

Abstract

We propose a flux calibration system for ALMA that uses one of the ACA antennas to produce accurate fluxes for the compact phase calibrators, rather like the small calibration telescope used with the Sloan Survey. The process has two steps. First, the gain of one of the small ACA antennas is measured to an accuracy of 1% by comparison of its response to a bright planet with that of a standard gain horn. The next step uses that calibrated antenna to measure accurately the fluxes of the phase calibrators that will be used during the next few hours. Scaling the amplitude of the map to the fluxes of the phase calibrators will produce a map with accurate brightness. Since the phase calibrators are in the same part of the sky as the unknown, the extinction correction is automatically accomplished by this scaling.

1 Introduction

Imaging with ALMA with brightness accuracies of 1% or better requires calibration sources in the sky whose fluxes are known that well. With the possible exception of MWC349, there are at present no known compact sources of constant flux at mm/submm wavelengths, let alone accurately measured. It is possible to characterize the gain of an antenna to the requisite accuracy; however, receiver changes, maintenance activity on the antenna, as well as normal wear and changes in the course of use will spoil the calibration, requiring frequent remeasurement. Some sort of continuous calibration system is necessary.

We propose a strategy for calibration of the ALMA system at the 1% level based on an experiment in which we have demonstrated such a calibration accuracy on one of the BIMA antennas at 28.5 GHz. The gain calibration is to be established on one of the ACA antennas by an interferometric comparison process using all the ACA antennas. The standard for the measurement is a small horn, of gain about 40 dB less than that of an ACA antenna, mounted on the edge and aligned on-axis. The horn will be of simple and rugged design and will remain gain-stable over time. A bright planet is observed with the ACA, with fringes observed alternately between the standard horn and the other ACA antennas, and the antenna to which it is attached and the other antennas [see fig 1]. The ratio of the two alternate correlations is the voltage ratio of the ACA antenna gain and that of the standard horn.

This interferometer measurement has a number of important advantages over the usual total power comparison. The cross-correlation of the standard horn and a dish is 1% (20 dB voltage ratio) of that between two dishes, rather than the total power ratio which is 10^{-4} . This is readily measured to 1% accuracy on a strong planet. Furthermore, since only the correlated signal contributes in the measurement, side-lobe response and multipath echos, the bane of all antenna calibrations, are completely eliminated. Also, the atmospheric extinction is common in the ratio and cancels out.

Once the antenna gain is known, the fluxes of moderately bright sources can be measured with this single ACA antenna equipped with regulated hot and cold loads.

2 The 28.5 GHz Experiment

Details of the experiment can be found in Gibson and Welch (in preparation), and only the main aspects will be summarized here. We used one of the BIMA antennas at 28.5 GHz with a special receiver based on a HEMT amplifier (Carlstrom, personal communication). The experiment had two parts. The first was the interferometric measurement of the antenna gain, and the second was the measurement of the flux of Jupiter using accurate hot and cold loads in the receiver.

Figure 2 shows the basic circuit arrangement for the gain measurement including two transfer switches. Two switches were used, and actuated simultaneously to provide high isolation between the large signal from the regular feed and the weaker signal from the standard horn. Over-moded waveguide (for low-loss) was used to carry the horn signal into the cabin. A coil of extra waveguide was included in order to equalize the delay paths. The standard horn is mounted on the edge of the main antenna, co-aligned, and with apertures coplanar.

Wrixon and Welch (1972) established that a well-machined pyramidal standard gain horn is characterized to better than 1% by Schelkunoff's gain formula (1955). Accordingly, an extremely rigid standard horn of appropriate dimensions was machined from aluminum with high precision. The waveguide losses were painstakingly measured using an HP 8720 network analyzer. Observations were made in a compact array and all baselines were used and scaled appropriately for the resolution of the extended source ($43''$) Switch reproducibility was adequate, and the scatter in the measured correlations

was small. The flux of Jupiter was 115 Jy during the experiment. The antenna aperture efficiency was found to be 0.66 with an uncertainty of less than 1%. There were a number of very small corrections. The BIMA antenna surface is utterly stable at 28.5 GHz, with no elevation effects. Likewise, relative to the beamwidth at that frequency, pointing errors are negligible. The second part was the measurement of the flux of Jupiter with the calibrated antenna. An ambient temperature load and a liquid nitrogen load were put in the circuit. The same waveguide switches were used to cycle them in and out of the measurement. There were many on/off measurements of Jupiter, and there was a small correction for extinction based on tipping curves. The result (9/25/00) gives a disk temperature of $142.1 \pm 2\text{K}$ including all errors for Jupiter at 28.5 GHz.

