ALMA Band 2/3

WP4: Passive Components I - Feedhorns - Electromagnetic Study

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Abstract
This report shows the results about the electromagnetic study of circular corrugated horns to be used as feed for the ALMA radio telescope. The study first addresses the specifications of the ALMA band 2, 67-90GHz; it is then investigated the way to extend the operative band also to the ALMA band 3, 84-116GHz, thus resulting in a horn operating in the full 67-116GHz joint bandwidth. Simulation results show the possibility to have a high performance feed covering the whole 67-116GHz ALMA band. This report is done in the framework of the 'ALMA band 2/3' project funded by ESO.

1 Introduction

The ALMA radio telescope has been recently inaugurated with an official ceremony at the ALMA site (2013 March 13th) when this report was being written. Huge and almost exhaustive documentation about ALMA can be found in the NRAO memo series [1]: this report will focus only the technical aspects related to the electromagnetic study of a feed for band 2 (67-90GHz) and for the joint band 2/3 (67-116GHz).

The specifications adopted for the horn are given in the following Table I:

Table I

Feed Horn Specifications		
	Band 2	Band 2/3
Bandwidth [GHz]	67-90	67-116
Return loss [dB]	>30	>30
Insertion loss [dB]	TBD	TBD
Cross-Polar Maximum [dB]	<-30	<-30
ET [dB@deg]*; W0[mm]*	12@17; 4.73	12@17; 4
Technology	Circular Corrugated Horn	Circular Corrugated Horn
Throat Flange	UG387/U	UG387/U
Throat input diameter	TBD	TBD
Max envelope	TBD	TBD

* ET, the Edge Taper, is the loss at the defined edge angle with respect to the on-axis maximum at the central frequency (the mean of the band edges, 78.5GHz for band 2 and 91.5 GHz for band 2/3). W0 is the waist at the central frequency of the gaussian beam best fitting the feed radiation pattern.

The specifications for band 2 are quite standard and consequently the related feed design is quite easy and no particular problems were found. This is not the case for the band2/3 feed, basically due to the very broad band, where non-standard solutions were searched for and applied to match requirements. The following paragraphs will show the results obtained in this study.

2 ALMA band 2 feed horn

Two horns with different corrugation profile are proposed in band 2: linear the first (LP2), sinusoidal the second (SP2). The main reason for this is to investigate different solutions giving slightly different features in the performance.

Both profiles are compared in Fig. 1. Volumes in the electromagnetic models are not significantly different: about 50 mm in length and 20 mm in diameter and these figures should be approximately the same also in the fabricated device.

The phase centre is quite stable in the bandwidth: the phase centre position related to the radiating aperture (inside the horn) changes from 1 mm to 2.5 mm (SP2) and from 2 mm to 4 mm (LP2).

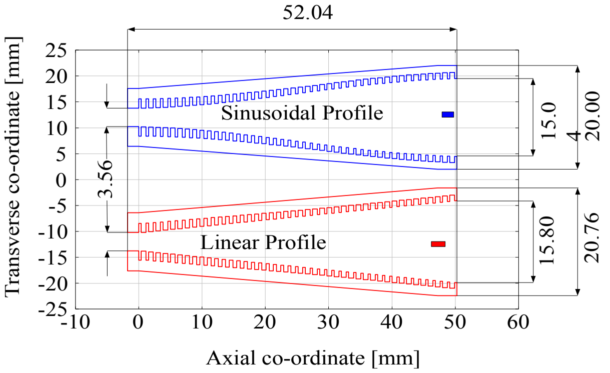


Fig. 1: On-axis longitudinal cut of circular corrugated feed horns. Linear Profile (LP2) and Sinusoidal Profile (SP2). The rectangle inside the profiles shows the phase centre position in the bandwidth.

The two horns also show return loss basically-identical performance. Both reflection coefficient curves are below -30 dB and are very close to each other (Fig. 2).

