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THE LANDSAT PROGRAM

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ABSTRACT

This paper gives a description and present status of NASA's Landsat program, including the orbital coverage, payload, data processing, and data products. Data uses are discussed in general terms. Also discussed are NASA's plans for the Landsat-C and Landsat-D missions and the improved capabilities represented by these missions.

INTRODUCTION

The potential for global land survey utilizing spaceborne sensors began in the form of hand-held cameras operated by Gemini and Apollo astronauts. Observations were expanded into the infrared region of the electromagnetic spectrum in the later Apollo and Skylab flights. Meanwhile, the Tiros satellite became the first successful unmanned earth observatory equipped with small visible light TV cameras. In July 1972, however, a new era in spaceborne earth observation technology began with the launch of the first Earth Resources Technology Satellite, ERTS-1. The spacecraft was later more descriptively renamed Landsat-1. Landsat-1 was followed two and one-half years later by the launch of Landsat-2 in January 1975. A Landsat-C launch is planned for late 1977 or early 1978, and Landsat-D is scheduled to be launched in 1981.

MISSION DESCRIPTION

Landsat-1 and -2 were launched from the Western Test Range utilizing the two-stage Delta launch vehicle augmented by nine solid rockets. Landsat-C will be similarly launched. The spacecraft is placed in a circular, near-polar orbit with a 99° inclination which is sun-synchronous--that is, the orbital plane precession rate is equal to the earth's rotation rate about the sun, thus allowing the spacecraft to view a given point on the earth at the same local time for each orbit. This will permit essentially the same surface sun angle conditions to exist for a given time of the year for all imagery taken and simplify the data extraction. Orbital altitude is 495 nautical miles (917 kilometers). The orbit is nearly repetitive each day, and the exact ground track is repeated every 18 days or 251 orbits. On succeeding days, the ground track moves in a westerly direction and is separated by 159 kilometers from the preceding day's track. With both Landsat-1 and -2 in orbit, significant improvement in the study of dynamic observed phenomena is possible due to the resulting increased frequency of observation of a given area by the two-satellite system. Landsat-D's orbital altitude will be lowered to 438 nautical miles (705 kilometers) in order to achieve higher spatial resolution and to permit more economic Space Shuttle retrieval and replacement.

LANDSAT PAYLOADS

The Landsat-1 and -2 payloads, essentially identical, include a four-band Multispectral Scanner (MSS), a Return Beam Vidicon (RBV) camera system, and a Data Collection System (DCS) used to relay to a ground receiver measurements taken by remote, unmanned data collection platforms.

The MSS, the primary Landsat earth observation sensor, is an electronic imaging device, utilizing an oscillating flat mirror which reflects incoming earth-reflected electromagnetic energy onto the faces of twenty-four detectors through connecting glass fibers and appropriate color filters. Table 1 summarizes the MSS characteristics.

The instantaneous field of view of each detector subtends an earth-area square of 79 meters on a side from the nominal orbital altitude. Field stops are formed for each line imaged during a scan and, for each spectral band, by the square input end of an optical fiber. Six of these fibers in each of four bands are arranged in a 4 by 6 matrix in the focused area of the telescope.

Light impinging on each glass fiber is conducted to an individual detector through an optical filter, unique to the spectral band served. An image of a line across the swath is swept across the fiber each time the mirror scans, causing a video signal to be produced at the scanner electronics output for each of 24 channels. These signals are then sampled, digitized, and formatted into a serial digital data stream by a multiplexer. The sampling interval is 9.95 μsec, corresponding to a cross track motion of the instantaneous field of view of 56 meters.

The along-track scan is produced by the orbital motion of the spacecraft. The nominal orbital velocity causes an along-track motion of the subsatellite point of 6.47 km/sec neglecting spacecraft perturbation and earth rotation effects. By oscillating the mirror at a rate of 13.62 Hz, the subsatellite point will have moved 474 meters along track during the 73.42 millisecond active scan and retrace cycle. The width of the along-track field of view of six detectors is also 474 meters. Thus, complete coverage of the total 185 kilometer wide swath is obtained. The line scanned by the first detector in one cycle of the active mirror scan lies adjacent to the line scanned by the sixth detector of the previous mirror scan. Figures 1 and 2 show this scanning arrangement and composite scan pattern.

