NASA has combined the Earth and Space Sciences into a new mission directorate called the Science Mission Directorate. The Science Mission Directorate will carry out the scientific exploration of our Earth, the planets, moons, comets, and asteroids of our solar system and beyond; chart the best route of discovery; and reap the benefits of Earth and space exploration for society. A major objective of the NASA science instrument development programs is to implement science measurement capabilities with small or more affordable spacecraft so development programs can meet multiple mission needs and, therefore, make the best use of limited resources. NASA is fostering innovations that support implementation of the Earth Science (ES) and Space Science (SS) integrated international undertaking to study the Earth and space systems. The Science Mission Directorate Programs define the platforms as the host systems for science instruments. That is, they provide the infrastructure for an instrument or suite of instruments. Traditionally, the term ‘platform’ would be synonymous with ‘spacecraft,’ and it certainly does include spacecraft. However, ‘platform’ is intended to be much broader in application than spacecraft and is intended to include non-traditional hosts for sensors and instruments such as airborne platforms (piloted and unpiloted aircraft, balloons, drop sondes, and sounding rockets). These application examples are given to illustrate the wide diversity of possibilities for acquiring Earth and space science data consistent with the future vision of the Science Mission Directorate and indicate types of platforms for which technology development is required.

Subtopics

S8.01 Guidance, Navigation and Control

Lead Center: GSFC
Participating Center(s): JPL

Future science architectures will include observation and sensing platforms of varying type, size and complexity in a number of mission-operational regimes, trajectories and orbits. Advanced Guidance Navigation and Control (GN&C) technology is required for these platforms to address high performance and reliability requirements while simultaneously satisfying low power, mass, volume and affordability constraints. In particular, there are many technology gaps in challenging orbital environments, including highly elliptical Earth orbits, libration point orbits, and lunar and planetary orbits.

A vigorous effort is needed to develop guidance, navigation and control methodologies, algorithms, and sensor-actuator technologies to enable revolutionary science missions. Of particular interest are highly innovative GN&C
technology proposals directed towards enabling scientific investigators to exploit new vantage points, develop new sensing strategies, and implement new system-level observational concepts that promote agility, adaptability, evolvability, scalability, and affordability. Novel approaches for the autonomous control of distributed spacecraft and/or the management of large fleets of heterogeneous and/or homogeneous assets are desired. Specific areas of research include:

**GN&C System Technologies**

Innovative GN&C solutions are sought for scientific instrument and laser communication system pointing, tracking, and stabilization. Proposals that exploit and combine recent advances in spacecraft attitude determination and control, advanced electro-mechanical packaging, MEMS technology, and ultra-low power microelectronics are encouraged. Of particular interest is technology to provide alternative solutions to challenging GN&C problems such as spacecraft relative range and attitude determination while in close formation and/or during rendezvous/proximity operations.

**GN&C Sensors and Actuators**

Advanced technology sensors and actuators are sought such as Sun sensors, Earth sensors, star/celestial object trackers, fine guidance sensors, gyroscopes, accelerometers, inertial measurement units, navigation devices, magnetometers, reaction/momentum wheels, control-moment gyros, magnetic torquers, tethers, attitude control thrusters, etc. These devices should have enhanced capabilities and performance as well as reduced cost, mass, power, volume, and reduced complexity for all platform GN&C system elements. Of particular interest are technologies that will provide a sensing or actuation function, having performance (e.g., dynamic range, stability, accuracy, noise, sensitivity, bandwidth, control authority, etc.) consistent with the state-of-the-art, with significantly reduced mass, power, volume, and cost. Technologies having the potential for significantly increased performance without additional mass, power, volume, and cost are also of interest. These resource reduction and/or performance improvement factors should be quantified in the proposal and show a minimum factor of 2 with a goal of 10 or greater. Highly autonomous and robust GN&C devices with multifunctional capabilities are of particular interest.

Innovations in Global Positioning System (GPS) receiver hardware and algorithms that use GPS code and carrier signals to provide spacecraft navigation, attitude, and time. Of particular interest are GPS-based navigation techniques that may employ Wide Area Augmentation System (WAAS) corrections.

Novel approaches to autonomous sensing and navigation of multiple distributed space platforms. Of particular interest are specialized sensors and measurement systems for formation sensing and relative navigation functions.

