REMOTE SENSING

Space Orbits of Remote Sensing Satellites

OVERVIEW

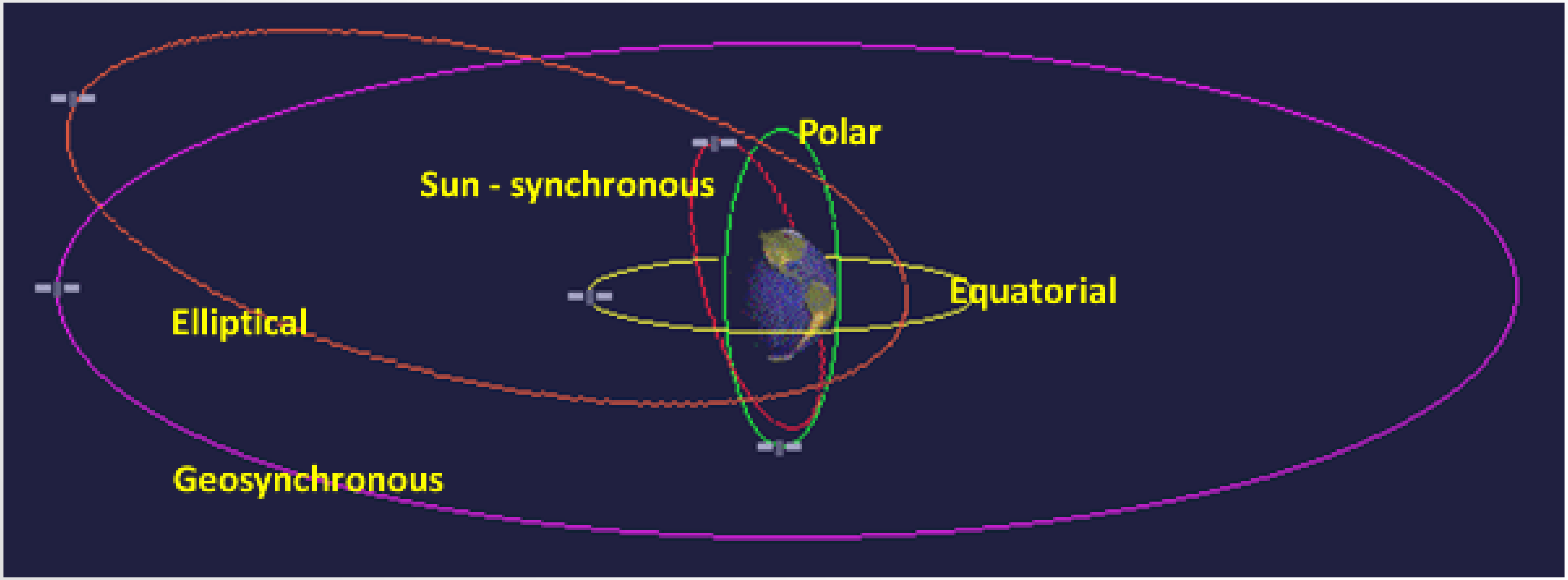
Classification by Orbit Altitude
Classification by Orbital Characteristics
Design Requirements and Characteristics of Remote Sensing Satellite Orbits
Orbit Design Analysis of Microwave Remote Sensing Satellite
Analysis and Design of Multi-mission Orbits for Optical Remote Sensing Satellite
Design of Satellite Multi-mission Orbit Parameters

CLASSIFICATION BY ORBIT ALTITUDE

Orbital type	Abbreviation	Orbit altitude (km)	Eccentricity	Inclination (°)	Orbital period
Geostationary orbit	GEO	35,786	0	0	1 sidereal day
Geosynchronous orbit	GEO		Close to 0	0–90	1 sidereal day
Highly elliptical orbit	HEO		≥0.25 to <1	0–90	
Medium Earth orbit	MEO	2000–30,000	0 to high	0–90	
Low Earth orbit	LEO	200–2000	0 to high	0–90	>90 min

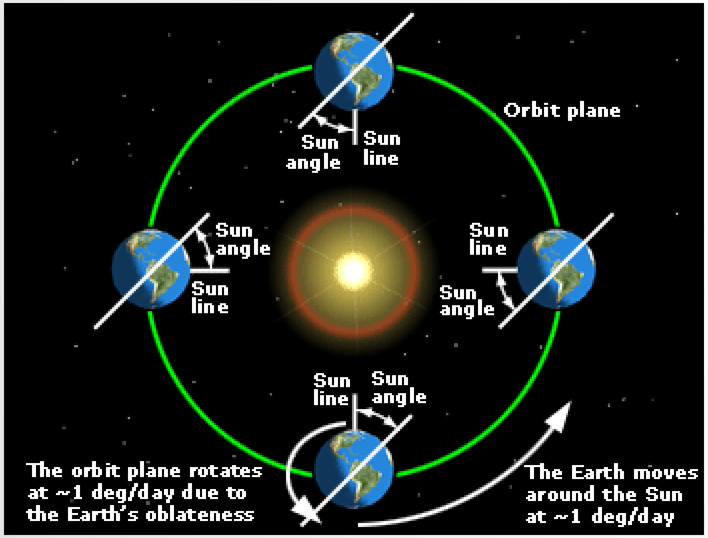
CLASSIFICATION BY ORBITAL CHARACTERISTICS

The satellites orbiting the Earth will be affected by the Earth's noncentral gravity, solar–lunar gravity, atmospheric resistance, and other perturbation forces, in which the noncentral gravity of the Earth causing the perturbation of orbital elements is the maximum perturbation factor.

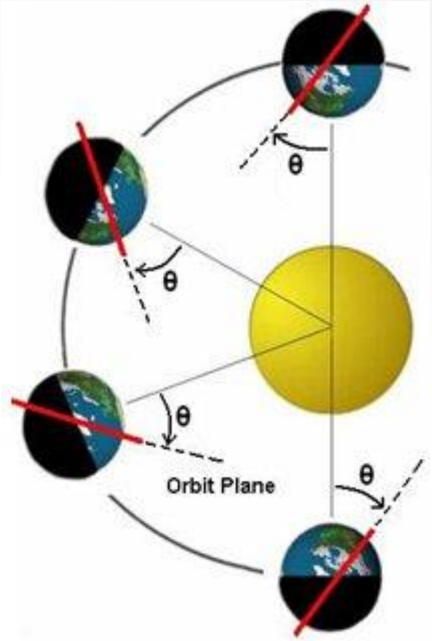


CLASSIFICATION BY ORBITAL CHARACTERISTICS

Sun-Synchronous Orbit



The Sun-synchronous orbit refers to the orbit with the plane precession angular velocity same as the average angular velocity of the sun moving in the ecliptic.

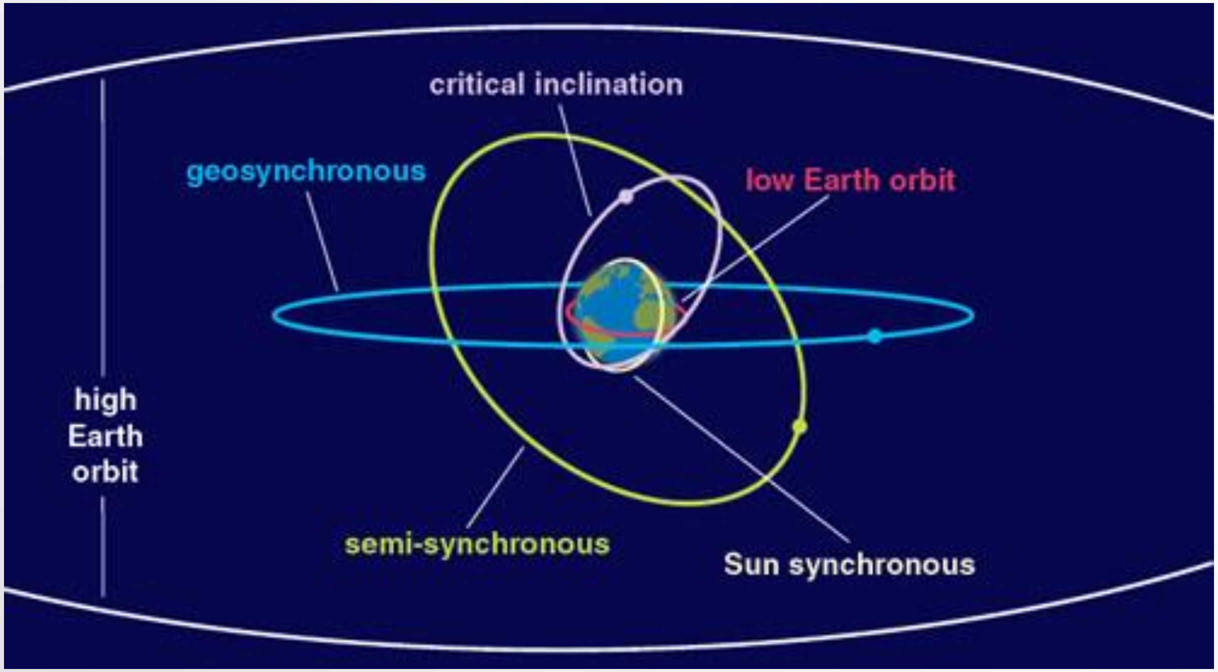


Sun-synchronous orbits pass over the same spots on the ground at the same solar time of day (not necessarily every day). The orbits are designed this way on purpose: it is very useful in remote sensing to have the same lighting conditions for repeated scenes, in order to detect changes in vegetation, topography, or human activity.

CLASSIFICATION BY ORBITAL CHARACTERISTICS

Orbit with Critical Inclination

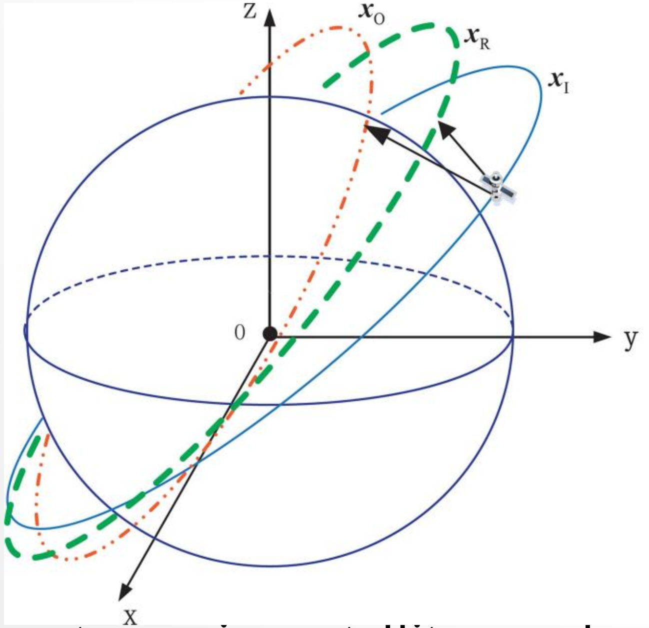
Critical inclination orbit is the orbit with an inclination equal to 63°26 or 116°34. The change rate of the argument of perigee and the eccentricity of the orbit with critical inclination are close to zero, and the stability of the satellite in this orbit will be limited by the orbital eccentricity. The greater the eccentricity, the better the stability is. Due to stationary apsidal lines of the orbit with critical inclination, it can be guaranteed that the perigee or the apogee is always located at a certain latitude.



CLASSIFICATION BY ORBITAL CHARACTERISTICS

Recursive Orbit

Recursive orbit refers to the orbit on which a satellite's sub-satellite point trajectories overlap every certain lap.

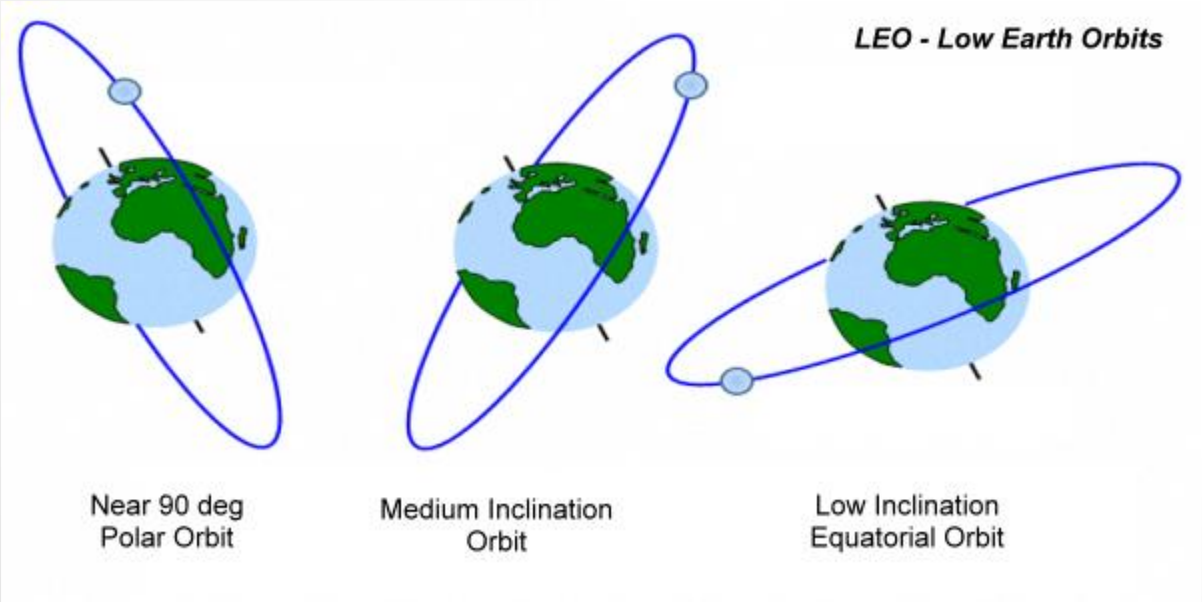


For some census-type remote sensing satellites, such as surveying and mapping satellites, regular sub-satellite point imaging to the same target is required. The characteristics of the regular repeat of the ground trace of the orbit sub-satellite point just meet the requirements of this mission. Therefore, this type of satellite usually chooses the Sun-synchronous recursive orbit, which combines both the characteristics of the sun synchronization and recursive orbit.

CLASSIFICATION BY ORBITAL CHARACTERISTICS

Frozen Orbit

The frozen orbit refers to the orbit whose change rate of the argument of perigee and eccentricity are both zero. In general, the frozen orbit contains an arch geostationary orbit with an arbitrary inclination. Different from the critical inclination orbit, the frozen orbit is not limited to a specific inclination.



CLASSIFICATION BY ORBITAL CHARACTERISTICS

Geostationary Orbit

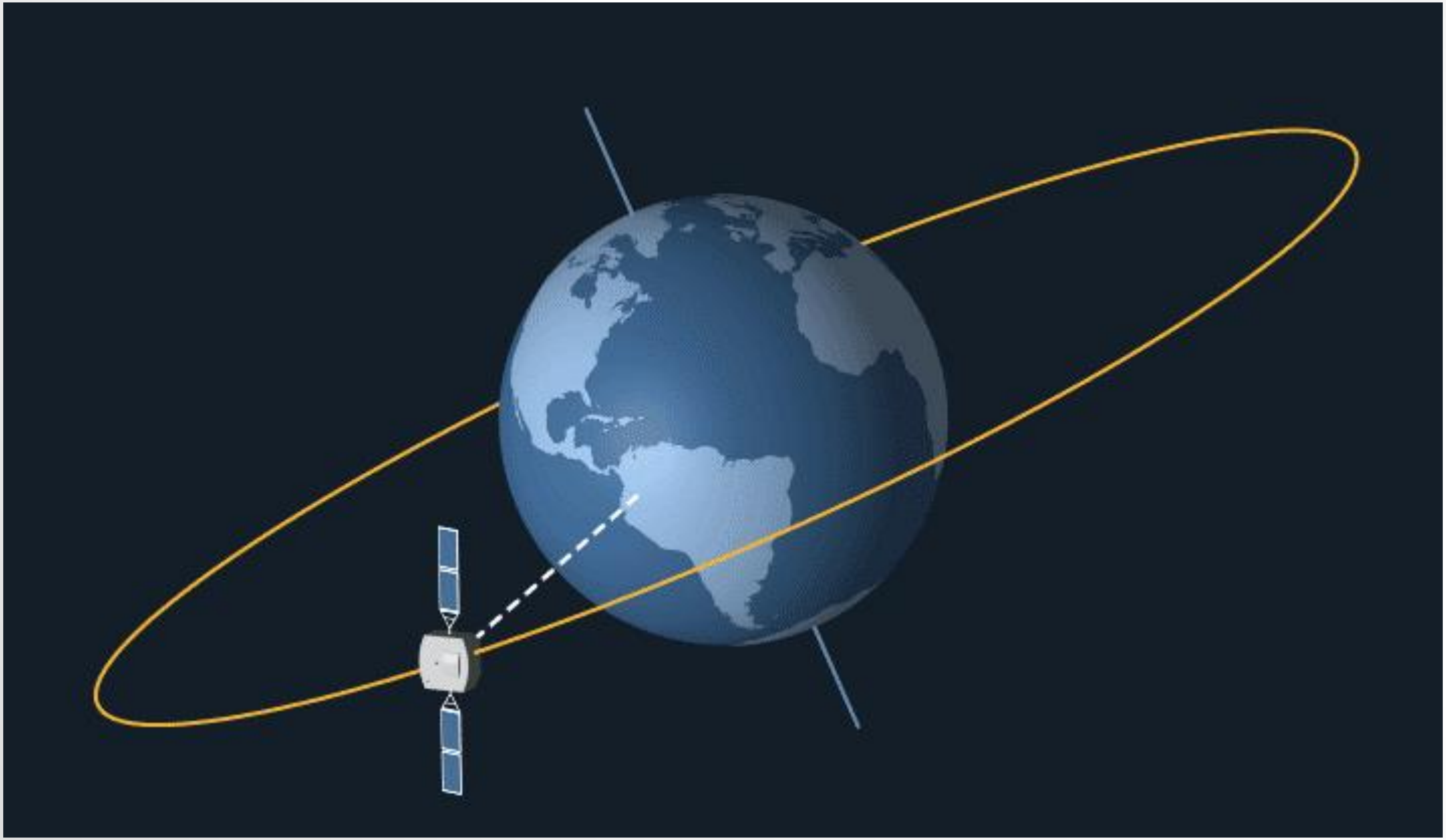
A geostationary orbit also referred to as a geosynchronous equatorial orbit (GEO), is a circular geosynchronous orbit 35,786 kilometers (22,236 miles) above Earth's equator and following the direction of Earth's rotation.

- If we need a satellite for the purpose which needs this satellite to remain at a particular distance from the earth all the time, then we need circular orbits so all the points in circular orbit are at an equal distance from the earth's surface. The circular equatorial orbit is exactly in the plane of the equator on the earth.
- If the satellite is moving in the circular-equatorial orbit and its angular velocity is equal to the earth's angular velocity, the satellite is said to be moving along with the earth. This satellite would appear stationary from the earth and this orbit would be called Geostationary Orbit.

- The orbit is circular
- The orbit is in the equatorial plane i.e. directly above the equator and thus inclination is zero.
- The angular velocity of the satellite is equal to the angular velocity of the earth
- Period of revolution is equal to the period of rotation of the earth.
- Finish one revolution around the earth in exactly one day i.e. **23 hours, 56 Minutes, and 4.1 seconds**
- There is **ONLY** one geostationary orbit.

CLASSIFICATION BY ORBITAL CHARACTERISTICS

Geostationary Orbit



CLASSIFICATION BY ORBITAL CHARACTERISTICS

Geosynchronous Orbit

There is a difference between the **geostationary and <u>geosynchronous orbits</u>**. We should note that while other orbits may be many**, there is ONLY ONE Equatorial orbit,** i.e. the orbit which is directly above the earth's equator. Sometimes we send a satellite into space which though has a period of revolution that is equal to the period of rotation of the earth, but its orbit is neither equatorial nor Circular.

•So, this satellite will finish one revolution around the earth in exactly one day i.e. **23 hours, 56 Minutes, and 4.1 seconds,** yet it does **NOT** appear stationary from the earth.

•It looks oscillating but **NOT** stationary and that is why it is called Geosynchronous. So, the main features of a geosynchronous satellite are as follows:-

Features of Geosynchronous Orbits-

•The orbit is **NOT** circular

•The orbit is **NOT** in the equatorial plane i.e. directly above the equator, it's in an inclined orbit

•The angular velocity of the satellite is equal to the angular velocity of the earth

•Period of revolution is equal to the period of rotation of the earth.

•Finish one revolution around the earth in exactly one day i.e. 23 hours, 56 Minutes, and 4.1 seconds

•There are many geosynchronous orbits.

Note – that it is practically **NOT** possible to achieve an absolute geostationary orbit. So, the terms geostationary and geosynchronous are used alternatively.

DESIGN REQUIREMENTS AND CHARACTERISTICS OF REMOTE SENSING SATELLITE ORBITS

The worldwide main high-resolution optical remote sensing satellites are dominated by the Sun-synchronous orbit with LTDN at 10:30, and there are also cases where the Sun-synchronous orbits with LTDN at 13:30 have been selected.

Satellite	Country	Launch time	Orbit altitude (km)	LTDN	Resolution at sub-satellite point (m)
GeoEye—1	USA	2008	684	10:30	0.41
World View—2	USA	2009	770	10:30	0.46
World View—3	USA	2014	617	10:30/13:30	0.31
World View—4	USA	2016	617	10:30/13:30	0.31
Pleiades—1	France	2011	694	10:30	0.50

DESIGN REQUIREMENTS AND CHARACTERISTICS OF REMOTE SENSING SATELLITE ORBITS

According to the application characteristics of high-resolution optical remote sensing satellite, the main mission requirements are as follows:
(a) Application requirement for global coverage

(b) Requirement on high resolution, large swath, and fast revisit

When the pixel size and focal length of the optical camera are determined, the higher the orbit altitude is, the lower the resolution is. For high-resolution optical remote sensing satellites, due to the high Ground Sampling Distance (GSD) requirement and the constraints of its optical field of view, the imaging swath of the camera is generally small, usually several kilometers to more than ten kilometers. For such remote sensing satellites, repeated sub-satellite point observation of global targets will lead to a very long recursive period, so that rapid revisit is generally achieved through altitude maneuvers. The revisit ability of satellite revisit depends on both the orbit altitude and attitude maneuverability. For a satellite at an altitude of 500 km, a 5-day revisit can be achieved by attitude side-sway (±35°), while a 1-day revisit can be realized by attitude side-sway (±60°) for a satellite at an altitude of 680 km.

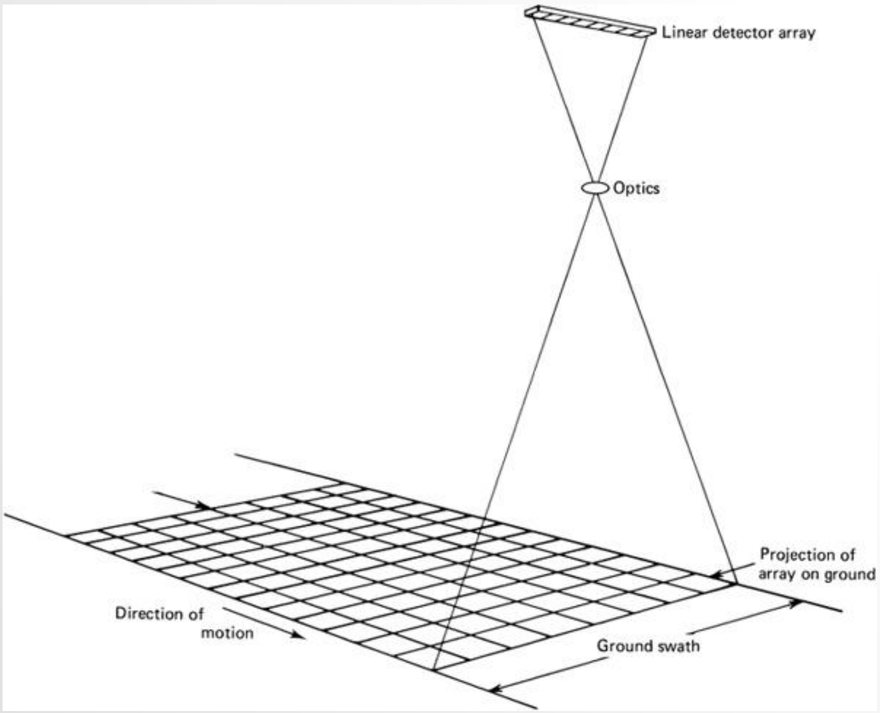
DESIGN REQUIREMENTS AND CHARACTERISTICS OF REMOTE SENSING SATELLITE ORBITS

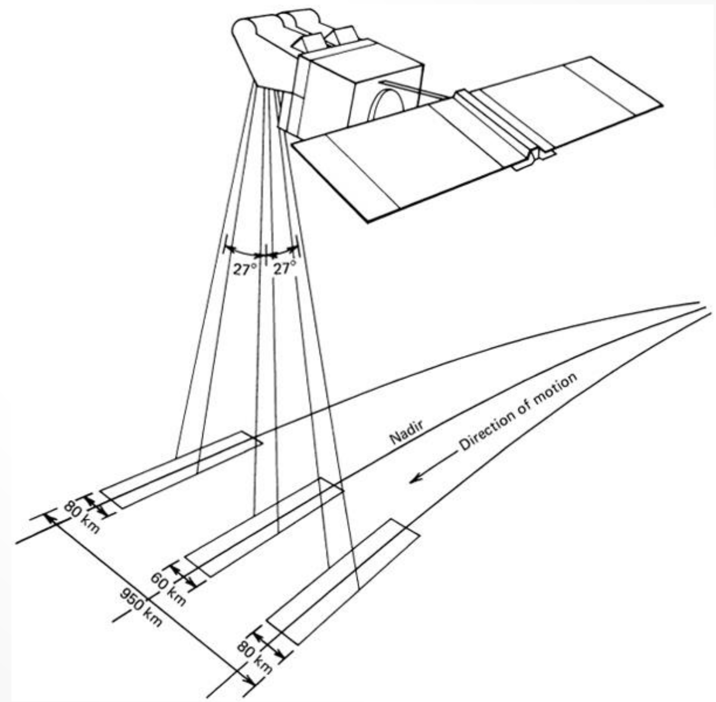
(c) Requirement on lighting conditions

When optical imaging of ground targets is carried out, the ground targets shall satisfy certain lighting conditions, that is, to meet the requirements of sun elevation angle. The sun elevation angle refers to the elevation angle of the sun's rays relative to the local horizon. The sun elevation is an important parameter of optical imaging remote sensing, which is usually between 10° and 70°. From this perspective, the selection of an orbit with stable lighting conditions is very important for optical imaging remote sensing satellites.