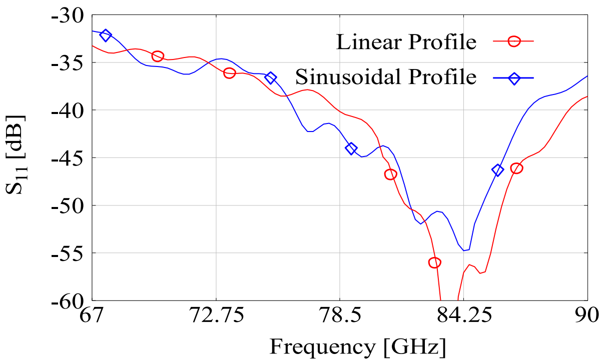


Fig. 2: Horn reflection coefficient: Linear Profile LP2 and Sinusoidal Profiled SP2.

As regards the maximum of the cross-polarization component of the radiated field it has to be noticed that the LP2 horn seems to be slightly better, as shown in Fig. 3.

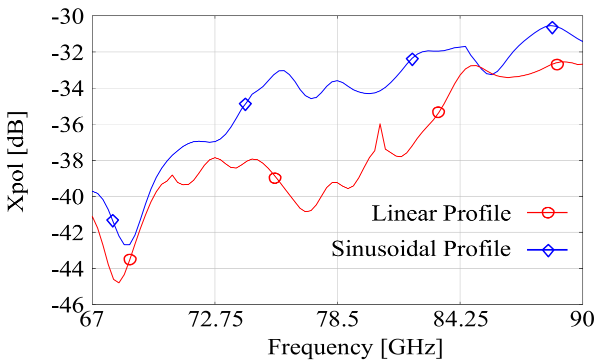


Fig. 3: Horn cross-polarization maximum versus frequency: Linear Profile LP2 and Sinusoidal Profiled SP2.

The expected beam pattern of the horns is given in Fig. 4 for the 45°-plane cut. Both co-polar (Cpol) and cross-polar (Xpol) field components are plotted. The two co-polar curves intercept the -12dB@17deg point to meet the taper specification at the central frequency of 78.5 GHz.

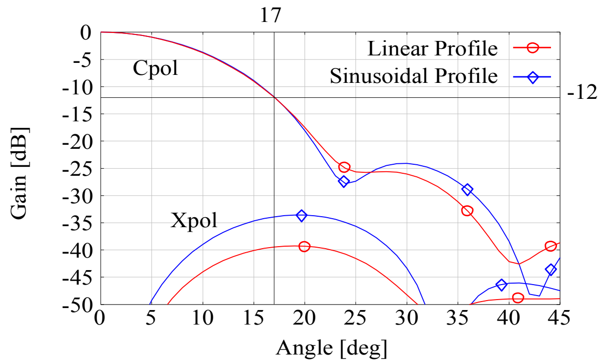


Fig. 4: Co-polar Cpol and cross-polar Xpol feed pattern: Linear Profile LP2 and Sinusoidal Profiled SP2.

Some features of the two horns are summarized in Table II.

Table II

Band 2 Feed Horn Performance		
	Linear Profile	Sinusoidal Profile
Bandwidth [GHz]	67-90	67-90
Return loss [dB]	>32	>33
Insertion loss [dB]	NC	NC
Cross-Polar Maximum [dB]	<-32	<-30
ET [dB@deg@GHz]	11.8@17@91.5	12.2@17@91.5
Technology	Circular Corrugated Horn	Circular Corrugated Horn
Throat Flange	UG387/U	UG387/U
Throat input diameter [mm]	3.56	3.56
Envelope (Height X Diameter) [mm]	52.04 x 20.76	52.04 x 20.0

3 ALMA band 2/3 feedhorn

The optimization of the feed horn performance to match the requirements was very difficult in the joint 2/3 band, due to its very large broadness, close to one octave. Two horns are proposed at the end of this process, having different corrugation profile: linear the first (LP23), sinusoidal the second (SP23). Both profiles are compared in Fig. 5. Also in this case the space occupation is basically the same and the phase centre position related to the radiating aperture (inside the horn) changes from 0.5 mm to 5.4 mm (SP23) and from 1.2 mm to 6.5 mm (LP23); respect to the band 2 horns, this larger range is associated to the broader bandwidth.

