Geostationary satellites radiating unmodulated beacon signals at a given frequency, in the range from 11.2 to 12.75GHz, are used as far-field signal sources [3]. When the radio telescope scans a source, the signal is captured using a feed horn located at the prime focus (*test* feed). In order to provide a phase reference for the holography measurement, a second antenna pointing the radio-source is also needed (*reference* antenna). In this case, both test and reference antennas are installed at opposite sides of the subreflector cabin, as it is depicted in Fig. 1.1. In this configuration, as the reference antenna is in the optical axis of the telescope, it is automatically oriented towards the source, and both receivers are identically affected by atmospheric fluctuations.

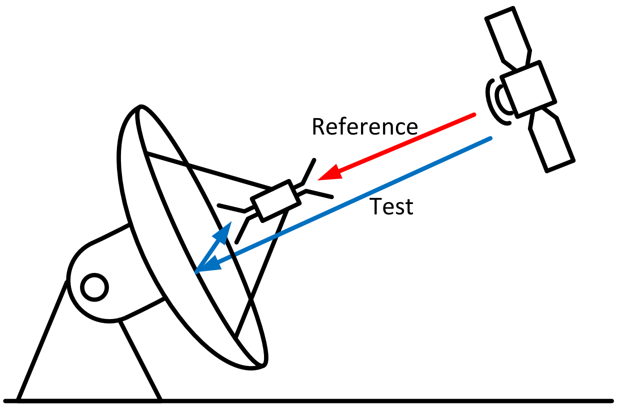


Fig. 1.1: Simplified scheme of a coherent holography system.

During the last years, campaigns of holographic measurements and panel adjustments with the 40-m primary reflector have allowed accuracy improvement to 194 µm *rms* [2]. In such studies, it was observed that the repeatability of the outer rings was appreciably worse compared to that of the central rings of the parabola, due to weaker illumination of the external sections. In order to reduce the surface error budget down to 150 µm *rms*, a new test feed horn providing more uniform illumination is proposed. On the other hand, further improvement can be expected if a reference antenna with higher directivity is used. This report presents the design and characterization of two new antennas for the two receivers of the microwave holography system of the Yebes 40-m radio telescope.

2 Feed horn for the test receiver

2.1 Test antenna currently in use

The feed antenna used up to now for holography campaigns with the 40-m telescope is a commercial choked horn antenna, model *XM-140* from *Swedish Microwave-SMW* (Fig. 2.1). The focal ratio at the prime focus is f/D=0.375, and the angle subtended by the parabola from the feed is 134.8 deg. The radiation pattern of the feed at the edge of the parabola (i.e., θ=67.4 deg) falls about -9.7 dB compared to that in the center [4]. The illumination is further reduced by the so called “free-space taper”, which is -3.2 dB in this configuration. Therefore, the total edge taper (ET) is about -12.9 dB. Although this value is closed to the optimum for maximum efficiency of a parabolic reflector, it has been concluded that a more uniform illumination is required for holography purposes in order to improve the repeatability of the outer reflector panels [2].

In order to compare with the new antenna design under the same conditions, the radiation characteristics of the XM-140 feed horn have been recently reevaluated at the Yebes anechoic chamber. The measured radiation patterns in magnitude and phase, for left-handed circular polarization (LHCP), are shown in Fig. 2.2. The normalized pattern at -67.4 deg corresponds well, on average, with that obtained in previous tests (about -9.7 dB) [4].

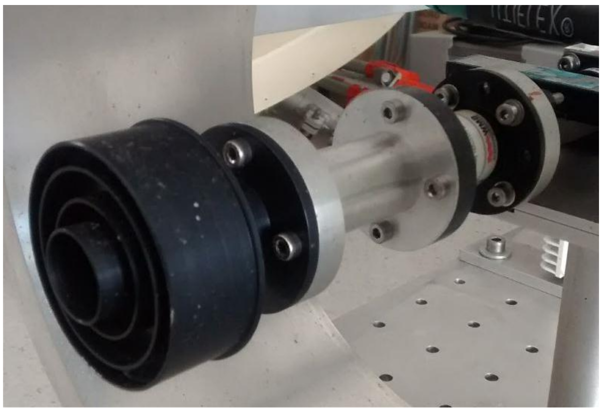


Fig. 2.1: Photograph of the XM-140 feed horn currently in use for the test channel.