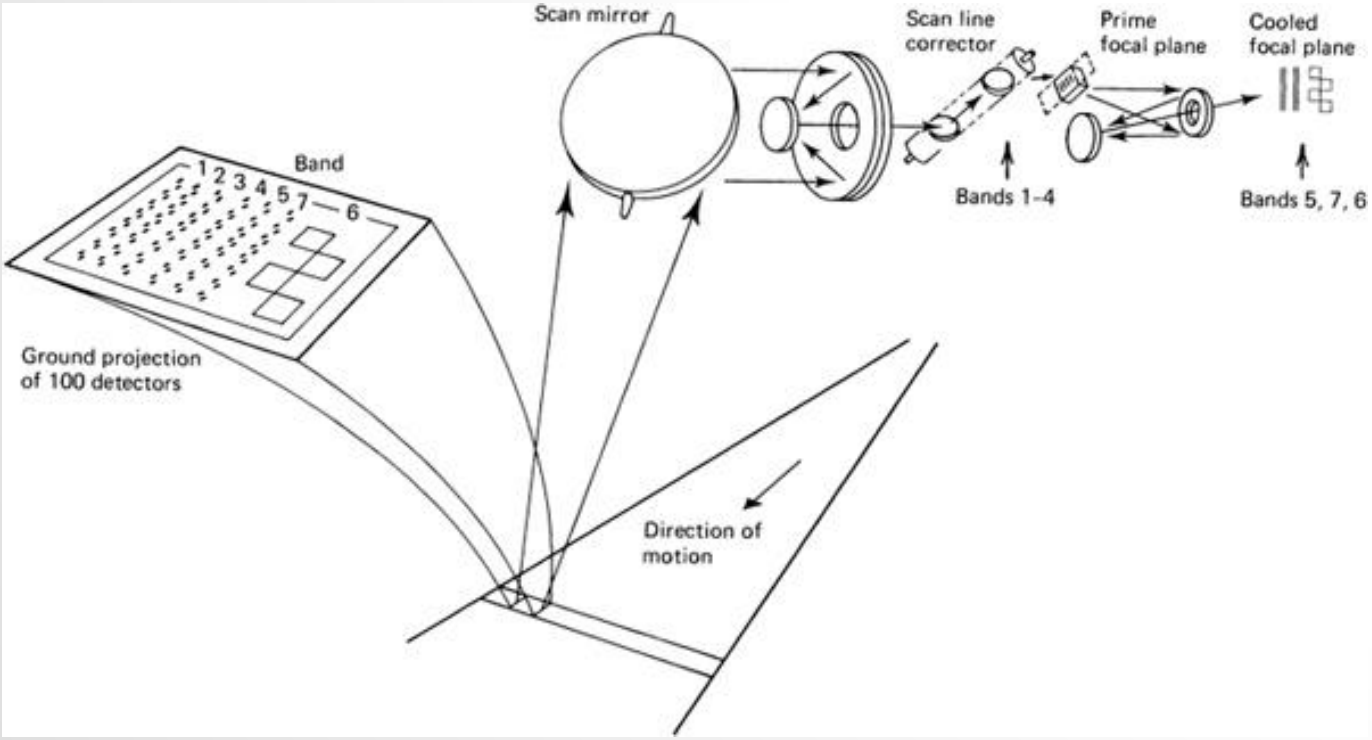
(d) Requirement of orbit maneuver and maintenance

Along-track/Push-broom scanner (SPOT)





Whiskbroom sensor(Landsat)



LIDAR SCANNING MECHANISM AND GROUND PATTERNS

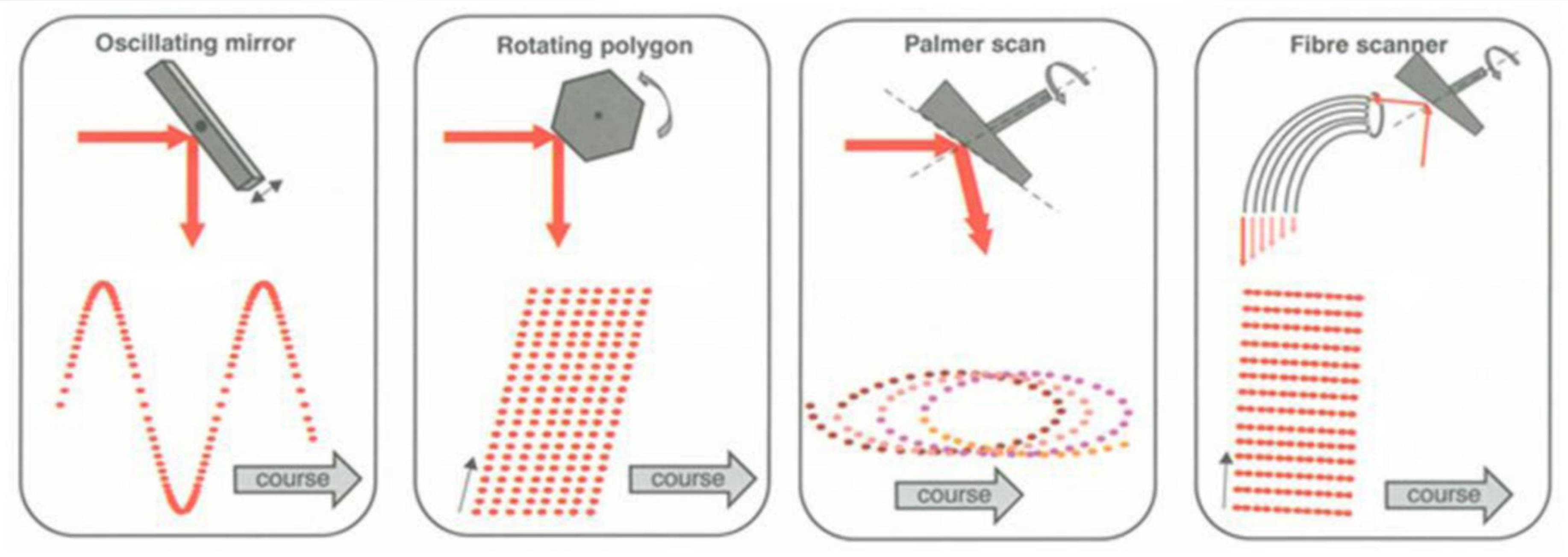
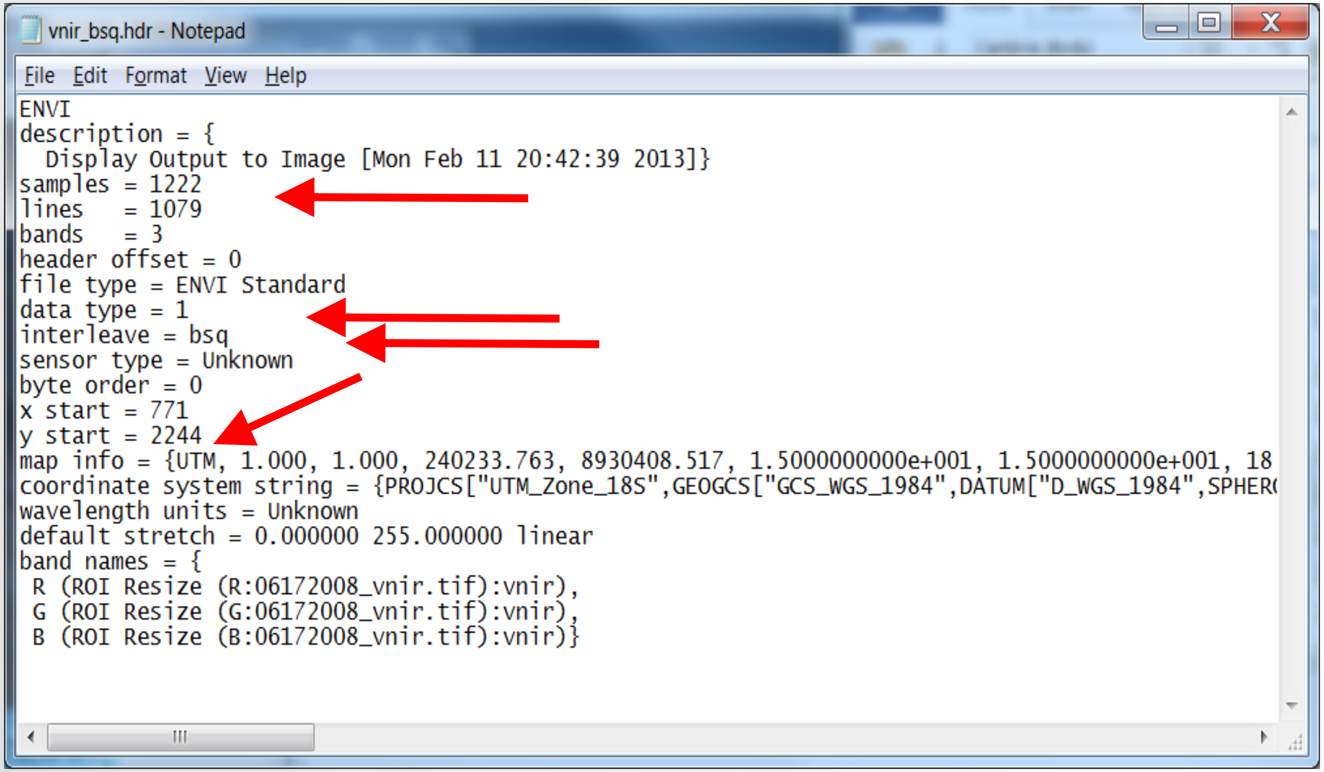


Figure from Vosselman, G.; Maas, H.G. *Airborne and Terrestrial Laser Scanning*

HEADER INFORMATION?



vnir_bsq.hdr - Notepad

File Edit Format View Help

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 B (ROI Resize (B:06172008_vnir.tif):vnir)}
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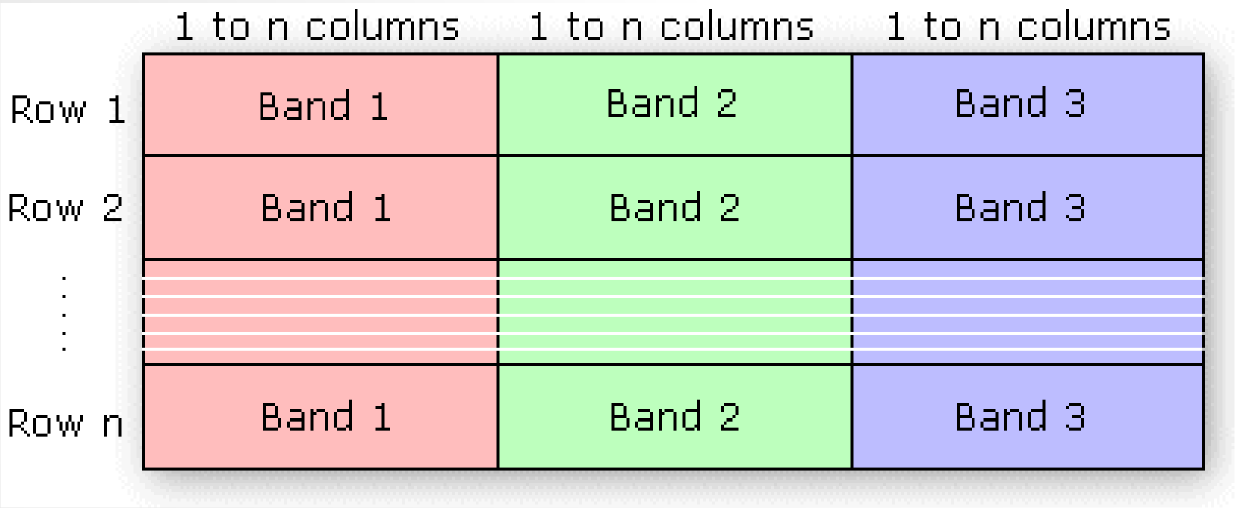
REMOTE SENSING DATA STRUCTURE

- BIL (Band Interleaved by Line)
- BIP (Band Interleaved by Pixel)
- BSQ (Band Sequential)

BIL (BAND INTERLEAVED BY LINE)



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255	255	255	255	255	255	255	255	0	0	64	64	128	128	255	255	0	0	0	0	0	0	0	0
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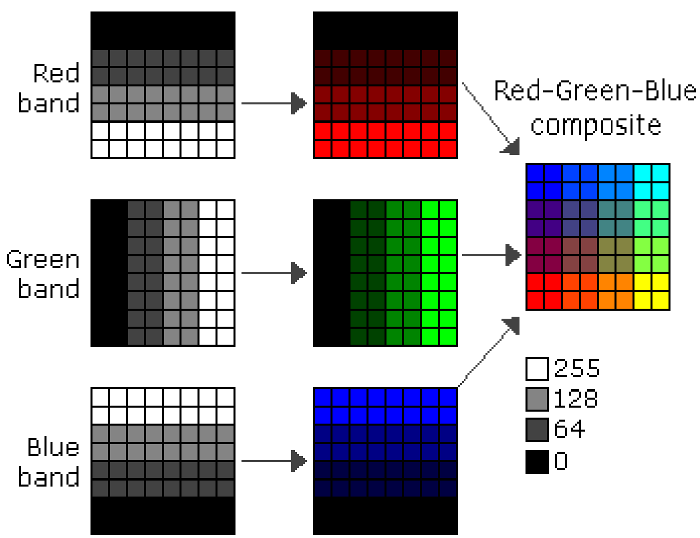
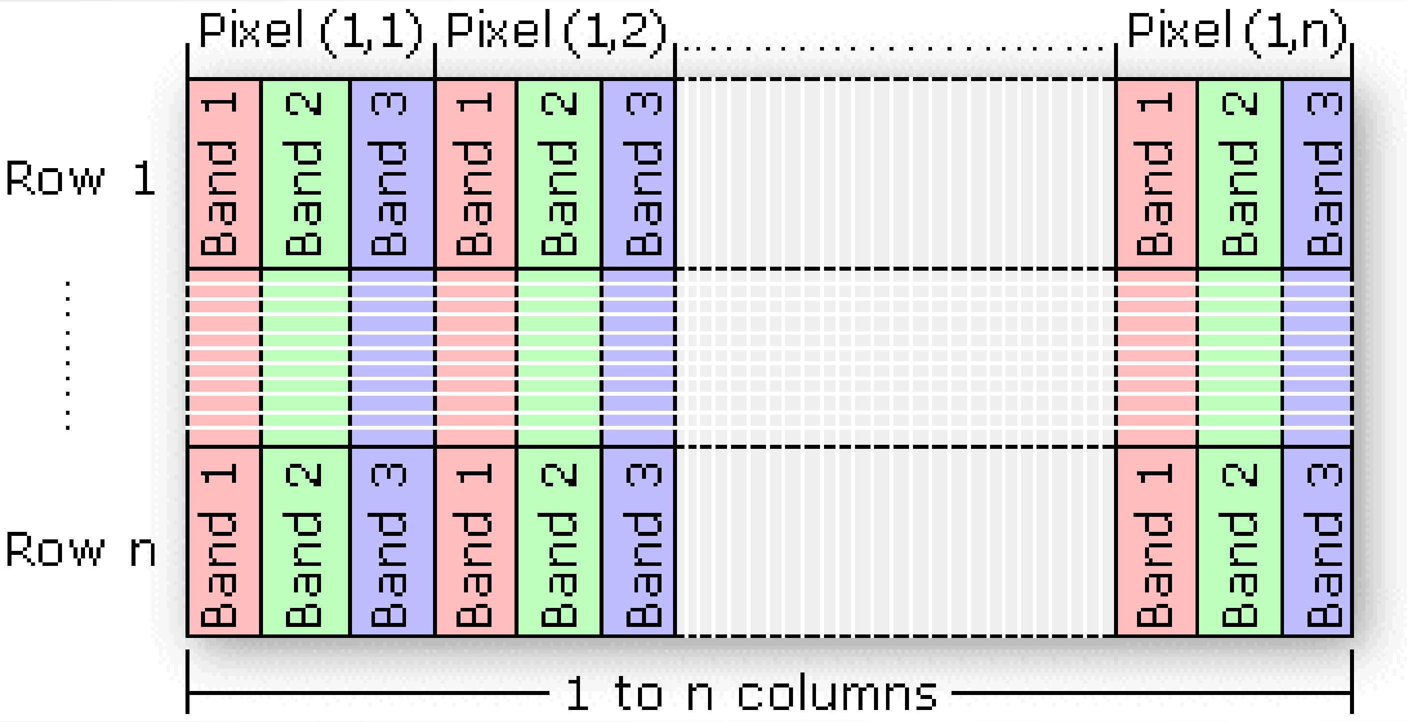


BIP (BAND INTERLEAVED BY PIXEL)



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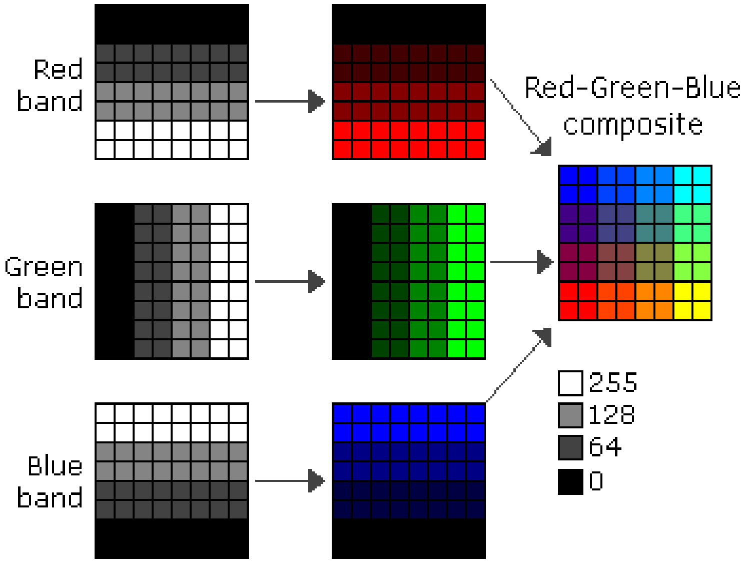
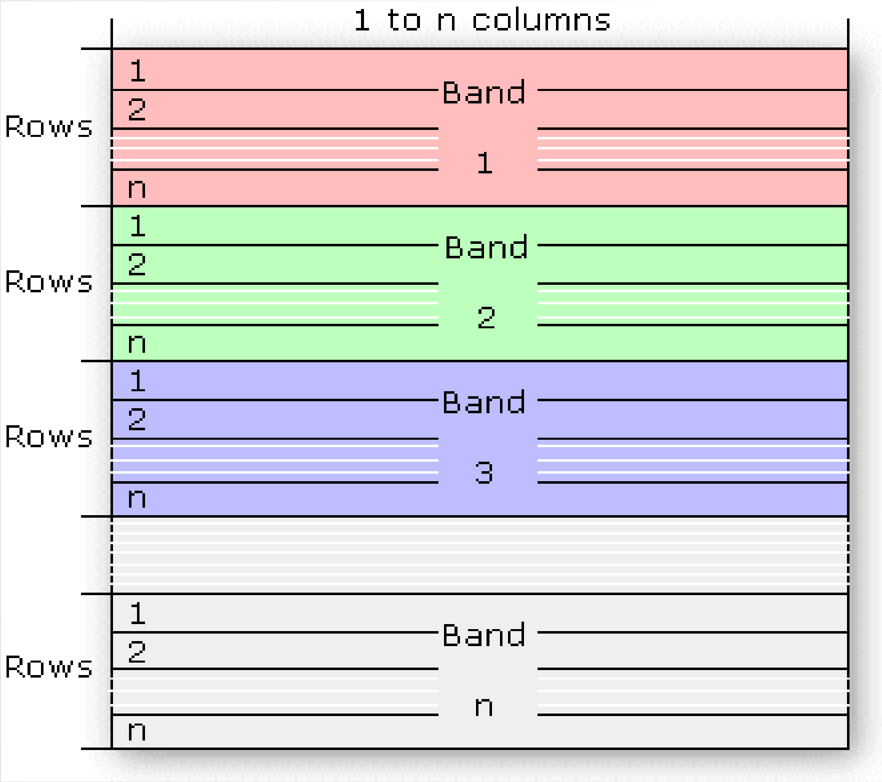


BSQ (BAND SEQUENTIAL)



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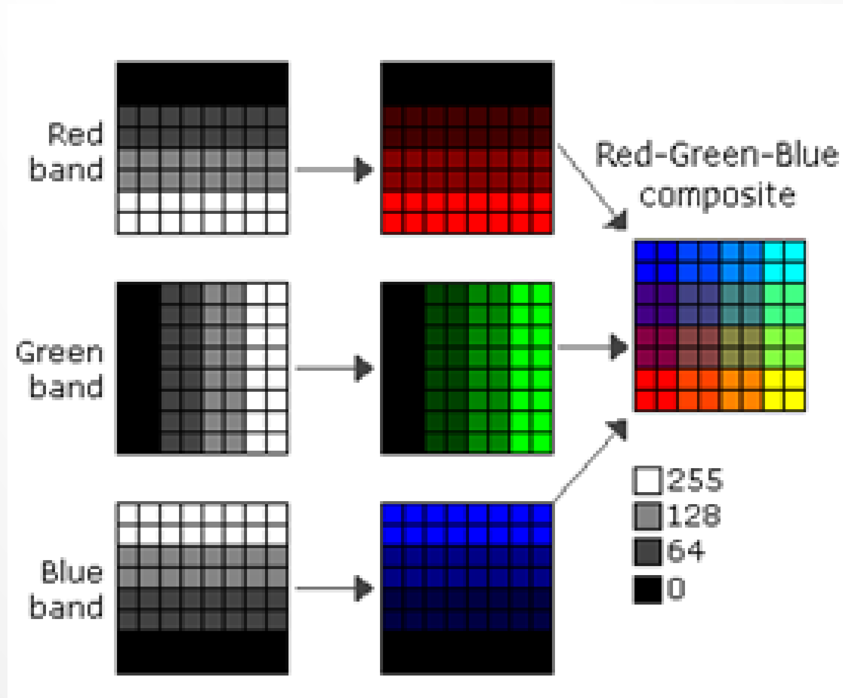


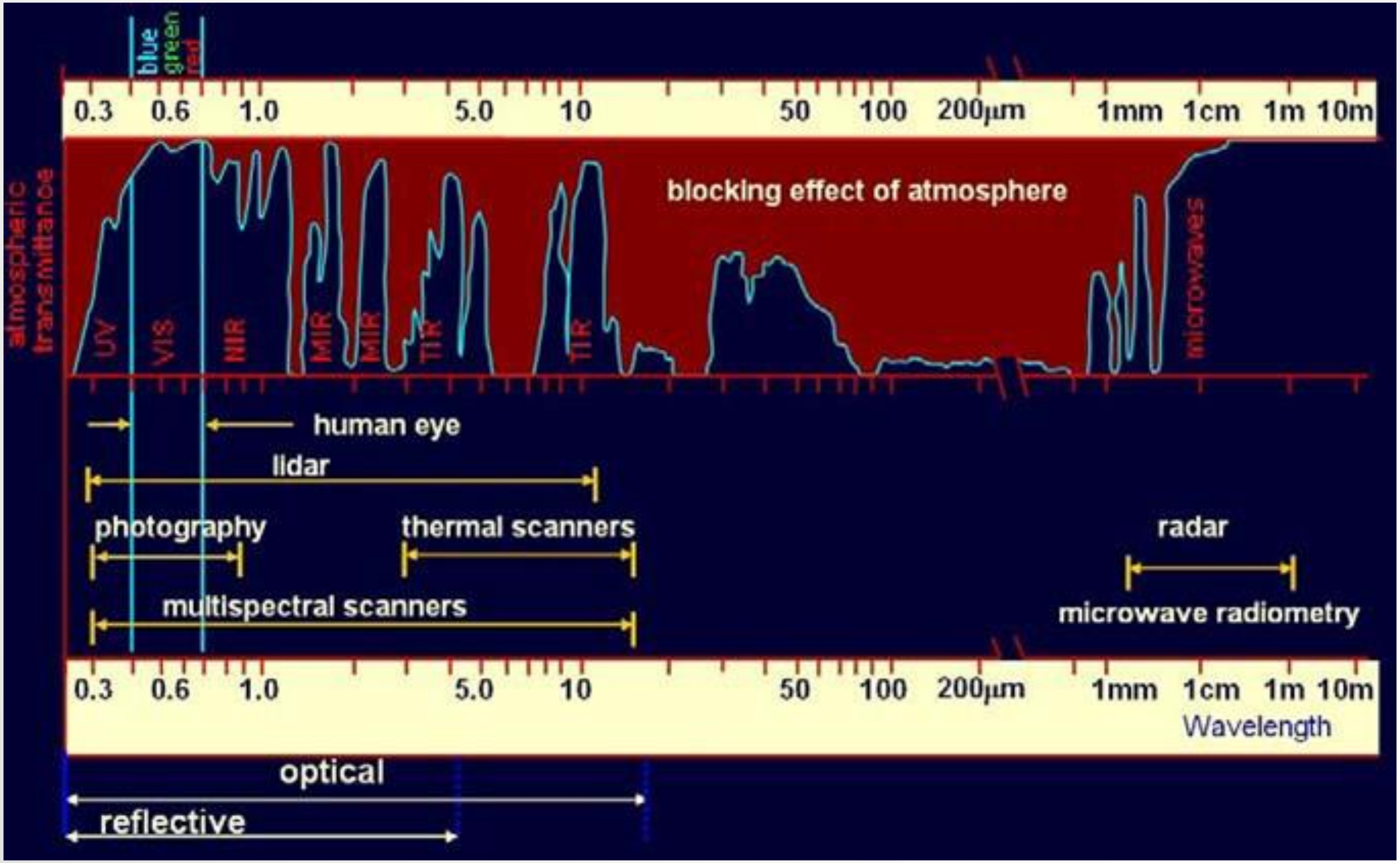
Data Acquisition Systems

Overview

Utilized portions of the electro-magnetic radiation.
- Visible band.
- Infrared band.
- LIDAR systems.
- Microwave band (RADAR).

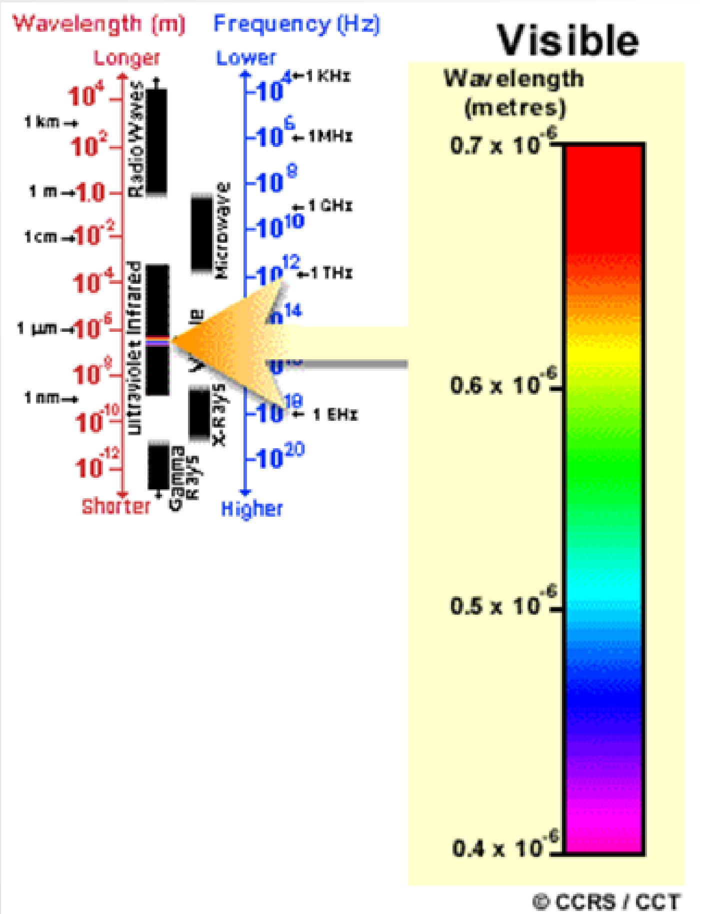
Optical sensors (scanning operational principles):
- Frame imaging systems.
- Linear array scanners.
  - Push-broom scanners.
  - Panoramic linear array scanners.
- Electro-mechanical scanners.
- LIDAR operational principles.
- RADAR operational principles.
- Discussion items:
  - Stereo-coverage for 3-D restitution.
  - Processing of B/W & color films.
  - Satellite orbits.
  - Earth observing satellites.
  - Using spectral information for recognition and classification purposes.

