is compatible with proven Schottky diode mixer/detector technologies.

The development of such technology will benefit applications where submillimeter-wave heterodyne array designs are required. The main fields are national security, planetary exploration, and biomedicine. For national security, wideband submillimeter radars could be an effective tool for the standoff detection of hidden weapons or bombs concealed by clothing or packaging. In the field of planetary exploration, wideband submillimeter radars can be used as a spectrometer to detect trace concentrations of chemicals in atmospheres that are too cold to rely on thermal imaging techniques. In biomedicine, an imaging heterodyne system could be helpful in detecting skin diseases.

This work was done by Goutam Chattopadhyay, John J. Gill, Anders Skalare, Choonsup Lee, and Nuria Llombart, and Peter H. Siegel of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to NPO-46969, volume and number of this NASA Tech Briefs *issue, and the page number.*

Automated Cryocooler Monitor and Control System

Small-scale cryogenic cooler applications include medical imaging for MRI systems and infrared sensor cooling.

NASA's Jet Propulsion Laboratory, Pasadena, California

A system was designed to automate cryogenically cooled low-noise amplifier systems used in the NASA Deep Space Network. It automates the entire operation of the system including cool-down, warm-up, and performance monitoring. The system is based on a single-board computer with custom software and hardware to monitor and control the cryogenic operation of the system. The system provides local display and control, and can be operated remotely via a Web interface.

The system controller is based on a commercial single-board computer with onboard data acquisition capability. The commercial hardware includes a microprocessor, an LCD (liquid crystal display), seven LED (light emitting diode) displays, a seven-key keypad, an Ethernet interface, 40 digital I/O (input/output) ports, 11 A/D (analog to digital) inputs, four D/A (digital to analog) outputs, and an external relay board to control the high-current devices.

The temperature sensors used are commercial silicon diode devices that provide a non-linear voltage output proportional to temperature. The devices are excited with a 10-microamp bias current. The system is capable of monitoring and displaying three temperatures.

The vacuum sensors are commercial thermistor devices. The output of the sensors is a non-linear voltage proportional to vacuum pressure in the 1-Torr to 1-millitorr range. Two sensors are used. One measures the vacuum pressure in the cryocooler and the other the pressure at the input to the vacuum pump. The helium pressure sensor is a commercial device that provides a linear voltage output from 1 to 5 volts, corresponding to a gas pressure from 0 to 3.5 MPa (≈500 psig).

Control of the vacuum process is accomplished with a commercial electrically operated solenoid valve. A commercial motor starter is used to control the input power of the compressor. The warm-up heaters are commercial power resistors sized to provide the appropriate power for the thermal mass of the particular system, and typically provide 50 watts of heat.

There are four basic operating modes. "Cool" mode commands the system to cool to normal operating temperature. "Heat" mode is used to warm the device to a set temperature near room temperature. "Pump" mode is a maintenance function that allows the vacuum system to be operated alone to remove accumulated contaminants from the vacuum area. In "Off" mode, no power is applied to the system.

This work was done by Michael J. Britcliffe, Theodore R. Hanson, and Larry E. Fowler of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47246

Broadband Achromatic Phase Shifter for a Nulling Interferometer

A uniform broadband phase shift is achieved while minimizing intensity, polarization, and chromatic spread differences between interferometer beams.

Goddard Space Flight Center, Greenbelt, Maryland

Nulling interferometry is a technique for imaging exoplanets in which light from the parent star is suppressed using destructive interference. Light from the star is divided into two beams and a phase shift of π radians is introduced into one of the beams. When the beams are recombined, they destructively interfere to produce a deep null. For monochromatic light, this is implemented by introducing an optical path difference (OPD) between the two beams equal to $\lambda/2$, where λ is the wavelength of the light. For broadband light, however, a different phase shift will be introduced at each wavelength and the two beams will not effectively null when recombined.

Various techniques have been devised to introduce an achromatic phase shift — a phase shift that is uniform across a particular bandwidth. One popular technique is to use a series of dispersive elements to introduce a wavelength-dependent optical path in one or both of the arms of the interferometer. By intelligently choosing the number, material and thickness of a series of glass plates, a nearly uniform, arbitrary phase shift can be introduced between two arms of an interferometer.

