Novel calibration system with sparse wires for CMB polarization receivers

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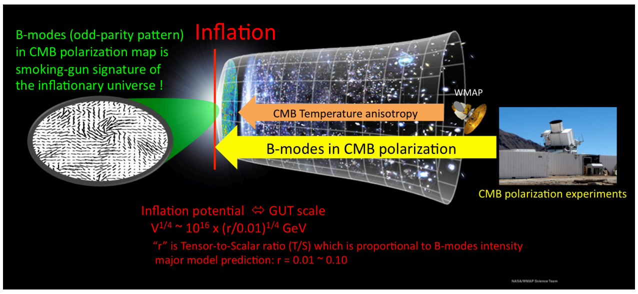
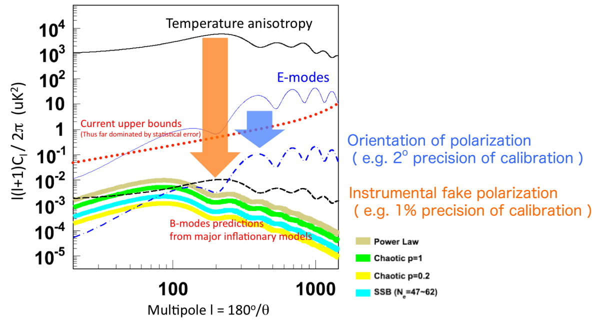
1. Introduction

◆ B-modes in CMB polarization - Quest for signal from inflationary universe !



To achieve better sensitivity to faint B-mode signal, CMB polarization experiments aim to maximize the number of detector elements, resulting in a large focal plane receiver.

◆ Two major systematic biases for B-mode search

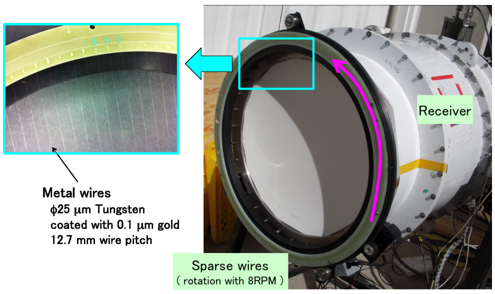


Calibration of relative responsivities(*) and relative detector angles among detectors is important to minimize the biases. (* especially for antenna-coupled detectors)
Target precisions to search B-modes down to r≈ 0.01 : 0.3% (0.5°) for each of them

It is essential to have a system which allows us to calibrate all detectors on the large focal plane "simultaneously" .

2. Calibration System

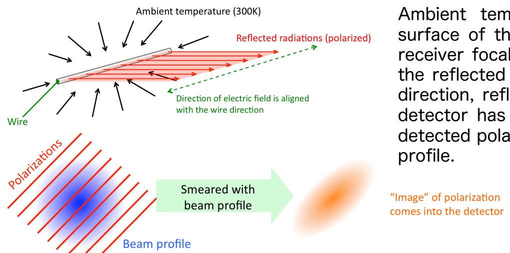
◆ Application for QUIET 95GHz receiver



Parallel metal wires are fixed on a glass epoxy ring (ϕ57 cm of inner diameter). The glass epoxy ring containing the wires is mounted on a steel ring, which itself is held next to the receiver window via three wheel bearings. A motor is used to rotate the ring. The wires fully cover each detector's beam envelope.

About the QUIET experiment and its polarization detector:
- QUIET collaboration, arXiv:1012.3191 [astro-ph.CO] (2010), to apper in ApJ.
- K. A. Cleary, Proc. SPIE, 7741, 77412N (2010).

◆ Mechanism to generate the polarization signal

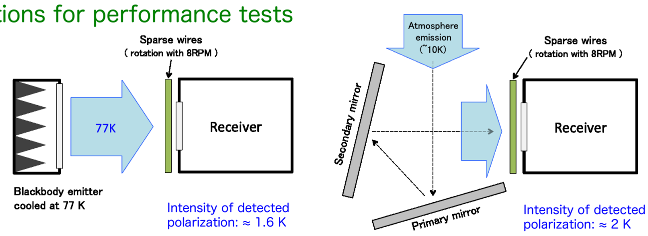


Ambient temperature is reflected from the surface of the wire, and then enters into the receiver focal plane. Since the electric field of the reflected radiation is aligned with the wire direction, reflected radiation is polarized. Each detector has finite beam resolution, therefore, detected polarization is smeared with the beam profile.