Utilized Portions of the EM-Spectrum



EM Radiation (Wavebands)

Sensors Operating in the Visible Band



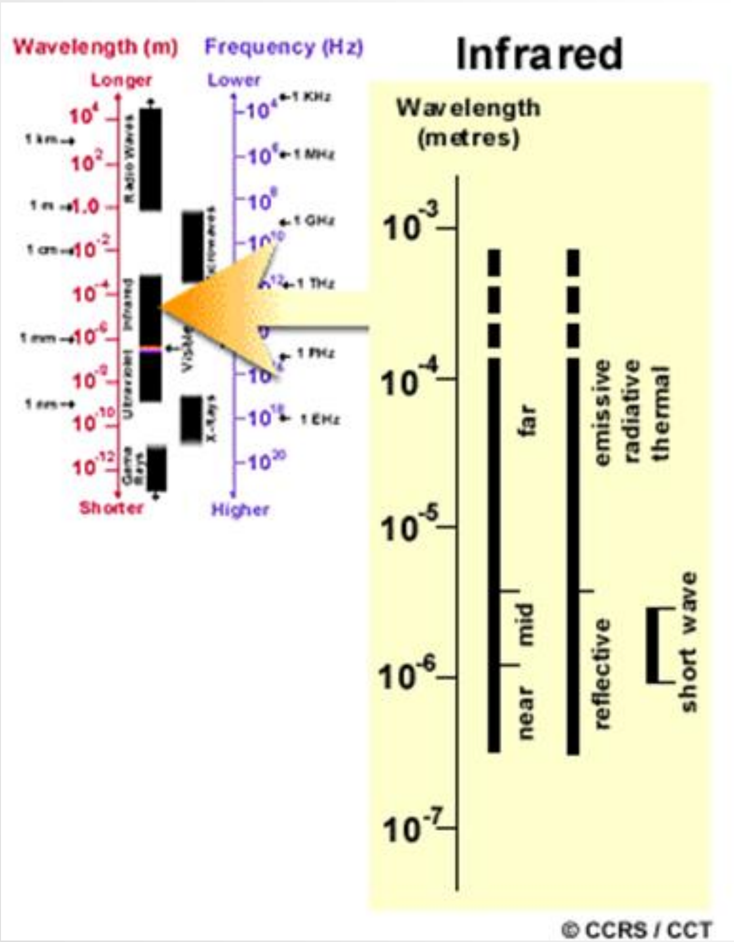
Visible Sensors

RC 30

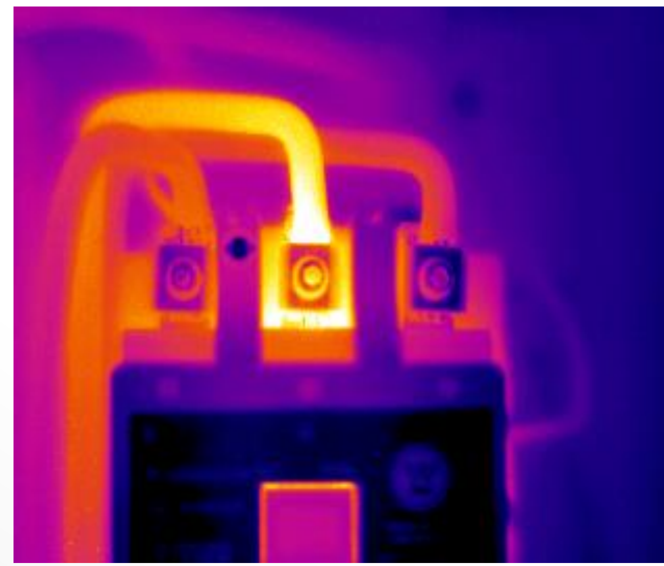
VEXCEL

ADS 80

Infrared Band

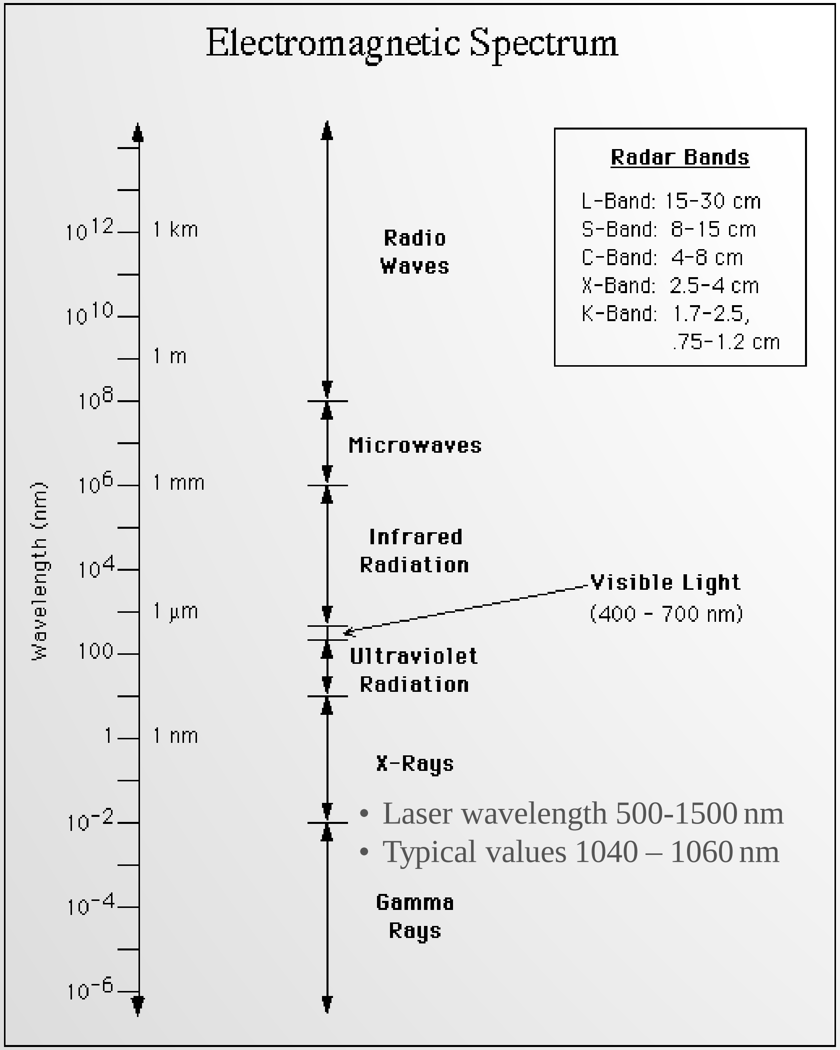


EZ THERM



Loose Connection in Breaker Box

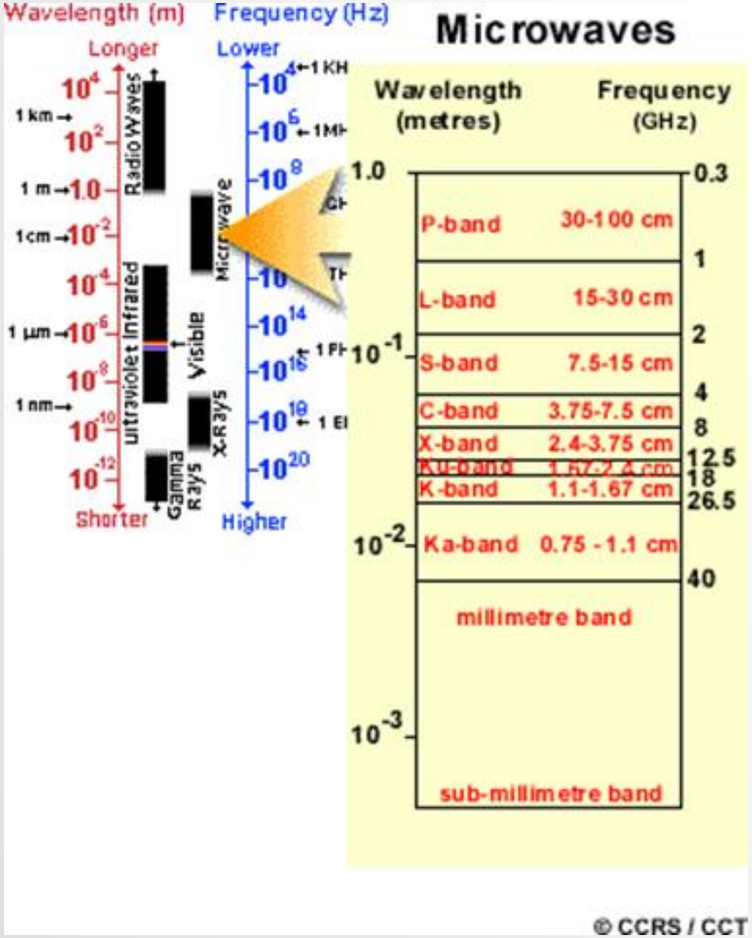
LIDAR Systems



- Laser wavelength 500-1500 nm
- Typical values 1040 – 1060 nm

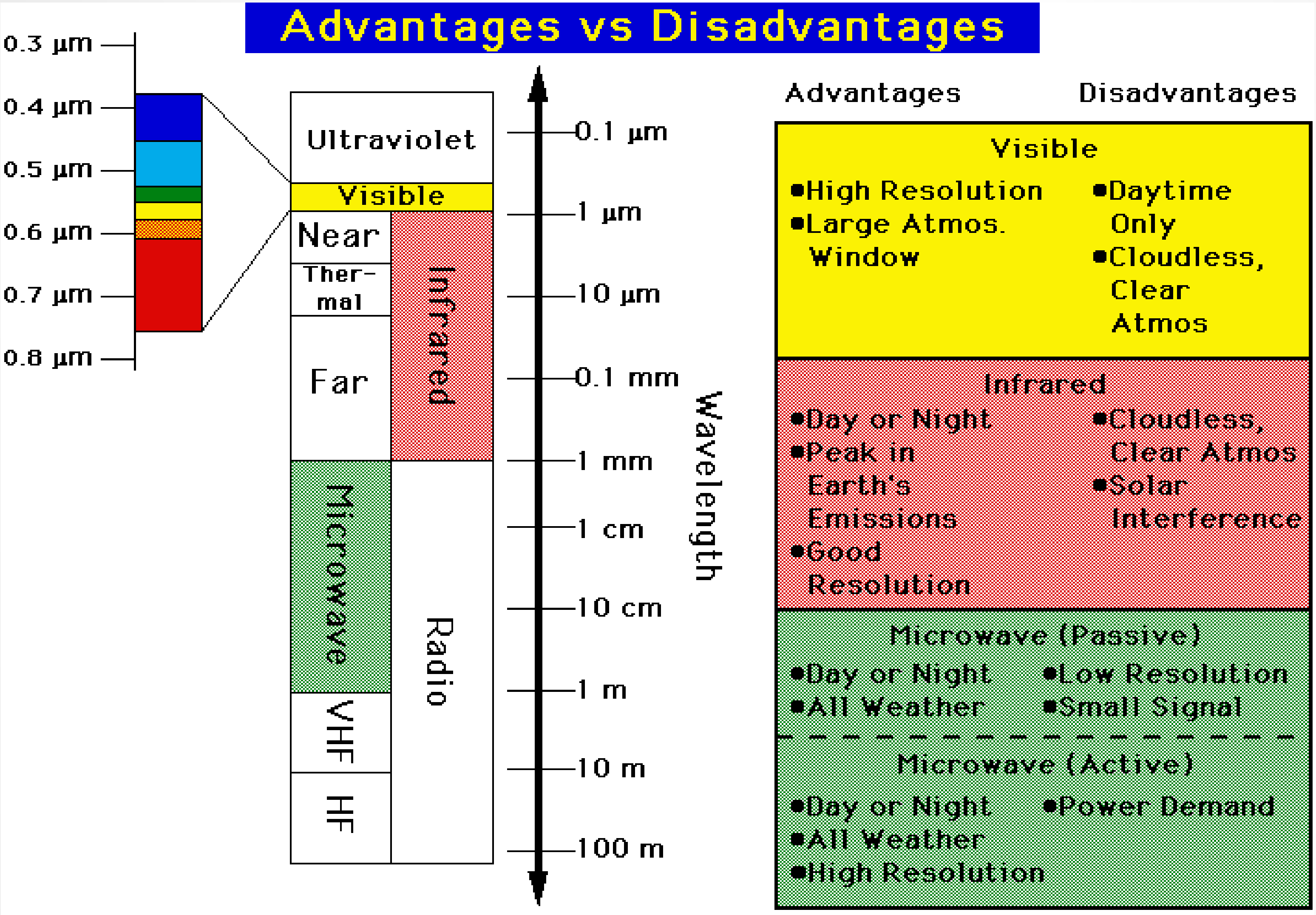
ALS 40

Microwave Sensors



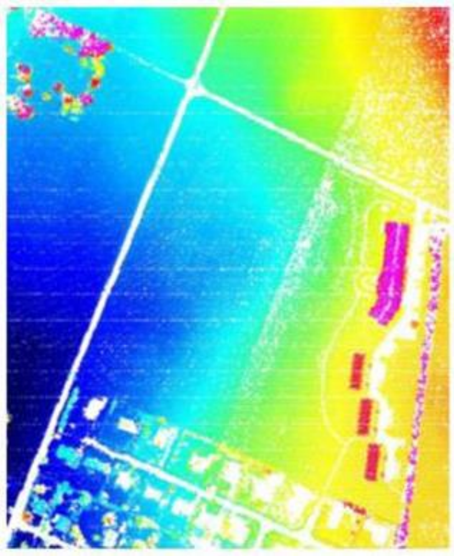
Black bulge under fuselage covers the radar antenna

EM Radiation (Wavebands)



Data

LIDAR Range & Visible Imagery

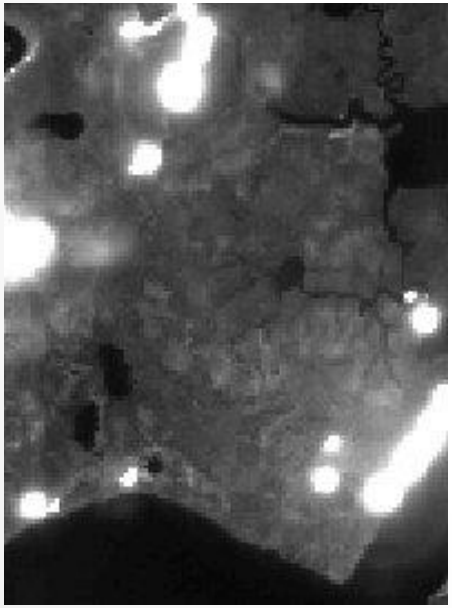


Visible & LIDAR Intensity Imagery

Data

Visible & Thermal (Far-Infrared) Imagery

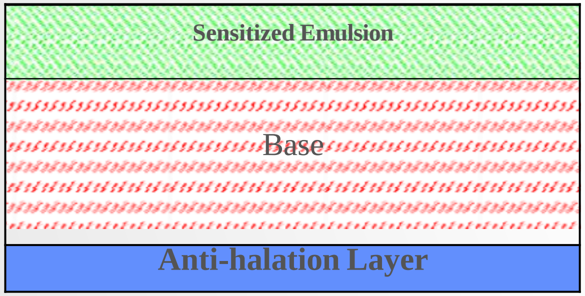
True Color
Image



Thermal
Image

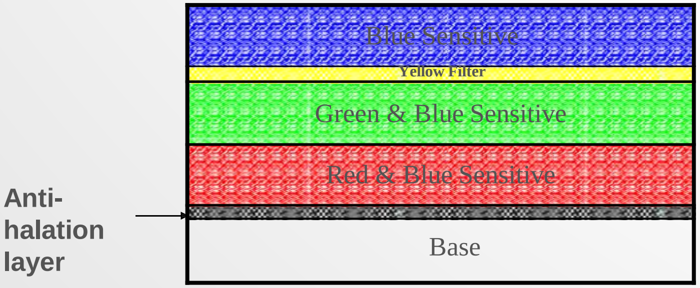
RADAR & Visible Imagery

Optical Sensors. Operational Principles

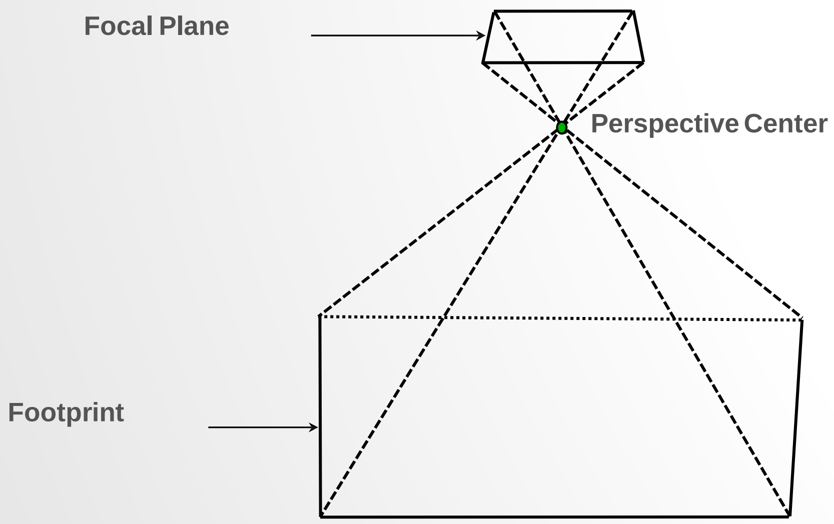


- Emulsion:
  - Micro-thin layer of gelatin in which light-sensitive ingredients (silver bromide crystals) are suspended.
- Base:
  - Transparent flexible sheet on which light sensitive emulsion is coated.
- Anti-halation layer:
  - Prevents transmitted light through the base from reflecting back towards the emulsion.

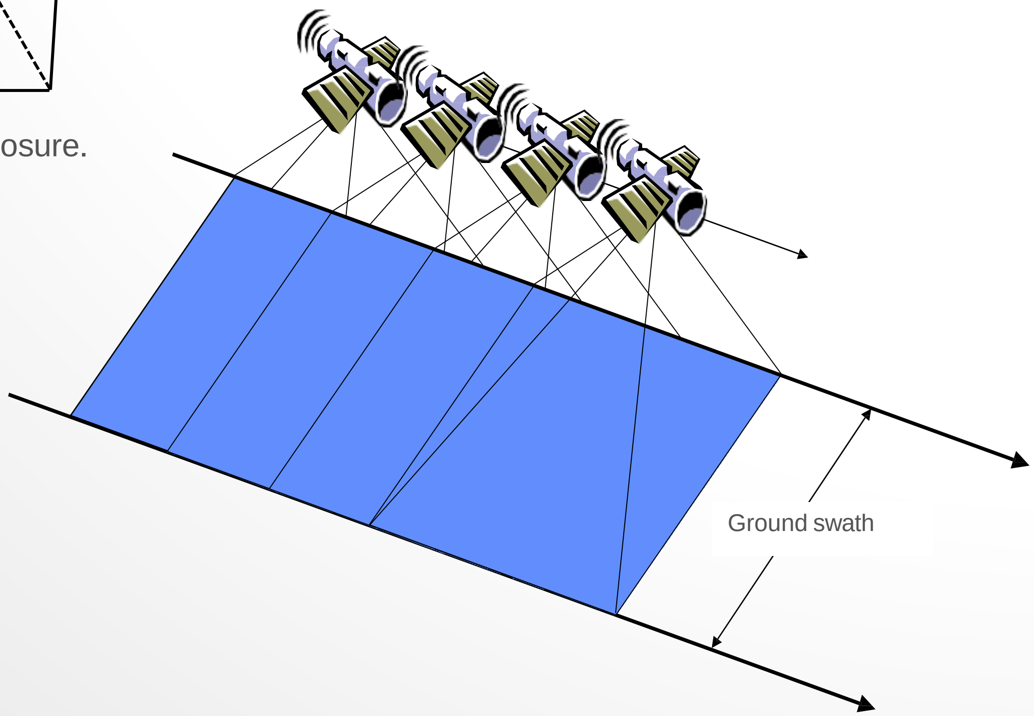
- Negative film:
  - Bright areas in the object space appear dark and dark areas appear bright.
  - Directions are inverted.
- Inverse film (diapositive):
  - Bright areas in the object space appear bright and dark areas appear dark.
  - Image and object space directions are compatible.



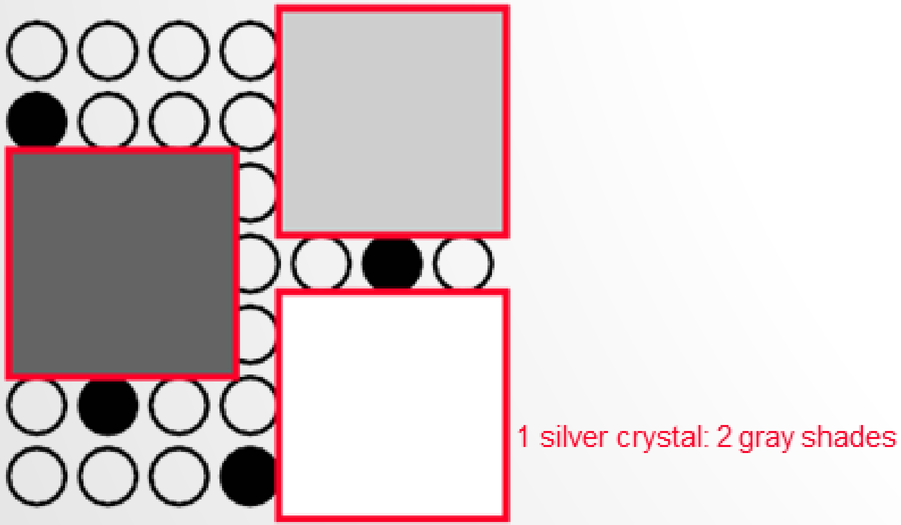
Frame Camera

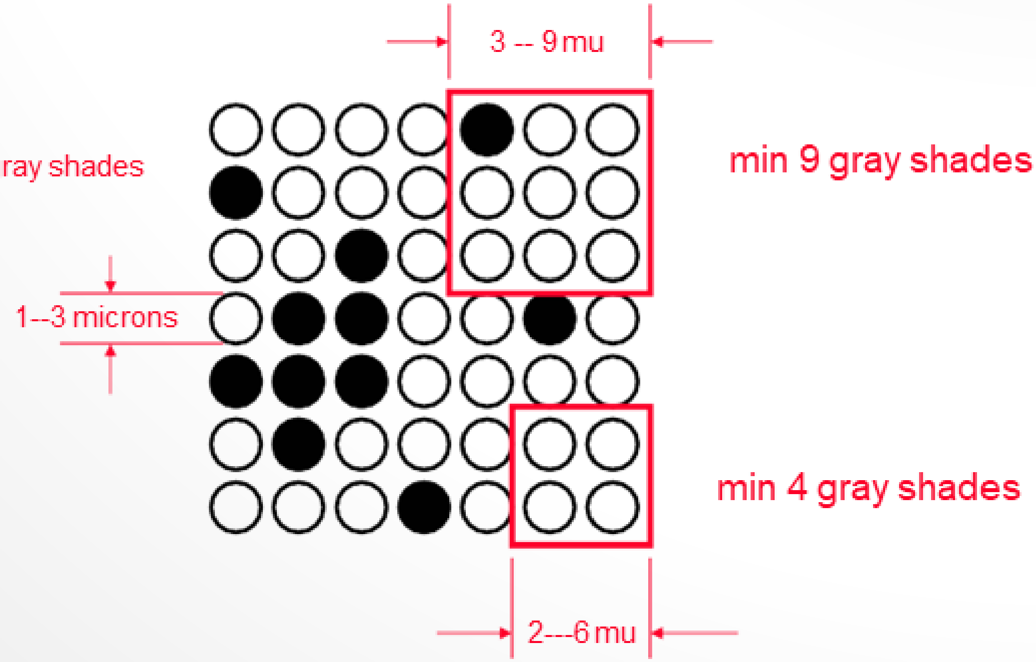


- The image footprint is captured through a single exposure.

