ITMO

Getting of Color Digital Images

Image Processing

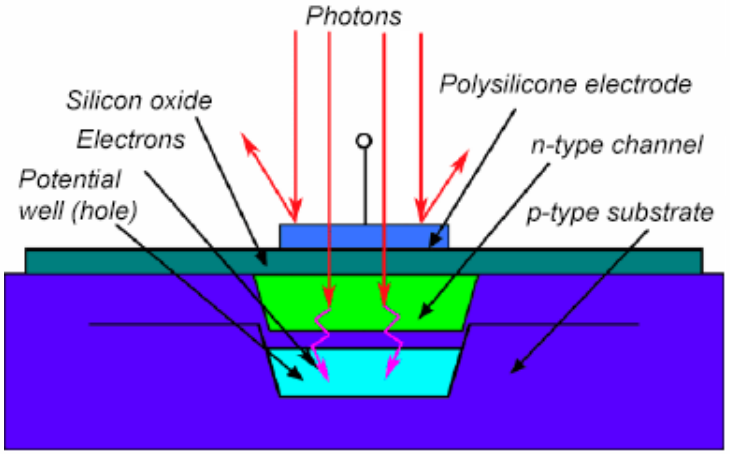
Getting of Color Digital Images (hardware part)

Pixel as a sensor

- The film and digital cameras operation principle: photography subject fixation using the light energy acting on a light-sensitive material.
- The converting a photon into an electron process: recording sensor is a *photodiode*.

Pixel as a sensor

- p-type substrate with
  - transparent dielectric,
  - light-transmitting electrode (forms a potential well).



CCD pixel cross-section

Pixel as a sensor

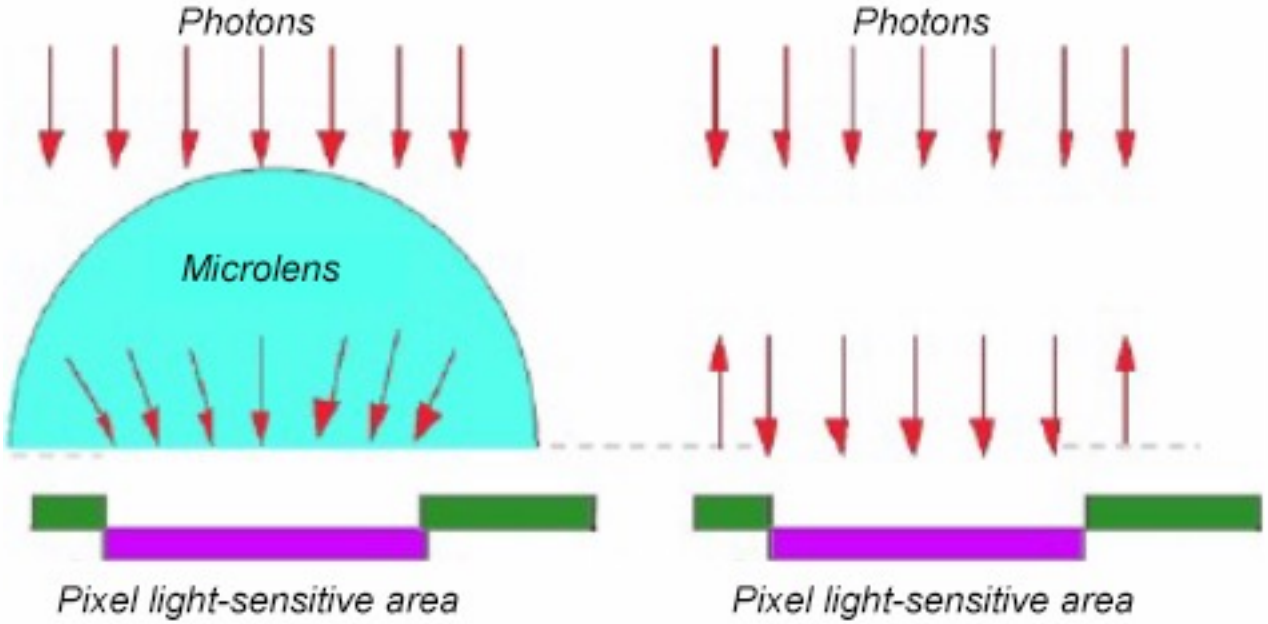
- The the photons «fate» hitting the pixel:
  - *Ricochet,*
  - **Absorption,**
  - *Break through.*
- Charge coupled device (CCD):
  - Photon -> electron: absorption of a quantum of light by the crystal lattice of a semiconductor, stand out:
    - either a pair "electron + hole",
    - or a single electron (with impurities in the semiconductor).

Pixel as a sensor

- Storage of charge carriers (electrons or electron + hole pairs):
  - n-type channels on the p-type substrate;
  - on top of the channels – transparent electrodes (polycrystalline silicon);
- As a result, a potential well is formed under the n-type channel.
- The more photons fall on a pixel, the higher the charge accumulated in the potential well will be.
- *The photocurrent* is the potential well charge.
- Photocurrent readout: sequential shift registers convert a string of charges at the input to a train of pulses at the output (analog signal).

Pixel as a sensor

- To increase sensitivity: microlenses



Single pixel size: 3-8 microns

Sensor types

- **CCD** are charge coupled devices.
  - For their development the authors W. Boyle and J. Smith received the Nobel Prize in 2009.
  - The signal is read out sequentially from each cell, row by row.
  - The next image is possible only when the previous one is already fully formed.
- **CMOS** are devices based on symmetric complementary metal oxide semiconductors.
  - Coordinates in the matrix are set for each cell.
  - The signal from each cell is read out individually.

