NO. 191 ON THE CAPABILITIES OF THE SPIN-SCAN IMAGING TECHNIQUE*

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ABSTRACT

A summary description is made of spin-scanning devices for various space missions. Compared to television, scan-imaging has remarkable advantages and these are listed at the end of the paper.

The first spin-scan imaging camera was conceived by V. E. Suomi for the Applied Technology Satellite ATS-I and built by the Santa Barbara Research Center. It was launched into geostationary orbit over the Pacific Ocean in December 1966 and has been in continuous operation ever since. An improved

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instrument, the Multicolor Spin-Scan Cloud Camera (MSSCC) was launched in November 1967 on ATS-III. It is situated at 35,800 km altitude above the Amazon River and still being used on a regular daily schedule.

The two cameras are quite similar in size and design, with the primary difference being that the ATS-I camera is monochromatic, using a single S-11 photomultiplier filtered to give a response of 0.475-0.630μ. The ATS-III camera has a 12.5 cm Wynn-Rosin telescope (elliptical primary and spherical secondary mirror) F/3, with three photo-etched circular apertures used as field stops in the focal plane, each 38μ in diameter, giving a resolution of 100μr or 3.6 km on the surface of the earth at the satellite subpoint.

The field stop apertures admit light to flexible glass fibers which are used to transport light to the three photomultiplier sensors mounted on the camera frame separate from the movable telescope. The photocathodes used are S-20 for the red channel (0.55-0.63μ) and S-11 for the green and blue channels (0.48-0.58μ and 0.38-0.48μ).

The telescope is stepped in latitude by 0.13 milli-radians once each spacecraft revolution. The stepping motion is from north to south, while the spacecraft spin axis is parallel to that of the earth. Thus, at 100 rpm nominal spin rate, a full disk image of the earth 18° wide is generated in 2407 lines in 24 minutes. The instantaneous field of view dwell time is 10μ sec although horizontal sampling can be done every 3.5μ sec to take full advantage of the available communications bandwith.

The principal interest for this COSPAR Symposium lies in high resolution. The resolution, generally, can be improved by reducing focal-plane aperture size and/or going to a larger focal length. Either solution will require increased information bandwidth and correspondingly degraded signal-to-noise ratio. The photomultiplier reaction time may also become a problem as the field of view dwell time decreases. All of these drawbacks can be counteracted by slowing down the *spin rate* of the spacecraft and/or using a larger *telescope diameter*. The exact tradeoffs to be made depend on the practical system constraints.

As an example, the second-generation Visible Infrared Spin-Scan Radiometer (VISSR) to be flown on the Synchronous Meteorological Satellite (SMS) in October 1972 is constrained to have a 20-minute picture time, 70-kg combined instrument and electronics weight, and 1-km ground resolution with 2.8:1 signal-to-noise ratio at 0.5% albedo and a visible bandpass of 0.55-0.75μ. The thermal-imaging channels are to have $\leq$1.4°K noise-equivalent temperature difference for a 200°K scene. The resulting design is a 40.6-cm diameter F/7 all-reflective Ritchey Chrêtien (aspheric) telescope with 2.91 m effective focal length. The photomultiplier sensors for the visible channels are operated in parallel behind rectangular glass fibers whose ends form 61μ x 73μ field-stop apertures in the primary focal plane, yielding resolution of approximately 25μr with a 2.4μ sec dwell time at 100 rpm. Information bandwidth and photomultiplier response time are adequate. The thermal-channel images in the 10.5-12.6μ atmospheric-window band using radiatively-cooled HgCdTe intrinsic IR detectors with 0.25 mr resolution.

The Multispectral Scanner (MSS) also being built by the Santa Barbara Research Center for the polar orbiting Earth Resources Technology Satellite (ERTS) utilizes a 23-cm aperture F/3.3 Cassegrain telescope with 59μ square glass fibers as field stops. This yields 77μr resolution from low orbit (~65 m ground resolution at nadir). Photomultipliers are used for three observation channels in the 0.5-0.8μ region and photodiodes for a 0.8-1.1μ band. In addition, HgCdTe detectors are used for thermal imaging in the 11μ window.

Infrared imaging and radiometry from earth orbiters has also been done with point scanning sensors in the Nimbus weather satellite program (the Medium Resolution and High Resolution Infrared Radiometer experiments) and in the Improved TIROS Operational Satellite (ITOS) scanning radiometer. A picture obtained on ITOS-1 is on the front cover of the 6 August 1971 issue of *Science* (Rao *et al.*, 1971). Currently, improved scanners are under development for ITOS. Two of us (Suomi and Krauss) proposed a Line Scan Radiometer (LSR) for the Mariner Venus/Mercury 1973 (MVM) mission. The camera used the slow attitude drift of the 3-axis stabilized spacecraft to generate the line stepping function and a small focal-plane scan-mirror to generate the scan along a line, substituting for the absence of spacecraft spin. The lead time available was unfortunately not sufficient to carry the concept through breadboard stage to flight hardware and an essentially pre-existing TV system with new optics will be used on the mission instead.

Consequently, the Imaging Photopolarimeter experiment of Gehrels on Pioneer F and G (F to be launched in March 1972) is the only line scan imager now being applied to non-earth oriented missions. As such, it is not a good example for high resolution because the resolution was restricted by spacecraft capabilities. The Pioneer is small and provides for a relatively cheap reconnaissance mission of the asteroid belt and of the Jovian radiation environment, as a precursor for more sophisticated missions such as the Grand Tour of the Outer Planets, for which launch dates exist in 1977 and 1979. The Pioneer data link handles, when near Jupiter, at best 2048 bits/s. There is no on-board data storage, only a buffer, and the best ground resolution at closest encounter (2 Jupiter radii from the surface) will be 150 km compared with the best earthbased resolution of 600 km.