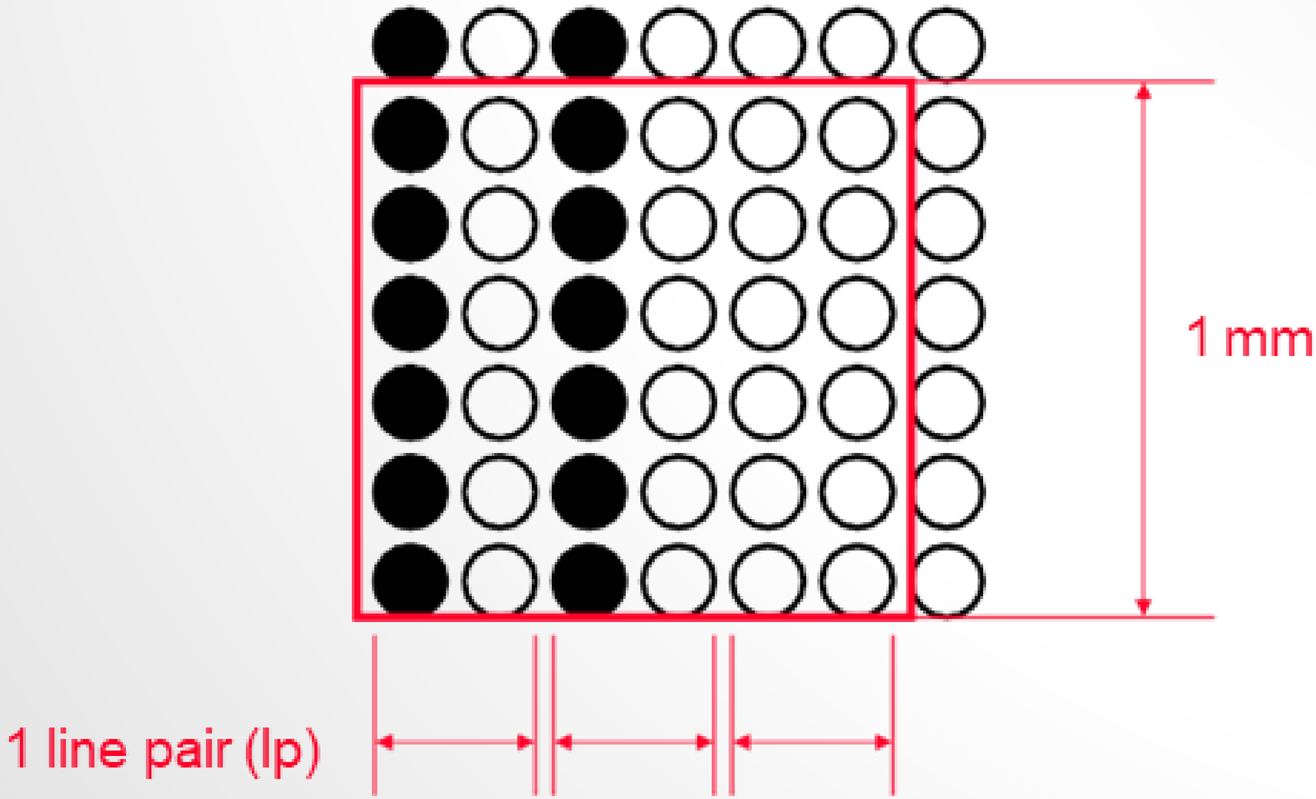


Radiometric Resolution: Perceiving Gray Shades

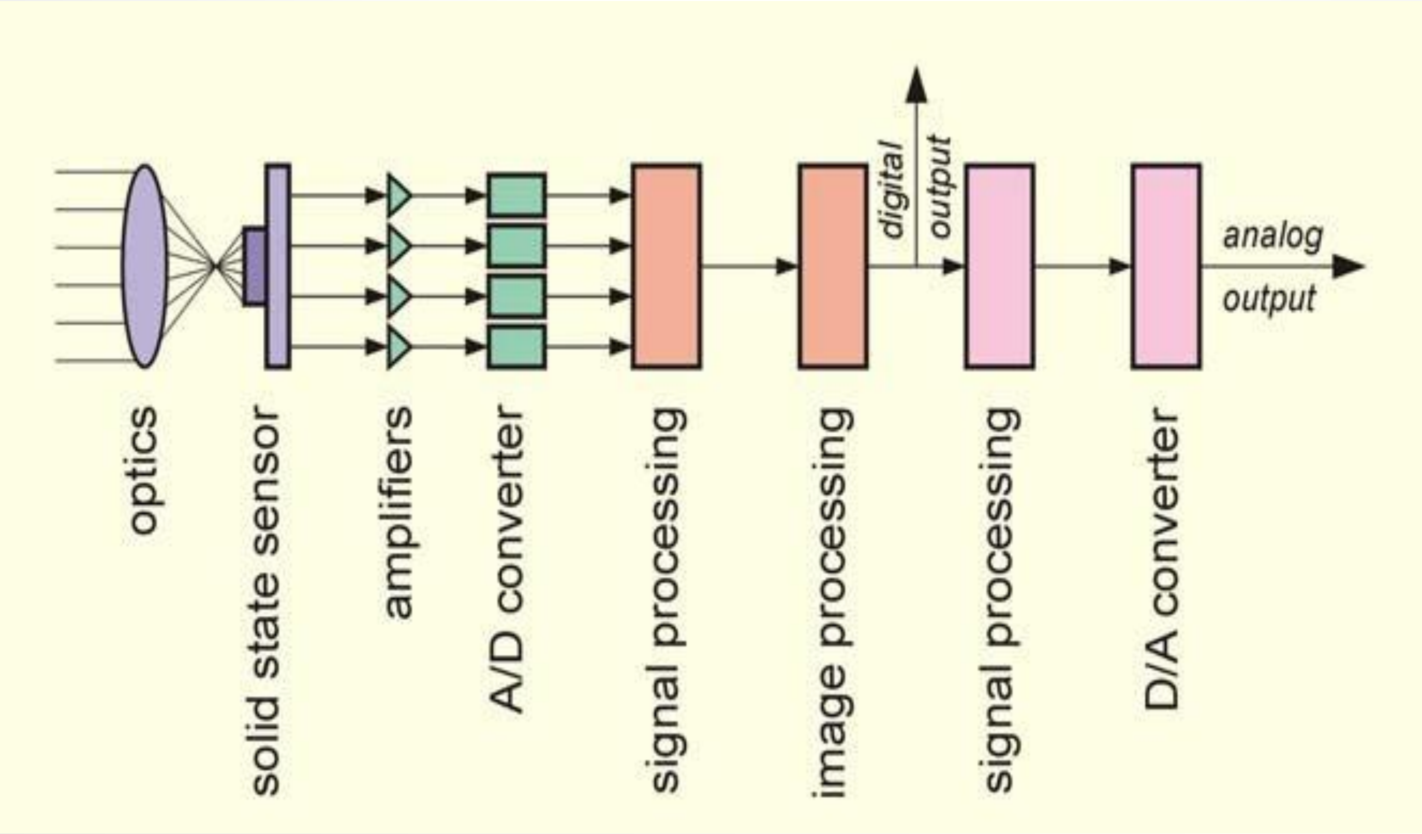




Spatial Resolution: lp/mm



Digital Cameras



Block Diagram of a Digital Camera

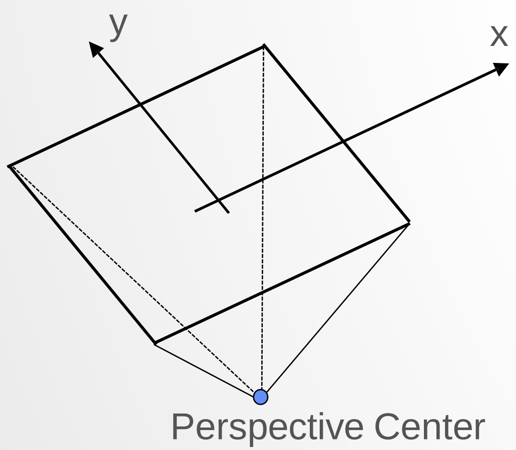
Film Resolution and Pixel Size

- Film resolution
  - –Fine grained emulsions > 100 lp/mm
  - –Including atmosphere + optics ~100 lp/mm
  - –Hazy conditions 40 lp/mm
- Pixel Size
  - –Pixel size = 1/2 of smallest detail to be resolved
  - –Smallest detail: lp/mm
  - –Pixel size = 1/(2*lp/mm)
    - 100 lp/mm pixel size = 1000 μm/200 = 5 μm
    - 40 lp/mm pixel size = 1000 μm/80 = 12.5 μm

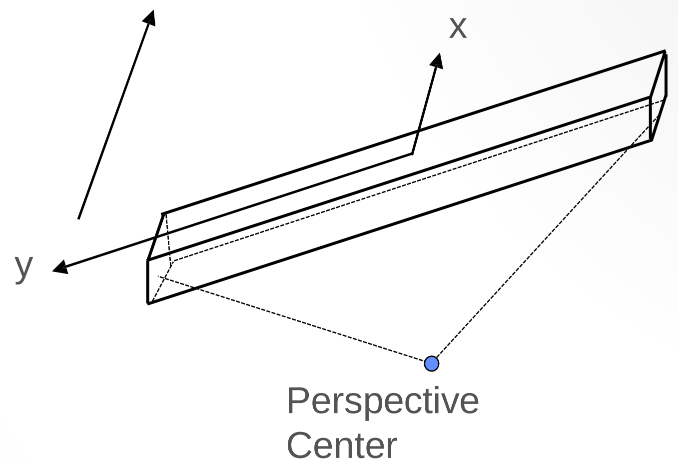
Resolution and Storage Requirement

Pixel Size [micron]	Number of Pixels	Storage Requirement (uncompressed) [MB]
960	240 • 240	0.058
480	480 • 480	0.230
240	960 • 960	0.922
120	1920 • 1920	3.686
60	3840 • 3840	14.746
30	7680 • 7680	58.982
15	15360 • 15360	235.931
7.5	30720 • 30720	943.721

Linear Array Scanners



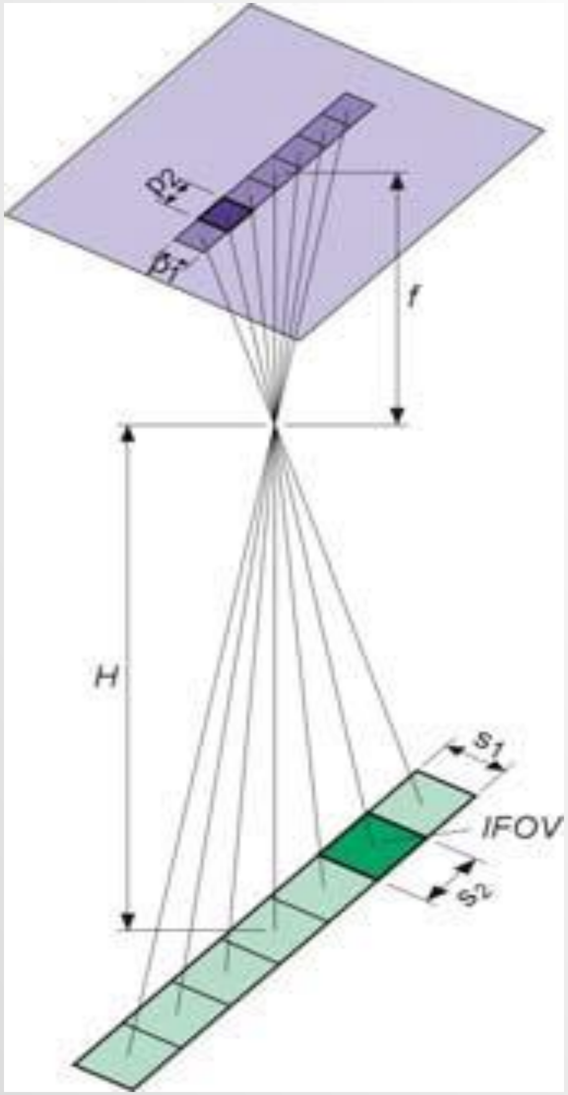
Frame Camera

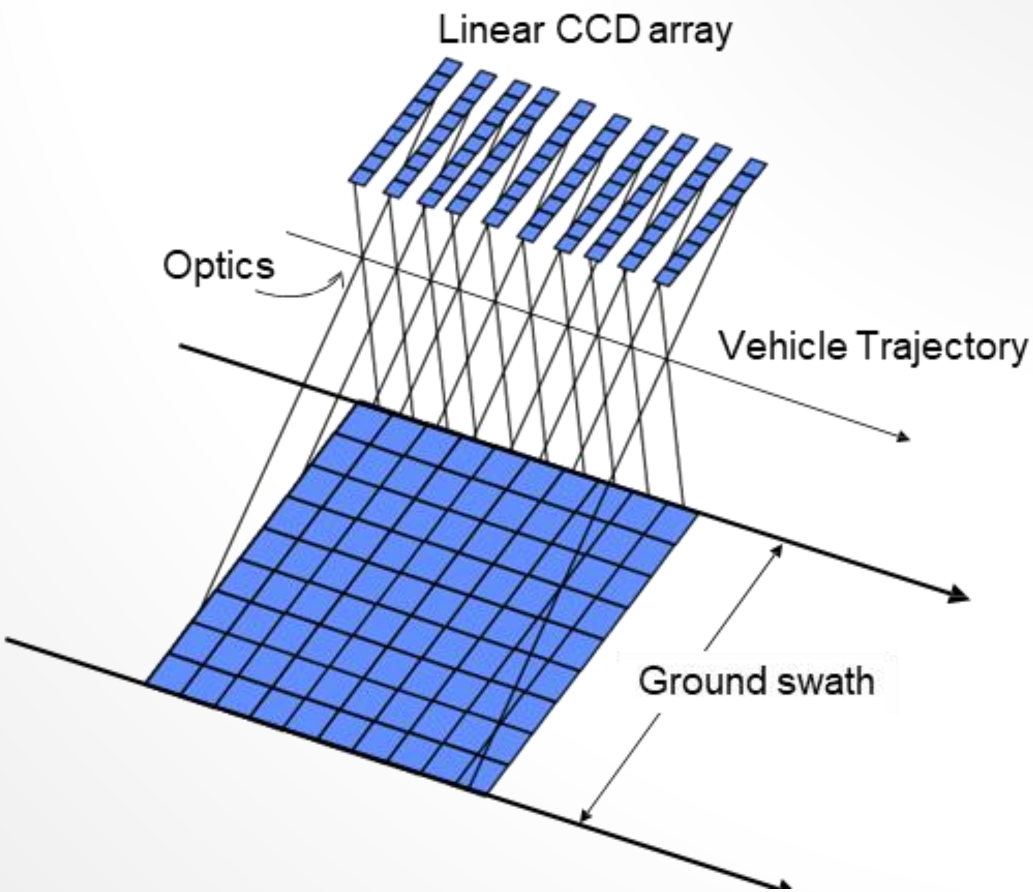


Single Push Broom Scanner

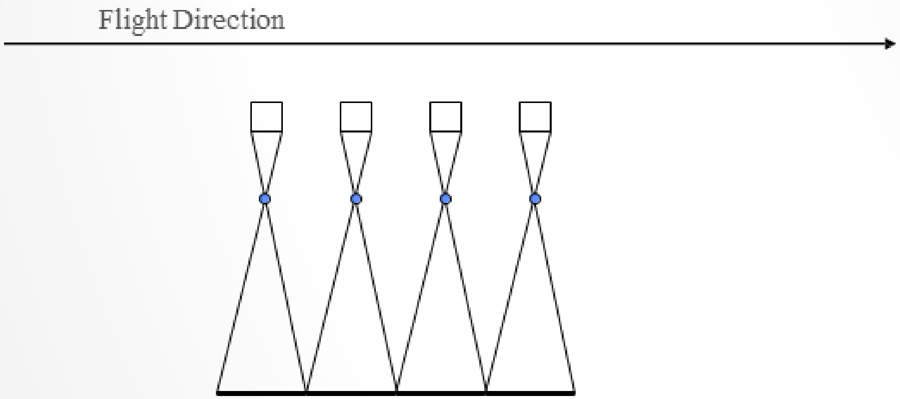
- Digital frame cameras capture images through a single exposure of a two-dimensional CCD array.
- Linear array scanners capture scenes with large ground coverage and high geometric and radiometric resolutions through multiple exposures of few scan lines along the focal plane.
- Successive coverage of different areas on the ground is achieved either through:
  - The motion of the imaging platform (push-broom scanners).
  - The motion of the sensor relative to the imaging platform (panoramic scanners).

Principle of Single Push Broom Scanner

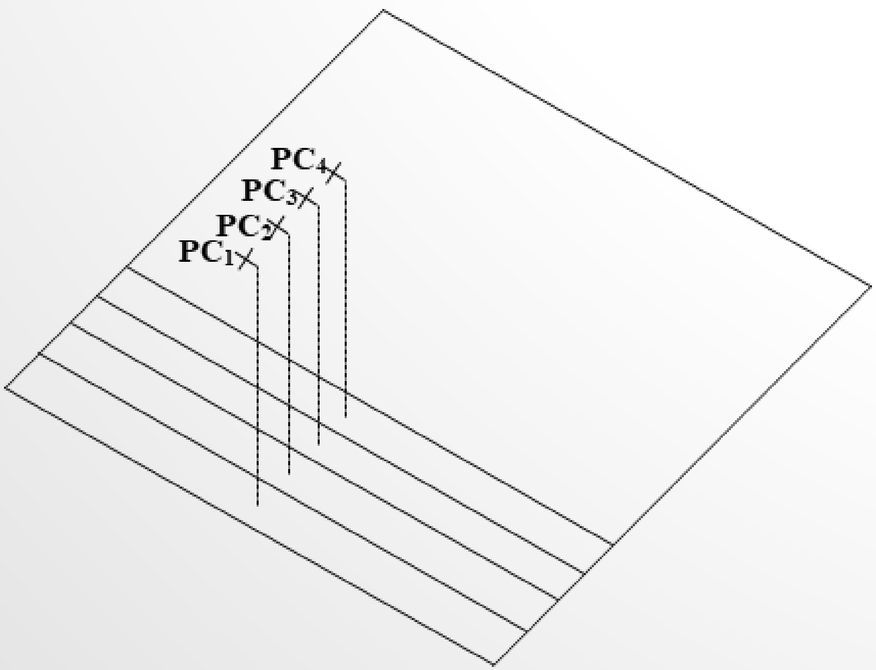




Push Broom Scanner: Successive Coverage



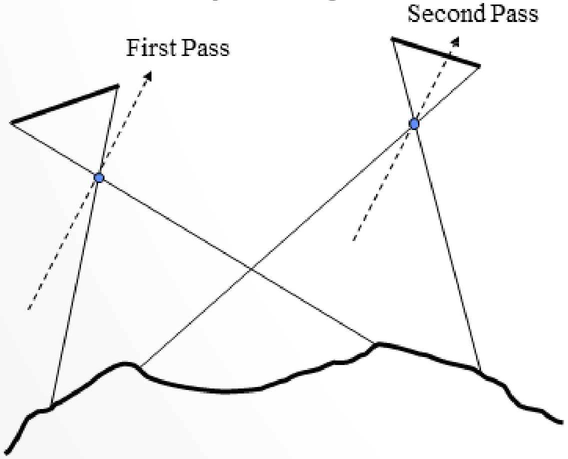
$$V \times \Delta t = \text{pixel size} \times H/c$$



Single Push Broom Scanner Stereo Coverage

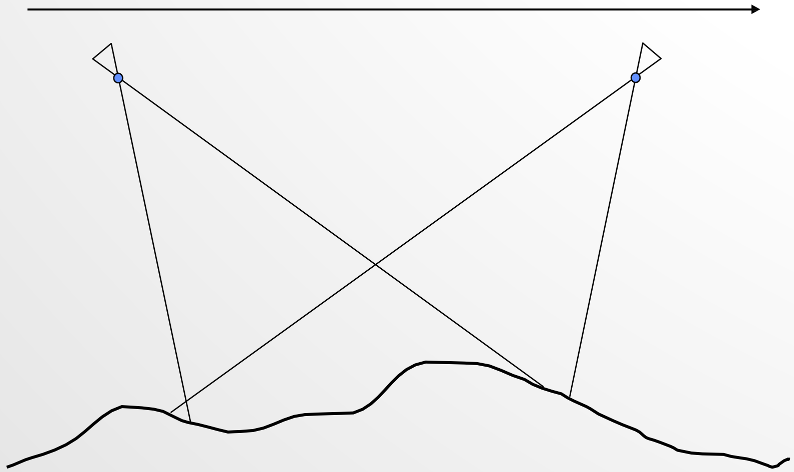
SPOT Stereo Coverage

- Stereo coverage is achieved by tilting the sensor across the flight direction.

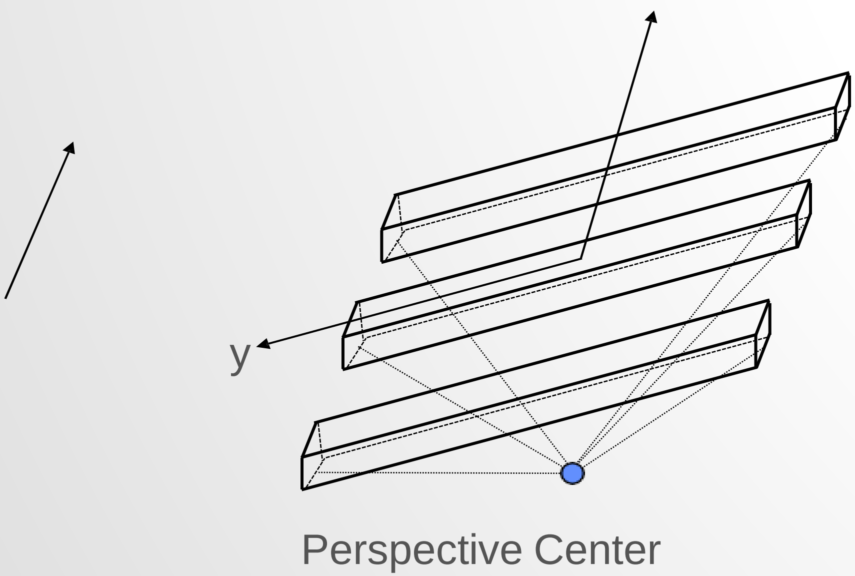


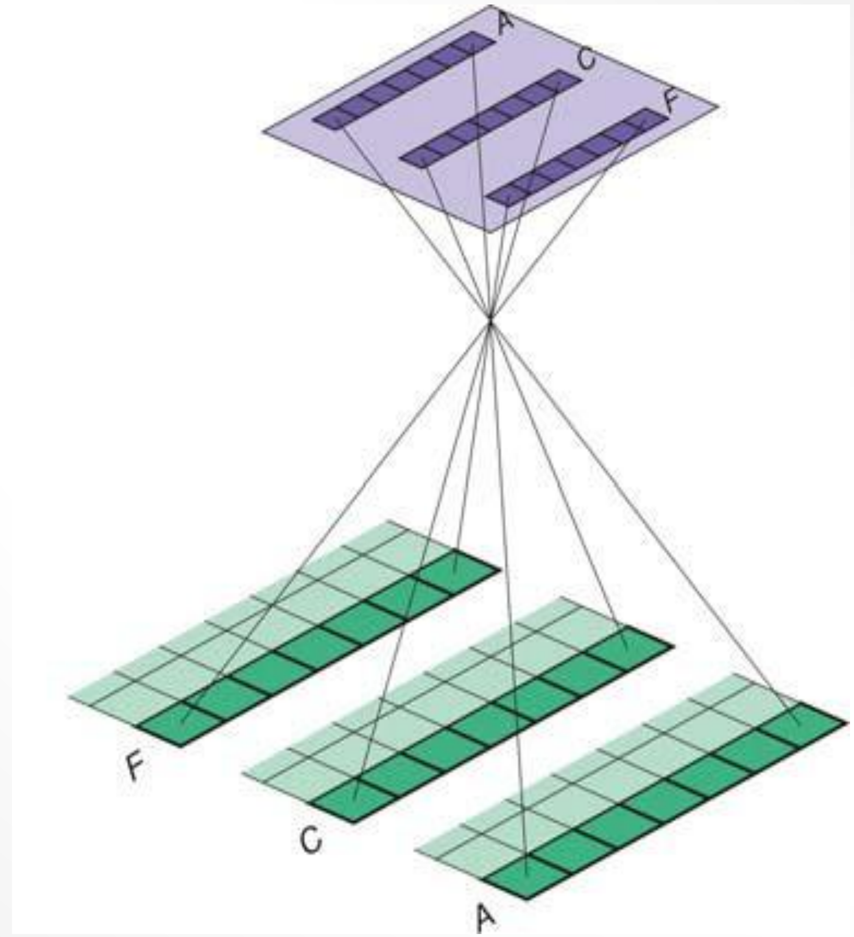
IKONOS Stereo-Coverage

- Stereo coverage is achieved by tilting the sensor along the flight direction.

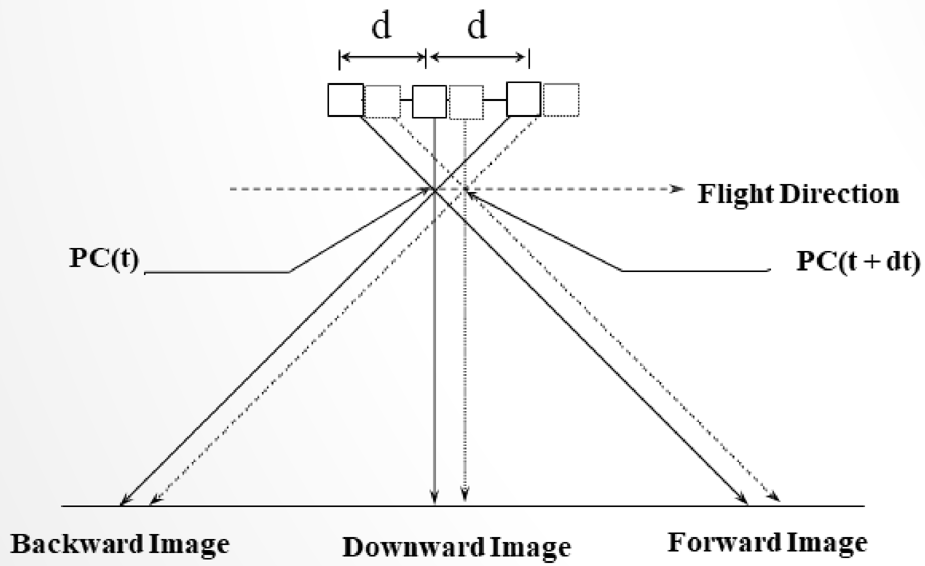


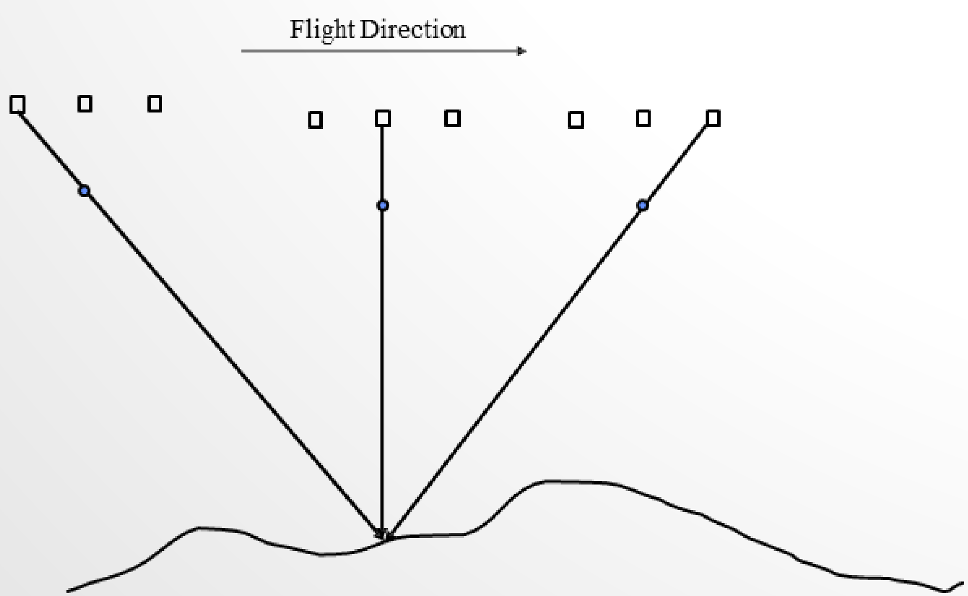
Principle of Three-Line Scanner





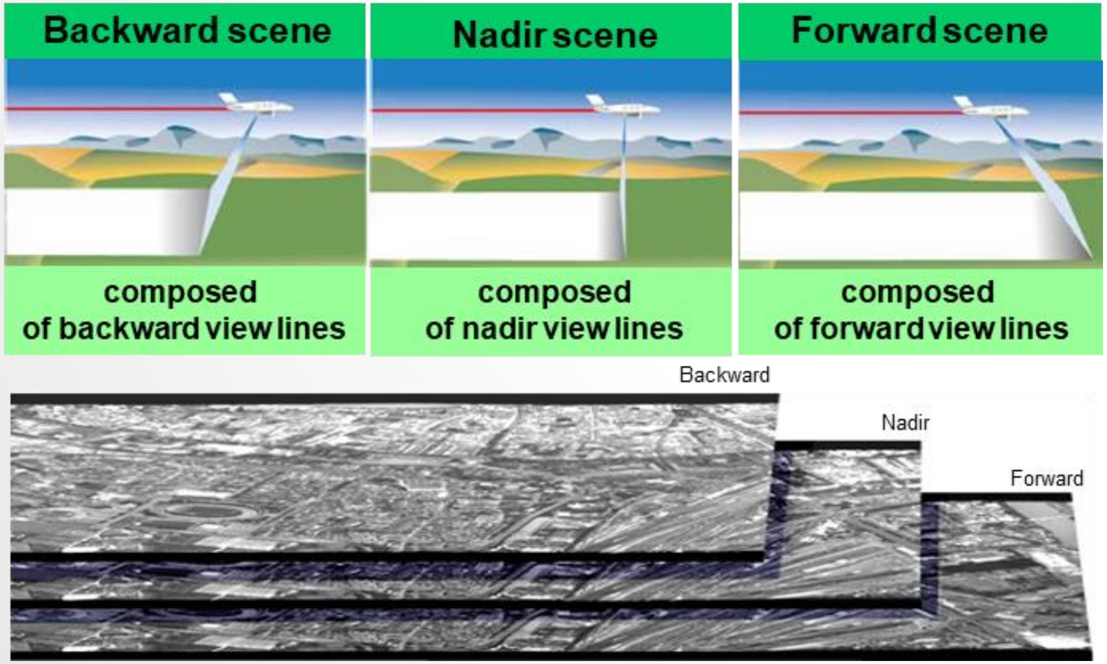
Three-Line Scanner (MOMS)





- Triple coverage is achieved by having three scanners in the focal plane.

