UNIT 1  PRINCIPLES OF REMOTE SENSING

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1.1 INTRODUCTION

In MGY-001, you have been introduced to geoinformatics, concepts of geospatial data including maps and mapping. You also got an overview of applications of geoinformatics. Now you will study the three main components of geoinformatics i.e. remote sensing, GIS and GPS. In this course you will be introduced to remote sensing while the latter two would be covered in MGY-003. In this unit you would be introduced to the concept and basic principles of remote sensing. Remote sensing works on the basis of electromagnetic radiation (EMR), hence, the characteristics of EMR and the governing radiation laws would also be discussed.

Objectives

After studying this unit you should be able to:

- define remote sensing;
- list out major landmarks in the history of remote sensing;
- mention the components of remote sensing;
- describe electromagnetic energy and its properties;
- explain electromagnetic spectrum and its major divisions; and
- discuss important radiation laws governing remote sensing.
1.2 REMOTE SENSING

Remote sensing can be broadly defined as the process of sensing (i.e. acquiring information) from distance. It is formally defined as the science or technique of obtaining information about objects on the surface of the Earth without physically coming into direct contact with them. The process of remote sensing involves making observations and recording radiation coming from Earth features by sensors such as cameras, scanners, radiometers, etc. These sensors are mounted in platforms (such as helicopters, aeroplane, space shuttle and satellites) located at a particular altitude above the Earth’s surface.

We can relate our eyes functioning as a sensor which record information about the objects without touching them. And, the brain is like a data storage as well as data processing device, which stores, processes and creates image of the objects. However, remote sensing includes not only what is visual, but also what can’t be seen with the eyes.

1.2.1 Definition

There are number of definitions of remote sensing and some of the most referred are given below:

Sabins (1978) has defined remote sensing as “a method that employs electromagnetic energy such as light, heat, and radio waves as the means of detecting and measuring target characteristics”. Further, he excludes electrical, magnetic, and gravity methods from remote sensing because they measure force fields rather than electromagnetic radiation.

According to Lillesand and Kiefer (1979), remote sensing is “the science and art of obtaining useful information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation”.

Campbell (2002) has defined remote sensing as “the practice of deriving information about the Earth’s land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the Earth’s surface”.

According to the American Society for Photogrammetry and Remote Sensing (ASPRS), remote sensing is “the measurement or acquisition of information of some property of an object or phenomenon, by a recording device that is not in physical or intimate contact with the object or phenomenon under study” (Colwell, 1983). In 1988, ASPRS adopted a combined definition of photogrammetry and remote sensing which states that “Photogrammetry and remote sensing are the art, science and technology of obtaining reliable information about physical objects and the environment, through the process of recording, measuring and interpreting imagery and digital representations of energy patterns derived from non-contact sensor systems” (Colwell, 1997).

As you have noticed, some of the definitions refer to remote sensing as both an ‘art’ and ‘science’. Let us now understand why it is called both ‘art’ and ‘science’. Remote sensing is a ‘science’ when information is extracted from...
remote sensing data using mathematical and statistical methods based on some scientific facts whereas it is an ‘art’ when the remote sensing data is analysed using background or prior knowledge that cannot be measured and is obtained through experience. However, remote sensing analysts usually draw inferences from both the science and art of remote sensing analysis to derive information from remote sensing data.

1.2.2 Remote Sensing System

You now know that remote sensing is a tool for gathering information about objects at a distance. However, it is not just about a sensor or platform. There are several steps in remote sensing system as shown in Fig. 1.1.

![Diagram of remote sensing system](image1.png)

**Fig. 1.1: Basic components of remote sensing; A – Energy source, B – Energy interactions with the atmosphere and sensors, C – Interaction of EMR with Earth surface features, D – Detection of signals by the sensor, E – transmission of remotely sensed data to ground stations, and F – processing and utilisation of the data. Information derived from remote sensing data is generally presented in the form of a map or table**

- **Source of Energy (A):** The first and very important requirement for remote sensing is an energy source which provides electromagnetic energy to the Earth. It may be either from natural (e.g. solar radiation) or artificial (e.g. RADAR) sources. For remote sensing, Sun’s radiations are commonly used as a source of energy.

- **Interaction of energy with the atmosphere (B):** When energy travels from its source to the Earth surface, it comes in contact with the Earth’s atmosphere where it interacts with atmospheric constituents. The energy reflected from Earth’s surface is received by remote sensors. In this process the energy once again interacts with atmosphere.

- **Interaction with Earth surface features (C):** Energy reaching the Earth surface through the atmosphere interacts with the Earth surface features. The interaction and its outcome depend on the characteristics of the features and the energy.

- **Recording of energy by the sensor (D):** After interacting with Earth surface features the reflected and emitted energy travels to the sensor. And, the sensor records the reflected and emitted energy.
Introduction to Remote Sensing

- **Transmission, reception, and processing of the recorded signals (E):** The energy recorded by the sensor is transmitted in the form of signals to receiving and processing station on the Earth. The signals are in electronic form and are processed and converted into an image.