Both horns have an input diameter of 3.08 mm, while the aperture diameter is 12.92 mm for SP23 and 13.72 mm for LP23. To match the return loss requirements, trickier in the lower part of the band, an iris in the throat region have been designed. The horns have the same length of 38.44 mm and a diameter of 17.2 mm (SP23) and 18.0 mm (LP23). To be noticed that the UG387/U standard flange is larger (19.05 mm) than the two diameters, so that both horns are virtually under the shadow of their flanges.

Due to the broadness of the bandwidth and the stringent requirements there would probably be only very little room to change the optimized geometry without loosing something in the performance.

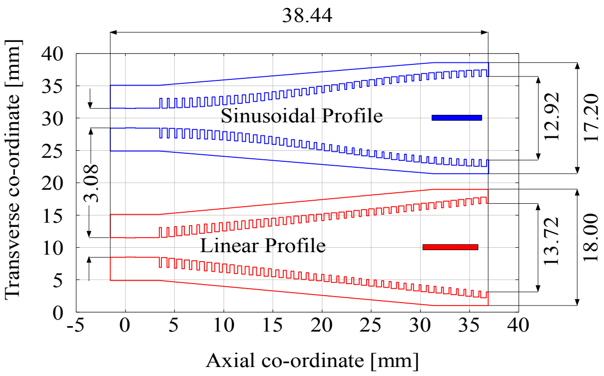


Fig. 5: On-axis longitudinal cut of the circular corrugated feed horns. Linear Profile (LP23) and Sinusoidal Profile (SP23). The rectangle inside the profiles shows the phase centre position in the bandwidth (67-116GHz).

One of the major problems in the design was to keep the reflection coefficient down -30 dB in the lower part of the bandwidth. The throat iris allowed to solve this problem and the reflection coefficient requirements are satisfied in the whole bandwidth (Fig. 6).

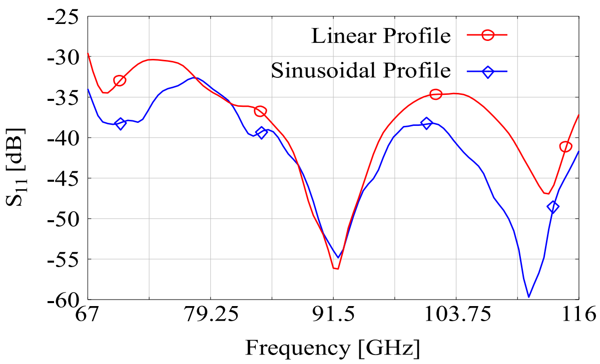


Fig. 6: Horn reflection coefficient: Linear Profile LP23 and Sinusoidal Profile SP23.

Another major problem was the cross-polarization level in the higher part of the bandwidth. At the end of the optimization the cross-polarization component of the field has been however kept below the desired level, as shown in Fig. 7.

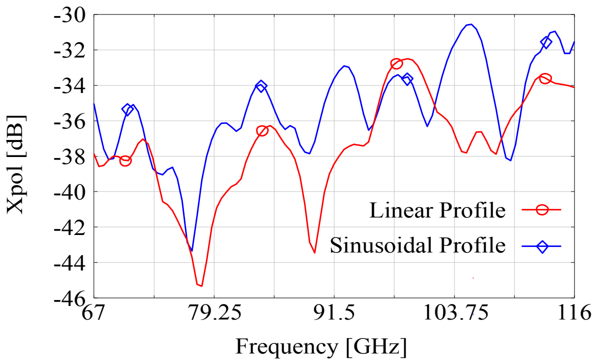


Fig. 7: Horn cross-polarization maximum versus frequency: Linear Profile LP23 and Sinusoidal Profile SP23.

The taper specification was not a relevant problem. Comments and results are the same as in the case of the horn in band 2. The plots in Fig. 8 shows the expected co-polar (Cpol) and cross-polar (Xpol) components of the radiated field at 91.5GHz in the 45° plane cut.