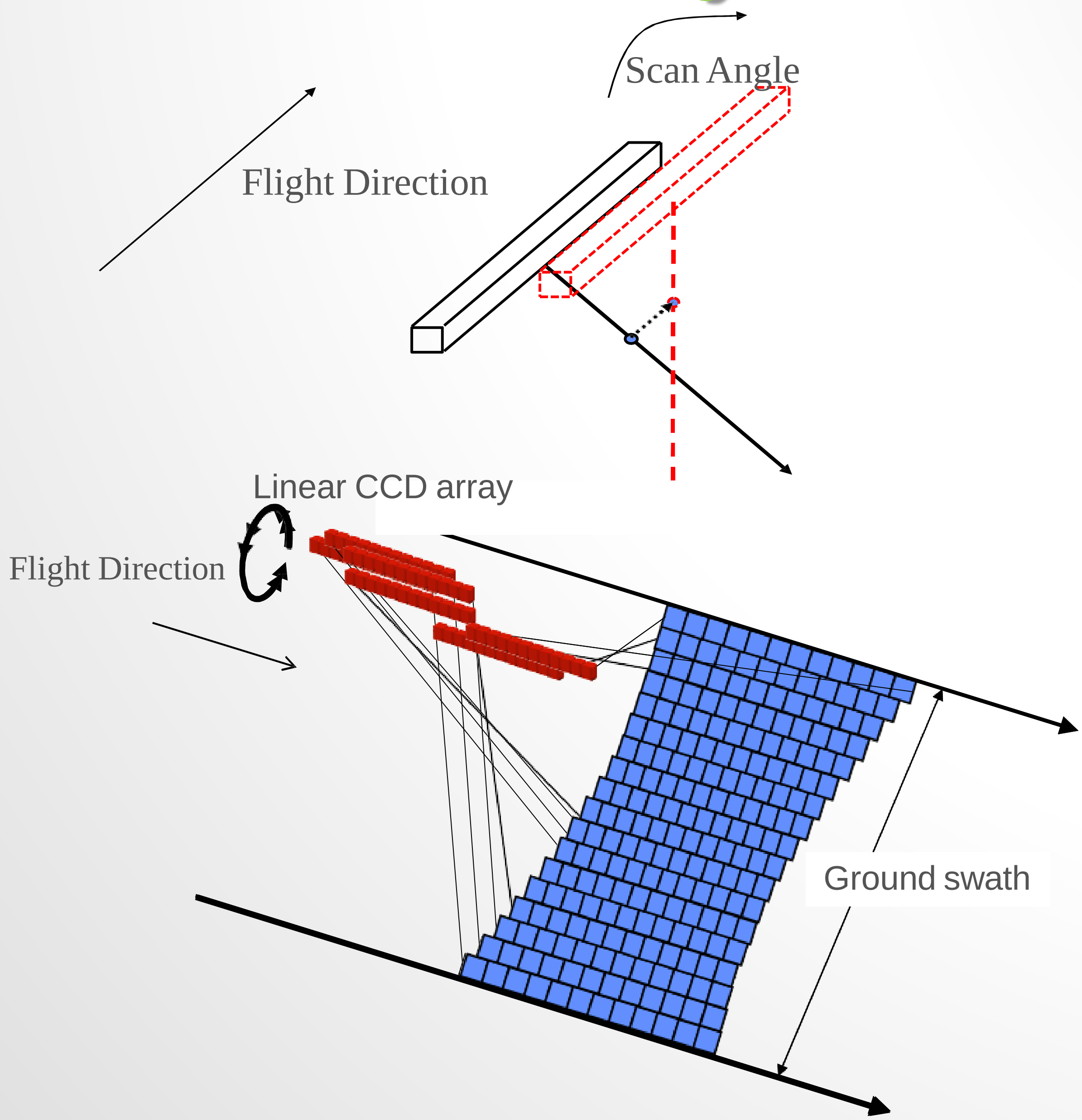
Three-Line Scanner (Triple Coverage)



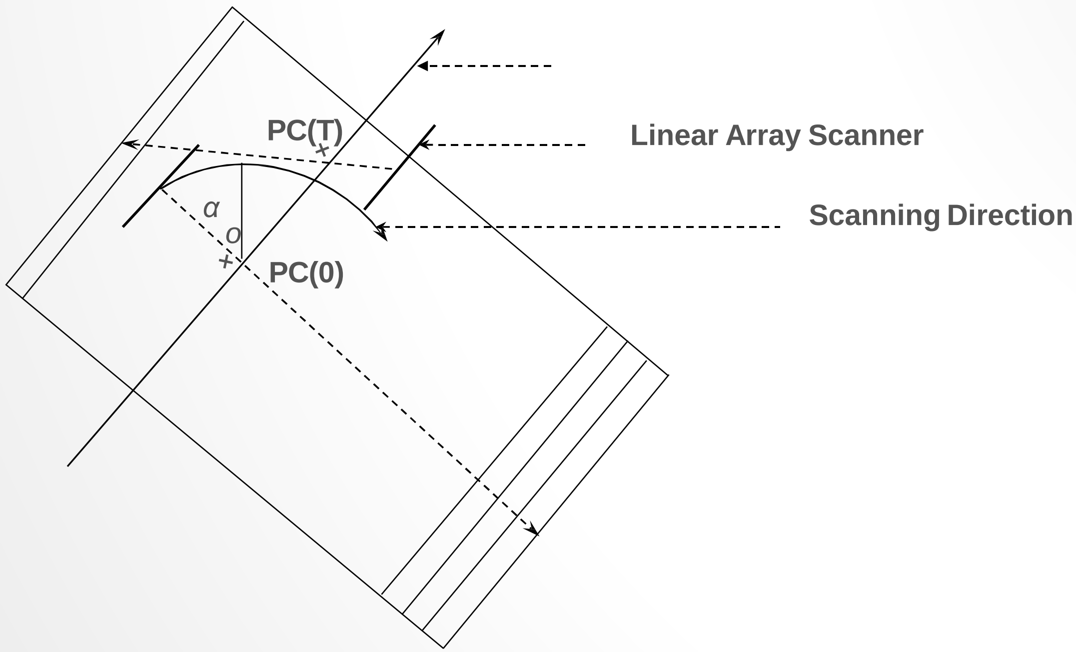
Single/Three-Line Push Broom Scanners: Stereo Coverage

- Stereo coverage can be obtained through:
  - Tilting the sensor across the flight direction (SPOT).
    - The stereo is captured in two different orbits.
    - Problem: Significant time gap between the stereo images (possible variations in the object space and imaging conditions).
  - Tilting the sensor along the flight direction (IKONOS).
    - The stereo is captured along the same orbit.
    - Short time gap between the stereo-images (few seconds).
    - Problem: reduced geometric resolution (scale = $f * \cos(\alpha) / H$).
    - Problem: Non-continuous stereo-coverage.
  - Implementing more than one scan line in the focal plane (MOMS & ADS 40).
    - The stereo images are captured along the same flight line.
    - For three-line scanners, triple coverage is possible.
    - Short time gap between the stereo images (few seconds).
    - Continuous stereo/triple coverage.
    - Same geometric resolution (scale = f/H).
    - Problem: Reduced radiometric quality for the forward and backward looking scanners (quality degrades as we move away from the camera optical axis).

Panoramic Linear Array Scanner

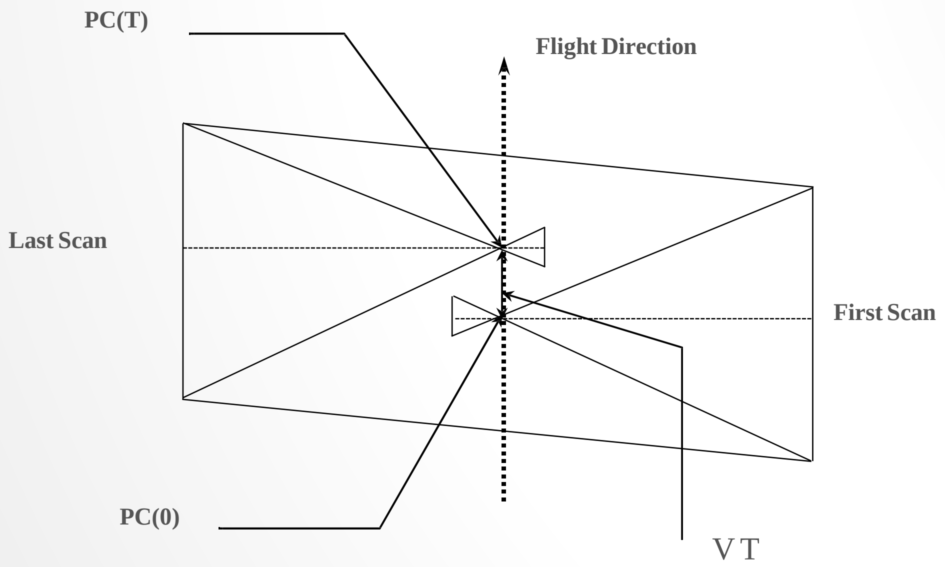


Panoramic Linear Array Scanner



- The scan line is parallel to the flight direction.
- Coverage of successive areas on the ground is established by rotating the sensor across the flight direction.
- The imaging platform moves forward as we rotate the scan line across the flight direction.
- Question:
  - What is the shape of the scene footprint?

Scene Footprint



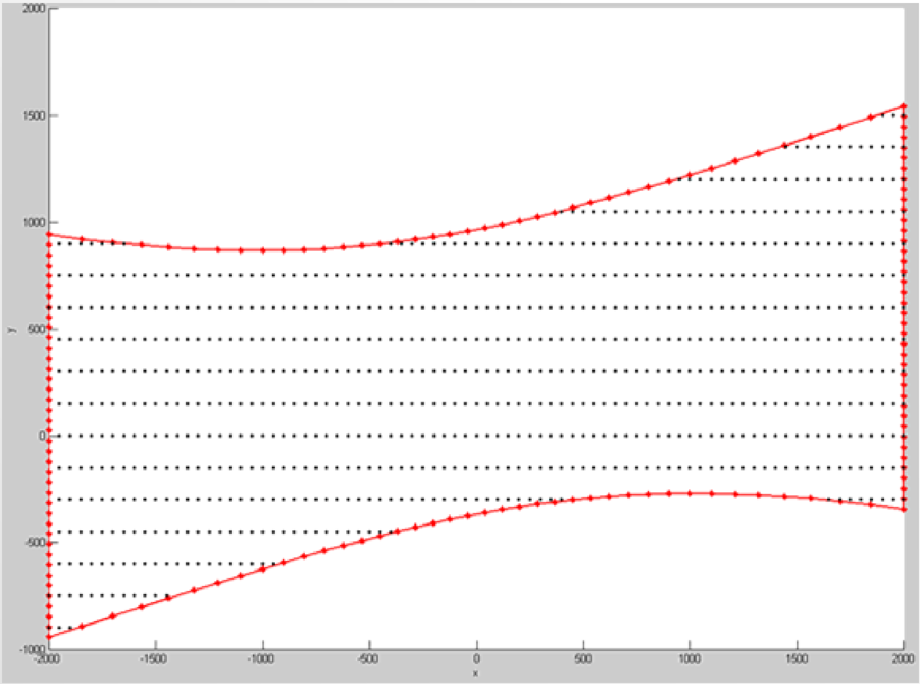


Image Coordinate Layout

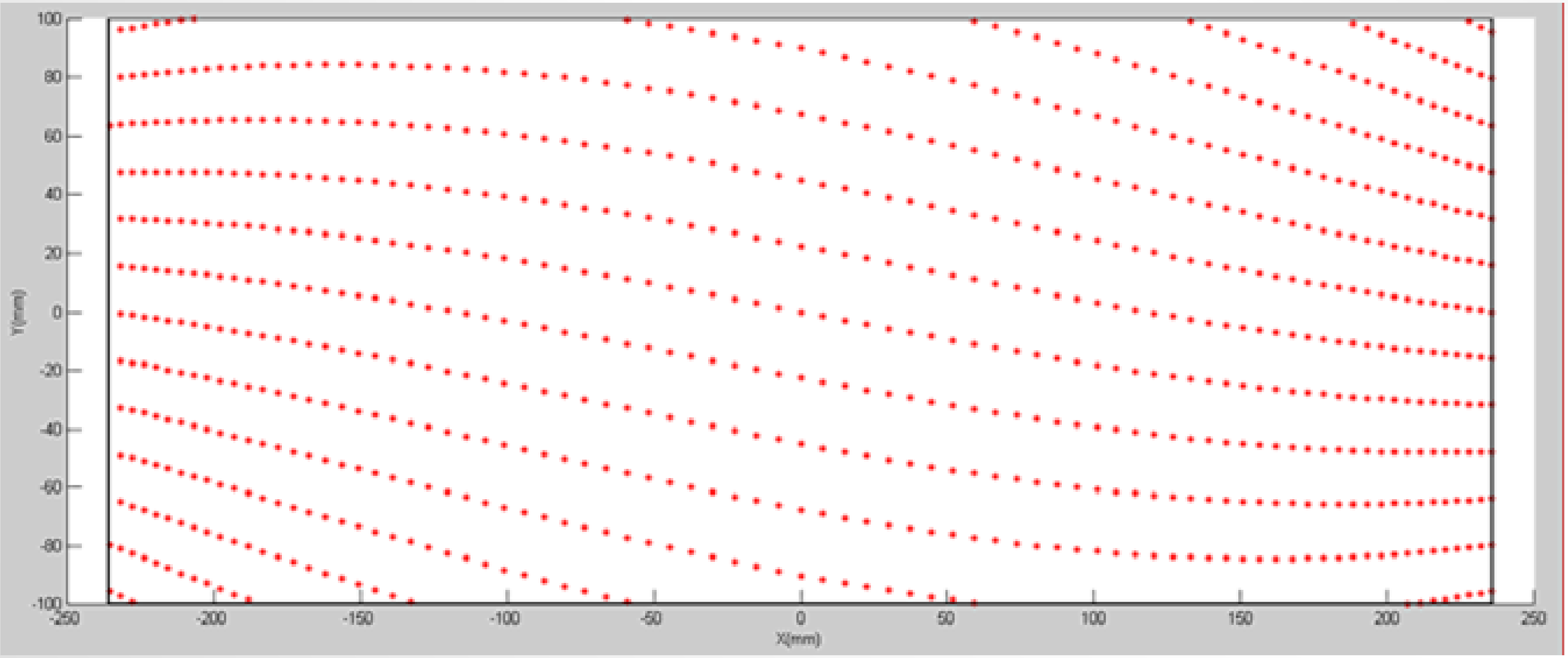
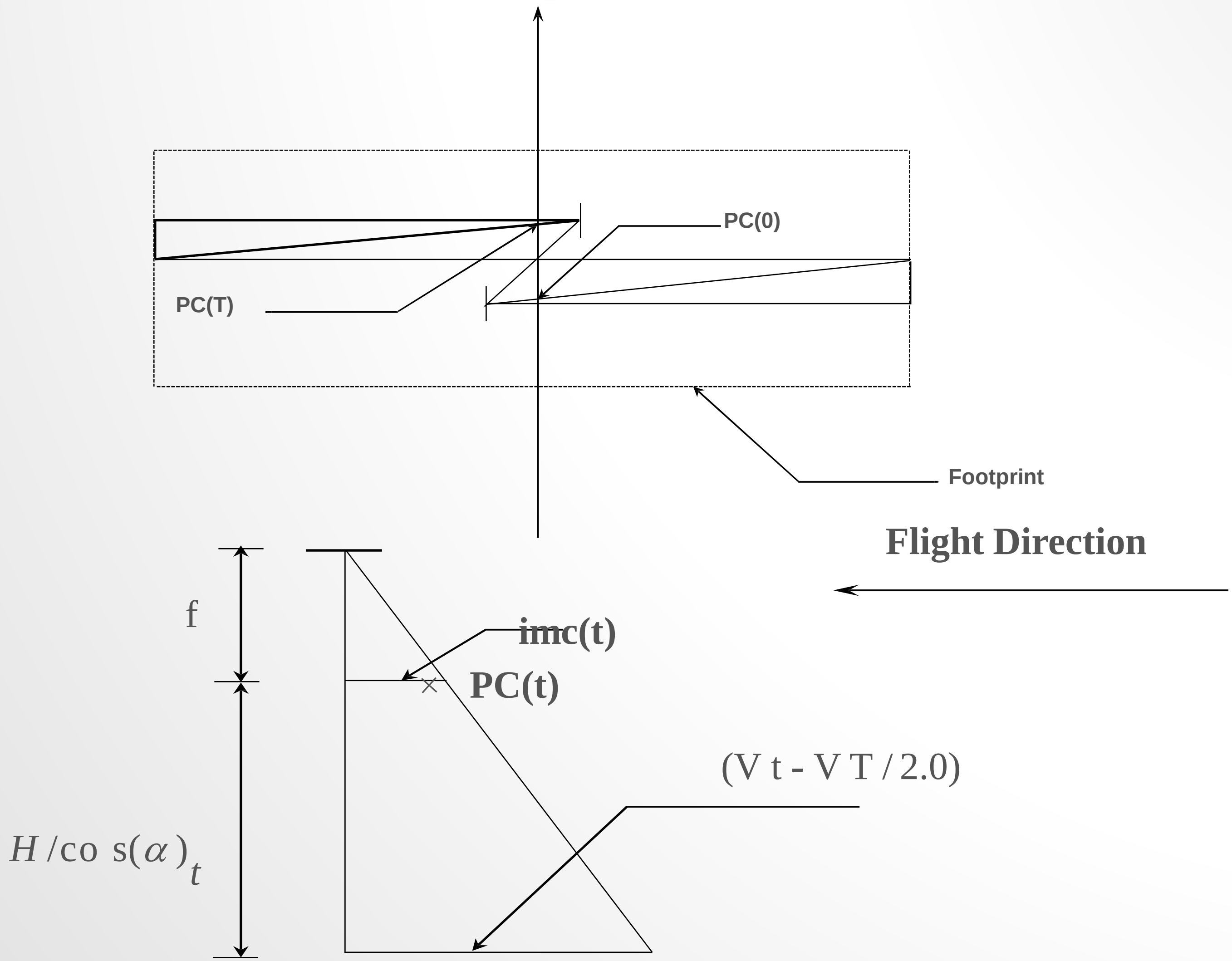
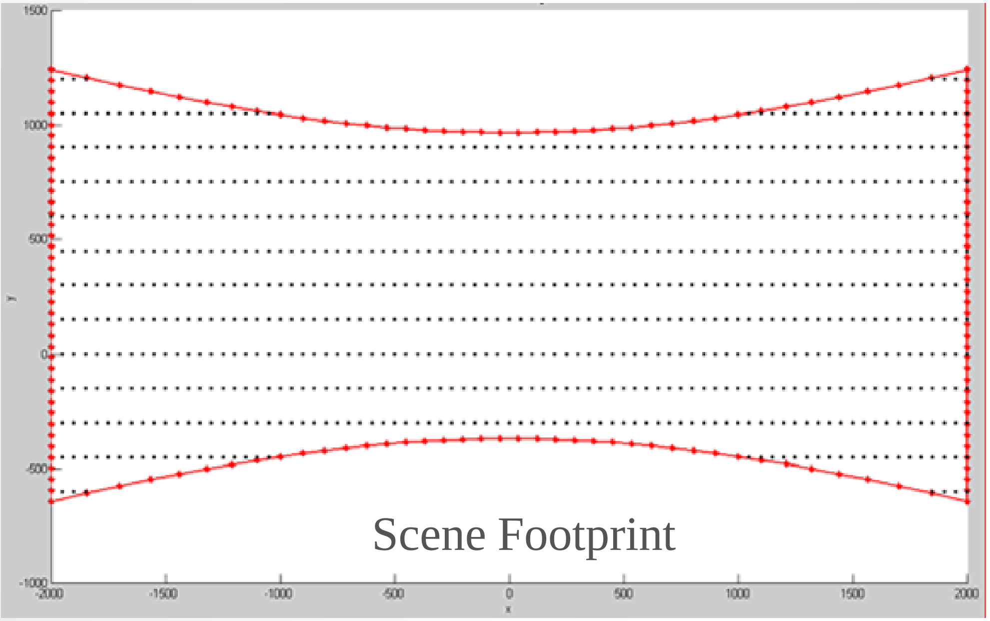


Image Motion Compensation



$$imc(t) = (Vt - VT/2)\,\frac{f}{f + H/\cos(\alpha_t)} \approx (Vt - VT/2)\,\frac{f\cos(\alpha_t)}{H}$$

Image Motion Compensation



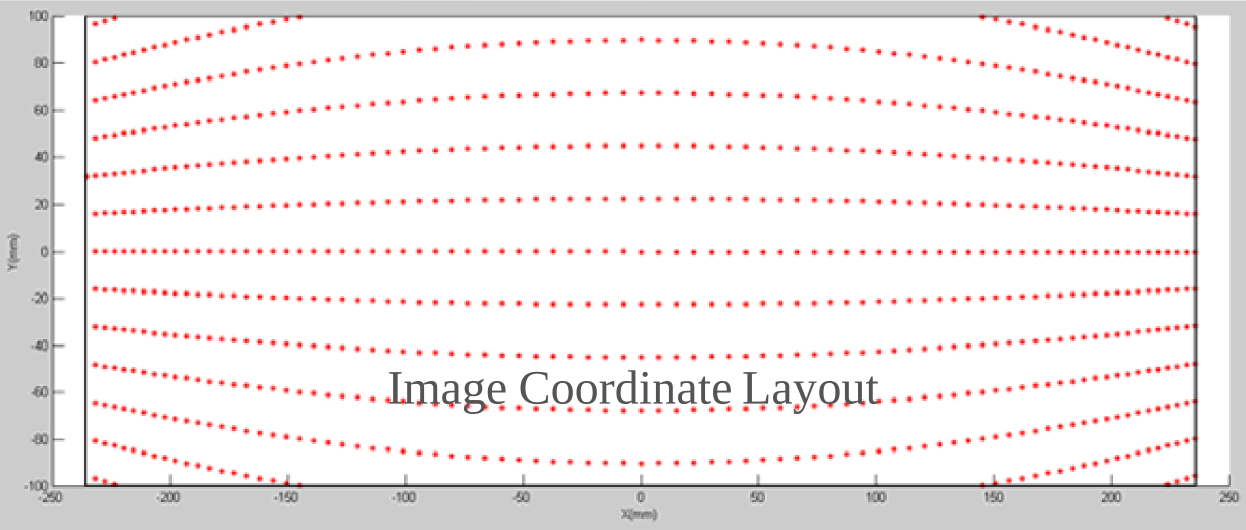


Image Motion Compensation

Raw Scene

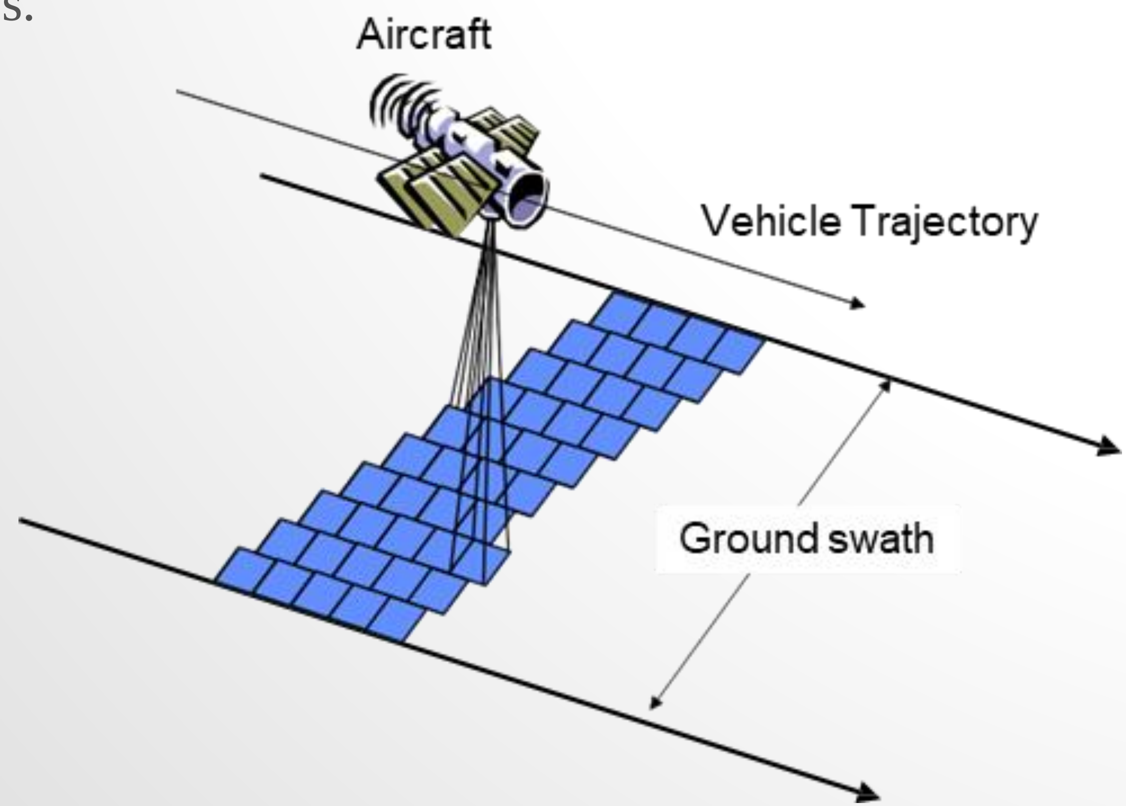
Rectified Scene

Panoramic Linear Array Scanner

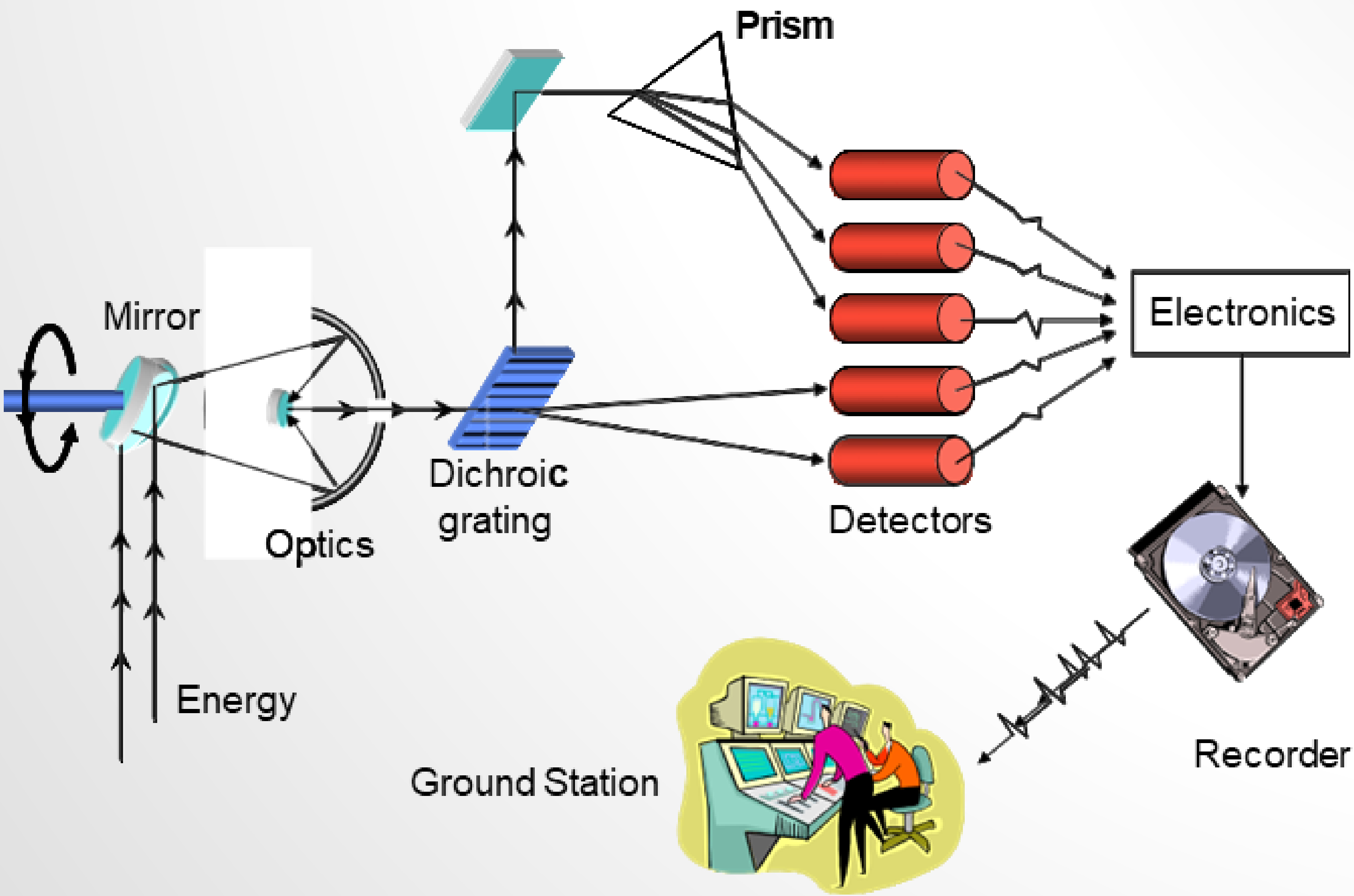
- Stereo coverage for panoramic linear array scanners can be obtained in the same way as frame cameras.
  - Overlap between successive images along the same flight line.
  - Side lap between images along adjacent strips.
- Scale will vary along the columns of the final scene.
  - $S_t = f * \cos(\alpha_t) / H$.