- **Utilisation of the data (F):** The processed image is interpreted and analysed to extract information about the object of interest.

The above mentioned components comprise the remote sensing system and underline the importance of energy and its interaction with atmosphere and Earth features.

1.2.3 Advantages and Limitations

After understanding the concept of remote sensing let us now look at its advantages and limitations.

Remote sensing has several advantages as listed below:

- it provides a synoptic view
- it is a cost effective means of data collection
- it can provide data in wavelengths beyond the sensing capability of human eye
- it can acquire data of inaccessible areas
- it is an unobtrusive means of data collection which does not change characteristics of the object or phenomenon being observed
- it provides historical data sets which is useful to know characteristics of an object in a given point of time in past.

Advantages of remote sensing have been oversold and despite having several advantages remote sensing has following limitations:

- it is sometimes found that appropriate data is not available or easily acquired particularly in the tropical regions where cloud cover obstructs acquisition of image because not all sensors can ‘see’ through cloud
- remote sensing equipments can become uncalibrated with time resulting into errors in data collected.

1.3 HISTORY OF REMOTE SENSING

Let us now get an idea about historical developments of remote sensing. The era of remote sensing is considered to have begun in 1858 when a balloonist, G. Tournachon (alias Nadar) took photographs of Paris from his balloon. Later, messenger pigeons, kites, aeroplanes, rockets and unmanned balloons were also used for early imaging. However, history of remote sensing can be linked with the development and understanding of optics and aeronautics. Aristotle (300BC) is credited with the first experiments on optics. Galileo Galilei (1609) and Sir Issac Newton (1666) scientifically explained optics and spectrometry. The systematic aerial photography began during the World War I for military surveillance and reconnaissance purposes. During World War I, aeroplanes were used on a large scale for these purposes as the aeroplanes were proved more reliable and stable platforms for Earth observation than
balloons. However, the important developments of aerial photography and photo interpretation took place during World War II. During this time span, the development of other imaging systems such as near-infrared photography, thermal sensing and radar also took place.

The development of artificial satellites in the later half of the 20th century allowed remote sensing to progress to a global scale. As a consequence various Earth resources (e.g. Landsat) and weather (e.g. Nimbus) satellites and more recent missions such as RADARSAT and UARS provided global measurements of various data for civil, research, and military purposes. Table 1.1 gives a brief historical overview of development in the remote sensing technology. Space probes to other planets have also provided the opportunity to conduct remote sensing studies in extra terrestrial environments; synthetic aperture radar aboard the Magellan spacecraft provided detailed topographic maps of Venus, while instruments aboard SOHO allowed studies to be performed on the Sun and the solar wind, just to name a few examples.

<table>
<thead>
<tr>
<th>Year</th>
<th>Milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800</td>
<td>Discovery of infrared by Sir W. Herschel</td>
</tr>
<tr>
<td>1801</td>
<td>Theory of the perception of the colour by Thomas Young</td>
</tr>
<tr>
<td>1839</td>
<td>Beginning of practice of photography</td>
</tr>
<tr>
<td>1859</td>
<td>Photography from balloons</td>
</tr>
<tr>
<td>1873</td>
<td>Description of electromagnetic spectrum by J.C. Maxwell</td>
</tr>
<tr>
<td>1909</td>
<td>Photography from airplanes</td>
</tr>
<tr>
<td>1916</td>
<td>Aerial reconnaissance during the World War I</td>
</tr>
<tr>
<td>1935</td>
<td>Development of radar in Germany</td>
</tr>
<tr>
<td>1940</td>
<td>Applications of non-visible part of electromagnetic spectrum during World War II</td>
</tr>
<tr>
<td>1959</td>
<td>First space photograph of the Earth by Explorer-6</td>
</tr>
<tr>
<td>1960</td>
<td>Launch of the first TIROS meteorological satellite</td>
</tr>
<tr>
<td>1970</td>
<td>Skylab remote sensing observations from the space</td>
</tr>
<tr>
<td>1972</td>
<td>Launch of the first Earth resource satellite (Landsat-1)</td>
</tr>
<tr>
<td>1972</td>
<td>Rapid advances in digital image processing</td>
</tr>
<tr>
<td>1982</td>
<td>Launch of new generation of Landsat sensors (Landsat-4)</td>
</tr>
<tr>
<td>1986</td>
<td>Launch of French Earth observation satellite (SPOT-1)</td>
</tr>
<tr>
<td>1986</td>
<td>Development of hyperspectral sensors</td>
</tr>
<tr>
<td>1990</td>
<td>Development of high resolution space borne systems</td>
</tr>
<tr>
<td>1995</td>
<td>Launch of RADARSAT</td>
</tr>
<tr>
<td>1998</td>
<td>Advancements towards low cost one-goal satellite missions</td>
</tr>
<tr>
<td>1999</td>
<td>Launch of MODIS Terra EOS, Landsat-7 ETM+ and Earth observation satellites by commercial space agencies (IKONOS)</td>
</tr>
<tr>
<td>2000</td>
<td>Launch of SRTM</td>
</tr>
<tr>
<td>2002</td>
<td>Launch of ENVISAT, SPOT-5 and Launch of MODIS Aqua</td>
</tr>
<tr>
<td>2006</td>
<td>Launch of RADARSAT-2</td>
</tr>
</tbody>
</table>

RADARSAT is a constellation of pair of Canadian Remote Sensing satellites.

