National Aeronautics and Space Administration

FY23 Strategic Initiatives Research and Technology Development (SRTD)

High temperature superconducting MgB_2 heterodyne receivers

Principal Investigator: John Pearson (380)**; Co-Investigators:** Daniel Cunnane (389), Christopher Curwen (386), Boris Karasik (386), Jonathan Kawamura (386), Changsub Kim (389), Changyun Yoo (386)

Strategic Focus Area: Long-Wavelength Detectors | **Strategic Initiative Leader:** Charles Lawrence

Objectives: The primary objective of this effort is to raise the technology readiness level (TRL) of terahertz (THz) MgB_2 Hot-Electron Bolometer (HEB) mixer from TRL 3 to TRL 5 while taking full advantage of 20K operation.

Our objectives to this task in FY23 were:

- Improve the efficiency of testing and evaluating of MgB_2 HEB devices.
- Design a receiver front-end quasioptical 6-pixel mixer block.
- Systematically study mixer performance as a function of the device impedance, critical temperature, and other thin-film parameters.
- Understand the reliability of the mixers and devices through quantification of the effects of oxygen and humidity.

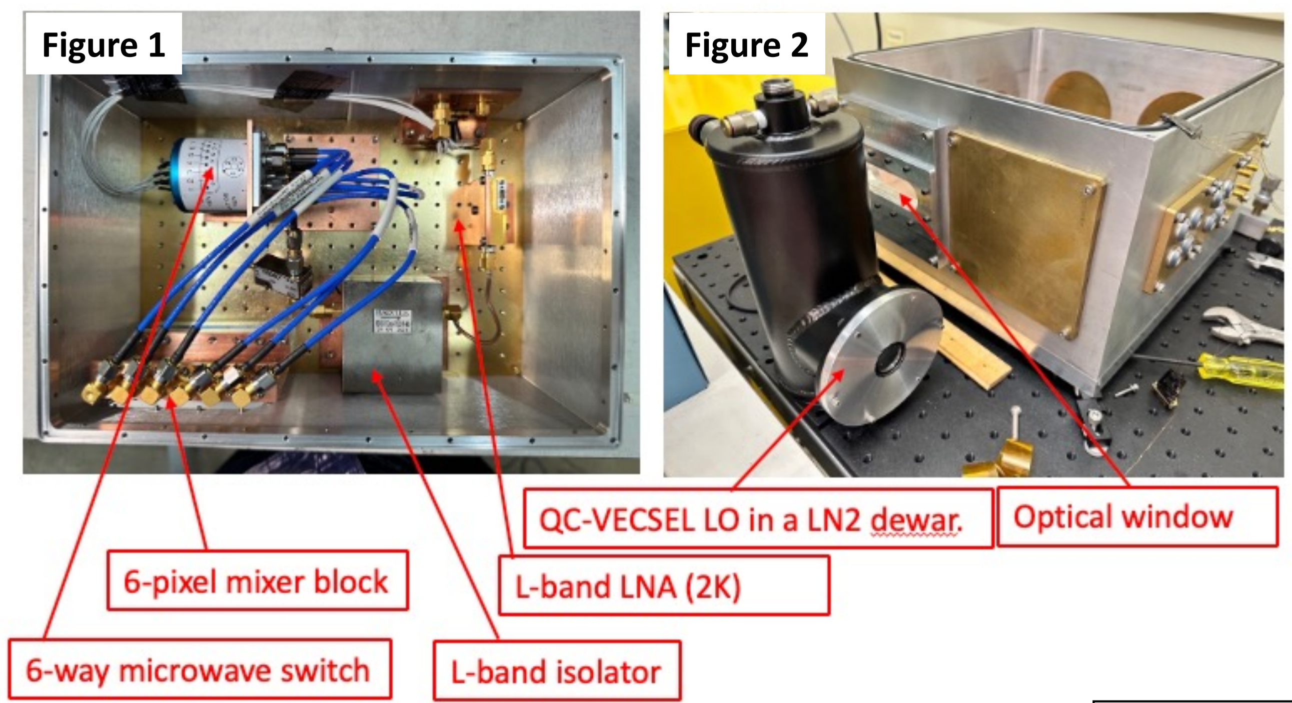
Background: From a strategic perspective, the technology developed in this proposal will be the key technology for future space missions requiring heterodyne receivers that would follow in this time order: 1. Balloon or SmallSat instrument (proof of concept) 2. SMEX/MIDEX-class survey mission 3. Far-IR Flagship 4. THz interferometer pathfinder 5. Swarm Imaging Interferometer.

