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 by Asayama for band [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.

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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 the 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 the Fundamental Gaussian Beam Mode analysis [2]. We used High Density Polyethylene (HDPE) in our lens design with dielectric constant of 2.3. The final optimized lens design has the dimensions of 19.4 cm in diameter, 5.09 cm thick at the centre of the lens, and it has a focal length 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].

The first studied feed is a corrugated standard conical horn that was designed following the concept presented in reference [4]. The second corrugated horn was designed instead by C. Granet who uses its own developed techniques to create an optimum feed model. We used Ansoft HFSS 11 [5] software tool to optimize the first horn profile and to check the performances of both horns. In Fig.2, the radiation patterns at 38 GHz and the profile dimensions of the conical and spline corrugated horns are presented. It can be directly noted that the performance of the spline horn in terms of size, first side lobe location, and cross-polar level are much better than the standard conical horn design. But probably the mayor drawback that spline horn design can have is that its corrugation tooth dimension is too small compared to the other horn and therefore could present some construction limitation when using milling techniques.

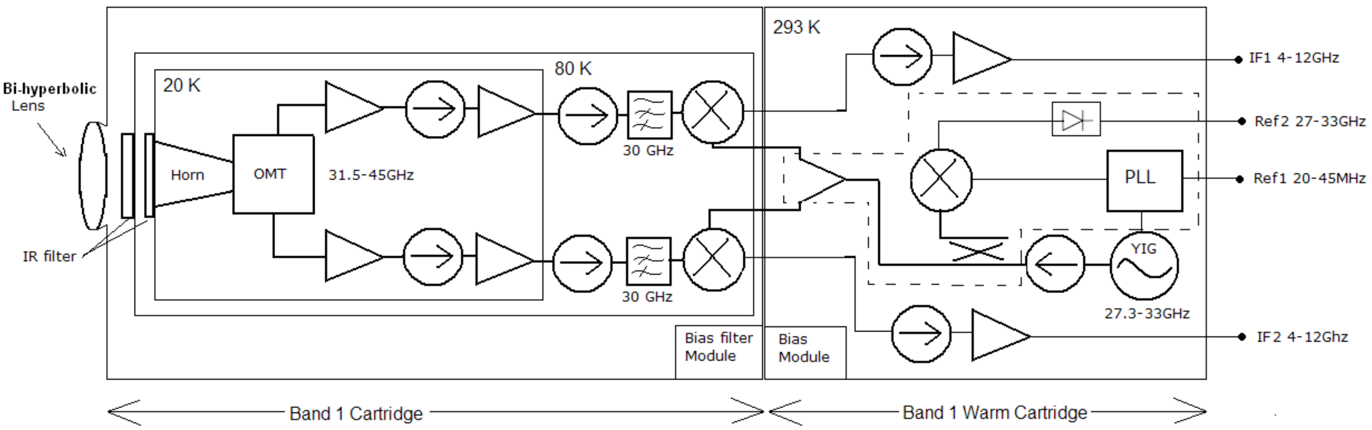

Fig. 1. Layout of the receiver for band 1 of ALMA. The incoming RF signal is coupled with the horn via a lens (Sec. III-A). The signal is then divided in its polarization components in an OMT (Sec. III-0). Then, each polarization signal is amplified in two consecutive HEMT's at 20 K (Sec. III-C). Finally, 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 [Ref.].

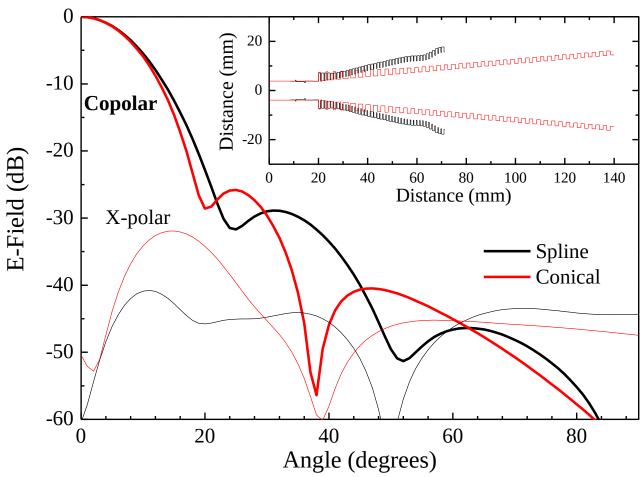

Fig. 2. Radiation patterns at 38 GHz of the spline and conical corrugated horns whose profiles are shown in the inset.

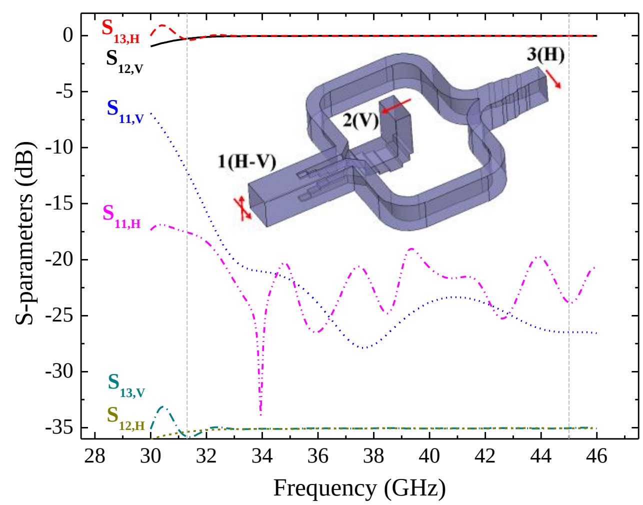

Fig. 3. Calculated S-parameters of the proposed orthomode transducer shown in the inset. The inset also shows the port numbers and the polarizations that each of them carries, H (horizontal) or V (vertical). Vertical dashed lines show the band-1 frequency range.

