National Aeronautics and Space Administration

FY23 Topic Areas Research and Technology Development (TRTD)

THz Superconducting On-Chip Fourier Transform Spectrometers

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Strategic Focus Area: Direct/Coherent Detectors and Arrays

Objectives: Hyperspectral imaging with a Fourier Transform Spectrometer (FTS) in front of a focal plane array (FPA) has high flight heritage. Sky-signal is optically split with one path including a moving mirror for added delay. The two are recombined and spectroscopy is achieved through the resulting interferogram for every pixel. At THz this becomes difficult, the path length required to cause a delay for reasonable resolution ($R>10^4$) is over a meter. This technology aims to induce a delay <u>on-chip</u> using the non-linear kinetic inductance in a superconducting line, at sub-mm wavelengths. Rather than an optomechanical method to generate an interferogram, the kinetic inductance can be increased by DC biasing the line. This is the heart of the Superconducting On-Chip Fourier Transform Spectrometer (SOFTS) technology [1, 2], Fig. 1. Due to novel superconducting engineering, SOFTS is more than 200x smaller than free-space FTS. Thus SOFTS is directly integrated with detectors and antennas, enabling compact spaxels. A kilospaxel SOFTS frontend will fit on a FPA of ~30 cm diameter. We are using MgB2 as its larger superconducting gap will enable low loss signal transmission in THz frequencies [3, 4]. The objective in year 1 of the proposal is to measure loss in inverted microstrip MgB2 transmission lines. Thereafter these lines will be coupled with hybrid couplers, antennas and detectors to realize THz SOFTS.

Background: SOFTS architecture is show below with all components as on-chip superconducting elements. Here the current (I) biased MgB2 transmission lines, with delay τ [seconds] is key for interferometry.

