BHARATHIDASAN UNIVERSITY
Tiruchirappalli - 620 024
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Programme : 6 year Integrated M.Tech in Geological Technology and Geoinformatics

Course title : Principles of Remote Sensing
Course code : MTGT 0304

UNIT – III
Sensors and Platforms

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Satellites and Sensors

In order for a sensor to collect and record energy reflected or emitted from a target or surface, it must reside on a stable **platform** removed from the target or surface being observed.

Platforms for remote sensors may be situated on the ground, on an aircraft or balloon (or some other platform within the Earth's atmosphere), or on a spacecraft or satellite outside of the Earth's atmosphere.

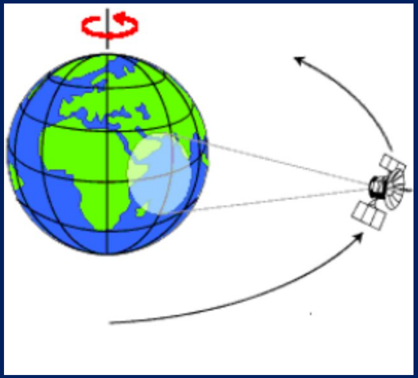

CANADA

Satellite Characteristics
Orbits and Swaths

The path followed by a satellite is referred to as its **orbit**. Satellite orbits are matched to the capability and objective of the sensor(s) they carry.

Orbit selection can vary in terms of altitude (their height above the Earth's surface) and their orientation and rotation relative to the Earth.

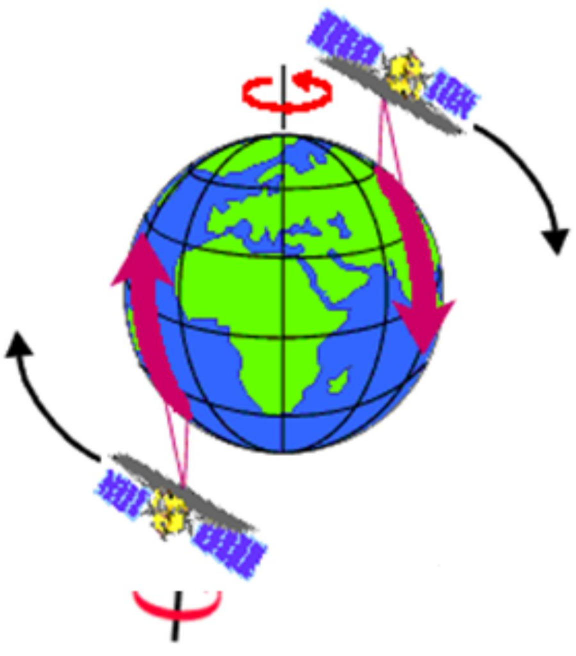
Satellites at very high altitudes (~36,000 km), which view the same portion of the Earth's surface at all times have Geostationary orbits.



Many remote sensing platforms are designed to follow an orbit (basically north-south) which, in conjunction with the Earth's rotation (west-east), allows them to cover most of the Earth's surface over a certain period of time.

These are **near polar orbits**, so named for the inclination of the orbit relative to a line running between the North and South poles.

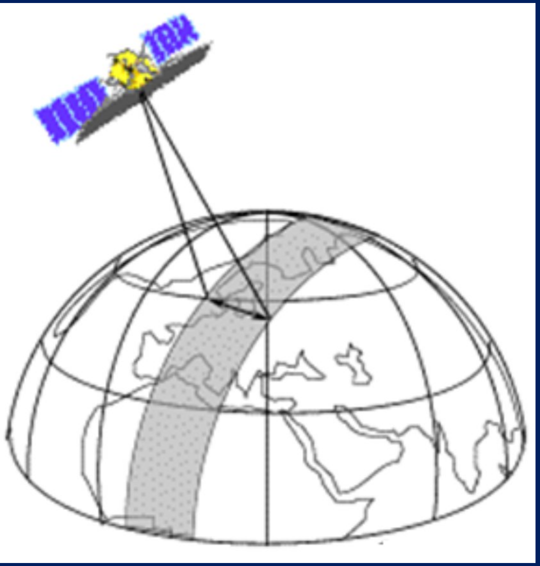
Many of these satellite orbits are also sun-synchronous such that they cover each area of the world at a constant local time of day called local sun time..



Most of the remote sensing satellite platforms today are in near-polar orbits, which means that the satellite travels northwards on one side of the Earth and then toward the southern pole on the second half of its orbit.

These are called **ascending and descending passes**, respectively.

If the orbit is also sun synchronous, the ascending pass is most likely on the shadowed side of the Earth while the descending pass is on the sunlit side. Sensors recording reflected solar energy only image the surface on a descending pass, when solar illumination is available. Active sensors which provide their own illumination or passive sensors that record emitted (e.g. thermal) radiation can also image the surface on ascending passes.



As a satellite revolves around the Earth, the sensor "**sees**" a certain portion of the Earth's surface. The area imaged on the surface, is referred to as the **swath**. Imaging swaths for space borne sensors generally vary between tens and hundreds of km wide. As the satellite orbits the Earth from pole to pole, its east-west position wouldn't change if the Earth didn't rotate.

However, as seen from the Earth, it seems that the satellite is shifting westward because the Earth is rotating (from west to east) beneath it. This apparent movement allows the satellite swath to cover a **new area with each consecutive pass**.

The satellite's orbit and the rotation of the Earth work together to allow complete coverage of the Earth's surface, after it has completed one complete cycle of orbits.

The quality of remote sensing data consists of its **Spatial**, **Spectral**, **Temporal** and **Radiometric resolutions**.

Spatial Resolution

Fineness of the details that can be extracted from a satellite image.

High spatial resolution : 0.41 - 4 m,
Medium spatial resolution: 4 - 30 m
Low spatial resolution : 30 - > 1000 m.

For some remote sensing instruments, the distance between the target being imaged and the platform, plays a large role in determining the detail of information obtained and the total area imaged by the sensor. Sensors onboard platforms far away from their targets, typically view a larger area, but cannot provide great detail.

Images where only large features are visible are said to have **coarse** or **low resolution**. In **fine** or **high resolution** images, small objects can be detected.

Military sensors for example, are designed to view as much detail as possible, and therefore have very fine resolution.

Commercial satellites provide images with resolutions varying from a few meters to several kilometers. Generally speaking, the finer the resolution, the less total ground area can be seen.

Spectral resolution

Number of spectral bands in which the sensor can collect reflected radiance, this is equivalent to the number of sensors carried by the platform. Ranges from 3 to 220 bands.

Different classes of features and details in an image can often be distinguished by comparing their responses over distinct wavelength ranges. Broad classes, such as water and vegetation, can usually be separated using very broad wavelength ranges –the visible and near infrared.