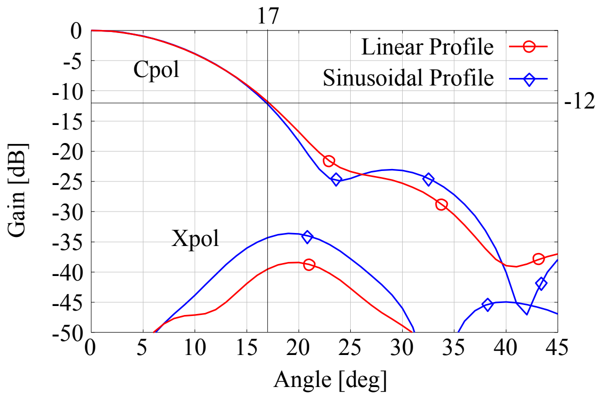


Fig. 8: Co-polar Cpol and cross-polar Xpol feed pattern: Linear Profile LP23 and Sinusoidal Profiled SP23.

The performance of the two horns is summarized in Table III:

Table III

Band 2/3 Feed Horn Performance		
	Linear Profile	Sinusoidal Profile
Bandwidth [GHz]	67-116	67-116
Return loss [dB]	>30	>32
Insertion loss [dB]	NC	NC
Cross-Polar Maximum [dB]	<-33	<-31
ET [dB@deg@GHz]	11.8@17@91.5	12.2@17@91.5
Technology	Circular Corrugated Horn	Circular Corrugated Horn
Throat Flange	UG387/U	UG387/U
Throat input diameter [mm]	3.08	3.08
Envelope (Height X Diameter) [mm]	38.44 x 18.0	38.44 x 17.2

3.1 ALMA band 2/3 feedhorn: further development

It was agreed to define an interface between the horn and the OMT based on a circular waveguide of 2.93 mm diameter. Thus the first optimization (LP23) and (SP23) has been revised and the results of the corresponding new linear and sinusoidal profile versions, named (LP23_v2) and (SP23_v2), are shown in this paragraph. In Table IV the performance of the v2 feed horns is summarized: Envelope, taper, return loss and cross-polarization show no or insignificant changes with respect to the previous horns, while the new throat geometry is compatible with the input waveguide interface (2.93 mm diameter) of an already optimized Orthomode Transducer (OMT) in the ALMA band 2/3 by people from IRAM [2], collaborating in the project.

Table IV

Band 2/3 Feed Horn v2 Performance		
	Linear Profile	Sinusoidal Profile
Bandwidth [GHz]	67-116	67-116
Return loss [dB]	>30	>31
Insertion loss [dB]	NC	NC
Cross-Polar Maximum [dB]	<-32	<-30
ET [dB@deg@GHz]	11.8@17@91.5	12.2@17@91.5
Technology	Circular Corrugated Horn	Circular Corrugated Horn
Throat Flange	UG387/U	UG387/U
Throat input diameter [mm]	2.93	2.93
Envelope (Height X Diameter) [mm]	38.44 x 18.0	38.44 x 17.2

The corrugation geometry of the two horns is detailed in the axial section of the electromagnetic model in Fig. 9.

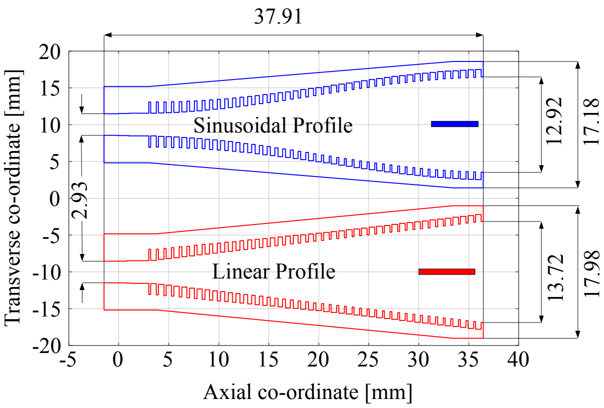


Fig. 9: On-axis longitudinal cut of circular corrugated feed horns. Linear Profile (LP23_v2) and Sinusoidal Profile (SP23_v2). The rectangles inside the profiles show the phase centre position in the bandwidth (67-116GHz).