**S8.02 Command and Data Handling**

Lead Center: GSFC
The goal for this subtopic is the development of advanced space technology and concepts to further high-performance science image and data processing. The instrument electronics must operate reliably and effectively for long periods of time in harsh environments. These systems require management of data and products, low power, and radiation.

The objective for this development goal is to elicit novel concepts, architectures, and component technologies that have realistic and achievable potential for flight applications and are responsive to the priority areas of this subtopic. Technologies will be selected based on the potential that their final end products are sustainable (affordable, reliable/safe, and effective) and will advance solutions to the challenges of reusability, modularity, and autonomy.

Priority areas are: reconfigurable/modular implementations; onboard science (data and image) processing and management; and low-power, radiation-resistant electronics. Additional information about the solicited technologies follows:

**Onboard Processing**

- Hardware technologies and architectures that support instrument science (data and image) processing and that are reconfigurable in flight and modular;
- Hardware-based algorithms for onboard data and image processing of raw science into multiple custom data products. The intent is to minimize onboard bandwidth constraints;
- Autonomous capability of hardware and algorithm management without ground intervention;
- Low-power electronics: in order to provide higher capabilities on smaller and/or less expensive instruments and decrease subsequent thermal load; and
- Radiation resistant electronics (hardware or application).

**S8.03 Long Range and Near Earth RF Communications**

Lead Center: JPL
Participating Center(s): GRC, GSFC

This subtopic seeks innovative technologies for long-range RF telecommunications supporting the needs of space missions. Proposals are sought in the following areas:

- Ultra-small, low-cost, low-power, modular deep-space transceivers, transponders, and components, incorporating MMICs and Bi-CMOS circuits;
• MMIC modulators with drivers to provide large linear phase modulation (above 2.5 rad), high-data rate (10-200 Mbps), BPSK/QPSK modulation at X-band (8.4 GHz), and Ka-band (32 GHz and 38 GHz);

• High-efficiency (>70 %) Solid-Sate Power Amplifiers (SSPAs), of both medium output power (10-50 W) and high-output power (150 W - 1 KW), using power combining techniques and/or wide-bandgap semiconductor devices at X-band (8.4 GHz) and Ka-band (32 GHz and 38 GHz);

• Traveling Wave Tube Amplifiers (TWTAs), SSPAs, modulators, and MMICs for 26 GHz Ka-band (lunar comm);

• TWTAs operating at millimeter wave frequencies and at data rates of 10 Gbps or higher;

• Ultra low-noise amplifiers (MMICs or hybrid) for RF front-ends (MEMS-based RF switches and photonic control devices needed for use in reconfigurable antennas, phase shifters, amplifiers, oscillators, and in-flight reconfigurable filters. Frequencies of interest include S-, X-, Ka-, and V-band (60 GHz). Of particular interest is Ka-band from 25.5-27 GHz and 31.5-34 GHz.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware demonstration that will, when appropriate, deliver a demonstration unit for testing at the completion of the Phase 2 contract.

S8.04 Spacecraft Propulsion

Lead Center: GRC
Participating Center(s): GSFC, JPL, JSC, MSFC

Innovations in propulsion technologies are needed to support the Science Mission Directorate (SMD) goals of better understanding the Earth-Sun system, exploring our solar system, and investigating the nature of the universe beyond our solar system. Planetary spacecraft need ever-increasing propulsive performance and flexibility for ambitious missions requiring high-duty cycles and years of operation. Satellites and satellite constellations have high-precision propulsion requirements, usually in volume- and power-limited envelopes. Propulsion systems must avoid contamination of instruments from thruster plumes. This subtopic seeks innovations in propulsion technologies to increase the capabilities of SMD spacecraft. Specifically, technology innovations are sought in the areas of solar electric propulsion, monopropellant technology, and miniature/precision propulsion.

