8 MICROWAVE AND LIDAR SENSING

8.1 INTRODUCTION

An increasing amount of valuable environmental and resource information is being acquired by sensors that operate in the *microwave* portion of the electromagnetic spectrum. In the context of the sensors we have discussed thus far, microwaves are not "micro" at all. That is, the microwave portion of the spectrum includes wavelengths within the approximate range of 1 mm to 1 m. Thus, the longest microwaves are about 2,500,000 times longer than the shortest light waves!

There are two distinctive features that characterize microwave energy from a remote sensing standpoint:

1. Microwaves are capable of penetrating the atmosphere under virtually all conditions. Depending on the wavelengths involved, microwave energy can "see through" haze, light rain and snow, clouds, and smoke.
2. Microwave reflections or emissions from earth materials bear no direct relationship to their counterparts in the visible or thermal portions of the spectrum. For example, surfaces that appear "rough" in the visible portion of the spectrum may be "smooth" as seen by mi-

> crowaves. In general, microwave responses afford us a markedly different "view" of the environment—one far removed from the views experienced by sensing light or heat.

In this chapter we discuss both airborne and spaceborne, as well as *active* and *passive*, microwave sensing systems. Recall that the term "active" refers to a sensor that supplies its own source of energy or illumination. *Radar* is an active microwave sensor, and it is the major focus of attention in this chapter. To a lesser extent, we also treat the passive counterpart to radar, the *microwave radiometer*. This device responds to the extremely low levels of microwave energy that are naturally emitted and/or reflected from ambient sources (such as the sun) by terrain features.

It should be recognized that practical resource management experience with radar and passive microwave systems is relatively limited compared to photographic or scanning systems. However, with the increasing availability of spaceborne radar data, the applications of microwave sensing have increased substantially.

We conclude this chapter with a brief introduction to *lidar* remote sensing. Like radar, lidar sensors are active remote sensing systems. However, they use pulses of laser light, rather than microwave energy, to illuminate the terrain. As with radar, the outlook for applications of such systems is an extremely promising one.

8.2 RADAR DEVELOPMENT

The word *radar* is an acronym for *radio detection and ranging*. As its name implies, radar was developed as a means of using radio waves to detect the presence of objects and to determine their distance and sometimes their angular position. The process entails transmitting short bursts, or pulses, of microwave energy in the direction of interest and recording the strength and origin of "echoes" or "reflections" received from objects within the system's field of view.

Radar systems may or may not produce images, and they may be ground based or mounted in aircraft or spacecraft. A common form of nonimaging radar is the type used to measure vehicle speeds. These systems are termed *Doppler radar* systems because they utilize Doppler frequency shifts in the transmitted and returned signals to determine an object's velocity. Doppler frequency shifts are a function of the relative velocities of a sensing system and a reflector. For example, we perceive Doppler shifts in sound waves as a change in pitch, as in the case of a passing car horn or train whistle. The Doppler shift principle is often used in analyzing the data generated from imaging radar systems.

Another common form of radar is the *plan position indicator (PPI)* system. These systems have a circular display screen on which a radial sweep indicates the position of radar "echoes." Essentially PPI radar images a continuously updated plan-view map of objects surrounding its rotating antenna. These systems are common in weather forecasting, air traffic control, and navigation applications. However, PPI systems are not appropriate to most remote sensing applications because they have rather poor spatial resolution.

Airborne and spaceborne radar remote sensing is done with systems that use an antenna fixed below the aircraft (or spacecraft) and pointed to the side. Such systems are termed *side-looking radar (SLR)*, or *side-looking airborne radar (SLAR)* in the case of airborne systems. Side-looking radar systems produce continuous strips of imagery depicting extensive ground areas that parallel the aircraft flight line.

Side-looking airborne radar was first developed for military reconnaissance purposes in the late 1940s. It became an ideal military reconnaissance system, not only because it affords nearly an all-weather operating capability, but also because it is an active, day-or-night imaging system. The military genesis of SLAR has had two general impacts on its subsequent application to civilian remote sensing uses. First, there was a time lag between military development, declassification, and civilian application. Less obvious, but nonetheless important, is the fact that military SLAR systems were developed to look at military targets. Terrain features that "cluttered" SLAR imagery and masked objects of military importance were naturally not of interest in original system designs. However, with military declassification and improvement in nonmilitary capabilities, SLR has evolved into a powerful tool for acquiring natural resource data.