Sensor types: CCD

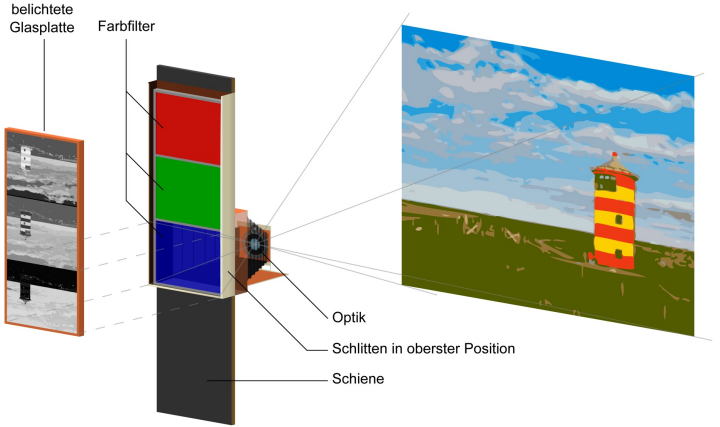
- **Advantages of CCD:**
  - low noise level;
  - high pixel fill factor (up to 100%);
  - high efficiency – 95% (the human eye has an order quantum efficiency of 1%);
  - high dynamic range (saturation current ratio to noise current, dB);
  - good sensitivity in the infrared spectrum range.
- **Disadvantages of CCD:**
  - sophisticated signal reading system;
  - high level of power consumption (up to 2-5 W);
  - more expensive than CMOS in manufacturing.

Sensor types: CMOS

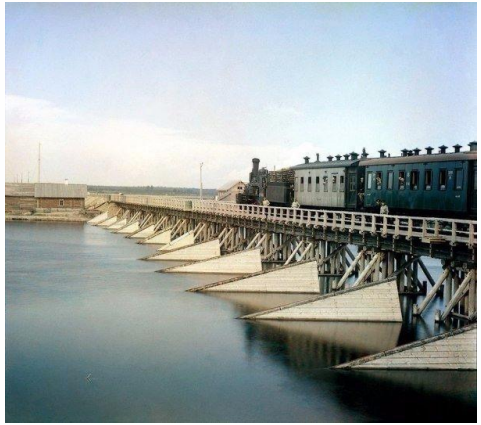
- **Advantages of CMOS:**
  - high performance (registration up to 500 frames per second);
  - low power consumption (100 times compared to CCD);
  - cheaper and easier CCD to manufacture;
  - actual technology (on the one crystal you can implement all the necessary additional circuits: ADC, processor, memory, i.e. a complete digital camera on the one crystal).
- **Disadvantages of CMOS:**
  - low pixel fill factor (effective pixel surface up to 75%, the rest is occupied by transistors);
  - high noise level (even in the absence of illumination, a significant current flows through the photodiode);
  - low dynamic range.

Hardware for images getting

- **Grayscale:** Combining pixels (CCD or CMOS) into rows or matrices produces an analog signal that is converted to a digital values matrix.
- **Obtaining a color image**: using light (color) filters.
- The first one experience is late 19th – early 20th century; photographer and inventor S.M. Prokudin-Gorsky.

