Proposal for a new amplitude calibration scheme for the ALMA receivers

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Introduction

This proposal outlines a means to make a prototype amplitude calibrator that will work within the ALMA 12m antennas. This calibrator will endeavours to reach the goal required by the Science IPT.

The ALMA project requires an accurate and precise amplitude calibration scheme. The goal for the accuracy of this calibrator is 1%, which is a very stringent. Two different schemes have been proposed to reach this goal:

1. The dual load calibrator
2. The Semi-transparent vane calibrator

Neither of these schemes could reach the desired accuracy level, and they both had large problems that could interfere with the proper working of the receivers on the telescope.

We propose a third calibration system, which is close to that used for the semi-transparent vane calibrator. Guilloteau and Bacmann discuss this in the ALMA memo 461. This report will describe the proposed calibrator in 2 parts. The first part will describe the calibrator, and the second part will describe the motorized system that can place the calibrator, in front of any of the ports. This system will not calibrate bands 1 and 2, which due to their beam size will need a separate calibrator. The calibrator for bands 1 and 2 would probably be an ambient load only.

The Calibration Scheme

The calibration scheme as described by Guilloteau and Bacmann page 6 section 6 “The Optimum Setup”, and is shown schematically below. Here it can be seen that the receiver can see the following:

A. Tsky
B. Tsky + Tamb/cool
C. Thot
D. Tsky + Thot
E. Tamb/cool

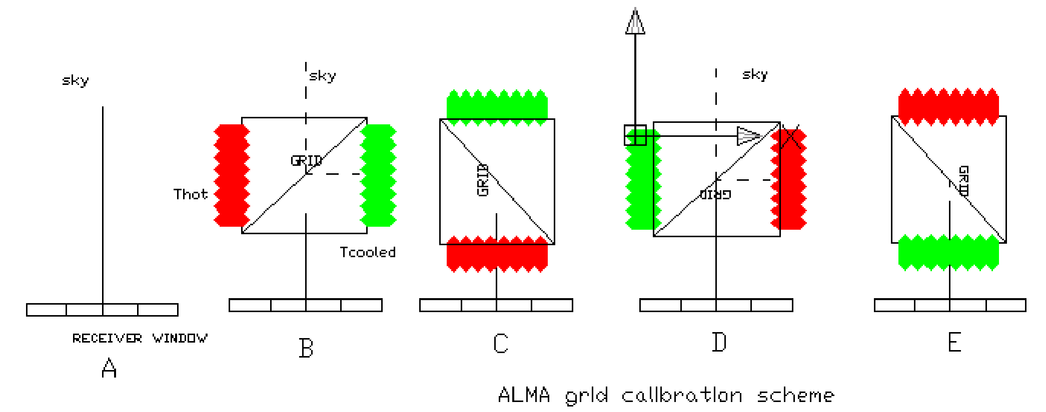

fig 1; The calibration scheme

To achieve this we can put make a cube that has 2 calibrated temperature loads as 2 sides. One of these loads will be heated Thot at about 120°C and the other at ambient or cooled about 10-15°C. In between these 2 loads at 45° to them will be a reflecting semi-transparent vane, which could be a grid at 45° to the E-vector, which would then act as a semi-transparent vane where 50% is reflection and 50% transmission. The box can rotate about its centre as shown, so that we could have the sequence B – E, shown above. To have the sequence A – E, we would need to move the calibration box in and out the receiver beam. To have an accurate calibration the whole sequence needs to be completed in the order of 3 seconds.

This system above could possibly be modified and simplified, after a further study. One possibility is to have a heated load and a grid as a semi-transparent vane, this time instead of the box rotating the grid is rotated on its axis. If the grid is rotated through 5 positions, say 0, 22.5, 45, 67.5, and 90 degrees, the measured receiver noise will be a known 5 different percentages between Tsky and Thot. Further to this could give a means of polarization calibration.

Before the manufacture of a prototype calibrator is started a study is required to determine the best and most cost worthy technique to follow from the 2 above ideas and perhaps further cogitations that could arrive.

Positioning equipment

A motorized positioning system is envisaged to place the calibration box in front of the receiver from bands 3-10.