Although SLR acquisition and analysis techniques have been developed to a high degree of sophistication, it should be pointed out that the application of radar technology to earth resource sensing is still in an active state of advancement. What determines the overall "radar reflectivity" of various earth resources features under various conditions is still not always known precisely. Even though much is yet to be learned about how radar signals interact with the natural environment, productive applications of existing radar technology have been many and varied. While the use of radar is continuing to increase in general, it is particularly extensive in regions where persistent cloud cover limits the acquisition of imagery in the optical portion of the spectrum.

The first large-scale project for mapping terrain with side-looking airborne radar was a complete survey of the Darien province of Panama. This survey was undertaken in 1967 and resulted in images used to produce a mosaic of a 20,000-km^2 ground area. Prior to that time, this region had never been photographed or mapped in its entirety because of persistent (nearly perpetual) cloud cover. The success of the Panama radar mapping project led to the application of radar remote sensing throughout the world. Since the early 1970s, extensive radar mapping programs have been conducted by several governments as well as by mining and petroleum companies.

In 1971, a radar survey was begun in Venezuela that resulted in the mapping of nearly 500,000 km^2 of land. This project resulted in improvements in the accuracy of the location of the boundaries of Venezuela with its neighboring countries. It also permitted a systematic inventory and mapping of the country's water resources, including the discovery of the previously unknown source of several major rivers. Likewise, improved geologic maps of the country were produced.

Also beginning in 1971, was Project Radam (standing for *Radar of the Amazon)*, a reconnaissance survey of the Amazon and the adjacent Brazilian northeast. At that time, this was the largest radar mapping project ever undertaken. By the end of 1976, more than 160 radar mosaic sheets covering an area in excess of 8,500,000 km^2 had been completed. Scientists used these radar mosaics as base maps in a host of studies, including geologic analysis, timber inventory, transportation route location, and mineral exploration. Large deposits of important minerals were discovered after intensive analysis was made of newly discovered features shown by radar. Mapping of previously uncharted volcanic cones, and even large rivers, resulted from this project. In such remote and cloud-covered areas of the world, radar imagery is a prime source of inventory information about potential mineral resources, forestry and range resources, water supplies, transportation routes, and sites suitable for agriculture. Such information is essential to planning sustainable development in such ecologically sensitive areas.

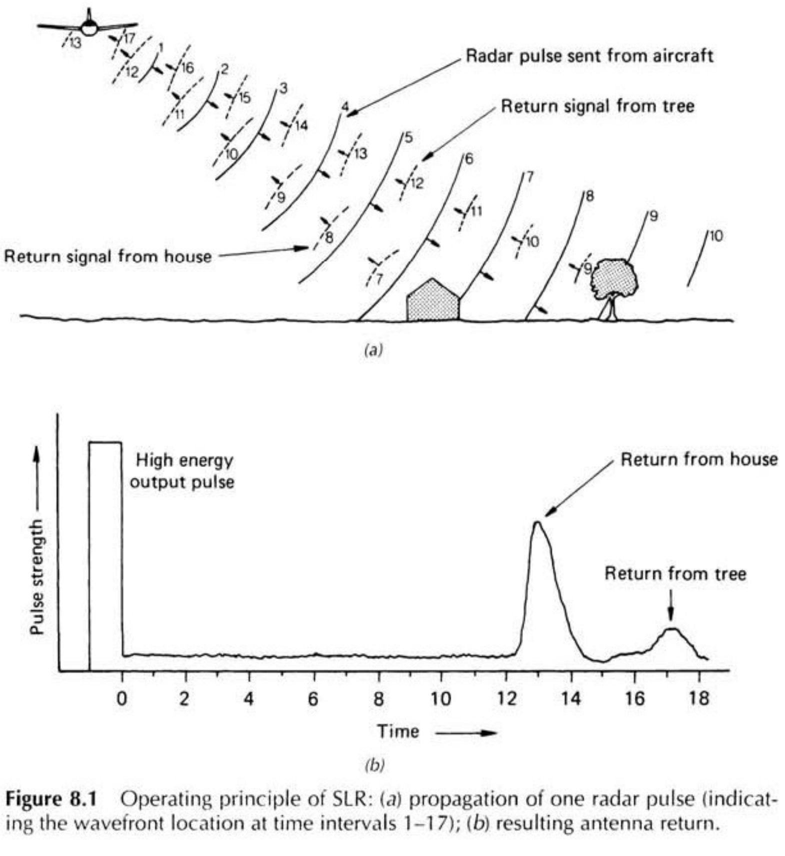
Radar imagery has also been used extensively to monitor the surface of the oceans to determine wind, wave, and ice conditions. Radar data have also been used to study (indirectly) ocean bottom contours under some conditions. Numerous other applications of radar have been demonstrated in the areas of geologic mapping, mineral exploration, flood inundation mapping, and small-scale thematic mapping.

