

Design of a Heterodyne Receiver for Band 1 of ALMA

N. Reyes, P. Zorzi, F. P. Mena, C. Granet, E. Michael, L. Bronfman, and J. May

Abstract—Here we present the design of a receiver that will cover the frequency range from 31 to 45 GHz. The receiver will use a horn and a lens to couple the incoming radiation into the waveguide structure. Then, an orthomode transducer will split the signal in two polarizations. Each one of them is then amplified and down converted using the upper sideband mixing scheme. The results of the electromagnetic modeling of every component are also presented here. We also discuss how the components will be implemented.

Index Terms—Millimeter wave receiver, HEMT, USB mixing.

I. INTRODUCTION

The Atacama Large Millimeter Array (ALMA) is the largest radio astronomical array ever constructed. Every one of its constituent antennas will cover the spectroscopic window allowed by the atmospheric transmission at the construction site with ten different bands. Despite being declared as a high scientific priority by the ALMA Scientific Advisory Committee, band 1 (31.3–45 GHz) was not selected for construction during the initial phase of the project [ref.]. However, Universidad de Chile has recently started a program for the construction of a prototype receiver for band 1 of ALMA. In this paper we present the design of the proposed receiver and the results of the electromagnetic modeling of several of its parts.

II. RECEIVER DESIGN

The schematics of the receiver we are proposing is presented in Figure 1. The incoming signal is brought to a horn via a lens. Two different corrugated versions have been studied, a conventional conical horn and an optimized spline-profile horn. The first results with the optimized horn demonstrate an improved performance (Sec. III.A). After the horn, the signal is divided in its linear polarization components using an orthomode transducer (OMT). We have scaled up the OMT introduced to ALMA by Asayama [1]

(Sec. III.B). Each polarization branch is first amplified and then down-converted independently. For amplification, we will use high electron mobility transistors (HEMT). In a first stage, we plan to test commercial chips that will be integrated at our laboratories. The design of the packaging is also presented (Sec. III.C). Given the frequency coverage of this band and the availability of the LO signal, an upper sideband mixing scheme has been selected. A high pass-band filter that cancels out the lower sideband is, therefore, needed. We have designed a multiple stage waveguide filter with a cut-off frequency of 30 GHz and a rejection of the image signal better than 20dB (Sec. III.D). Finally, the down-conversion and amplification of the intermediate signal is planned to be done with commercial components.

III. MODELING AND PROPOSED CONSTRUCTION METHODS

A. Optics and Horn

A bi-hyperbolic lens will refocus the ALMA Cassegrain antenna sub-reflector beam focus into a corrugated horn located inside the cryocooled receiver. This device will also act as a vacuum window of the receiver. The optimal lens design was carried out using a fundamental gaussian beam mode analysis [2]. We used high density polyethylene (HDPE) in our lens design which has a dielectric constant of 2.3. The final optimized lens design is 19.4 cm in diameter, 5.09 cm thick at the centre of the lens, and has a focal length of 18.8 cm. Both sides of the lens will be machine with rectangular grooves around the lens centre to form an anti-reflection layer that will minimize reflection losses [3].

We have analyzed two different corrugated horns, a standard conical horn, designed according to [4], and an optimized spline-profile horn. We used Ansoft HFSS 11 [5] to optimize the former and to check the performances of both horns. In Fig.2, the radiation patterns at 38 GHz and the profile dimensions of both corrugated horns are presented. It can be noted that the performance of the spline-profile horn in terms of size, first side lobe location, and cross-polar level are much better than the conical design. However, the thickness of the wall between corrugations in spline-profile horn design is much smaller than the same dimension in the other horn and, therefore, could present more challenges when constructed using milling techniques.

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N. Reyes, P. Zorzi, F. P. Mena, and E. Michael are with the Electrical Engineering Department, Universidad de Chile, Av. Tupper 2007, Santiago, Chile (corresponding author: +56-2-6784888; fax: +56-2-695 3881; e-mail: pmena@ing.uchile.cl).

C. Granet is with BAE Systems Australia Ltd, 40-52 Talavera Road, North Ryde 2113, Australia, Santiago, Chile.

L. Bronfman, and J. May are with the Astronomy Department, Universidad de Chile, Camino El Observatorio 1515, Santiago, Chile.

