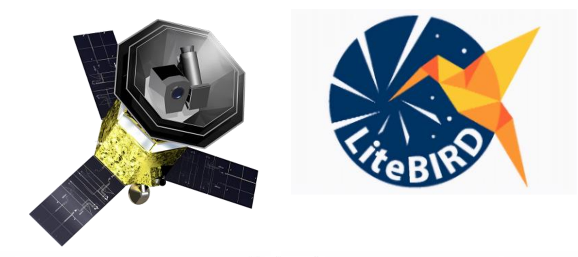
ID 251

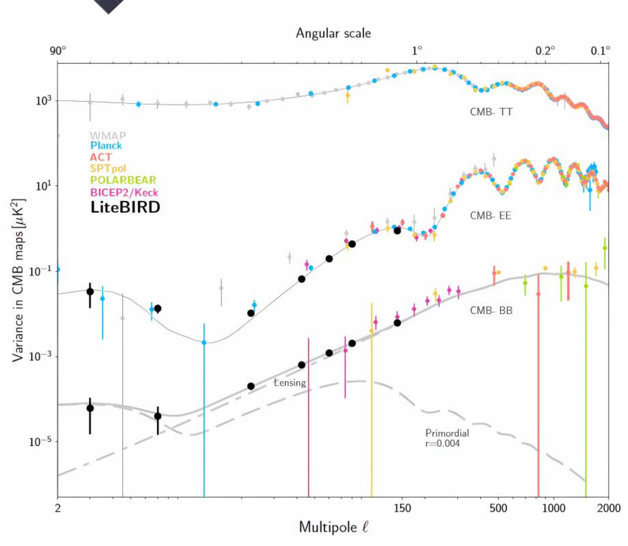
The frequency domain multiplexing for the LiteBIRD experiment cold readout

Eugenia Di Giorgi
Physics Department - University of Trento, Via Sommarive, 14, 38123 Povo TN
INFN Section of Pisa, Largo Bruno Pontecorvo, 3, 56127 Pisa PI
Physics Department - University of Pisa, Largo Bruno Pontecorvo, 3, 56127 Pisa PI

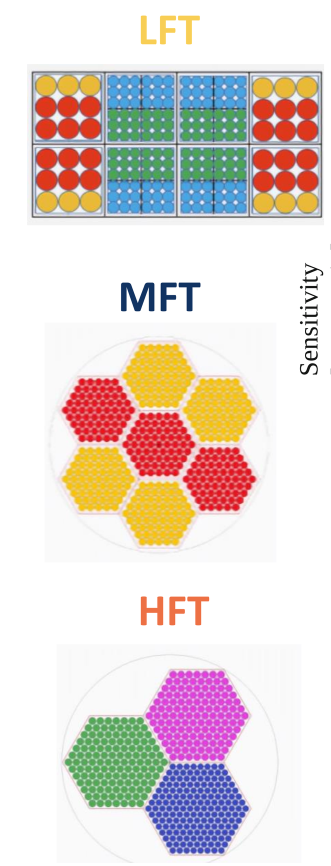
The LiteBIRD experiment

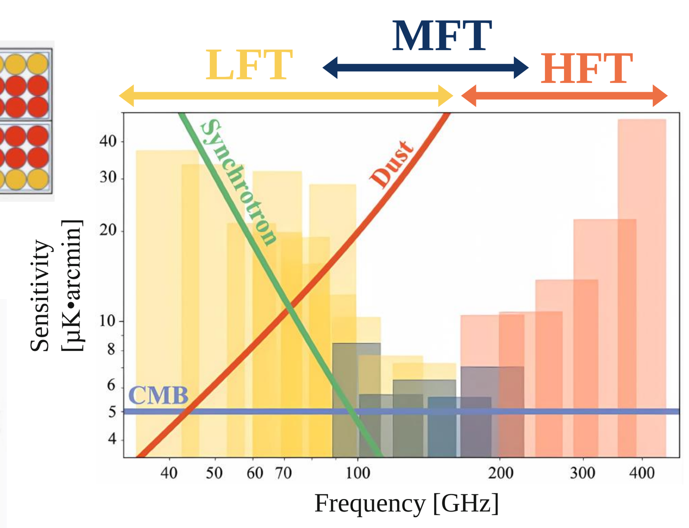
LiteBIRD (Lite (Light) satellite for the studies of B-mode polarization and inflation from cosmic background radiation detection) is a future three years space mission led by the Japan Aerospace Exploration Agency (JAXA). The goal is to study the polarization anisotropies of the Cosmic Microwave Backround (CMB) at large scale. In particular the focus will be on the B-mode polarization, which would be imprinted by the primordial gravitational waves predicted by the inflationary model. The B-mode polarization amplitude is described by the tensor-to-scalar ratio parameter *r*. The current upper limit on *r* is *r<0.032.* The main goal of LiteBIRD[1] is to lower this limit to *r<0.001.*