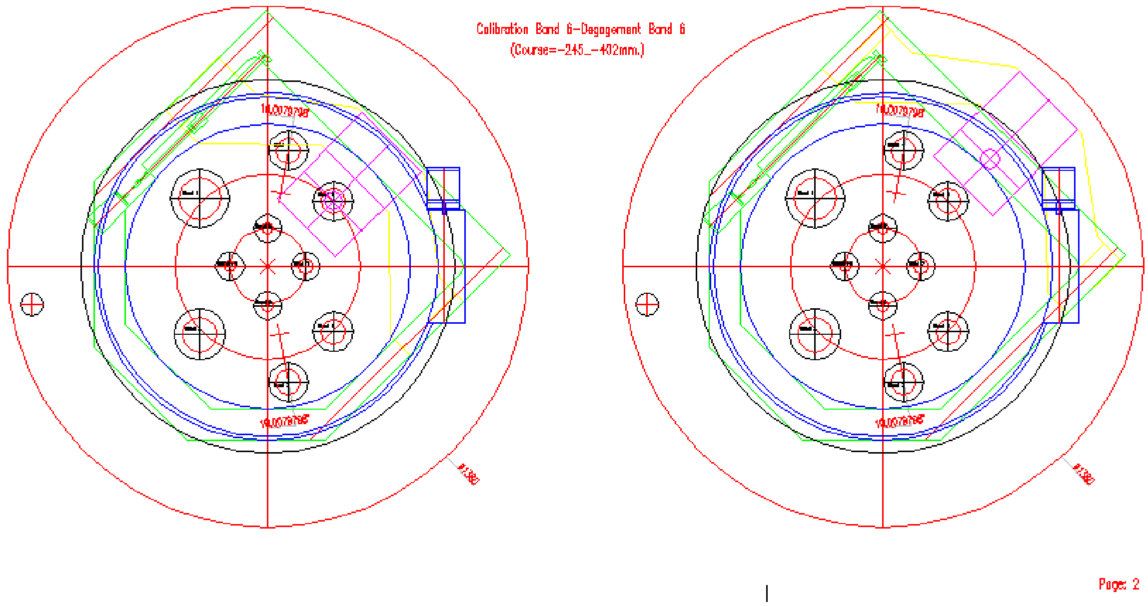

Figure 2 the calibration position for Band 6

The purple circle in the purple box is the calibrator. As it can be seen this can rotate on a rotational table whose axis is the centre of the cryostat. This table is fixed to the FESS. When the box comes to the correct radial position with respect to the receiver under test. The rotational motor stops. As can be seen in figure 2 for band 6, the box can be put into the beam by the use of a linear motor. With this the calibration sequence shown in figure 1 can commence. The total sequence should be completed in the order of 3 seconds. This sequence involves the following:

A. Box out of the beam for state A, Sky
B. Box in the beam for state B-E, where the box is rotated through either 180° in 3 steps if we require any of the 3 examples described in memo 461, which are as follows:
   - C, D, and E
   - C, D, and B
   - C, B, and E

After this the calibrator is taken out of the receiver beam.

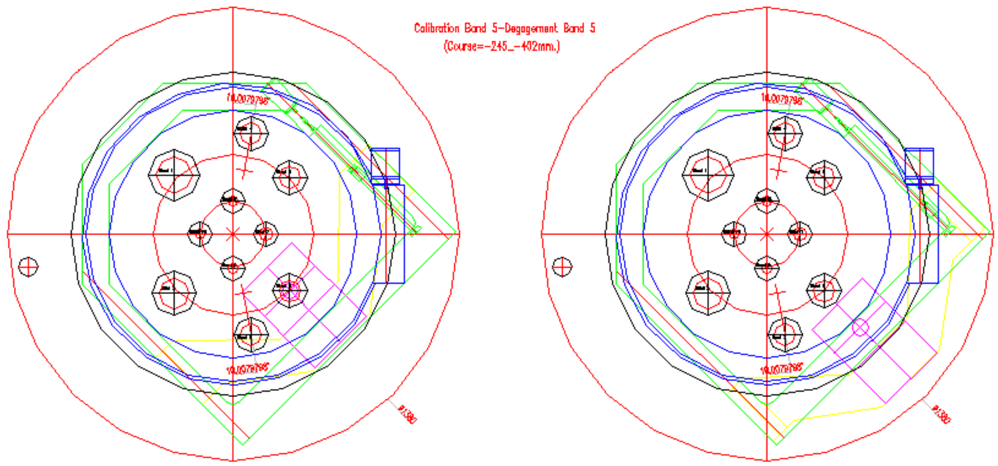

Figure 3 the calibrator positions for bands 5

This calibrator can be put in front of any of the beams including the WVR. During a calibration the box will never cut the beam of either the WVR or the band 3, except in the case for a calibration of band 10, where the calibration will interfere with the WVR. This constraint has meant that the calibration box cannot be big enough to calibrate the 2 lowest frequency bands 1 and 2. For these 2 bands, which will be HEMT receivers will have an ambient load only as a calibrator.
The motors required to position the calibrator, with the constraints required in position and speed will be stepper motors. The power consumption required for these will of the order of 2.5KW.