Other more specific classes, such as different rock types, may not be easily distinguishable using either of these broad wavelength ranges and would require comparison at much finer wavelength ranges to separate them. Thus, we would require a sensor with higher spectral resolution. Spectral resolution describes the ability of a sensor to define fine wavelength intervals. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band.

Temporal resolution

The temporal resolution specifies the revisiting frequency of a satellite sensor for a specific location.

High temporal resolution:< 24 hours - 3 days
Medium temporal resolution: 4 - 16 days
Low temporal resolution: > 16 days

Radiometric resolution

The radiometric resolution of an imaging system describes its ability to discriminate very slight differences in energy.

Radiometric resolution of a sensor is a measure of how many grey levels are measured between pure black (no reflectance) to pure white. In other words, radiometric resolution represents the sensitivity of the sensor to the magnitude of the electromagnetic energy.

The finer the radiometric resolution of a sensor the more sensitive it is to detecting small differences in reflected or emitted energy or in other words the system can measure more number of grey levels.

Radiometric resolution is measured in bits. Each bit records an exponent of power 2 (e.g. 1 bit = $2^1 = 2$).

The maximum number of brightness levels available depends on the number of bits used in representing the recorded energy.

2 bit image

8 bit image

Radiometric resolution and the corresponding brightness levels

Radiometric resolution	Number of levels	Example
1 bit	2^1 – 2 levels	
7 bit	2^7 – 128 levels	IRS 1A & 1B
8 bit	2^8 – 256 levels	Landsat TM
11 bit	2^{11} – 2048 levels	NOAA-AVHRR

Image data are generally displayed in a range of grey tones, with black representing a digital number of 0 and white representing the maximum value (for example, 255 in 8-bit data).

By comparing a 2-bit image with an 8-bit image, we can see that there is a large difference in the level of detail discernible depending on their radiometric resolutions. In an 8 bit system, black is measured as 0 and white is measured as 255. The variation between black to white is scaled into 256 classes ranging from 0 to 255.

Scanners

Remote sensing relies on detecting variations in reflected or emitted radiation from the Earth's surface in different regions of the electromagnetic spectrum.

Remote Sensing data is acquired using a scanning systems, which employ a sensor with a narrow field of view that sweeps over the terrain to build up and produce a 2-dimensional image of the surface.

Scanning systems can be used on both aircraft and satellite platforms and have essentially the same operating principles. Multi-band imaging employs the selective sensing of the energy reflected in multiple wavelength bands.

- Frame capture systems collect an image of a scene of one instant in time.

- The scanner records a narrow swath perpendicular to the flight path to build up an image.
  - Scanning rate is adjusted to the ground speed so that successive scans view adjacent swaths

Multi-Spectral Scanner (MSS) - a particular class of remote sensing device that sense radiation in multiple wavelength regions of the visible, near infrared, middle infrared and thermal infrared parts of the electromagnetic spectrum.

It is the most commonly used scanning system in remote sensing. For example the MSS onboard the first five Landsat missions were operational in 4 bands: **0.5-0.6, 0.6-0.7, 0.7-0.8, 0.8-1.1 µm**. Similarly, IRS LISS-III sensors operate in four bands (**0.52-0.59, 0.62-0.68, 0.77-0.86, 1.55-1.70 µm**) three in the visible and NIR regions and one in the MIR region of the EMR spectrum.

The Multispectral Scanners (MSS) were the first multispectral sensors to monitor Earth's resources from space.

Developed by Santa Barbara Research Center for NASA's Goddard Space Flight Center, the first MSS was carried aboard the Earth Resources Technology Satellite (ERTS-1), subsequently renamed LANDSAT 1.

MSS devices digitally record the detected Radiation in a number of defined wavelength 'channels' or 'bands'.

The principle of this mode of operation is the same as that of using filters on a camera to photograph limited parts of the visible spectrum.

For example, when using an appropriate filter to photograph only blue light, a purely red object would appear black since only blue radiation will pass through the filter to expose the film.

MSS operate in a number of different ways and generally it can be grouped into three basic categories depending on the mechanism used by the sensors to view each pixel.

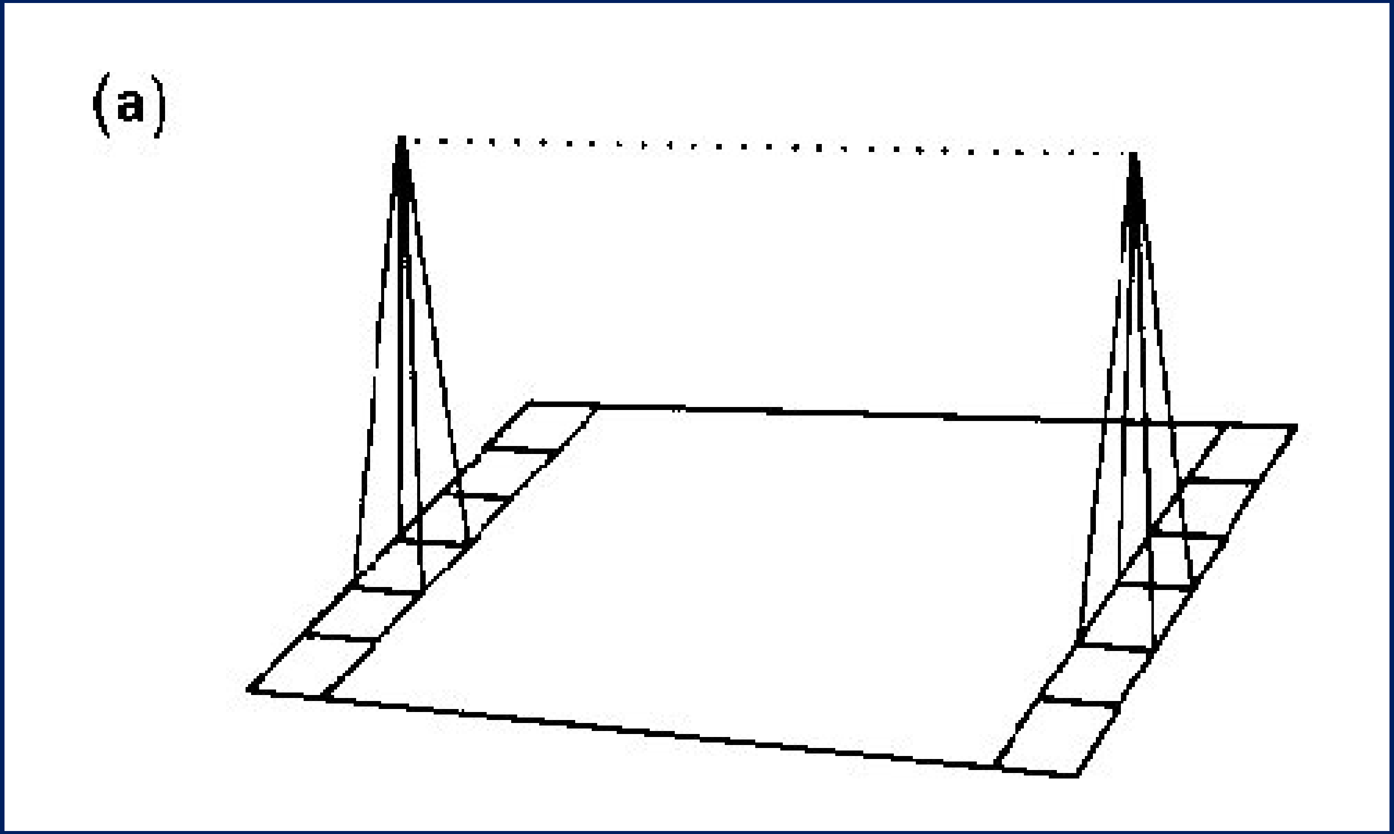
- **Electromechanical** - the sensor oscillates from side to side to form the image