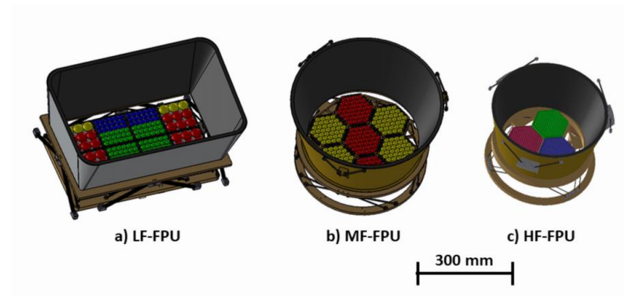




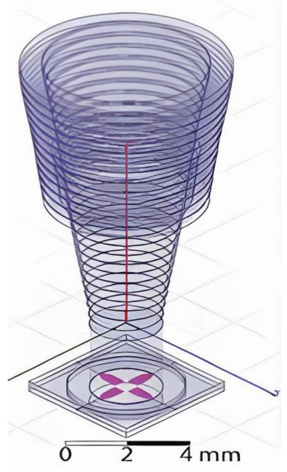
LiteBIRD will be equipped with three telescopes, the low (LFT), medium (MFT) and high (HFT) frequency telescopes. These will observe the sky in 15 different frequency bands between 40 GHz and 402 GHz.
The focal planes of LFT, MFT and HFT will be populated by around five thousands TES bolometers, clustered in subassemblies and in pixels.

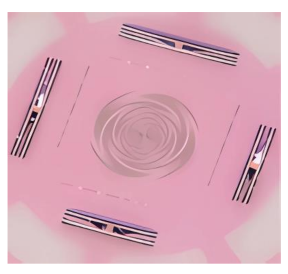






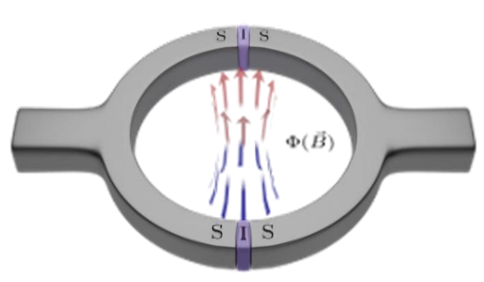
Detectors and cold readout





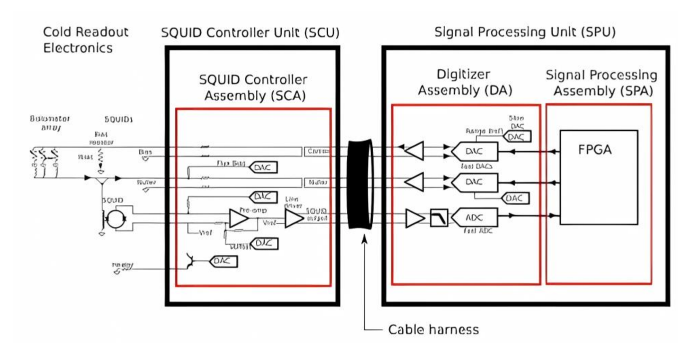
sinusoidal antennas for LFT and MFT and optical horn for HFT