Considering the 5 rpm spin of the spacecraft, the 2048 bits/s data link and other spacecraft limitations, 600μr is an optimum limit to the resolution. Consequently, a 2.5-cm telescope was large enough, and tne instrument itself weighs 5 kg - an optimum weight since the mission could accommodate it without eliminating other experiments. The advantages over a television system were studied at the time and the simplicity of an instrument using photomultipliers was important. Vidicons are considered to be more susceptible to the Jovian radiation belt. The fact that television would have taken a shorter exposure - a fraction of a second, compared to several minutes for a spin scan - would have reduced the image rectification problem which is considerable for a flyby of Jupiter as we are dealing with a fast trajectory of a rotating spacecraft flying past a rotating planet. The scan lines are far from straight. On the other hand, the geometric reconstruction is straightforward if good timing information and trajectory data are available. Television would be subject to smear limitations and small frame size and has its own peculiar brand of geometric distortions and photometric nonlinearities, especially at the edge of the field.

The imaging of Jupiter will be in two colors: blue (0.390-0.500μ) and red (0.595-0.720μ), and the range of visible phase angles will be quite large - much better than from earth. Besides the imaging capability, photopolarimetric data will be obtainable. These modifications are easily added to produce the combination for the Pioneer F and G Missions known as the Imaging Photopolarimeter. The data processing of the imaging is being developed by W. Swindell of the Optical Sciences Center at the University of Arizona. Details of the instrument have been published by KenKnight (1971).

A reasonable system for an outer-planet spacecraft with a sufficient data link would start with a 25-cm diameter telescope to keep the system weight down. Photo-etched field stops can be made in the 30-40μ range. Smaller sizes tend to have imperfections and rough edges. The same is true for glass fibers. While 5μ fibers can be drawn, the ends cannot be finished smooth enough to avoid large transmission losses. About 40μ is the present limit. Figure 1 shows what a 25-cm optical system can produce in resolution at 10:1 signal-to-noise ratio as a function of planet brightness (the vertical bars range from 0.1% to 100% albedo) and information bandwidth. A 10-μr resolution appears to be a reasonable limit. A relay-lens system should shorten the effective back focal length for IR imaging since smaller detectors are better. With ease, one could add a 10-μr field of view in the visible channel for highest resolution simply by increasing effective front focal length to 4 meters (F/16) and tolerating the reduction in signal-to-noise ratio.

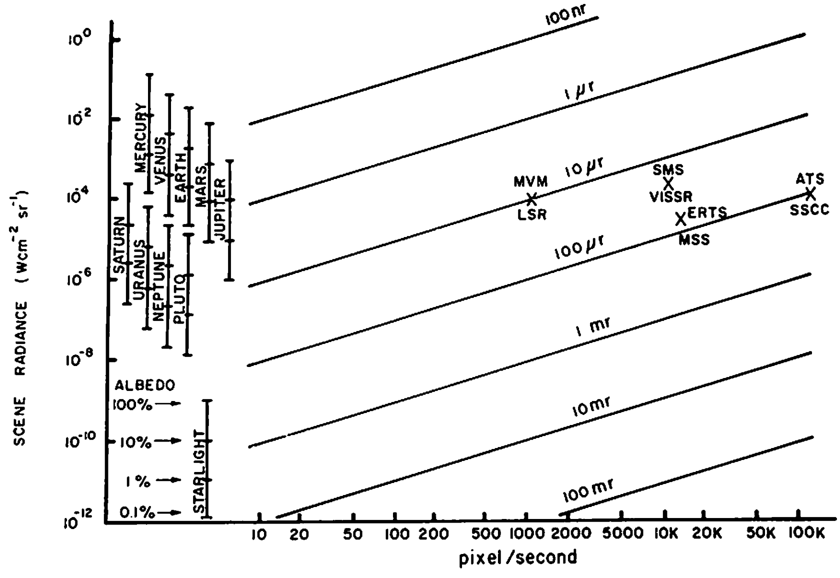

Figure 1 Resolution per scan line (25-cm optics, 10:1 signal-to-noise ratio at 50% response to 2:1 contrast target). The abbreviations of various space missions and instruments are explained in the text

In summary, the disadvantages of the spin-scan technique are (1) that it is not as "instantaneous"as television, (2) that the instrument requires a spinning spacecraft or mechanical scan mechanism, and (3) that it requires duty-cycle expansion and a buffer to best utilize the communications link.

We can name seven advantages of the spin-scan technique over a television system: (1) practically unlimited format of the field, whereas the 800-line scan of television will image only a part of the planet, and even at that the television has edge distortions; (2) the detectors are rugged and have wide dynamic range; (3) multiple detectors allow a wide spectral range; (4) multiple perfectly-registered images in several colors can be made by scanning with several detectors operating simultaneously; (5) the detectors are linear - ideal for combination with a photopolarimeter of ±0.1% precision; (6) redundancy in detectors is implicit in the design, yielding extremely high reliability,and (7) the instrument is relatively cheap and lightweight. Even at a heavy duty cycle as on ATS-III, the instrument is proving to be a workhorse of long life.

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