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Technology Focus: Sensors

Induction Charge Detector With Multiple Sensing Stages

Standard errors and detection limits are reduced by use of multiple stages.

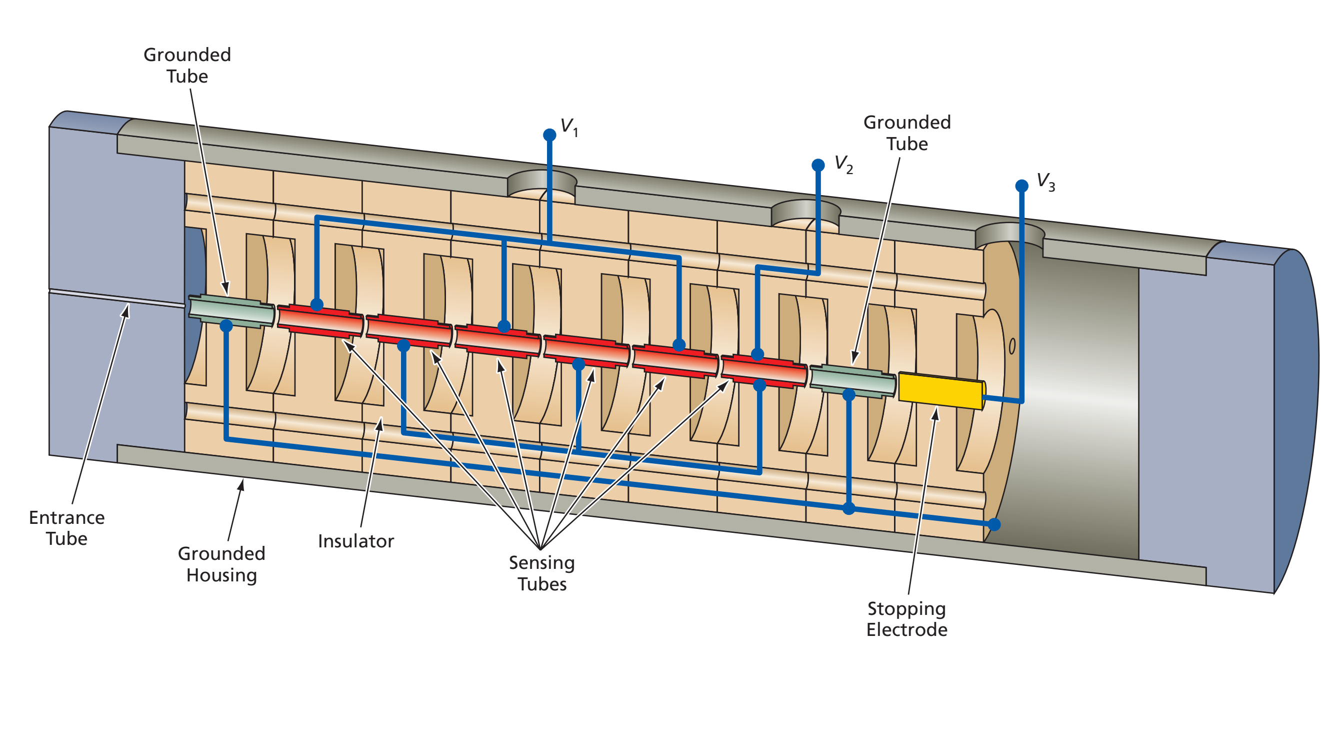
NASA's Jet Propulsion Laboratory, Pasadena, California

An induction charge detector with multiple sensing stages has been conceived for use in characterizing sprayed droplets, dust particles, large ionized molecules, and the like. Like related prior single-stage devices, each stage yields a measurement of the electric charge and the time of flight of the particle. In effect, an *n*-stage sensor yields *n* independent sets of such measurements from the same particle. The benefit of doing this is to increase the effective signal-to-noise ratio and thereby lower the charge-detection limit and the standard error of the charge measurement.

The sensor includes a set of collinear, equal-diameter, electrically conductive cylindrical tubes (sensing tubes) aligned with the path of incoming particles. The entrance to the sensor is a narrower tube that limits the number of entering particles (ideally to one at a time) and ensures that their trajectories remain close to the cylindrical axis. As a charged particle enters each sensing tube, it induces a charge on the tube nearly equal to its own. Each sensing tube is connected to an operational-amplifier circuit that senses the electric potential associated with the induced charge. The charge of the particle can be calculated from this electric potential and the capacitance of the tube. If the measurement is performed in a vacuum and the particle were accelerated by the use of a known voltage before it entered the sensor, then from (1) the time of flight of the particle as determined from durations of voltage peaks from two consecutive sensing tubes and (2) the known axial distance traversed by the particle, one can calculate the charge-to-mass ratio of the particle. Then from the charge-to-mass ratio and the measured charge, one can calculate the mass of the particle.

The principle of operation of the induction charge detector with multiple sensing stages is best described by reference to the figure, which shows a cutaway drawing of a three-stage prototype. In this case, there are eight electrically conductive tubes. The first and eighth tubes are electrically grounded. The second through seventh tubes are the sensing tubes; they are held in place by electrically insulating supports and are connected to operational amplifiers for measurement of the potentials as described in the next paragraph. Following the eighth tube is a final stopping electrode, which collects the charged particle and is connected to another operational amplifier for measurement of the potential associated with the charge. An electrically grounded housing surrounds all of the aforementioned parts.

