

tude ratio of two. The 0.1- and 0.2-W PAs, which are in the 1:2 power ratio, are initially combined in a branch-line hybrid that has a coupling value of 4.77 dB. Likewise, the combined output of the first branch-line hybrid is combined with the output from the third PA in a second branch-line hybrid, also with a coupling value of 4.77 dB. The measured combining efficiency at the center

frequency of 32.05 GHz is greater than 90% for a wide range of power ratios both below and above two. The measured return loss at the output port 1 and the isolation among the input ports 3, 5, and 6 of the three-way combiner are greater than 16 and 22 dB, respectively.

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*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-18688-1*

## Structural Health Monitoring With Fiber Bragg Grating and Piezo Arrays

**A nondestructive damage identification and assessment capability can be used in monitoring systems for maintenance and disaster avoidance.**

*Dryden Flight Research Center, Edwards, California*

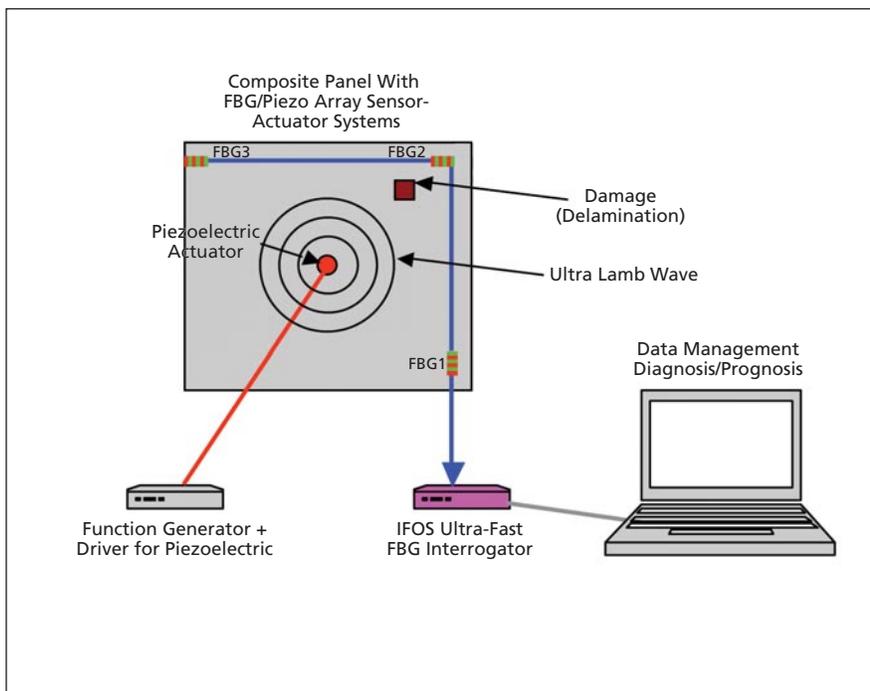
Structural health monitoring (SHM) is one of the most important tools available for the maintenance, safety, and integrity of aerospace structural systems. Lightweight, electromagnetic-interference-immune, fiber-optic sensor-based SHM will play an increasing role in more secure air transportation systems. Manufacturers and maintenance personnel have pressing needs for significantly improving safety and reliability while providing for lower inspection and maintenance costs. Undetected or untreated damage may grow and lead to catastrophic structural failure.

Damage can originate from the strain/stress history of the material, imperfections of domain boundaries in metals, delamination in multi-layer materials, or the impact of machine tools in the manufacturing process. Damage can likewise develop during service life from wear and tear, or under extraordinary circumstances such as with unusual forces, temperature cycling, or impact of flying objects. Monitoring and early detection are key to preventing a catastrophic failure of structures, especially when these are expected to perform near their limit conditions.

The ultimate goal of SHM technology is to develop autonomous (preventive) maintenance systems for continuous monitoring, inspection, and damage detection of structures with minimum labor involvement in real time, and in order to prevent catastrophic structural failure with timely service/maintenance. The ultimate solution will include both advanced hardware and advanced mathematical algorithms.