Solar Electric Propulsion

Technology advancements are needed to improve the capability of low- to medium-power electric propulsion systems, including ion, Hall, and advanced plasma thrusters. Areas where innovations are sought include power processing, long-life, high-efficiency cathodes and neutralizers, electrodeless plasma production, low-erosion materials for ion optics and Hall discharge chambers, high-temperature magnetic circuits, and next-generation thrusters. Innovations sought include, but are not limited to, those that improve performance, increase lifetime, reduce mass, and decrease cost. Improvements are also sought for propellant management system components including storage, distribution, and flow control to support solar electric propulsion applications.
Monopropellant Technology

Advancements are sought for propulsion systems using advanced monopropellants. Spacecraft using high-performance (Isp >275 s), high-density (>1 g/cc) monopropellant formulations will need high-durability catalyst materials or, alternatively, non-catalytic ignition technology for power-limited spacecraft. Critical component materials (e.g., tank bladders, valve seats, and filters) that are compatible with advanced monopropellants need to be developed. Performance and density improvements are sought for applications with very low propulsion requirements.

Miniature/Precision Propulsion

Propulsion technologies for miniature (less than 10 kg) spacecraft and for high-precision (impulse bit

S8.05 Energy Conversion and Storage for Space Applications

Lead Center: GRC
Participating Center(s): GSFC, JPL

Earth science observation missions will employ spacecraft, balloons, sounding rockets, surface assets, aircraft, and marine craft. Advanced power technologies are required for each of these platforms that address issues of size, mass, capacity, reliability, and operational costs. A vigorous effort is needed to develop energy conversion technologies that will enable the revolutionary Earth science missions. Exploiting innovative technological opportunities, developing power systems for adverse environments, and implementing system-wide techniques that promote scalability, adaptability, flexibility, and affordability are characteristics of the technological challenges to be faced and are representative of the type of developments required beyond the state-of-the-art.

The energy conversion technologies solicited include photovoltaics and thermophotovoltaics as well as related technologies such as array, concentrator, and thermal technologies. Specific areas of interest include:

- Photovoltaic cell and array technologies with significant improvements in efficiency, mass specific power, stowed volume, cost, radiation resistance, and wide operating conditions are solicited. Photovoltaic cell technologies for wide temperature operation and radiation environments are solicited;

- Potential array technologies of interest include rigid and deployable arrays, concentrators (rigid or inflatable, primary or secondary), ultra-lightweight arrays for lightweight, flexible, thin-film photovoltaic cells, and electrostatically clean spacecraft solar arrays;

- Proposals are sought addressing structural and microbatteries and rechargeable lithium-based batteries with advanced anode and cathode materials and advanced liquid and polymer electrolytes;

- Primary fuel cell systems that can function in high altitude platforms are solicited. These include primary H₂:Air systems that operate at low air pressure and H₂:O₂ systems;

- Future micro-spacecraft require distributed power sources that integrate energy conversion and storage
into a hybrid structure with microelectronics devices/instruments; and

- Thermal technology areas include heat rejection, composite materials, heat pipes, pumped loop systems, packaging and deployment, including integration with the power conversion technology. Highly integrated systems are sought that combine elements of the above subsystems to show system level benefits.

S8.06 Platform Power Management and Distribution

Lead Center: GRC

Participating Center(s): GSFC, JPL

NASA science missions employ Earth orbit and planetary spacecraft, along with terrestrial balloons, surface assets, aircraft, and marine craft as observation platforms. Advanced electrical power technologies are required for the electrical components and systems on these platforms to address the issues of size, mass, efficiency, capacity, durability, and reliability. Advancements are sought in power electronic devices, components, and packaging,

Power Electronic Materials and Components

Advanced magnetic, dielectric, and semiconductor materials, devices, and circuits are of interest. Proposals must address improvements in energy density, speed, efficiency, or wide temperature operation (-125°C to 200°C) with a high number of thermal cycles. Candidate devices and applications include transformers, inductors, semiconductor switches and diodes, electrostatic capacitors, current sensors, and cables.

Power Conversion, Motor Drive, Protection, and Distribution

Technologies that provide significant improvements in mass, size, power quality, reliability, or efficiency in electrical power conversion, motor drives, and protective switchgear components are of interest. Candidate applications include solar array regulators, battery charge and discharge regulators, power conversion, power distribution, fault protection, high-speed motors/generators, magnetic bearing drivers, and integrated flywheel energy storage and attitude control electronics.

Electrical Packaging

Thermal control technologies are sought that are integral to electrical devices with high heat flux capability and advanced electronic packaging technologies which reduce volume and mass or combine electromagnetic shielding with thermal control.