- **Linear array** an array of detectors is used to simultaneously sense the pixel values along a line, and

- **Central perspective** the sensing device does not actually move, relative to the object being sensed, during image formation so views all pixels from the same central position in a similar way to a photographic camera.

- Four types of scanning systems commonly used.
  - Across track (**whisk broom**).
  - Along track (**push broom**)
  - Spin scanner
  - Conical scanner

Electromechanical: sensor records pixels sequentially along each line from line center



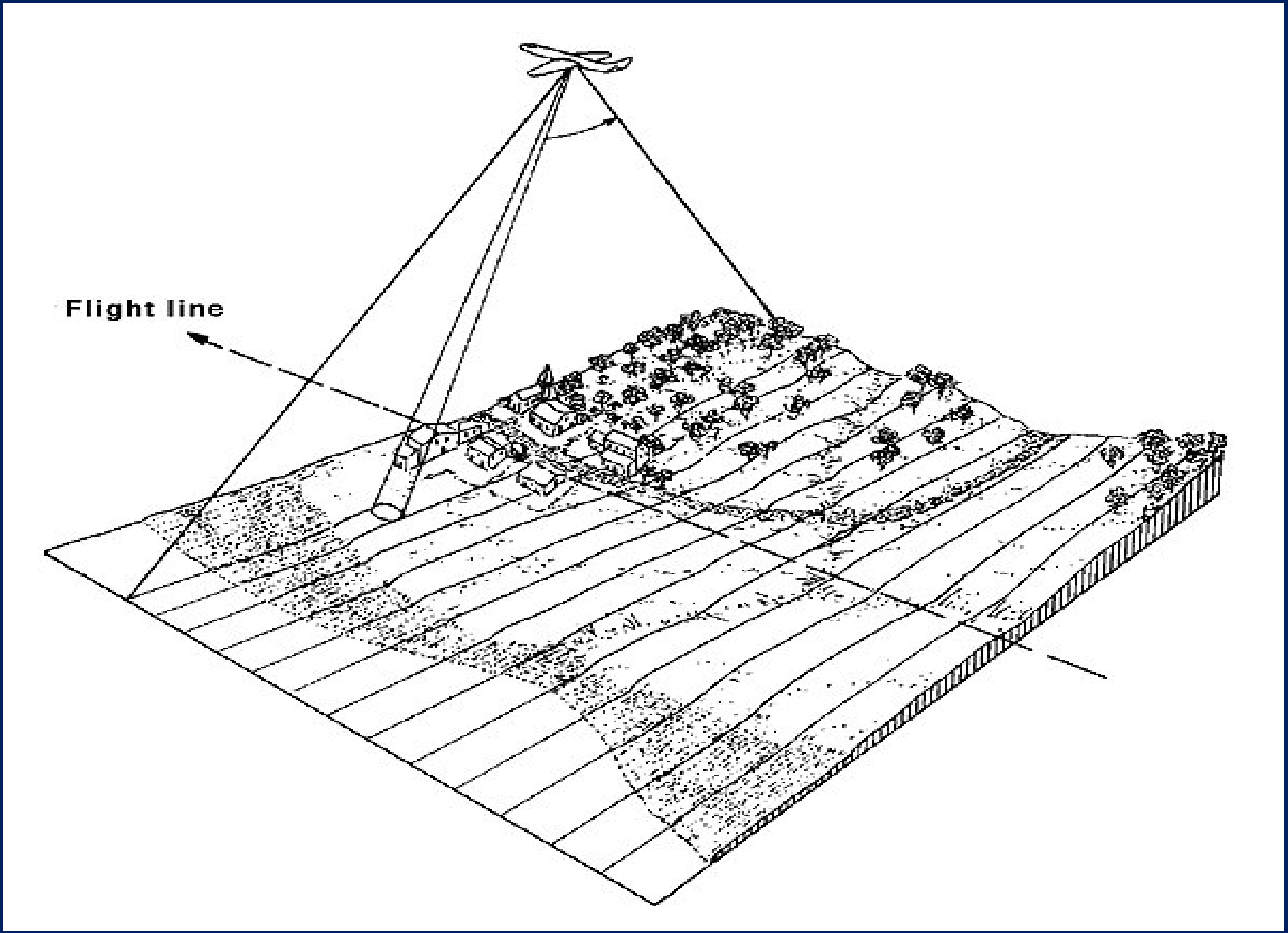
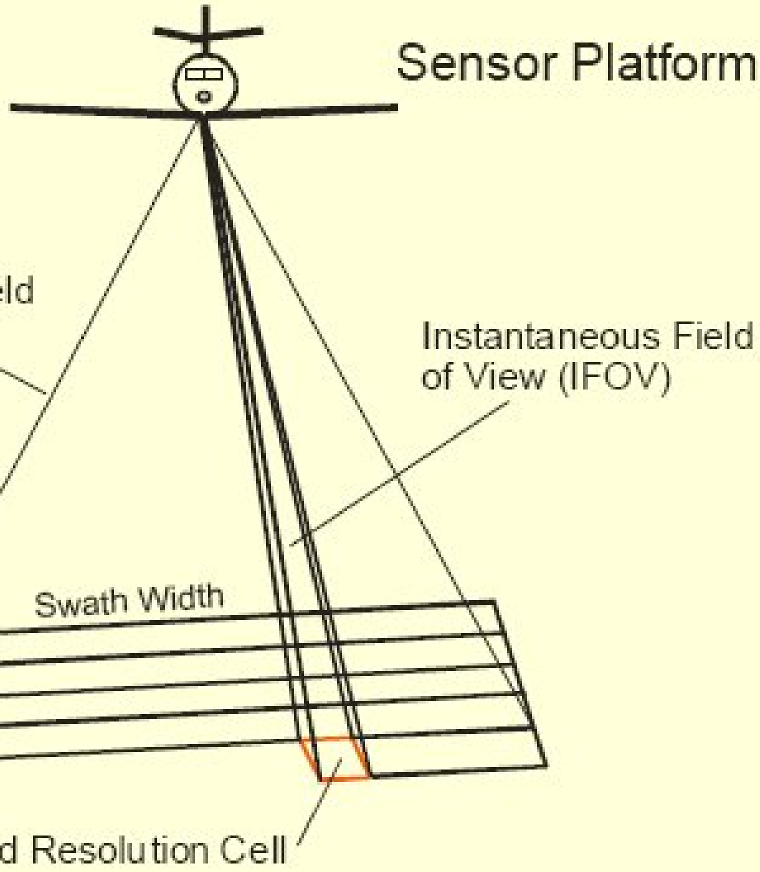


Image lines are formed sequentially by scanning side-to-side across flight path.