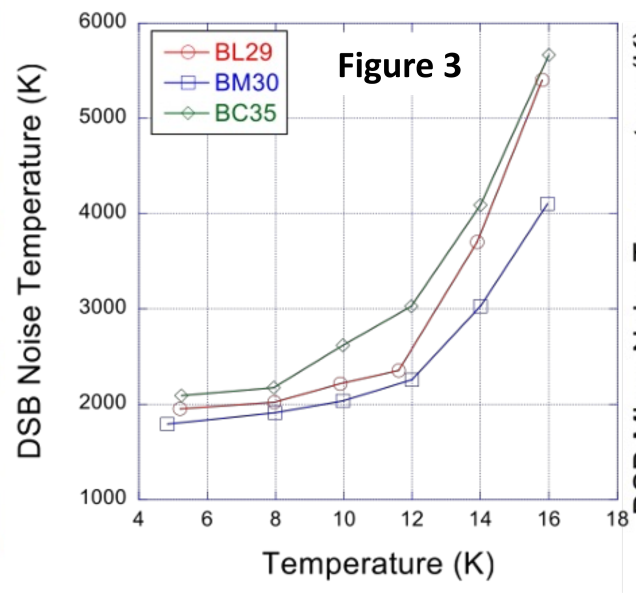
This effort will significantly reduce the cooling requirement, adjust the receiver architecture to take advantage of the warmer 20K operational temperature and produce components that can be flow over with near state-of-the-art performance. 20K operation is enabling for HEB mixers to achieve enough intermediate frequency (IF) bandwidth to fully resolve galaxies at several THz. The net result will be state-of-the-art heterodyne performance that can fit within a SMEX cost cap. The plan is to develop the necessary infrastructure for testing and development of MgB_2 HEB mixers. The effort focuses on constructing the necessary infrastructure for 20K testing and developing ~2 THz mixer designs while leveraging on going MgB_2 material developments. It also addresses MgB_2 HEB fabrication and qualification for flight applications along with systematically determining how to engineer MgB_2 receivers.

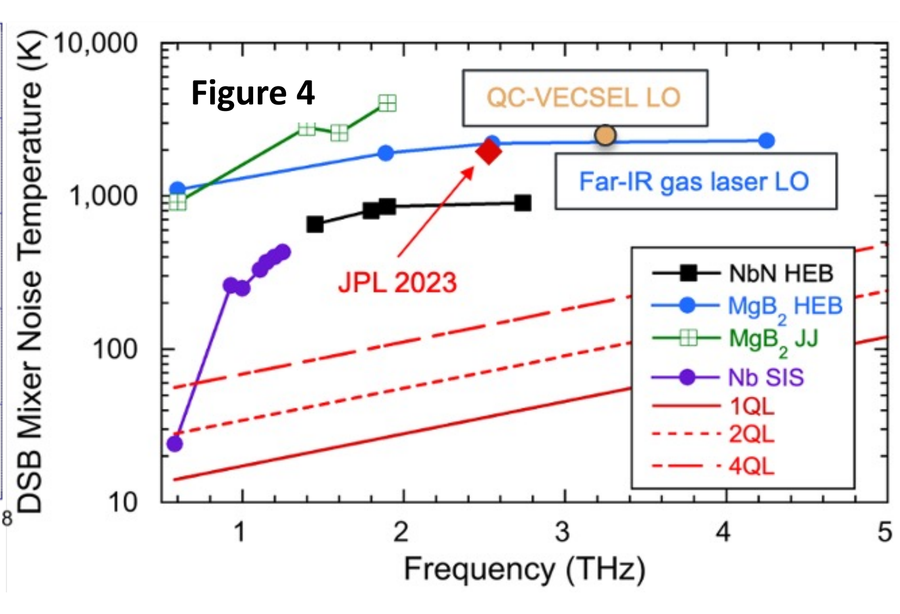
Approach and Results: One of the two primary activities for FY23 was the continuation of the test bench construction (Fig. 1). The test bench has been designed to work with existing single-pixel quasioptical mixers. The new receiver block has been designed to fit into the test bench in a minimally modified configuration. It holds HEB mixers devices as a 1×6 array. An external LO source (Fig. 2) is linearly translated for alignment with each pixel. The mixers and the LNA are placed completely inside a vacuum box; the infrastructure provides a thermal interface to a two-stage M22 Cryodyne Refrigeration System (Janis Research Co.) with a power lift to 1 W at 20 K and 8 W at 77 K. The HEB mixers and the LNA are placed on the 20 K platform.

