Current ESTO Microwave Investments

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Observational Technology Development

• ESTO has funded instrument and measurement concept development since 1998 through five NASA Research Announcements (NRAs).
  - Open, competitive, peer-reviewed solicitations
  - Components and instrument subsystems and systems
  - Evaluations based on relevance to the Earth Science Enterprise, technical innovation and feasibility, and management factors
• During development of each NRA, the solicitation's focus areas are determined based on science needs and technology gaps using the latest available information.
**Solicitations with Microwave Content**

<table>
<thead>
<tr>
<th>Year</th>
<th>IIP</th>
<th>ACT</th>
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<tbody>
<tr>
<td>1999</td>
<td>IIP-1</td>
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<td>2007</td>
<td>IIP-9</td>
<td>ACT-9</td>
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**Focus for Technology Solicitations**

<table>
<thead>
<tr>
<th>NRA Solicitations</th>
<th>Focus</th>
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<tr>
<td>NMP EO-1 (Space Validation) '96</td>
<td>Validate technologies contributing to the cost reduction and increased capabilities for future land imaging missions. (Landsat data)</td>
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<td>$192M</td>
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<td>IIP Round 1 (Instruments) '98</td>
<td>Open and unconstrained; covering active and passive optical and active and passive microwave instruments</td>
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<td>27 for $39M</td>
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<td>NMP EO-3 (Space Validation) '98</td>
<td>Validate technologies contributing to the cost reduction and increased capabilities for future weather forecasting (Future GOES)</td>
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<td>ATI Component Technology (ACT Round 1) '99</td>
<td>Core instrument technology; covering active and passive optical, and active and passive microwave instrument components</td>
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<td>AIST Round 1 (Info Systems) '99</td>
<td>On-board space-based information systems applications including data processing, organization, analysis, storage, and transmission; intelligent sensor and platform control; and network configuration</td>
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<td>30 for $26M</td>
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<td>IIP Round 2 (Instruments) '01</td>
<td>Microwave radiometry, radar, laser/lidar instruments</td>
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<td>ACT Round 2 (Components) '02</td>
<td>Antenna, electronics, detectors, and optics components</td>
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<td>IIP Round 3 (Instruments) '02</td>
<td>Topo &amp; surface change, Gravity field measurements, sea ice thickness, snow cover, GEO (trop profiles, atm-temp-moisture and rainfall, coastal region), L1 or L2 innovation</td>
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<td>AIST Round 2 (Info Systems) '03</td>
<td>Space/Ground-based, Computational Technology</td>
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Past Investments

- ESTO has selected numerous microwave remote sensing proposals under observational technology NRAs:
  - Instrument Incubator Program (IIP-1, 1998)
    - Radar altimeters; limb sounders; precipitation radar; sounding and imaging radiometers, submillimeter radiometer
  - Advanced Technology Initiatives Program (ATIP, 1999 aka ACT-1)
    - Terahertz limb sounder; Ka-band active feed array; SAR on-board processor; radiometer calibration system, low-power digital correlator, and low-power receiver
  - Instrument Incubator Program (IIP-2, 2001)
    - Advanced precipitation radar antenna, radiometer with interference suppression, dual low-frequency soil moisture radar, lightweight rainfall radiometer, ultra-stable salinity radiometer
  - Advanced Component Technology (ACT-2, 2002)
    - Reconfigurable SAR, SAR transmit/receive modules, microstrip antenna arrays, microstrip antenna feeds, radiofrequency A/D converter
  - Instrument Incubator Program (IIP-3, 2002)
    - Airborne Interferometric SAR, multi-static SAR, GEO precipitation radar, snow/ice radar, GEO sounding radiometer
Measurements with Microwave Technique

**Weather**
- Atmospheric Temperature and Water Vapor
- Cloud Particle Properties*
- Cloud System Structure*
- Global Precipitation
- Storm Cell Properties

**Climate Variability**
- Ocean Surface Currents
- Ocean Surface Winds
- Ocean Surface Topography
- Sea Surface Salinity
- Sea Ice Thickness & Extent
- Ice Surface Topography*

**Water & Energy Cycle**
- Snow Cover
- Snow Water Equivalent
- Freeze-Thaw Transition
- Global Precipitation
- River Stage
- Height/Discharge
- Soil Moisture

**Earth Surface & Interior**
- Land Surface Topography*
- Surface Deformation
- Terrestrial Reference Frame (VLBI)

**Atmospheric Composition**
- Atmospheric Temperature and Water Vapor
- Cloud Particle Properties*
- Cloud System Structure*

**Carbon Cycle & Ecosystems**
- Biomass *
- Vegetation Canopy *
- *Radar Complementary

Defined Measurement Threshold and Goal Requirements

http://esto.nasa.gov/estips

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RF Spectrum

**ACTIVE**
- Lichten
- Njoku
- Edelstein
- Moussessian
- Yush
- Hensley
- Sarabandi
- Meghiddon
- Hussein
- Fu
- Ze
- Raney
- Sadowy
- Popopolymerou
- Gudim
- Knowles
- Gumm
- Herman