The four bands use the earth reflected energy to distinguish earth characteristics such as vegetation, water, crops, crop stress, geological phenomena, etc. Spectral information, or signatures, reflected in the four bands of the MSS cause variations in the output signals of the detectors proportional to variations in the received spectral energy. These analog signals are converted into a digital data stream for storage on one of two tape recorders onboard the satellite for subsequent transmission when over a ground station or are directly transmitted in real time to a ground receiving station. Each MSS image transmitted and processed by a ground station covers an area 100 by 100 nautical miles square (185 kilometers) with a spatial resolution of 79 meters. In the four and one-half years of Landsat-1 operation, approximately 250,000 MSS images have been processed, representing a repetitive observation area of approximately two billion, five hundred million square miles. Landsat-2's processed imagery represents a repetitive observation area of a little less than half of that of Landsat-1. As a note of interest, the Landsat-1 MSS mirror has thus far completed more than 130 million oscillations.

The second instrument system onboard Landsat, the RBV system, consists of three Return Beam Vidicon television-type cameras. The RBV's view the same 100 nautical mile square ground scene as does the MSS and collect reflected energy from the earth in three spectral bands from 0.475 to 0.83 micrometers. When the cameras are shuttered to collect data, the resulting image received is stored on the photosensitive face of each RBV tube, which are then scanned to produce video outputs. The cameras are scanned in sequence, requiring about 3.5 seconds to read out each of the three images. To produce overlapping images of the ground along the direction of satellite motion, the cameras are shuttered every twenty-five seconds.

The Landsat Data Collection System (DCS) obtains data from remote, automatic data collection platforms, which are equipped by specific investigators, and relays the data to ground stations whenever the Landsat spacecraft can mutually view any platform and any one of the ground stations. Each DCS platform collects data from as many as eight sensors, supplied by the cognizant investigator, sampling such local environmental conditions as temperature, stream flow, snow depth, or soil moisture. Data from any platform is available to investigators within 24 hours from the time the sensor measurements are relayed by the spacecraft. As a point of interest, the Landsat-1 and -2 DCS have conducted over 1,200,000 platform interrogations.

As previously mentioned, the payloads for Landsat-1 and -2 are identical. Landsat-C's payload will, however, include upgrading of the MSS and the RBV's in order to increase the usefulness and quality of the data collected. A fifth channel, sensing the 10.5 to 12.5 micrometer spectral band in the thermal infrared region, will be added to the MSS. This fifth band will provide a temperature resolution of 1.5° K at a spatial resolution of 240 meters and aid in the detection and analysis of dynamic changes that are characterized by temperature differences. The RBV system is being modified to a two-camera panchromatic system operating in the same 0.53 to 0.75 micrometer visible regions. Optics improvements in these two RBV cameras will result in a 40 meter RBV spatial resolution capability. A single RBV image will now be reduced to a 50 nmi scene; and, to insure total coverage of an MSS scene, each camera is now shuttered so that four RBV images are equivalent to one 100 nmi by 100 nmi MSS scene.

LANDSAT DATA PROCESSING AND DISSEMINATION

Landsat data is received at three U.S. ground stations and recorded on magnetic tapes. These magnetic tapes are shipped to a Data Processing Facility at Goddard Space Flight Center where required geometric and radiometric corrections are made to the data. The data is then archived and sent to the Federal Data Centers for distribution to the many users and use investigators. This processed imagery data is made available to users in the form of computer compatible magnetic tapes, 70 mm negatives, and black and white and color composite prints.

Interest in Landsat data is world-wide. Italy, Canada, and Brazil have constructed their own receiving and processing stations. These countries have direct access to the Landsat satellite and its imagery when it passes over their receiving stations and pay NASA an annual fee for this satellite service. About a half-dozen other countries have signed MOU's (Memorandum of Understanding) or are in the preliminary discussion stage preparatory to the installation of their own receiving and processing stations.

An upgraded data processing facility is being developed to support the Landsat program and will utilize an all-digital processing technique instead of the present hybrid system. This facility will also make it possible to process Landsat data on a routine basis in one to two days instead of the present five to seven days. This facility will be partially operational in September 1977 and fully operational by March 1978. This new capability will improve the timeliness of Landsat data and significantly improve useful data applications because the all-digital processing will significantly improve the geometric accuracy of the data and permit more sophisticated data extraction techniques.