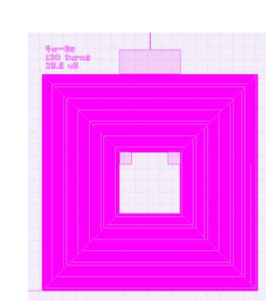
The LiteBIRD detection chain is based on the use of superconducting Transistor Edge Sensor (TES) bolometers. They convert a temperature variation in an electrical signal. Each optical TES will be connected to a bandpass filter to select the frequency of sky observation and to a polarization sensitive antenna. The bolometers are read by Superconducting QUantum Interference Devices (SQUIDs) which work as trans-amplifiers.



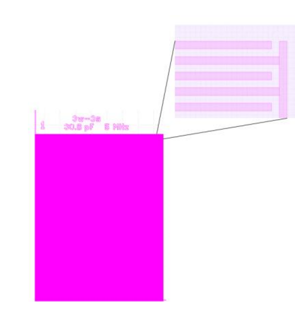
Frequency domain multiplexing

The LiteBIRD readout exploits the Frequency Domain Multiplexing (FDM), which is performed by connecting an LC filter to each TES on the cold stage and using a warm electronics featuring an FPGA to generate the multiplexing tones on the warm stage.
The signal biased at different multiplexing frequencies coming from each TES is summed to the others and sent to a low input impedence SQUID.
The LC filters will be completely lithographed lumped elements, with the inductors designed as rectangular coils and the capacitors as interidigitated capacitors.





coil inductors

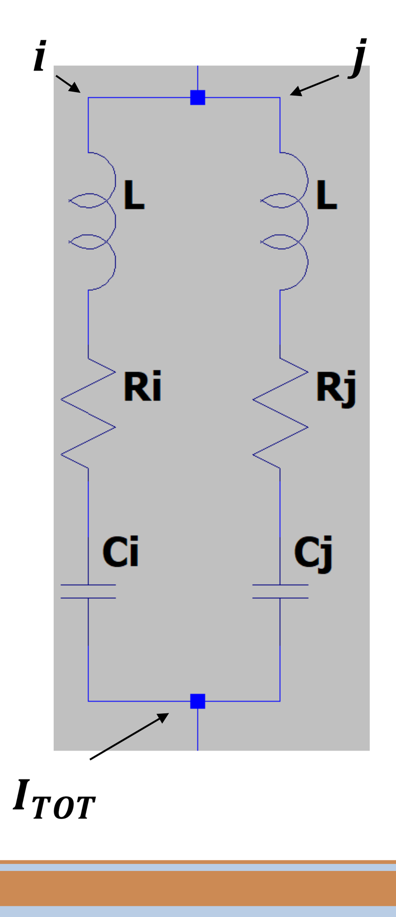


interdigitated capacitors

Crosstalk model and preliminary results

In this communication I describe my work about *crosstalk* on the FDM configuration.
Crosstalk is a systematic effect which can affect the signal processing and jeopardize the measurements. It can lead to a leakage of signal from one multiplexing channel to the adjacent ones.
Each detector is associated to a frequency channel and to a polarization angle. The crosstalk effect causes a cross-coupling between the readout legs and therefore between the frequency channels and the polarization angles.
For a representative two legs circuit:

$$xtalk = \frac{dI_{TOT}(\omega_j)/d\,R_i}{dI_{TOT}(\omega_i)/d\,R_i}$$

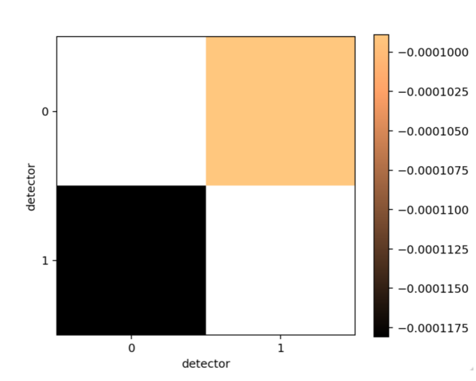


Crosstalk contributions:

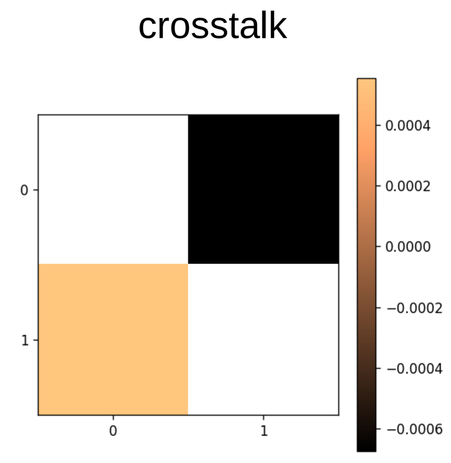
- carrier leakage crosstalk – given by the overlapping of the LC resonances tails, caused by the non-zero off-resonance impedance
- mutual induced crosstalk – given by the mutual inductance on the coil inductors

Preliminary results on a two legs circuit at a distance of 10 mm from one another

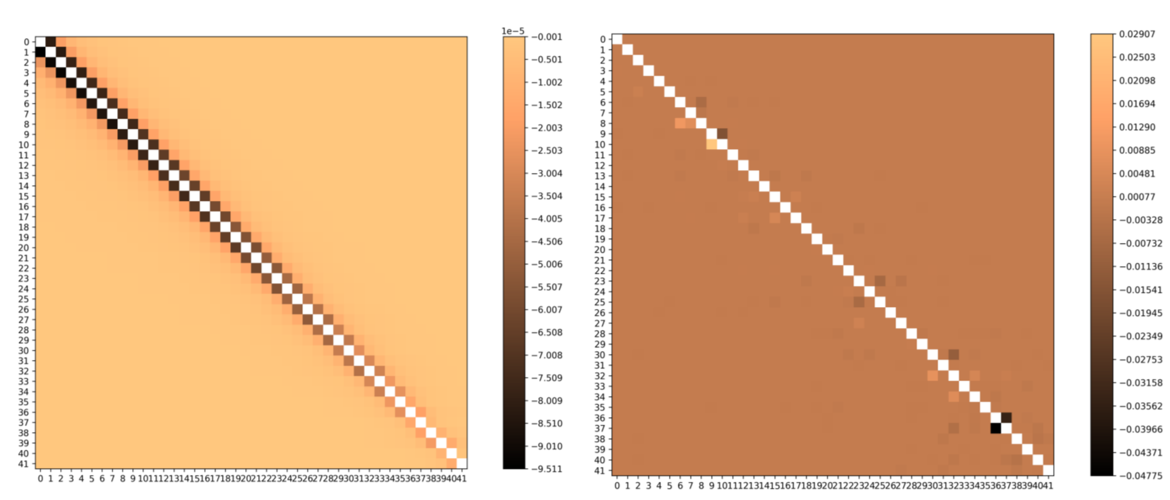
carrier leakage crosstalk

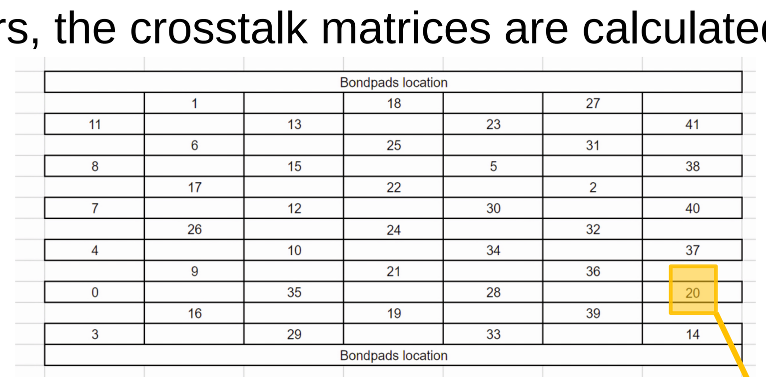


mutual inductance crosstalk

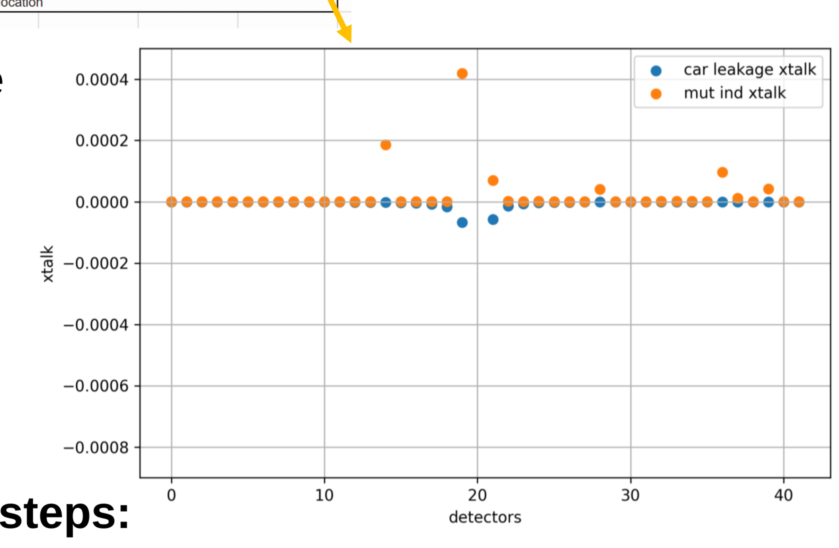


Expanding the calculation to a first design of 42 filters properly arranged in a realistic design, we can calculate the crosstalk level for the two contributions I mentioned.
The very first preliminary results are showing that the latter is a more relevant effect.
Given the disposition described in the table below (the numbers are related to the multiplexing frequencies values) and defined some distances between the LC filters, the crosstalk matrices are calculated.





Numerical results for the crosstalk contribution on the detector leg related to the 20th higher multiplexing frequency are presented .



detectors	car leak ct	mut ind ct
21	-5.78×10^{-5}	6.91×10^{-5}
19	-6.70×10^{-5}	4.19×10^{-4}
14	-2.07×10^{-6}	1.85×10^{-4}

detectors	car leak ct	mut ind ct
28	-7.87×10^{-7}	4.03×10^{-5}
36	-1.64×10^{-7}	9.58×10^{-5}
39	-1.09×10^{-7}	4.19×10^{-5}

Conclusions and next steps:
The preliminary results show that LC resonators both close in space and in multiplexing frequency are more affected by the mutual inductance crosstalk rather than the leakage current crosstalk. A realistic analytical value will be obtained once the final LC chip layouts will be designed. Also the multiplexing frequency scheduling and the assignment between multiplexing frequencies and TESs need to be defined. I am currently working on electromagnetic simulations with Sonnet Software to find consistency in my analytical calculations. I am also working on the definition of the multiplexing frequency scheduling for the three telescopes with the aim of getting some definitive crosstalk matrix to include in the LiteBIRD instrumental model database.

References

[1]E.Allys et al., (LiteBIRD Collaboration), “Probing Cosmic Inflation with the LiteBIRD Cosmic Microwave Background Polarization Survey”, arXiv:2202.02773, 2022
[2]Hazumi et al., (LiteBIRD Collaboration), “LiteBIRD satellite: JAXA's new strategic L-class mission for all-sky surveys of cosmic microwave background polarization”, SPIE Digital Library, https://doi.org/10.1117/12.2563050, 2020

Acknowledgements

This communication was produced while attending the PhD program in in Space Science and Technology at the University of Trento, Cycle XXXVIII, with the support of a scholarship co-financed by the Ministerial Decree no. 351 of 9th April 2022, based on the NRRP - funded by the European Union - NextGenerationEU - Mission 4 "Education and Research", Component 2 "From Research to Business", Investment 3.3

The Italian *LiteBIRD* phase A contribution is supported by the Italian Space Agency (ASI Grants No. 2020-9-HH.0 and 2016-24-H.1-2018), the National Institute for Nuclear Physics (INFN) and the National Institute for Astrophysics (INAF).