**PASSIVE**
- VHF
- UHF
- L band
- S band
- C band
- X band
- K band
- Millimeter
- Submillimeter

Investments cover a broad range of frequencies.
Round 1 IIP Microwave Projects

Fu, Lee-Lueng, Jet Propulsion Laboratory
Advanced Altimeter for Ocean Studies
Objective
- Design next generation ocean altimeter which integrates altimeter/radiometer/GPS into one instrument and reduces mass, power, and volume
- Provide significant increase in science:
  - Global measurement of 2-D surface currents
  - Full global sampling of ocean mesoscale eddies, which have the largest contribution to ocean kinetic energy spectrum

Gaier, Todd, Jet Propulsion Laboratory
Millimeter-Wave MMIC Atmospheric Temperature and Humidity Sensors
Objective
- Develop compact, low cost radiometric sensors for the 100-140 and 170-210 GHz bands using monolithic microwave integrated circuit (MMIC) technology.
- The substantial (order of 100) reduction of volume and mass enables arrays of sensors with much greater capability than single-beam sensors.

Herman, Benjamin, M., University of Arizona
Active Tropospheric Ozone and Moisture Sounder
Objective
- ATOMS, an atmospheric remote sensing instrument, employs microwave crosslinks at frequencies between 10 and 200 GHz between pairs of low-orbiting spacecraft to perform active atmospheric limb sounding.
- Measure concentrations of ozone and water vapor.
- Provides efficient new window on atmospheric chemistry and climate.

Im, Eastwood, Jet Propulsion Laboratory
A Second Generation Spaceborne Precipitation Radar
Objective
- Design a dual-frequency, dual polarization, Doppler precipitation radar for space applications.
- Improve rain vertical structure measurement, hydrometeor discrimination, swath coverage.
- Reduce mass by a factor of 2-3x from the current state of practice.
- Construct and fly an aircraft instrument.
Kummerow, Christian, NASA GSFC
A Small Lightweight Radiometer to Improve the Temporal Sampling of Rainfall
Objective
• Develop a microwave radiometer that is small enough, light enough, and cheap enough to allow multiple copies to be flown in order to overcome the current serious rainfall sampling limitations
• Combine scanning mirror and thinned array channels to allow accommodation on a small bus

Lambrigtsen, Bjorn, Jet Propulsion Laboratory
High Altitude MMIC Sounding Radiometer (HAMSR) on a Remotely-Piloted Aircraft
Objective
• Design a multifunction sounder for temperature, water vapor, cloud liquid water, and rain in a single package.
• Reduce size, power, and mass and improve performance.
• Build and test an airborne instrument.

LeVine, David, NASA GSFC
Two Dimensional Synthetic Aperture Radiometer for Microwave Remote Sensing from Space
Objective
• Develop a prototype aircraft passive microwave instrument employing aperture synthesis in two dimensions
• Demonstrate viable S/N, calibration, conical scan, and polarimetric operation

Zuffada, Cinzia, Jet Propulsion Laboratory
GOALS: GPS-Based Oceanographic and Atmospheric Low-Earth Orbiting Sensor
Objective
• Assess the science utility of the GPS signal reflected off the ocean for sea-surface topography and develop receiver for on-board tracking and processing
Round 1 IIP Microwave Projects

Njoku, Eni, Jet Propulsion Laboratory
Study of a Spaceborne Microwave Instrument for High Resolution Remote Sensing of the Earth Surface Using a Large Aperture Mesh Antenna

Objective
• Develop a system concept for a space instrument that will provide accurate global measurement of ocean salinity and soil moisture.
• Incorporate in the concept a large rotating mesh antenna to measure microwave emission and backscatter.

Raney, Keith, JHU Applied Physics Laboratory
Delay Doppler Phase (D2P) Radar Altimeter

Objective
• Demonstrate, through airborne field tests, the viability and desirability of an innovative altimeter using the delay/Doppler technique to enhance along-track resolution, precision, and power requirements and the phase monopulse technique to mitigate cross-track slope errors.
• Demonstrate use over open ocean and ice sheets.