SPACECRAFT STATUS AND PLANS

Landsat-1, designed for a one-year lifetime, passed its fourth anniversary in orbit this past July. To be sure, it has problems: both tape recorders are out of operation and the attitude control gas is almost gone. Nevertheless, it continues to return excellent data to the six direct readout stations located in the U.S. and abroad.

Landsat-2 continues to operate well after two years in orbit, but with only one tape recorder fully operable. To relieve the load on the remaining operable tape recorder, a portable ground station has been deployed in Pakistan for direct ground acquisition of MSS imagery in support of the LACIE program. A special LACIE recording capability has also been implemented at the Italian station to reduce the remaining tape recorder utilization.

The Landsat-C development is on schedule for a September 1977 launch readiness. The new five-band MSS and improved resolution RBV have been completed, shipped to the prime contractor, and integrated with the spacecraft. It is our plan to complete the spacecraft and all necessary functional and environmental tasks to insure a September 1977 launch readiness. However, we are considering an option to postpone the launch for a period, up to six months, to minimize the potential data gap in multispectral imagery before Landsat-D can be launched. The decision to delay the launch of Landsat-C is dependent on the continued satisfactory operation of Landsat-2, and the decision will probably not be made before this summer.

The procurement of a new-generation, significantly more powerful sensor, called the Thematic Mapper (TM), has been initiated; and a contractor to develop the instrument has been selected. Present plans call for delivery of a flight-worthy instrument by the middle of CY 1980. This will make the delivery of this new and powerful instrument compatible with the planned launch of Landsat-D in the first quarter of CY 1981.

Landsat-D, included in the FY 1978 budget submission as a New Start, will be the test bed for the Thematic Mapper. This instrument will provide significant improvements in the ability to detect and identify smaller areas because of its higher spatial resolution (30 meters) and be capable of discriminating significantly more shades of gray per picture element (256 or 64 radiometric resolution elements) than the Landsat-C MSS. Additionally, the TM will utilize additional, optimized spectral bands to provide increased refinement in the ability to classify vegetation, crops, crop status, and other natural resources and geological features. The performance characteristics of this instrument are given in Table 2.

Full utilization of the TM's resolution capability demands a more precise attitude control system than Landsat-C; additionally, the increased spatial and radiometric resolution require significant improvement in the spacecraft's data handling and communication system. To accommodate these new requirements, NASA has chosen the new multimission spacecraft as the spacecraft bus to support the TM.

Use of this spacecraft's modular concept will also permit Shuttle retrieval and the resultant repair or replacement of failed spacecraft elements when the Space Shuttle becomes operational. The transmission of the additional instrument data will be facilitated by utilization of the Tracking and Data Relay Satellite System (TDRSS) relay capability to a single U.S. ground receiving station. In this way, no onboard recording capability is required. As a backup to the single Landsat-D high gain TDRSS antenna, a direct readout capability to ground stations at X-band will also be provided. This will also allow the continued direct reception of imagery data by foreign ground stations.

We had originally planned to include an MSS in the instrument complement for Landsat-D, but the addition of this instrument was not authorized. Incorporation of the MSS would have provided data continuity to the domestic and foreign users who did not demand or require the improved TM data. NASA is presently surveying the user community to determine the degree of user demand in the continuity of MSS data and to solicit financial support to help defray the cost associated with the inclusion of the MSS on Landsat-D. If sufficient financial support is found, NASA will reconsider its decision not to fly the MSS. It should also be noted that the MSS would serve as a backup instrument to the new TM and, consequently, would reduce the Landsat-D mission risks.