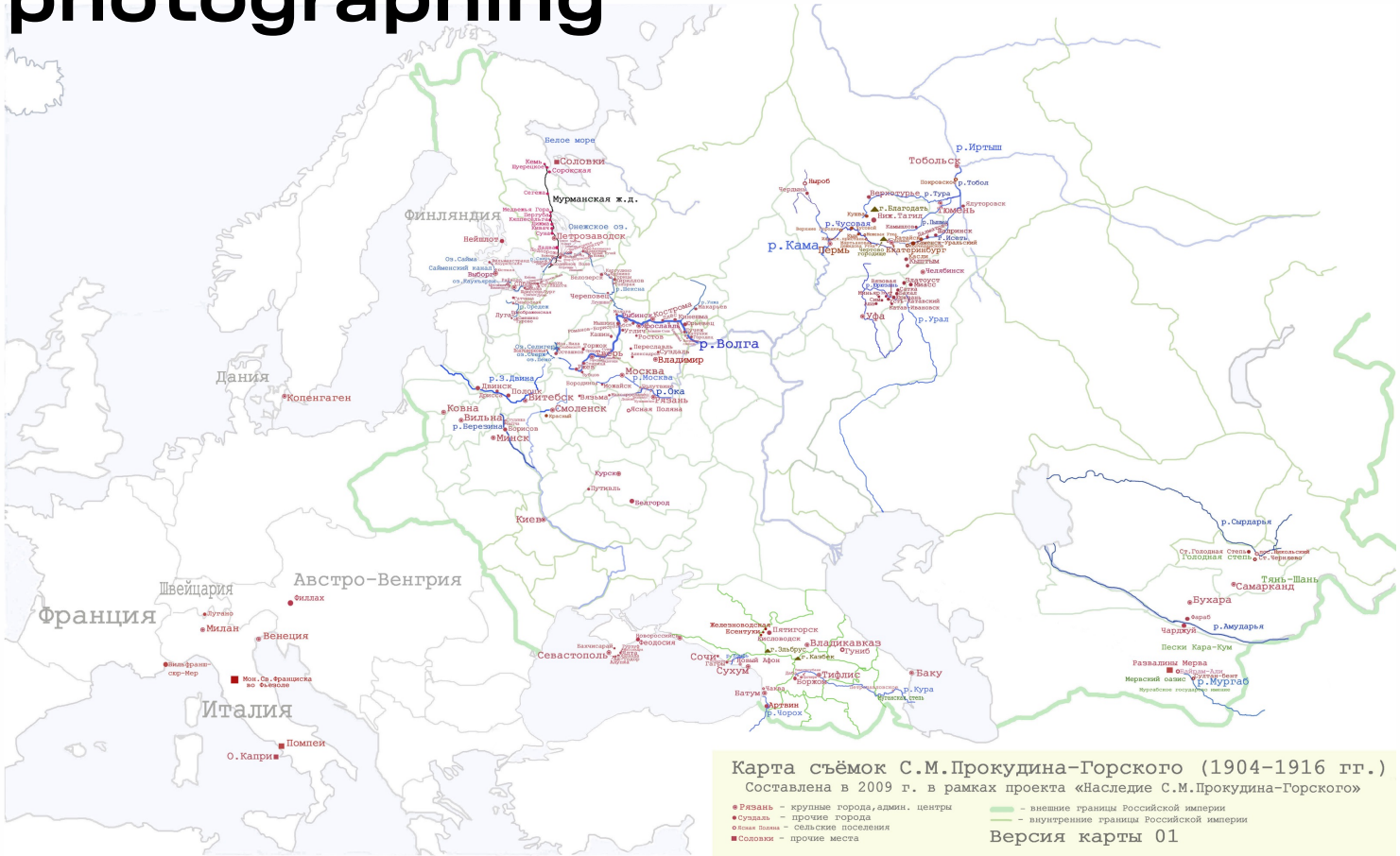


Prokudin-Gorsky photos

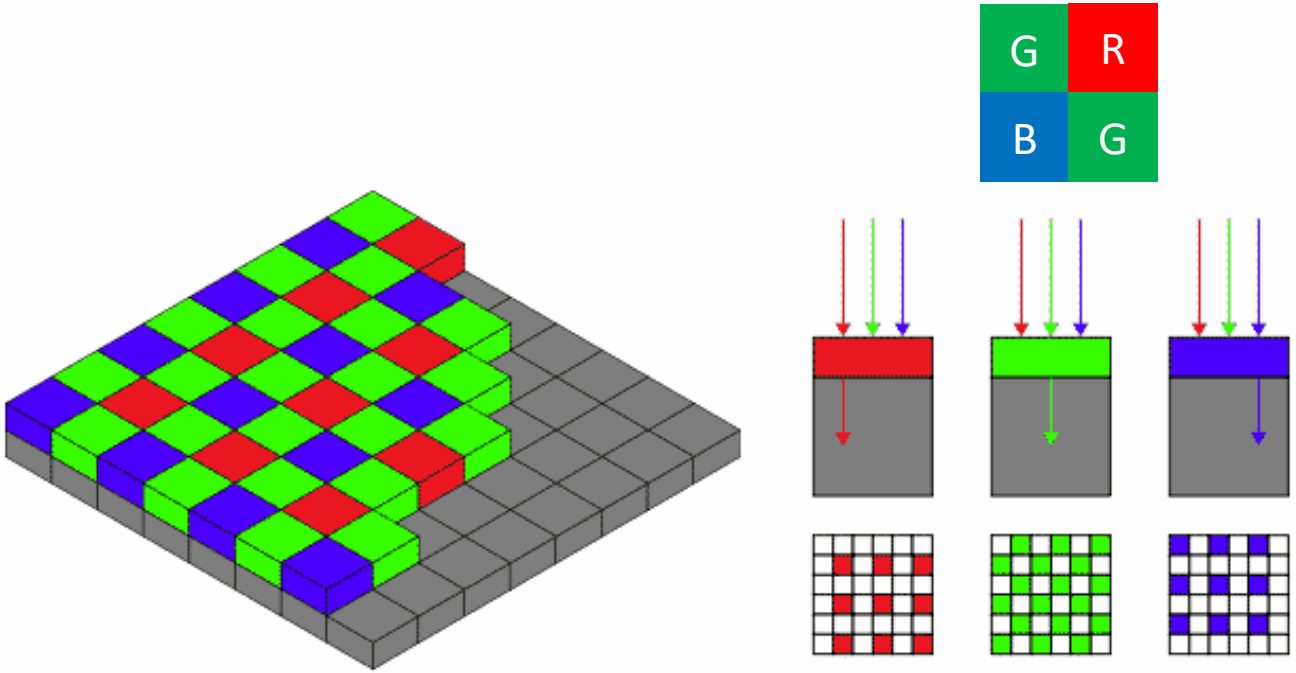


Map of Prokudin-Gorsky photographing



Color images: CCD sensors

- The matrix of photosensitive elements is covered with a light filters matrix. For example, Bayer's mosaic.



Color images: CCD sensors

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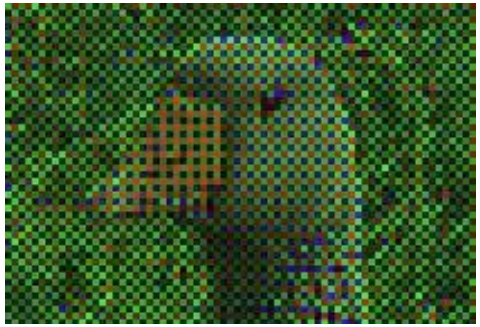
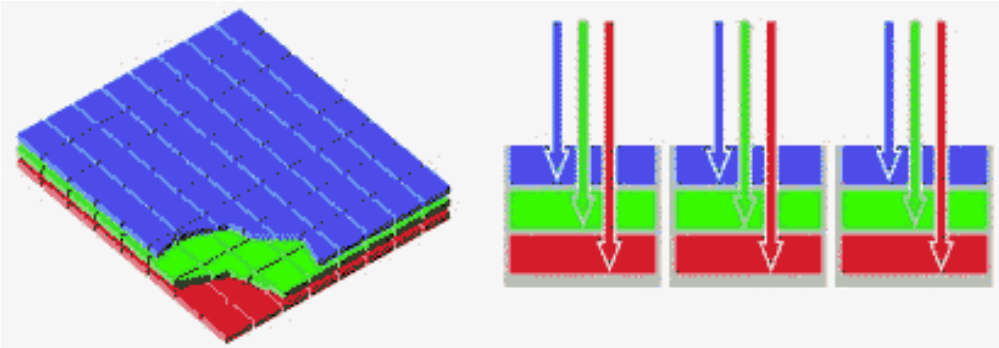
- The image matrix consists of three primary different intensities colors pixels mosaic.
- More green is registered due to the human vision features.
- The missing colors in each pixel are calculated by interpolating the tiled image.

