A Log-Periodic Focal-Plane Architecture for Cosmic Microwave Background Polarimetry

by

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Abstract

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We describe the design, fabrication, and laboratory-demonstration of a novel dual-polarized multichroic antenna-coupled Transition Edge Sensor (TES) bolometer. Each pixel separates the incident millimeter radiation into two linear polarization channels as well as several frequency channels (bands). This technology enables us to realize bolometer arrays for Cosmic Microwave Background (CMB) polarimetry measurements that map the sky at multiple colors while simultaneously boosting the optical throughput over what would have been attained from arrays of single-frequency channel detectors. Observations at multiple frequency channels are important for differentiating polarized galactic foregrounds and atmospheric fluctuations from the CMB.

Each pixel couples free-traveling radiation onto lithographed microstrip transmission lines prior to the bolometers using a dual-polarized broadband antenna known as a sinuous antenna. The transmission lines are integrated onto the back of the antenna arms and the antennas are in direct contact with an extended-hemispherical lens. We show measurements of scale model (4-12GHz) and to-scale (80-240Hz) antennas to demonstrate high antenna-gain, low cross-polarization contamination, and efficient coupling over a 1-2 octave bandwidth.

We have developed microstrip circuits that divide the antenna's wide bandwidth into smaller channels. In one scheme, two or three frequency channels can be extracted from the antenna's received power using microstrip circuits known as diplexers and triplexers. These avoid atmospheric spectral lines and are well suited to terrestrial observations. We can also partition this bandwidth into contiguous bands using cochlear channelizers inspired by the physiology of the human ear; this design is most advantageous for satellite missions where there are no concerns about atmospheric contamination. We present design methodologies for these circuits and show measurements of prototypes coupled to TES bolometers to verify acceptable performance. We also describe the fabrication of a broadband anti-reflection coating for the contacting lenses and demonstrate that lens-coupled sinuous pixels receive more power with the coatings than without. Finally, we remark on the last un-resolved challenge of forming symmetric beams and balun designs that may help form patterns more useful for polarimetry.

This technology is a candidate for use in the Polarbear ground-based experiment. By packing more detectors into the focal-plane than can be done with monochromatic pixels, multichroic pixels will allow Polarbear to map the sky much faster. This technology is also candidate for future space-based missions as well, where multhchroic pixels will allow a less massive payload and hence a lower cost mission. Finally, we envision using arrays of similar pixels in sub-millimeter observations of high-redshift galaxy clusters as well (e.g.example Sunyaev-Zeldovich Effect measurements). However, we require more sophisticated lithography and etching techniques to shrink these pixels to a size suitable for such wavelengths.

Professor Adrian T. Lee
Dissertation Committee Chair

In memory of Huan Tran, who provided crucial early leadership on this project and dragged me out of complacency on a number of occasions. He missed seeing the final results from these efforts by a few weeks; I think he would have gotten a kick out of them.

Contents

List of Figures

List of Tables

Acknowledgements

The research described in this thesis is the result of several peoples' ideas coming together, so this section is important to give credit where it is due.

I owe a deep thanks to my advisor Adrian Lee who has been incredibly patient and allowed me an unusual degree of freedom to pursue some pretty wild detectors ideas. He is also unique in our field right now by training students in both microwave design and clean-room fabrication; I was delighted to recently learn that these skills are in high demand. I also am in debt to Paul Richards who always made himself available when troubleshooting his renowned "Sewer-pipe" interferometer. His astonishingly methodical knowledge of obscure material properties was also invaluable. Thanks to Bill Holzapfel for loaning some old ACBAR optical filters that are important parts of Dewar 576's filter stack; there's no way I could have done these measurements without those. Finally, Greg Engargiola worked with me on simulations of the sinuous as well as designs for the CPW-balun that is outlined in Chapter 9.

My fellow graduate students and post-docs have had an enormous impact on this work as well. I'm damn near certain that at least half of the ideas in here were originally from Mike Myers. And while he was always two or three conceptual steps ahead of me, he was classy enough to simply make suggestions and let me work out many of the details. Sherry Cho and Jared Mehl trained me in the Berkeley Microlab and I worked along-side Eric Shirokoff and Kam Arnold when actually fabricating devices; we were frequently all-night-long microlab partners allowing all parties to make rapid progress. Trevor Lanting taught me much of what I know about cryogenics and provided useful guidance on how to modify Dewar 576 after he handed it off to me. Ziggy Kermish also provided the crucial suggestion of using copious amounts of porous teflon to make my filter stack work on it's first try; it's not supposed to be that easy. Erin Quealy has made phenomenal progress on anti-reflection coatings for our lenses and her pioneering measurements of TMM's optical properties were the foundation for our efforts on a broadband coating described in chapter 7. I didn't really make it work as well as I'd like, so there's plenty of room for her to improve. Finally, it's been a pleasure training Aritoki Suzuki as my replacement; if I have nothing but graduate students like him someday, I'm sure my career will be smooth sailing. This project is left in competant hands.

For the past three years, this project has been a collaboration with Gabriel Rebeiz's group at UC San Diego's Electrical Engineering Department and his graduate students have been also been enormously helpful. Chris Galbraith shared his trade-secrets on tuning up his elegant cochlear channelizer described in chapter 8. Jen Edwards and Gabriel were the first to think clearly about the impedance of the antenna and to point out that it was not truly self-complimentary and that the excitations of interest are not eigenmodes. We also developed ray-tracing algorithms in parallel with San Deigo (see Chapter 4), but Jen made her's work first. She generously helped trouble-shoot my code and pointed out that we need to consider image currents through the ground-plane when doing the diffraction integrals. Subtle, eh?

I also owe a debt of gratitude to people outside my group that made life enjoyable when I wasn't hunkered down in the lab. This includes other graduate students in the department who I'd share a beer with on Friday afternoons, fellow residents of"Casa del Physics," "Salad House" and "Prospect House," and of course Anne Takazawa and Donna Sakima for helping guide me and many others through Berkeley's notorious red tape. My folks, who live just over the hills, were always happy to have me over for dinner to escape from Berkeley for a few hours.

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