UARS (Upper Atmosphere Research Satellite) was a NASA operated orbital observatory whose mission was to study the Earth’s atmosphere, particularly the protective ozone layer.

SOHO (Solar and Heliospheric Observatory) is a spaceborne solar observatory jointly developed by European Space Agency (ESA) and National Aeronautics and Space Administration (NASA) of USA to study the Sun from its deep core to the outer corona and the solar wind. Launched in 1995 it began its normal operations in May 1996. Originally planned as a two year mission, it still continues to operate after over fifteen years in space. Till date it has discovered over 2100 comets.

Refer to Unit 4 Sensors and Platforms, for details on platforms, orbits and types of sensors.
Introduction to Remote Sensing

It would be appropriate here to also list major milestones in the history of Indian remote sensing as given in Table 1.2.

Table 1.2: Major milestones in the history of Indian remote sensing
(source: http://isro.org/satellites/allsatellites.aspx)

<table>
<thead>
<tr>
<th>Year</th>
<th>Milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>1920</td>
<td>First use of aerial photography</td>
</tr>
<tr>
<td>1962</td>
<td>Establishment of a rocket launching station</td>
</tr>
<tr>
<td>1972</td>
<td>Establishment of the Department of Space</td>
</tr>
<tr>
<td>1975</td>
<td>Launch of the First Indian satellite ‘Aryabhatta’</td>
</tr>
<tr>
<td>1979</td>
<td>Launch of the Earth observation satellite ‘Bhaskara’</td>
</tr>
<tr>
<td>1982</td>
<td>Launch of INSAT-1A</td>
</tr>
<tr>
<td>1988</td>
<td>Launch of the First Indian Remote Sensing Satellite programme, IRS-1A</td>
</tr>
<tr>
<td>1991</td>
<td>Launch of IRS-1B</td>
</tr>
<tr>
<td>1994</td>
<td>Launch of IRS-P2</td>
</tr>
<tr>
<td>1995</td>
<td>Launch of INSAT-2C</td>
</tr>
<tr>
<td>1997</td>
<td>Launch of IRS-1D</td>
</tr>
<tr>
<td>1999</td>
<td>Launch of OCEANSAT-1 (IRS-P4)</td>
</tr>
<tr>
<td>2001</td>
<td>Launch of the GSAT-1 and Technology Evaluation Satellite (TES)</td>
</tr>
<tr>
<td>2002</td>
<td>Launch of KALPANA (METSAT)</td>
</tr>
<tr>
<td>2003</td>
<td>Launch of RESOURCESAT-1 (IRS-P6)</td>
</tr>
<tr>
<td>2005</td>
<td>Launch of CARTOSAT-1 (IRS-P6)</td>
</tr>
<tr>
<td>2007</td>
<td>Launch of CARTOSAT-2</td>
</tr>
<tr>
<td>2008</td>
<td>Launch of Chandrayaan-1</td>
</tr>
<tr>
<td>2009</td>
<td>Launch of ANUSAT, OCEANSAT-2 and RISAT-2</td>
</tr>
<tr>
<td>2010</td>
<td>Launch of CARTOSAT-2B</td>
</tr>
<tr>
<td>2011</td>
<td>Launch of YOUTHSAT, RESOURCESAT-2 and Megha-Tropiques</td>
</tr>
</tbody>
</table>

Recent developments include, beginning in the 1960s and 1970s, with the development of computer processing of satellite images. Following the successful demonstration flights of Bhaskara-1 and Bhaskara-2 satellites launched in 1979 and 1981, respectively, India began to develop the indigenous Indian Remote Sensing Satellite (IRS) series of satellites to support the national economy in the areas of agriculture, water resources, forestry and ecology, geology, marine fisheries and coastal management. Data from the IRS series is received and disseminated by several countries all over the world. With the advent of high-resolution satellites new applications in the areas of urban sprawl, infrastructure planning and other large scale applications for mapping have been initiated. The IRS series of satellites is the largest constellation of remote sensing satellites for civilian use in operation today in the world. These satellites are placed in polar sun-synchronous orbit and provide data in a variety of spatial, spectral and temporal resolutions.

In the next section, you will be introduced to the various sources of the electromagnetic energy and their characteristics.
Check Your Progress I

1) List out the steps of remote sensing system.

