Plans for a 1% Absolute Flux Experiment at 100 GHz

James Gibson and Jack Welch
UC Berkeley

October 20, 2003

Abstract

We propose to carry out an absolute planet flux measurement based on an accurate antenna gain calibration at 100 GHz with the BIMA array, attaining an uncertainty of only about 1%. The scheme is based on the addition of a standard horn of accurately known gain into the array. Based on the outcome, we expect to propose hardware for the ALMA array which can obtain accurate fluxes of standard sources at any convenient time, using the ACA.

1 Introduction

Gibson and Welch (2003) were able to calibrate the gain of one of the 6 m BIMA millimeter wavelength antennas to an accuracy of about 1% at 28.5 GHz and then measure the flux of Jupiter to an uncertainty of 1.6% at that frequency. Fitting this result with a model spectrum of the Jovian emission, Gibson et al (2003) were able to show that ammonia is likely globally subsaturated in the planet's upper atmosphere. Because the ammonia density is a very steep function of temperature in this part of the atmosphere, the high accuracy of the measurement was necessary. There are many other problems for which such high accuracy is essential, and therefore we propose to develop a technique for accurate amplitude calibration, based on the 28.5 GHz experiment, which can be used for the ALMA telescope. The plan is to test the technique at 100 GHz with one of the BIMA antennas.

Berkeley-Illinois-Maryland Assn @ Hat Creek

2 The Basic Scheme

The key idea is the addition of a standard gain horn to the array of small antennas, the BIMA array, or the ACA in the case of ALMA. The gain of the horn can be calculated (or measured) to better than 1%, and this gain can then be transfered to the other antennas through the observation of a bright planet, like Jupiter. The gain of the horn is about 40 db less than that of an array antenna, but the cross correlation of its signal from the planet with that of one of the array antennas is 1% of the signal correlation between two array antennas, and that signal can be accurately measured. In the Gibson and Welch (2003) experiment the horn was mounted at the edge of one of the BIMA antennas, and a waveguide circuit equipped with switches allowed either the antenna feed horn or the standard horn to be connected to the antenna's receiver. Jupiter was then observed with the array, first with the regular feed connected, and then with the standard horn connected. The ratio of the signal correlation with each other antenna between the two observations was the voltage ratio of the antenna gain to that of the standard horn. Adding that ratio to the gain of the standard horn then gave the antenna gain, and the accuracy was about 1%. In this part of the experiment the precise flux of Jupiter does not matter, and no extinction correction is required. Waveguide transmission losses were measured with a Network Analyzer. The correlator serves as an accurate power meter. The receiver bandwidth of 800 MHz entails a correlation length of only about 30 cm along the signal path, and this effectively eliminates the problems of multipath propagation to the standard horn.

In the second part of the experiment, the antenna with the accurately known gain was used to measure the flux of Jupiter. For this, two waveguide loads, one at ambient temperature and one at liquid nitrogen temperature, were added to the microwave circuit for accurate calibration of the system temperature. An accurate HP power meter was used as power detector. The flux of Jupiter was measured by many on/off observations, and the extinction was measured by many tipping curves. The final result, including the addition of the brightness of the 2.74K CMB and the subtraction of synchrotron emission, is a disk brightness of 142.9K ±2.3K (1.6%).

3 The Plan for the 100 GHz Experiment

The first step will be to do the 28.5 GHz experiment at 100 GHz with some refinements that should improve the accuracy. The BIMA array will be used again. The first refinement will be to use switches from Millitec with better repeatability. The second is to use two feed horns in the antenna focal plane with rapid switching between them for better stability in the final flux measurement. For the extinction measurement, we will use the standard gain horn with a backing shield behind it. This antenna will have a predictable pattern for which an accurate correction can be made for the horizontal extent of the atmosphere. Earlier experiments using this for extinction corrections for CMB experiments showed that this method works well. We plan to use a borrowed HP8510 Network analyzer with λ3mm receivers to make the waveguide loss measurements. Venus, Saturn and/or Jupiter will be the strong source for transferring the gain. Hot and cold waveguide loads similar to the ones used at 28.5 GHz will again be used to measure the system temperature.

We will then repeat this measurement using a different technique for comparison. In this experiment, we will determine the complex gains of all the array antennas by amplitude closure relations using the array augmented with the standard gain horn. Once all the array antenna gains are known, then the planets, or any other sources can have their fluxes measured with the array. It will require measuring the system temperature of the horn using ambient and cold loads that are coupled to the aperture of the horn. The system temperatures of all the antennas must also be known accurately. The system temperature calibration of the horn by external loads should be straight forward, based on earlier experience (c. f. Miner et al, 1972).This alternative to what Gibson and Welch did was suggested by Stephane Guilloteau (private communication), and if it can be made to work as well is probably the best way to extend the standard horn technique to frequencies higher than 250 GHz. For both schemes, we will take all the precautions that we did at 28.5 GHz, and more steps will be necessary. Frequent pointing calibrations will be necessary. Antenna gain changes of up to 2% over all elevations will require careful modeling from our holography data. The extinction measurements with standard horn will require using the chopping switches for stability. The goal will be measurement of a planet flux to 1%

accuracy.

4 Equipment requirements

The BIMA array will be available for the experiment. Once all the special equipment is prepared, we expect to take over the array for about a week to do the actual experiments. This should allow time to repeat the observations and, perhaps, do a calibration at more than one frequency. A lot of miscellaneous waveguide and receiver components are available from previous receivers. We will assemble a special receiver for one antenna and the horn. We plan to use a mmic receiver chilled to 20K followed by a Schottky diode mixer in an available dewar. We have one transfer switch but will need to buy a second. We will have to build feed horns and the standard horn. We will stabilize the receiver temperature as before. Also, we must build the two standard loads. For these we will copy the k-band loads we used before.

Our schedule is to assemble the new receiver and make all the needed measurements of waveguide losses, along with testing the reproducibility of the waveguide switches during the next few months. We expect to carry out the experiments on the array in late April or early May of 2004. As well as for the planets, we plan to make an absolute calibration of MWC349. If this source should turn out to be stable, we can combine its 100 GHz measurement with our 28.5 GHz value to produce an accurate overall calibration spectrum. Based on previous knowledge of this source we expect to see something close to the $\nu^{0.6}$ spectrum of an ionized outflow.

5 Budget