$$\tau(I) = \sqrt{\mathcal{L}_0\mathcal{C}}\sqrt{1+\alpha(I/I_*)^2+\dots}$$

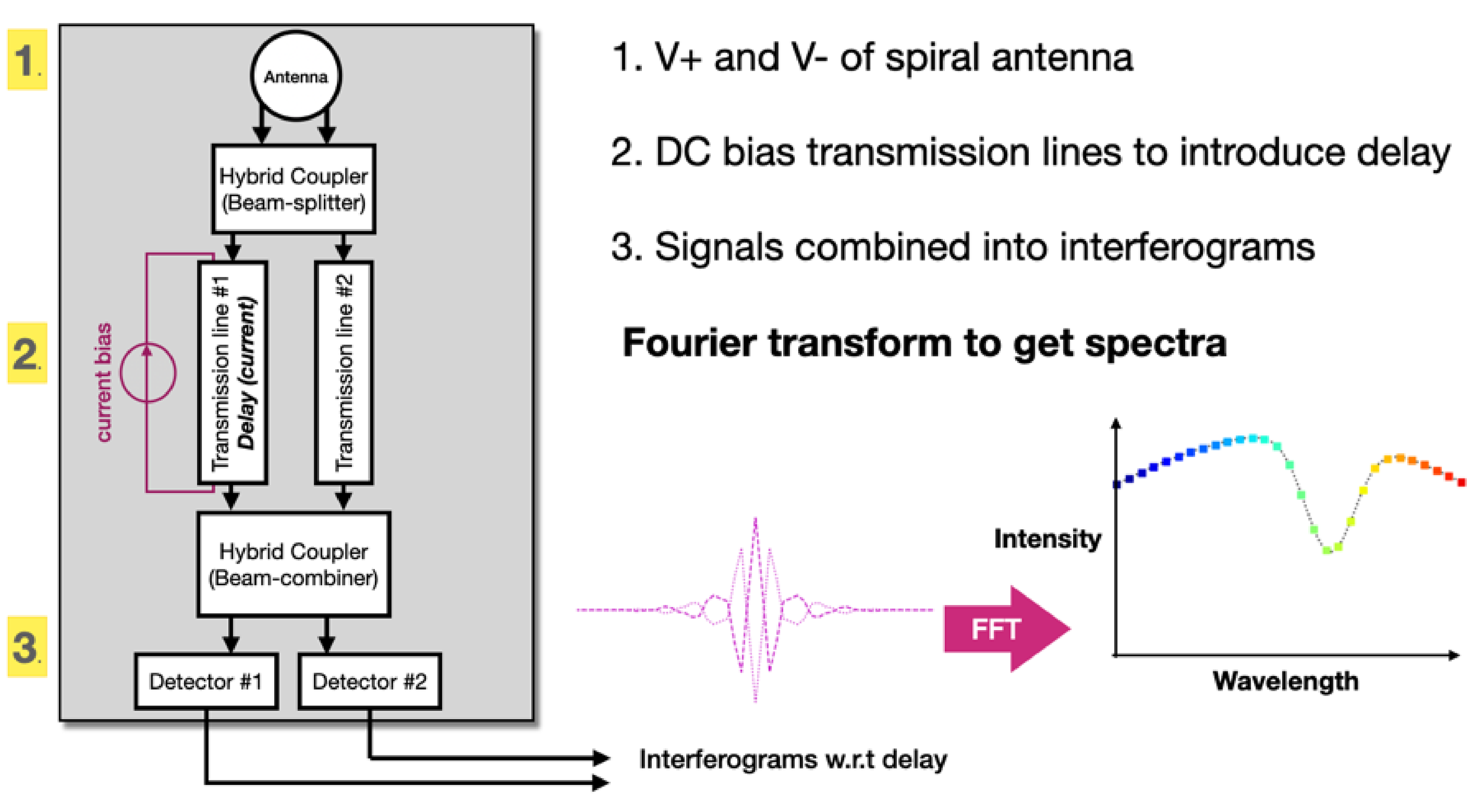


Fig. 1. SOFTS operating principle

Approach and results: We begun with transmission line development. We have improved our fabrication process and advanced almost an order of magnitude in current dependent delay (τ).
CPW test devices show delays > 3 fs/ square; a practical line has $>10^6$ squares of MgB2, enabling sub-ns delays, so a $R>10^4$ spectrometer.
We have since made microstrip (MS) devices which is the ultimate architecture for SOFTS. A MS line with resonators for loss measurement at GHz frequencies is shown in Fig. 2. Ultimately we will measure transmission at near-THz frequencies with dual bolometers, before fabricating a THz-SOFTS spaxel.

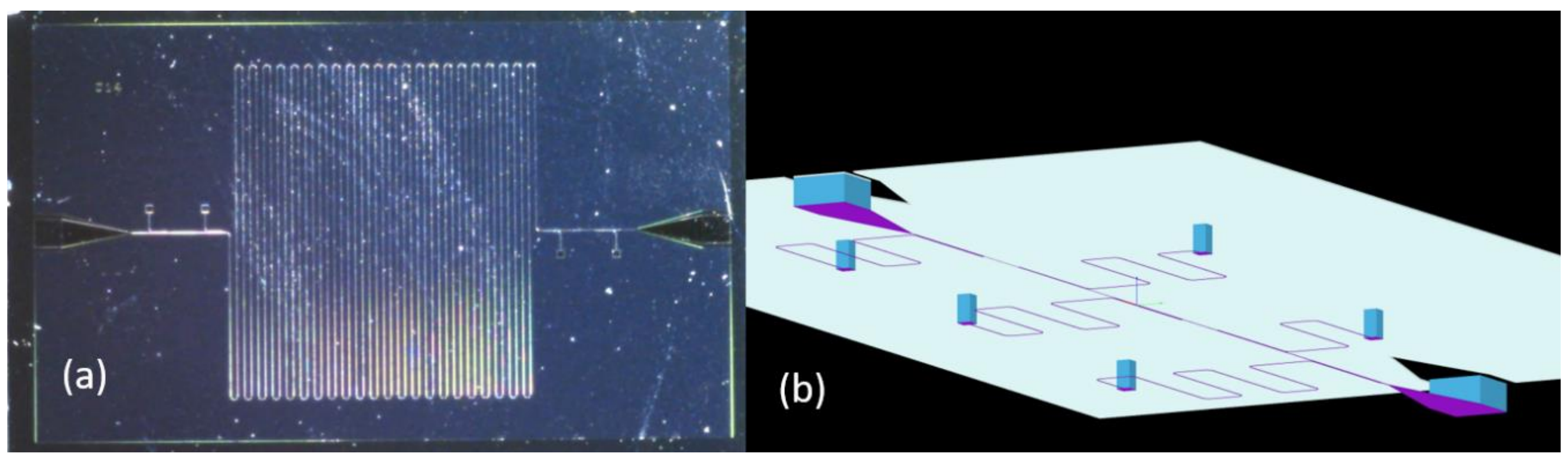


Fig. 3. The first inverted microstrip devices made with MgB2 have been fabricated in this effort. This architecture is solely capable of carrying high frequency signals on chip with low loss. (a) Optical image of a meander chip. All MgB2 meander and resonators are covered by a Nb ground plane. (b) Schematic of MgB2 microstrip resonators (purple) covered by a Nb ground (light blue) the dielectric layers are not shown but Nb via is shown in darker blue.