The unit of EMR is \( \text{Wm}^{-2}\text{ster}^{-1}\mu\text{m}^{-1} \) i.e. the rate of transfer of energy (watt, W) recorded at a sensor per square metre on the ground, for one steradian (i.e. solid angle) from a point on Earth’s surface to the sensor, per unit wavelength being measured.

1.4 ELECTROMAGNETIC RADIATION AND ITS PROPERTIES

The most familiar form of electromagnetic radiation (EMR) is visible light. We see the world around us with the help of information reaching to our eyes. The sense associated with eyes is known as sight or vision and is stimulated by light. Eyes convert the incoming light into electrical signals and convey them to brain, which creates picture/image in our mind after processing. Similarly, as discussed in the last section, sensors record energy which has interacted with Earth surface features. This energy serves as the main communication link between the sensor and the object. In this section, we will discuss about the electromagnetic energy and its properties.

As you know, energy is the ability to do work. When a work is carried out, energy is transferred from one body to another or from one place to another. These energy transfers take place in three ways, i.e. conduction, convection and which occurs when one body transfers its kinetic energy to another by colliding with it. Heating and boiling of water in a bowl is the example of convection in which the kinetic energy of water molecules is transferred from one place to another by physical movement of the molecules. Heating of an iron rod at one end and transfer of heat to the other end of the rod is an example of conduction wherein energy transfer takes place by direct contact.

Another way of energy transfer takes place in the form of electromagnetic radiation. When you feel heat despite standing away from a fire is an example of radiation. Unlike conduction and convection, radiation does not require a medium to transfer energy through. Radiant energy is defined as the energy carried by electromagnetic radiation. And, you should remember that everything that has a temperature above absolute zero radiates energy.

For remote sensing, Sun is the source of electromagnetic radiation (EMR). The Sun may be assumed to be a blackbody with surface temperature around 6000°K. When Sun is used as an energy source for remote sensing it is known as passive remote sensing but when artificial source of electromagnetic energy is used it is known as active remote sensing. Examples of active remote sensing are radar and lidar.

It would be useful here to understand the basic properties of EMR because electromagnetic energy forms the basic source for remote sensing.
1.4.1 Electromagnetic Radiation Models

To explain the nature of EMR and its propagation through space and its interaction with matter two different models, i.e. Wave model and Particle model have been given.

a) Particle Model of Electromagnetic Energy

The particle model of electromagnetic energy was given by Sir Isaac Newton in 1704. According to this theory light behaves as a stream of particles or corpuscles and travels in straight line. He also knew that light had wave like characteristics based on his experiments. Following are the properties of the particle model of electromagnetic energy:

- light travels in straight lines
- light can be reflected
- light can travel through a vacuum

b) Wave Model of Electromagnetic Energy

The wave model was formulated by Maxwell in 1862. According to this theory, light travels like a wave which has electric and magnetic fields. This model is able to explain phenomenon such as propagation, dispersion, reflection, refraction and interference of electromagnetic waves. Eventually, work of some scientists seemed to point out that there were aspects of light that could be explained more clearly using a wave model.

c) Wave Particle Duality

Scientists like Huygens (1690) and Young (1804) had given definite proof that light behaves like a wave. Planck and Einstein showed that light must be a particle. It seems as though one must be right, and the other wrong. Both aspects (wave and particle) make up light at the same time. This leads us to the current way of describing light, the model known as Wave Particle Duality. Wave particle duality postulates that all matter exhibits both wave and particle properties. Albert Einstein was able to come up with a solution as long as he assumed that energy came in little pieces, called Quanta. This led Einstein to come up with a theory that joined the idea of Quanta to an explanation of light. This meant the light came in little pieces that were named photons. This also helped to explain the phenomenon called Blackbody Radiation.

1.4.2 Properties of EMR

Electromagnetic fields have many interesting properties. These properties make them very unique and enrich the science of remote sensing. Let us now discuss about these properties in brief. Three characteristics of EMR, which are particularly important for understanding the concept of the remote sensing, are wavelength, amplitude and frequency.

- wavelength is the distance over which the wave’s shape repeats (Fig. 1.2). It is usually determined by considering the distance between consecutive corresponding points of the same phase, such as crests or troughs. It is measured in μm and denoted by Greek letter ë.
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- **Frequency** is the number of occurrences of a repeating event per unit time (Fig. 1.2). It is measured in Hertz (Hz) and denoted by Greek letter $\lambda$.

- **Amplitude** is the maximum extent of a vibration or oscillation (Fig. 1.2).