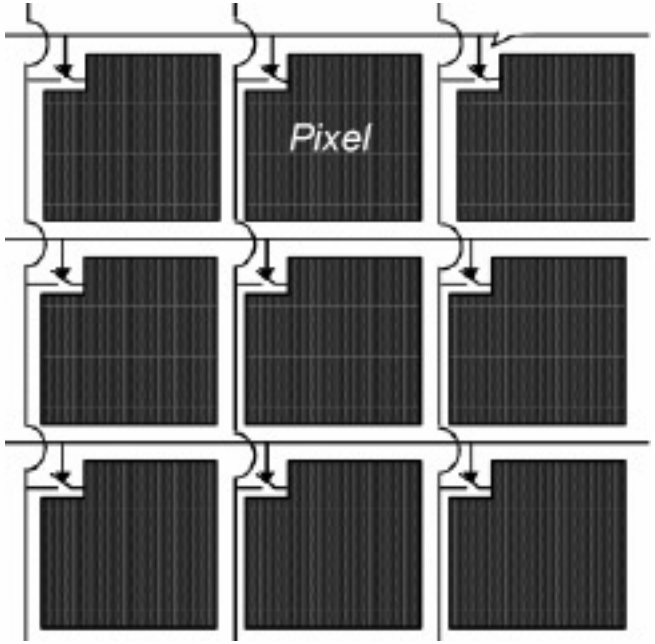




Color images: CMOS sensors

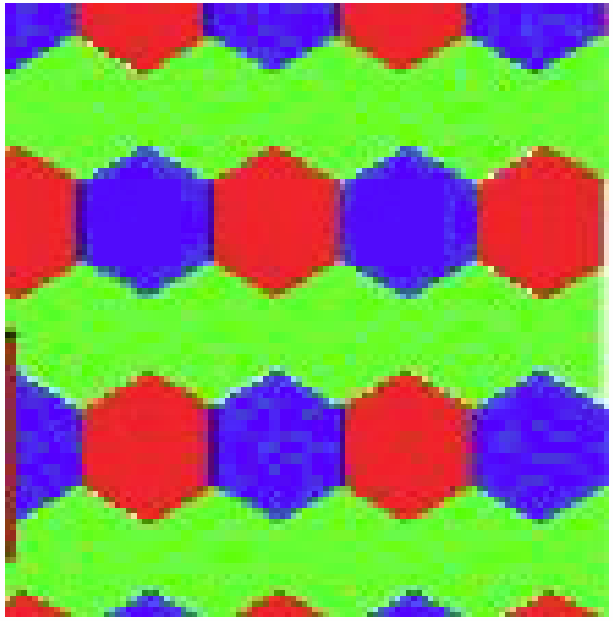
- The each pixel photocell consists of three layers that transmit wavelengths of different ranges.
- The resulting electrons and «holes» are accumulated in three potential wells (one for each layer).
- Advantage: no mosaicity and interpolation (precision).
- Disadvantages: photons absorption during the transition between layers (sensitivity).



Sensors forms (shapes)



L-shape (for CMOS and CCD)



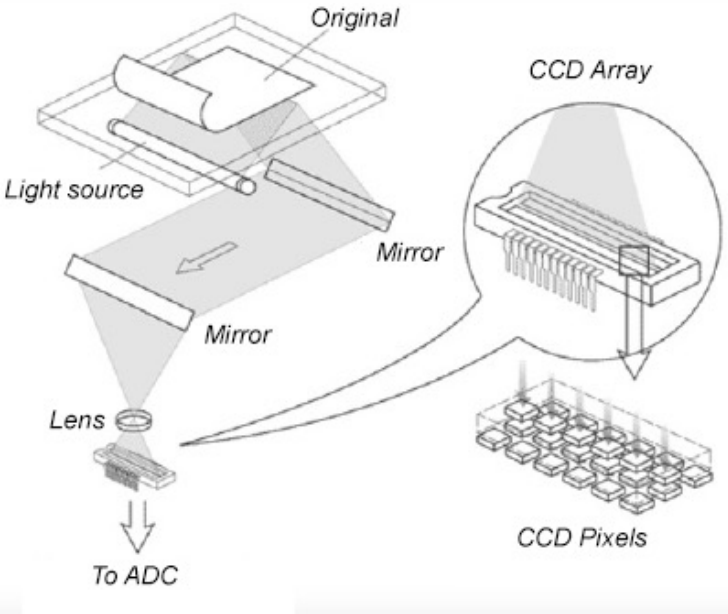
Hexagonal shape Fujifilm Super CCD

Devices for Getting Images

Scanner

- **Scanners:**
  - A scanning carriage with a light source moves along the scanned document.
  - The reflected light through the optical system of the scanner (lens and mirrors or prisms) enters the CCD array.
  - It creates one line of the image.
- Scanner resolution: 300x1200 dpi:
  - Optical resolution: 300 dpi;
  - Mechanical resolution

  (step of carriage displacement) – 1200 dpi.

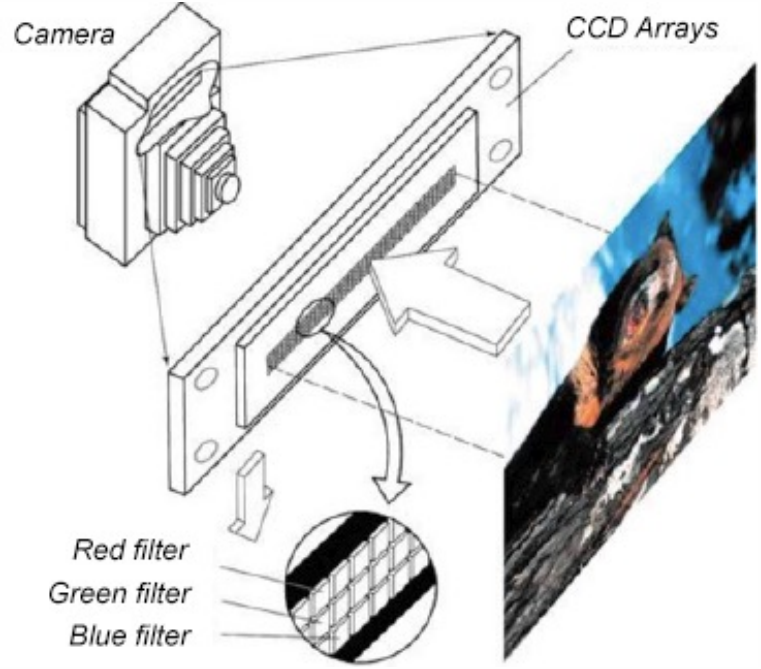


Digital cameras

- Instead of film, CCD or CMOS sensors are used.
- **Specifications:**
  - **Sensor dynamic range** – the number of shades of gray (brightness levels) distinguished by the sensor between absolutely black and absolutely white colors (the widest range is for negative film);
  - The **bit depth** of the color representation.
- Camera designs (constructions):
  - Rear scan cameras;
  - Three-frame cameras;
  - Single-frame cameras with one sensor;
  - Single-frame cameras with three sensors.