Radar remote sensing from space began with the launch of *Seasat* in 1978 and continued with the Shuttle Imaging Radar (SIR) and Soviet Cosmos experiments in the 1980s. Beginning in 1991, three radar satellites were launched within an 11-month period. These were the *Almaz-1*, *ERS-1*, and *JERS-1* systems launched by the former Soviet Union, European Space Agency, and Japan, respectively. These systems were followed by Canada's first *Radarsat* satellite in 1995. Hence, the 1990s initiated a new era in terms of the broad-scale availability of radar data collected from space. This trend continued into the new century with the globe-spanning Shuttle Radar Topography Mission and ESA's *Envisat*, the most advanced satellite radar system yet launched. Several sophisticated new radar satellite systems are scheduled for deployment in the next 5 years, beginning with those developed by Canada (*Radarsat-2*) and Japan (*ALOS*). The field of spaceborne radar remote sensing thus continues to be characterized by rapid technological advances, an expanding range of sources of data, and a high level of international participation.

8.3 SIDE-LOOKING RADAR SYSTEM OPERATION

The basic operating principle of a SLR system is shown in Figure 8.1. Microwave energy is transmitted from an antenna in very short bursts or pulses. These high energy pulses are emitted over a time period on the order of microseconds (10^{-6} sec). In Figure 8.1, the propagation of one pulse is shown by indicating the wavefront locations at successive increments of time. Beginning with the solid lines (labeled 1 through 10), the transmitted pulse moves radially outward from the aircraft in a constrained (or narrow) beam. Shortly after time 6, the pulse reaches the house, and a reflected wave (dashed line) is shown beginning at time 7. At time 12, this return signal reaches the antenna and is registered at that time on the antenna response graph (Figure 8.1*b*). At time 9, the transmitted wavefront is reflected off the tree, and this "echo" reaches the antenna at time 17. Because the tree is less reflective of radar waves than the house, a weaker response is recorded in Figure 8.1*b*.

By electronically measuring the return time of signal echoes, the range, or distance, between the transmitter and reflecting objects may be determined.



(a)

(b)

Figure 8.1 Operating principle of SLR: (*a*) propagation of one radar pulse (indicating the wavefront location at time intervals 1–17); (*b*) resulting antenna return.

Since the energy propagates in air at approximately the velocity of light c, the slant range, $\overline{\text{SR}}$, to any given object is given by

$$\overline{\text{SR}} = \frac{ct}{2} \tag{8.1}$$

where

$\overline{\text{SR}}$ = slant range (direct distance between transmitter and object)
c = speed of light (3×10^8 m/sec)
t = time between pulse transmission and echo reception

(Note that the factor 2 enters into the equation because the time is measured for the pulse to travel the distance both to and from the target, or twice the range.) This principle of determining distance by electronically measuring the transmission–echo time is central to imaging radar systems.

One manner in which SLR images are created is illustrated in Figure 8.2. As the aircraft advances, the antenna (1) is continuously repositioned along the flight direction at the aircraft velocity V_a. The antenna is switched from a transmitter to a receiver mode by a synchronizer switch (2). A portion of each transmitted pulse (3) is returned (as an echo) from terrain features occurring along a single antenna beamwidth. Shown in (4) is the return signal from one line of data. Return signals (echoes) are received by the airborne antenna, processed, and then recorded (5). Spaceborne systems operate on the same general principle.