Round 1 IIP Microwave Projects

Dinardo, Steve, Jet Propulsion Laboratory
Submillimeter-Wave Cloud-Ice Radiometer (SWICR)

Objective
• Advance the submm cloud sensing technique maturity to the level needed to enable global characterization of cirrus.
• Design and fabricate an airborne radiometer covering the 183 to 648 GHz frequency range.
• Prepare the system for an aircraft flight.
Round 1 ACT Microwave Projects

Karasik, Boris, Jet Propulsion Laboratory
Small and Smart Sensor for Atmospheric Terahertz Limb Sounding

Objective

- Development of a hot-electron heterodyne mixer based on the high transition temperature superconductor (HTS) 
  \( \text{YBa}_2\text{Cu}_3\text{O}_{7-\delta} \) for application to atmospheric high-resolution spectroscopy observations
- This technology would enable a tunable, broadband THz instrument to meet the needs of stratospheric chemistry measurements

Sadowy, Gregory, Jet Propulsion Laboratory
A Ka-band Active Array for Remote Sensing of Precipitation

Objective

- To develop a dual-polarized electronically-scanned Ka-band (35 GHz) subarray for the PR-2 antenna.
- Development of this subarray will provide a proof-of-concept as well as a design that can easily be adapted for a future flight program.

Gudim, Mimi, Jet Propulsion Laboratory
Synthetic Aperture (SAR) Radar On-board Azimuth Pre-Filter Processor

Objective

- Use high density FPGA technology to develop a prototype on-board azimuth pre-processing filter for synthetic aperture radar (SAR) systems, to reduce downlinked data volume by a factor of 4 or more (selectable factor)
- Tailor the architecture to allow incorporation of the processor into future SAR missions.

Kim, Edward, NASA GSFC
Controlled-Correlation Subsystem for On-board Receiver Calibration of Synthetic Thinned Array Radiometers (STAR) and Fully-Polarimetric (FP) Microwave Radiometers

Objective

- Develop a low-power subsystem for in-flight STAR/FP receiver calibration including a signal source with correlation properties, and a correlation receiver for realistic test conditions/optimization.
- STAR radiometers can provide high spatial resolution imaging without requiring a filled aperture or a moving antenna
**Round 1 ACT Microwave Projects**

**Piepmeier, Jeffrey, NASA GSFC**
**Ultra Low-Power Digital Correlator for Passive Microwave Polarimetry**

**Objective**
- Develop and ultra-low-power, radiation-tolerant, CMOS, 500 MHz, 3-level, digital, complex cross-correlator for passive microwave polarimetry.
- Develop the correlator with a path to space flight use.

**Doiron, Terrence, NASA GSFC**
**Development of a Low Power, Miniaturized Module for the Next Generation of Microwave Radiometers**

**Objective**
- Design a receiver module with a power consumption of < 0.25W per frequency per polarization (approximately 1W per module) and a mass of approx. 0.2 kg.
- With a noise temperature of <250K it will directly address the implementation of many future hydrology missions.

**Round 2 IIP Microwave Projects**

**Im, Eastwood, Jet Propulsion Laboratory**
**Advanced Precipitation Radar Antenna and Instrument (APRA)**

**Objective**
- Develop a half-size (2.6m x 2.6m) model of a lightweight, deployable, dual frequency, wide-angle beam-pointing antenna for spaceborne rainfall measurements.
- Incorporate the antenna’s physical and performance characteristics into the overall system design of the Second-Generation Precipitation Radar (PR-2).

**Johnson, Joel, The Ohio State University**
**Digital Receiver With Interference Suppression for Microwave Radiometry**

**Objective**
- Design and build a prototype L-band radiometer and demonstrate operation in the presence of interference.
- Demonstrate improved bandwidth which will enable improved accuracy and sensitivity of soil moisture and salinity measurements.
Moghaddam, Mahta, University of Michigan
Microwave Observatory of Subcanopy and Subsurface (MOSS)
Objective
• Design, develop, and test a prototype UHF/VHF radar antenna feed system to enable 7-10 day observations of subcanopy & subsurface soil moisture at 1Km res. Long and thin apertures are synthesized using a dual-frequency feed subilluminating a 30-m parabolic mesh reflector.
• Generate validation science data set through ground experiments with a UHF/VHF tower radar.

Smith, Eric, NASA GSFC
Lightweight Rainfall Radiometer
Objective
• A new passive microwave radiometer instrument that uses advanced MMIC and digital correlator chip technology to measure precipitation (10.7 GHz)
• Synthetic-Thinned Array Radiometer (STAR) technology: lightweight, miniaturized, 50% less power, fixed-non deployable antenna for large apertures, and low recurring cost

Wilson, Bill, Jet Propulsion Laboratory
Ultra Stable Microwave Radiometers for Future Sea Surface Salinity Missions
Objective
• Research and development for an advanced precision spaceborne radiometer to measure sea surface salinity (SSS).
• A measurement accuracy of 0.1 psu (practical salinity unit, or parts per thousand) requires a radiometer with high accuracy and a calibration stability of 0.05 K for 8 days.
Round 2 ACT Microwave Projects

Edelstein, Wendy, Jet Propulsion Laboratory
Ultra-High Efficiency L-band T/R Modules for Large Aperture Scanning Antennas
Objective
- Develop a lightweight, high-power, high-efficiency L-band T/R module for use in SAR antennas.
- The T/R module performance goal is to achieve an overall module efficiency of 70% with a minimum of 30-Watts output power at L-band frequencies.