![Sinusoidal wave](image1.png)

**Fig. 1.2**: Sinusoidal wave of (a) short wave length (high frequency) and (b) long wavelength (low frequency)

Some of the other properties of EMR are listed below:

- the electric (E) and magnetic (F) fields are always perpendicular to the direction of travel of the wave (as shown in Fig. 1.3). Thus, the wave is a transverse wave

- the electric field is always perpendicular to the magnetic field (Fig. 1.3)

![Propagating EM wave](image2.png)

**Fig. 1.3**: Propagating electromagnetic (EM) wave with speed C in x direction and electric and magnetic field corresponding to EM wave (source: www.ccrs.nrcan.gc.ca/glossary/index_e.php?id=3104)

Albert Einstein was a German-born theoretical physicist. He is often regarded as the father of modern physics for his achievement in developing the theory of general relativity. He received Nobel Prize in Physics in 1921 for his contribution to theoretical physics, and especially for his discovery of the law of the photoelectric effect.

**Transverse waves**: These waves move perpendicular to the direction of energy transfer.

**Sinusoidal**: A smooth repetitive succession of waves or curves. This wave pattern occurs often in nature, including ocean waves, sound waves, and light waves.
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Light emitted by the Sun, a flame or a lamp is created by electric charges that vibrate in different directions and create an electro-magnetic wave that vibrates in a variety of directions. We can assume the light waves as vibrating in a vertical and horizontal plane as shown in the figure below.

- the cross product of electric and magnetic fields always gives the direction of travel of the wave
- the variations of fields are sinusoidal, so also are the transverse waves. Moreover, the fields vary with the same frequency and in phase with each other (Fig. 1.3)
- the speed (c) at which electromagnetic waves move in vacuum is 299,792,458 m/s (~ 3×10^8 m/s). If you send a beam of light along an axis and ask your friends to measure its speed while they move at different speeds along that axis, either in the direction of the light or opposite it, they will all measure the same speed for the light. This result is amazing and very different from what would have been found if your friends had measured the speed of any other type of wave. For other waves, the speed of the observers relative to the wave would have affected their measurements
- if you measure the travel time of a pulse of EMR from one point to another, you are not really measuring the speed of the EMR but rather the distance between those two points
- the plane containing the E vectors is called the plane of oscillation of the wave, hence, the wave is said to be plane polarised in the y direction in Fig. 1.3 which shows an electromagnetic wave with vertical (linear) polarisation.

1.4.3 Electromagnetic Spectrum

As you have studied, EMR is a form of energy exhibiting wave like behaviour as it travels through space. EMR ranges from very high energy radiation such as gamma rays and X rays through ultraviolet light, visible light, infrared radiation and microwaves to radio waves. The range of frequencies of EMR is known as electromagnetic spectrum (Fig. 1.4). You should note that the division of the electromagnetic spectrum is for practical use. The gamma rays and X rays are potentially dangerous and also the ultraviolet light is powerful enough to cause sunburn. Human eyes use visible light to see objects. We can feel infrared radiation as heat. We employ microwaves in microwave ovens and radio waves are used for communications. All the types of EMR are wave forms which travel at the speed of light. The radiation can be defined in terms of either their wavelength or frequency. Shorter wavelength radiations (infrared or shorter) are generally described in terms of its wavelength, whereas longer wavelength radiations (microwave, etc.) are generally described in terms of its frequency.

In remote sensing, mostly visible, infrared and microwave bands are used. Fig. 1.4 shows the electromagnetic spectrum, which covers the wavelength (frequency) from 10^{-12} to 10^4 m (10^{20} to 10^4 Hz). Table 1.3 gives details of nomenclature of microwave and radio wave frequencies used in remote sensing and Table 1.4 gives the information on microwave bands used in the microwave sensors.
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Fig. 1.4: Electromagnetic spectrum with wavelength and frequency information of different spectrum bands (source: www.ccrs.nrcan.gc.ca/resource/tutor/fundam/index_e.php)

Table 1.3: Nomenclature of microwave and radio wave frequency

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
<th>Frequency</th>
<th>Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>EHF</td>
<td>Extremely High Frequency (Microwaves)</td>
<td>30-300 GHz</td>
<td>1mm-1cm</td>
</tr>
<tr>
<td>SHF</td>
<td>Super High Frequency (Microwaves)</td>
<td>30-3 GHz</td>
<td>1cm-10cm</td>
</tr>
<tr>
<td>UHF</td>
<td>Ultra-High Frequency (Microwaves)</td>
<td>3GHz-300 MHz</td>
<td>10cm-1m</td>
</tr>
<tr>
<td>VHF</td>
<td>Very High Frequency</td>
<td>300-30 MHz</td>
<td>1m-10m</td>
</tr>
<tr>
<td>HF</td>
<td>High Frequency</td>
<td>30-3 MHz</td>
<td>10m-100m</td>
</tr>
<tr>
<td>MF</td>
<td>Medium Frequency</td>
<td>3MHz-300 kHz</td>
<td>100m-1km</td>
</tr>
<tr>
<td>LF</td>
<td>Low Frequency</td>
<td>300-30 kHz</td>
<td>1-10km</td>
</tr>
<tr>
<td>VLF</td>
<td>Very Low Frequency</td>
<td>30-3 kHz</td>
<td>10-100km</td>
</tr>
<tr>
<td>VF</td>
<td>Voice Frequency</td>
<td>3kHz-300 Hz</td>
<td>100-1000km</td>
</tr>
<tr>
<td>ELF</td>
<td>Extremely Low Frequency</td>
<td>300-30 Hz</td>
<td>1000-10000km</td>
</tr>
</tbody>
</table>