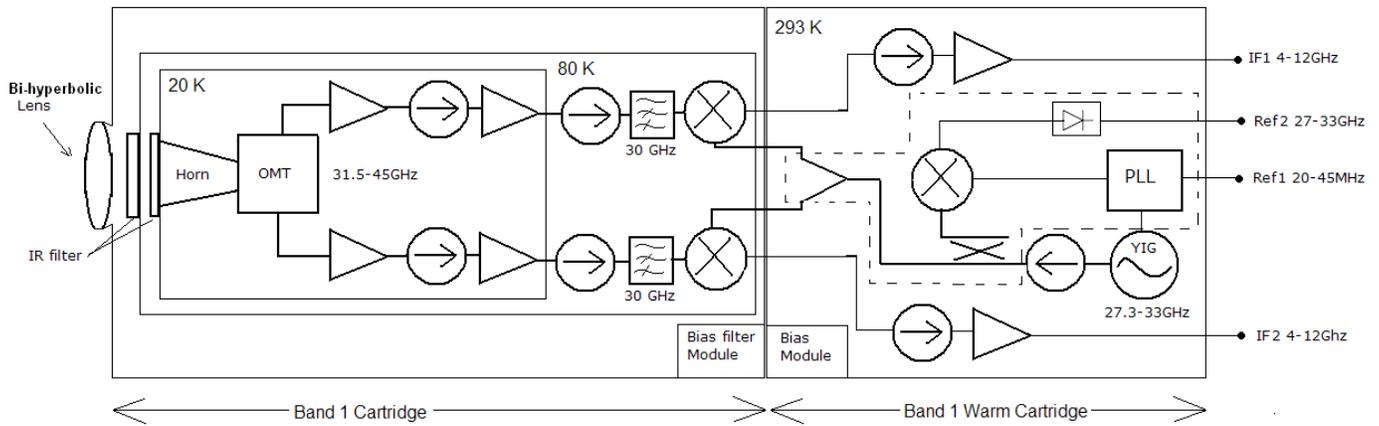


Fig. 1. Layout of the receiver for band 1 of ALMA. The incoming RF signal is coupled with the horn via a lens (Sec. III-A). The signal is then divided in its polarization components in an OMT (Sec. III-B). Then, each polarization signal is amplified in two consecutive HEMT's at 20 K (Sec. III-C). Finally, the amplified signals are filtered to suppress the lower sideband and mixed in separate Schottky diodes (Sec. III-D). Dashes lines represent the LO block developed by NRAO.

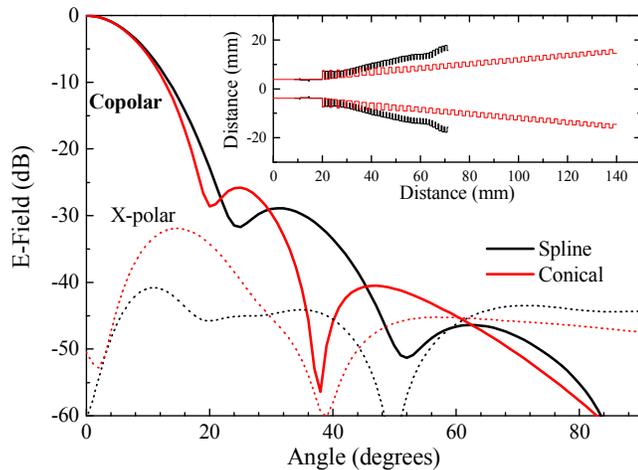


Fig. 2. Radiation patterns at 38 GHz of the spline and conical corrugated horns whose profiles are shown in the inset.

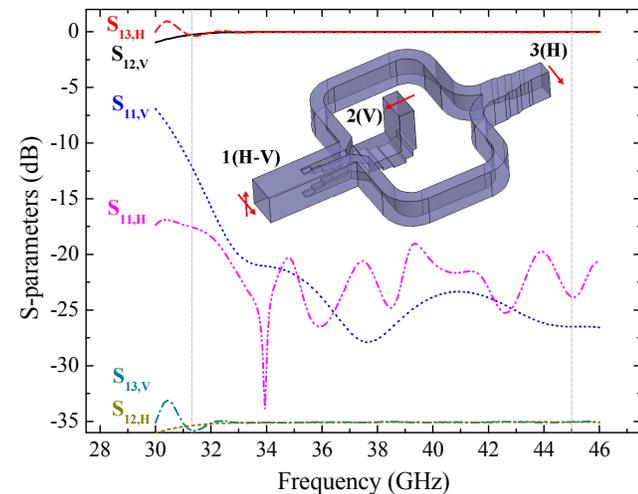


Fig. 3. Calculated S-parameters of the proposed orthomode transducer shown in the inset. The inset also shows the port numbers and the polarizations that each of them carries, H (horizontal) or V (vertical). Vertical dashed lines show the band-1 frequency range.