3 A Calibration Strategy for ALMA

Because the bright compact radio sources vary considerably in time and one cannot depend on the antenna gains being sufficiently stable with time, it will be important to make absolute gain calibrations frequently. We imagine equipping one of the ACA antennas for this purpose. It would assume a role similar to the smaller calibration telescope used by the Sloan Survey. There would be a standard gain horn for each receiver band, and these would be located around the edge of the dish. The receivers of that antenna would be equipped with waveguide switches and well-regulated thermal loads so that calibration, as described above, could be carried out in any band. After a planet has been observed interferometrically to get the large antenna gain, the antenna will measure the fluxes of sources to be used as phase calibrators during the next days or hours. The antenna gain measurement at every band will probably need to be done infrequently, so that the entire ACA will not be taken up for this purpose very much. Measuring the fluxes of the bright phase calibrators with the calibrated antennas will have to be done frequently but should not take very long at any given frequency. These fluxes will have to be monitored. The advantage of this plan is that the phase calibrators needed in every observation will have fluxes known to 1% and accurate images should result from scaling maps to them. Extinction correction of the map is also accomplished in this scaling.

One important issue is the question of how to make extinction correction during the amplitude calibration of the phase calibrators. At 28.5 GHz the

correction was small and tipping curves were sufficient. At much higher frequencies, the opacity is larger and the effects of unknown ground pick-up and distant sidelobes become more serious. Based on tests we have made, we find that a more accurate measure can be obtained by tracking the fringe amplitude of a bright source as a function of zenith angle on a short baseline. Using the interferometer avoids the problems of multipath and ground pick-up. Good gain stability in the receivers will be required for this step. Also, good pointing accuracy is essential.

