Design of a testbed for the study of system interference in space CMB polarimetry

T. Ghigna [a,b], T. Matsumura [b], M. Hazumi [b,c,d,e], S. L. Stever [b], Y. Sakurai [b], N. Katayama [b], A. Suzuki [f], B. Westbrook [g], and A. Lee [g,f]

[a] University of Oxford, [b] Kavli IPMU, [c] KEK, [d] ISAS-JAXA, [e] SOKENDAI, [f] LBNL, [g] UC Berkeley

Abstract

LiteBIRD is a proposed JAXA satellite mission to measure the CMB B-mode polarization with unprecedented sensitivity ($\sigma_r \sim 0.001$). To achieve this goal, ~ 4000 state-of-the-art TES bolometers will observe the whole sky for 3 years from L2. These detectors, as well as the SQUID readout, are extremely susceptible to EMI and other instrumental disturbances e.g. static magnetic field and vibration. As a result, careful analysis of the interference between the detector system and the rest of the telescope instruments is essential. This study, in an early phase of the project, is particularly important in order to reduce risks and do a sanity-check before final assembly of the whole instrument. We report a plan for the preparation of a cryogenic testbed to study the interaction between the detectors and other subsystems, especially a polarization modulator unit consisting of a magnetically-rotating half wave plate. We also present the requirements, current status and preliminary results.

Introduction

At Kavli IPMU, as part of the LiteBIRD collaboration, we are responsible for the development of the Low Frequency Telescope (LFT) Polarization Modulator Unit (PMU), consisting of a continuously rotating Superconductive Magnetic Bearing (SMB), a gripping mechanism, a rotation angle encoder and a multi-layer sapphire Achromatic Half Wave Plate (HWP) with the required Anti Reflection Coating (ARC).

Before the pre-flight assembly of the full telescope, we plan to adapt an existing ADR cryostat to host a cryogenic polarimeter to study the detector performance, together with the HWP, as part of a full telescope system. The two main challenges for such a system are the extremely low saturation power of space-optimized bolometers (~ 0.5 pW) and the limited cooling capacity of an ADR cryostat (120 mJ at 0.1 K).

Test Plan:

The main goal of LiteBIRD is the detection of the primordial B-mode signal on large scales. However, this is impossible without detailed knowledge of the instrument and its possible systematics, as past experiments have shown. We identified the items to test with the proposed assembly, the potential issues, and the possible sources.

Source **Tests**	Mechanical Cooler	ADR	Lens	Filters	PMU & HWP	Environment
White Noise	**V**	**M**	**O**	**O**	**V, M, O**	**O, CR, SL**
1/f Noise	**T, V**	**T, M**	**T**	**T**	**T, V**	**T, CR, SL**
Correlated Noise		**M**			**M, S**	**CR**
Spurious Signals		**M**	**SW**	**SW**	**S, SW**	**SL, CR**
Time Constant(s)		**M**			**S**	**CR**
Gain Stability	**T**	**T, M**	**T, O**	**T, O**	**T, O**	**T, CR, O, SL**
Beam & Side Lobes			**G**	**G**	**S, G**	**SL**
Bandpass (with FTS)			**SW**	**SW**	**SW**	
I to P Leakage			**G**	**G**	**S, G**	
Polarization Angle					**S**	

