quency mode; analysis of the results led to the conclusion that this mode is useful for measuring thicknesses between 0.5 and 1 m.

Several modifications have been conceived for implementation in further development toward an improved practical system:

- The system would function in a single frequency-band / mode (100 to 1,200 MHz) that would afford a resolution of about 15 cm.
- There would be a single antenna system that would be optimized for the entire 100-to-1,000-MHz frequency band.
- To enable ice-thickness surveys over larger areas, the system would be made capable of operating aboard a low-flying aircraft that could be either piloted or robotic.
- Data-processing techniques to deconvolve the system response have been developed on the basis of impulse-response measurements over a calm ocean. Implementation of these techniques in the system would enable correction for imperfections of the system and would thereby increase the effective sensitivity of the system.

This work was done by Prasad Gogineni and Pannir Kanagaratnam of the University of Kansas and Benjamin M. Holt of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-45565

Vertical Isolation for Photodiodes in CMOS Imagers

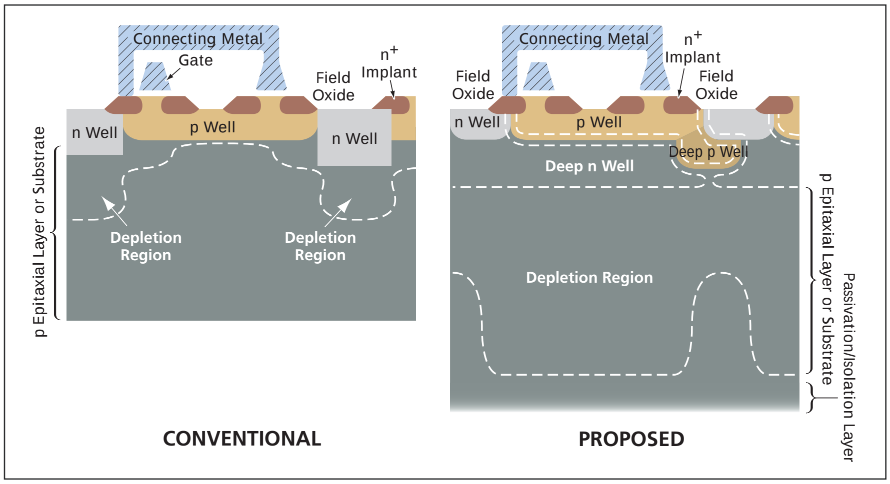
Diffusion cross-talk would be reduced substantially.

NASA's Jet Propulsion Laboratory, Pasadena, California

In a proposed improvement in complementary metal oxide / semiconductor (CMOS) image detectors, two additional implants in each pixel would effect vertical isolation between the metal oxide / semiconductor field-effect transistors (MOSFETs) and the photodiode of the pixel. This improvement is expected to enable separate optimization of the designs of the photodiode and the MOSFETs so as to optimize their performances independently of each other. The purpose to be served by enabling this separate optimization is to eliminate or vastly reduce diffusion cross-talk, thereby increasing sensitivity, effective spatial resolution, and color fidelity while reducing noise.

Ideally, the spatial resolution of an imager should be limited by the geometric pixel size. However, in most practical image detectors, resolutions are limited, not by geometric pixel sizes, but by cross-talk. (As used here, "cross-talk" denotes the response of a pixel to light focused on an adjacent pixel.) Cross-talk degrades spatial resolution of an imager, reduces overall sensitivity, compromises color fidelity, and leads to additional noise in the image after color correction. Diffusion cross-talk occurs where photogenerated charge carriers can move to neighboring charge-accumulation sites — in particular, where junction diodes in adjacent pixels have insufficient depletion widths.

The left side of the figure presents a schematic cross section of a typical conventional CMOS imager pixel containing a junction diode connected to the source of a reset MOSFET. The junction diode is formed between the n well and the p epitaxial layer (or p substrate). The n well is connected to the source of the reset MOSFET through an n^+ implant. The reset MOSFET and an associate source-follower MOSFET are n-type and are placed inside a p well. For reasons too complex to present in this article, the depletion width is too small to prevent lateral diffusion of photo-induced charge carriers in the undepleted (field-free) epitaxial region. In the absence of a guiding electric field, photoelectrons generated in the epitaxial layer substrate diffuse omnidirectionally between pixels, thereby causing cross-talk.



The **Proposed CMOS Imager Pixel** device structure would be similar to the conventional one but would include deep p and n wells.

The maximum supply potential in a CMOS process is between 3 and 5 V. When potential drops are taken into account, the reverse bias across the diode is between 2 and 3 V. At these reverse biases, the p-n junction depletion width is too small to prevent diffusion cross-talk, especially for longer wavelength light, In principle, the depletion width could be increased significantly by applying a large reverse bias (e.g., 50 V) to the p epitaxial layer or substrate. However, because of (1) the electrical connection between the p well and the p epitaxial layer or substrate and (2) a requirement to keep at the most between 3 and 5 V across the CMOS devices, it is not possible to apply such a large reverse bias in this device structure. This prompts the proposed improvement in device structure.