Table 1.4: Nomenclature of the microwave bands as used in the microwave sensors

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelength</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm-Band</td>
<td>1-7.5mm</td>
<td>40-300 GHz</td>
</tr>
<tr>
<td>Ku-Ka-Band</td>
<td>0.75-2.5 cm</td>
<td>12-40 GHz</td>
</tr>
<tr>
<td>X-Band</td>
<td>2.5-4 cm</td>
<td>8-12 GHz</td>
</tr>
<tr>
<td>C-Band</td>
<td>4-8 cm</td>
<td>4-8 GHz</td>
</tr>
<tr>
<td>S-Band</td>
<td>8-15 cm</td>
<td>2-4 GHz</td>
</tr>
<tr>
<td>L-Band</td>
<td>15-30 cm</td>
<td>1-2 GHz</td>
</tr>
</tbody>
</table>
A **blackbody** is an ideal surface which absorbs the entire radiations incident upon it. It is a perfect absorber and a perfect radiator observing all the incident radiation reflecting none and emitting radiation at all wavelengths. Because no light is reflected or transmitted, the object appears black when it is cold.

**Solid angle** ($\Omega$) is a two-dimensional angle in three-dimensional space that an object subtends at a point. Hence, it is a three-dimensional cone and is a measure of how large that object appears to an observer looking from that point. In other words, it is the angle that, seen from the center of a sphere, includes a given area on the surface of that sphere. The value of the solid angle is equal to the size of that area divided by the square of the radius of the sphere ($\Omega = A/r^2$). A small object nearby may subtend the same solid angle as a larger object farther away (for example, the small/near Moon can totally eclipse the large/remote Sun because as observed from a point on the Earth, both objects fill almost exactly the same amount of sky).

**Check Your Progress II**

1) List out the basic properties of EMR.

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### 1.5 ELECTROMAGNETIC RADIATION LAWS

Remote sensing is based on properties of electromagnetic energy. The properties of EMR interacting with matter are systematised in a simple set of rules called **radiation laws**, which define quantitative aspects of the properties of electromagnetic energy. These laws apply when the radiating body is what physicists call a **blackbody radiator**. So, before studying radiation laws, let us understand what a blackbody is. Generally, blackbody conditions apply when the radiator has very weak interaction with the surrounding environment and can be considered to be in a state of equilibrium. Although stars do not satisfy perfectly the conditions to be blackbody radiators, they do to a sufficiently good approximation that it is useful to view stars as approximate blackbody radiators.

Let us now understand the concept of blackbody. All materials above absolute zero (-273.14°C) temperature emit radiation. If you look at two different kinds of material, each at the same temperature, you will find that the radiation being emitted by them is different. This led physicists to invent the perfect emitter, known as a blackbody, which emits the maximum amount of radiation at each wavelength. Although some materials come very close to being perfect emitters in some wavelength ranges, no real materials are a perfect blackbody. Fortunately, the radiation inside a cavity whose walls are thick enough to prevent any radiation from passing directly through them can be shown to be the radiation that would be emitted by a blackbody (Fig. 1.5). By observing the radiation inside the cavities, physicists knew the empirical relationship between blackbody radiation and the two variables on which it depends, i.e. temperature and wavelength.

![Fig. 1.5: Illustration showing concept of a blackbody. Radiation passing through the small cavity is completely absorbed in a blackbody](image)

We will now discuss the fundamental laws of radiation which are important for understanding EMR and more relevant to remote sensing.
Planck made the revolutionary assumption that an oscillating atom in the wall of a cavity can exchange energy with the radiation field inside a cavity only in discrete bundles called *quanta* or *photon*. He defined a constant \( (h) \) to relate frequency \( (i) \) to radiant energy \( (Q) \) as given below:

\[
Q = hi \tag{1}
\]

where,

\( Q \) = Radiant energy,
\( i \) = frequency, and
\( h \) is known as Planck’s constant.

With this assumption, he showed that the radiation being emitted by a blackbody is given by Planck’s Radiation Law, which governs the intensity of radiation emitted by unit surface area into a fixed direction (i.e. solid angle) from the blackbody as a function of wavelength for a fixed temperature. The Planck’s Law can be expressed through the following equation:

\[
B_{\lambda}(T) = \frac{2\pi^2 \hbar c}{\lambda^5 \left( e^{\frac{hc}{\lambda kT}} - 1 \right)} \tag{2}
\]

where,

\( B_{\lambda}(T) \) is known as spectral radiant exitance (in Wm\(^2\)sr\(^{-1}\)\(\mu\)m\(^{-1}\)) at wavelength \( \lambda \) (in \( \mu \)m) and temperature \( T \) (in K),
\( \hbar \) is Planck’s constant \( (6.626 \times 10^{-34} \text{ J.s}) \)
\( c \) is the velocity of light \( (2.998 \times 10^8 \text{ ms}^{-1}) \), and
\( k \) is the Boltzmann constant \( (1.380 \times 10^{-23} \text{ JK}^{-1}) \).