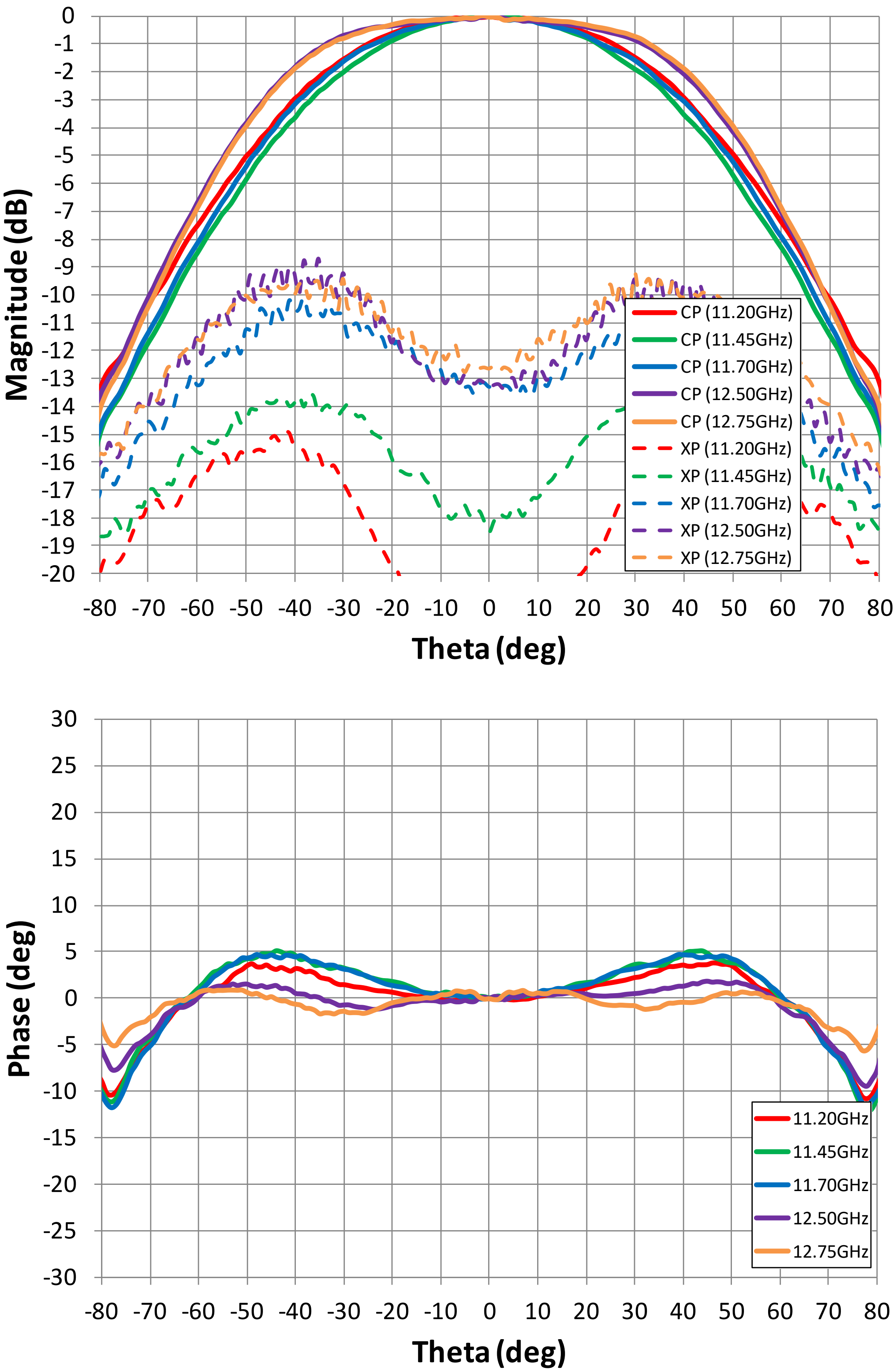


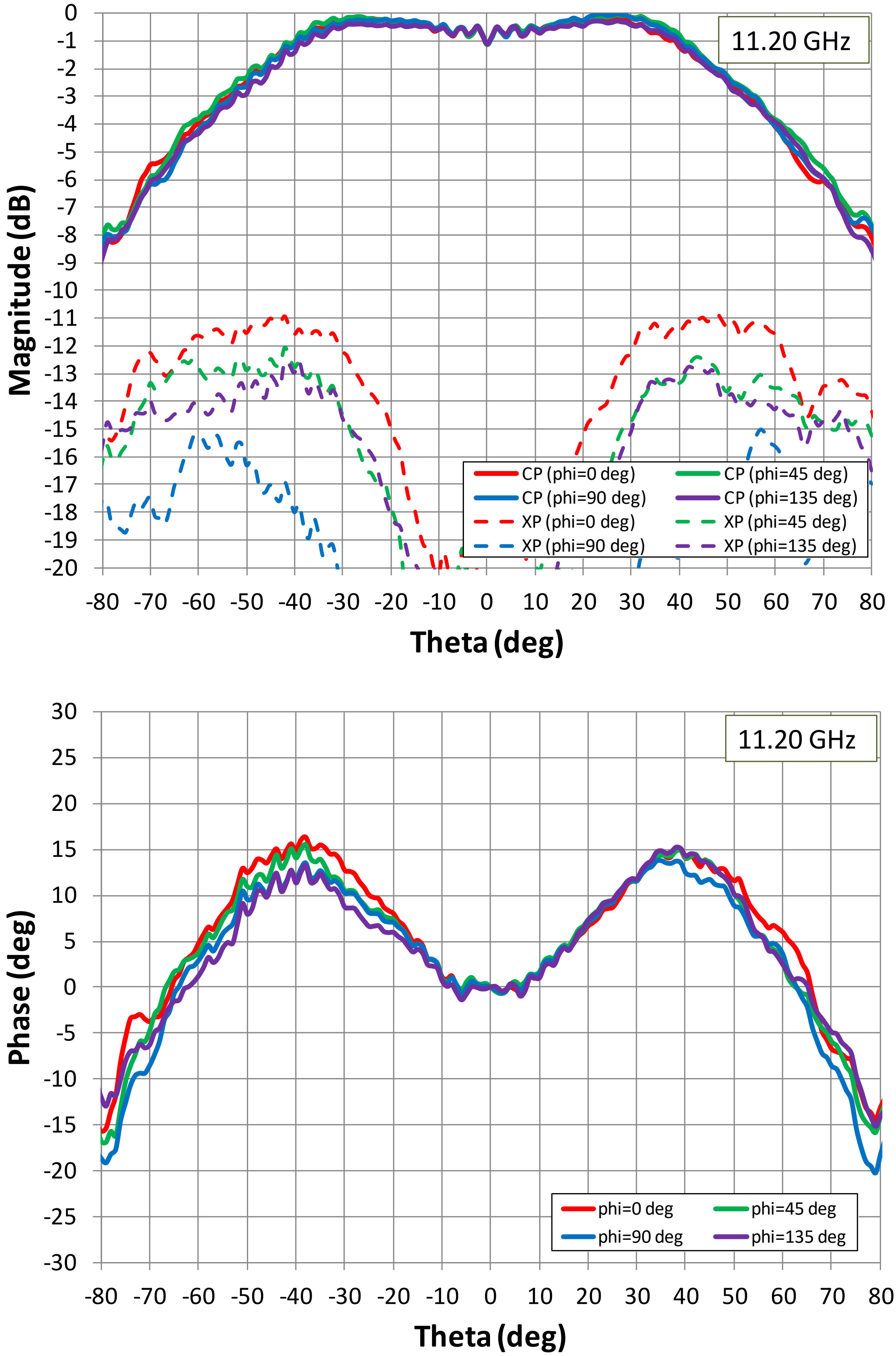
Fig. 2.2: Radiation patterns in LHCP of the XM-140 feed horn, measured in magnitude (co-polar CP, and cross-polar XP) and phase (relative to the optimum phase center at each frequency).

2.2 New test antenna

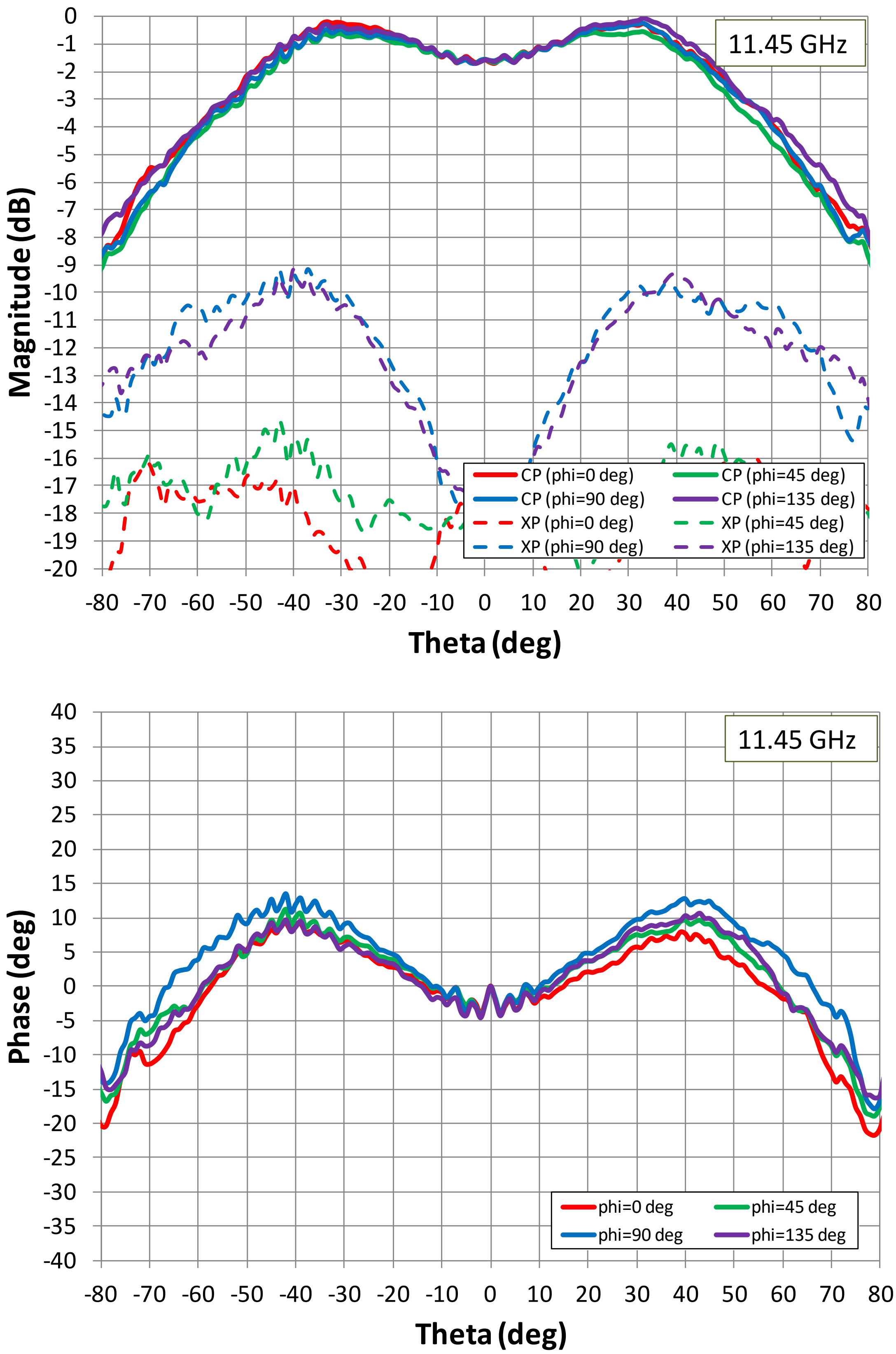
In order to improve the illumination of the outer panels of the parabola, a new antenna design with wider field characteristics has been developed. The image of the new horn antenna is shown in Fig. 2.3. The topology basically consists of an open-ended waveguide (diameter of 18 mm) with a surrounding circular reflective plane at a given distance behind the aperture. Such a plane reflects forward the back-radiation of the aperture, and therefore modifies the radiation pattern of the open-ended waveguide alone [6][7]. If the separation between the aperture and the plane is chosen to be about one-eighth of wavelength, the reflected power is combined out-of-phase with that radiated forward by the aperture at boresight ($\theta = 0$ deg), and progressively in-phase as the angle increases. In practice, this translates into a significantly wider beamwidth with a small downfall at the center of the diagram. Additionally, the outer quarter-wave choke serves also to improve, to a lesser extent, the beamwidth of the antenna.

Fig. 2.3: Photograph of the new feed horn of the test channel of the holography system.