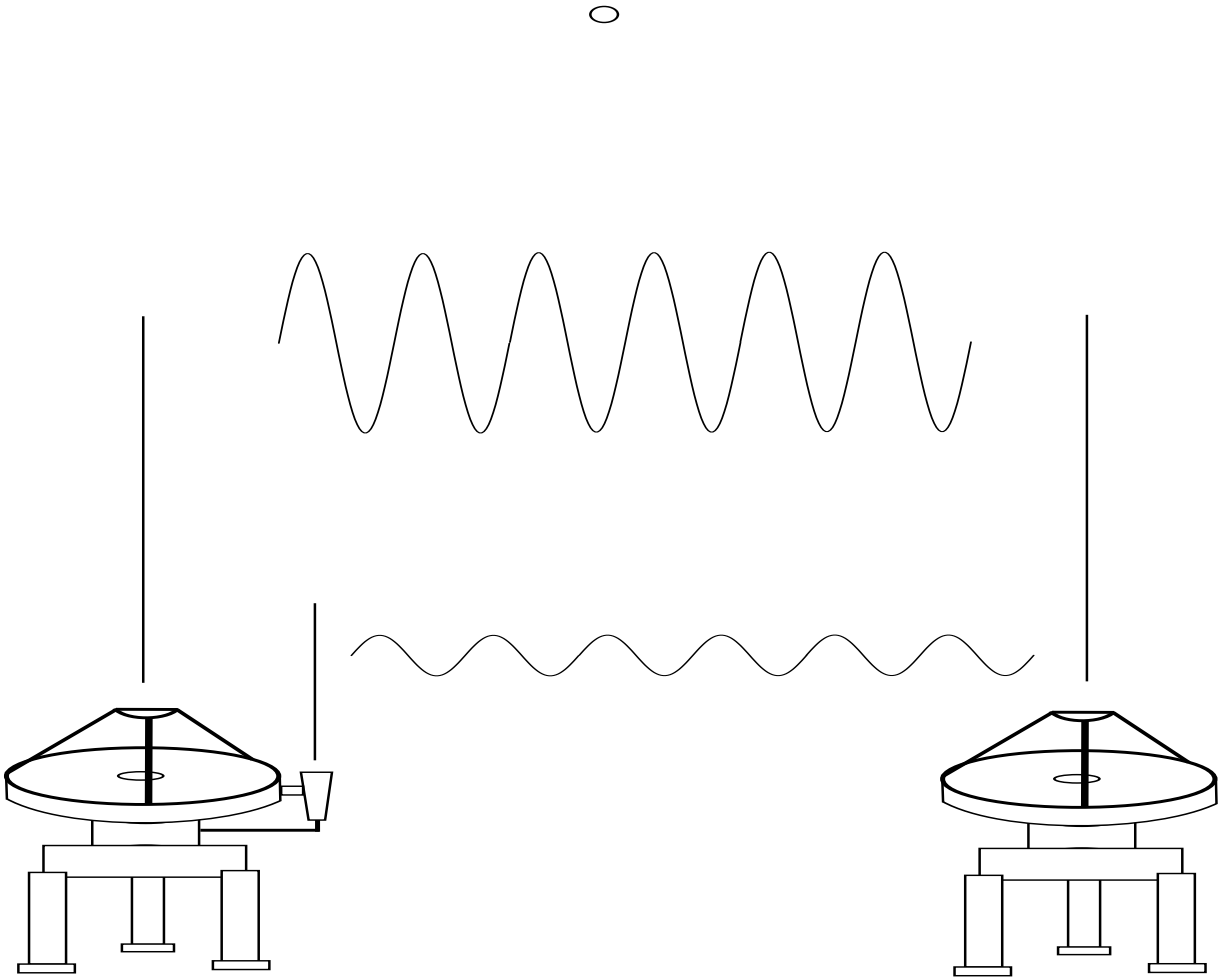


Figure 1: The overall arrangement for the gain measurement. Either the standard gain horn or the regular feed can be connected to the receiver of the antenna on the left.

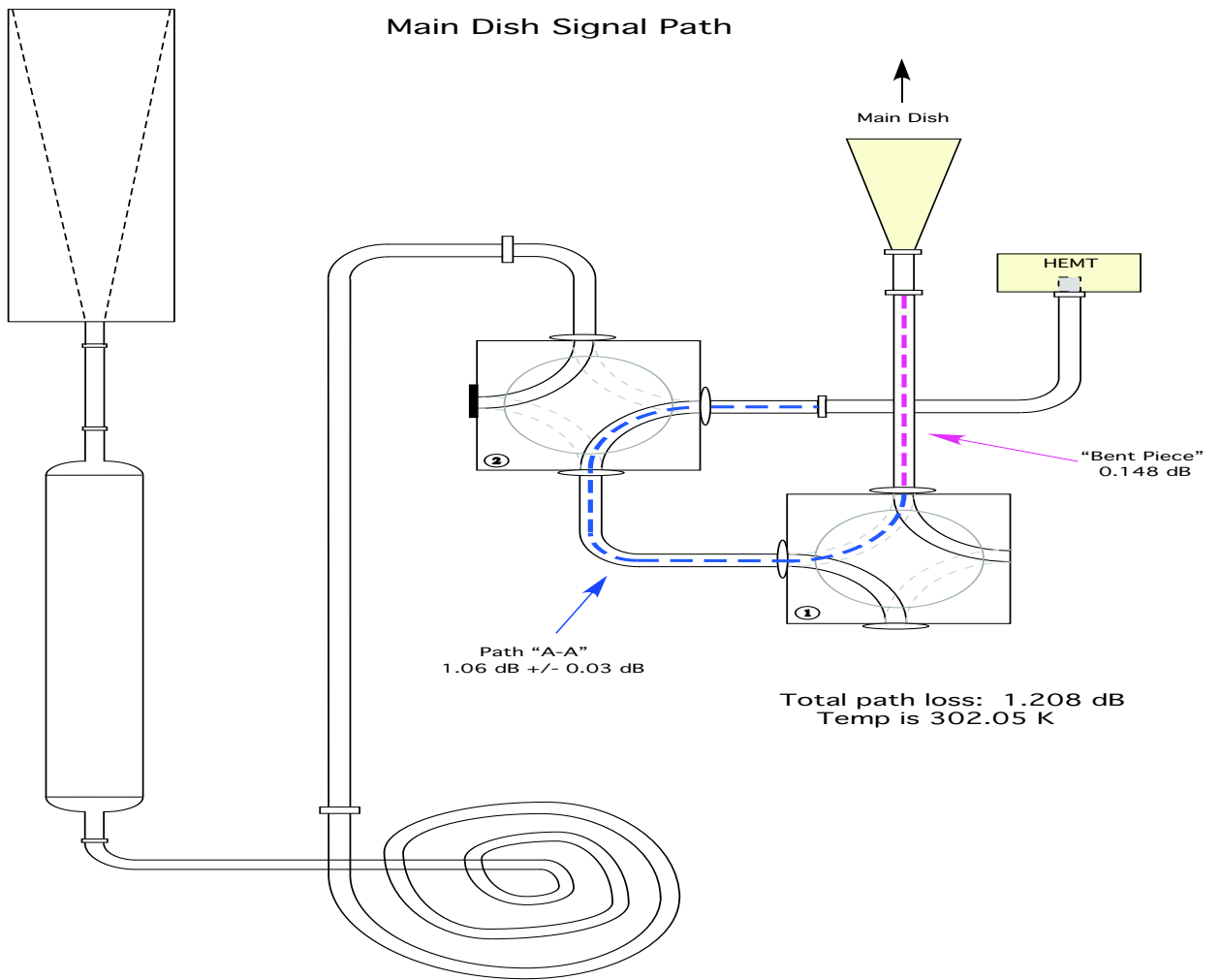


Figure 2: The circuit showing how either the standard horn or the feed may be switched to the receiver.