Knowles, Gareth, Qortek
Multiband Reconfigurable Synthetic Aperture Radar
Objective
- Investigate the combining of advanced antenna engineering concepts with Frequency Selective Surfaces (FSS) implemented by Active Tuned Dielectric Materials (ATDM) and tuning achieved using Thin Film Transistors (TFT).
- Provide thin, lightweight reconfigurable conformal multiband arrays for space-based SAR systems.

Round 2 ACT Microwave Projects

Moussessian, Alina, Jet Propulsion Laboratory
T/R Membranes for Large Aperture Scanning Antennas
Objective
- Design, construct, and test Transmit/Receive (T/R) modules compatible with very large flexible membrane phased arrays.
- Flexible thin-film membrane antennas have the potential to replace rigid manifold antenna architectures and reduce the weight, volume, and associated cost of space-based radars.

Papapolymerou, John, Georgia Tech
Lightweight, Deployable, Dual-Frequency/Polarization Microstrip Antenna Array for Remote Sensing of Precipitation
Objective
- Develop and demonstrate concepts and techniques that enable lightweight, deployable and low cost antenna arrays for remote sensing.
- Develop and demonstrate a 2x2 dual frequency/polarization microstrip array system on-a-package (SOP) including RF MEMS switches and phase shifters.
Piepmeier, Jeffrey, NASA GSFC
Low-Power Radio-Frequency Analog-To-Digital Converter (RF-ADC) for Digital Microwave Radiometry with Application to Soil Moisture Remote Sensing
Objective
• Develop a low-power (less 330 mW) RF-ADC for L-band digital microwave radiometers

Yueh, Simon, Jet Propulsion Laboratory
Compact, Lightweight Dual-Frequency Microstrip Antenna Feed for Future Soil Moisture and Sea Surface Salinity Missions
Objective
• Develop an innovative, compact, lightweight, dual-frequency antenna feed for future soil moisture and sea surface salinity (SSS) missions.
• Support future high-resolution soil moisture and SSS systems operating at low (L-band) microwave frequencies having large reflectors with multiple feeds.

Round 3 IIP Microwave Projects
Hensley, Scott, Jet Propulsion Laboratory
Rapid-Repeat Deformation Measurement Capability for the NASA AIRSAR System
Objective
• Develop a repeat pass radar interferometry capability for measuring rapidly deforming surfaces on a UAV or Proteus aircraft.
• Develop a polarimetric, electronically scanned, L-band array and associated radar system that is an easily deployed instrument with radar steering that can be linked to on-board INU.

Hussein, Ziad, Jet Propulsion Laboratory
Cryospheric Advanced Sensor: A Spaceborne Microwave Sensor For Sea Ice Thickness and Snow Cover Characteristics
Objective
• Develop a combined spatial and frequency domain interferometer (SI/FDI) radar instrument for determining sea ice thickness and snow cover characteristics and do a field demonstration.
• Develop technology to support a future cryospheric spaceborne mission that will combine frequencies required for both sea ice thickness (VHF-band) and snow cover characteristics (Ku-band).
Round 3 IIP Microwave Projects

Im, Eastwood, Jet Propulsion Laboratory
NEXRAD-In-Space (NIS): A Radar for Monitoring Hurricanes from Geostationary Orbit
Objective
• Develop a system design for a Ka-band, Doppler radar in geostationary orbit for monitoring hurricanes and severe storms with a deployable, 28-m aperture, spherical antenna reflector and the 35-GHz spiral scan antenna feed set.
• Prototype a 1.5-m model of the NIS antenna reflector/feed set to verify the pattern performance during scan.

Lambrigtsen, Bjorn, Jet Propulsion Laboratory
GeoSTAR: Geostationary Synthetic Thinned Aperture Radiometer
Objective
• Develop a prototype for GeoSTAR and use it to demonstrate the 2-D thinned array measurement concept and the required technology for mm-wave STAR instruments.
• Develop a roadmap to an operational flight GeoSTAR instrument on a NOAA GOES mission.

Sarabandi, Kamal, University of Michigan
Geostationary/Low-Earth Orbiting Radar Image Acquisition System (GLORIA): A Multi-Static GEO/LEO SAR Satellite Constellation for Earth Observation
Objective
• Provide a study for a new advanced concept in synthetic aperture radar remote sensing.
• Investigate comparative performance, phenomenological surface scattering, and system feasibility.
• ESTO has invested in many microwave remote sensing systems through open, competitive, peer-reviewed solicitations.
• These investments in active and passive microwave and millimeter-wave measurement concepts are directly enabling and enhancing the many measurements required by the Earth science program at NASA.