Pioneer 9 Cosmic Dust Detector (CDD)

The Pioneer 9 Cosmic Dust Detector was designed to (1) measure the cosmic dust flux density in the solar system; (2) determine the distribution of cosmic dust concentrations in the Earth's orbit; (3) determine the gradient, flux density, and speed of particles in meteor streams; and (4) perform an in-flight control experiment on the reliability of the microphone as a cosmic dust sensor. The experiment instrumentation, which was mounted in the equator of the satellite with its axis radial to the satellite spin axis that was perpendicular to the ecliptic plane, consisted of a front film-grid particle impact sensor array and a rear film-grid sensor array, spaced 5 cm apart, and an acoustical impact plate upon which the rear film was mounted. The basic setup involved a 4 x 4 array of sensors in front and a 4 x 4 array in back. A particle's flight direction could be determined by the location of the sensor detecting it in front and the location in back, with the velocity determined by the time between the detections, and the particle energy by the amplitude of the detections. The acoustic detector behind the back array could also give an estimate of the impact energy.

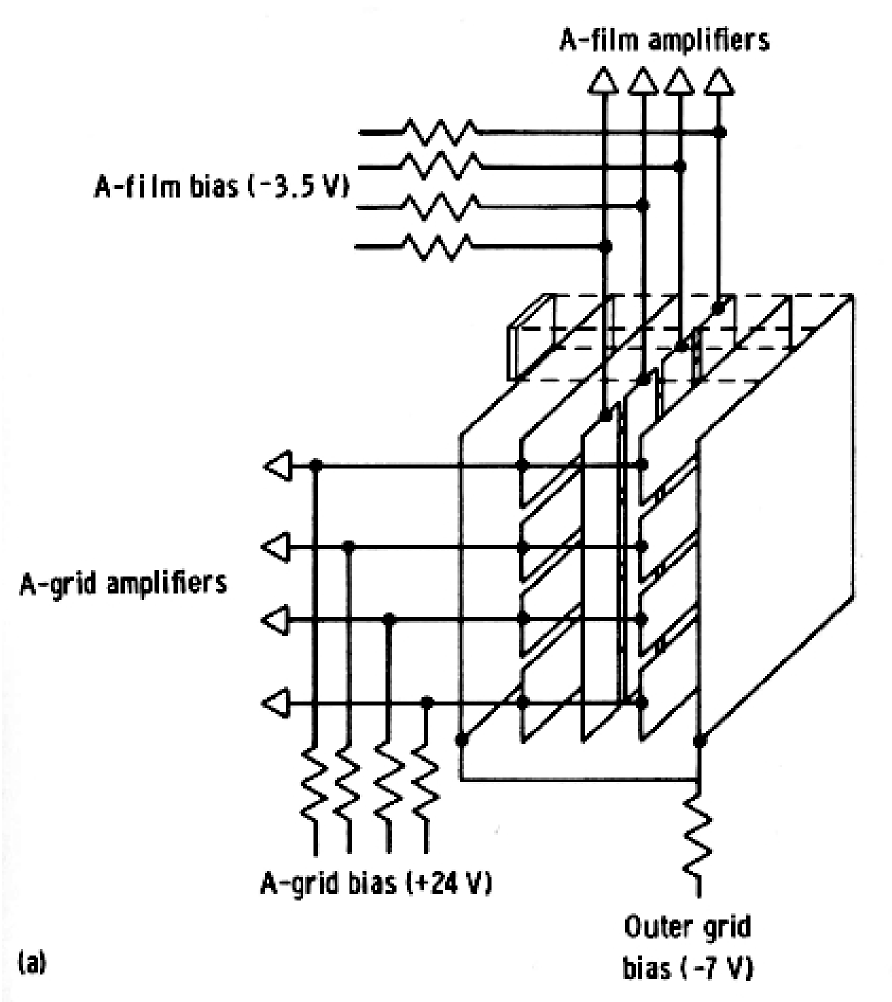

Figure 1 - Front planar sensor array electronics configuration, expanded view

The front planar sensor array (Figure 1) was recessed 3 cm into the experiment housing and had five basic components, all were approximately 10 cm square sheets stacked in a parallel fashion. The outermost component was a thin beryllium copper wire mesh, called the suppressor grid, which was held at a potential of -7 volts. The mesh was supported by a thin lexan[1] structure which formed an array with 4 x 4 square (2.5-cm on a side) openings. Mounted on the other side of the support structure was the collector grid, made of four parallel 2.5 x 10 cm thin beryllium copper wire grid strips oriented horizontally covering the 10 cm x 10 cm detector area and maintained at +24 V. The front film sensor consisted of four 2.5 x 10 cm strips oriented vertically and composed of an eight-layer composite -- 300-Å (angstrom) thick aluminum, 700-Å parylene[2] encapsulation, 500-Å copper, 300-Å aluminum, 3000-Å parylene substrate, 300-Å aluminum, 500-Å copper, a beryllium-copper support mesh, and 700-Å parylene encapsulation. The film was held at