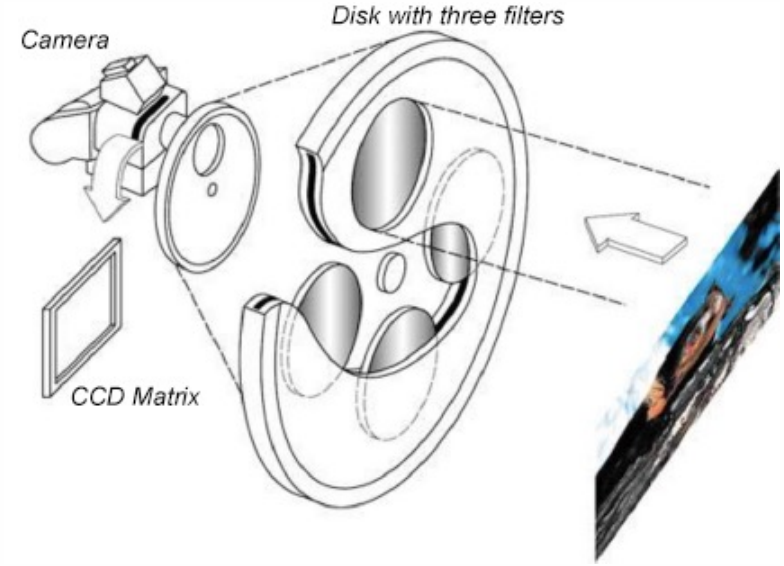
Rear scan cameras

- Rear scan design.
- Low performance, very high quality (resolution).



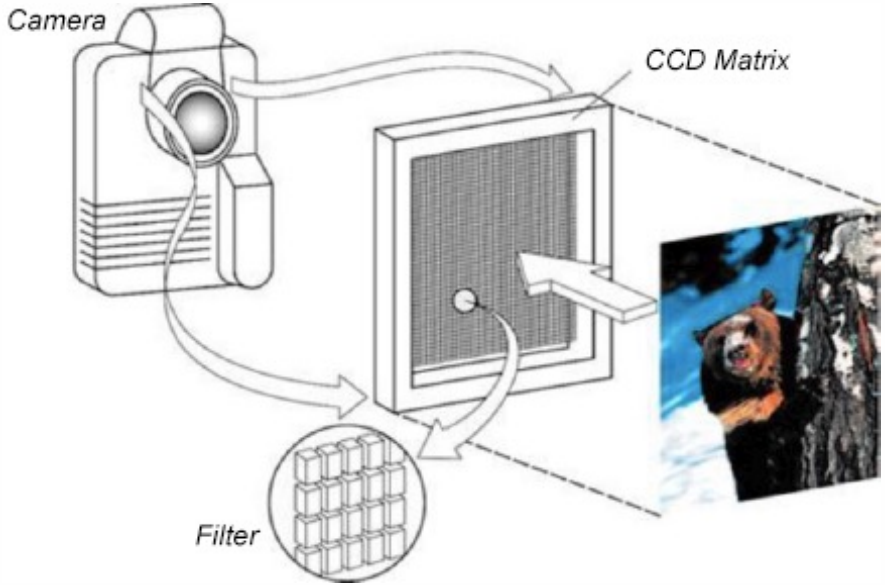
Three-frame cameras

- Three frames are taken through three light filters on a CCD matrix.
- High quality, relatively high performance.



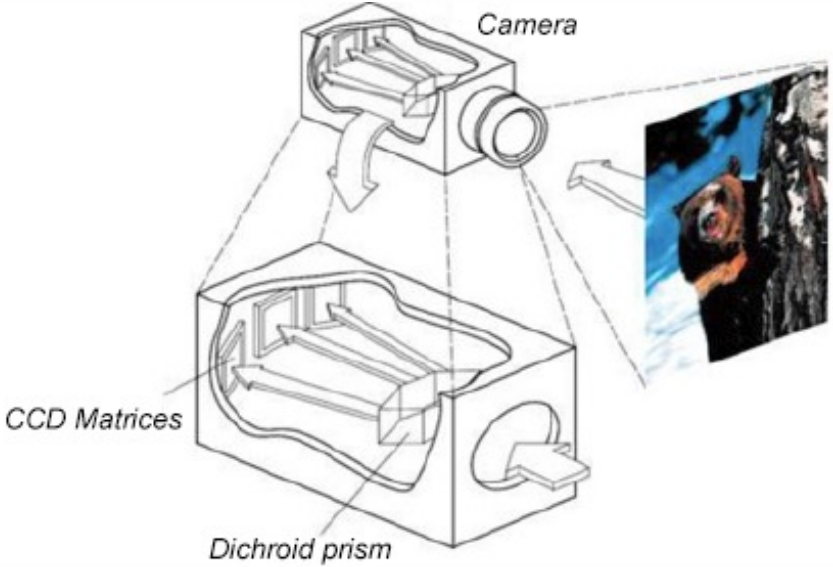
Single-frame cameras with one sensor

- It makes one shot through a matrix film filter.
- High speed, medium color rendition and resolution.



Single-frame cameras with three sensors

- The light flux is divided by a dichroid prism into three, each of which falls on its own matrix.
- High speed, good color rendition and resolution.

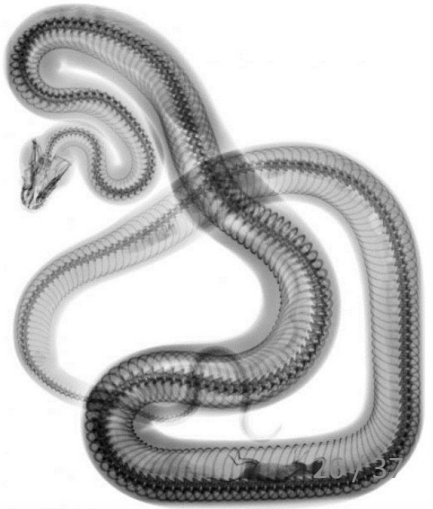


Ultrasonic sensors

- The basis of ultrasonic images is the piezoelectric effect:
  - If single crystals of some chemical compounds are deformed under the influence of ultrasonic waves, opposite electric charges appear on these crystals' surfaces.
  - If an alternating electric charge is applied to them, mechanical vibrations arise in the crystals with the emission of ultrasonic waves.
  - One and the same piezoelectric element can alternately be a receiver and a source of ultrasonic waves.

X-Ray devices

- X-rays have a wavelength of 0.01 to 1 nm and are capable of penetrating solid objects.
- Images are recorded based on the different attenuation of radiation as it passes through various objects (tissues).
- The radiation is projected onto a flat electron matrix that stores the charge.
- Three methods of signal conversion are used for reading:
  - straight;
  - photoconductivity method;
  - scintillation.