The distance from the radiating aperture (inside direction) of the phase centre of the two horns are in the range 1.2-6.5 mm (LP23_v2) and 0.5-5.2 mm (SP23_v2).

The reflection coefficient at the throat of the LP23_v2 and SP23_v2 horns is given in the plots in Fig. 10. Both curves are below -30 dB in the whole bandwidth. All the performance plots here given are the expected results coming from computations using a Mode Matching (MM)-based non-commercial software package. In the case of the SP23_v2 horn other two commercial software packages are used to confirm predicted performance, one based on Finite Element (FE) and the other on Finite Difference (FD). The main reason for this is to have a crosscheck about the reliability of the predictions. The FE software analysis is applied to the *mandrel model* of the horn (Fig. 11a) while the FD to the horn *prototype model* (Fig. 11b).

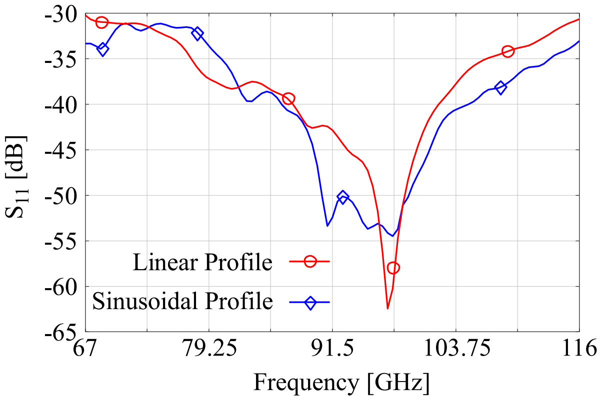
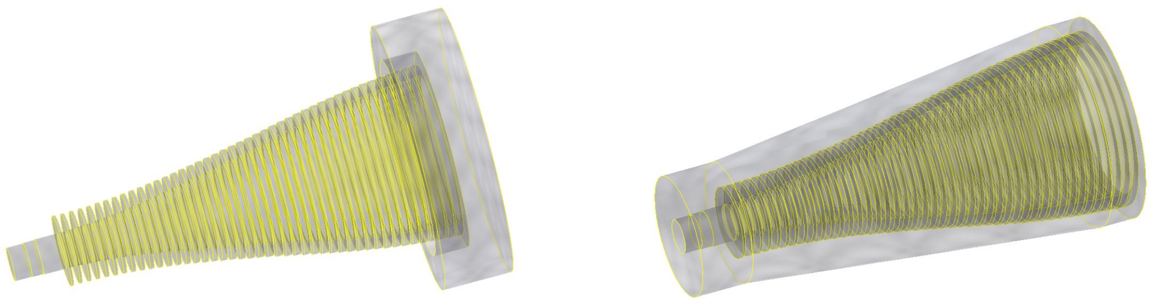


Fig. 10: Horn reflection coefficient: Linear Profile LP23_v2 and Sinusoidal Profile SP23_v2.

Both FE and FD electromagnetic models have the same reliability and accuracy (the name *mandrel* and *prototype* would be misunderstanding). The FE model sees the horn as a vacuum (air) region bounded by a perfect electric material surface, except at the aperture region, where perfect absorbing material is used to account for radiation. The FD model sees the horn in its more realistic version, corresponding to a realistic prototype, with the physical metallic structure of the horn inside a larger vacuum (air) volume closed by an absorbing surface accounting for radiation. In both cases, the input throat port is modeled in the same way as a waveguide port exciting the horn with a TE_{11} mode.



a) Mandrel model b) Prototype model

Fig. 11: Mandrel and prototype electromagnetic models used in the electromagnetic analysis of FE and FD software.

As shown in Fig. 12, the comparison among MM, FE and FD regarding the reflection coefficient curves is excellent.