Whiskbroom Scanner



Dwell time is the time an individual ground resolution cell is within the IFOV. Larger IFOVs lead to longer dwell time and higher signal to noise ratio (S/N)

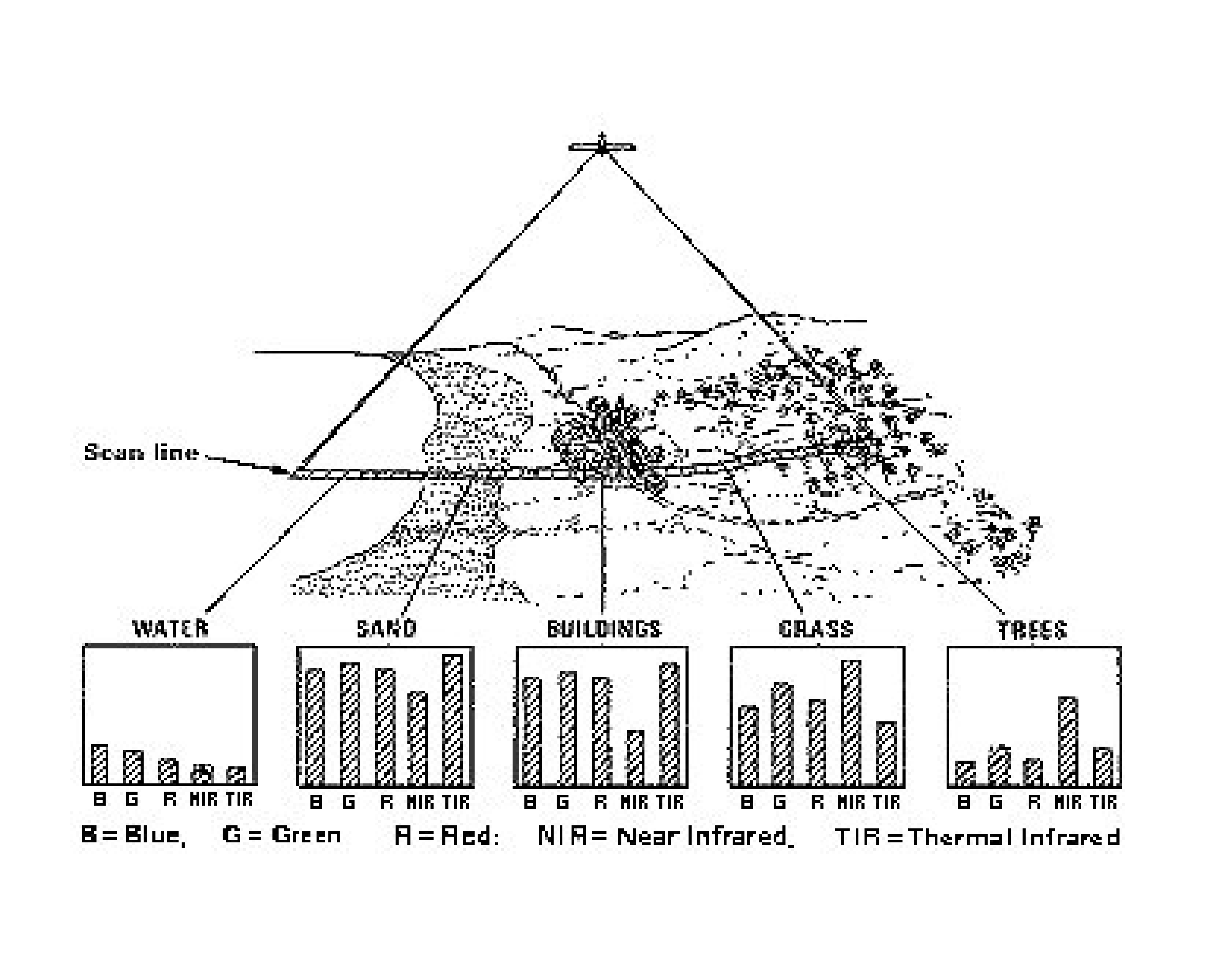
This type of scanner uses an oscillating mirror to reflect the radiation onto its detectors. These detectors are located behind filters which allow broad spectral bandwidths to pass through. The detected radiation is converted into a continuous electronic signal which is then sampled at regular time intervals to give discrete measurements, or pixels, along each scan line.

The main limitation of this scanning mechanism is the restricted time available to read each detector. This generally requires that such scanners have rather broad spectral bands to achieve an adequate signal-to-noise ratio. The oscillating movement of the mirror may also result in some inconsistencies in the scanning rate, leading to geometric problems in the imagery.