*Radiant exitance* is the power of electromagnetic radiation per unit area radiated by a surface. When it is considered for a specific frequency in the spectrum it is called *spectral radiant exitance*.

As shown in Fig. 1.6, the Planck’s Law gives a distribution that peaks at a certain wavelength. The peak shifts to shorter wavelengths for higher temperatures, and the area under the curve grows rapidly with increasing temperature.

**Emission** is the process by which a body emits EMR usually as a consequence of its temperature only.

**Transmission** is the passing of radiation through a substance without significant attenuation.

**Absorption** is a process by which radiation is converted to other types of energy (especially heat) by a material. It causes reduction in strength of an electromagnetic wave propagating through a medium.
1.5.2 The Wien and Stefan-Boltzmann Laws

The behaviour of blackbody radiation is described by the Planck’s law. From the Planck’s law, one can derive two other radiation laws i.e. the Stefan-Boltzmann law and the Wien’s displacement law. These two laws illustrated below are very important in remote sensing to understand characteristics of EMR:

Stefan-Boltzmann law defines relationship between total emitted radiation \( E \) and temperature and is expressed as:

\[
E = \sigma T^4
\] ........................................................ (3)

where,

\( E \) = radiant energy per surface unit measured in Watts m\(^{-2}\) leaving a blackbody 
\( \sigma = 5.6697 \times 10^{-5} \) (Watts m\(^{-2}\) k\(^{-4}\) is the Stefan-Boltzmann constant, and 
\( T \) = absolute temperature of the blackbody in Kelvin (K).

The Wien’s displacement law defines the relationship between the wavelength of the radiation emitted and the temperature of the object and is expressed as:

\[
\lambda_{\text{max}} = \frac{h}{kT}
\] ...................................................... (4)

where,

\( \lambda_{\text{max}} \) is the wavelength at which radiance is maximum (unit of the \( \lambda \) is in Angstroms), and 
\( T \) is the absolute temperature in Kelvin (K).

The Wien’s Displacement law gives the wavelength of the peak of the radiation distribution, while the Stefan-Boltzmann law gives the total energy being emitted at all wavelengths by the blackbody (which is the area under the Planck’s law curve). Thus, the Wien’s law explains the shift of the peak to shorter wavelengths as the temperature increases, while the Stefan-Boltzmann law explains the growth in the height of the curve as the temperature increases. Notice that this growth is very large, since it varies as the fourth power of the temperature.

1.5.3 Kirchhoff’s Law

Kirchhoff, a physicist, demonstrated in 1860 that a body acts as a perfect blackbody if

- the sides of the body are maintained at a constant absolute temperature (temperature of blackbody)
- a very small hole in comparison to the dimensions of the body is made in the body itself.

We know from the principle of conservation of energy that when a surface intercepts incident (incoming) radiation it interacts with it and some amount of radiation is reflected, absorbed and transmitted. This can be expressed as

\[
E_i = E_r + E_a + E_t
\] .................................................. (5)
where, 
\[ E_i \text{ is incident radiation} \]
\[ E_r \text{ is reflected radiation} \]
\[ E_a \text{ is absorbed radiation, and} \]
\[ E_t \text{ is transmitted radiation} \]

Equation (5) can be written as

\[ \frac{E_i}{E_i} = \frac{E_r}{E_i} + \frac{E_a}{E_i} + \frac{E_t}{E_i} \]

Or \[ 1 = \bar{n} + \bar{a} + \bar{t} \]

where,

is a coefficient of reflection (reflectivity),

is a coefficient of absorption (absorptivity), and

is a coefficient of transmission (transmissivity).

Values of \( \bar{n} \), \( \bar{a} \) and \( \bar{t} \) ranges between 0 and 1 and from Equation (7) we understand that transparent bodies only transmit \( (\bar{t} = 1) \), or opaque bodies do not transmit \( (\bar{n} + \bar{a} = 1) \). You should note that there is no existence of any body which shows constant behaviour in all the wavelengths. Hence, reference to a definite wavelength or spectral range (band width) is always used.

Before discussing the Kirchhoff’s law it is necessary to introduce the term emissivity \( (\bar{a}) \). Emissivity expresses the efficiency with which the body irradiates. It is defined as

\[ \bar{a} = \frac{E_{\text{emitted energy by the real body at } T}}{E_{\text{emitted energy by the black body at } T}} \]

Or, \[ \bar{a} = \frac{M}{M_b} \]

where,

\( \bar{a} \) is emissivity,

\( M \) is emittance of a given object,

\( M_b \) is emittance of a blackbody at the same temperature, and

\( T_0 \) is absolute zero temperature.