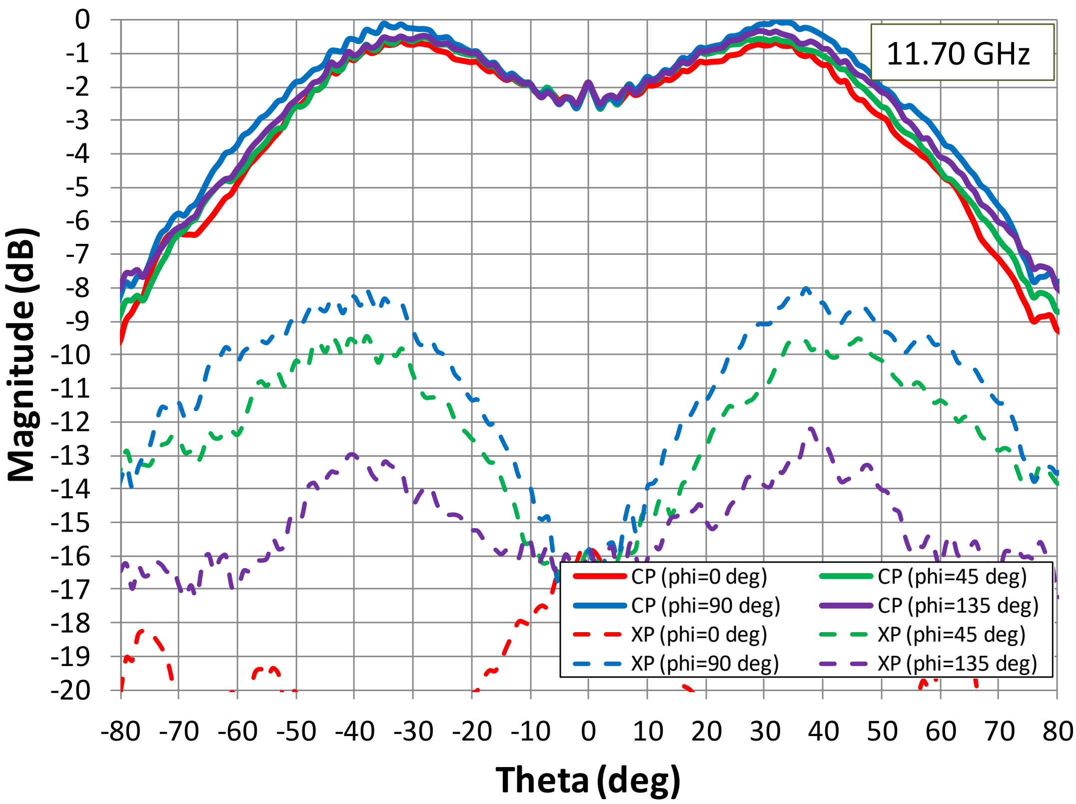
The radiation patterns of the proposed antenna feed, measured in LHCP at the five frequencies of interest (i.e., 11.20, 11.45, 11.70, 12.50, and 12.75 GHz), are shown in Fig. 2.4 (a-e). In this case, it can be observed how the radiation pattern at the edge of the parabola (θ=67.4 deg) is about -5.4 dB, which means an improvement of more than 4 dB compared to the former design. As a counterpart, the phase response is less uniform in the new design. This phase has been obtained relative to the phase center position at each frequency. In any case, the ripple can be compensated via software during the holography analysis. The position of the phase center relative to the plane of the aperture is plotted in Fig. 2.5. There is a variation of 4.5 mm between the lower and upper frequencies, so the feed should be adequately moved to align the phase center with the focal point of the antenna at the corresponding frequency of operation. The measured radiation characteristics are summarized in Table 2.1.

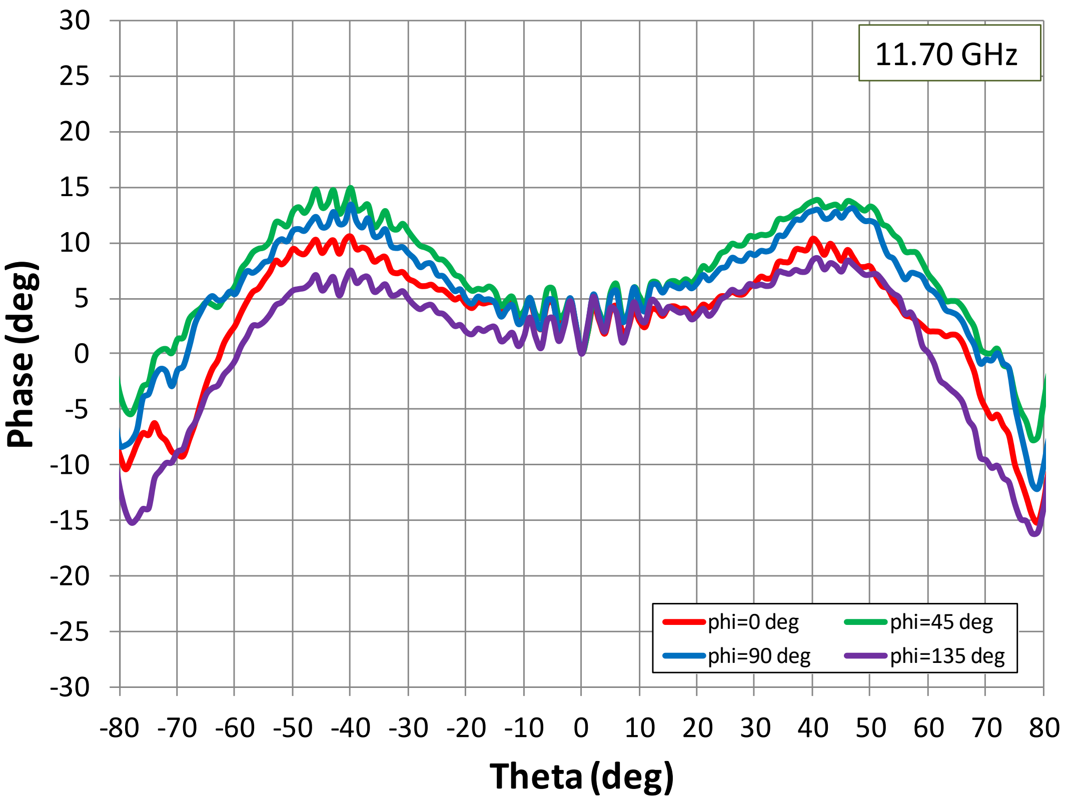

11.20 GHz
Magnitude (dB)
Theta (deg)
CP (phi=0 deg)
CP (phi=45 deg)
CP (phi=90 deg)
CP (phi=135 deg)
XP (phi=0 deg)
XP (phi=45 deg)
XP (phi=90 deg)
XP (phi=135 deg)
11.20 GHz
Phase (deg)
Theta (deg)
phi=0 deg
phi=45 deg
phi=90 deg
phi=135 deg

(a)

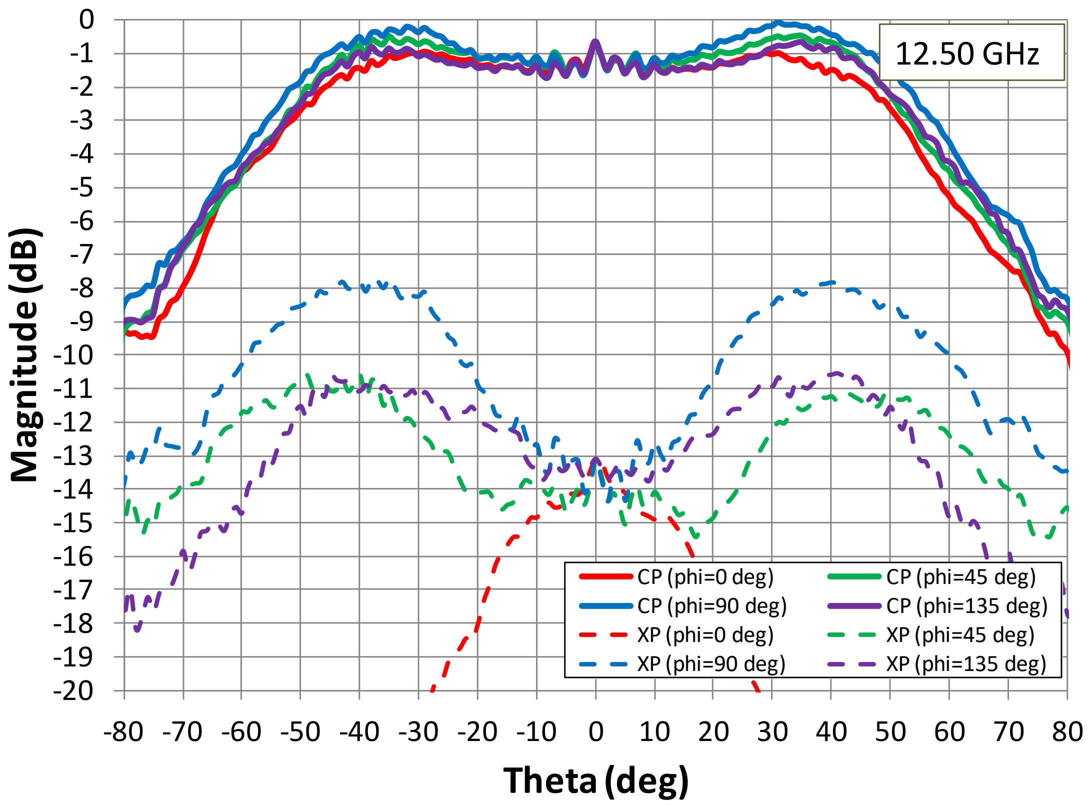

11.45 GHz
Magnitude (dB)
Theta (deg)
CP (phi=0 deg)
CP (phi=45 deg)
CP (phi=90 deg)
CP (phi=135 deg)
XP (phi=0 deg)
XP (phi=45 deg)
XP (phi=90 deg)
XP (phi=135 deg)
11.45 GHz
Phase (deg)
Theta (deg)
phi=0 deg
phi=45 deg
phi=90 deg
phi=135 deg