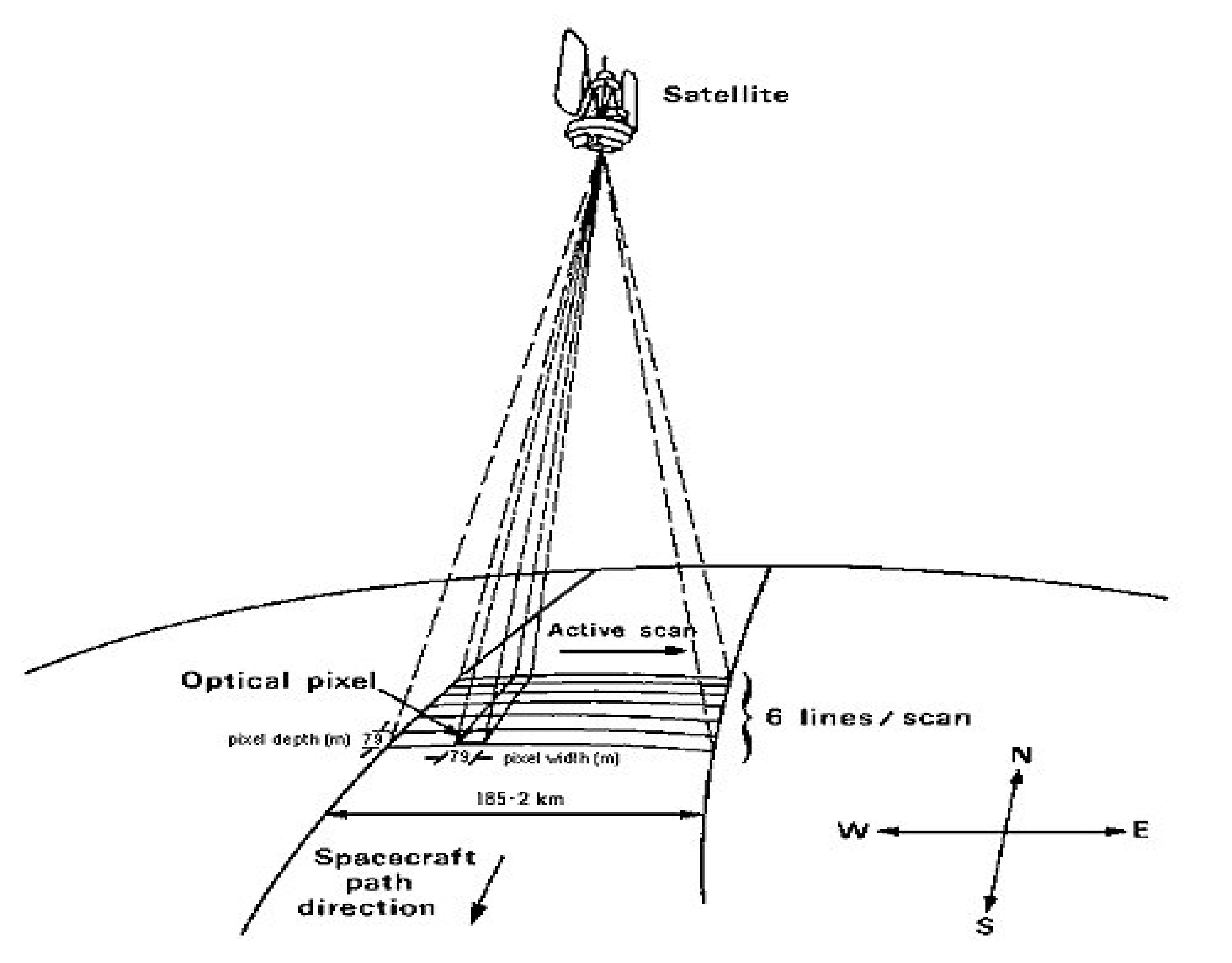
Landsat MSS and TM sensors use oscillating electromechanical scanners. This system operates six sensors for each spectral band, so that six lines of image data are received each time the scanner moves from side-to-side.

The satellite travels from north to south as the sensing systems scan west to east. These combined movements produce the characteristic westerly skew in Landsat imagery. Also, since the six lines are being imaged by separate detectors, slight miscalibration between the detectors can lead to a striping pattern in the imagery.

Each set of radiance readings along the line represents a pixel in the image.



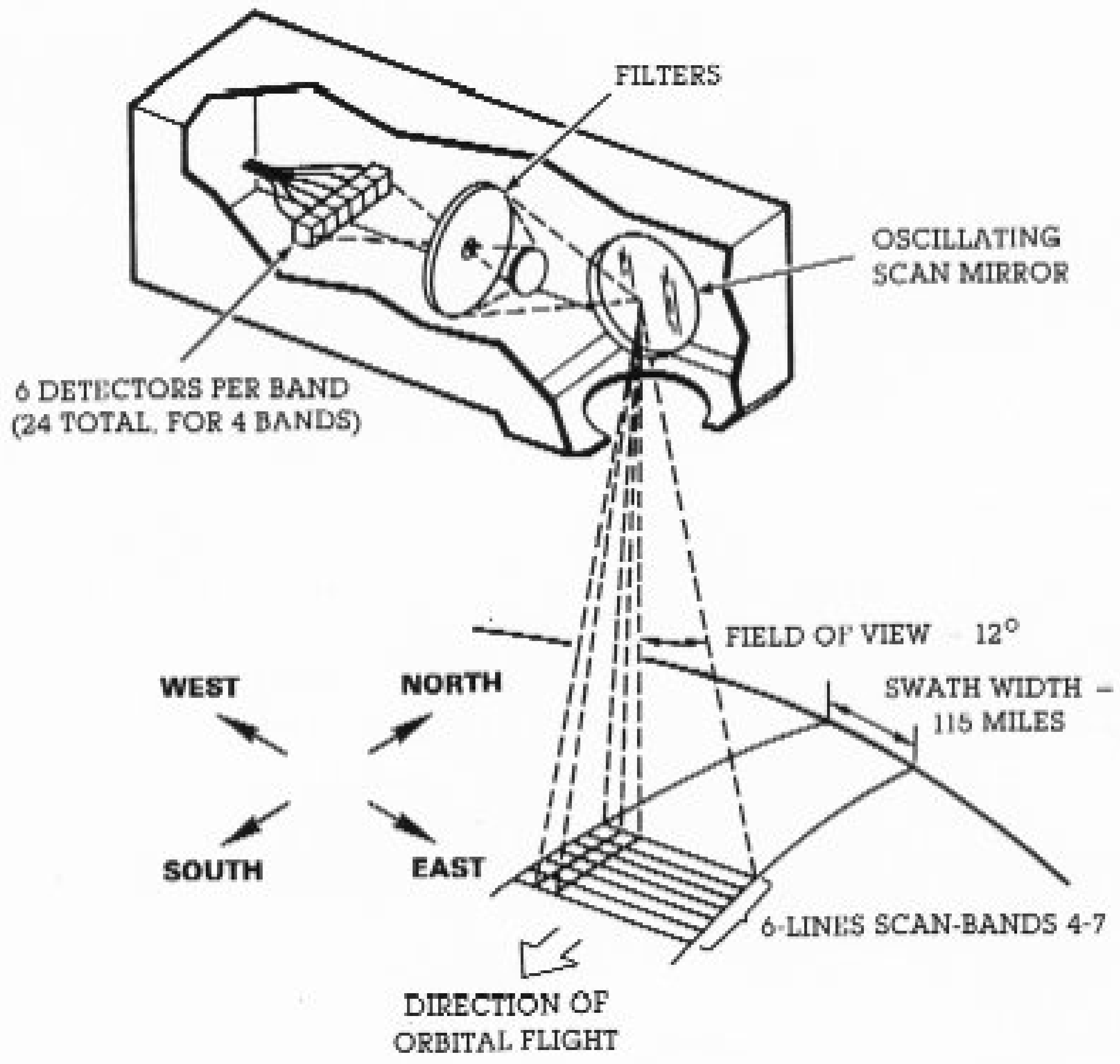
Landsat MSS operation. Six sensors for each band allow six image lines to be recorded during each scan.