B. Orthomode Transducer

A “Dual Ridged” OMT has been adopted [1]. A preliminary model is illustrated in the inset of Fig. 3 and its

main dimensions are presented in Table 2. This model was also optimized using Ansoft HFSS. The simulated S-parameters of this model are shown in the main panel of Fig. 3. We can note that this OMT should work properly between the 33 to 45 GHz range. Some further optimization work, especially at lower frequencies, is needed to cover the entire bandwidth properly.

TABLE 1 MAIN DIMENSIONS OF THE ORTHOMODE TRANSDUCER (INSET OF FIG. 3)

Parameter	Dimensions (mm)
Input square waveguide	5.69×5.69
Output rectangular waveguide	5.69×2.845
Distance between ports 1 and 3	54.0
Distance between lateral waveguides	34.0

C. Amplification

The strategy proposed for the band 1 receiver is to amplify the RF signal by 30 or 40 dB to allow the use of a commercial Schottky mixer at either 80 K or at ambient temperature. This amplification signal will be done by a HEMT amplifier.

As a first stage we will test low noise amplifiers from Hittite (ALH376). This MMIC have a noise figure of 2.2dB and 20 dB of amplification at room temperature. The chip will be integrated at our laboratory. We have defined that the input and output of the amplification block will be WR22 waveguides. The coupling of the signal into the MMIC will be done by a waveguide-to-microstrip transition where we have compared rectangular [6] and radial probes [7]. We have found that radial probes have better response than the rectangular ones as shown in Figure 5.

D. Filter for Lower-Sideband Suppression and Down Conversion

A high pass filter cancels out the lower sideband signal before the down-conversion. For band 1 case we need a filter with a cut-off frequency of 30 GHz, with the pass-band at 31-45 GHz and a rejection band of more than 20dB at frequencies lower than 29 GHz.

To design the filter we have followed [8] and [9]. We simulated the filter as a cascaded transmission lines with each section having physical dimensions a_i and c_i , a propagation constant β_i and impedance Z_{0i} . (see inset of Fig. 4). The dimensions a_i and c_i were optimized to have a filter with a maximum rejection at the sideband and a maximum transmission at the RF frequency. After the optimization process a three stage filter was selected. The dimensions are shown in Table 2. The performance of the filter was checked using a full electro-magnetic simulator (HFSS). The attenuation of the filter in the rejection band is more than 18dB. The transmission is better than 99% over the whole pass band. The results are summarized in Figure 4. If better response is needed, a higher order filter could be used.

Using this filter the sideband rejection ratio of the receiver is better than 20dB in 99% of the LO configurations. The worst case is a rejection ratio of 18.5 dB where the LO is at 33 GHz and we are observing an RF of 37 GHz.

Since the noise is dominated by the amplifier we can use a Schottky mixer at either 80 K or room temperature for the down-conversion without a penalty in noise. We are planning to use a commercial balanced mixer from Quinstar. The main problem that we see in this solution is the relative high LO power required by this device. Other mixers have to be studied to reduce the LO power requirements.

TABLE 2 DIMENSIONS OF THE WAVEGUIDE FILTER (INSET OF FIG. 4)

Parameter	Dimensions (mm)
a_1, a_7	5.69
a_2, a_6	5.41
a_3, a_5	5.27
a_4	4.99

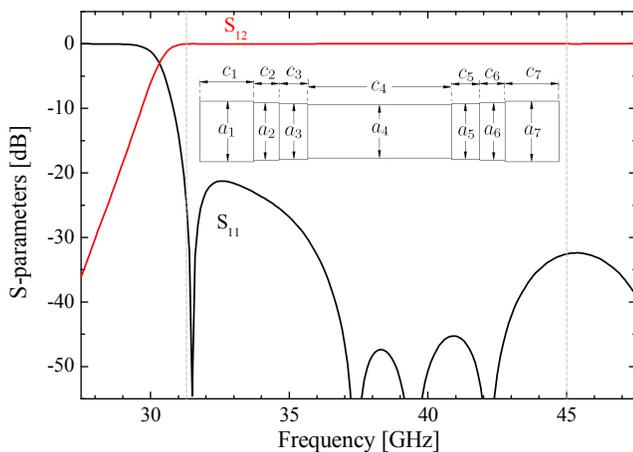


Fig. 4. S-parameters of the waveguide filter shown in the inset. In the frequency range of interest (vertical dashed lines), the transmission is better than -0.05 dB and the reflection lower than -20 dB.