Emissivity is dimensionless and its value lies between 0 and 1. The value of 0 refers to a non-radiating source and 1 refers to a blackbody. Since the blackbody absorbs all the energy and at the same time emits radiation with higher efficiency, its value of emissivity is equal to 1.

Kirchhoff demonstrated that in the infrared portion of the electromagnetic
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spectrum, the emissivity of an object generally equals its absorptance, i.e.
\[ \hat{\alpha} = \hat{\beta} \] ................................................................. (10)

From the above equation it can be said that good absorbers are good emitters and
good reflectors are poor emitters. Hence, from Equations (7) and (10) we can
express that
\[ \hat{n} + \hat{\alpha} + \hat{\delta} = 1 \] ......................................................... (11)

Since, most real world materials are usually opaque to thermal infrared radiation,
we can assume transmittance \( \hat{\delta} = 0 \), hence
\[ \hat{n} + \hat{\alpha} = 1 \] ............................................................ (12)

You should remember that this equation is important as it describes why objects
appear as they do on thermal infrared images. Since, the terrain theoretically does
not lose any incident energy to transmittance, all energy leaving the object accounts
for by the relationship between reflectivity (\( \hat{n} \)) and emissivity (\( \hat{\alpha} \)).

1.6 SUMMARY

In the present unit you have studied that:

- Remote sensing is an art and science of obtaining information about objects
  from a distance.
- Remote sensing, which started with the understanding of optics, has now led to
  the development of multispectral, hyperspectral and microwave remote sensing
  satellites.
- Remote sensing processes include energy source or illumination, radiation and
  its interaction with the atmosphere, interaction with the target, recording of
  energy by the sensor, transmission, reception and processing, interpretation,
  analysis and application.
- EMR is of primary interest in remote sensing. Sun is the most important source
  of EMR and the full moon is the next strong source of EMR.
- Models of light were divided into two groups, i.e. particle model and wave
  model.
- In EMR the electric and magnetic fields are always perpendicular to the
direction of travel of the wave.
- The range of frequencies of EMR is known as electromagnetic spectrum
and covers the wavelength from \( 10^{-12} \) to \( 10^4 \) m (\( 10^{30} \) to \( 10^{4} \) Hz).
- Kirchhoff’s radiation law regulates the relationship among the coefficients
  of reflection, transmission, absorption and emission.
- Planck’s radiation law defines the behaviour of the energy emitted by a
  surface as a function of wavelength and temperature.
- Stefan-Boltzmann’s radiation law furnishes the total quantity of energy emitted
  by a surface calculated on the whole electromagnetic spectrum, for any
• Wien’s displacement law points out the wavelength value in correspondence with the maximum electromagnetic emission at a defined temperature.

1.7 UNIT END QUESTIONS

1) What is remote sensing?
2) What are the basic properties of electromagnetic radiation?
3) Discuss in brief about electromagnetic radiation laws.

1.8 REFERENCES

• http://isro.org/satellites/allsatellites.aspx
• www.ccrs.nrcan.gc.ca/glossary/index_e.php?id=3104
• www.ccrs.nrcan.gc.ca/resource/tutor/fundam/index_e.php

All the above websites were retrieved between May 14 and October 30, 2011.

1.9 FURTHER/SUGGESTED READING

• http://rst.gsfc.nasa.gov/Front/tofc.html
• www.jars1974.net/pdf/02_Chapter01.pdf.

1.10 ANSWERS

Check Your Progress I

1) The processes of remote sensing are illumination by an energy source, interaction of energy with the atmosphere while travelling to the Earth, interaction of EMR with the Earth surface features, interaction of energy with the atmosphere while travelling to the sensor, recording of energy by the sensor in form of signals, transmission of the signals to ground station, reception and processing by ground station, and utilisation by users.

Check Your Progress II

1) The basic properties of EMR are frequency, wavelength and amplitude.

Unit End Questions: (Hints)

1) Refer to section 1.2.
Appendix 1: Some common prefixes for standard units of measurement

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<th>Symbol</th>
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<th>Common name</th>
</tr>
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<td>G</td>
<td>$10^9$</td>
<td>billion (US)</td>
</tr>
<tr>
<td>mega</td>
<td>M</td>
<td>$10^6$</td>
<td>million</td>
</tr>
<tr>
<td>kilo</td>
<td>k</td>
<td>$10^3$</td>
<td>thousand</td>
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<tr>
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<td>c</td>
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</tr>
<tr>
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<td>m</td>
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<td>n</td>
<td>$10^{-9}$</td>
<td>thousand millionth</td>
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2) Refer to section 1.4.
3) Refer to section 1.5.