TABLE 1

MULTISPECTRAL SCANNER CHARACTERISTICS

Band	Spectral Range (micrometers)	Radiometric Performance SNR (min.)	Radiometric Performance NETD (max.)	Spatial Resolution (meters)
1	0.50 - 0.60	71		79
2	0.60 - 0.70	57		79
3	0.70 - 0.80	38		79
4	0.80 - 1.10	77		79
5*	10.40 - 12.50		1.5^{o}K	237

Digitization - 6 bits

Data Rate - 15 Mbits/sec

*Landsat-C only

TABLE 2

THEMATIC MAPPER CHARACTERISTICS

Band	Spectral Range (micrometers)	Radiometric Performance SNR (min.)	NETD (max.)	Spatial Resolution (meters)
1	0.45 - 0.52	85		30
2	0.52 - 0.60	170		30
3	0.63 - 0.69	143		30
4	0.76 - 0.90	249		30
5	1.55 - 1.75	75		30
6	10.40 - 12.50		$0.5^{o}K$	120

Digitization - 8 bits

Data Rate - 83 Mbits/sec

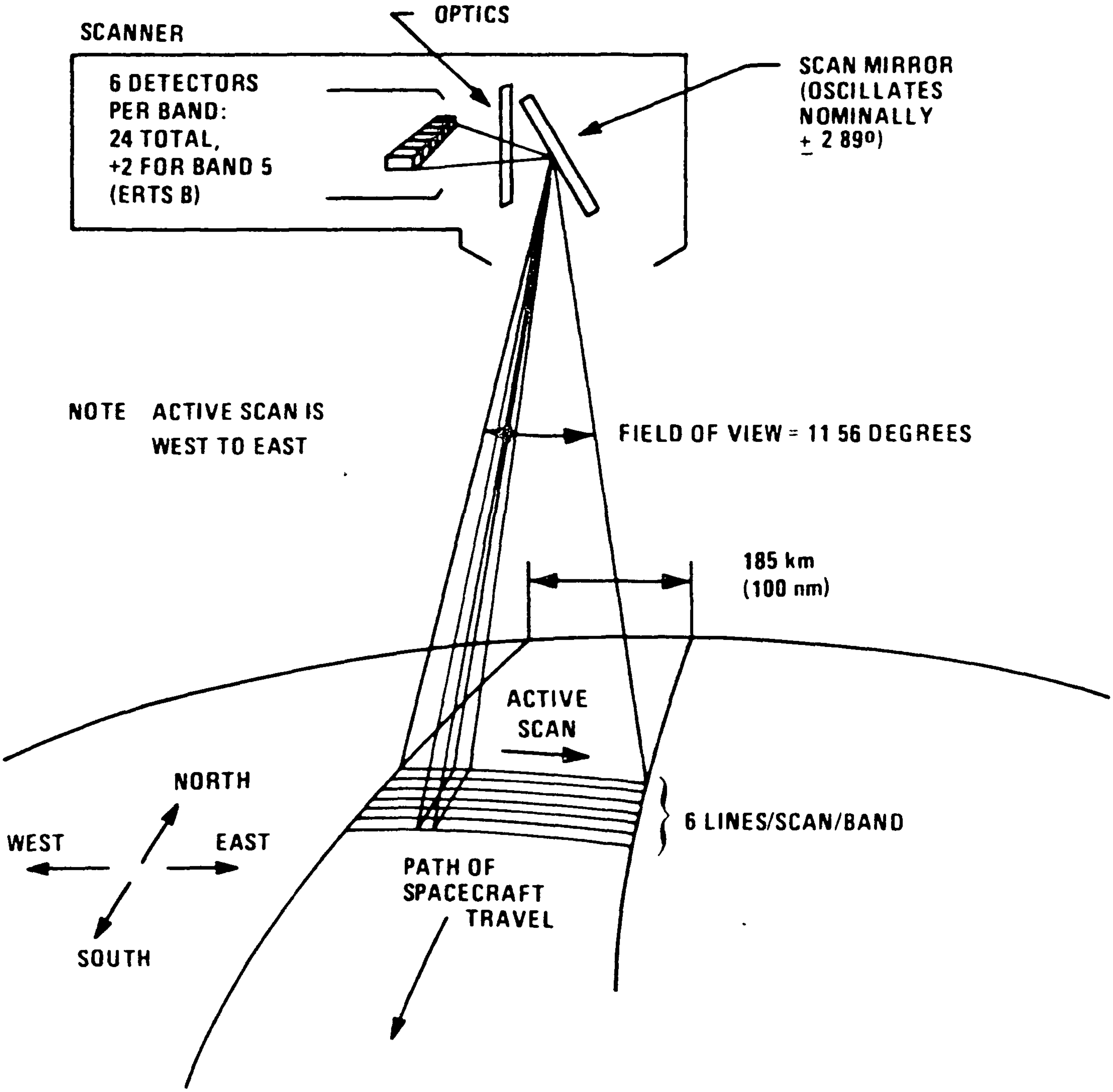

Figure 1. MSS Scanning Arrangement

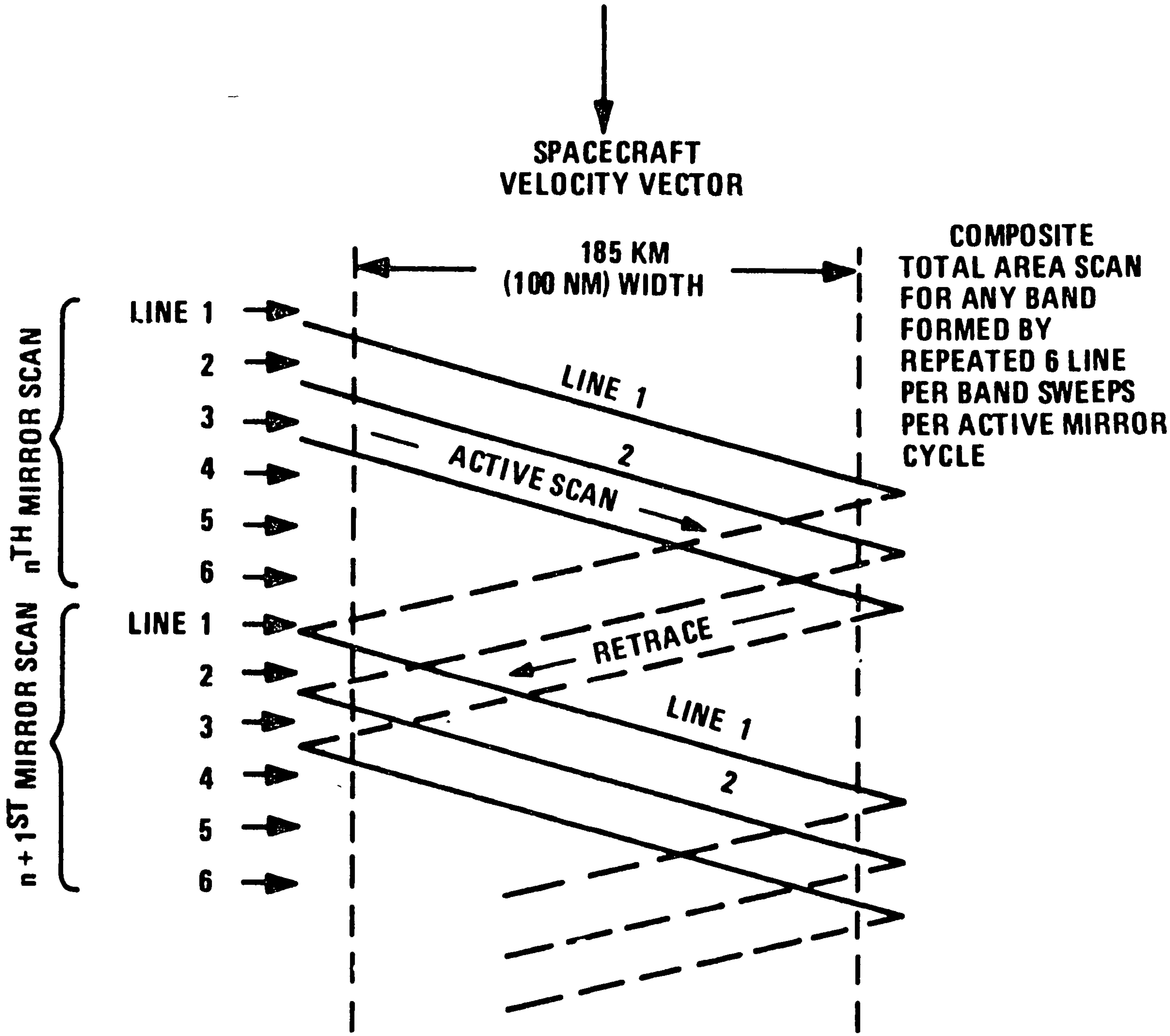

Figure 2. Ground Scan Pattern for a Single MSS Detector