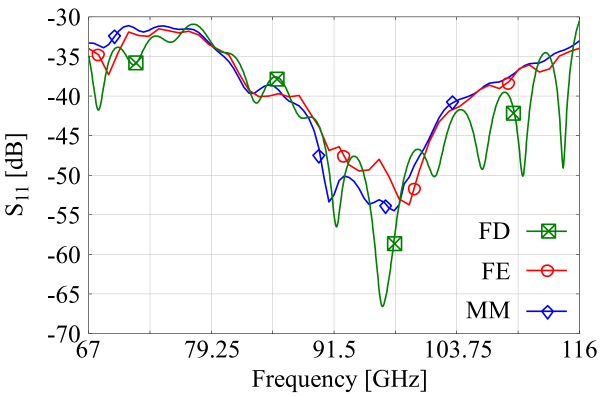


Fig. 12: Reflection coefficient comparison among MM, FE and FD analysis for the SP23_v2 horn.

Also as regards cross-polarization maximum (Fig. 13) and beam pattern (Fig. 14), the v2 upgrades of the band 2/3 horns show no appreciable differences with respect to the previous versions.

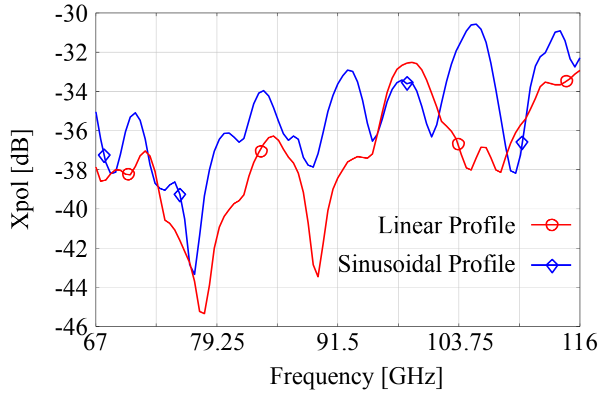


Fig. 13: Horn cross-polarization maximum versus frequency: Linear Profile LP23_v2 and Sinusoidal Profile SP23_v2.

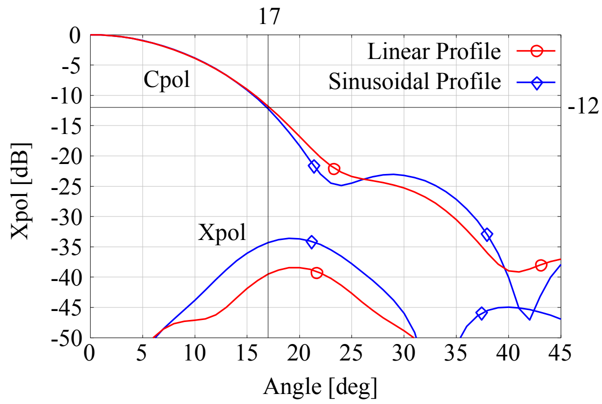


Fig. 14: Co-polar and cross-polar feed pattern at 91.5GHz in the 45° plane cut: Linear Profile LP23_v2 and Sinusoidal Profile SP23_v2.

4 Conclusion

In this report different feed options have been investigated for the ALMA band 2 from an electromagnetic point of view. Two horns matching the requirements are presented, having different corrugation profile: a linear profiled (LP2) and a sinusoidal profiled (SP2) horn. It has been also addressed the feasibility of a feed for a joint band 2/3 ALMA receiver, highlighting that, from the feed point of view and concerning the electromagnetic performance, this is virtually feasible. Also for the band 2/3 joint case two different profiles (linear (L23) and sinusoidal (S23)) times two versions (LP23_v2 and SP23_v2), for a total of four different corrugated horns, have been presented.
In absence of prototypes, and thus of measurements, an important cross-check between different software packages has been done, validating the accuracy of the electromagnetic model and the reliability of the simulated performance.
To conclude the last step of design task, as further development of the work described in this report, efficient prototyping processes need to be investigated and applied, and tests to be made.

References

1 https://science.nrao.edu/facilities/alma/aboutALMA/Technology/ALMA_Memo_Series
2 Anne Laure Fontana, IRAM, Grenoble, France, Private Communications