

more cost effectively without sacrificing sensor performance or the aircraft time on station.

The results of the initial analysis and numerical design indicated strong potential for an antenna array that would satisfy all of the design requirements for a replacement HIRAD array. Multiple common aperture antenna methodologies were employed to achieve exceptional gain over the entire spectral frequency band while ex-

hibiting superb VSWR (voltage standing wave ratio) values.

Element size and spacing requirements were addressed for a direct replacement of the thicker, lower-performance, stacked patch antenna array currently employed for the HIRAD application. Several variants to the multiband arrays were developed that exhibited four, equally spaced, high efficiency, "sweet spot" frequency bands, as well as the option for a high-perform-

ance wideband array. The 0.25-in. ( $\approx 6.4$  mm) thickness of the antenna stack-up itself was achieved through the application of specialized antenna techniques and meta-materials to accomplish all design objectives.

*This work was done by John Little of Spectra Research, Inc. for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-33005-1.*

## Complementary Barrier Infrared Detector (CBIRD) Contact Methods

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

The performance of the CBIRD detector is enhanced by using new device contacting methods that have been developed. The detector structure features a narrow gap adsorber sandwiched between a pair of complementary, unipolar barriers that are, in turn, surrounded by contact layers. In this innovation, the contact adjacent to the hole barrier is doped n-type, while the contact adjacent to the electron barrier is doped p-type.

The contact layers can have wider bandgaps than the adsorber layer, so long as good electrical contacts are made to them. If good electrical contacts are made to either (or both) of the barriers, then one could contact the barrier(s) directly, obviating the need for additional contact layers. Both the left and right contacts can be doped either n-type or p-type. Having an n-type contact layer next to the electron barrier creates a second

p-n junction (the first being the one between the hole barrier and the adsorber) over which applied bias could drop. This reduces the voltage drop over the adsorber, thereby reducing dark current generation in the adsorber region.

*This work was done by David Z. Ting, Cory J. Hill, and Sarath D. Gunapala of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47042*

## Autonomous Control of Space Nuclear Reactors

**Autonomous operation and safety are addressed simultaneously.**

*John H. Glenn Research Center, Cleveland, Ohio*

Nuclear reactors to support future robotic and manned missions impose new and innovative technological requirements for their control and protection instrumentation. Long-duration surface missions necessitate reliable autonomous operation, and manned missions impose added requirements for failsafe reactor protection. There is a need for an advanced instrumentation and control system for space-nuclear reactors that addresses both aspects of autonomous operation and safety.

The Reactor Instrumentation and Control System (RICS) consists of two functionally independent systems: the Reactor Protection System (RPS) and the Supervision and Control System (SCS). Through these two systems, the RICS both supervises and controls a nuclear reactor during normal operational states, as well as monitors the operation of the reactor

and, upon sensing a system anomaly, automatically takes the appropriate actions to prevent an unsafe or potentially unsafe condition from occurring. The RPS encompasses all electrical and mechanical devices and circuitry, from sensors to actuation device output terminals.

The SCS contains a comprehensive data acquisition system to measure continuously different groups of variables consisting of primary measurement elements, transmitters, or conditioning modules. These reactor control variables can be categorized into two groups: those directly related to the behavior of the core (known as nuclear variables) and those related to secondary systems (known as process variables). Reliable closed-loop reactor control is achieved by processing the acquired variables and actuating the appropriate device drivers to maintain the reactor in a safe operating state. The SCS must prevent a devia-

tion from the reactor nominal conditions by managing limitation functions in order to avoid RPS actions.

The RICS has four identical redundancies that comply with physical separation, electrical isolation, and functional independence. This architecture complies with the safety requirements of a nuclear reactor and provides high availability to the host system. The RICS is intended to interface with a host computer (the computer of the spacecraft where the reactor is mounted).

The RICS leverages the safety features inherent in Earth-based reactors and also integrates the wide range neutron detector (WRND). A neutron detector provides the input that allows the RICS to do its job. The RICS is based on proven technology currently in use at a nuclear research facility. In its most basic form, the RICS is a ruggedized, compact data-acquisition and control system that

could be adapted to support a wide variety of harsh environments. As such, the RICS could be a useful instrument outside the scope of a nuclear reactor, including military applications where fail-safe data acquisition and control is

required with stringent size, weight, and power constraints.

*This work was done by John Merk of Aurora Flight Sciences for Glenn Research Center. For more information, contact kimberly.a.dalgleish@nasa.gov.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-19014-1.*

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## High-Power, High-Speed Electro-Optic Pockels Cell Modulator

*Goddard Space Flight Center, Greenbelt, Maryland*

Electro-optic modulators rely on a change in the index of refraction for the optical wave as a function of an applied voltage. The corresponding change in index acts to delay the wavefront in the waveguide. The goal of this work was to develop a high-speed, high-power waveguide-based modulator (phase and amplitude) and investigate its use as a pulse slicer. The key innovation in this effort is the use of potassium titanyl phosphate (KTP) waveguides, making the high-power, polarization-based waveguide amplitude modulator possible. Furthermore, because it is fabricated in KTP, the waveguide component will withstand high optical power and have a significantly higher RF modulation figure of merit (FOM) relative to lithium niobate.

KTP waveguides support high-power TE and TM modes — a necessary requirement for polarization-based modulation as with a Pockels cell.

High-power fiber laser development has greatly outpaced fiber-based modulators in terms of its maturity and specifications. The demand for high-performance nonlinear optical (NLO) devices in terms of power handling, efficiency, bandwidth, and useful wavelength range has driven the development of bulk NLO options, which are limited in their bandwidth, as well as waveguide based LN modulators, which are limited by their low optical damage threshold.

Today, commercially available lithium niobate (LN) modulators are used for laser formatting; however, because of

photorefractive damage that can reduce transmission and increase requirements on bias control, LN modulators cannot be used with powers over several mW, dependent on wavelength.

The high-power, high-speed modulators proposed for development under this effort will enable advancements in several exciting fields including lidar-based remote sensing, atomic interferometry, free-space laser communications, and others.

*This work was done by Justin Hawthorne and Philip Battle of AduR, Inc. for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16559-1*