Whiskbroom (point) Sensors/Scanners

- Point sensor images a single point at a time.
- Pixels within each line of the image are generated by scanning in the cross track direction with mechanical motion.
- A new image line is generated by the platform motion.
- The combined side-to-side and forward motion gives rise to the whiskbroom scanner scenes.

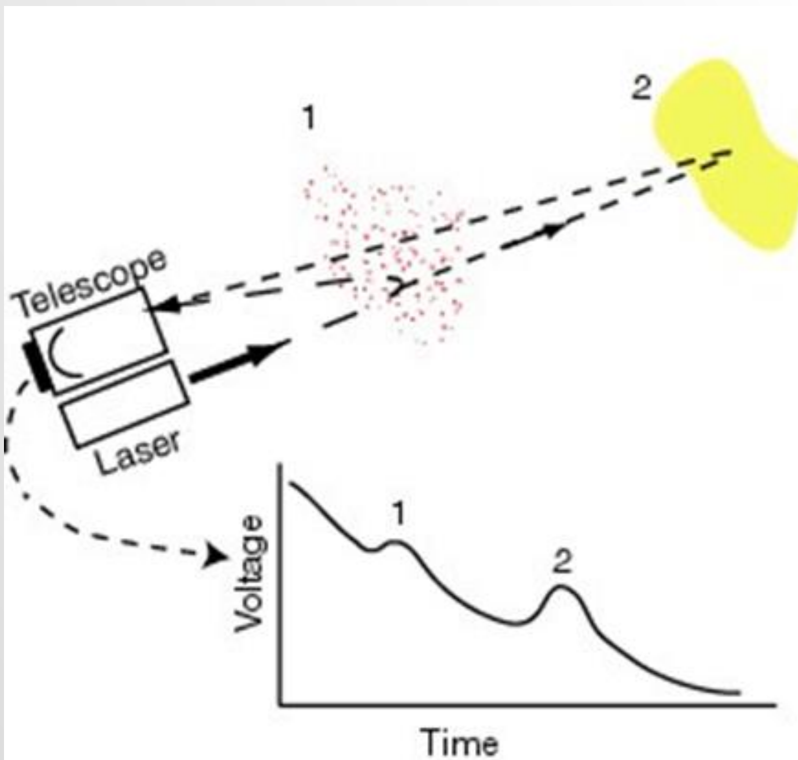


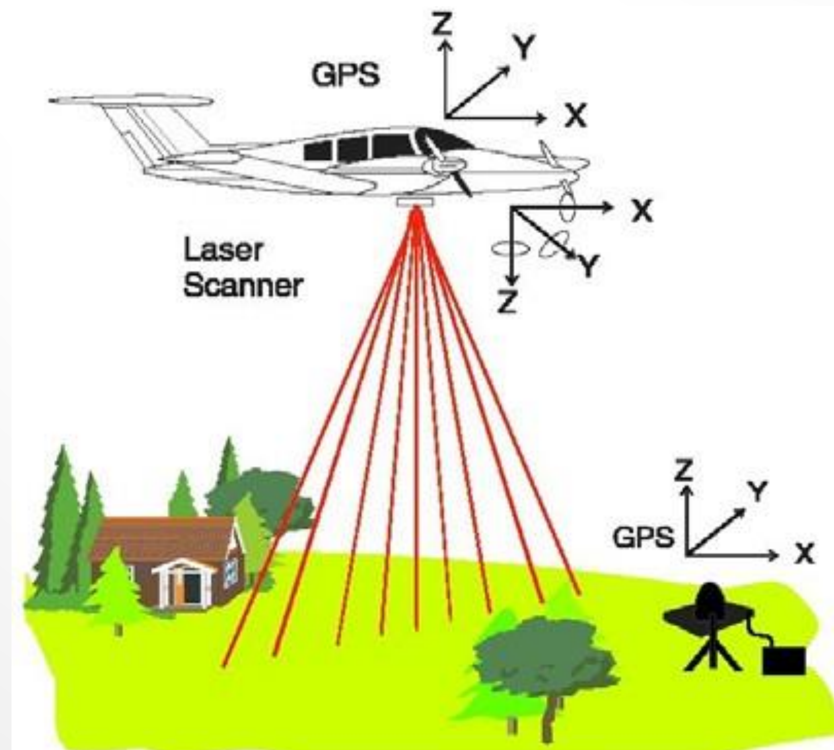
Whiskbroom Scanners



LIDAR Operational Principles

- The LIDAR instrument transmits light out to a target.
- The transmitted light interacts with and is changed by the target.
- Some of this light is reflected / scattered back to the instrument where it is analyzed.
- The change in the properties of the light enables some property of the target to be determined.
- The time for the light to travel out to the target and back to the LIDAR is used to determine the range to the target

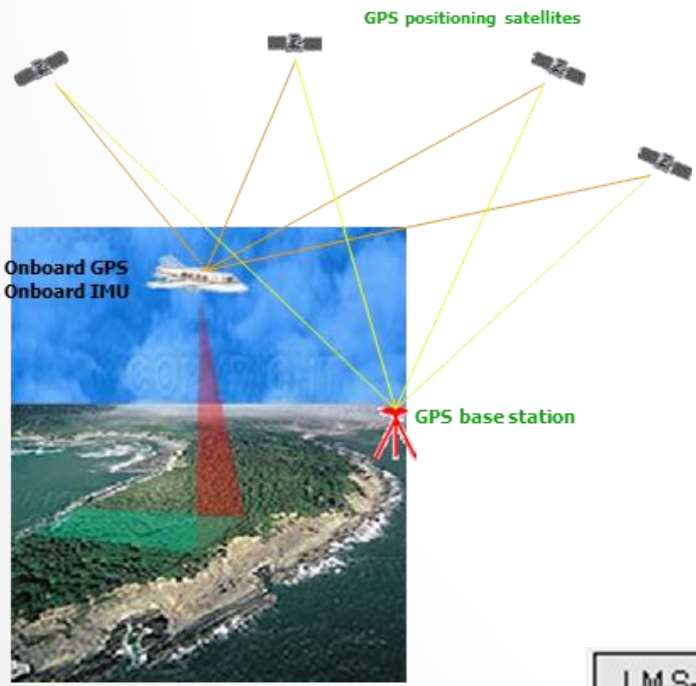


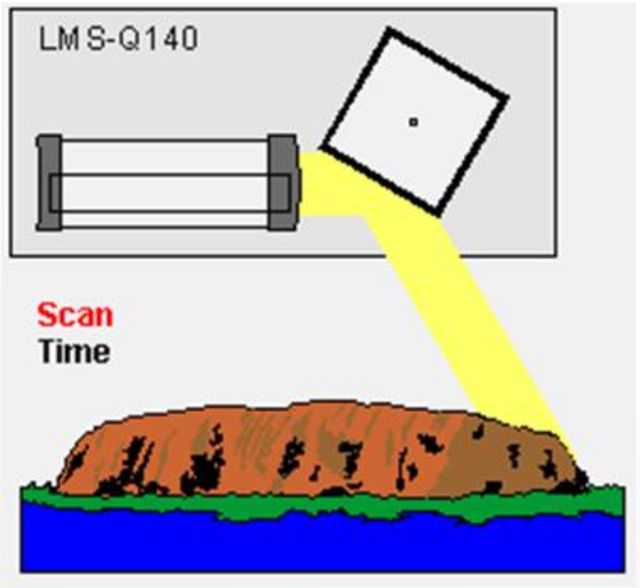


LIDAR: Operational Principles

Three Measurement Systems

1. Position: GPS
2. Attitude: IMU
3. Laser Scanner emits laser beams with high frequency and collects the reflections. Time is accurately measured.

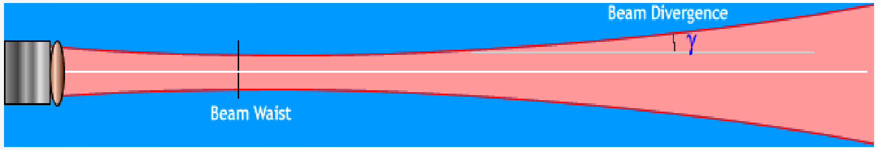




GEOSPATIAL DATA FUSION

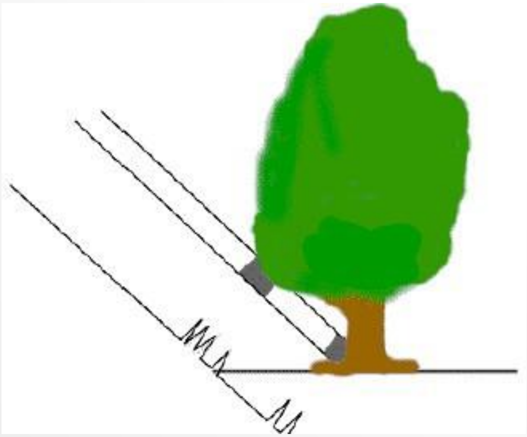
LIDAR: Operational Principles

- Beam divergence from 0.2 - 1 mrad.



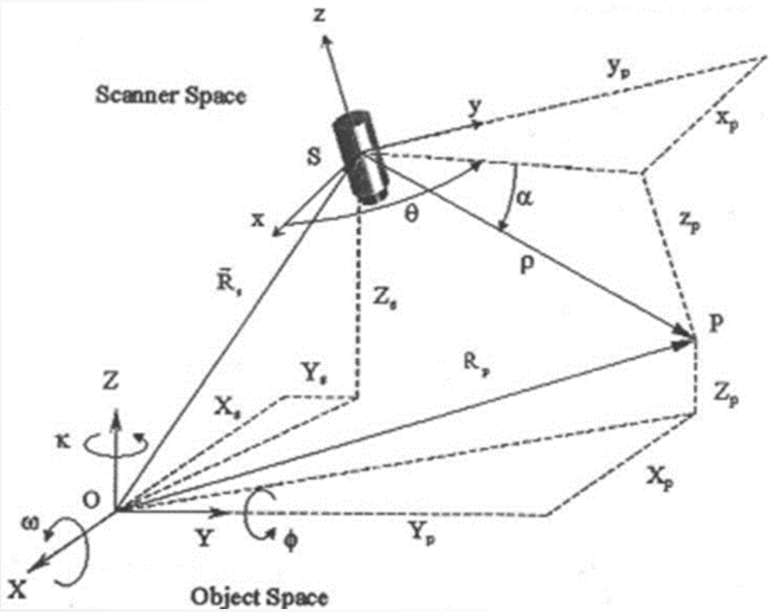
LIDAR Footprint

Wide Beam (0.8 mrad)	Narrow Beam (0.2 mrad)
• 0.8m diameter at 1000m • 2.4m diameter at 3000m	• 0.2m diameter at 1000m • 0.6m diameter at 3000m



- Range = (travel time * speed of light) / 2.0.
- Range + pointing direction + GPS + IMU ⇒ XYZ.

LIDAR: Operational Principles



- Point coordinates relative to the LIDAR reference frame.

$$\begin{bmatrix} X_L \\ Y_L \\ Z_L \end{bmatrix} = \begin{bmatrix} \rho \cos\alpha \, \cos\theta \\ \rho \cos\alpha \sin\theta \\ \rho \sin\alpha \end{bmatrix}$$

- ρ: Measured Range.
- (α, θ): The orientation of the laser beam relative to the LIDAR reference frame.

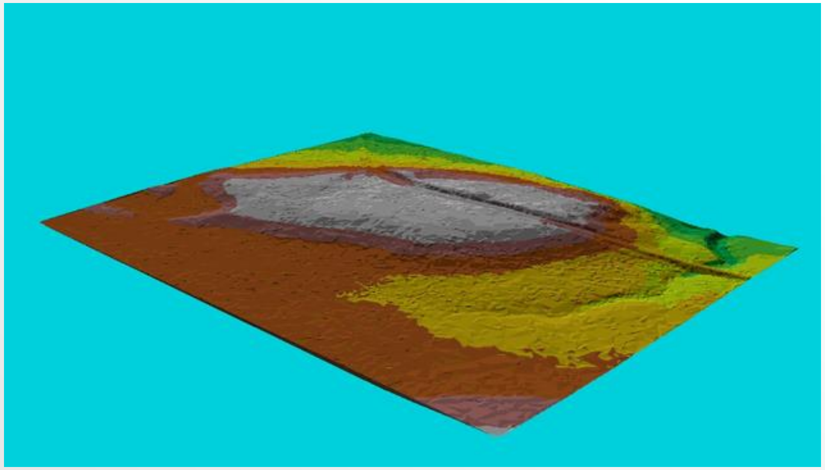
- Point coordinates relative to the object reference frame.

$$\begin{bmatrix} X_P \\ Y_P \\ Z_P \end{bmatrix} = \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix}_{GPS} + R_{(\omega,\phi,\kappa)\,INS} \begin{bmatrix} X_L \\ Y_L \\ Z_L \end{bmatrix}$$

LiDAR: Applications

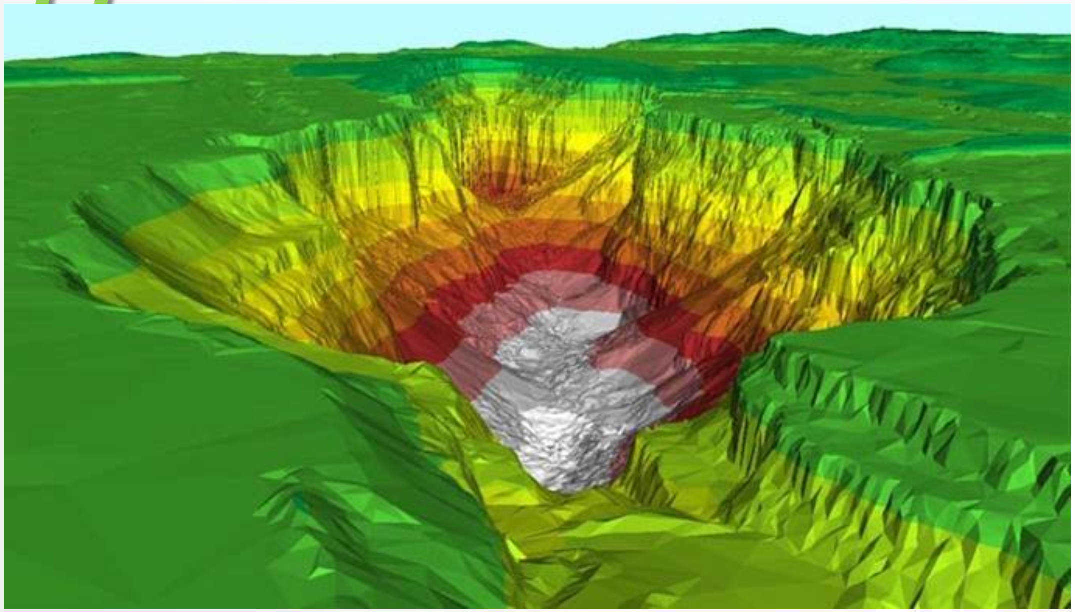
Highway Expansion

Cut & Fill

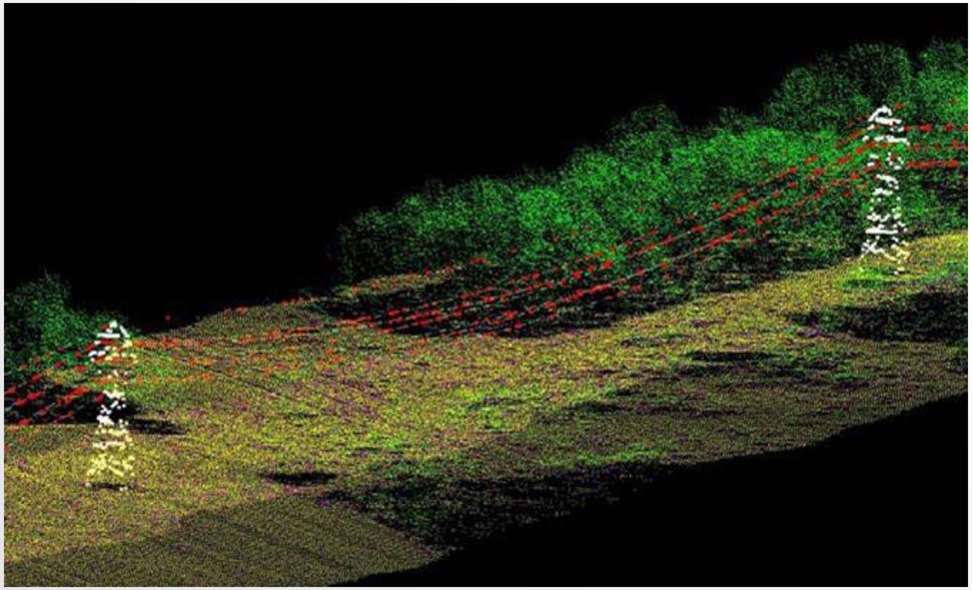


LiDAR: Applications

Mining & Construction



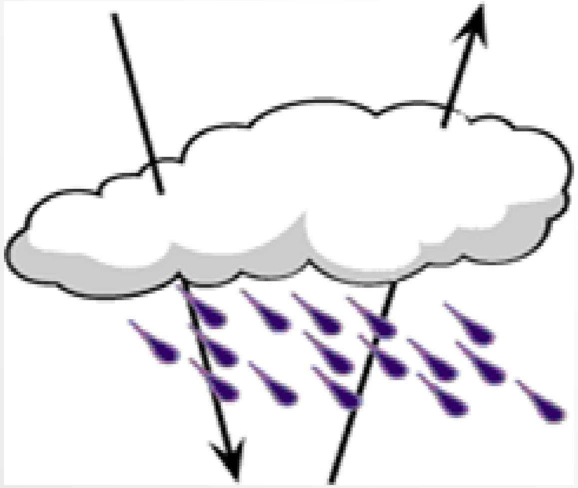
Power Line Mapping



Radio Detection And Ranging (RADAR): Operational Principles

Distinctive Characteristics of Microwave

- Capability of penetrating the atmosphere under virtually all conditions.
- Different view of the environment – “rough” in the visible portion and “smooth” in the microwave.

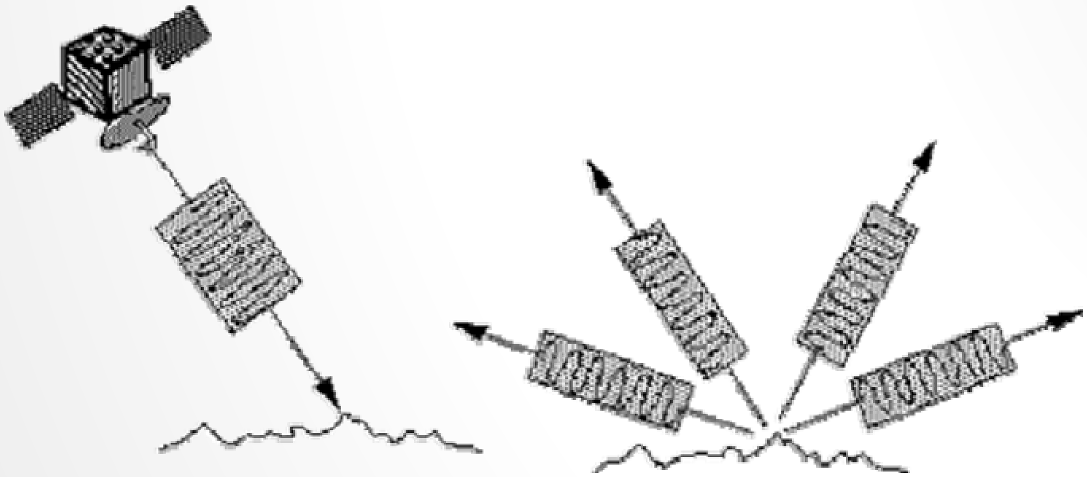


RADAR Wavelengths

Band	Wavelength (cm)
K	0.83-2.75
X	2.75-5.21
C	5.21-7.69
S	7.69-19.4
L	19.4-76.9
P	76.9-133

- The division of RADAR spectral bands are entirely arbitrary.
- The shortest wavelengths are designated K-band.
  - They provide the best radar resolution.
  - They are partially blocked by water vapor and their cloud penetrating capability is limited.
  - They are used by ground-based weather systems to track heavy cloud-cover and storms.
- Therefore, X-band is typically the shortest wavelength range used for imaging RADAR.

RADAR Operational Principles

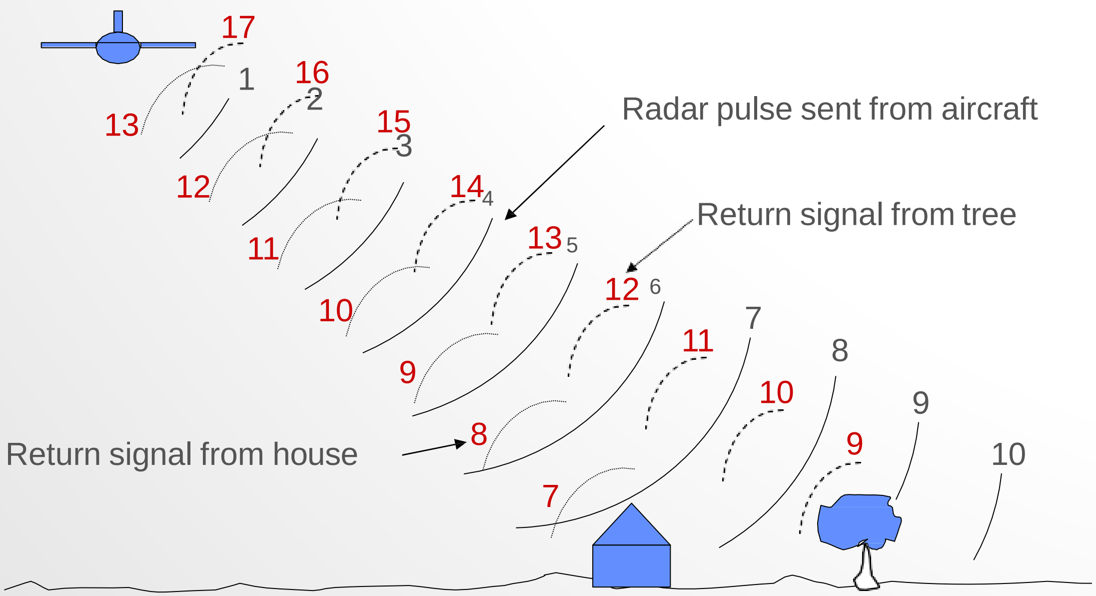


Radar transmits a pulse and measures reflected echo (backscatter)

- An antenna transmits microwave energy to the ground as a series of pulses.
- When a pulse strikes an object, it is scattered in all directions.
- Small portion of the signal (backscatter) is returned to the RADAR and received by the antenna.
- The strength of the backscatter signal and the transit time from transmission to receipt are recorded.
  - The backscatter amplitudes defines the pixel brightness value.
  - The time delay and known radiation speed are used to derive ranges to ground objects.

