ELECTRO-OPTICAL SYSTEMS

The film is replaced by an electro-optical device which converts the radiation in an electrical signal. Many of these systems combine the responses in specific bands in the visibile, near infrared and thermal infrared regions.

DETECTORS FOR VISIBLE AND NEAR INFRARED

PHOTODIODES

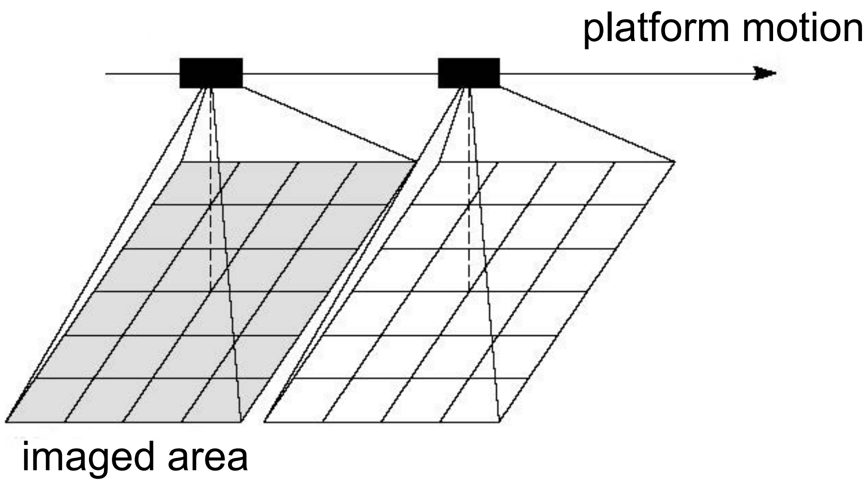
The photodiode is reverse biased and the incident photons generate a current.
The minimum photon energy (and thus the maximum photon wavelength) are determined by the semiconductor bandgap:
silicon (Si) is sensitive up to 1.1 μm,
germanium (Ge) up to 1.7 μm,
lead sulfide (PbS) up to 3 μm,
indium antimonide (InSb) up to 5 μm.
In order to take an image, the photodiodes can be combined in large arrays.

CHARGE COUPLED DEVICES (CCDs)

These devices are composed of a large number of elements which are light sensitive and can store the free charges generated by the photons. Most of the CCDs are based on silicon and are sensitive up to 1.1 μm.

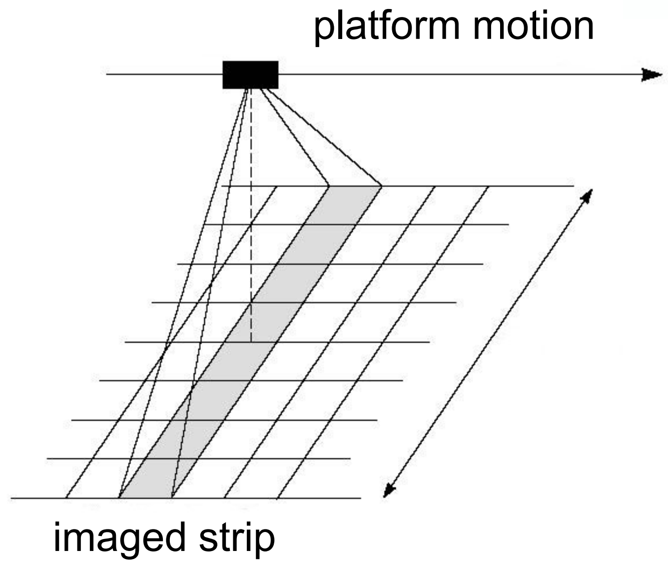
A two-dimensional detector array can acquire a single-shot two-dimensional image. The electro-optical system is carried by a platform (an airplane or a satellite) which can be in motion with respect to the target. It may be necessary to compensate for the movements to avoid blurring of the image.