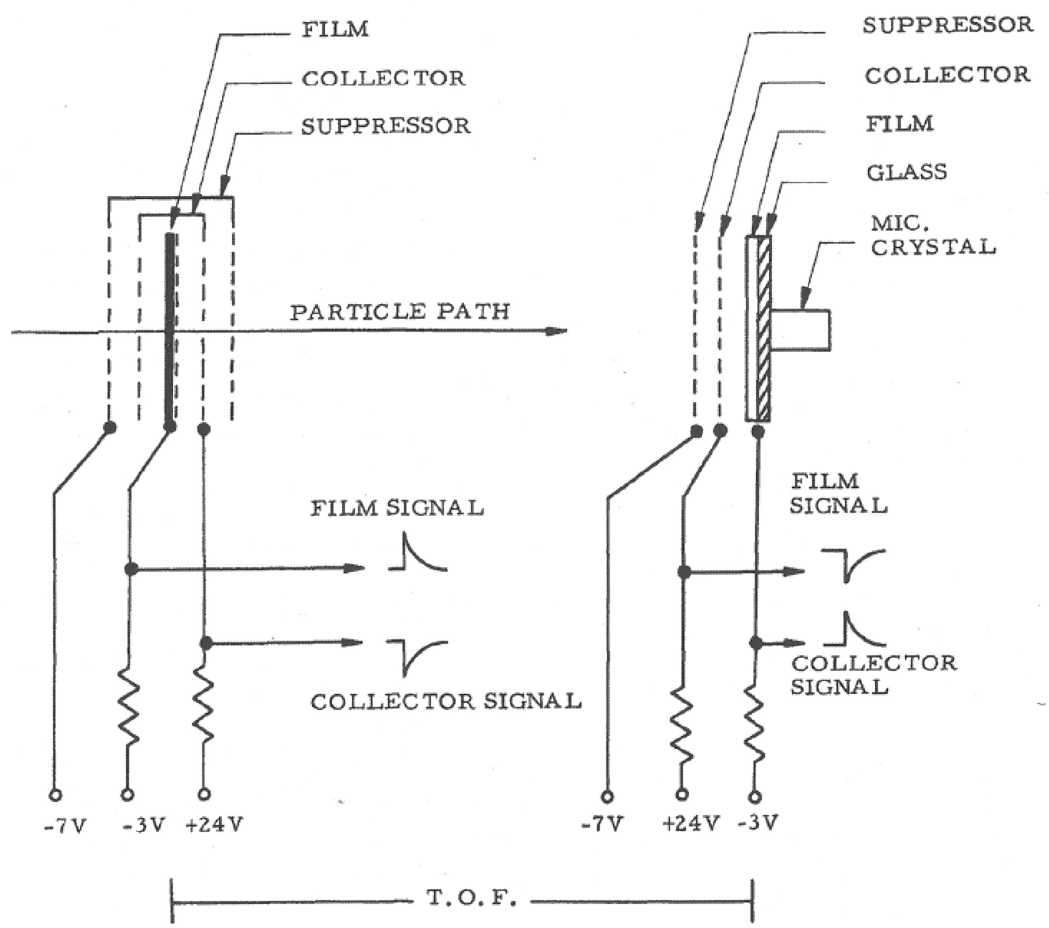

Figure 2 - Front and rear sensor arrays

-3 V. Behind the film sensor array was another collector grid, identical to the first and electrically connected. Directly behind the collector grid was a suppressor grid identical to the front suppressor grid and connected to it electrically.

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[1] Temperature and impact resistant polycarbonate
[2] Chemical vapor deposited poly(p-xylylene) polymers

The rear sensor array was set up like the front array (Figure 2), but with only a front suppressor and collector grid. The film sensor array was attached to a 60-micrometer thick molybdenum sheet cemented to a quartz acoustical sensor plate and microphone crystal.

The upper left segment of the front film-grid array and the upper right segment of the rear film-grid array were used as controls. The sections of film and grid for those segments were potted in an epoxy resin that prevented the products of ionization caused by impacts from being collected on the grids or films. The coating did not shield the grids from electric or magnetic radiation, so those segments could detect noise but not impacts. A microphone control was also included in the lower right corner of the rear plate, having 1/15th the area of the rest of the plate. The control consisted of a live microphone exposed to the same environment as the main microphone; a ratio of about 1:15 would be expected for detection of impacts on the two microphones.

The operation of the sensors was based on two basic measurable phenomena that occur when a hypervelocity particle impacts on a surface -- (1) formation of plasma and (2) transfer of momentum. When a high energy hypervelocity particle strikes the front film (see figures 2 and 3), it produces an ionized plasma. Electrons from the plasma are kept within the array by the negatively charged suppressor grid and collected on the positively charged collector grid, producing a negative pulse which is amplified and recorded. The positive ions from the plasma are collected on the negatively biased film, producing a positive pulse. Pulse-height analysis yields an estimate of the kinetic energy of the particle. The particle, continuing on its path, strikes the rear array and generates a second set of pulses. The location of a front array impact is determined by the combination of grid (horizontal strip) and film (vertical strip) pulses, yielding 1 of 16 possible locations (each 2.5 square cm) for the front array. Combining this with the location of the (slightly later) impact on 1 of the 16 locations on the back array yields 1 of a total of 256 possible combinations / directions. If the particle momentum is sufficient it will strike the acoustic plate and generate a signal. A peak-pulse-height analysis of the acoustic signal gives the remaining momentum of the particle. Each strip is connected to a separate amplifier, which in turn feeds into an accumulator counter.