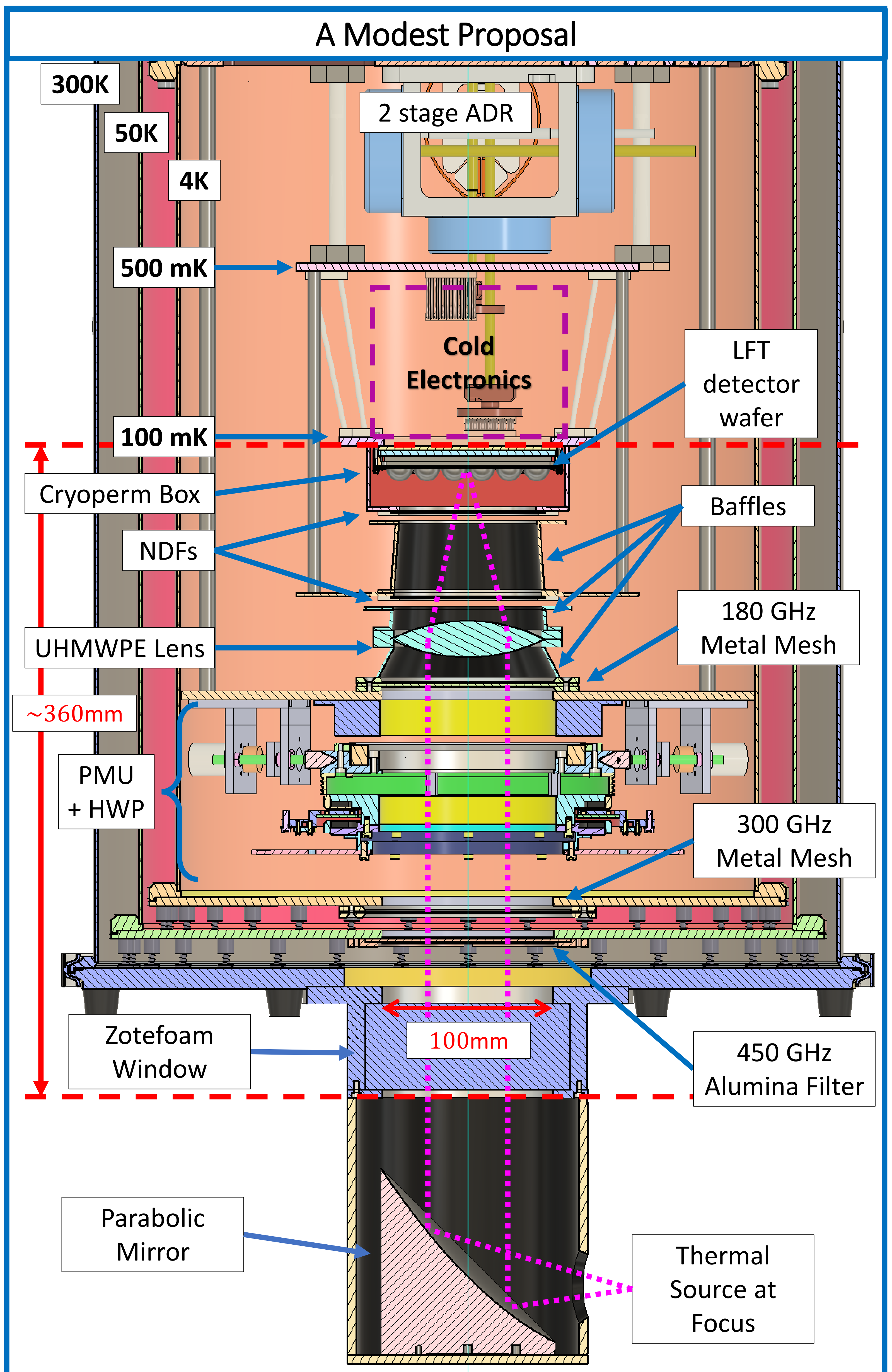
Potential Issues:

- **V** = Vibrations,
- **M** = Magnetic Field,
- **O** = Optical Loading,
- **S** = Synchronous Signals,
- **SL** = Stray Light,
- **SW** = Standing Waves,
- **CR** = Cosmic Rays,
- **T** = Thermal Instability,
- **G** = Ghosting

Requirements:

The LiteBIRD collaboration has been very active in the past few years, with detailed studies of the system requirements and the calibration plan to meet the science goal. At IPMU we conducted some of these studies, specifically deriving requirements on the knowledge of the bandpass resolution ($\Delta\nu \sim 0.5$ GHz) and the gain uncertainty at the end of the mission, between $\lesssim$ few % and $\sim 0.1\%$ depending on the frequency band (*Ghigna et al. in prep*). Our first goal is to test the possibility of achieving this level of accuracy.