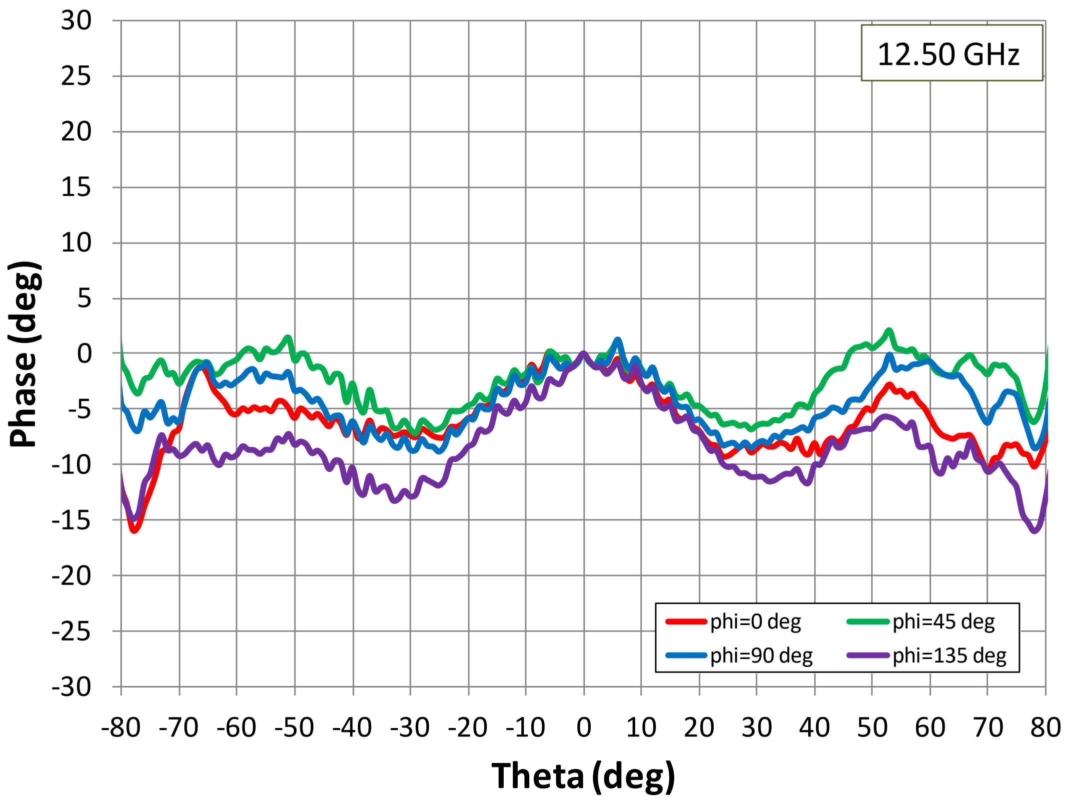
(b)


11.70 GHz
Magnitude (dB)
Theta (deg)
CP (phi=0 deg)
CP (phi=45 deg)
CP (phi=90 deg)
CP (phi=135 deg)
XP (phi=0 deg)
XP (phi=45 deg)
XP (phi=90 deg)
XP (phi=135 deg)