Calibration performance

In the ALMA memo 461, the following parameters are required to be known to the precision given below:

1. The coupling fraction should be known to within 0,008, i.e. 1.6% precision.
2. The ambient temperature should be known to better than 0.3K
3. The Hot load temperature should be known to better than 0.6K
4. Measurement errors should not significantly exceed 0.1K, i.e. the gain stability should be better than $3x10^{-4}$ on the measurement timescale. If not several measurements must be averaged together to get the required precision.

The coupling errors

To couple the loads it is proposed to use a grid. In theory if the wires are at 45° to the E vector we will have 50% coupling to the sky and 50% to the load. However the specifications for the front-end give the following:

- Cross polar coupling between the 2 polarisations < -20dB
- Cross polar difference between the antennas < -20dB
- Polarisation alignment the E vector radial with in +/- 1°.

This means that there can be an error in the alignment of the cartridge by 2°, but this must be consistent for all of the cartridges
A freestanding wire grid will have losses, which changes with frequency due to 3 reasons:

1. Ohmic losses that will increase with frequency, but at a known rate.
2. The grid construction i.e. wire diameter with respect to the wire spacing, but this will be consistent with all of the grids and known.
3. Errors in the grid manufacture.

Loads

Guilloteau et al have talked about 2 different scenarios:

1. a heated load and an ambient temperature load.
2. A heated load and a cooled load, this scheme will probably not be used.

To heat or cool a load and at the same time be accurate of its temperature across a large frequency range such as ALMA bands 3 – 10 is not a trivial undertaking. The return loss of the load should be less than –30dB. There are a few load designs that appear to do this. However the material used is not ideal for a heated or cooled load. The problem is that the means of heat transfer has to be done by conduction and the load materials are not good heat conductors. Added to this the penetration depths of the microwave powers to be incident on to the load decrease with frequency.
The Rutherford Appleton Laboratories. RAL, with the MARSCHALS project have an interesting design of load where an aluminium block is machined with pyramidal shapes. On top of these pyramids epoxy based absorber of about 2mm thick is deposited on to the surface.

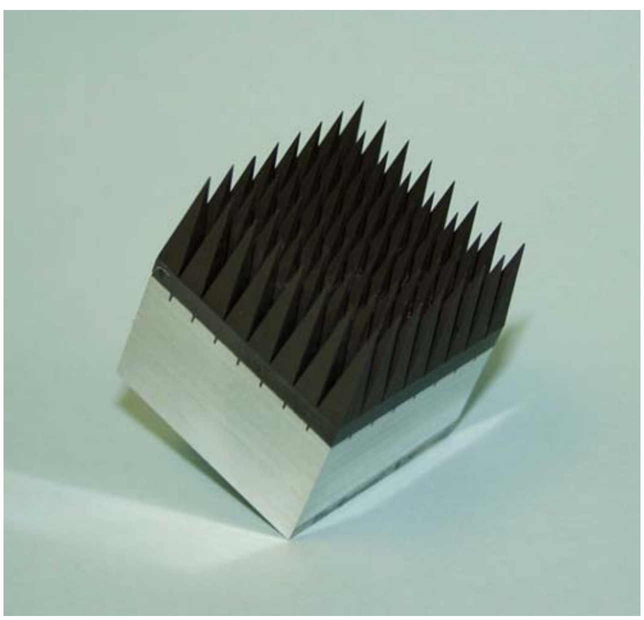

Figure 4 RAL calibration load

There are a number of other ideas that should be followed to achieve a good calibration load, which are:

1. To see if there is another material available that has a higher coefficient of thermal conductivity. There are at least 2 possibilities, which are the RAM absorber made by Thomas Keating Ltd in England or a ceramic absorber made by Kyocera in Japan.
2. Redesign the loads to be lighter and smaller