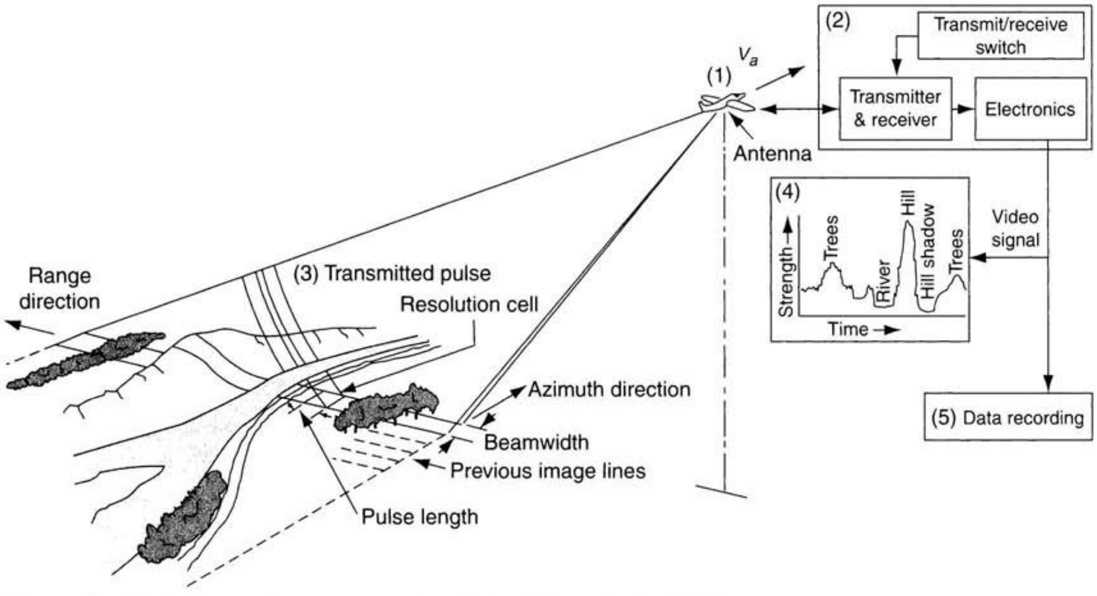


Figure 8.2 Side-looking radar system operation. (Adapted from Lewis, 1976.)