A Modest Proposal

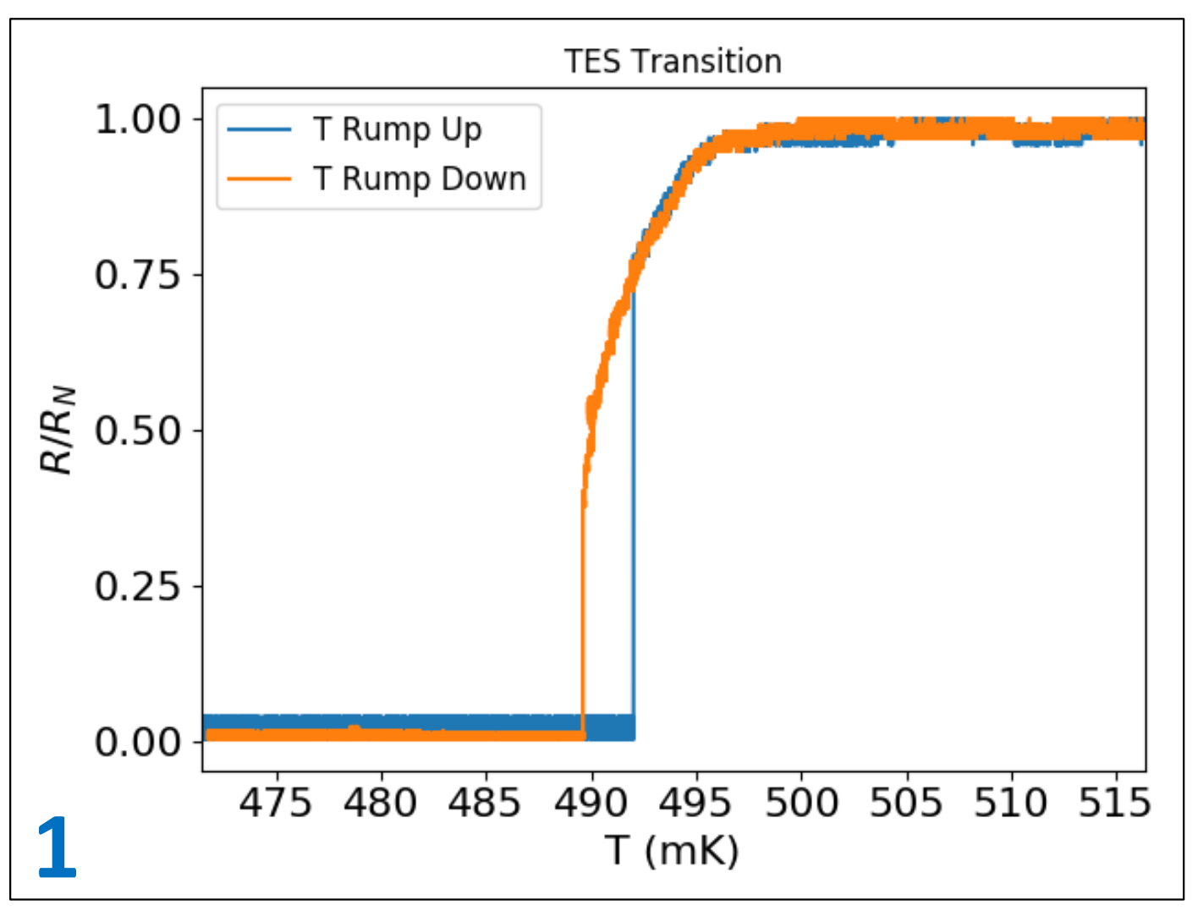


Test-bed configuration:

