ACTIVE SENSORS
REMOTE SENSORS

Passive Sensors

• Aerial Cameras
• Visible and IR Scanners
• Thermal

Active Sensors

• Acoustic Sensors
• Microwave (Radar)
• Lidar
**Platforms**: Where the sensors are mounted.

**Sensors**: Instruments on the platforms.

- ETM+
- AVIRIS
- GER 1500
CHAPTER 7:
ACTIVE MICROWAVE
FIGURE 7.1. Active and passive microwave remote sensing. (a) Active microwave sensing, using energy generated by the sensor, as described in this chapter. (b) Passive microwave sensing, which detects energy emitted by the Earth’s surface, described in Chapter 9.
FIGURE 7.2. Radar image of a region near Chattanooga, Tennessee, September 1985 (X-band, HH polarization). This image has been processed to produce pixels of about 11.5 m in size. From USGS.
FIGURE 7.4. Geometry of an imaging radar system. The radar beam illuminates a strip of ground parallel to the flight path of the aircraft; the reflection and scattering of the microwave signal from the ground forms the basis for the image.
SLAR Data of Puerto Rico

SLAR Data of Puerto Rico
FIGURE 7.5. Radar layover. In the ground-range domain, $AB$ and $BC$ are equal. Because the radar can measure only slant-range distances, $AB$ and $BC$ are projected onto the slant-range domain, represented by the line $bac$. The three points are not shown in their correct relationship because the slant-range distance from the antenna to the points does not match to their ground-range distances. Point $B$ is closer to the antenna than is point $A$, so it is depicted on the image as closer to the edge of the image.
FIGURE 7.6. Radar foreshortening. Projection of $A$, $B$, and $C$ into the slant-range domain distorts the representations of $AB$ and $BC$, so that $ab$ appears shorter, steeper, and brighter than it should be in a faithful rendition, and $bc$ appears longer, shallower in slope, and darker than it should be.
# ELECTROMAGNETIC SPECTRUM

![Electromagnetic Spectrum Diagram]

## TABLE 7.1. Radar Frequency Designations

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-band</td>
<td>107–77 cm</td>
</tr>
<tr>
<td>UHF</td>
<td>100–30 cm</td>
</tr>
<tr>
<td>L-band</td>
<td>30–15 cm</td>
</tr>
<tr>
<td>S-band</td>
<td>15–7.5 cm</td>
</tr>
<tr>
<td>C-band</td>
<td>7.5–3.75 cm</td>
</tr>
<tr>
<td>X-band</td>
<td>3.75–2.40 cm</td>
</tr>
<tr>
<td>Ku-band</td>
<td>2.40–1.67 cm</td>
</tr>
<tr>
<td>K-band</td>
<td>1.67–1.18 cm</td>
</tr>
<tr>
<td>Ka-band</td>
<td>1.18–0.75 cm</td>
</tr>
<tr>
<td>VHF</td>
<td>1–10 m</td>
</tr>
<tr>
<td>UHF</td>
<td>10 cm–1 m</td>
</tr>
</tbody>
</table>
FIGURE 7.8. X- and P-band SAR images, Colombia. The X-band image, collected at wavelengths of 2–4 cm, records features in a view that resembles a view similar to that of an aerial photograph. Longer wavelengths of the P-band image reveals features below the vegetation canopy and, in some instances, below the soil surface, depicting terrain and land use features. From FUGRO-EarthData.
FIGURE 7.9. Radar polarization. Many imaging radars can transmit and receive signals in both horizontally and vertically polarized modes. By comparing the like-polarized and cross-polarized images, analysts can learn about characteristics of the terrain surface. From NASA-JPL. P45541, SIR C/X SAR, October 1994.
Look direction is the direction at which the radar signal strikes the landscape, is important in both natural and man-made landscapes. Look directions perpendicular to topographic alignment will tend to maximize radar shadow, whereas look directions parallel to topographic orientation will tend to minimize radar shadow.

**FIGURE 7.10.** Radar shadow. Radar shadow increases as terrain relief increases and depression angle decreases.
The look angle is the depression angle of the radar and varies across an image, from relatively steep at the near-range side of the image to relatively shallow at the far-range side. The exact values of the look angle vary with the design of specific radar systems. The spatial resolution, at least in the across-track direction, varies with respect to depression angle.

**FIGURE 7.11.** Look angle and incidence angle.
REAL APERTURE SYSTEMS

FIGURE 7.12. Azimuth resolution. For real aperture radar, the ability of the system to acquire fine detail in the along-track axis derives from its ability to focus the radar beam to illuminate a small area. A long antenna, relative to wavelength, permits the system to focus energy on a small strip of ground, improving detail recorded in the along-track dimension of the image. The beam width ($\beta$) measures this quality of an imaging radar. Beam width, in relation to range ($R$), determines detail—region 1 at range $R_1$ will be imaged in greater detail than region 2 at greater range $R_2$. Also illustrated here are side lobes, smaller beams of microwave energy created because the antenna cannot be perfectly effective in transmitting a single beam of energy.
FIGURE 7.13. Effect of pulse length. (a) Longer pulse length means that the two objects shown here are illuminated by a single burst of energy, creating a single echo that cannot reveal the presence of two separate objects. (b) Shorter pulse length illuminates the two objects with separate pulses, creating separate echoes for each object. Pulse length determines resolution in the cross-track dimension of the image.
SYNTHETIC APERTURE SYSTEMS

FIGURE 7.14. Synthetic aperture imaging radar. Synthetic aperture systems accumulate a history of backscattered signals from the landscape as the antenna moves along path abc.
**Doppler Effect**: Objects within the landscape experience different frequency shifts in relation to their distances from the aircraft track. At a given instant, objects at the leading edge of the beam reflect a pulse with an increase in frequency (relative to the transmitted frequency) due to their position ahead of the aircraft, and those at the trailing edge of the antenna experience a decrease in frequency.