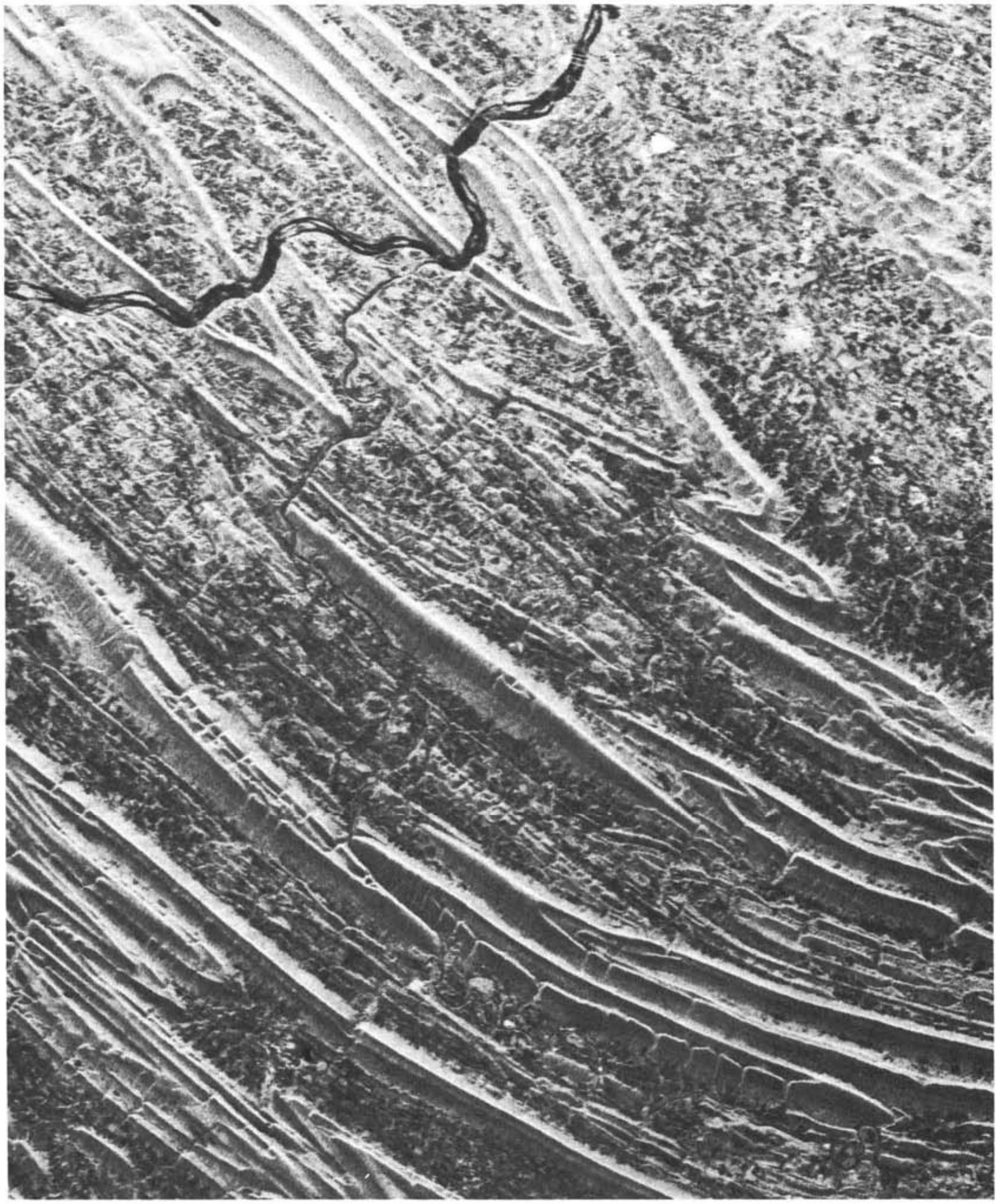


Figure 8.3 Seasat SLR image of Appalachian Mountains of Pennsylvania, L band, midsummer. Scale 1 : 575,000. (Courtesy NASA/JPL/Caltech.)

Figure 8.3, a satellite radar image of an area of folded sedimentary rocks in the Appalachian Mountains of Pennsylvania, illustrates the appearance of radar images. Here, the "sidelighting" nature of SLR images obtained as illustrated in Figure 8.2 is apparent. In Figure 8.3, the signals from the radar system in the spacecraft were transmitted toward the bottom of the page, and the signals received by the radar system are those reflected back toward the top of the page. Note that the topographic slopes of the linear hills and valleys associated with the folded sedimentary rocks that face the spacecraft return strong signals, whereas the flatter areas and slopes facing away from the spacecraft return weaker signals. Note also that the river seen at upper left is dark toned because of specular reflection away from the sensor. (Section 8.8 describes earth surface feature characteristics influencing radar returns in some detail.)

Figure 8.4 illustrates the nomenclature typically used to describe the geometry of radar data collection. A radar system's *look angle* is the angle from