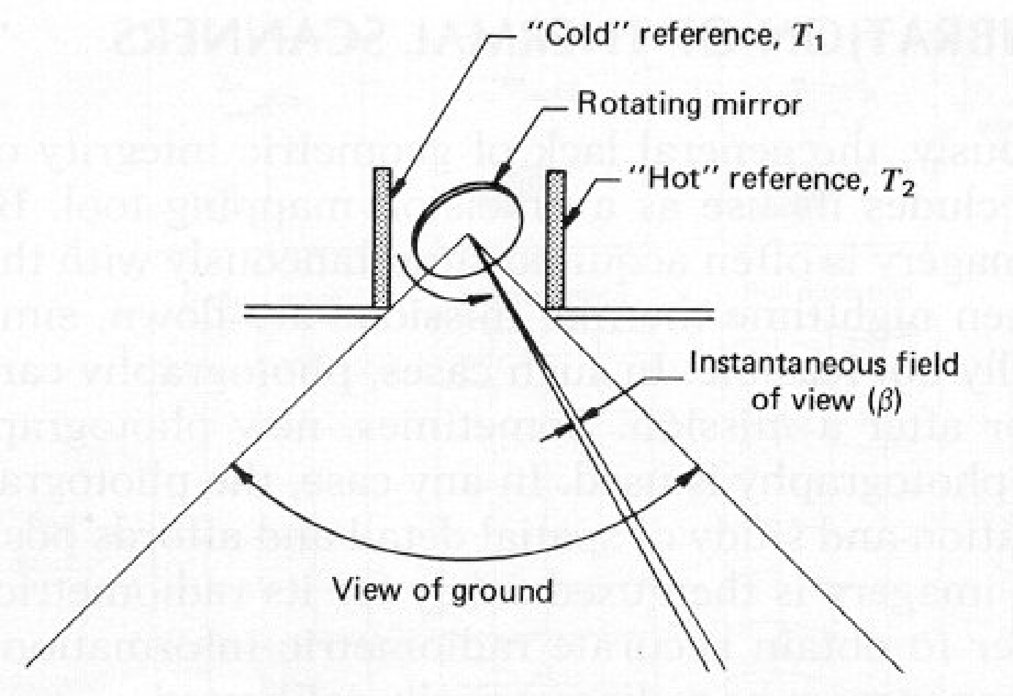


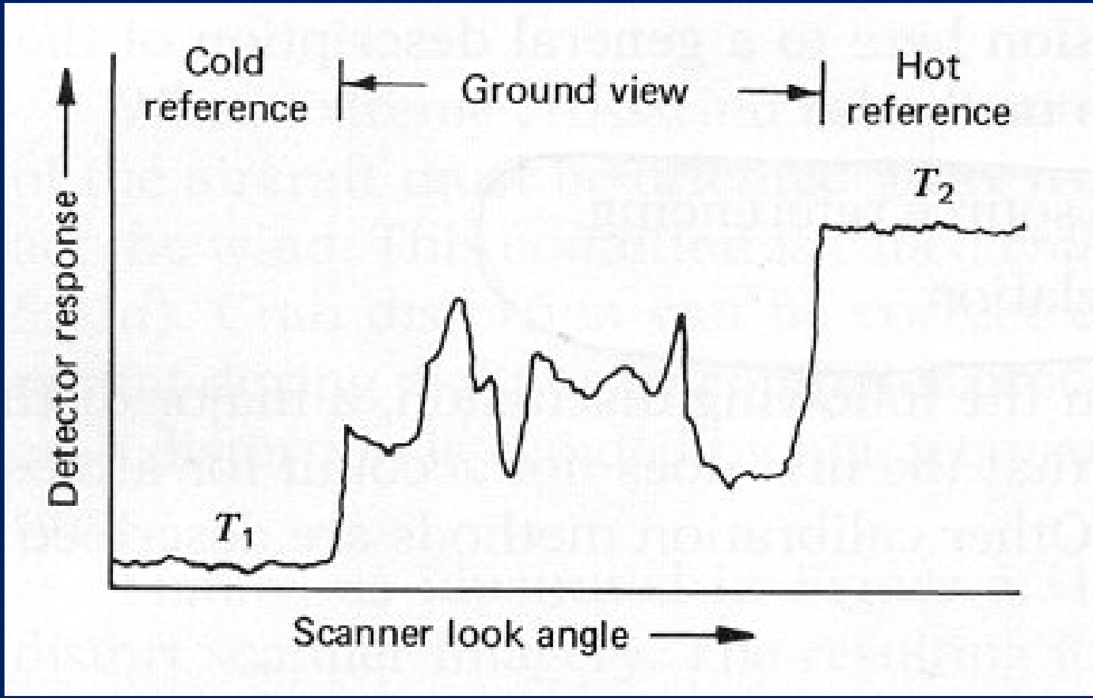
Across track scanner

- Record brightness values along a scan line 1 pixel the time.
- The rotating or oscillating mirror directs the sensors field of view to repeatedly sweep across the terrain.

MSS SCANNING ARRANGEMENT

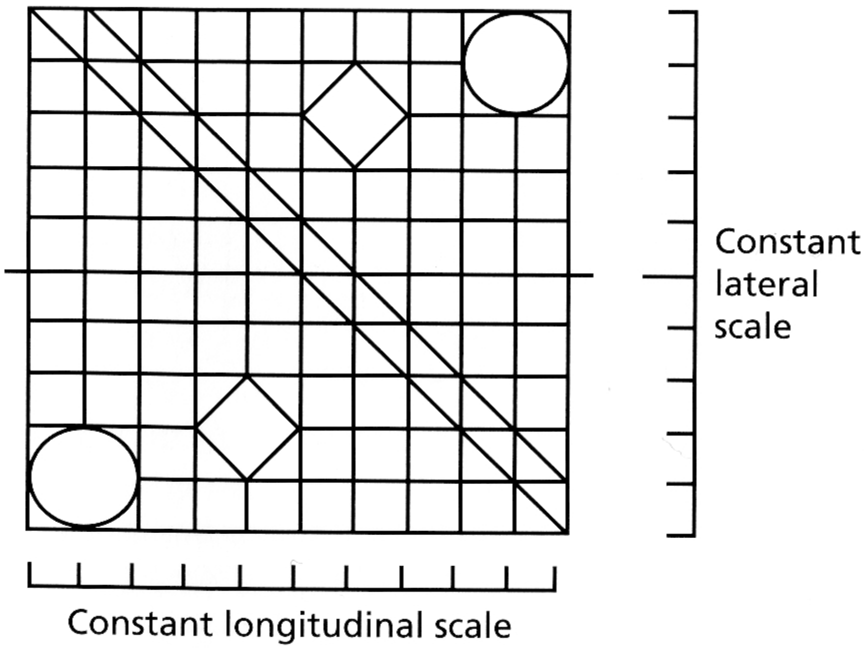



"Cold" reference, T_1
Rotating mirror
"Hot" reference, T_2
Instantaneous field of view (β)
View of ground