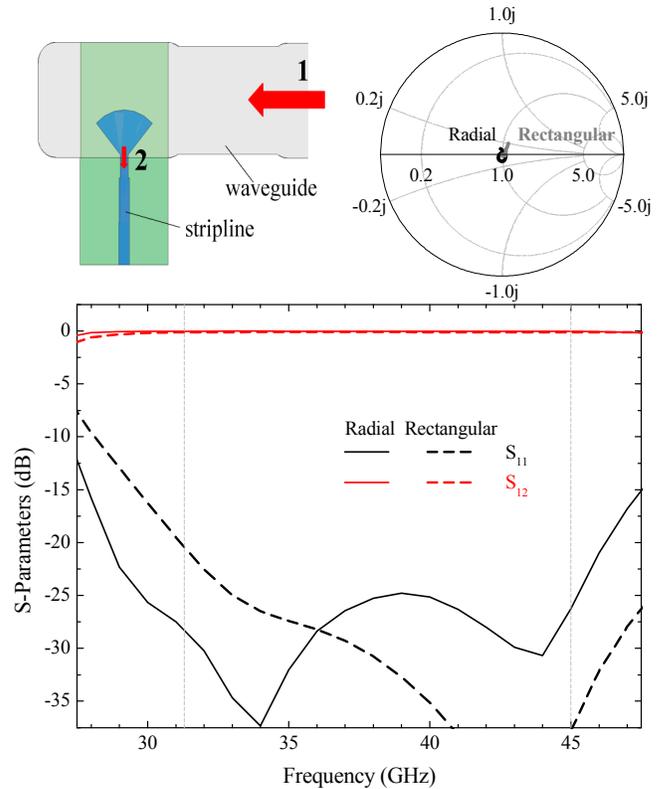


Fig. 5. *Top panel*: Waveguide-to-stripline transition that will be used to package the HEMT chips for amplification. The transition shown here (left) uses a radial probe to couple the incoming radiation into the stripline. When compared with the more traditional rectangular probe, the simulation results plotted in the Smith chart (right) show that a better coupling is obtained with the radial probe. *Bottom panel*: S-parameters of waveguide-to-stripline transitions using rectangular and radial probes, respectively.

IV. CONCLUSIONS

We have presented here the design of a receiver covering the 31–43-GHz band. This is the first step towards the construction of a prototype receiver for band 1 of ALMA. Once constructed, it will contribute importantly to the state of the art of the largest radio telescope array in the world. Moreover, in possession of this band, ALMA would be in the capability of performing very-large-base interferometry with other facilities around the world.

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REFERENCES

- [1] S. Asayama, "Double-ridged Orthomode Transducer for ALMA Band 4 receiver," NAOJ internal MEMO, 2007.
- [2] J. W. Lamb, "Miscellaneous data on materials for millimeter and submillimeter optics," *Int. J. Infrared Millim. Waves*, vol. 17, no. 12, pp. 1997–2034, Dec. 1996.
- [3] J.W. Lamb, "Cross-polarization and astigmatism in matching grooves," *Int. J. Infrared Millim. Waves*, vol. 17, no. 12, pp. 2159–2165, Dec. 1996.
- [4] C. Granet and G. L. James, "Design of Corrugated Horns: A Primer," *IEEE Antennas and Propagation Magazine*, Vol. 47, No. 2, April 2005.

- [5] High Frequency Structure Simulator (HFSS), version 11, Ansoft Corporation, Pittsburgh, PA, USA.
- [6] Yoke-Choy Leong, Weinreb, S., "Full Band Waveguide-to-Microstrip Probe Transition," Microwave Symposium Digest, 1999 IEEE MTT-S International Volume 4, Page(s):1435 -1438
- [7] J. Kooi et al., "A full-height waveguide to thin-film microstrip transition with exceptional RF bandwidth and coupling efficiency," Int. J. Infrared Millimeter Waves, vol. 24, no. 3, pp. 261 - 284, Mar. 2003.
- [8] Pozar, "Microwave Engineering" John Wiley & Sons, Second edition 1998
- [9] LIU A_-Shyi , WU Ruey-Beei and LB Yi-Cheng, "A compact design of W-band high-pass waveguide filter using genetic algorithms and full-wave finite element analysis," IEICE transactions on electronics ISSN 0916-8524 ,2005, vol. 88, no8, pp. 1764-1771.