Approach and results *(continued)***:** We have designed devices for THz transmission / loss measurements, Fig.3. One detector is connected with a short MS line, and another with a long one (20mm). Both receive signal from a broad band antenna. A room temperature FTS is scanned, with a blackbody source, and the ratio of the measured spectra provides the loss tangent. This device has all the necessary ingredients for a full SOFTS spaxel. A hybrid coupler is being designed, and will be integrated in subsequent fabrication steps.

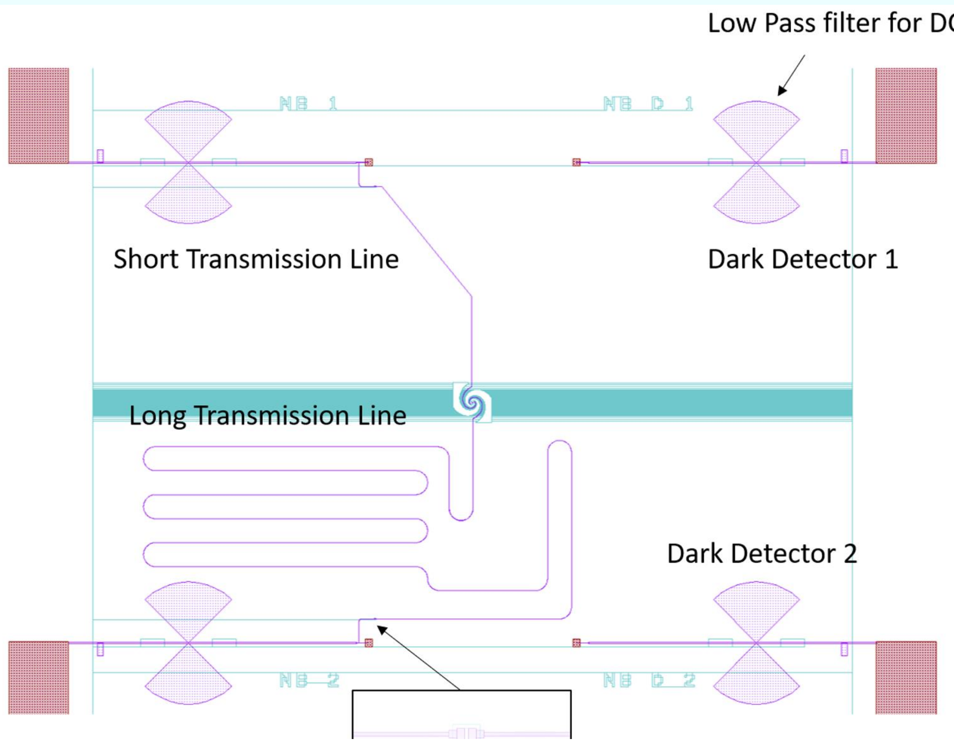
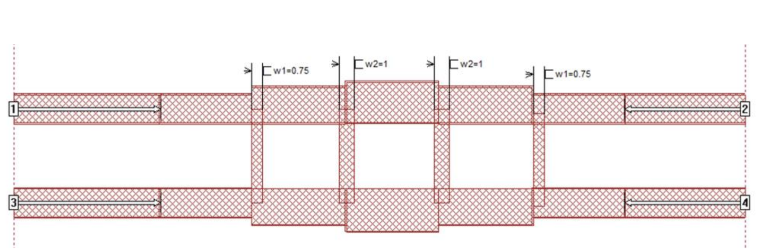


Fig. 3. THz loss measurement device. Two detectors receive power from the antenna via long & short lines. This measurement will further validate most key components needed to realize THz SOFTS. THz Hybrid coupler schematic below, design in progress.



Significance/Benefits to JPL and NASA : Under this RTD we will develop a full SOFTS spaxel resolving multiple CO-lines in one observation (350-700 GHz).
We will also demonstrate low loss capability in our MgB2 thin films, which has several applications appropriate for future NASA astrophysics science missions. As highlighted in the recent roadmap paper [6], SOFTS and related astrophotonics technologies will enable compact, efficient and high throughput space-based astronomical instruments soon.
The phase shifting in our devices will also enable multiple applications: commercial cryogenic phase shifters, to applications in polarization and beam steering for remote sensing instruments (GHz-THz), where insertion loss would be prohibitive with other techniques.

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