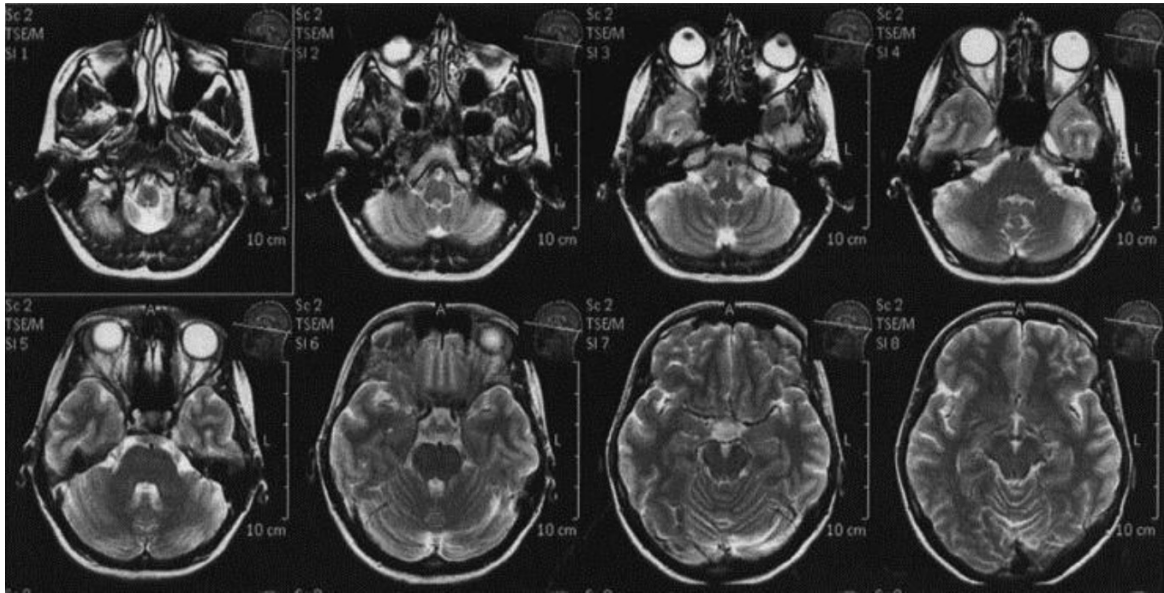


Tomography

- Tomography is a method of obtaining a layer-by-layer object internal structure image.
- According to the operation principle they are divided into tomographs:
  - Based on nuclear magnetic resonance (magnetic resonance imaging, MRI);
  - On the basis of X-ray radiation (computed tomography, CT).

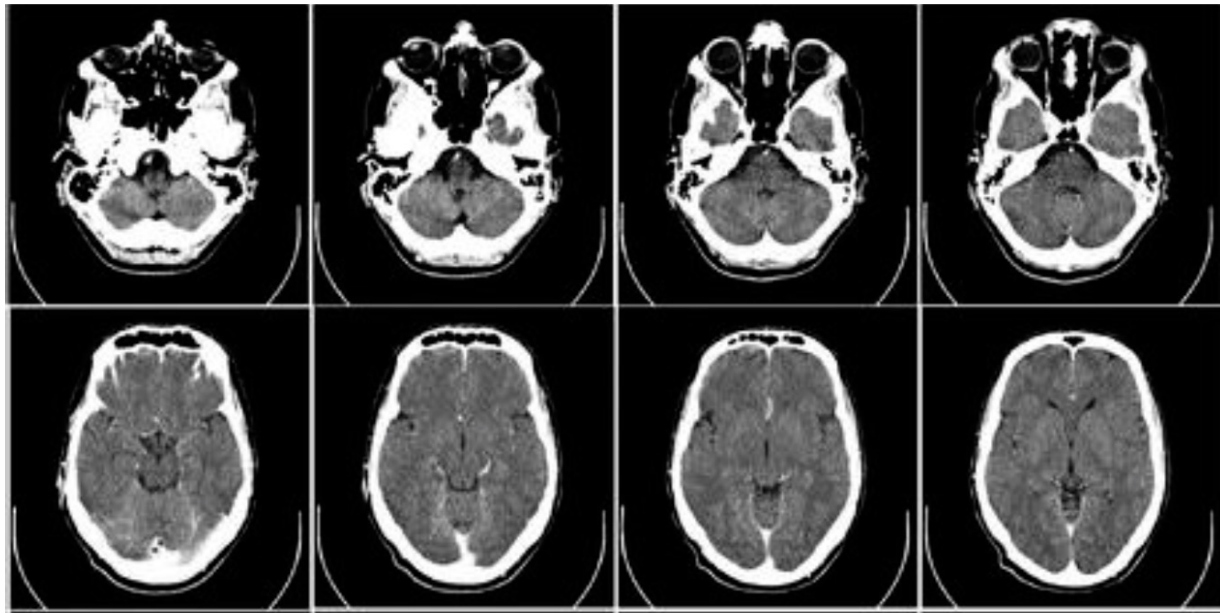
Tomography: NMR (MRI)

- Method based on measuring the electromagnetic response of the hydrogen atoms nuclei when they are excited by a certain combination of electromagnetic waves in a constant magnetic field of high intensity.
- Better for soft tissue.



