



## Physical Sciences

### **LVGEMS Time-of-Flight Mass Spectrometry on Satellites**

**This technology has applications in plant contaminant monitoring, clinical and medical diagnostics, and homeland security and defense.**

*Goddard Space Flight Center, Greenbelt, Maryland*

NASA's investigations of the upper atmosphere and ionosphere require measurements of composition of the neutral air and ions. NASA is able to undertake these observations, but the instruments currently in use have their limitations. NASA has extended the scope of its research in the atmosphere and now requires more measurements covering more of the atmosphere. Out of this need, NASA developed multipoint measurements using miniaturized satellites, also called nanosatellites (e.g., CubeSats), that require a new generation of spectrometers that can fit into a 4×4 in. (≈10×10 cm) cross-section in the upgraded satellites. Overall, the new mass spectrometer required for the new depth of atmospheric research must fulfill a new level of low-voltage/low-power requirements, smaller size, and less risk of magnetic contamination.

The Low-Voltage Gated Electrostatic Mass Spectrometer (LVGEMS) was developed to fulfill these requirements. The LVGEMS offers a new spectrometer that eliminates magnetic field issues associated with magnetic sector mass spectrometers, reduces power, and is about 1/10 the size of previous instruments. LVGEMS employs the time of flight (TOF) technique in the GEMS mass spectrometer previously developed at

Goddard Space Flight Center. However, like any TOF mass spectrometer, GEMS requires a rectangular waveform of large voltage amplitude, exceeding 100 V — that means that the voltage applied to one of the GEMS electrodes has to change from 0 to 100 V in a time of only a few nanoseconds. Such electronic speed requires more power than can be provided in a CubeSat.

In the LVGEMS, the amplitude of the rectangular waveform is reduced to about 1 V, compatible with digital electronics supplies and requiring little power. Thus, the LVGEMS concept makes possible very low power (< 0.5 W) mass spectrometers 1 to 2 in. (≈2.5 to 5 cm) in length; fitting and working well in CubeSats. With less voltage and power, there is also less risk of voltage breakdown at the spectrometer electrodes and less magnetic interference from the supporting electronics. Because of its small size, the LVGEMS can be part of an instrument suite, like the NASA/NRL WINCS (Winds-Ions-Neutral Composition Suite) that provides neutral and ion composition with other instruments providing the neutral wind, ion drift, and temperatures. Perhaps the main advantage of an instrument suite is that instruments like GEMS share electronics and power with other sensors,

thus minimizing the power consumed per spectrometer — another enabler for CubeSat missions for ionosphere-thermosphere science.

In an orbiting TOF spectrometer, measurements are difficult because all atoms and molecules species enter at the same velocity; therefore all incident atoms and molecules have the same TOF, making it impossible to differentiate between species. However, the newly developed LVGEMS mass spectrometer provides the ability to accelerate and add the same kinetic energy to all species, and this results in each species having its own unique TOF value for easy identification.

The principal feature of this invention is to enable TOF mass spectrometry in low-Earth-orbit investigations of the thermosphere at the time when new missions require multi-point measurements using large numbers of nanosatellites. LVGEMS offers a solution that requires no magnetic fields, no high-frequency voltages of high amplitudes, uses power less than 0.5 W, and has dimensions measured in a few cm (one inch or less).

*This work was done by Federico Herrero of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16255-1*

### **Surface Inspection Tool for Optical Detection of Surface Defects**

**The small, dual-picture tool enables both macro and micro views.**

*John F. Kennedy Space Center, Florida*

The Space Shuttle Orbiter windows were damaged both by micrometeor impacts and by handling, and required careful inspection before they could be reused. The launch commit criteria required that no defect be deeper than a critical depth. The shuttle program used a refocus microscope to perform a quick pass/fail determination, and then followed up with mold impressions to

better quantify any defect. However, the refocus microscope is slow and tedious to use due to its limited field of view, only focusing on one small area of glass at a time. Additionally, the unit is bulky and unable to be used in areas with tight access, such as defects near the window frame or on the glass inside the Orbiter due to interference with the dashboard. Bulky camera equipment

was needed to acquire images for later processing and storage. The long depth of field of the refocus microscope provided crisp images of the defect, but didn't provide the user with a feel for depth of the defect since all parts of the image appear in focus.