**FIGURE 7.15.** Frequency shifts experienced by features within the field of view of the radar system.
INTERPRETING RADAR IMAGES

Brightness Values
Radar Equation
Speckle
Moisture
Roughness
Corner Reflection
## TABLE 7.3. Summary of Some SAR Satellite Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Dates</th>
<th>Bands</th>
<th>Polarizations</th>
<th>Lead organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERS-1</td>
<td>1991–2000</td>
<td>C-band</td>
<td>VV</td>
<td>European Space Agency</td>
</tr>
<tr>
<td>JERS-1</td>
<td>1992–1998</td>
<td>L-band</td>
<td>HH</td>
<td>Japan</td>
</tr>
<tr>
<td>SIR-C</td>
<td>1994</td>
<td>X/C/L-bands</td>
<td>full</td>
<td>USA</td>
</tr>
<tr>
<td>RADARSAT</td>
<td>1995–present</td>
<td>C-band</td>
<td>HH</td>
<td>Canada</td>
</tr>
<tr>
<td>ERS-2</td>
<td>1995–present</td>
<td>C-band</td>
<td>VV</td>
<td>European Space Agency</td>
</tr>
<tr>
<td>ENVISAT</td>
<td>2002–present</td>
<td>C-band</td>
<td>dual</td>
<td>European Space Agency</td>
</tr>
<tr>
<td>ALOS</td>
<td>2006–present</td>
<td>L-band</td>
<td>full</td>
<td>Japan</td>
</tr>
<tr>
<td>RADARSAT-2</td>
<td>2007–present</td>
<td>C-band</td>
<td>full</td>
<td>Canada</td>
</tr>
<tr>
<td>TerraSAR-X</td>
<td>2007–present</td>
<td>X-band</td>
<td>full</td>
<td>Germany</td>
</tr>
<tr>
<td>COSMO-SkyMed Constellation</td>
<td>2007–present</td>
<td>X-band</td>
<td>full</td>
<td>Italy</td>
</tr>
<tr>
<td>TanDEM-X</td>
<td>2010–present</td>
<td>X-band</td>
<td>full</td>
<td>Germany</td>
</tr>
</tbody>
</table>
X-BAND ANTENNA AT UPRM

RADARSAT

SAR

LANDSAT-7

ETM+
FIGURE 7.23. RADARSAT SAR geometry.
Applications of SAR Data in Puerto Rico

Physical Oceanography: Internal Waves
MOSAIC OF SAR IMAGES
OF PUERTO RICO
Interferometric SAR (inSAR), uses two SAR images of the same region acquired from two different positions. In a very rough sense, SAR interferometry is comparable to the use of stereo photography to determine topography of a region by observation from two different perspectives. However, SAR interferometry is applied not in the optical domain of photogrammetry but in the realm of radar geometry, to exploit radar’s status as an active sensor.
CHAPTER 8: LIDAR
A lidar is similar to the more familiar radar, and can be thought of as a laser radar.

A lidar also transmits and receives electromagnetic radiation, but at a higher frequency. Lidars operate in the ultraviolet, visible and infrared region of the electromagnetic spectrum.
Because lidars are based on an application of lasers, they use a form of coherent light—light that is composed of a very narrow band of wavelengths—very "pure" with respect to color.
FIGURE 8.2. Schematic diagram of a simple laser. Energy, such as electricity, is applied to a substance, such as lasable gases (e.g., nitrogen, helium–neon) or materials (e.g., ruby crystals). When the materials return to their normal state, they emit coherent light, which is intensified before release by multiple reflections between the mirrored surfaces. Intensified light then can then pass through the semitransparent mirror to form the beam of coherent light that is emitted by the instrument.
FIGURE 8.4. Schematic diagram of a lidar scanner. (1) The system’s laser (coordinated by the electronic component) generates a beam of coherent light, transmitted by a fiber optic cable to (2) a rotating mirror, offset to provide a scanning motion. The laser light is directed to a bundle of fiber optic cables that are twisted to provide a linear beam and then directed through a system of lenses toward the ground. The energy received back from the terrain is received by another system of lenses and processed to form an image.
FIGURE 8.8. Acquisition of lidar data. Lidar systems acquire data by scanning in the pattern suggested by the top diagram; details vary according to specific systems. The pattern of returns is then interpolated to generate the regular array that forms the lidar image. Examples of actual scan pattern and interpolated data are depicted in Plate 12.
FIGURE 8.9. Schematic diagram of primary and secondary lidar returns.
FIGURE 8.10. Primary and secondary lidar returns from two forested regions. This illustration represents lidar return from two separate forested areas, shown in profile. The dots near the top of the diagram represent the returns that are received first (primary returns), and the dots at the lower and central portions of the diagram represent the return received later (secondary returns). Note the contrast between the dome-shaped canopy formed by the crowns of the deciduous forest (left) and the peaked crowns of the coniferous canopy (right). The coniferous forest has only sparse undergrowth, while the deciduous forest is characterized by abundant undergrowth. From Peter Sforza and Sorin Popescu.
LITE flew on shuttle mission STS-64 in September, 1994.

LITE was the first successful demonstration of operating a lidar from space.

LITE was designed to measure clouds and aerosols, the small particles of "stuff" in the air that includes cloud droplets.
Read Chapters 7 and 8.