B. Orthomode Transducer

A "Dual Ridged" OMT construction designed by Assayama has been adopted [1]. A preliminary model is illustrated in Fig. 3 and its main dimension features are presented in Table 2. This model was also optimized using Ansoft HFSS. The simulated s-parameters of this model are shown in the below part of Fig. 3, and from these results we can note that it should work properly between the 33 to 45 GHz range. Some further optimization work, specially at lower frequencies, it 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 ambient temperature. The signal will be amplified by a HEMT amplifier.

As a first stage we will test some 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 signal will be coupled by a microstrip to waveguide transition to the stripline. We have designed rectangular an radial probes following [][]. We found that radial probes have better response than rectangular, as shown in Figure 5. We have also worked on the bias circuit for the MMIC avoiding resonances in the structure.

D. Filter for Lower-Sideband Suppression and Down Conversion

The high pass filter cancels out the LSB signal before the down-conversion. For this 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 with more than 20dB at frequencies lower than 29 GHz.

To design the filter we have followed [61] and [62]. We simulated the filter as a cascaded transmission lines. Each section of the filter with physical dimensions of A_i and C_i, is modeled by a transmission line with a propagation constant β_i and impedance Z_{0i}.

The dimension A_i and C_i where 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 showed 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 room temperature for the down-conversion without a penalty in noise. We will 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)
$a1, a7$	5.69
$a2, a6$	5.41
$a3, a5$	5.27
$a4$	4.99

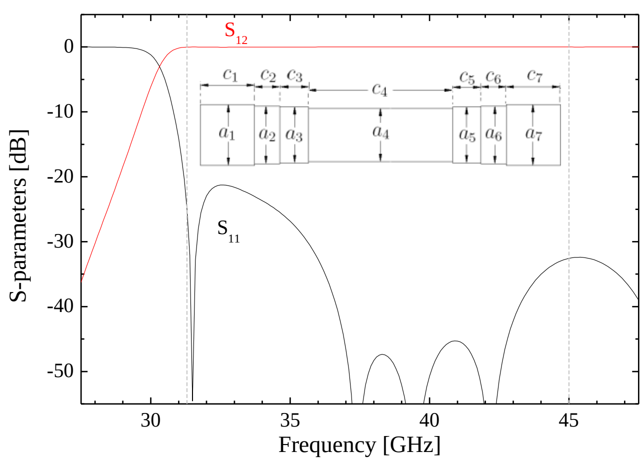

Fig. 4. S-parameters of the waveguide filter shown in the inset. In the frequency range of interest (vertical dashed lines), the transmission is better than –0.05 dB and the reflection lower than –20 dB.

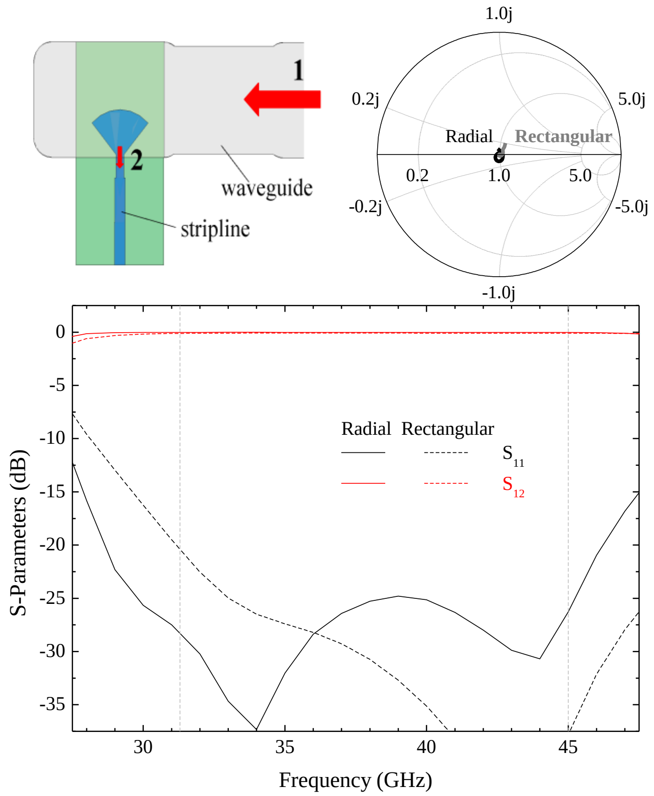

Fig. 5. *Top panel*: Waveguide-to-stripline transition that will be used to package the HEMT chips for amplification. The transition shown here (left) uses a radial probe to couple the incoming radiation into the stripline. When compared with the more traditional rectangular probe, the simulation results 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 smaller telescopes around the world.

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