Calibration System of AMiBA Project

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Abstract

AMiBA is a 3mm wavelength astronomical interferometer consisting of 0.6m to 1.2m antennae. An artificial source is required for its calibration. We present an approach of using a tunable CW source to calibrate the phase and amplitude response. Performance and problems of the system are discussed.

Introduction

Array for Microwave Background Anisotropy (AMiBA) [1][2] is an interferometer aiming to determine the cosmological parameters, mainly the matter density Ω_m and the density perturbation normalization σ_8 , by measuring the anisotropy in the Cosmic Microwave Background (CMB) radiation at arcminute scale. Though the measurement on CMB angular power spectrum can probe the early universe, its main science target at probing the more recent large-scale structures, i.e. galaxy clusters, through the Sunyaev-Zel'dovich (SZ) effect [3], which results from the distortion in CMB radiation's frequency spectrum due to the inverse Compton scattering by hot electrons contained within galaxy clusters.

AMiBA operates at 86 - 102 GHz and will eventually consist of 19 antennae / 171 baselines. The array sits on a single platform and the longest baseline will be 6m, yielding the highest angular resolution 2 arcmin. While a set of 0.6m diameter antennae were designed to suit the initial CMB angular power spectrum measurement, another set of 1.2m antennae will be in use to optimize collection of the galaxy cluster SZ effect signal. Correlation of each baseline currently takes place in a wide-band 4-lag analog correlator [4][5] at 2 - 18 GHz intermediate frequency (IF).

A common way of calibration is to observe a strong point source and calibrate out the instrument-introduced phase and amplitude errors. However, point sources that are sufficiently strong in 3mm, for our relatively small antenna size 0.6m or 1.2m, are rare. An artificial calibrator is therefore required to calibrate the phase and amplitude response of the receiver system frequently.

Artificial Calibrator

A straight forward way to investigate the system response is to send a CW signal that sweeps through the entire passband and determines the spectral response

both in amplitude and in phase. A block diagram of the system can be found in Fig. 1.

Fig. 1: AMiBA calibration system block diagram. The two dashed boxes 'Feedback' and 'Broadband Noise' were not included in the test result shown in Fig.3. The YTO output 10.5-13GHz tunable CW signal. The signal is doubled and distributed to each receiver. An independent phaseshifter is introduced in each path to create relative phase difference. Finally the signal is multiplied by four (x4) and coupled into receiver for correlation.

The 4-lag analog correlator contains four mixers, which have relative delays of (-37.5, -12.5, 12.5, 37.5) picosec respectively in an ideal case. During calibration, output of a particular mixer can be written as

$$L(f; \tau_i) = D_i + P(f)R(f; i) \times \cos(\phi_{sys} + \phi_{cal} + 2\pi(f - f_{LO})\tau_i). \quad (1)$$

$P(f)$ represents the input CW power. $R(f; i)$ indicates the system amplitude response as a function of frequency and mixer variation. Apart from the system phase response ϕ_{sys} , the output is also affected by calibration system path difference ϕ_{cal} , actual IF delay τ_i , and the system DC offset D_i .

In order to break the degeneracy, we introduce a variable phase shifter in each calibration signal path as shown in Fig. 1. A full cycle of fringe in each baseline is sampled at one frequency and repeated over the entire frequency band. Fitting a sinusoidal function to data at one frequency determines $R(f;i)$, D_i and $\phi_{cal} + \phi_{sys} + 2\pi\tau_i(f - f_{LO}) = \phi_{cal} + \phi_{sys}$. ϕ_{sys} and τ_i need not be distinguished, since ϕ_{sys} gives as good description of the system response. To single out ϕ_{cal} , it requires an additional astronomical source, such as Jupiter, which calibrates ϕ_{sys} directly. It then combines with the artificial calibrator data to determine ϕ_{cal} .

As a calibrator, its ϕ_{cal} and $P(f)$ should be stable, or the variation be known. To achieve the later goal, we include a feedback system to monitor the calibrator variation (Fig. 1). In particular, we insert a coupler at the end of distribution and couple out a weak signal. The signal is sent back to the central source and mixed with a signal before distribution. This allows for monitoring the phase variation of the calibrator.

Applying Calibration Data

The calibration data $R(f;i)$ and ϕ_{sys} can be thought of as an array of complex response $C(i, f_j)$, or simply C_{ij} . With a broad band signal, $P(f_j)$ or P_j , coming through, the mixer output in matrix representation is

$$L_i = C_{ij} P_j \cdot \Delta f \quad (2)$$

By trying to find an inverse matrix C_{ij}^{-1} [3], one can use the calibration information for transform mixer output data back into complex power spectrum as in complex visibility [6]

$$P_j = (C_{ij})^{-1} L_i / \Delta f \quad (3)$$

In AMiBA's case, i runs from 1 to 4, whereas one can sample arbitrarily number in frequency points. The inversion of matrix C_{ij} is therefore not unique with infinitely many degenerate solutions. The choice of solution is an optimization problem.

Initial Test Result

Initial test at three frequencies of the system is shown in Fig. 2. As explained earlier, the relative phase in vertical axis consists of $\phi_{cal} + \phi_{sys} + 2\pi\tau_i(f - f_{LO})$. The solid lines indicate the ideal contribution of $2\pi\tau_i(f - f_{LO})$, to which the measured data were quite consistent. The displacement of points from the lines is a measure of $\phi_{cal} + \phi_{sys}$. Further tests are required to test other aspects of the system's function.

Fig. 2: CW calibration source test at three different input frequencies 100, 94 and 88 GHz, corresponding to IF frequencies 16, 10 and 4 GHz respectively. Horizontal axis shows the passband frequency range. Vertical axis shows the relative phase between two receivers. Points are measured results. Lines represent the ideal case for each lag.

Known Issues and Plans

The calibration source is distributed from a common source on the platform to each receiver. Unlike an astronomical source, it is not capable of detecting the phase error induced by the platform deformation. Such phase error must be measured or modeled by other methods. Efforts have been directed to measuring the deformation and eventually compensating the error automatically.

Another issue concerns the stability of the calibration system. The feedback signal is coupled from before the final harmonic generator. The variation in the harmonic generator is not monitored and hence efforts should be made to minimize this. We plan to investigate how severe the variation is and the potential improvement effect of thermal insulation of the device.

We plan to have a fully working 2-element system by September 2005 and a complete system at beginning of 2006.

References

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