A CMOS imager pixel as proposed, depicted on the right side of the figure, would include a deep n well and a deep p well in addition to the conventional n and p wells. The photodiode would be formed by the deep n well and the p epitaxial layer or substrate. The anode end (n end) of the diode would be connected to the n^+ source implant of the reset MOSFET through the conventional n well. The reset and source-follower MOSFETs would reside in the p well as in the conventional device structure.

Unlike in the conventional device structure, the deep n well would electrostatically separate the p well in the vertical direction from the p epitaxial layer or substrate. The horizontal isolation of photodiodes in adjacent pixels from each other would be achieved by the deep p wells: Each deep p well would establish a potential barrier that would prevent electrons in the deep n wells of adjacent pixels from communicating with each other.

Inasmuch as the conventional and deep p wells would both be electrostatically isolated from the p epitaxial layer or substrate by the deep n well, any reverse (negative) bias could be applied to the p epitaxial layer or substrate without causing the potential difference between the n and p wells to increase beyond the typical conventional range of 2 to 3 V. Depending upon the resistivity of the substrate, a back-side reverse bias in excess of 50 V could be applied to achieve depletion widths as large as 50 μm, while the MOSFETs could be operated with conventional CMOS power supplies and biases. Thus, the incorporation of the deep n well and p well would allow the integration of a photodiode with a very large back-bias and very large depletion width alongside state-of-the-art MOSFETs with small supply voltages, resulting in the development of high-performance CMOS imager sensors.

This work was done by Bedabrata Pain of Caltech for NASA's Jet Propulsion Laboratory.

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:

Innovative Technology Assets Management
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-2240
E-mail: iaoffice@jpl.nasa.gov

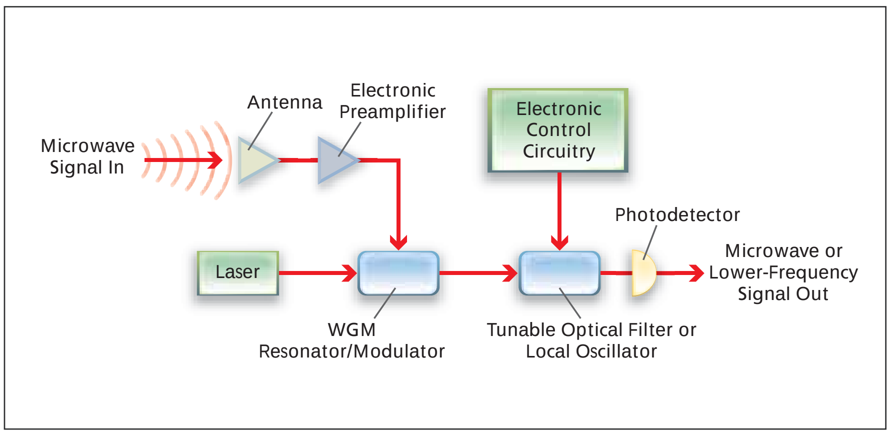
Refer to NPO-41226, volume and number of this NASA Tech Briefs *issue, and the page number.*

Wide-Band Microwave Receivers Using Photonic Processing

One receiver would have the functionality of multiple traditional heterodyne microwave receivers.

NASA's Jet Propulsion Laboratory, Pasadena, California

In wide-band microwave receivers of a type now undergoing development, the incoming microwave signals are electronically preamplified, then frequency-up-converted to optical signals that are processed photonically before being detected. This approach differs from the traditional approach, in which incoming microwave signals are processed by purely electronic means. As used here, "wide-band microwave receivers" refers especially to receivers capable of reception at any frequency throughout the range from about 90 to about 300 GHz. The advantage expected to be gained by following the up-conversion-and-photonic-processing approach is the ability to overcome the limitations of currently available detectors and tunable local oscillators in the frequency range of interest.



A **Microwave Signal Is Up-Converted** to an optical signal, then filtered or otherwise processed photonically before being detected.

In a receiver following this approach (see figure), a preamplified incoming microwave signal is up-converted by the method described in the preceeding article. The frequency up-converter exploits the nonlinearity of the electromagnetic response of a whispering-gallery-mode (WGM) resonator made of $LiNbO_3$. Up-conversion takes place by three-wave mixing in the resonator. The WGM resonator is designed and fabricated to function simultaneously as an electro-optical modulator and to exhibit resonance at the microwave and optical operating frequencies plus phase matching among the microwave and optical signals circulating in the resonator. The up-conversion is an efficient process, and the efficiency is enhanced by the combination of microwave and optical resonances.

The up-converted signal is processed photonically by use of a tunable optical filter or local oscillator, and is then detected. Tunable optical filters can be made to be frequency agile and to exhibit high resonance quality factors (high Q values), thereby making it possible to utilize a variety of signal-processing modalities. Therefore, it is anticipated that when fully developed, receivers of this type will be compact and will be capable of both wide-band and narrow-band signal processing. Thus, one compact receiver of this type would afford the functionality that, heretofore, could have been obtained only by use of multiple heterodyne microwave receivers.

This work was done by Andrey Matsko, Lute Maleki, Vladimir Iltchenko, Nan Yu, Dmitry Strekalov, and Anatoliy Savchenkov of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-45313