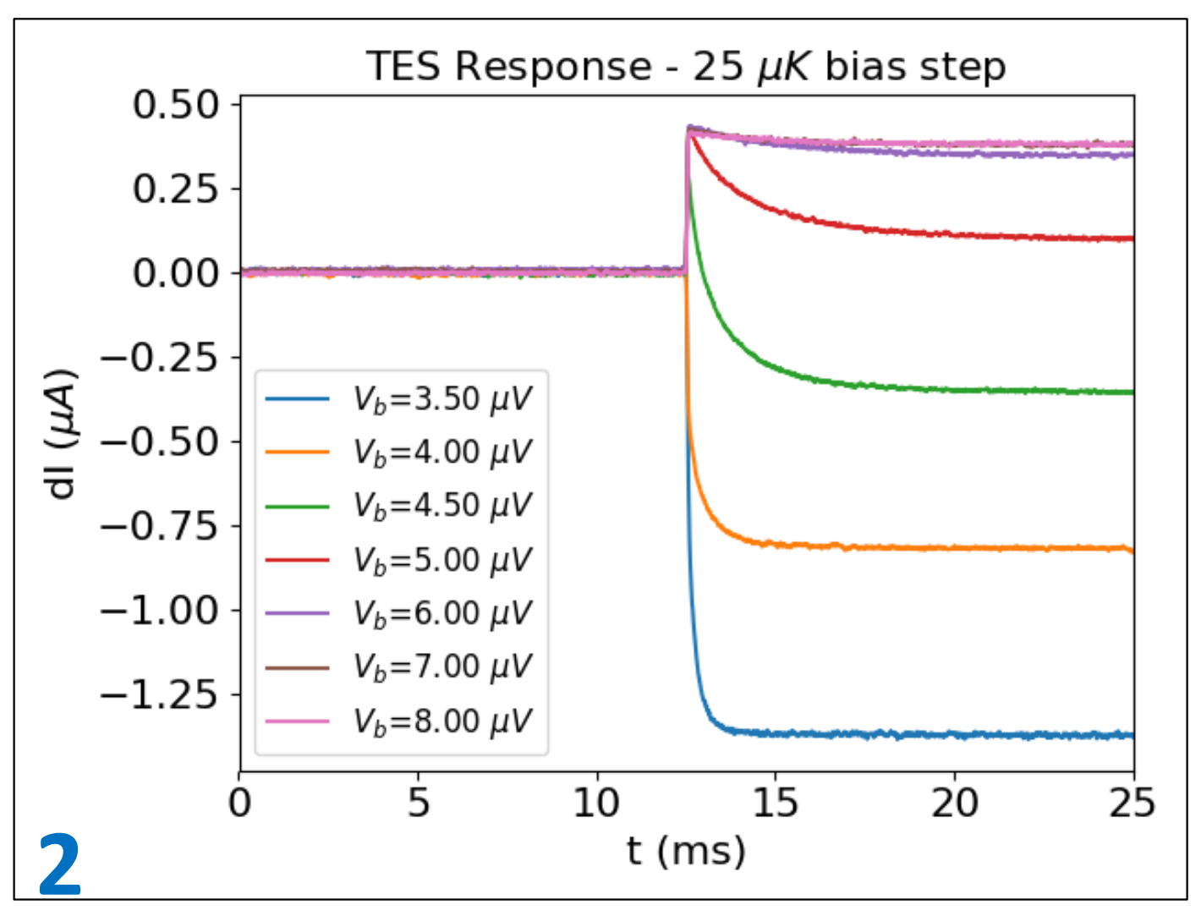
The driving requirements for the system above, other than cooling capacity constraints and detector saturation power, are the need of collimating the beam through the HWP to study its optical properties and a static magnetic field < 0.2 G at the focal plane.