STEP-STARE IMAGING



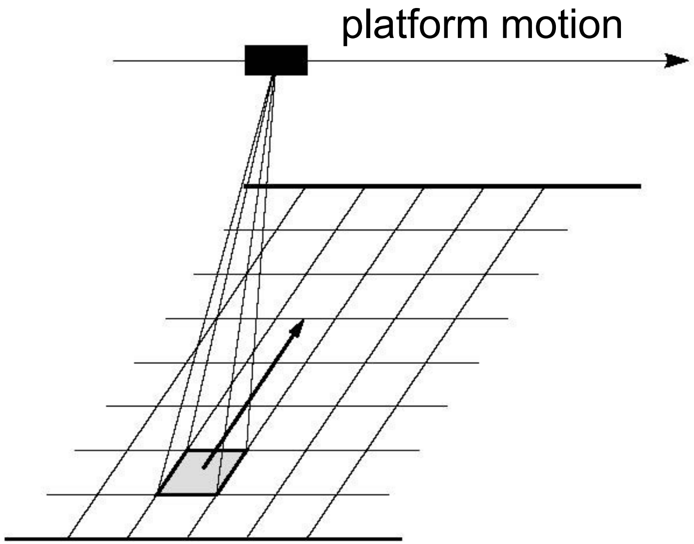
The detector array stares at a scene and then moves on to stare at the next scene.

PUSH-BROOM IMAGING

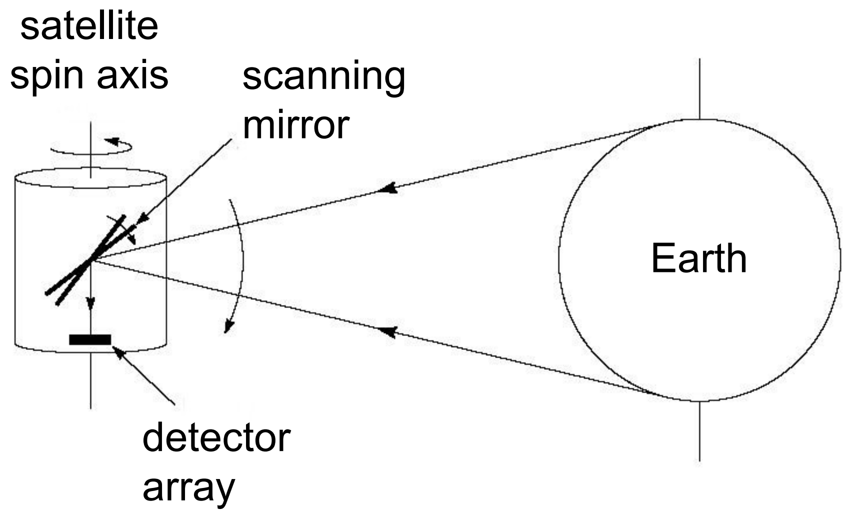


If the detector is a linear array, the image scanning is obtained by using the motion of the platform.

WHISK-BROOM IMAGING



SPIN-SCAN IMAGING



In the case of a line scanner there is a single detector and scanning in the direction perpendicular to the motion of the platform is achieved by means of a rotating mirror.

For geostationary imagers, scanning in the east-west direction is obtained by spinning the satellite about its north-south axis, while north-south scanning is achieved by using a mirror rotating in a series of steps.

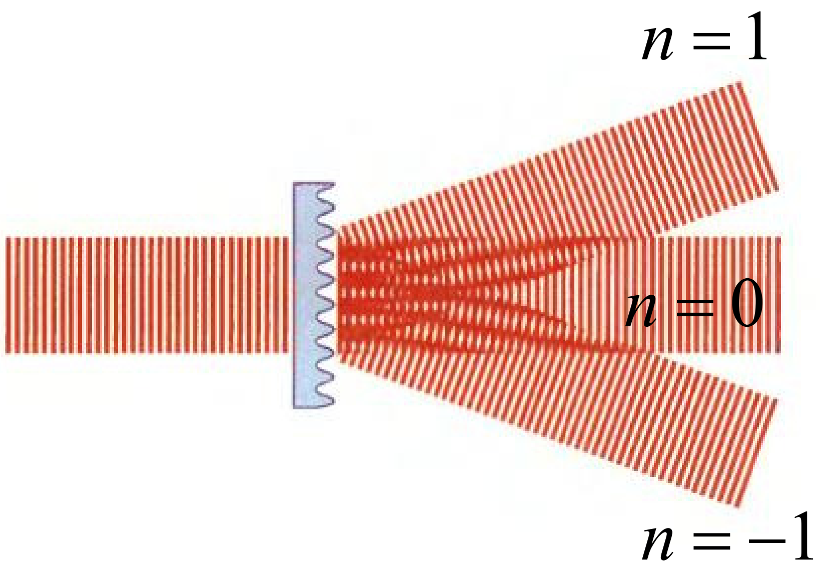
Most visible and near infrared instruments used to observe the Earth's surface are able to take images in different bands. High spectral resolutions are obtained by using diffraction gratings followed by filters. Alternatively, a single detector can be scanned mechanically across the spectrum.

