NASA SBIR 2022 Phase I Solicitation

S11.04 Sensor and Detector Technologies for Visible, Infrared (IR), Far-IR, and Submillimeter

Lead Center: JPL

Participating Center(s): ARC, GSFC, LaRC

Scope Title:
Sensor and Detector Technologies for Visible, Infrared (IR), Far-IR, and Submillimeter

Scope Description:
NASA is seeking new technologies or improvements to existing technologies to meet the detector needs of future missions, as described in the most recent decadal surveys (links are external):


Please note:

1. Technologies for visible detectors are not being solicited this year.
2. Technologies for lidar detectors are not being solicited this year.
3. For FY 2022 emphasis will be placed on Earth-Science-related technologies (infrared (IR) and far-IR detectors and technologies).

Low-power and low-cost readout integrated electronics:

- Photodiode arrays: In-pixel digital readout integrated circuit (DROIC) for high-dynamic-range IR imaging and spectral imaging (10 to 60 Hz operation) focal plane arrays to circumvent the limitations in charge well
capacity, by using in-pixel digital counters that can provide orders-of-magnitude larger effective well depth, thereby affording longer integration times.

- **Microwave kinetic inductance detector/transition-edge sensor (MKID/TES) detectors:** A radiation-tolerant, digital readout system is needed for the readout of low-temperature detectors such as MKIDs or other detector types that use microwave-frequency-domain multiplexing techniques. Each readout channel of the system should be capable of generating a set of at least 1,500 carrier tones in a bandwidth of at least 1 GHz with 14-bit precision and 1-kHz frequency placement resolution. The returning-frequency multiplexed signals from the detector array will be digitized with at least 12-bit resolution. A channelizer will then perform a down-conversion at each carrier frequency with a configurable decimation factor and maximum individual subchannel bandwidth of at least 50 Hz. The power consumption of a system consisting of multiple readout channels should be at most 20 mW per subchannel or 30 W per 1-GHz readout channel. That requirement would most likely indicate the use of a radio-frequency (RF) system on a chip (SoC) or application-specific integrated circuit (ASIC) with combined digitizer and channelizer functionality.

- **Bolometric arrays:** Low-power, low-noise, cryogenic multiplexed readout for large-format two-dimensional (2D) bolometer arrays with 1,000 or more pixels, operating at 65 to 350 mK. We require a superconducting readout capable of reading 2 TES per pixel within a 1 mm$^2$ spacing. The wafer-scale readout of interest will be capable of being indium-bump bonded directly to 2D arrays of membrane bolometers. We require row and column readout with very low crosstalk, low read noise, and low detector noise-equivalent power degradation.

### Far-IR/submillimeter-wave detectors:

- **Novel materials and devices:** New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH$_4$, N$_2$O) or broadband energy balance in the IR and far-IR from geostationary and low-Earth orbital platforms. Of particular interest are new direct detector or heterodyne detector technologies made using high-temperature superconducting films (e.g., thin-film YBCO, MgB$_2$, or multilayered engineered superconductors with tunable critical temperature) or engineered semiconductor materials, especially 2D electron gas (2DEG) and quantum wells (QW).

- **Array receivers:** Development of a robust wafer-level packaging/integration technology that will allow high-frequency-capable interconnects and allow two dissimilar substrates (i.e., silicon and GaAs) to be aligned and mechanically "welded" together. Specially develop ball grid and/or through-silicon via (TSV) technology that can support submillimeter-wave (frequency above 300 GHz) arrays. Compact and efficient systems for array receiver calibration and control are also needed.

- **Receiver components:** Development of advanced terahertz receiver components is desired. Such components include:
  - Novel concepts for room-temperature-operated receivers for Earth science with competitive noise performance (goal of 5 times the quantum limit in the 500 to 1,200 GHz range).
  - Local oscillators capable of spectral coverage 2 to 5 THz, output power up to >2 mW, frequency agility with >1 GHz near chosen terahertz frequency, and continuous phase-locking ability over the terahertz-tunable range with <100-kHz line width. Both solid-state (low-parasitic Schottky diodes) as well as quantum cascade lasers (for $f >$ 2 THz).
  - Components and devices such as mixers, isolators, and orthomode transducers, working in the terahertz range, that enable future heterodyne array receivers.
  - Novel receiver architectures such as single-sideband heterodyne terahertz receivers and high-precision measurement accuracy for multiple lines.
  - ASIC-based SoC solutions are needed for heterodyne receiver backends. ASICs capable of binning >6 GHz intermediate frequency bandwidth into 0.1- to 0.5-MHz channels with low power dissipation (<0.5 W) would be needed for array receivers.
  - Novel quasi-optical devices for terahertz beam multiplexing for a large (16+) number of pixels with >20% bandwidth.
  - Low-power, low-noise intermediate-frequency (IF) amplifiers that can be used for array receivers. Both cryogenic as well as room temperature operated.
  - Novel concepts for terahertz preamplifiers from 300 GHz to 5 THz.
Expected TRL or TRL Range at completion of the Project:

2 to 4

Primary Technology Taxonomy:
Level 1: TX 08 Sensors and Instruments
Level 2: TX 08.1 Remote Sensing Instruments/Sensors

Desired Deliverables of Phase I and Phase II:

- Analysis
- Prototype

Desired Deliverables Description:

For Phase I activities the deliverables are nominally feasibility studies, detailed design, or determination of the trade space and detailed optimization of the design, as described in a final report. In some circumstances simple prototype models for the hardware can be demonstrated and tested.