Detected polarization signal is proportional to the products of the inverse of the wire pitch, beam profile and the difference between the reflected ambient temperature and the background load temperature.

◆ Two configurations for performance tests

System tests were performed in the laboratory as well as at the observation site (Atacama desert in Chile, 5,080 m above the sea level)



(a) System setup in the laboratory (b) System setup on the telescope mount

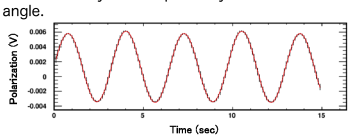
3. Performance

◆ Tests in the laboratory

By rotating the steel ring carrying the wires, it is possible to vary the angle between the detector angle (γ) and the direction of the polarization, i.e. the direction of the wires (θ). A sinusoidal response is observed by the polarization detector as a function of the rotation angle,

$$S(\theta) = G \cdot P \cos(2(\theta - \gamma)),$$

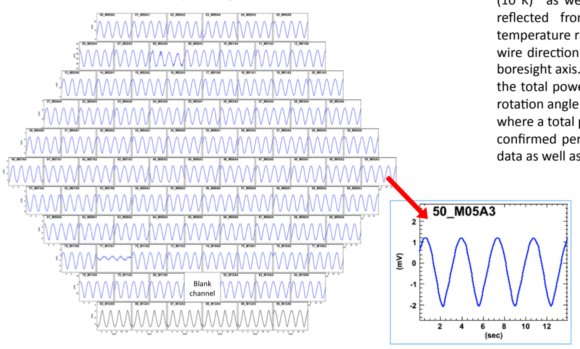
where S is the detector response, G is the detector responsivity, and P is the intensity of the polarization signal. Note that one cycle of the sinusoidal response is twice frequency of the rotation cycle. From the amplitude and phase of the sinusoidal response, we can extract simultaneously the responsivity and the detector angle.



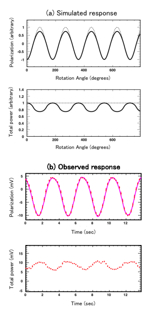
By using 30 sec of data, we measured the relative angles and relative responsivities to 0.3° and 1% statistical precision respectively. Other calibration confirmed the 1.6 K polarization signal from the wires.

◆ Tests at the observation site

We also observed the sinusoidal response curves in all detectors. This is the good demonstration that we can calibrate the relative responses among detectors simultaneously by using this calibration system.



In closer examination of the measured curves, the detector responses did not follow perfectly the sinusoidal curves. The periodical distortions were caused by a non-uniformity in the reflected radiation. The sky temperature (10 K) as well as the ambient temperature (300 K) are reflected from the wires. The fraction of ambient temperature radiation is maximized (minimized) when the wire direction is parallel (perpendicular) to the telescope boresight axis. In the case of a uniform reflection intensity, the total power response should not depend on the wire rotation angle. However this is in contrast to our situation, where a total power response variation is clearly seen. We confirmed periodical variations of the total power in the data as well as simulation.



Such a bias can be resolved by fitting for the polarization response using the observed total power response. The precision of calibration is limited by the stability of the total power response, which is generally much worse than that of the polarization response. Thus far, the precision of the calibration is limited to 0.8° and 2.8% for relative angles and relative responsivities, respectively. By putting the wire ring horizontally, resulting in uniformity of the reflected radiation, it is possible to eliminate this bias. Therefore, for the future, we have prospects that the in-field calibrations can be improved to the same level as the in-lab calibrations.

4. Conclusion

We developed a novel calibration system that rotates a large "sparse" metal wires, in front of and fully covering the field of view of the receiver focal plane. This system allow us to calibrate all detectors simultaneously and rapidly. The system played a successful role for receiver calibration of QUIET. The sucessful performance revealed that system is applicable to other experiments on different technologies, e.g. antenna-coupled bolometers.