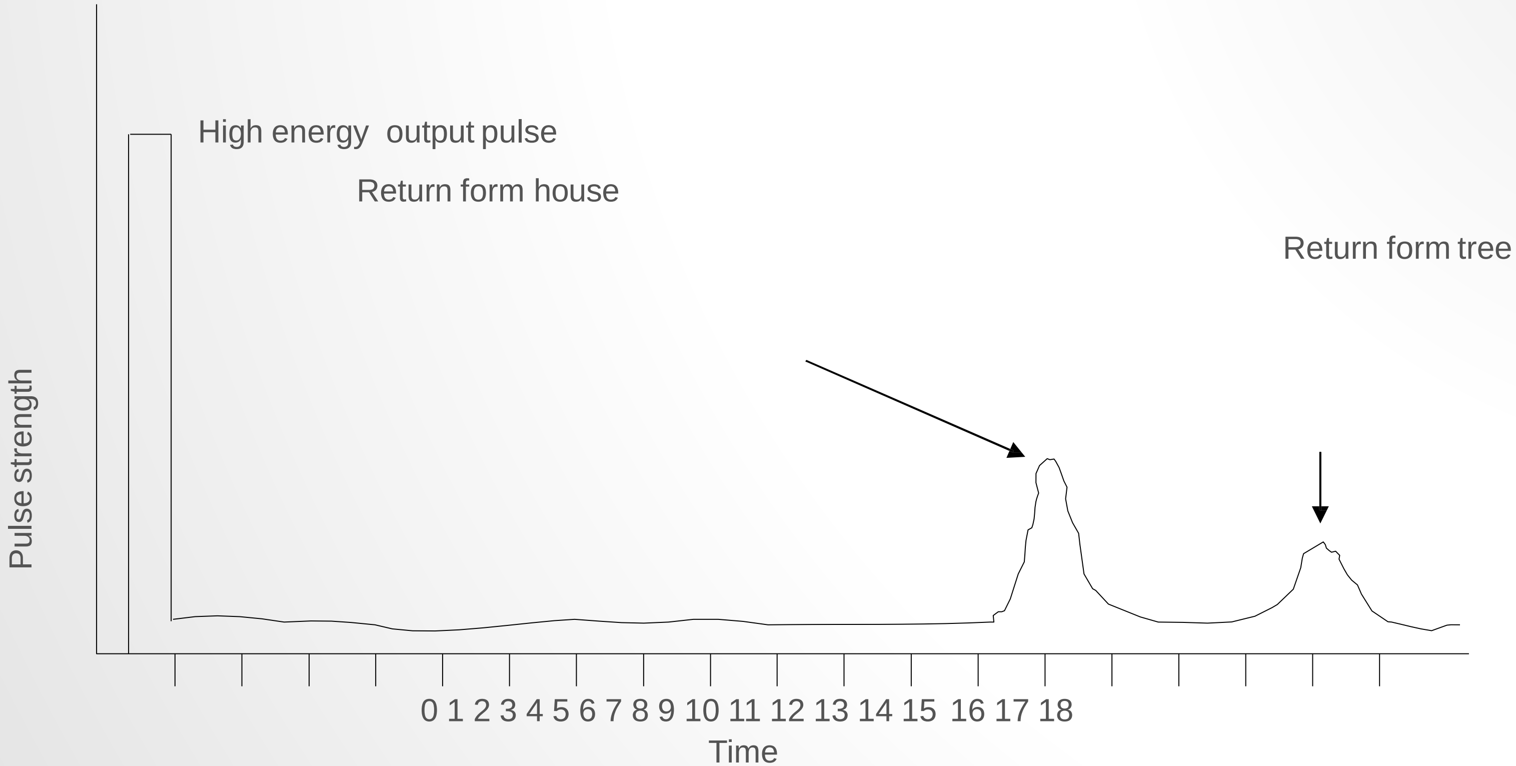
Side Looking RADAR (SLAR)

The antenna transmits a fan-shaped beam in a direction orthogonal to the flight direction.
The backscatter signals arrive sequentially from objects within the RADAR beam as a function of their range to the antenna.
As the radar moves along its flight pass, a different section of ground is illuminated with each transmitted pulse.
Since the RADAR motion is continuous, the illumination of the ground forms a series of overlapping scans.



Propagation of one radar pulse

Side Looking RADAR (SLAR)



Resulting antenna return

- The following factors will influence the RADAR reflectivity:
  - Collection geometry and topography.
  - Surface roughness
  - Dielectric constant.

Collection Geometry & Topography

Incident angle:
- The angle between the RADAR line of sight and the normal to the geoid surface.

Local incident angle:
- The angle between the RADAR line of sight and the surface normal.

The local incident angle accounts for the influence of the topography.
The local incident angle is the major factor affecting the strength of the RADAR return.

The reflectivity decreases as the local incident angle increases since most of the RADAR energy is reflected away from the sensor.
An increase in the surface slope increases the strength of the return.
This effect is greatest when the normal to slope coincides with the RADAR line of sight.

Surface Roughness

The radar backscatter increases as the roughness increases. A surface is smooth relative to the RADAR energy if its height variation is less than one-eighth of the RADAR wavelength Specular scatter.

- Specular surfaces reflect RADAR waves away from the antenna.
- The backscatter is very weak (water bodies appear very dark).

Rough surfaces (diffuse reflectors) produce strong backscatter signal.

Dielectric Constant

Dielectric constant is a measure of the reaction of the material to the presence of an electric field.

Materials with high dielectric constants are very good reflectors of RADAR energy.

- Water has a dielectric constant of 80, while the value for dry land surface ranges from 3 to 8.

Calm water body is a Specular reflector with a high dielectric constant.

- It strongly reflects energy away from the antenna (it appears black).

Disturbed water surface (e.g., in a storm)/wave crests provide strong returns and they appear bright.

Radar is good for making soil moisture maps.

- The combination of the high dielectric constant of the water and the surface roughness provided by the soil or vegetation create bright return areas from moist soil.
- This would not be the case for dry regions.

Satellite Orbits: Classification

Geostationary (zero inclination) orbits.
- Geosynchronous orbits

Low inclination orbits.

Near polar orbits.
- Sun-synchronous orbits.

Geostationary Orbits

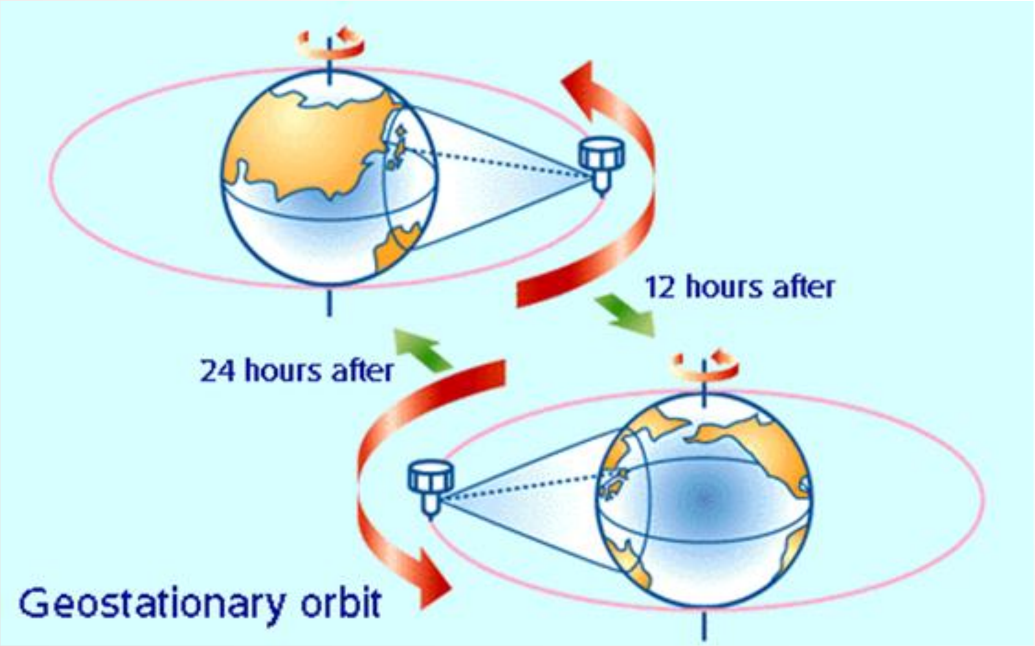
Geostationary satellites enable a quasi-continuous time sampling over certain regions on Earth.

These satellites are geosynchronous, meaning their orbits keep them synchronized with Earth rotation.

- They take 24 hours to complete one orbit.

When these satellites orbit above the equator, with zero inclination, they are also geostationary (fixed) relative to a point on the equator.

- They observe the Earth without any significant relative motion.

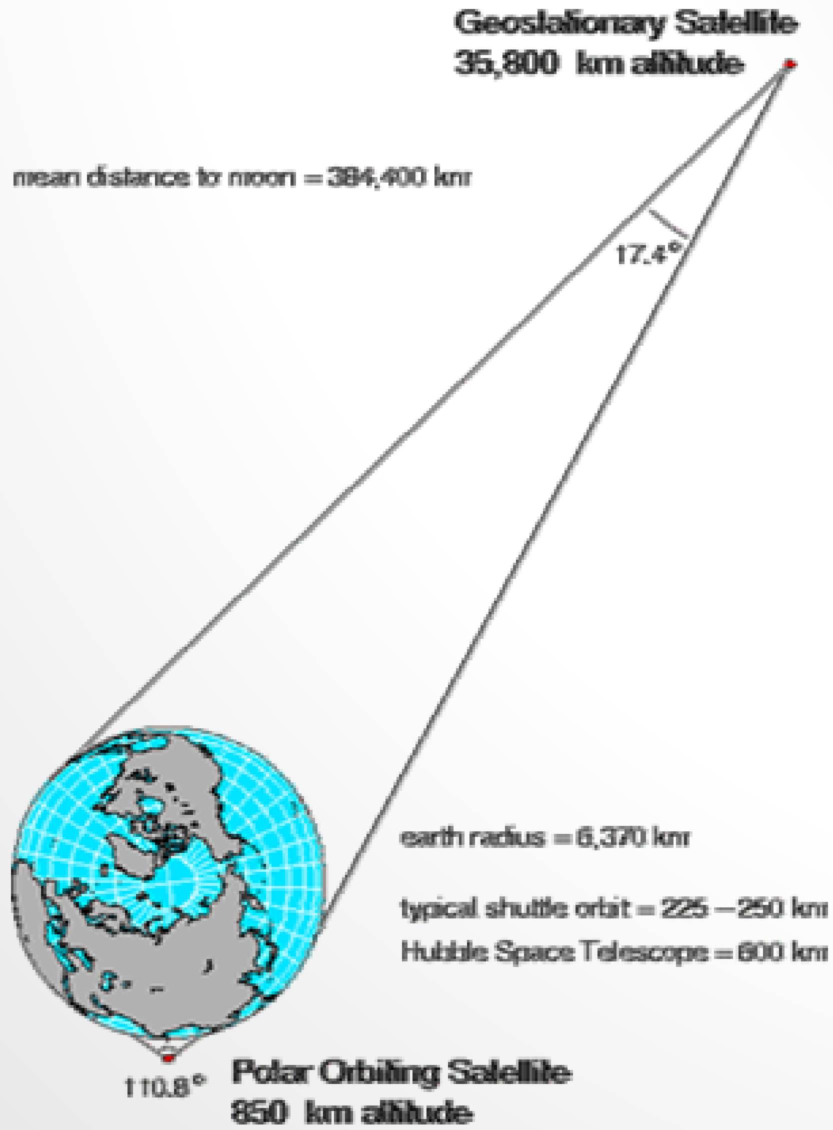


Geostationary Orbits

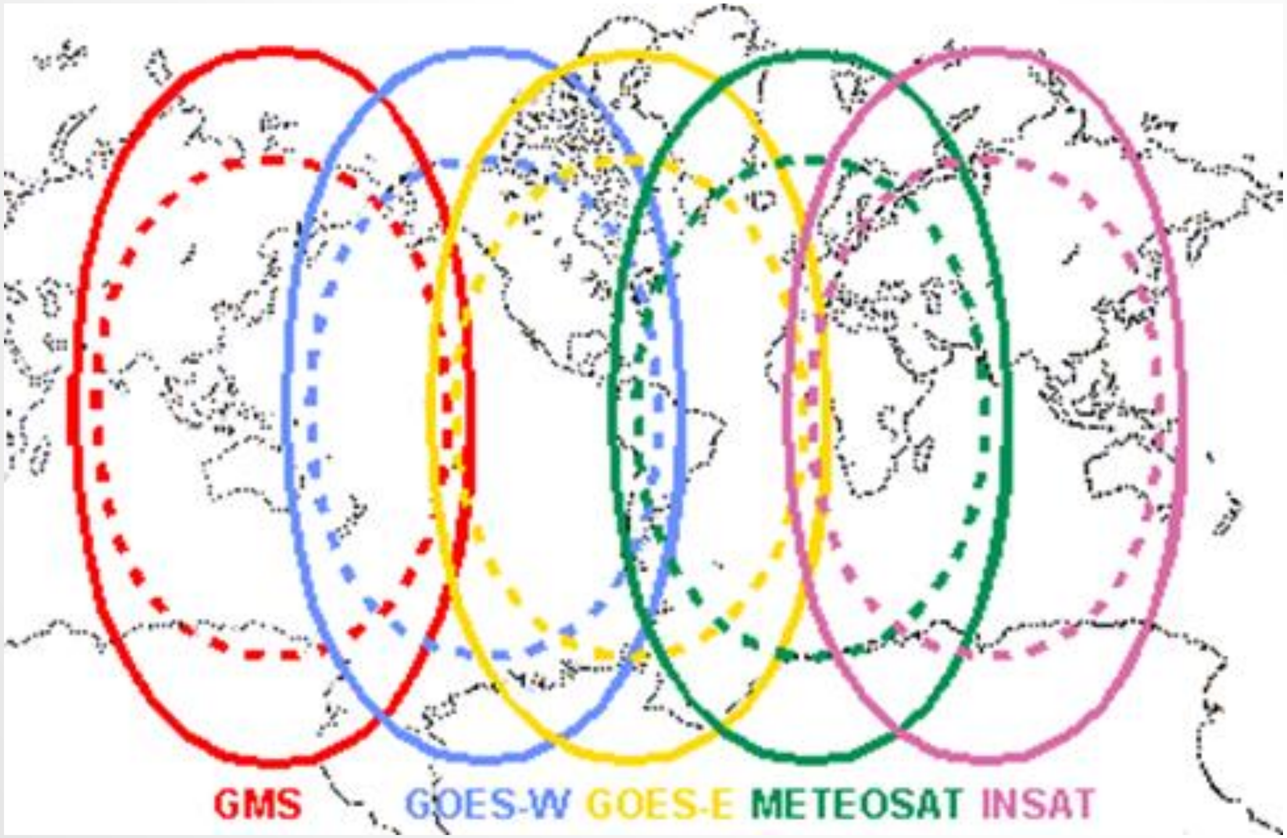
There is only one orbit in which a satellite can be geostationary.
To have a 24 hour orbital period, they must keep an orbital altitude of 35,780 km (22,234 mi, or about 5.61 Earth radii), which sets their speed at 3.07 km/s (6,868 mph).
An equatorial point travels underneath at a speed of about 0.465 km/s (1,040 mph).

At this distance, and with a wide field of view (FOV), they see the Earth as a full disk, but the area covered is less than a hemisphere, being about 1/4th of the planetary surface.
This results in a much wider field of view than is possible for polar orbiting satellites.
– However, the large distance from earth causes geostationary satellites to have much poorer spatial resolution than polar orbiting satellites.

Field of View: Geostationary Vs. Polar Orbits



Geostationary Satellites



Areas viewed by geostationary meteorological satellites.
– The solid line shows the limits;
a satellite sees nothing outside this area.
a dashed line encloses the area of useful data.

GOES Imagery

Geostationary Operational Environmental Satellite

Channel	Channel Name	Central Wave-length	Resolution km E/W x N/S	Example Meteorological Applications
1	Visible	0.65 µm	0.57 x 1.00	Produces high resolution black and white photographs of earth and clouds.
2	Shortwave infrared	3.90 µm	2.30 x 8.00	At night, can be used to track low- level cloud fields and thus infer near- surface wind circulation.

GOES provides frequent images at five different wavelengths, including a visible wavelength channel and four infrared channels

GOES Imagery

Channel	Channel Name	Central Wave-length	Resolution km E/W x N/S	Example Meteorological Applications
3	Water vapor channel	6.70 µm	2.30 x 8.00	Detects mid- and upper-level water vapor and clouds. Can derive upper-level wind vectors with the winds plotted on the image
4	Window channel	10.70 µm	2.30 x 4.00	Cloud top temperatures, nighttime tracking of storm systems.
5	Dirty window/ split window IR	12.00 µm	2.30 x 4.00	Sensitive to low level water vapor.

Geostationary Orbits: Advantages & Limitations

- Large spatial coverage.
  - Five geostationary satellites are enough to cover all of the non-polar regions of the Earth.
- Permanent visibility of the satellite allows for continuous telecommunications and high rate of observations repetition.
  - Near continuous time sampling - 30 min and 15 min for Meteosat, few minutes for GOES.
- One ground segment is enough for satellite monitoring.

- Polar regions are not observed.
- Not adequate for very high spatial resolution of the ground.
  - For example, in visible and infrared wavelengths, the resolution could not reasonably be better than 1 km.
- Active measurements are not feasible at such a distance from the Earth.
- Some perturbations of the solar electricity power supply to the satellite occur during eclipse phenomena.

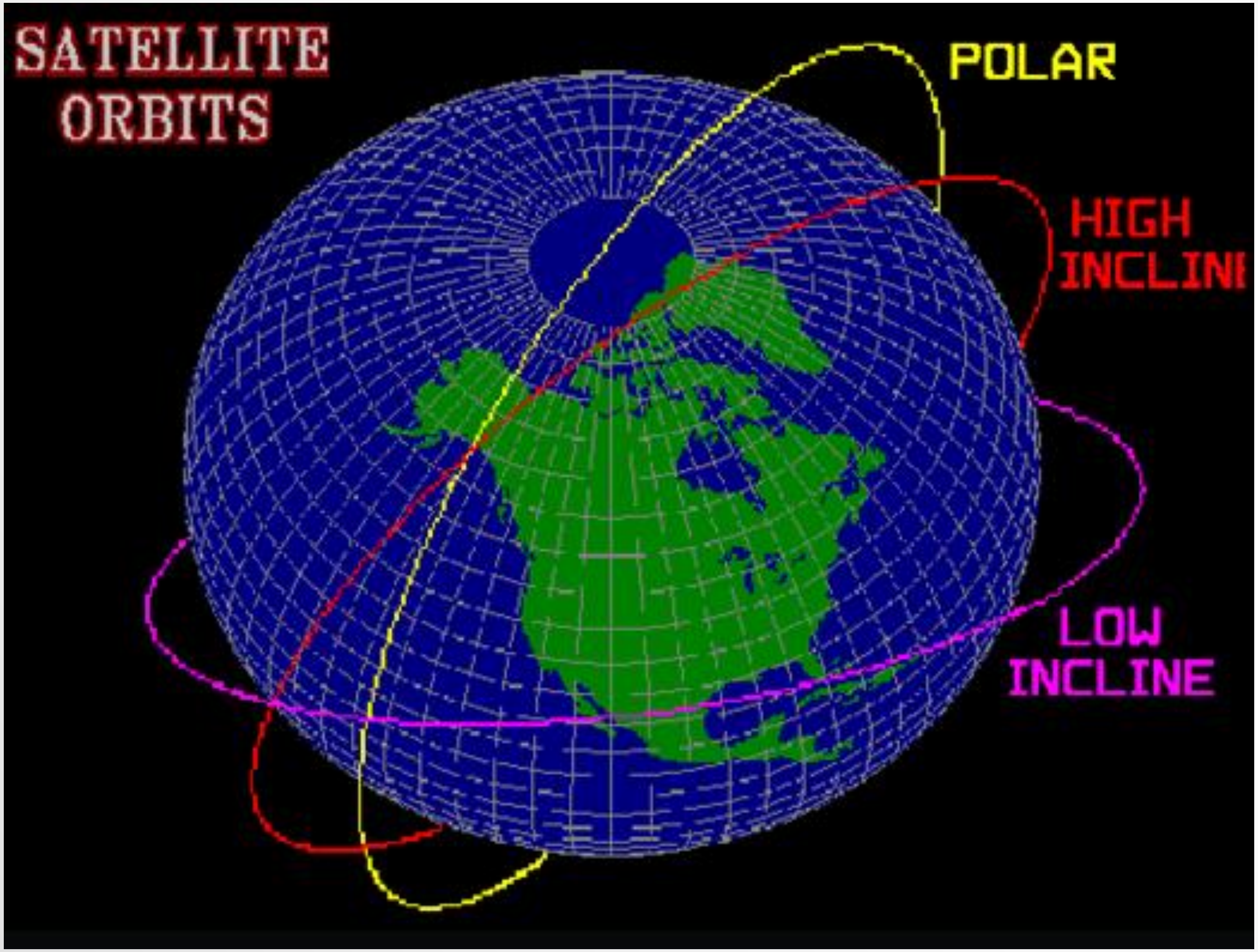
Geostationary Orbits: Applications

- **Meteorology**: real time operational survey of the troposphere, cloud systems, sea, and land surface temperatures.
- **Telecommunications**: world wide operational telecommunication systems for telephones, TV, and digitized transmission lines.
- **Army**: alarm systems - detection of rocket launches.

Low Inclination Orbits

- Low Inclination Orbits fall between near polar orbits and geostationary orbits.
- They have an inclination between 0 degrees (equatorial orbit) and 90 degrees (polar orbit).
- These orbits may be determined by the region on Earth that is of most interest (i.e., an instrument to study the tropics may be best put on a low inclination satellite), or by the latitude of the launch site.
- The orbital altitude of these satellites is generally on the order of a few hundred km.
  - The orbital period is on the order of a few hours.
- These satellites are not sun-synchronous.
  - So they will view a place on Earth at varying times.

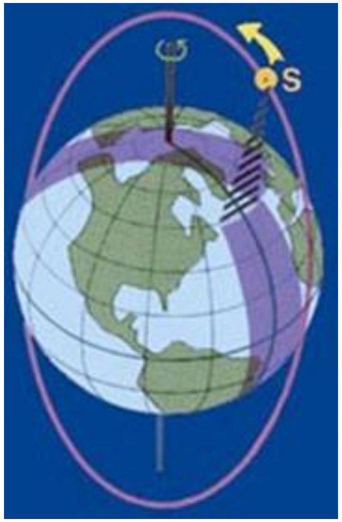
Polar, High Inclination, and Low Inclination Satellite Orbits



Polar Orbiting Environmental Satellites

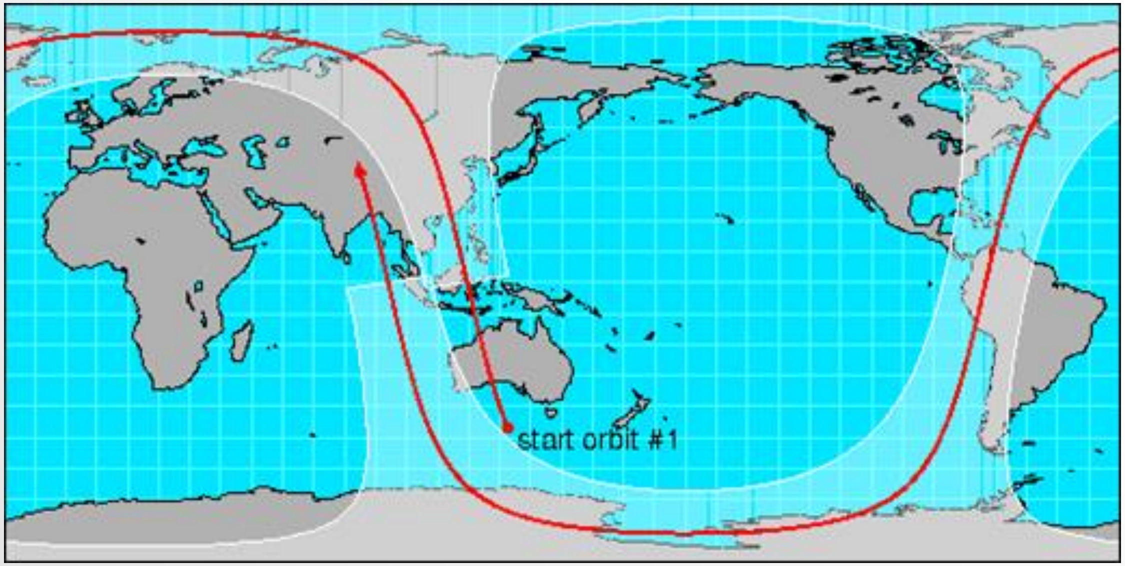
- Due to the rotation of the Earth, it is possible to combine the advantages of low-altitude orbits with global coverage, using near-polar orbiting satellites, which have an orbital plane crossing the poles.
- These satellites are launched into orbits at high inclinations to the Equator, such that they pass across high latitudes near the poles.
- Most POES orbits are circular to slightly elliptical at distances ranging from 700 to 1700 km (435 - 1056 mi) from the geoid.
- At different altitudes they travel at different speeds.

Near Polar Orbit



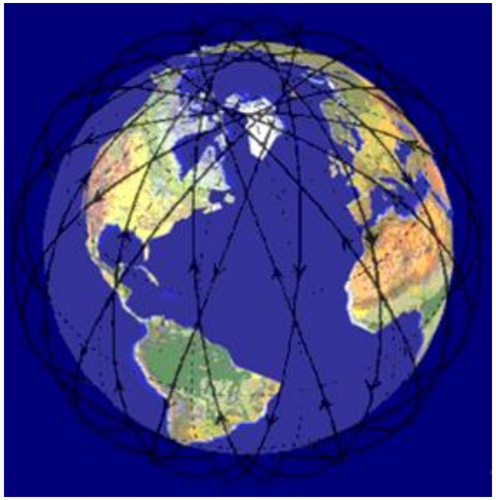
- The ground track of a polar orbiting satellite is displaced to the west after each orbital period, due to the rotation of the Earth.

- This displacement of longitude is a function of the orbital period (often less than 2 hours for low altitude orbits).