For Phase II studies a working prototype that can be tested at one of the NASA centers is highly desirable.

State of the Art and Critical Gaps:

Efficient multipixel readout electronics are needed both for room-temperature operation as well as cryogenic temperatures. We can produce millions-of-pixel detector arrays at IR wavelengths up to about 14 µm, only because there are ROICs available on the market. Without these, high-density, large-format IR arrays such as quantum well IR photodetectors, HgCdTe, and strained-layer superlattices would not exist. The Moore's Law corollary for pixel count describes the number of pixels for the digital camera industry as growing in an exponential manner over the past several decades, and the trend is continuing. The future of long-wave detectors is moving toward tens of thousands of pixels and beyond. Readout circuits capable of addressing their needs do not exist, and without them the astronomical community will not be able to keep up with the needs of the future. These technology needs must be addressed now, or we are at risk of being unable to meet the science requirements of the future:

- Commercially available ROICs typically have well depths of less than 10 million electrons.
- 6- to 9-bit, ROACH-2 board solutions with 2,000 bands, <10 kHz bandwidth in each are state of the art (SOA).
- IR detector systems are needed for Earth imaging based on the recently released Earth Decadal Survey.
- Direct detectors with $D \sim 10^9$ cm-rtHz/W achieved in this range. Technologies with new materials that take advantage of cooling to the 30 to 100 K range are capable of $D \sim 10^{12}$ cm-rtHz/W. Broadband (>15%) heterodyne detectors that can provide sensitivities of 5× to 10× the quantum limit in the submillimeter-wave range while operating at 30 to 77 K are an improvement in the SOA because of the higher operating temperature.
- Detector array detection efficiency <20% at 532 nm (including fill factor and probability of detection) for low-after-pulsing, low-dead-time designs is SOA.
- Far-IR bolometric heterodyne detectors are limited to 3-dB gain bandwidth of around 3 GHz. Novel superconducting material such as MgB$_2$ can provide significant enhancement of up to 9 GHz IF bandwidth.
- Cryogenic low-noise amplifiers (LNAs) in the 4 to 8 GHz bandwidth with thermal stability are needed for focal plane arrays, Origins Space Telescope (OST) instruments, Origins Survey Spectrometers (OSSs), MKIDs, far-IR imagers and polarimeters (FIPs), Heterodyne Instrument on OST (HERO), and the Lynx Telescope. DC power dissipation should be only a few milliwatts.
- Another frequency range of interest for LNAs is 0.5 to 8.5 GHz. This is useful for HERO. Other NASA systems in the Space Geodesy Project (SGP) would be interested in bandwidths up to 2 to 14 GHz.
- 15 to 20 dB gain and <5 K noise over the 4 to 8 GHz bandwidth has been demonstrated.
Currently, all space-borne heterodyne receivers are single pixel. Novel architectures are needed for ~100-pixel arrays at 1.9 THz.

The current SOA readout circuit is capable of reading 1 TES per pixel in a 1-mm² area. 2D arrays developed by NIST have been a boon for current NASA programs. However, NIST has declined to continue to produce 2D circuits or to develop one capable of a 2-TES-per-pixel readout. This work is extremely important to NASA’s filled, kilopixel bolometer array program.

2D cryogenic readout circuits are analogous to semiconductor ROICs operating at much higher temperatures. We can produce detector arrays of millions-of-pixels at IR wavelengths up to about 14 µm, only because there are ROICs available on the market. Without these, high-density, large-format IR arrays such as quantum well infrared photodiode, HgCdTe, and strained-layer superlattices would not exist.

Relevance / Science Traceability:

- Future short-, mid-, and long-wave IR Earth science and planetary science missions all require detectors that are sensitive and broadband with low power requirements.
- Future astrophysics instruments require cryogenic detectors that are supersensitive and broadband and provide imaging capability (multipixel).
- Aerosol spaceborne lidar as identified by the 2017 decadal survey to reduce uncertainty about climate forcing in aerosol-cloud interactions and ocean ecosystem carbon dioxide uptake. Additional applications in planetary surface mapping, vegetation, and trace-gas lidar.
- Earth radiation budget measurement per 2007 decadal survey Clouds and Earth’s Radiant Energy System (CERES) Tier-1 designation to maintain the continuous radiation budget measurement for climate modeling and better understand radiative forcings.
- Astrophysical missions such as OST will need IR and far-IR detector and related technologies.
- LANDSAT Thermal Infrared Sensor (TIRS), Climate Absolute Radiance and Refractivity Observatory (CLARREO), BOREal Ecosystem Atmosphere Study (BOREAS), Methane Trace Gas Sounder, or other IR Earth-observing missions.
- Current science missions utilizing 2D, large-format cryogenic readout circuits:
  - HAWC + (High Resolution Airborne Wideband Camera Upgrade) for SOFIA (Stratospheric Observatory for Infrared Astronomy) future missions
  - PIPER (Primordial Inflation Polarization Experiment), balloon-borne.
  - PICO (Probe of Inflation and Cosmic Origins), a probe-class cosmic microwave background mission concept.

References:

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