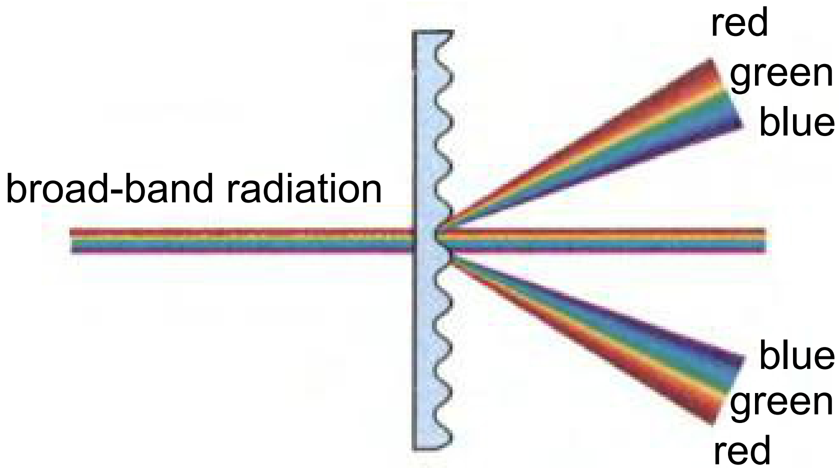
A diffraction grating can be made of a transparent plate with periodically varying thickness or by ruling lines on the plate.

A plane wave striking the grating at normal incidence is diffracted in many plane waves (corresponding to different orders and making different angles to the normal).

$$\boxed{\sin\theta_n = n\frac{\lambda}{d}}$$

where θ_n is the diffraction angle of the n^{th} order
(for light of wavelength λ impinging on a grating with period d)





DETECTORS FOR THERMAL INFRARED (TIR)

PHOTODIODES

In the wavelength range 3-15 μm the corresponding photon energy is about 0.1-0.4 eV and this makes difficult to find suitable semiconductors:
indium antimonide (InSb) up to 5 μm,
mercury cadmium telluride, MCT ($Hg_{0.2}Cd_{0.8}Te$) up to 15 μm,
mercury doped germanium (Ge:Hg) up to 15 μm.
It may be necessary to cool these quantum detectors in order to reduce the number of photons generated by the detector itself and to increase the sensitivity.

THERMAL DETECTORS

These devices provide a wide spectral range but, if compared to photodiodes, they exhibit much lower sensitivity and longer response time. Thermal detectors are used only for wavelengths significantly longer than 15 μm.

1) Thermistor bolometer: consists of a material (like carbon or germanium) whose resistance varies with temperature.
2) Thermocouple: a potential difference is generated across a couple of junctions between different metals when the junctions have dissimilar temperatures (Seebeck effect).
3) Pyroelectric detector: a change in temperature redistributes the carriers in a crystal and the resulting potential difference can be measured.

TIR imagers do not require high spectral resolution: usually the 3-15 μm range is split in two channels (1 μm wide) and centered around 4 μm and 10 μm (in order to avoid the strong water absorption at 6-7 μm).

Planck formula

$$L_\lambda = \frac{2hc^2}{\lambda^5} \frac{1}{\exp\left(\frac{hc}{\lambda k_B T}\right) - 1}$$

intrinsic sensitivity of a TIR observation

$$\boxed{S = \frac{T}{L_\lambda} \frac{\partial L_\lambda}{\partial T}} = \frac{\partial L_\lambda}{L_\lambda} / \frac{\partial T}{T}$$

S around 4 μm is three times larger than at 10 μm, but sunlight radiation is 50 times larger at 4 μm than at 10 μm: for this reason during day-time the 8-14 μm band is preferred to the 3-5 μm band.