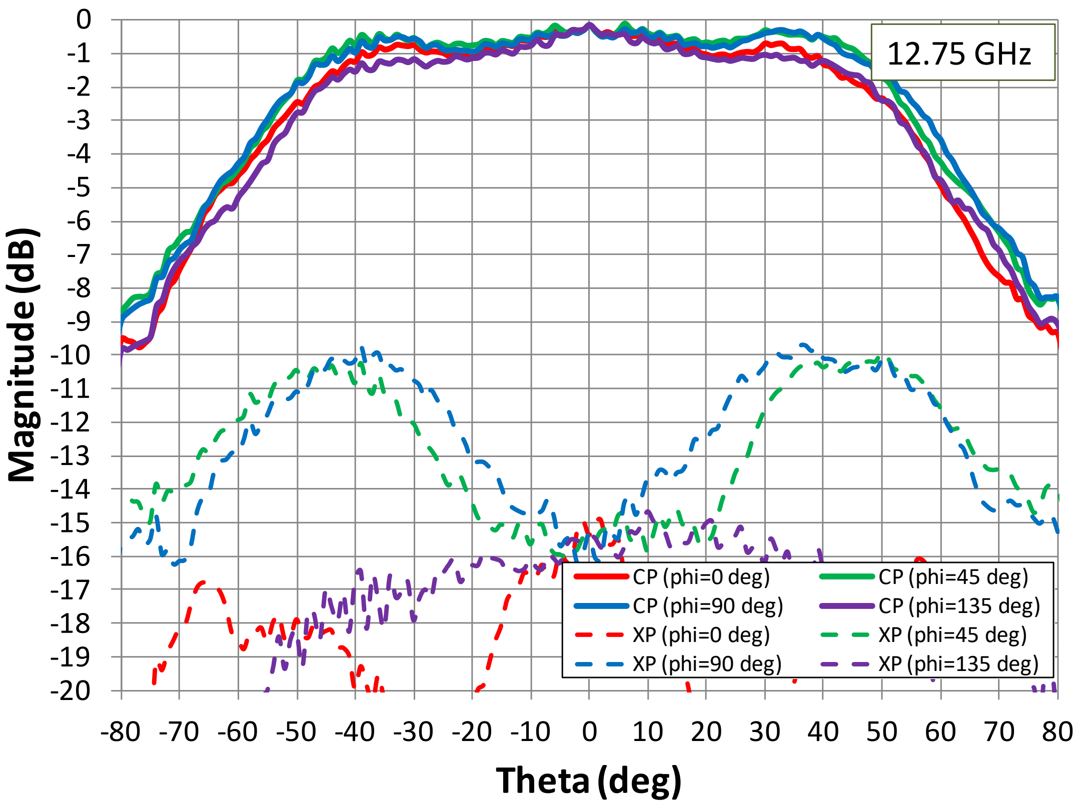

11.70 GHz
Phase (deg)
Theta (deg)
phi=0 deg
phi=45 deg
phi=90 deg
phi=135 deg

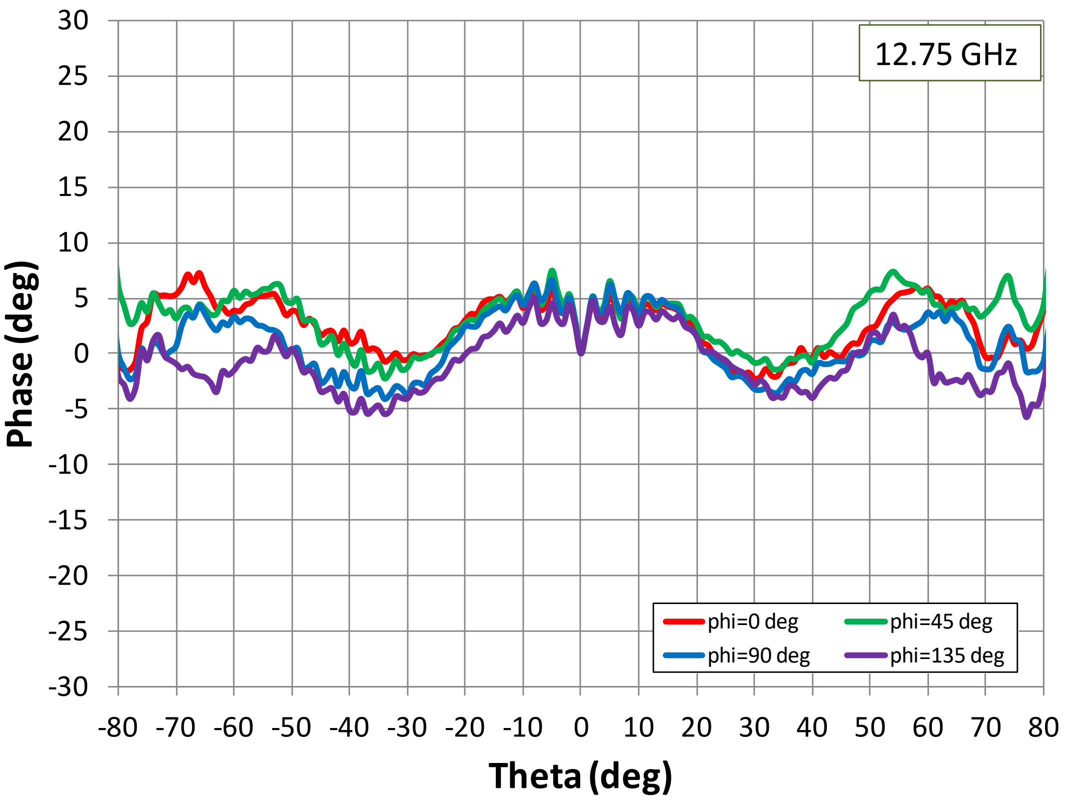
(c)


12.50 GHz
Magnitude (dB)
Theta (deg)
CP (phi=0 deg)
CP (phi=45 deg)
CP (phi=90 deg)
CP (phi=135 deg)
XP (phi=0 deg)
XP (phi=45 deg)
XP (phi=90 deg)
XP (phi=135 deg)


12.50 GHz
Phase (deg)
Theta (deg)
phi=0 deg
phi=45 deg
phi=90 deg
phi=135 deg

(d)





(e)

Fig. 2.4: Radiation patterns in LHCP of the new feed horn antenna for the test receiver, measured in magnitude (co-polar CP, and cross-polar XP) and phase, at (a) 11.20, (b) 11.45, (c) 11.70, (d) 12.50, and (e) 12.75 GHz.

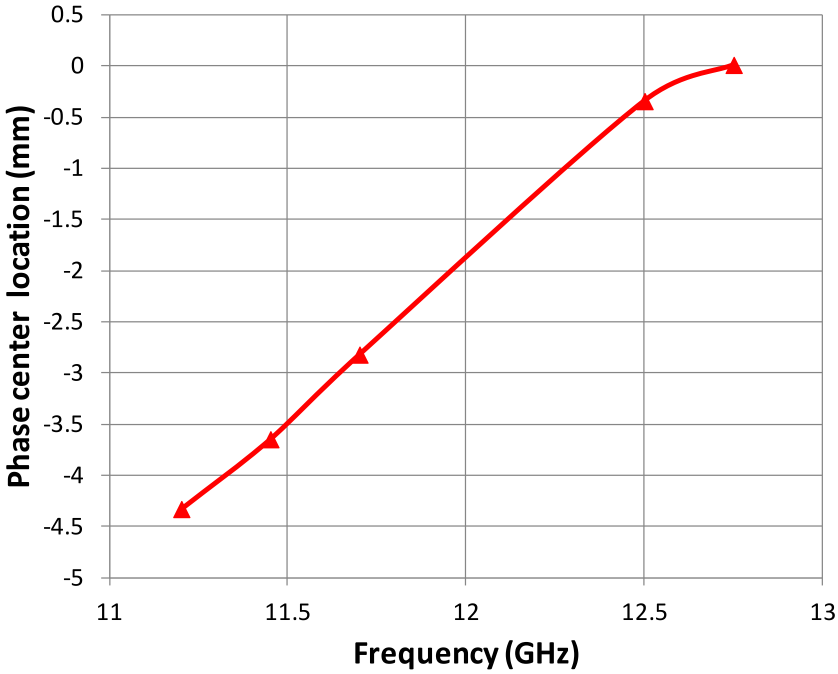


Fig. 2.5: Measured phase center location of the new feed horn antenna for the test receiver, relative to the plane of the aperture (negative means inside the waveguide).

Table 2.1: Comparison of measured taper values of the XM-140 and the new feed horn antenna for the test receiver.

		Former design (XM-140) [4]	New design
Pattern (τ) at θ=67.4 deg	11.20 GHz	-9.57 dB	-5.30 dB
	11.45 GHz	-9.61 dB	-5.25 dB
	11.70 GHz	-9.64 dB	-5.27 dB
	12.50 GHz	-9.79 dB	-5.49 dB
	12.75 GHz	-9.93 dB	-5.86 dB
	average	**-9.71 dB**	**-5.43 dB**
Free-space taper (A)		-3.2 dB	-3.2 dB
Edge taper ($ET = \tau + A$)	11.20 GHz	-12.77 dB	-8.50 dB
	11.45 GHz	-12.81 dB	-8.45 dB
	11.70 GHz	-12.84 dB	-8.47 dB
	12.50 GHz	-12.99 dB	-8.69 dB
	12.75 GHz	-13.13 dB	-9.04 dB
	average	**-12.91 dB**	**-8.63 dB**

3 Antenna for the reference receiver

3.1 Reference antenna currently in use

The antenna used at the present to provide the reference signal for the holography system of the 40-m radio telescope is a lensed corrugated horn with a maximum directivity of about 25 dBi and 3-dB beamwidth of 11.3 deg at Ku band. A picture of the antenna mounted on the subreflector cabin and the measured radiation patterns at 11.7 GHz are shown in Fig. 3.1.

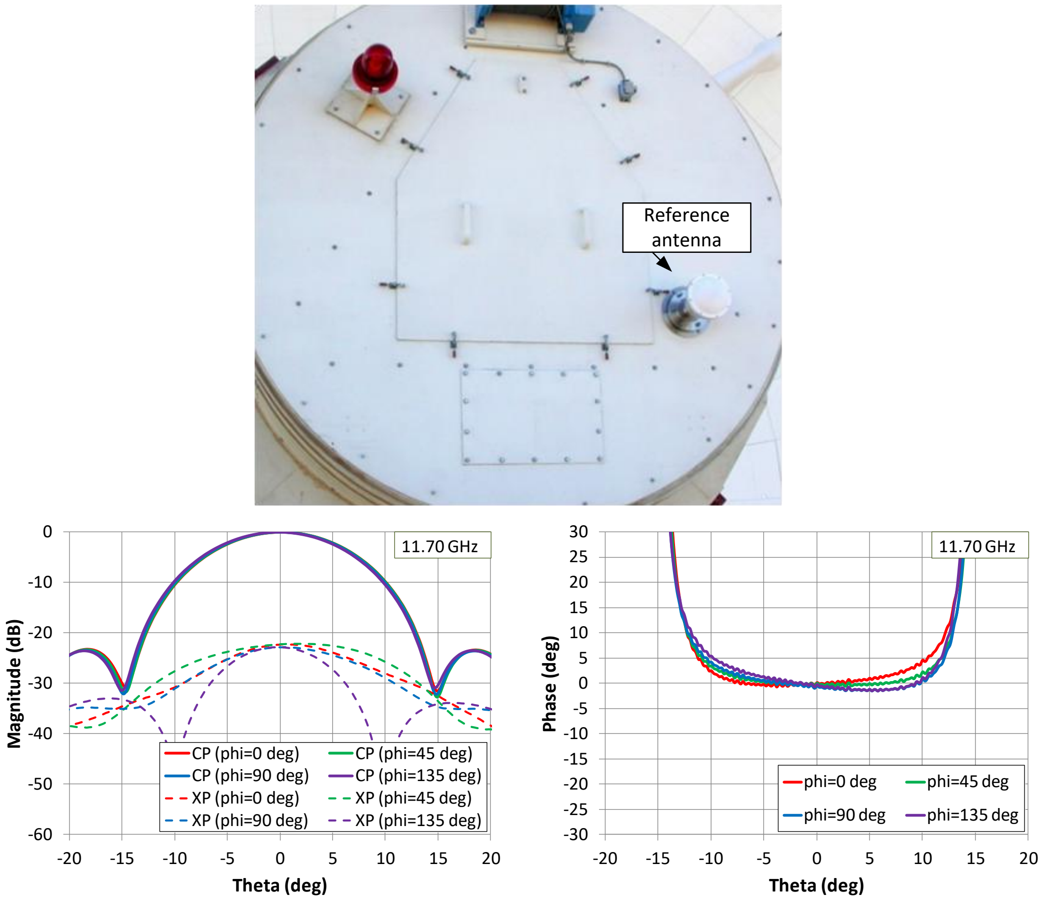


Fig. 3.1: Photograph of the lensed horn currently used as reference antenna, and measured radiation patter at 11.7 GHz.