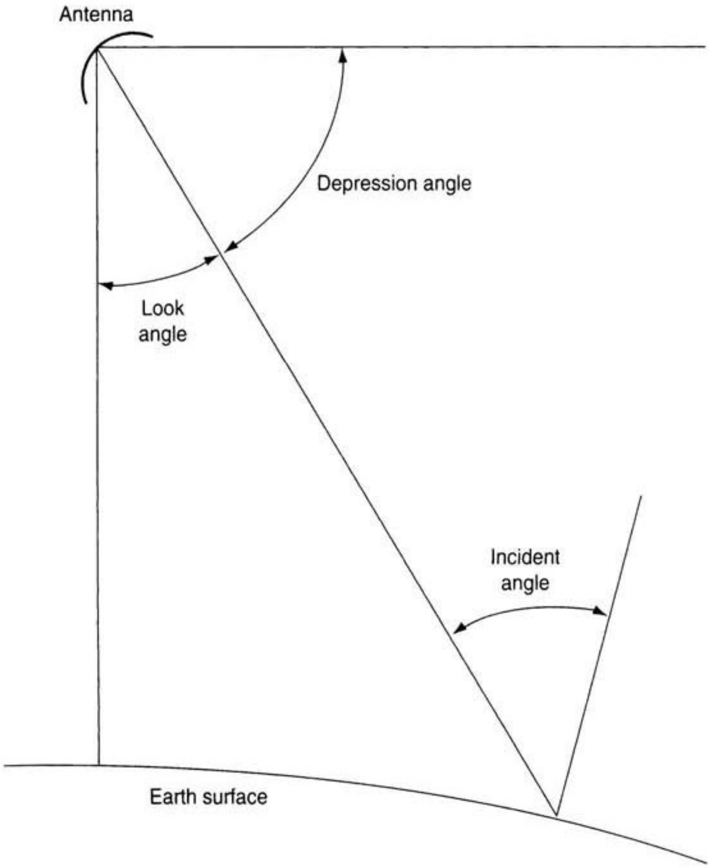


Figure 8.4 Nomenclature for the geometry of radar data collection.

nadir to a point of interest on the ground. The complement of the look angle is called the *depression angle*. The *incident angle* is the angle between the incident radar beam at the ground and the normal to the earth's surface at the point of incidence. (The incident angle is often referred to using the grammatically incorrect term "incidence angle" in the literature. The two terms are synonymous.) In the case of airborne imaging over flat terrain, the incident angle is approximately equal to the look angle. In radar imaging from space, the incident angle is slightly greater than the look angle due to earth curvature. The *local incident angle* is the angle between the incident radar beam at the ground and the normal to the ground surface at the point of incidence. The incident angle and the local incident angle are the same only in the case of level terrain.

The ground resolution cell size of an SLR system is controlled by two independent sensing system parameters: *pulse length* and *antenna beamwidth*. The pulse length of the radar signal is determined by the length of time that the antenna emits its burst of energy. As can be seen in Figure 8.5, the signal pulse length dictates the spatial resolution in the direction of energy propagation. This direction is referred to as the *range* direction. The width of the antenna beam determines the resolution cell size in the flight, or *azimuth*, direction. We consider each of these elements controlling radar spatial resolution separately.

Range Resolution

For an SLR system to image separately two ground features that are close to each other in the range direction, it is necessary for the reflected signals

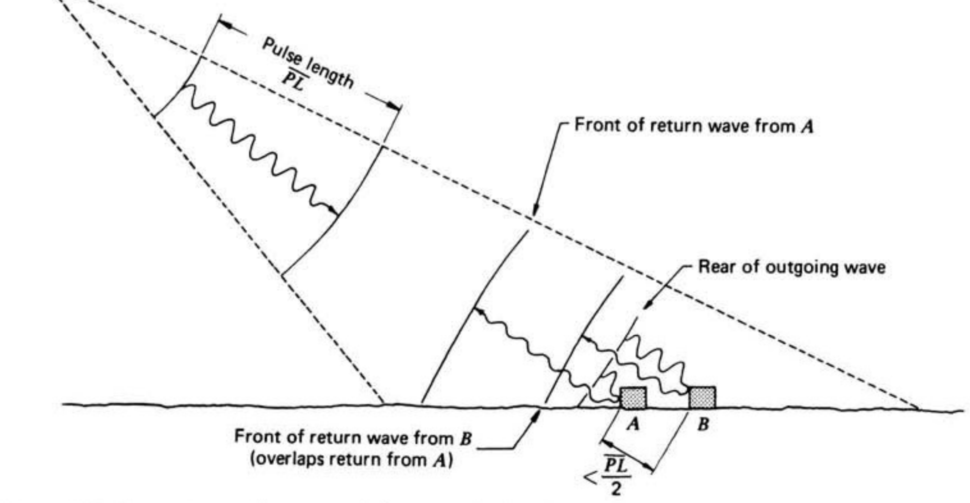


Figure 8.5 Dependence of range resolution on pulse length.