Current dark test setup (DC SQUID readout):

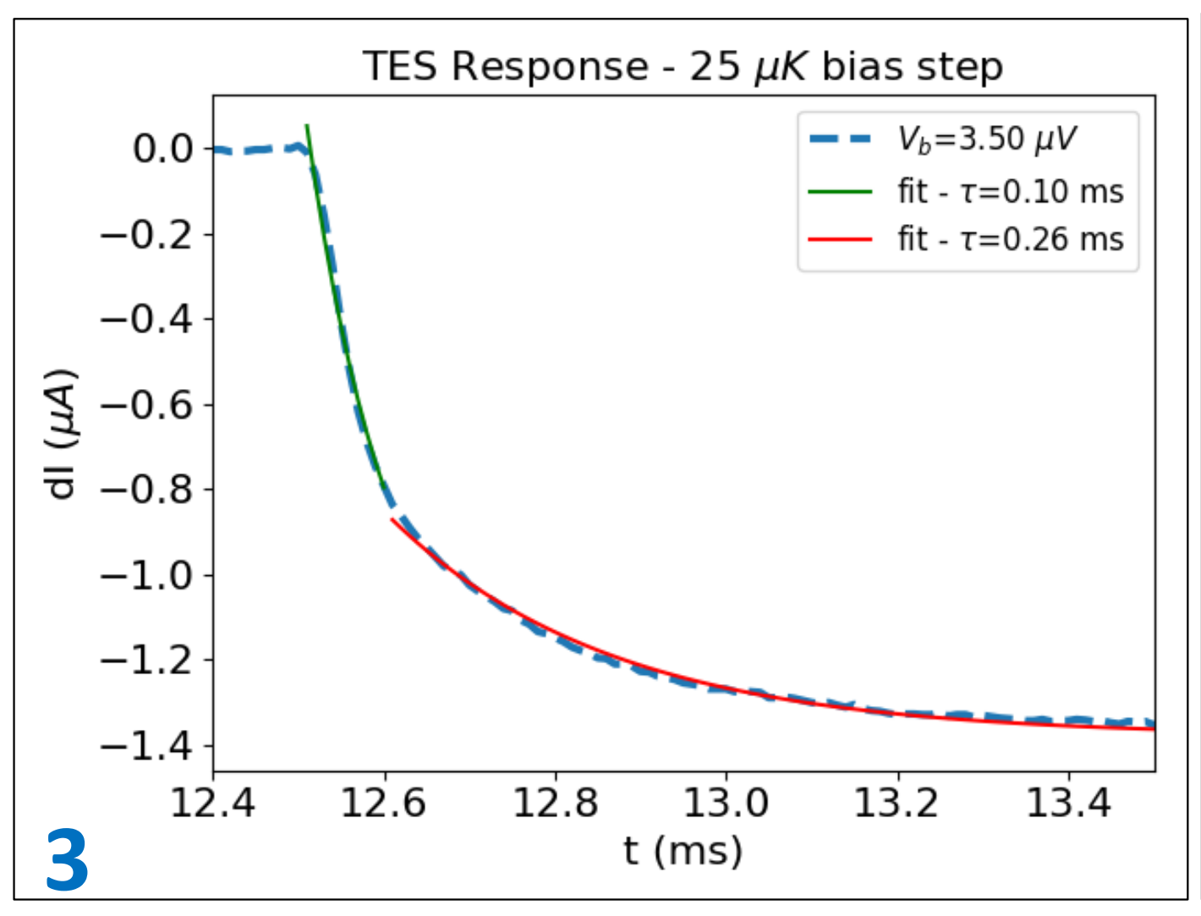
In preparation for the proposed system, we put together a simple setup consisting of a few DC SQUIDs, to start studying the detector response and noise properties. As an example, in Fig. 1 we show the measured superconductive transition of a TES detector (not LiteBIRD-specific). In Fig. 2 we show the TES response to a "bias step" for different voltage biases. Note the stabilization of the response going from high (loop gain $\mathcal{L} \sim 0$) to low voltage bias ($\mathcal{L} \gg 1$). Using the response in Fig. 2, we can also measure the time constant of the detector (Fig. 3). Finally, in Fig. 4 we show a simulation of the TES response, useful to validate the data. Preliminary results of the noise estimation give a noise floor of $\sim 5 \times 10^{-9} \mathrm{A}/\sqrt{\mathrm{Hz}}$. Further tests we plan to perform with this system include measurement of the saturation power and susceptibility to external magnetic fields and cosmic rays.