The second, fourth, and sixth sensing tubes constitute a three-stage sensing electrode. They are electrically connected to each other, the potential on them is denoted V_1, and they are con-



Six of the Eight Electrically Conductive Tubes (the sensing tubes) are connected to operational amplifiers, arranged in successive pairs for measurement of V_1–V_2 peaks induced by a passing charged particle.

nected to the input terminal of an operational amplifier. Similarly, the third, fifth, and seventh sensing tubes constitute another three-stage sensing electrode; they are electrically connected to each other, the potential on them is denoted V_2, and they are connected to the input terminal of another operational amplifier. The potential on the stopping electrode is denoted V_3, and this electrode is connected to the input terminal of a third operational amplifier. In operation, V_1–V_2 is measured as a function of time. As a particle travels along the sequence of six tubes, it induces a three-cycle V_1–V_2 waveform, each cycle representing the reading from one of the three sensor stages. The charge measurement for each stage can be calculated as the product of (1) the magnitude of the corresponding V_1–V_2 peak reading and (2) a calibration factor obtained from the V_3 reading.

If the readings are analyzed in the time domain, then the use of n detector stages reduces the standard error of the charge measurement, which is proportional to $n^{-1/2}$. On the other hand, because of its periodicity, the waveform lends itself naturally to analysis in the frequency domain. The minimum detectable charge can be reduced, in the case of frequency-domain analysis, by increasing the number of available waveform cycles and, hence, by increasing the number of stages.

However, increasing the number of stages without limit does not reduce the frequency-domain minimum detectable charge without limit and does not reduce the time-domain standard error without limit. The reason for this is that increasing the number of stages increases the sensor input capacitance, thereby reducing sensitivity. This obstacle can be overcome by the use of a multiblock sensor assembly, recording the output of each block independently. Each block would comprise a multiple-stage sensor as described above, except that the number of stages (not necessarily 3) would be chosen, in conjunction with other design parameters, to optimize performance.

This work was done by Manuel Gamero-Castaño of Caltech for NASA's Jet Propulsion Laboratory. For more information contact iaoffice@jbl.nasa.gov. NPO-44736

Generic Helicopter-Based Testbed for Surface Terrain Imaging Sensors

This flexible field test system is designed for sensors that require an aerial test platform.

NASA's Jet Propulsion Laboratory, Pasadena, California

To be certain that a candidate sensor system will perform as expected during missions, we have developed a field test system and have executed test flights with a helicopter-mounted sensor platform over desert terrains, which simulate Lunar features. A key advantage to this approach is that different sensors can be tested and characterized in an environment relevant to the flight needs prior to flight. Testing the various sensors required the development of a field test system, including an instrument to validate the "truth" of the sensor system under test. The field test system was designed to be flexible enough to cover the test needs of many sensors (lidar, radar, cameras) that require an aerial test platform, including helicopters, airplanes, unmanned aerial vehicles (UAV), or balloons. To validate the performance of the sensor under test, the dynamics of the test platform must be known with sufficient accuracy to provide accurate models for input into algorithm development. The test system provides support equipment to measure the dynamics of the field test sensor platform, and allow computation of the "truth" position, velocity, attitude, and time.

The first test of the field test system provided verification and truth measurements to the LAND (Lunar Access Navigation Device) laser radar, which enable the comparison of the instrument data versus "ground truth" measurement. The instrumentation includes a GPS (Global Positioning System) receiver, Inertial Measurement Unit (IMU), two visible cameras, a support video camera, and a data collection and time-tagging system. These instruments are mounted on a gyro-stabilized gimbal platform attached to the nose of a helicopter. The gimbal is covered by a dome to reduce the amount of aerodynamic drag on the helicopter, with an observation window, which allows the instruments to view the ground below. The gyro-stabilized platform operates in both "nadir" mode, with the sensors pointed with a fixed angle to the ground, and in "geo" mode, in which the gimbal is directed to a fixed GPS location on the ground. The modes can be changed by a ground team via radio remote control during flight.

During an actual flight test, the flight verification equipment includes three computers for collecting data and controlling instruments. The first laptop performs the timing and synchronization of all equipment and logs IMU and GPS data, as well as recording the synchronization pulses from the LAND system (this could potentially be any other sensor) and provides the image trigger pulses to the cameras. These data are fed to the laptop through an interface box into a PCMCIA (Personal Computer Memory Card International Association) interface card, which contains a field-programmable gate array (FPGA). This part of the system builds on heritage from a field test done for the Descent Imager Motion Estimation System (DIMES) project for the Mars Exploration Rover project in 2002.

A second laptop contains a GUI to control the LAND system. Commands are sent through an Ethernet interface to the LAND computer using TCP/IP protocol (Transmission Control Protocol/Internet Protocol). These commands control the start/stop of the laser radar, and the number of lidar frames to gather for a single run, as well as also giving estimated altitude measurements to the LAND system. A third computer acts as a digital video recorder (DVR) for acquiring and time-tagging images taken by the two visible cameras.

Summarizing, the architecture includes the use of guidance and control instruments, data collection equipment, flight and ground procedures, ground fixed position reference targets, and data analysis tools. The test system also provides the processing of the collected instrument data, and includes image motion compensation