following an error-minimization approach. Precise measurements are obtained by synchronizing data by use of linear interpolation and a dual-camera trajectory solution. Velocities of objects are also estimated in this model.

The affine camera model does not require advance knowledge of the positions and orientations of the cameras. This is because ultimately, positions and orientations of the cameras and of all objects are computed in a coordinate system attached to one object as defined in its CAD model.

Initially, the software developed to solve the equations of the affine camera model implemented a gradient-descent algorithm for finding a solution of a matrix · vector equation that minimizes an error function. Whereas photogrammetric analyses typically entailed weeks of measurements and computations to obtain accurate results from a given set of images, this software yielded solutions in times of the order of minutes. A more recent version of the software solves the affine-camera-model equations directly by means of a matrix inversion in a typical computation time of the order of a second.

This work was done by Steve Klinko, John Lane, and Christopher Nelson of ASRC Aerospace for Kennedy Space Center. KSC-12665/3/705

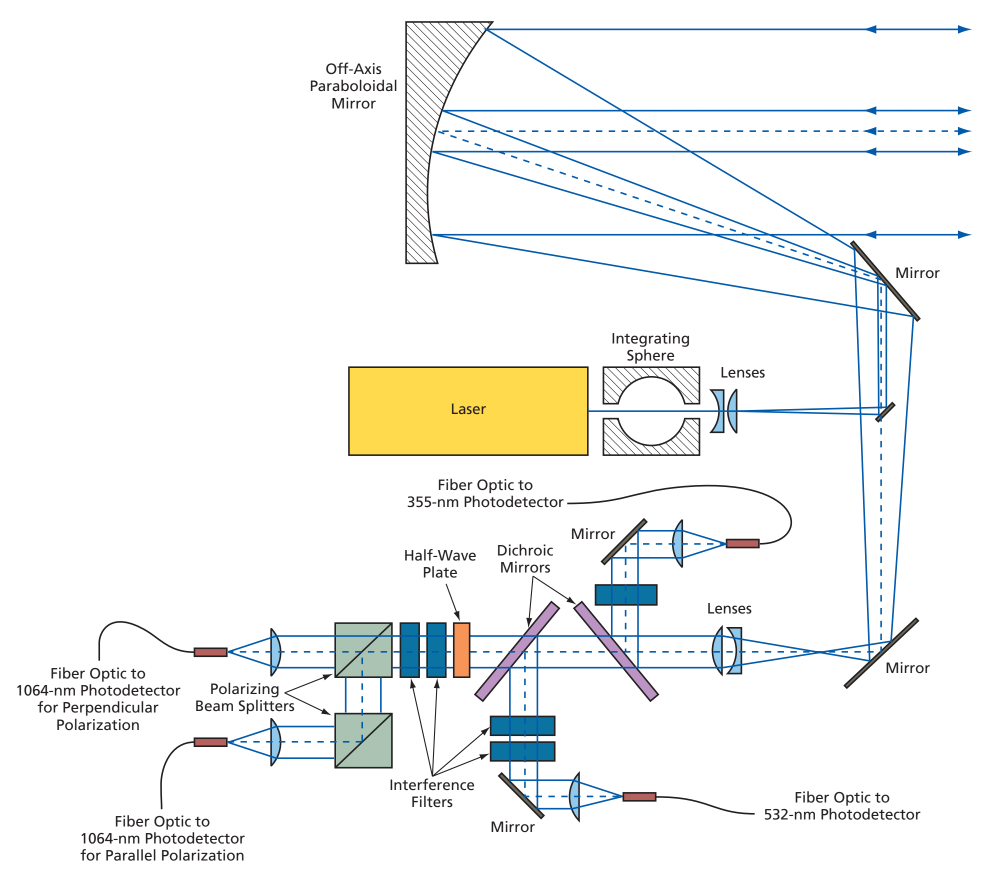
Lidar System for Airborne Measurement of Clouds and Aerosols

This is an eye-safe, rugged, all-solid-state system.

Goddard Space Flight Center, Greenbelt, Maryland

The figure schematically depicts a lidar system for measuring optical properties of clouds and aerosols at three wavelengths. The system is designed to be operated aboard the NASA ER-2 aircraft, which typically cruises at an altitude of about 20 km — above about 94 percent of the mass of the atmosphere. The system can also be operated aboard several other aircraft, and a version for use on Unmanned Aerial Vehicles (UAVs) is presently under construction. In addition to the requirement for fully autonomous operation in a demanding airborne environment, three other main requirements have governed the design: (1) to make the system eye-safe at the operating altitude; (2) to make the system as lightweight as possible, yet rugged; and (3) to use solid-state photon-counting detectors fiber-coupled to the receiver.

The laser transmitter is based on a Nd:YVO$_4$ laser crystal pumped by light coupled to the crystal via optical fibers



This **Simplified Optical Layout** (not to scale) shows the main optical components of a lidar system designed for measuring selected optical properties of clouds and aerosols at three wavelengths.

from laser diodes that are located away from the crystal to aid in dissipating the heat generated in the diodes and their drive circuits. The output of the Nd:YVO_4 crystal has a wavelength of 1064 nm, and is made to pass through frequency-doubling and frequency-tripling crystals. As a result, the net laser output is a collinear superposition of beams at wavelengths of 1064, 532, and 355 nm.