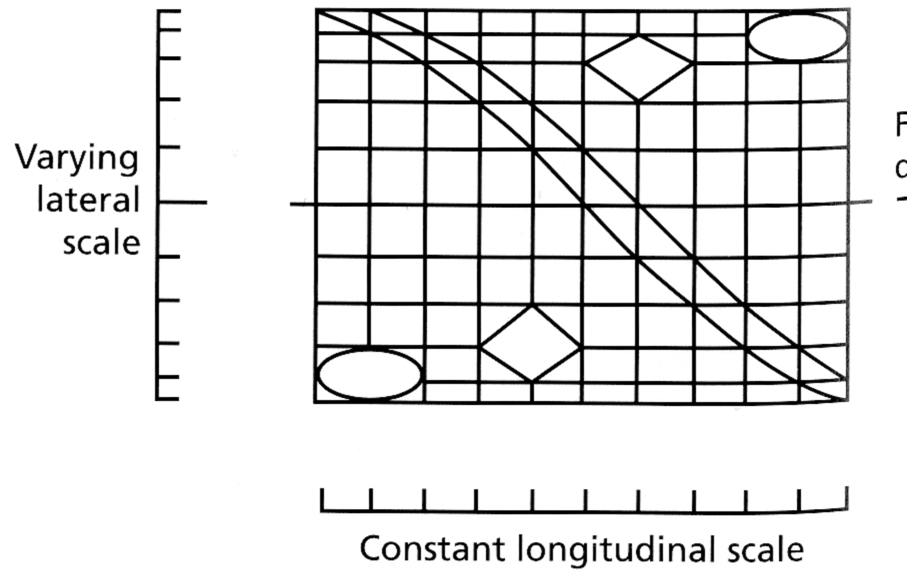

Cold reference
Ground view
Hot reference
T_2
T_1
Detector response
Scanner look angle

Across track scanner

- Collects data from the point directly below the sensor (nadir), and also to each side.
  - Therefore the distance between the sensor in the ground increases as the sensor moves along the scan line to each side
  - Therefore there is and across track change in scale



a. Vertical aerial photograph



b. Across-track scanner image

Across track scanner

- Ideally, the scanning rate is adjusted so that the forward motion causes an advance over the ground that is equal to the size of the ground resolution

- The dwell time is time it takes to collect a measurement for a single ground cell

  1. Smaller ground resolution size, means shorter dwell time

  2. Short time reduces the amount of energy captured – may lead to low signal : noise

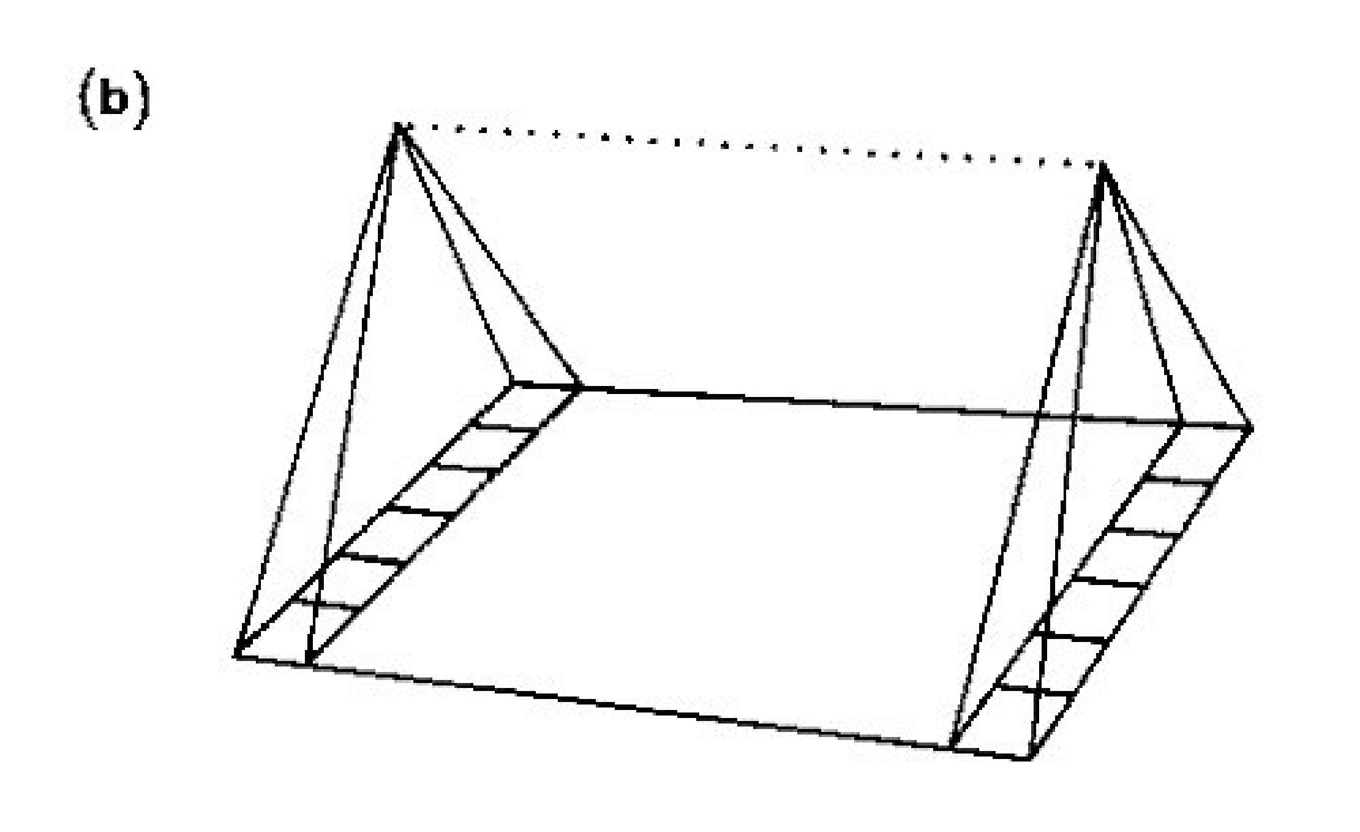
Across track scanner

- **Instantaneous Field of View** (IVOF) is the ground cell size
  - The smaller the IVOF, the better the spatial resolution
  - The larger the IFOV, the more energy is captured

b. Linear array: uses a linear array of 'Charge Coupled Device' (CCD) detectors to form an image line with each detector being used to read the value for an individual pixel along the line.