3.2 New reference antenna

In order to improve the quality of the reference signal, the lensed horn antenna will be replaced by a higher-gain satellite dish. The parabola is a commercial antenna, model *Digirapid 60* from *Telestar*. The diameter of the dish is 0.6 m, and provides directivity of 37 dBi, which is more than 10 dB higher than with the previous solution. The antenna is based on an offset design, with and offset angle of 25.6 deg and f/D of 0.62.

The feed horn for the offset reflector has been designed for maximum efficiency, which means edge taper of about -10 dB. In this case, the half subtended angle of the parabolic reflector is 37 deg. The fabricated feed is shown in Fig. 3.2, and is a conical horn antenna with two chokes. The measured radiation patterns are shown in Fig. 3.3. It can be observed how the edge taper (at θ=37 deg) presents values closed to the optimum, between -10 and -11 dB.

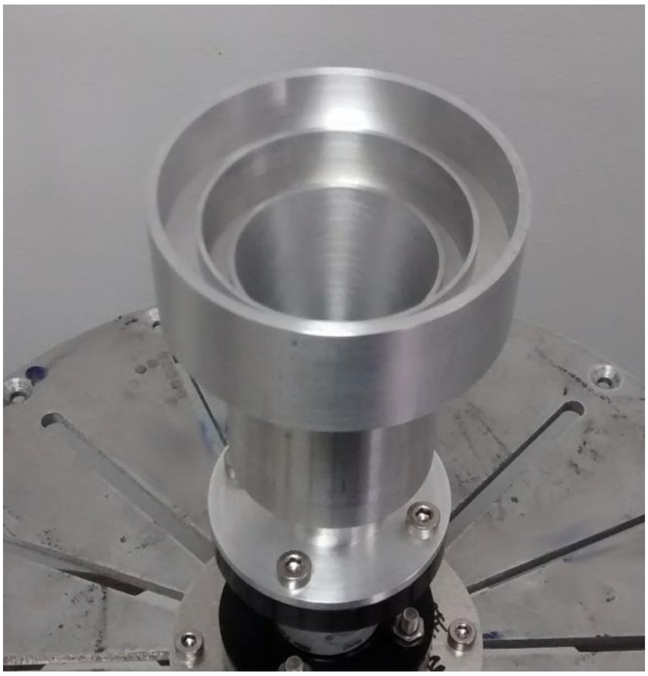


Fig. 3.2: Photograph of the feed horn for the reference parabolic antenna.

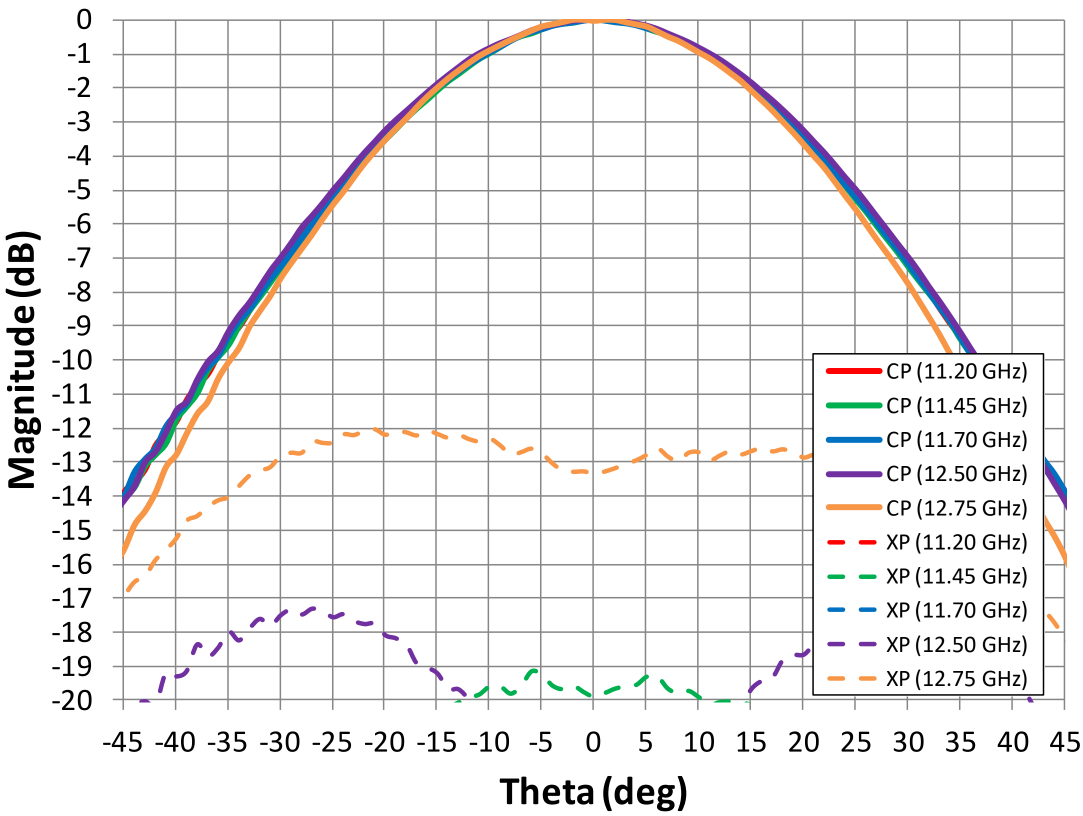


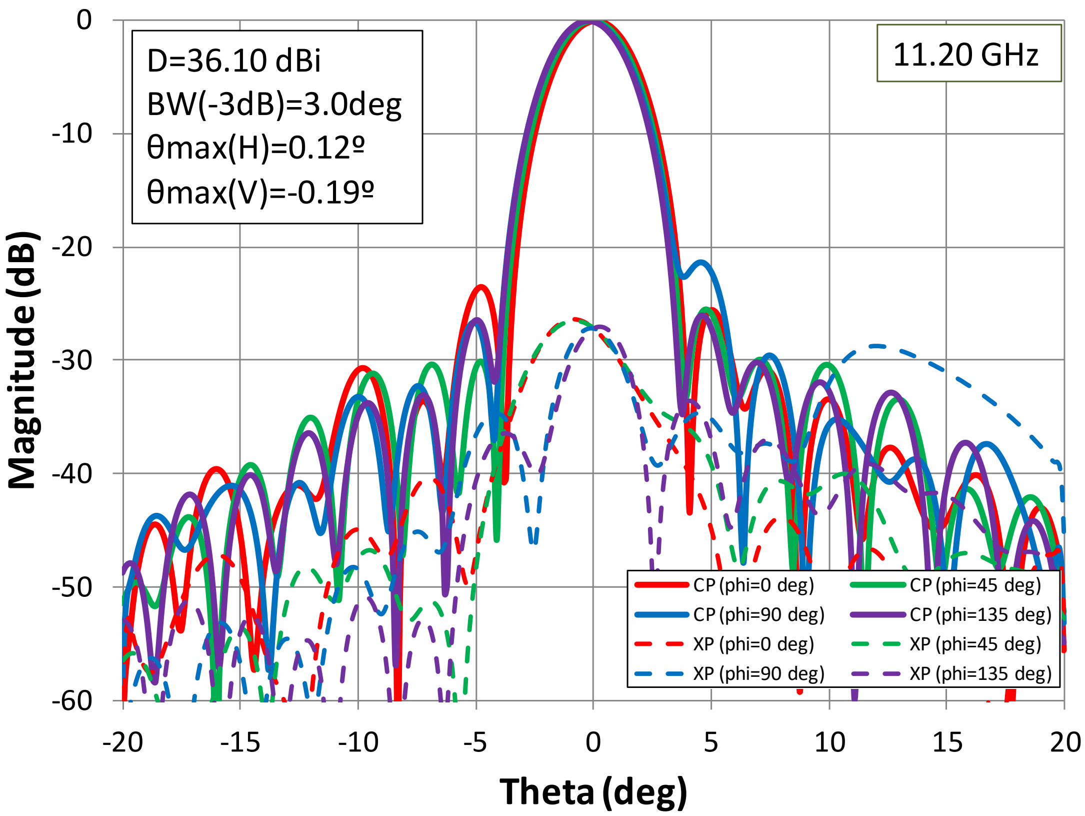
Fig. 3.3: Radiation patterns in LHCP of the feed horn for the reference parabolic antenna (co-polar CP, and cross-polar XP).