The laser operates at a pulse-repetition rate of 5 kHz, emitting per-pulse energies of 50 µJ at 1064 nm, 25 µJ at 532 nm, and 50 µJ at 355 nm. The transmitted laser beam and the returning laser light backscattered from atmospheric aerosols and molecules pass through a telescope, the primary optical element of which is an off-axis parabolic mirror having an aperture diameter of 20 cm. The combination of the off-axis arrangement and other features is such that none of the transmitting aperture is obscured and only about 20 percent of the receiving aperture is obscured.

The returning light collected by the telescope is separated into wavelength components by use of dichroics and narrowband interference filters suppress solar background. The 1064-nm signal is further separated into parallel and perpendicular polarization components. A half-wave plate is inserted in the 1064-nm path to enable calibration of the parallel- and perpendicular-polarization channels. Each resulting output wavelength component is coupled via an optical fiber to a photodetector.

An important feature of this system is an integrating sphere located between the laser output and the laser beam expander lenses. The integrating sphere collects light scattered from the lenses. Three energy-monitor detectors are located at ports inside the integrating sphere. Each of these detectors is equipped with filters such that the laser output energy is measured independently for each wavelength. The laser output energy is measured on each pulse to enable the most accurate calibration possible.

The 1064-nm and 532-nm photodetectors are, more specifically, single-photon-counting modules (SPCMs). When used at 1064 nm, these detectors have approximately 3 percent quantum efficiency and low thermal noise (fewer than 200 counts per second). When used at 532 nm, the SPCMs have quantum efficiency of about 60 percent. The photodetector for the 355-nm channel is a photon-counting photomultiplier tube having a quantum efficiency of about 20 percent.

The use of photon-counting detectors is made feasible by the low laser pulse energy. The main advantage of photon-counting (in contradistinction to processing of analog photodetector outputs) is ease of inversion of data without need for complicated calibration schemes like those necessary for analog detectors. The disadvantage of photon-counting detectors is that they inherently have narrow dynamic ranges. However, by using photon-counting detectors along with a high-repetition-rate laser, it is possible to obtain wide dynamic range through accumulation of counts over many pulses.

This work was done by Matthew McGill and V. Stanley Scott of Goddard Space Flight Center, Luis Ramos Izquierdo of LRI Corp., and Joe Marzouk of Sigma Space Corp. Further information is contained in a TSP (see page 1). GSC-14985-1

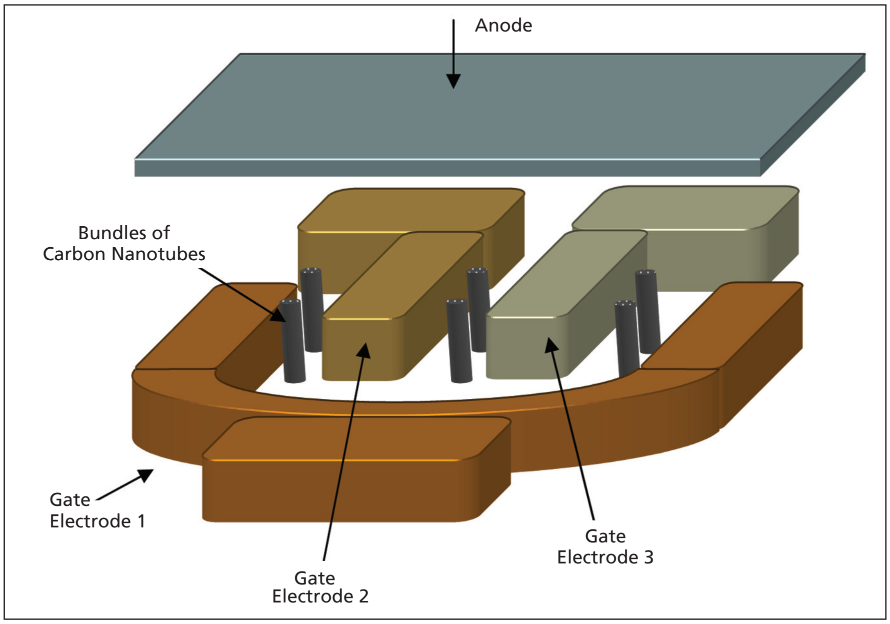
Radiation-Insensitive Inverse Majority Gates

These gates would be implemented as microscopic vacuum electronic devices.

NASA's Jet Propulsion Laboratory, Pasadena, California

To help satisfy a need for high-density logic circuits insensitive to radiation, it has been proposed to realize inverse majority gates as microscopic vacuum electronic devices. In comparison with solid-state electronic devices ordinarily used in logic circuits, vacuum electronic devices are inherently much less adversely affected by radiation and extreme temperatures.

The proposed development would involve state-of-the-art micromachining and recent advances in the fabrication of carbon-nanotube-based field emitters. A representative three-input inverse majority gate (see figure) would be a monolithic, integrated structure that would include three gate electrodes, six bundles of carbon nanotubes (serving as electron emitters) at suitable positions between the gate electrodes, and an overhanging anode. The bundles of carbon nanotubes would be grown on degenerately doped silicon substrates that would be parts of the monolithic structure. The gate electrodes would be fabricated



A **Three-Input Inverse Majority Gate** as proposed would be a microscopic vacuum electronic device containing bundles of carbon nanotubes positioned between gate electrodes to obtain controlled field emission of electrons from the bundles. In the presence of a fixed positive bias potential on the anode, the application of suitable (possibly smaller) bias potential to any two or all three gate electrodes would divert all the electron current from the anode.