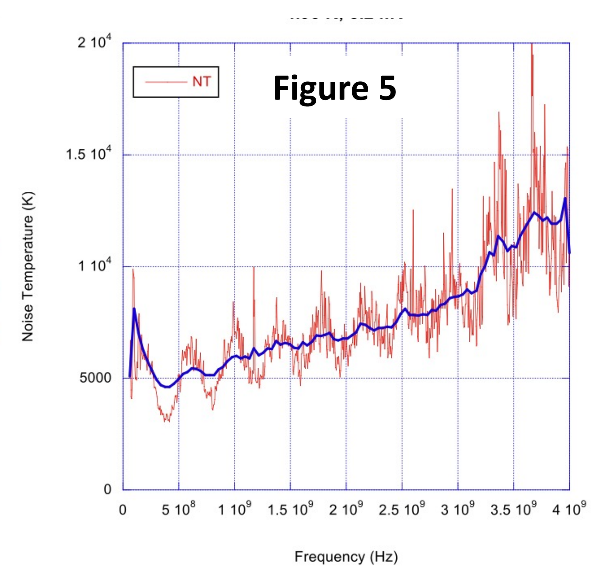
Another primary activity was the development of quasioptical MgB_2 HEB devices with high yield and good uniformity. The quasioptical configuration uses a small mixer device integrated with a broadband spiral planar antenna (2-5 THz bandwidth). The current mixer devices are made from 7-nm thick MgB_2 film sputtered on 300-µm-thick insulating Si substrate and are 2-µm wide and 0.75-µm long. Several HEB devices have been extensively tested at 2.5 THz. The critical temperature of these devices was in the range T_C = 23-25 K. The tests included characterization of the output IF noise, mixer conversion efficiency, receiver/mixer noise temperature, and the IF bandwidth. The mixer noise temperature of ≈ 1,700K (double-sideband, DSB) has been demonstrated (Fig. 3). This figure is among the best obtained in MgB_2 HEB mixer both at JPL and elsewhere (Fig. 4). The required LO power for such devices is ≈ 500 nW thus making these mixers compatible with the Schottky-diode frequency-multiplier chain (FMC) LO sources. The IF bandwidth of about 3.5 GHz has been found from both direct mixing of two microwave sources and the noise temperature dependence vs IF (Fig. 5). These devices, though promising, need further optimization as the operating temperature range is still relatively low, up to 12 K. This will be improved by using thicker (≈ 15nm) films with higher critical temperature.

Significance/Benefits to JPL and NASA: This task is to demonstrate a robust lab system for a SmallSat payload. By increasing TRL to 5, it will put JPL in much more competitive position for winning a SmallSat-class AO in the near-term. In addition, this technology enables a class of heterodyne array receivers which can be deployed on a large space telescope (e.g., MIDEX-class mission) at a significantly lower cost that the state-of-the-art (SOA) receivers requiring cryocooling to 4K. Finally, we envision applications in swarm interferometry in space using a constellation of SmallSats as well as a large interferometer on the Moon. The MgB_2 HEB mixer and quantum-cascade vertical-external-cavity surface-emitting laser (QC-VECSEL) technologies are unique and give to JPL a competitive edge.









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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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Publications:

- C. Kim and D. Cunnane, *20th Int. Conf. Low Temp. Det.,* Daejeon, South Korea, Jul. 23-28, 2023.
- C. Kim and D. Cunnane, *2023 CEC/ICMC23*, Honolulu, HW, USA, Jul 9-13, 2023.
- B. S. Karasik et al., *NRSM 2023*, Boulder, CO, USA, Jan. 10-14, 2023.
- B. Karasik et al., *ASC 2022*, Honolulu, NW, USA, Oct. 23-28, 2022.

PI/Task Mgr. Contact Information:

Tel: 818-354-6822, email: John.C.Pearson@jpl.nasa.gov