The offset parabolic antenna within the Yebes anechoic chamber for the radiation pattern characterization is shown in Fig. 3.4. The position of the feed has been manually adjusted looking for maximum directivity. The parabola is mounted on a flat aluminum panel, in such a way that the direction of propagation is adjusted to be perpendicular to such plane. It must be noted that offset reflectors operating in circular polarization inherently present beam tilting in the horizontal (azimuth) plane, in opposite directions for LHCP and RHCP. This tilt has been quantified in 0.25 deg in this case, but it has been partially compensated for RHCP by inserting plastic shims at the clamp. The measured radiation patterns are shown in Fig. 3.5. Beam pointing is better than 0.2 deg in both planes. The directivity is in the order of 36-37 dBi, and the 3-dB beamwidth is about 3 deg. The location of the extracted phase center in the plane transverse to the propagation axis is depicted in Fig. 3.6. There is and offset of about 5 and -27 mm for the axes x and y respectively, relative to the center of the rear mounting plate. This point should be properly aligned with the beam axis of the 40-m parabola when mounting the reference antenna at the subreflector.

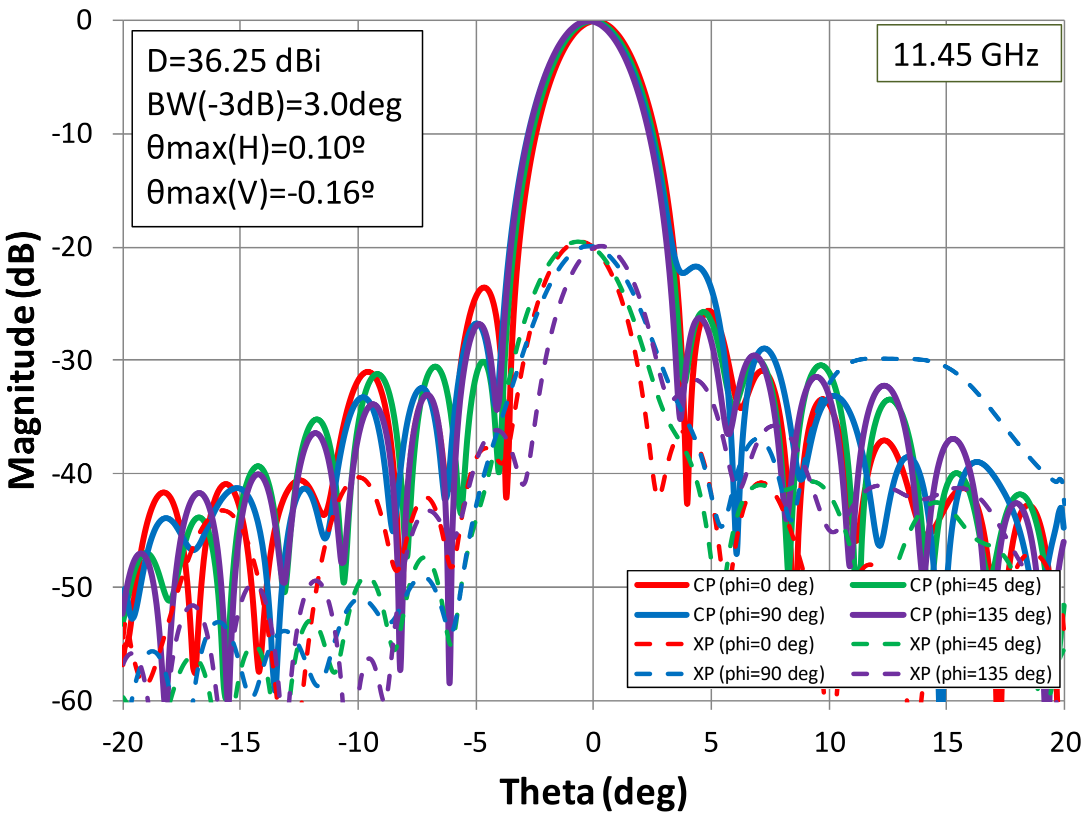
Fig. 3.4: Photograph of the new reference antenna.

Table 3.1: Comparison of the measured radiation parameters of the lensed corrugated horn and the new parabolic reflector for the reference receiver.

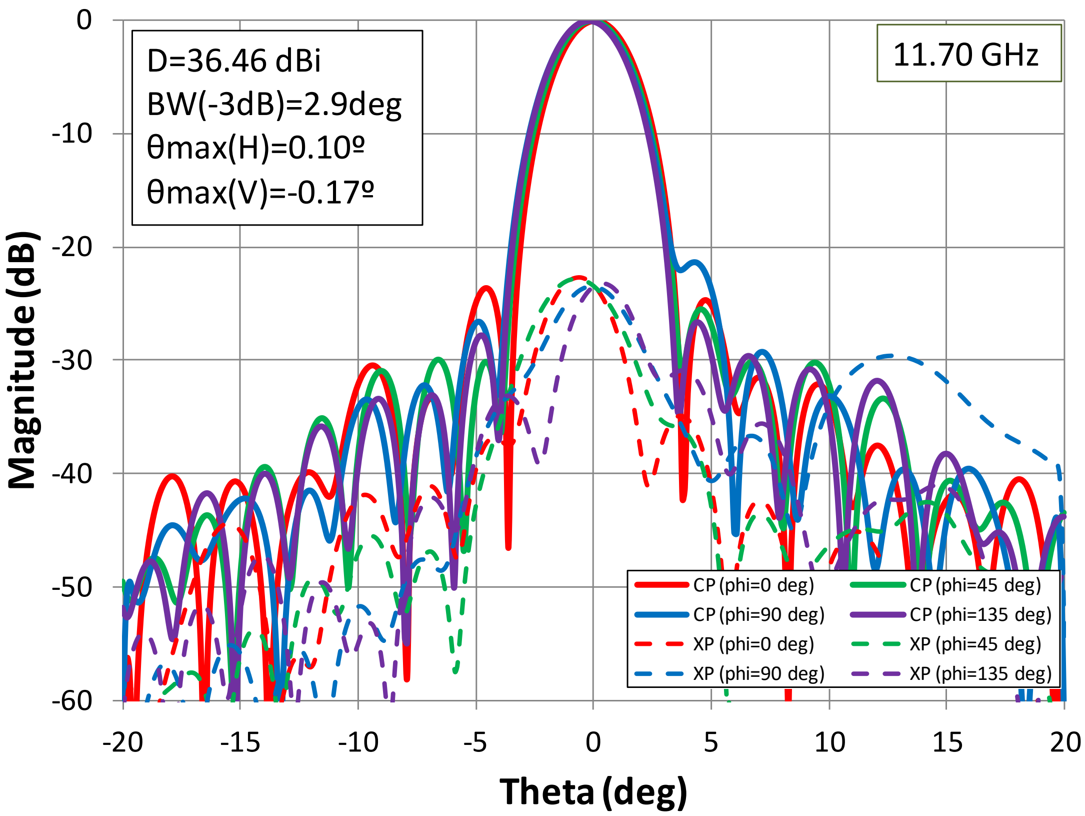
	Former reference antenna	New reference antenna
Topology	Lensed corrugated horn	Offset dish antenna
Directivity	25 dBi	36-37 dBi
Beamwidth (-3 dB)	11.3 deg	3.0 deg


D=36.10 dBi
BW(-3dB)=3.0deg
θmax(H)=0.12º
θmax(V)=-0.19º
11.20 GHz
Magnitude (dB)
Theta (deg)
CP (phi=0 deg)
CP (phi=45 deg)
CP (phi=90 deg)
CP (phi=135 deg)
XP (phi=0 deg)
XP (phi=45 deg)
XP (phi=90 deg)
XP (phi=135 deg)