Tomography: CT

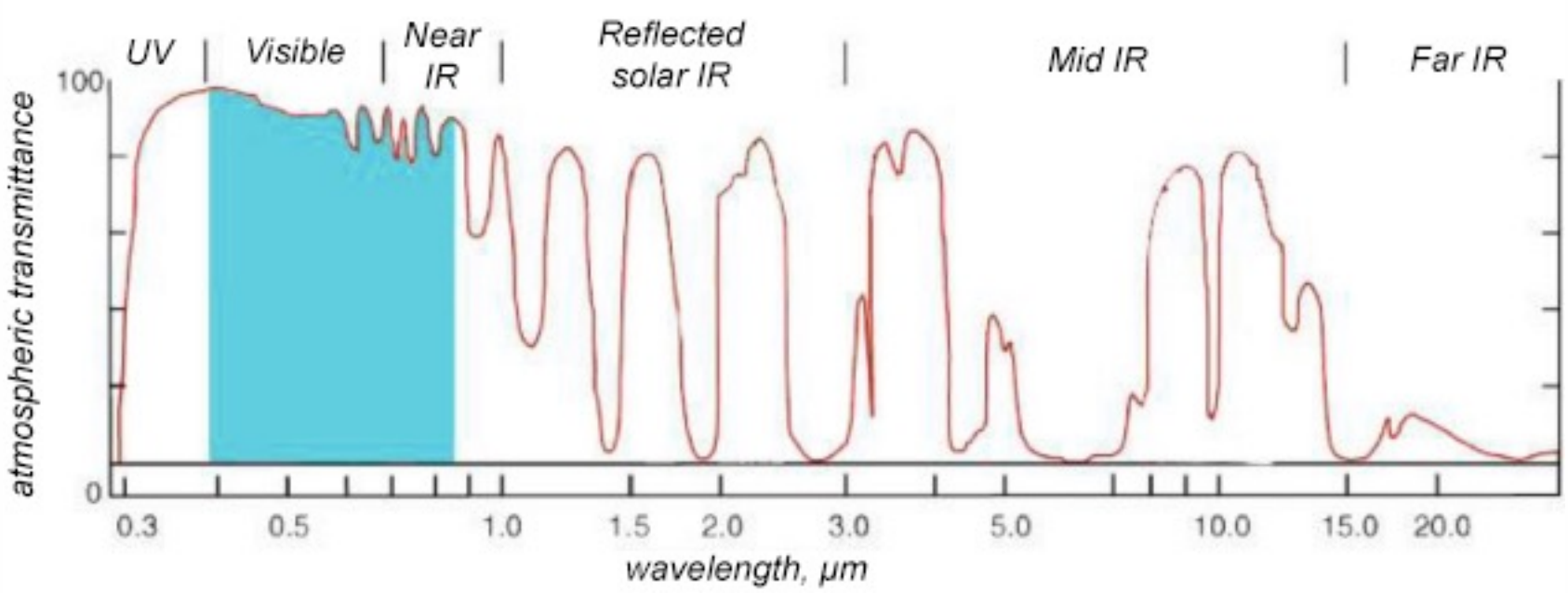
- Method consists in a computer reconstruction of a body cross-sectional image based on an analysis of X-ray absorption.
- CT detectors are 100 times more sensitive than X-ray film.
- Better for bones.



Earth remote sensing images

- These images are obtaining information about the state of the Earth's surface from measurements at a distance without direct contact of sensors with the surface.
- **By sounding method:**
  - Active – use a reflection initiated by an artificial source.
  - Passive – use the natural reflected radiation of objects.
- **By spectral range:**
  - Photographic systems;
  - Visible and infrared scanning systems;
  - Television optical systems;
  - Side-looking radar systems;
  - Scanning microwave radiometers.

Earth remote sensing images



Transparency window:

- visible region (380–720 nm);
- near infrared (720-1300 nm);
- mid-infrared region (1300-3000 nm).

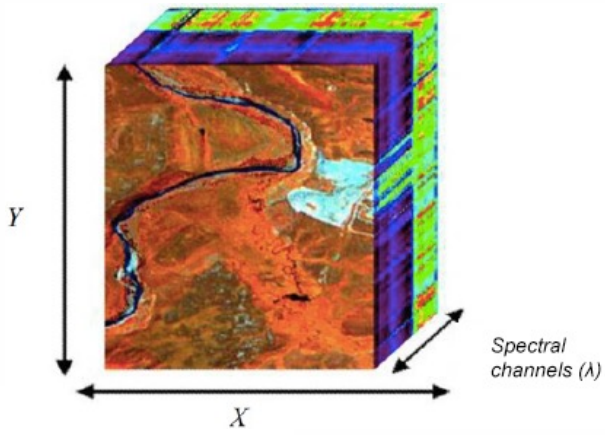
Earth remote sensing images

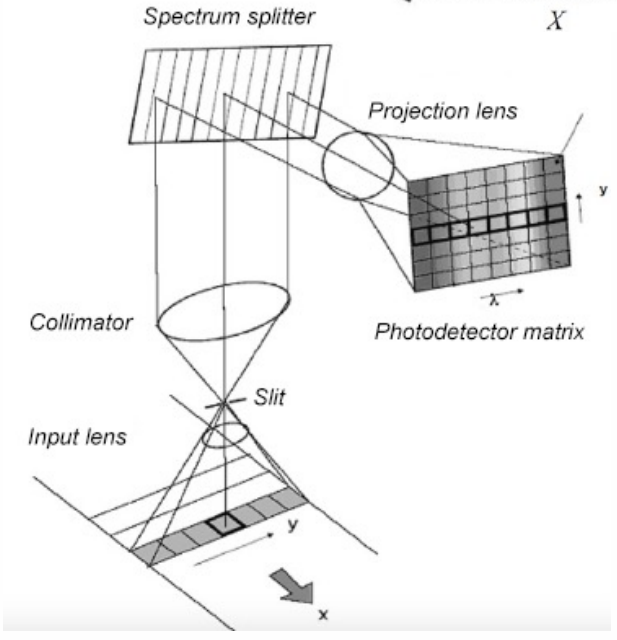
- Spatial resolution of the images:
  - Low (300-1000 m);
  - Medium (50-200 m);
  - Relatively high (20–40 m);
  - High (10–20 m);
  - Very high (1–10 m);
  - Super high (0.3–0.9 m).

- The main types of images:
  - Multispectral images;
  - Hyperspectral images.

Earth remote sensing images

- A set of grayscale images of one area of the terrain, recorded in several narrow spectral ranges, selected by filtering.
- Decomposition with the help of a prism of solar radiation reflected from an area of the Earth corresponding to one pixel with coordinates (x, y) into a line of sensors, each of which registers signals in a narrow spectral range.
  - All brightness values recorded by the ruler are assigned to one pixel.