This design is also referred to as a 'Pushbroom' scanner since the image is formed by the sensor being swept forward by the platform's velocity.

Linear array: pixels recorded simultaneously along each line using an array of detectors at line centre.



Along-track Scanners

- Pushbroom scanners capture narrow strips of data to build up an image
  - No mirrors, just a line of sensors
  - So the entire line gets captured simultaneously
  - Multiple linear arrays are used for multispectral data (or multiple viewing directions)

along-track scanner does not use any scanning mirrors, instead a linear array of detectors is used to simultaneously record the energy received from multiple ground resolution cells along the scan line. This linear array typically consists of numerous charged coupled devices (CCDs).

A single array may contain more than 10,000 individual detectors. Each detector element is dedicated to record the energy in a single. Also, for each spectral band, a separate linear array of detectors is used. The arrays of detectors are arranged in the focal plane of the scanner in such a way that the each scan line is viewed simultaneously by all the arrays. The array of detectors are pushed along the flight direction to scan the successive scan lines, and hence the name push-broom scanner. A two dimensional image is created by recording successive scan lines as the aircraft moves forward.

Along track scanner

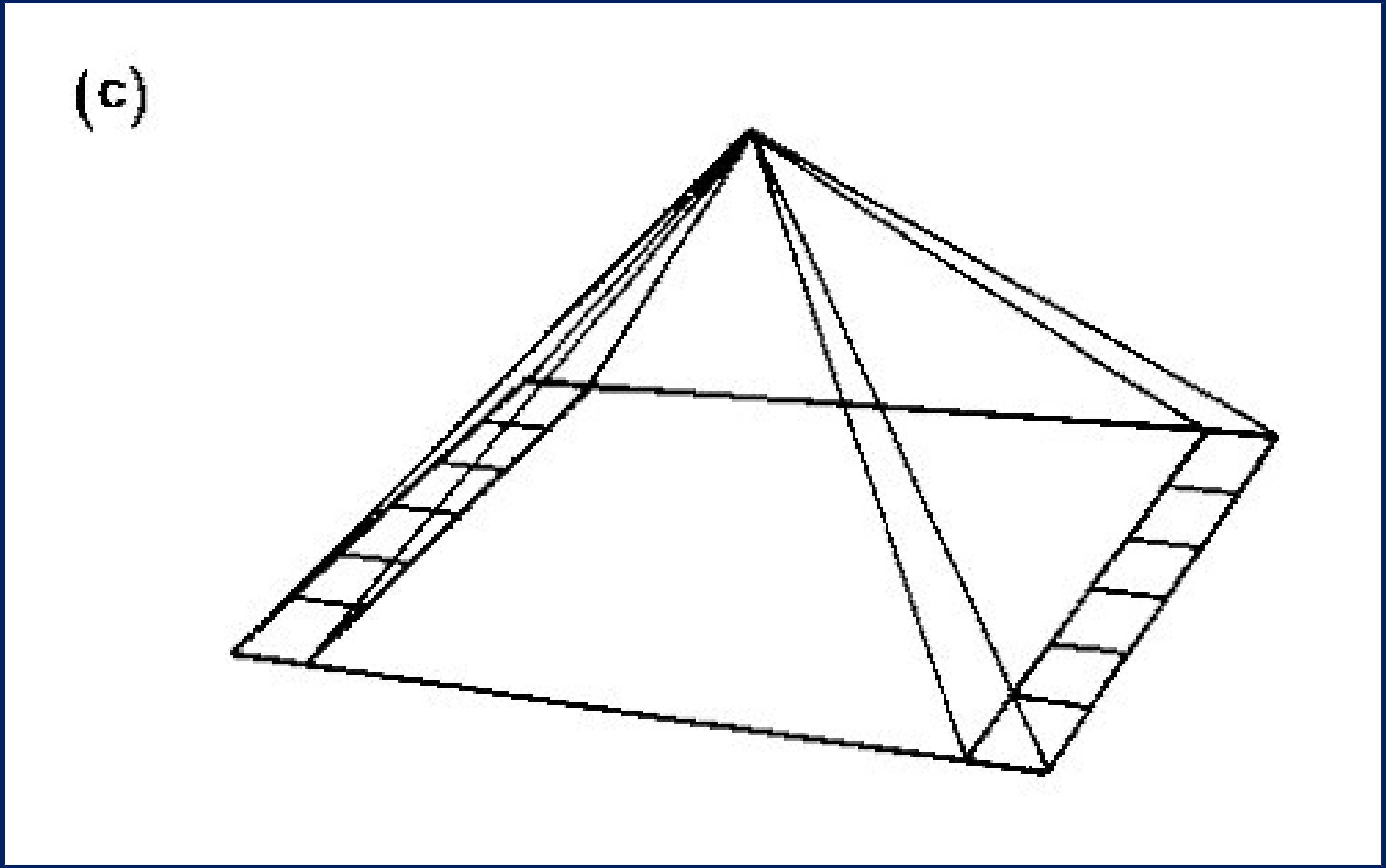
- Scanning mirror can introduce errors, so the array is more accurate geometrically
- No moving parts means more durable, and lower cost
- All the sensors are individually calibrated, so has higher radiometric accuracy as well
- Have longer dwell time
- Smaller size

c. **Central perspective**: The third category of scanning operation can utilise either electromechanical or linear array technology to form image lines but images each line from a perspective at the centre of the image rather than the centre of each line as discussed above.

This results in similar geometric distortions in an image to those which occur in photographic data.

In satellite-derived imagery however, radial displacement effects are barely noticeable because the field of view is so small relative to orbital altitude.

Central perspective: sensor is positioned at image Centre and records lines sequentially



Laboratory-based scanners commonly use the central viewing perspective for image formation. The extent of distortion in the resulting image depends on the optics of the scan configuration used, including the size of the original being scanned.

The early frame sensors used in Vidicon cameras (such as the Return Beam Vidicon in Landsats 1, 2 and 3) operated from a central perspective by exposing a two-dimensional array of detectors (or photosensitive tubes in the early models) for a shutter controlled time period.

Although operating with a different mechanism, imagery from the geostationary satellites is also essentially formed from this perspective.

Scanners see the energy within the systems **IFOV – Instantaneous Field Of View.** Diameter of the ground area when IFOV of the scanner is oriented directly beneath the aircraft can be determined by

$$D = H' \times \beta,$$

D – diameter of circular ground area viewed

H' – Flying height above the terrain

β - IFOV of the system

Instantaneous Field of View (IVOF) is the ground cell size

- The smaller the IFOV, the better the spatial resolution
- The larger the IFOV, the more energy is captured

Dwell time is the time taken to collect a measurement for a single ground cell.

Smaller ground resolution size, means shorter dwell time. Short time reduces the amount of energy captured – may lead to low signal : noise ratio.