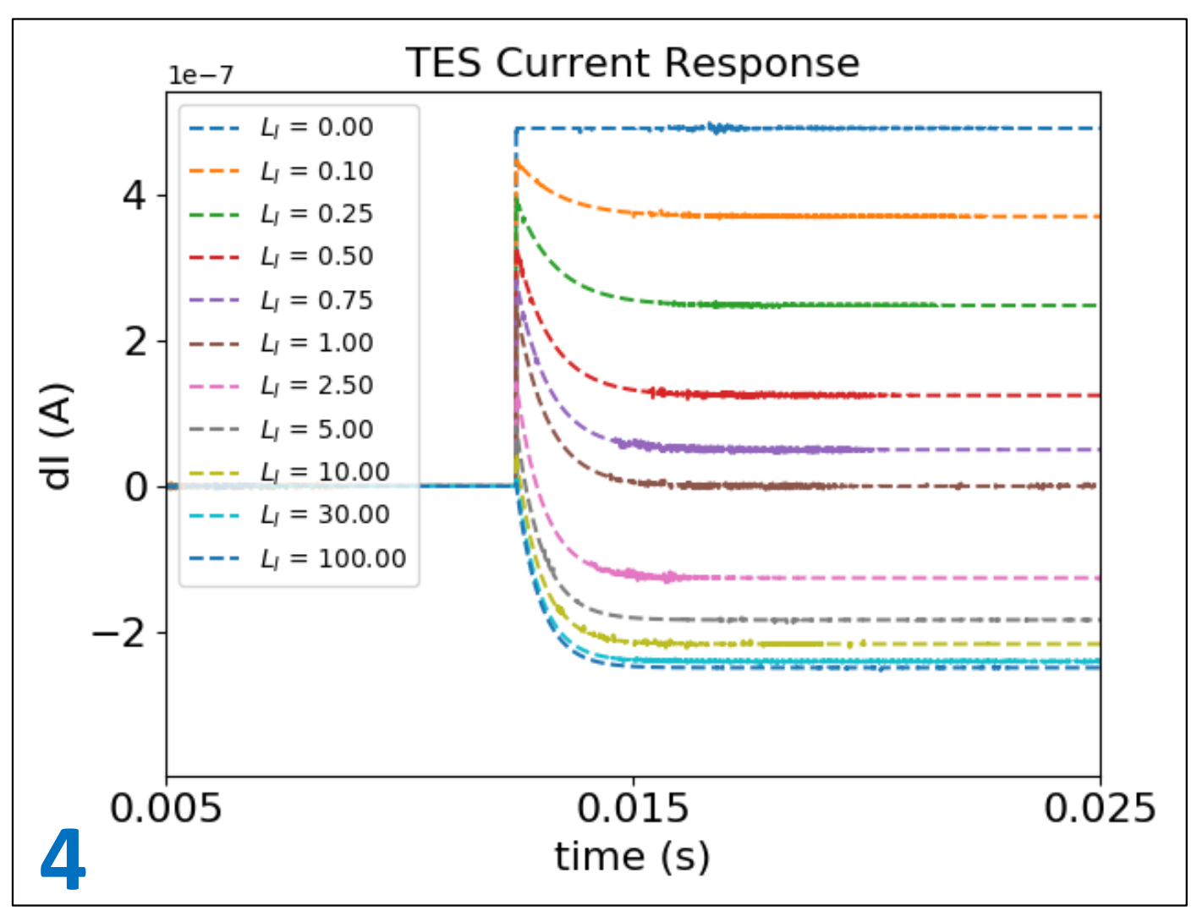
1



2



3



4

Conclusions:

We present a short summary of the results of the detector tests we are conducting at IPMU in preparation for assembling the proposed test-bed polarimeter to study and validate LiteBIRD LFT system and sub-system performances.

We believe this is a first but fundamental step to pave the way for the full telescope integration, because it will reduce risks, do a sanity-check, and build useful skills and capabilities inside the collaboration well ahead of the final delivery.