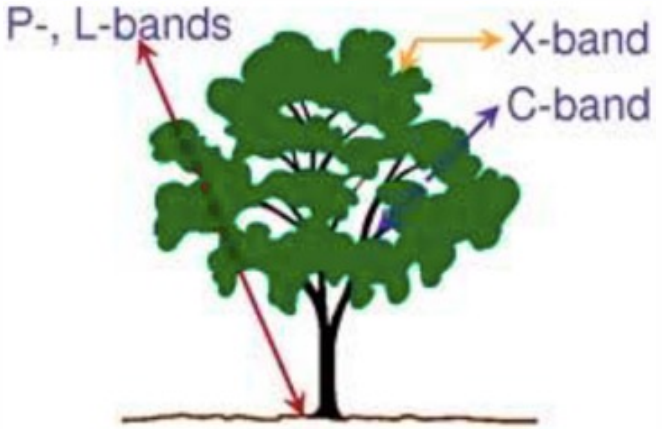




Radar images

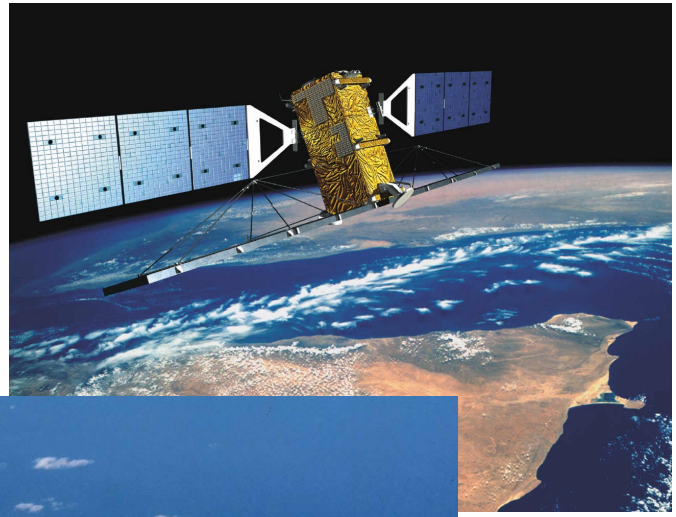
- The main principle: the ability of objects, in accordance with their coefficient of dielectric constant, to reflect in different ways narrowly directed radio pulses of the centimeter range (0.3-100 cm).

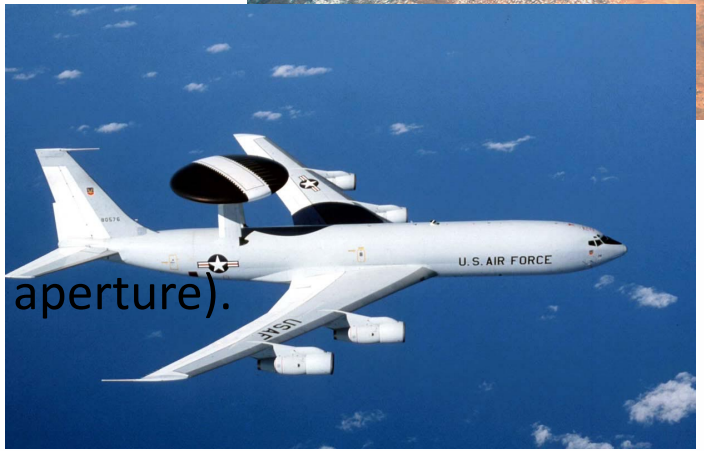
Name	Frequency, MHz	Wavelength, cm
Ka-band	40 000–26 000	0,8–1,1
K-band	26 500–18 500	1,1–1,7
Ku-band	18 500–12 500	1,7–2,4
X-band	12 500–8 000	2,4–3,8
C-band	8 000–4 000	3,8–7,5
S-band	4 000–2 000	7,5–15,0
L-band	2 000–1 000	15,0–30,0
P-band	1 000–300	30,0–100,0



Radar images resolution

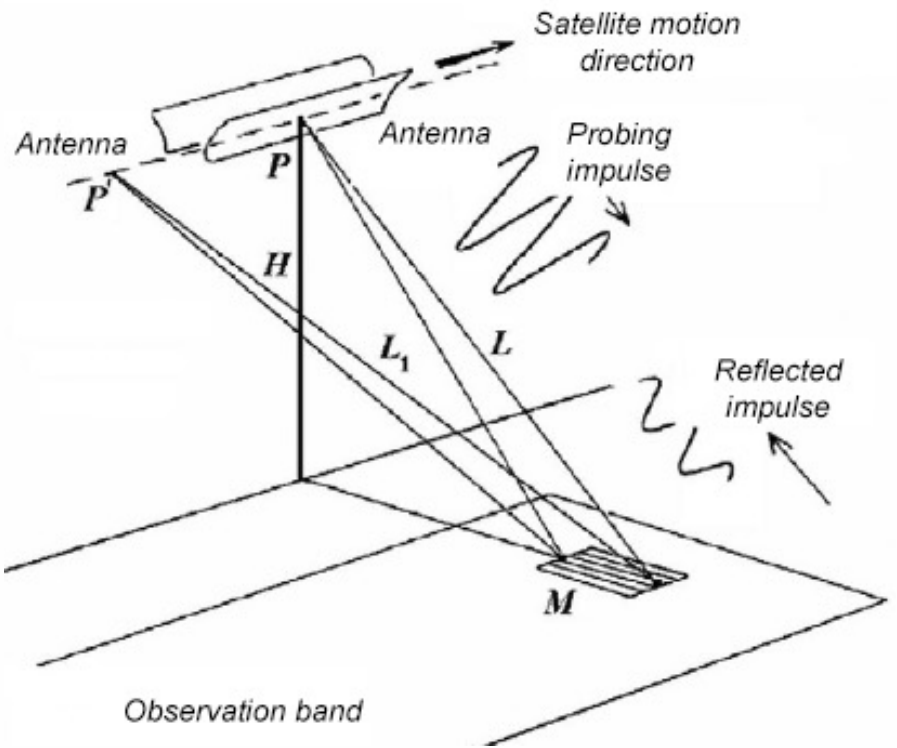
- Depends on the wavelength and size of the antenna.
- Example: radar with a wavelength of 2 cm on a flying aircraft:
  - Altitude: 10 km,
  - Resolution: 15 m.
- The same radar on the satellite:
  - Altitude: 500-1000 km,
  - Resolution: 1000-2000 m.
- Solution: RSA (radar with a synthetic aperture).





Synthetic aperture method

- Radar with a wavelength of 5 cm:
  - Altitude: 1000 km,
  - Resolution: 5 m.
- Coherent (phase-preserving) processing of scattered signals is performed for a fixed time interval, during which the satellite flies a certain distance (the length of the synthesized antenna).



THANK YOU FOR YOUR TIME!

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s.shavetov@itmo.ru