The surface inspection tool is a low-profile handheld instrument that provides two digital video images on a com-

puter for monitoring surface defects. The first image is a wide-angle view to assist the user in locating defects. The second provides an enlarged view of a defect centered in the window of the first image. The focus is adjustable for each of the images. However, the enlarged view was designed to have a focal plane with a short depth. This allows the user to get a feel for the depth of different parts of the defect under inspection as the focus control is varied. A light source is also provided to illuminate the defect, precluding the need for separate lighting tools. The software provides many controls to adjust image quality, along with the ability to zoom digitally the images and to capture and store them for later processing.

Two LED light sources are included for improved illumination, allowing the user to work without an external light source. The optics enable the two cameras to be mounted in a compact manner and allow them to focus on the same image. Software provided from the camera manufacturer provides the users the capability to view the two images simultaneously to facilitate rapid defect detection. The user may use a digital zoom to enlarge smaller details, if needed. Full-resolution digital images and limited-



The **Surface Inspection Tool** (left), shown in use (right). The handle was added to accommodate smaller hands and reduce user fatigue.

resolution video can be captured and stored for later processing.

The surface inspection tool addresses many of the limitations of the existing refocus microscope. It is smaller and provides a live video output on a laptop computer that allows the user to locate defects more rapidly. The camera with the microscope objective has a depth of focus of approximately 0.00014 in. ( $\approx 4 \mu\text{m}$ ) and a user-varied focus. This allows the user to gain a better understanding of the depth and character of the defect under inspection. Likewise, lower-resolution video capture is also an avail-

able feature not present with the refocus microscope.

The surface inspection tool consists of components that are more expensive than the refocus microscope. However, the inclusion of the wide-angle camera allows for inspection of a larger area at a time, making it quicker to scan and locate defects in large surfaces. This time savings, combined with the added features, may make it interesting enough to potential users to justify the added initial cost.

*This work was done by Mark Nurge, Robert Youngquist, and Dustin Dyer of Kennedy Space Center. Further information is contained in a TSP (see page 1). KSC-13580*

## Per-Pixel, Dual-Counter Scheme for Optical Communications

**Per-pixel processing scheme for single-photon detectors would require 10 to 100 times less beacon transmit power.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Free space optical communications links from deep space are projected to fulfill future NASA communication requirements for 2020 and beyond. Accurate laser-beam pointing is required to achieve high data rates at low power levels. For the highest pointing accuracy, a laser beacon transmitted from near the Earth receiver location is acquired and tracked by the space transceiver to obtain accurate knowledge of the Earth receiver position in the pitch and yaw degrees of freedom. This pointing knowledge is generated by forming estimates of the beacon transmitter location by centroiding the position of a focused spot on a focal plane detector array in the space transceiver, perhaps a two-by-two pixel array (a quad detector), but often on a larger array to ease initial spatial acquisition. The accuracy of those estimates, and, therefore, the accuracy of the space transceiver point-

ing, is a function of the received optical signal power, accepted optical background power, and detector readout noise. The centroiding performance of a typical focal plane array can be 10 to 100 times poorer than the shot noise limit due to readout noise. A focal plane array of single-photon detectors can fully close this gap, and thereby require 10 to 100 times less beacon transmit power, but specialized per-pixel processing circuitry is required.

This innovation is a per-pixel processing scheme using a pair of three-state digital counters to implement acquisition and tracking of a dim laser beacon transmitted from Earth for pointing control of an interplanetary optical communications system using a focal plane array of single sensitive detectors. It shows how to implement dim beacon acquisition and tracking for an interplanetary optical transceiver with a method

that is suitable for both achieving theoretical performance, as well as supporting additional functions of high data rate forward links and precision spacecraft ranging.

Spatial acquisition and tracking on the uplink laser beacon from Earth can be achieved on the space transceiver focal plane array by connecting two counters to every array pixel. This scheme provides a low-complexity method to monitor all pixels in the detector array until a beacon signal is detected. Temporal acquisition of the uplink laser beacon square wave signal is performed using outputs from a pair of phase-offset counters. The counters alternate among three states denoted by "up," "down," and "idle." In the up state, a counter increments its value when its pixel registers a photon arrival. In the down state, the counter decrements its value when a photon arrival is