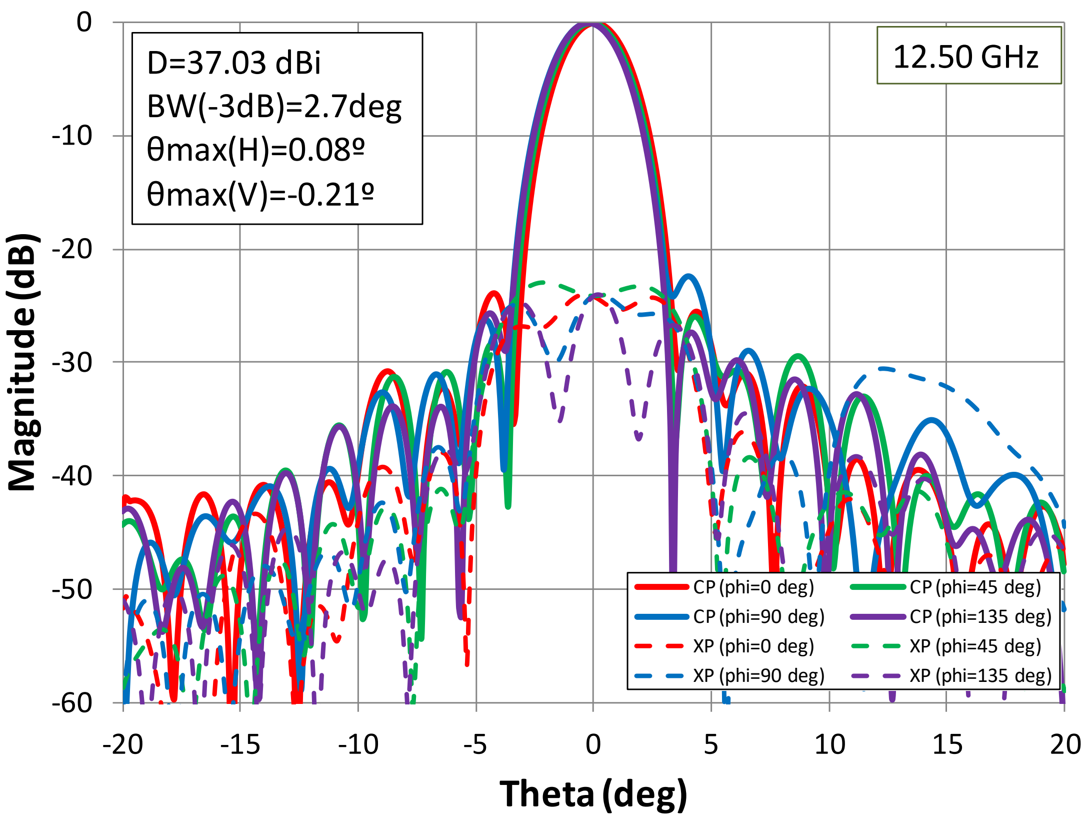
(a)


D=36.25 dBi
BW(-3dB)=3.0deg
θmax(H)=0.10º
θmax(V)=-0.16º
11.45 GHz
Magnitude (dB)
Theta (deg)
CP (phi=0 deg)
CP (phi=45 deg)
CP (phi=90 deg)
CP (phi=135 deg)
XP (phi=0 deg)
XP (phi=45 deg)
XP (phi=90 deg)
XP (phi=135 deg)

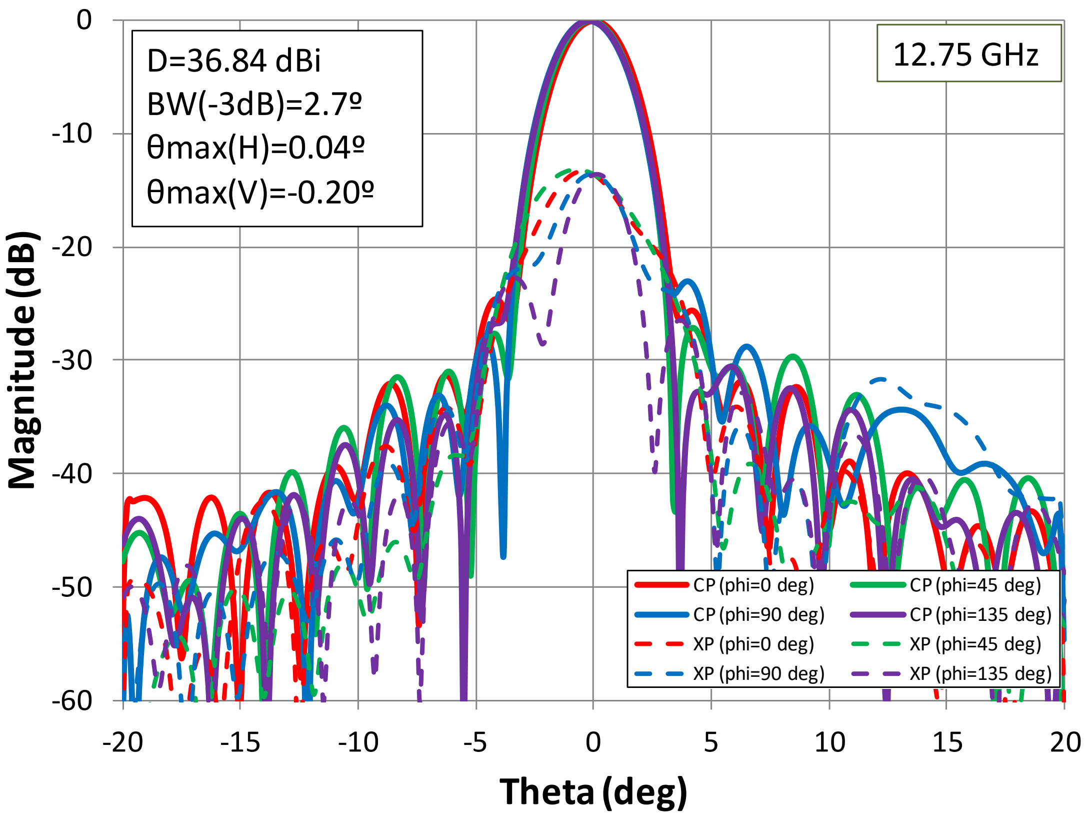
(b)


D=36.46 dBi
BW(-3dB)=2.9deg
θmax(H)=0.10º
θmax(V)=-0.17º
11.70 GHz
Magnitude (dB)
Theta (deg)
CP (phi=0 deg)
CP (phi=45 deg)
CP (phi=90 deg)
CP (phi=135 deg)
XP (phi=0 deg)
XP (phi=45 deg)
XP (phi=90 deg)
XP (phi=135 deg)

(c)


D=37.03 dBi
BW(-3dB)=2.7deg
θmax(H)=0.08º
θmax(V)=-0.21º
12.50 GHz
Magnitude (dB)
Theta (deg)
CP (phi=0 deg)
CP (phi=45 deg)
CP (phi=90 deg)
CP (phi=135 deg)
XP (phi=0 deg)
XP (phi=45 deg)
XP (phi=90 deg)
XP (phi=135 deg)

(d)



(e)

Fig. 3.5: Radiation patterns in RHCP of the new reference antenna (co-polar CP, and cross-polar XP), measured at (a) 11.20, (b) 11.45, (c) 11.70, (d) 12.50, and (e) 12.75 GHz.

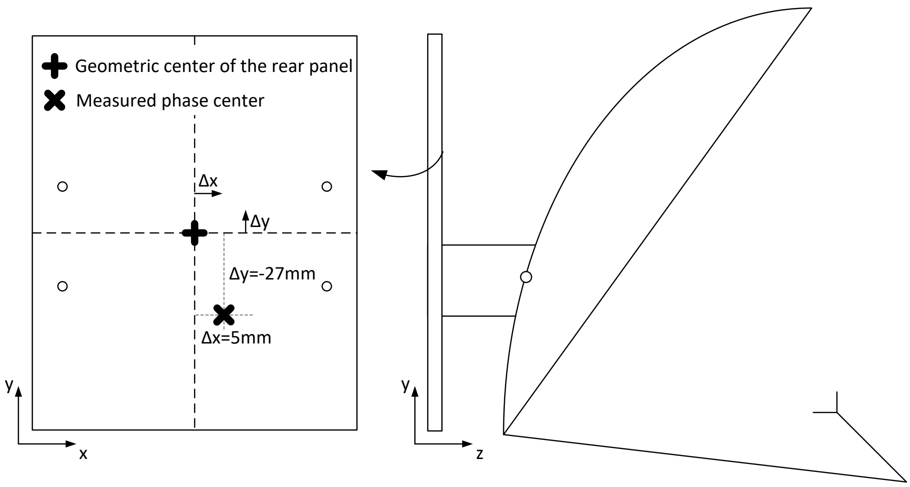


Fig. 3.6: Sketch of the parabolic reflector indicating the position of the measured phase center relative to the geometric center of the rear panel.

4 Conclusion

The design and characterization of two new radiating elements for the microwave holography system of the Yebes 40-m radio telescope has been presented in this report. In the case of the feed for the test channel, the new horn antenna design allows reducing the taper more than 4 dB compared to the former solution. This means more uniform illumination of the primary reflector, which in turn implies better repeatability for the alignment of the panels. In addition, a new reference antenna has been implemented. The use of a 0.6-m offset dish will allow increasing the directivity up to 36 dBi, about 10 dB higher than with the current solution, which will presumably improve the quality of the reference phase signal. In the coming months, both antennas will be mounted on the subreflector cabin, and the performance of the holography system will be checked with this new configuration.

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