On the hardware side, a high-speed, high-channel-count fiber-optic sensor interrogation system was developed. On the SHM algorithmic side, algorithmic methods were developed for characterizing the damage from sensory data collected over several strategically placed sensors.

A dynamic response-based damage detection technique is relatively easy to implement and offers a wealth of differential diagnostic capabilities. The basic assumptions of this technique are that the dynamic parameters such as natural frequencies, mode shapes, transfer functions, or response functions depend on the physical properties across the structures. Therefore, the changes in these dynamic characteristics can be used to locate and assess problem areas. Smart optical fiber Bragg grating (FBG) sensors have been increasingly used in SHM, and they could be either surface-bonded or embedded within the structures, and form an array of sensors for dynamic response measurement. For a small-scale demonstration, Lamb waves are excited by a single piezoelectric actuator and captured by three FBG sensors whose response is in turn captured by a parallel processing FBG interrogator ca-



The Fiber Bragg Grating/Piezo Array sensor-actuator system as a concept demonstration for structural health monitoring.

pable of sampling each sensor simultaneously at hundreds of kilohertz. The number of sensors required for damage detection is fewer than low-frequency techniques that can also use FBGs, such

as those based on the mode shapes of the structure.

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## Low-Gain Circularly Polarized Antenna With Torus-Shaped Pattern

**A shaped aperture is used, and rather than the standard linear bicone, a parabolic bicone was found to reduce the amount of phase variation as the aperture increases.**

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The Juno mission to Jupiter requires an antenna with a torus-shaped antenna pattern with approximately 6 dBic gain and circular polarization over the Deep Space Network (DSN) 7-GHz transmit frequency and the 8-GHz receive frequency. Given the large distances that accumulate en-route to Jupiter and the limited power afforded by the solar-powered vehicle, this toroidal low-gain antenna requires as much gain as possible while maintaining a beam width that could facilitate a  $\pm 10^\circ$  edge of coverage.

The natural antenna that produces a toroidal antenna pattern is the dipole, but the limited  $\approx 2.2$  dB peak gain would be insufficient. Here a shaped variation of the standard bicone antenna is proposed that could achieve the required gains and bandwidths while maintaining a size that was not excessive. The final geometry that was settled on consisted of a corrugated, shaped bicone, which is fed by a WR112 waveguide-to-coaxial-waveguide transition. This toroidal low-gain antenna (TLGA)

geometry produced the requisite gain, moderate sidelobes, and the torus-shaped antenna pattern while maintaining a very good match over the entire required frequency range. Its "horn" geometry is also low-loss and capable of handling higher powers with large margins against multipactor breakdown. The final requirement for the antenna was to link with the DSN with circular polarization. A four-layer meander-line array polarizer was implemented; an approach that was fairly well suited to the TLGA geometry.

The principal development of this work was to adapt the standard linear bicone such that its aperture could be increased in order to increase the available gain of the antenna. As one increases the aperture of a standard bicone, the phase variation across the aperture begins to increase, so the larger the aperture becomes, the greater the phase variation. In order to maximize the gain from any aperture antenna, the phase should be kept as uniform as possible. Thus, as the stan-

dard bicone's aperture increases, the gain increase becomes less until one reaches a point of diminishing returns.

In order to overcome this problem, a shaped aperture is used. Rather than the standard linear bicone, a parabolic bicone was found to reduce the amount of phase variation as the aperture increases. In fact, the phase variation is half of the standard linear bicone, which leads to higher gain with smaller aperture sizes. The antenna pattern radiated from this parabolic-shaped bicone antenna has fairly high side lobes. The Juno project requested that these sidelobes be minimized. This was accomplished by adding corrugations to the parabolic shape. This corrugated-shaped bicone antenna had reasonably low sidelobes, and the appropriate gain and beamwidth to meet project requirements.

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