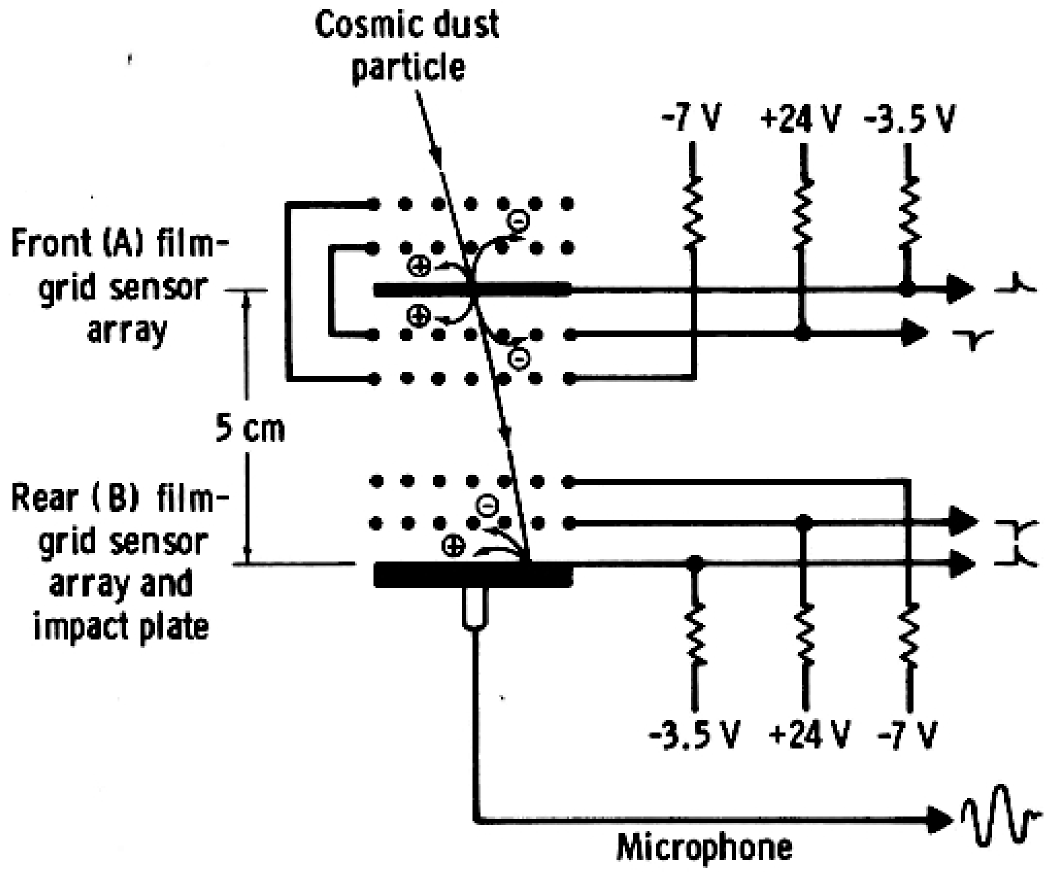

Figure 3 - Sensor operation during particle impact

When the front film is penetrated by a particle, a time-of-flight 4-MHz electronic clock is activated. The clock shuts off when the particle impacted on the rear film thus measuring particle speed and direction. Three general cosmic dust particle types were detectable -- (1) high-energy, hypervelocity particles (greater than $1x10^{-7}$ joules), which produced responses at both front and rear film sensors, (2) low-energy, hypervelocity particles (less than $1x10^{-7}$ joules), which produced responses only at the front film sensor, and (3) relatively large high-velocity particles (greater than 0.1 nanograms), which could pass through the front and rear film sensor arrays without generating a detectable plasma but could still impart a measurable impulse to the acoustical sensor. The acoustical sensors were designed to perform an in-flight study on the reliability of the microphone as a cosmic dust sensor in addition to performing as an impact sensor for this experiment. In-flight calibration was provided and initiated by ground command and monitored the experiment electronics in addition to providing a check on the physical condition of the plasma sensors. The sensors were calibrated prior to the flight by impacts with iron spheres ranging in mass from 1 nanogram to 0.1 picogram, accelerated by a 2-mv electrostatic accelerator to 2 to 10 km/s.

Pioneer 9 was launched on 8 November 1968 and entered a 0.75 x 0.99 AU heliocentric orbit. It was spin-stabilized at approximately 1 revolution/s and had an orbital velocity of about 30 km/s. Contact was maintained with the probe until May 1983.

Figures 1 and 3 are from the Apollo 17 Preliminary Science Report (1973). (The Pioneer 8 and Pioneer 9 Cosmic Dust Detectors were identical to the Lunar Ejecta and Meteorites Experiment (LEAM) detector on Apollo 17.) Figure 2 is from the Final Engineering Report for Cosmic Dust Detector Model ML 309-1.

References

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Berg, O.E., and F.F. Richardson, The Pioneer 8 Cosmic Dust Experiment, NASA Technical Note D-5267, July, 1969. (https://ntrs.nasa.gov/search.jsp?R=19690021680)

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