- Map of the ground path of one revolution of a typical near-polar orbiting satellite

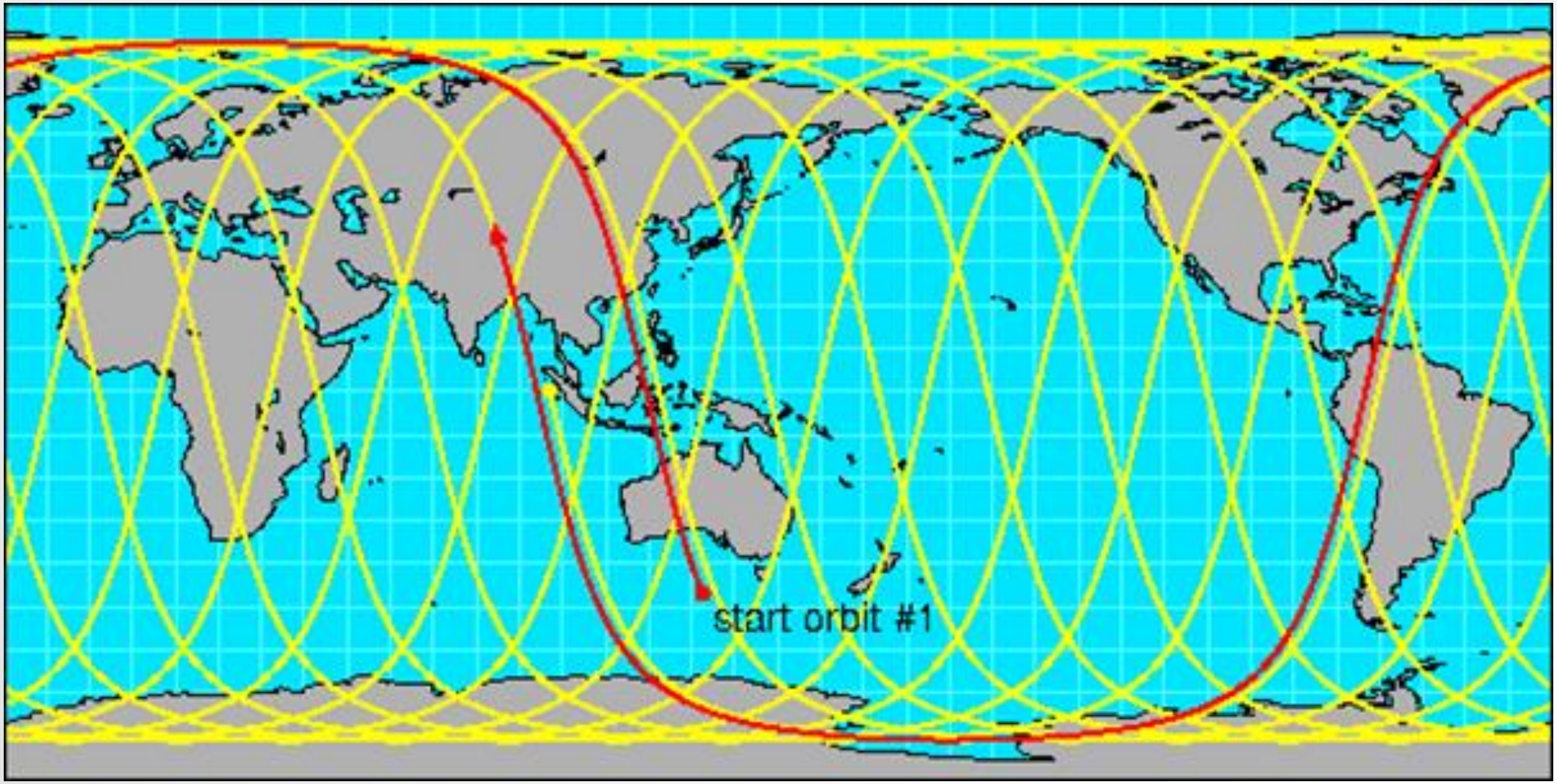
Near Polar Orbits



The orbit of a near polar satellite as viewed from a point rotating with the Earth.

- Depending on the ground swath of the satellite, it is possible to adjust the period (by varying the altitude), and thus the longitudinal displacement, in such a way as to ensure the observation of any point on the Earth within a certain time period.
- Most of the near polar meteorological satellites ensure complete global coverage of the Earth, during one day.

Near Polar Orbits

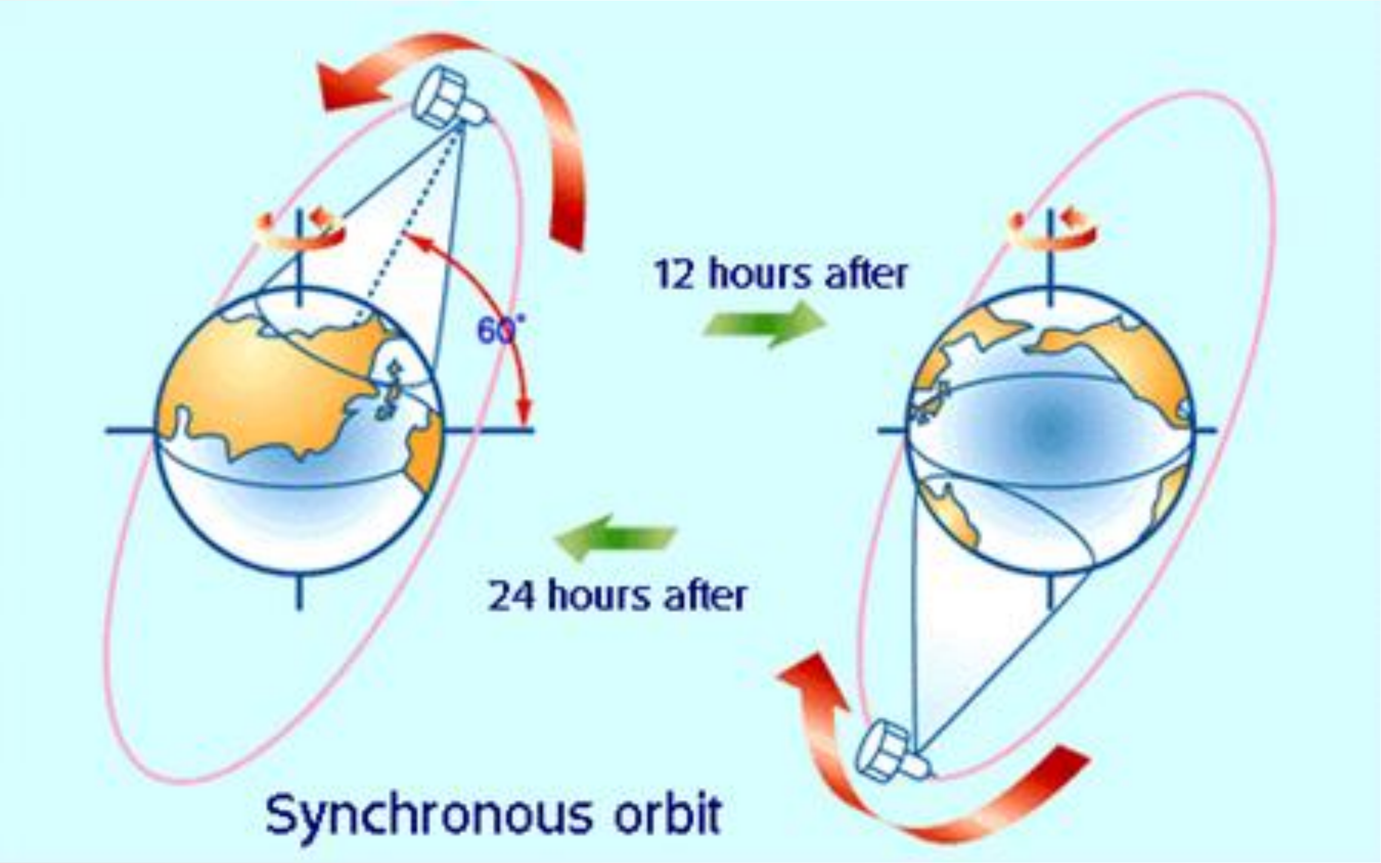


Ground paths of multiple orbital revolutions during one day for a near-polar orbiting satellite

Sun-Synchronous Orbiting Satellites

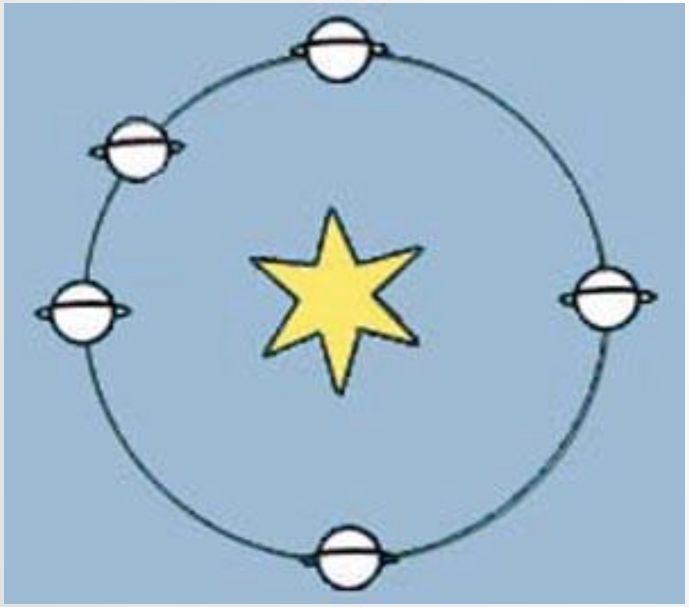
- Depending on orbital altitudes, angular velocities, and inclinations, polar orbiting satellites can be sun- synchronous.
- Sun-synchronous satellites cross some reference position (e.g., the equator) at the same local time.
- This time is usually between mid-morning and mid- afternoon on the sunlight side of the orbit.
- Sun-synchronous satellites pass over any given latitude at almost the same local time during each orbital pass.
- This orbital configuration applies to LANDSAT, SPOT, and some of the other land observers.
- In addition, for a given latitude and season, sun- synchronous satellites observe the Earth surface with a nearly constant sunlight ratio.
- This characteristic is useful for measurements in the visible and thermal wavelengths.

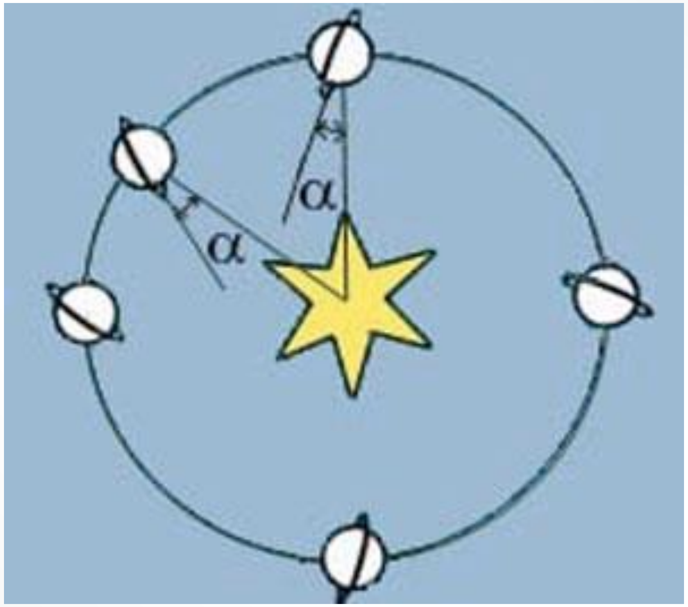
Sun-Synchronous Orbits



Example of the positions of a sun-synchronous satellite in 12 hour intervals.

Non Sun-Synchronous / Sun-Synchronous Orbits





Non sun-synchronous orbit as the Earth revolves around the sun

Sun-synchronous satellite orbit as Earth revolves around the sun.

Sun-Synchronous Orbits: Advantages

- The low altitude of a sun-synchronous orbit permits good ground resolution. It also enables easier active measurements with RADAR or LIDAR.
- The circular orbit implies a constant satellite velocity, which is important for having a regular scanning resolution along the satellite ground track.
- The near polar orbit allows a global coverage for the observation of the whole Earth.
- Orbit altitudes of between 700 and 900 km permits both a large ground swath, offering a daily global coverage, and a good ground resolution.

- Most of the Earth observing missions use sun-synchronous satellites in low near polar orbits (NOAA polar orbiting meteorological satellites, LANDSAT, SPOT, ERS, etc...).
- Sun-synchronism produces time-constant illumination conditions of the observed surfaces, except for seasonal variations.

This property is useful for many remote-sensing applications in Earth observation.
- Another property of interest is the nearly constant sunlight ratio of the satellite on each orbit, which implies a near constant solar energy supply for the satellite platform.

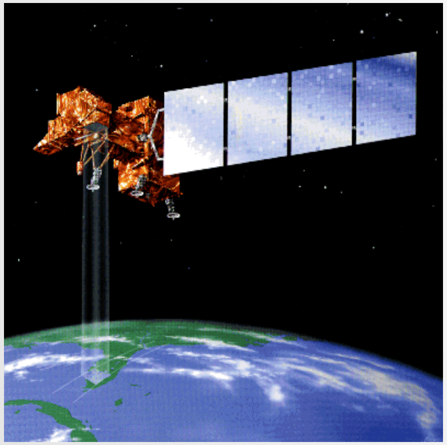
Sun-Synchronous Orbits: Limitations

- A continuous temporal observation is not possible with only one sun-synchronous satellite.

- It passes over polar regions on every orbital period, but much more rarely over equatorial regions (2 times a day for most current meteorological satellites; more generally it depends on the drift and the ground swath).

- A possibility to ease this difficulty could be to use a constellation of satellites.

Earth Observing Satellites: LANDSAT



LANDSAT 7

San Francisco and Surrounding Areas Bands 3,2,1

	Landsat1	Landsat2	Landsat3	Landsat4	Landsat5	Landsat6	Landsat7
Launched	July 23, 1972	January 22,1975	March 5, 1978	July 1, 1982	March 1, 1984	October , 1993	April 5, 1999
Decommi -ssioned	January 6, 1978	Feb 25, 1982	March 31, 1983	June 2001	-	Failure upon launch	-
RBV band	1-3	1-3	1-3	None	None	None	None
MSS band	4-7	4-7	4-8	1-4	1-4	None	None
TM band	None	None	None	1-7	1-7	1-7 (ETM+)	1-7 (plus ETM+)
Altitude	917 km	917 km	917 km	705 km	705 km	705 km	705 km
Repeat Cycles	18 days	18 days	18 days	16 days	16 days	16 days	16 days

Earth Observing Satellites: LANDSAT

LANDSAT Return Beam Vidicon (RBV)

	Band	Wavelength (μm)	Resolution (m)
Green	1	0.475-0.575	82
Red	2	0.58-0.68	82
Near IR	3	0.69-0.83	82

LANDSAT TM, ETM+ Sensor Characteristics

	Band	Wavelength (μm)	Resolution (m)
Blue	1	0.45 - 0.52	30
Green	2	0.52 - 0.60	30
Red	3	0.63 - 0.69	30
Near IR	4	0.76 - 0.90	30
SWIR	5	1.55 - 1.75	30
Thermal IR	6	10.40 - 12.50	120 (TM) 60 (ETM+)
SWIR	7	2.08 - 2.35	30
Panchromatic		0.5 - 0.9	15

Thematic Mapper (TM) & Enhanced Thematic Mapper Plus (ETM+)

Earth Observing Satellites: SPOT

Satellite Pour de l'Observation de la Terre

SPOT

Athens, 5m BW

Earth Observing Satellites: SPOT

- SPOT 1 (HRV): Launched on 22 February 1986, and withdrawn from active service on 31 December 1990.
- SPOT 2 (HRV): Launched on 22 January 1990 and is still operational.
- SPOT 3 (HRV): Launched on 26 September 1993.
  - An incident occurred on November 14, 1996.
  - After 3 years in orbit the satellite has stopped functioning.
- SPOT 4 (HRVIR): Launched on 24 Mar 1998.
- SPOT 5 (HRVIR): Launched on 3 May 2002.

Type	Sun-Synchronous
Altitude	832 km
Inclination	98.7 deg
Period	101 min
Repeat Cycle	26 days
Off-Nadir Revisit	1 to 3 days

Earth Observing Satellites: SPOT

SPOT HRV and HRVIR Instrument Characteristics

	Multi-Spectral Mode (XS)	Panchromatic Mode (P)
Instrument Field of View	4.13 deg	4.13 deg
Ground Sampling Interval (Nadir Viewing)	20 m by 20 m	10 m by 10 m
Pixel per Line	3000	6000
Ground Swath (Nadir Viewing)	60 km	60 km

- HRV: High Resolution Visible Image.
- HRVIR: High Resolution Visible Infrared.

Earth Observing Satellites: SPOT 1, 2, 3 & 4

HRV Spectral Bands

Mode	Band	Wavelength (µm)	Resolution (m)
Multi-spectral	XS1	0.50 - 0.59 (Green)	20
Multi-spectral	XS2	0.61 - 0.68 (Red)	20
Multi-spectral	XS3	0.79 - 0.89 (Near IR)	20
Panchromatic	P	0.51 - 0.73 (Visible)	10

HRVIR Spectral Bands

Mode	Band	Wavelength (µm)	Resolution (m)
Multi-spectral	XI1	0.50 - 0.59 (Green)	20
Multi-spectral	XI2	0.61 - 0.68 (Red)	20
Multi-spectral	XI3	0.79 - 0.89 (Near IR)	20
Multi-spectral	XI4	1.53 - 1.75 (SWIR)	20
Mono-spectral	M	0.61 - 0.68 (Red)	10

Earth Observing Satellites: SPOT 5

- Higher ground resolution: 5 meters and 2.5 meters (instead of 10 m) in panchromatic mode.
- Higher resolution in multi-spectral mode: 10 m (instead of 20 m) in all 3 spectral bands in the visible and near infrared ranges.
- The spectral band in the short wave infrared band (essential for VEGETATION data) is maintained at a resolution of 20 m.
- Field width of each instrument: 60 km.

Earth Observing Satellites: IRS-1C

IRS-1C

- IRS-1C launched in December 1995.
- IRS-1D launched in September 1997.

Munich Airport, Germany (IRS-1D)

- Indian Remote Sensing (IRS).
- IRS-1 is India's dedicated Earth resources satellite system operated by Indian Space Research Organization (ISRO) and the National Remote Sensing Agency (NRSA).
- The primary objective of the IRS missions is to provide India's National Natural Resources Management System (NNRMS) with remote sensing data.

Earth Observing Satellites: IRS-1C

Orbit Specifications

Type	Sun-Synchronous
Altitude	817 km
Inclination	98.69 deg
Period	101 min
Repeat Cycle	24 days

Sensor Specifications

- **LISS** (Linear Imaging Self Scanning Sensor): Multi-spectral 4-channel sensors.
- **PAN**: panchromatic
- **WiFS**: Wide Field Sensor

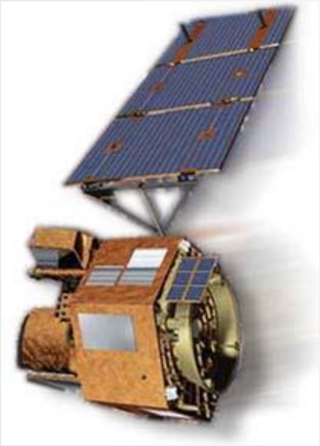
LISS and PAN Sensor Characteristics

Sensor	Band	Wavelength (μm)	Resolution (m)	Swath Width (km)
LISS	1	0.52 - 0.59 (Green)	23.5	142
LISS	2	0.62 - 0.68 (Red)	23.5	142
LISS	3	0.77 - 0.86 (Near IR)	23.5	142
LISS	4	1.55 - 1.75 (SWIR)	70	142
PAN		0.5 - 0.90	<10	70.5

WiFS

bands	Wavelength (μm)	Resolution (m)	Swath (km)
Red	0.62-0.68	189	774
Near IR	0.77-0.86	189	774

Earth Observing Satellites: EO-1



EO-1

Orbit Specifications

Type	Sun-Synchronous, 10:01 am descending node
Altitude	705 km
Inclination	98.2 deg
Period	99 min
Repeat Cycle	16 days

New York, NY
(Bands 3-2-1)

Sensor Characteristics

Spatial Resolution	30 m
Swath Width	7.75 km
Spectral Channels	242 unique channels. VNIR (70 channels, 356 nm - 1058 nm), SWIR (172 channels, 852 nm - 2577 nm)
Spectral Bandwidth	10 nm (nominal)
Digitization	12 bits
Signal-to-Noise Ratio (SNR)	161 (550 nm); 147 (700 nm); 110 (1125 nm); 40 (2125 nm)

Earth Observing Satellites: RESURS

- RESURS-O is a series of satellites for monitoring natural resources,
- Similar in function to the US LANDSAT series.
- Operation of the RESURS-O1 series was started in 1985.
- The launch of the RESURS-O1 was followed by two other satellites,
- The latest of which was in November 1994.

- **MSU-SK** (Multi-spectral Scanner of Moderate Resolution with Conical Scanning).
- **MSU-E** (High Resolution Multi-spectral Scanner with Electronic Scanning).
- The MSU-E is a narrow swath instrument (45 km) with 45 x 35 m resolution and 3 spectral bands (0.5 - 0.6 μm, 0.6 - 0.7 μm, and 0.8 - 0.9 μm).

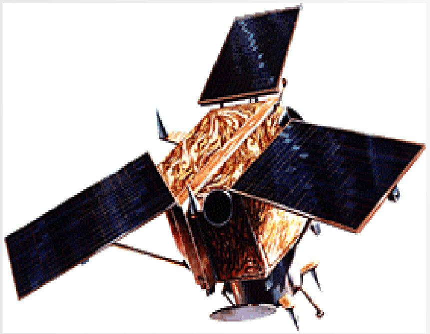
RESURS-O1 Orbit Specifications

Type	Sun-Synchronous
Altitude	678 km
Inclination	98.04 deg
Period	98 min
Repeat Cycle	21 days

MSU-SK Sensor Characteristics

Band	Wavelength (μm)	Pixel Size (m)
1	0.5 - 0.6 (green)	160
2	0.6 - 0.7 (red)	160
3	0.7 - 0.8 (near IR)	160
4	0.8 - 1.1 (near IR)	160
5	10.4 - 12.6 (thermal IR)	600

Earth Observing Satellites: IKONOS



IKONOS

Launched on
September 24, 1999

IKONOS Orbit Specifications

Type	Sun-Synchronous
Altitude	681 km
Inclination	98.1 deg
Descending node crossing time	10:30 am local solar time
Period	98 min
Off-Nadir Revisit	1.5 to 2.9 days at 40º latitude

Sensor Characteristics

Viewing Angle	Agile spacecraft, along track and across track pointing
Swath Width	11 km nominal at nadir
Image Modes	Single scene: 13 km x 13 km Strips: 11 km x 100 km up to 11 km x 1000 km Image mosaics: up to 12,000 sq. km
Metric Accuracy	12 m horizontal, 10 m vertical without GCP
Radiometric Digitization	11 bits

Earth Observing Satellites: IKONOS

Sensor Characteristics

Spectral Bands	wavelength (μm)	Resolution
1 (blue)	0.40 - 0.52	4 m
2 (green)	0.52 - 0.60	4 m
3 (red)	0.63 - 0.69	4 m
4 (NIR)	0.76 - 0.90	4 m
Panchromatic	0.45 - 0.90	1 m

IKONOS: Product Levels

- Level 0: Image Archive Product
- Level 1: Radiometrically Corrected Product
- Level 2: Standard Geometrically Corrected Product
- Level 3: Precision Geometrically Corrected Product
- Level 4: Ortho-rectified Product
- Level 5: Digital Terrain Matrix (DTM)
- Level 6: Algorithm Product
  - Level 6a: Pan-Sharpened Image Product
  - Level 6b: Band Ratio Image Product
- Level 7: Mosaic Product

Earth Observing Satellites: EROS-A1

Earth Remote Observation Satellite

EROS-A1

Deadhorse, Alaska

EROS-A1 Orbit Specifications

Type	Sun-Synchronous
Descending Node Crossing Time	9:45 am local solar time
Altitude	475 - 491 km
Inclination	97.3 deg
Period	94 min

Sensor Characteristics

Viewing Angle	Agile spacecraft along track and across track pointing (up to 45º from nadir)
Sensor Type	CCD
Ground Sampling Distance	1.8 m
Scanning	Asynchronous (up to 750 lines/second)
Radiometric Digitization	11 bits
Spectral Band	Panchromatic, 0.5 - 0.9 µm
Pixels-in-line	7800

Launched on 5 December 2000, EROS-A1

Earth Observing Satellites: Quickbird

Quickbird2

Montreal, Quebec

Quickbird-2 Orbit Specifications

Type	Sun-Synchronous
Altitude	450 km
Inclination	98 deg
Period	93.4 min.
Off-Nadir Revisit	1 to 3.5 days

Sensor Characteristics

Viewing Angle	Agile spacecraft, in-track and cross-track pointing +/- 30 deg nominal fore-and-aft and side-to-side, 45 deg maximum
Swath Width	17 km nominal at nadir
Image Strip Length	Up to 225 km
Metric Accuracy	23 m circular error (CE), 17 m linear error (LE) at 90% confidence (without ground control points)
Radiometric Digitization	11 bits

Spectral Band	Wavelength (µm)	Resolution (at nadir)	Resolution (at 30^{o} off nadir)
1 (blue)	0.45 - 0.52	2.5 m	2.9 m
2 (green)	0.52 - 0.60	2.5 m	2.9 m
3 (red)	0.63 - 0.69	2.5 m	2.9 m
4 (NIR)	0.76 - 0.89	2.5 m	2.9 m
Panchromatic	0.45 - 0.90	0.61 m	0.73 m

Earth Observing Satellites: ORBVIEW

Orbview3

Salt Lake city, Utah

Orbview3 was launched in June 26, 2003

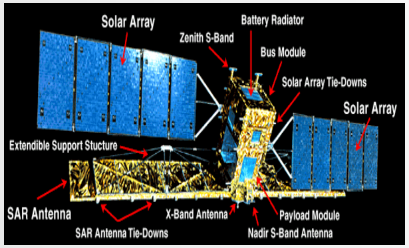
Orbview-3 Orbit Specifications

Type	Sun-Synchronous
Altitude	470 km
Revisit	Less than 3 days
Swath Width	8km

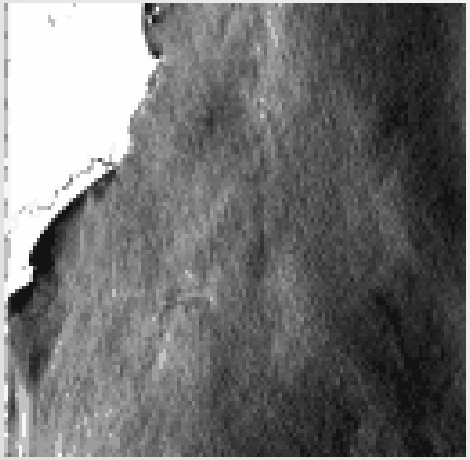
Sensor Characteristics

Spectral Band	Wavelength (μm)	Resolution
1 (blue)	0.45 - 0.52	4 m
2 (green)	0.52 - 0.60	4 m
3 (red)	0.625 - 0.695	4 m
4 (NIR)	0.76 - 0.90	4 m
Panchromatic	0.45 - 0.90	1 m

Microwave Remote Sensing Satellite RADARSAT-SAR



RADARSAT



13 Feb 1997
Cape Byron-Evans Head, northern NSW

RADARSAT Orbit

Type	Sun-Synchronous
Altitude	798 km
Inclination	98.6 deg
Period	100.7 min
Repeat Cycle	24 days

MODE	**RESOLUTION (m) Range 1 x azimuth (m)**	**LOOKS 2**	**WIDTH (km)**	**INCIDENCE ANGLE 3 (degrees)**
Standard	25 x 28	4	100	20-49
Wide - 1	48-30 x 28	4	165	20 - 31
Wide - 2	32-25 x 28	4	150	31 - 39
Fine resolution	11-9 x 9	1	45	37 - 48
ScanSAR narrow	50 x 50	2 - 4	305	20 - 40
ScanSAR wide	100 x 100	4 - 8	510	20 - 49
Extended (H)	22-19 x 28	4	75	50 - 60
Extended (L)	63-28 x 28	4	170	10 - 23

1. Nominal; ground range resolution varies with range
2. Nominal; range and processor dependent
3. Incidence angle depends on sub-mode