There are several constraints that make choosing the number, type, and thickness of materials a difficult problem, such as the size of the bandwidth to be nulled. Several solutions have been found for bandwidths on the order of 20 to 30 percent ($\Delta\lambda/\lambda_c$) in the mid-infrared region. However, uniform phase shifts over a larger bandwidth in the visible regime between 480 to 960 nm (67 percent) remain difficult to obtain at the tolerances necessary for exoplanet detection.

A configuration of 10 dispersive glass plates was developed to be used as an achromatic phase shifter in nulling interferometry. Five glass plates were placed in each arm of the interferometer and an additional vacuum distance was also included in the second arm of the interferometer. This configuration creates a phase shift of π radians with an average error of 5.97×10^{-8} radians and standard deviation of 3.07×10^{-4} radians. To reduce ghost reflections and interference effects from neighboring elements, the glass plates are tilted such that the beam does not strike each plate at normal incidence. Reflections will therefore walk out of the system and not contribute to the intensity when the beams are recombined.

Tilting the glass plates, however, introduces several other problems that must be mitigated: (1) the polarization of a beam changes when refracted at an interface at non-normal incidence; (2) the beam experiences lateral chromatic spread as it traverses multiple glass plates; (3) at each surface, wavelength-dependent intensity losses will occur due to reflection. For a fixed angle of incidence, each of these effects must be balanced between each arm of the interferometer in order to ensure a deep null.

The solution was found using a nonlinear optimization routine that minimized an objective function relating phase shift, intensity difference, chromatic beam spread, and polarization difference to the desired parameters: glass plate material and thickness. In addition to providing a uniform, broadband phase shift, the configuration achieves an average difference in intensity transmission between the two arms of the interferometer of 0.016 percent with a standard deviation of 3.64×10^{-4} percent, an average difference in polarization between the two arms of the interferometer of 5.47×10^{-5} percent with a standard deviation of 1.57×10^{-6} percent, and an average chromatic beam shift between the two arms of the interferometer of –47.53 microns with a wavelength-by-wavelength spread of 0.389 microns.

This work was done by Matthew R. Bolcar and Richard G. Lyon of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15830-1

Super Dwarf Wheat for Growth in Confined Spaces

Lyndon B. Johnson Space Center, Houston, Texas

USU-Perigee is a dwarf red spring wheat that is a hybrid of a high-yield early tall wheat (USU-Apogee) and a low-yield, extremely short wheat that has poor agronomic characteristics. USU-Perigee was selected for its extremely short height (≈0.3 m) and high yield — characteristics that make it suitable for growth in confined spaces in controlled environments. Other desirable characteristics include rapid development and resistance to a leaf-tip necrosis, associated with calcium deficiency, that occurs in other wheat cultivars under rapid-growth conditions (particularly, continuous light).

Heads emerge after only 21 days of growth in continuous light at a constant temperature of 25 °C. In tests, USU-Perigee was found to outyield other full dwarf (defined as <0.4 m tall) wheat cultivars: The yield advantage at a constant temperature of 23 °C was found to be about 30 percent. Originally intended as a candidate food crop to be grown aboard spacecraft on long missions, this cultivar could also be grown in terrestrial growth chambers and could be useful for plant-physiology and -pathology studies.

This work was done by Bruce Bugbee of Utah State University for Johnson Space Center. For more information, see www.usu.edu/cpl/Progression.pdf. MSC-24200-1

Fine Guidance Sensing for Coronagraphic Observatories

NASA's Jet Propulsion Laboratory, Pasadena, California

Three options have been developed for Fine Guidance Sensing (FGS) for coronagraphic observatories using a Fine Guidance Camera within a coronagraphic instrument. Coronagraphic observatories require very fine precision pointing in order to image faint objects at very small distances from a target star. The Fine Guidance Camera measures the direction to the target star.

The first option, referred to as Spot, was to collect all of the light reflected from a coronagraph occulter onto a focal plane, producing an Airy-type point spread function (PSF). This would allow almost all of the starlight from the central star to be used for centroiding. The second approach, referred to as Punctured Disk, collects the light that bypasses a central obscuration, producing a PSF with a punctured central disk. The final approach, referred to as Lyot, collects light after passing through the occulter at the Lyot stop.

The study includes generation of representative images for each option by the science team, followed by an engineering evaluation of a centroiding or a photometric algorithm for each option. After the alignment of the coronagraph to the fine guidance sys-