MODULE – 1 LECTURE NOTES – 2

EMR SPECTRUM

1. Introduction

In remote sensing, some parameters of the target are measured without being in touch with it. To measure any parameters using remotely located sensors, some processes which convey those parameters to the sensor is required. A best example is the natural remote sensing by which we are able to see the objects around us and to identity their properties. We are able to see the objects around us when the solar light hits them and gets reflected and captured in our eyes. We are able to identify the properties of the objects when these signals captured in our eyes are transferred to the brain and are analysed. The whole process is analogous to the man-made remote sensing techniques.

In remote sensing techniques, electromagnetic radiations emitted / reflected by the targets are recorded at remotely located sensors and these signals are analysed to interpret the target characteristics. Characteristics of the signals recorded at the sensor depend on the characteristics of the source of radiation / energy, characteristics of the target and the atmospheric interactions.

This lecture gives details of the electromagnetic spectrum. Details of the energy sources and the radiation principles are also covered in this lecture.

2. Electromagnetic energy

Electromagnetic (EM) energy includes all energy moving in a harmonic sinusoidal wave pattern with a velocity equal to that of light. Harmonic pattern means waves occurring at frequent intervals of time.

Electromagnetic energy has both electric and magnetic components which oscillate perpendicular to each other and also perpendicular to the direction of energy propagation as shown in Fig. 1.

It can be detected only through its interaction with matter.

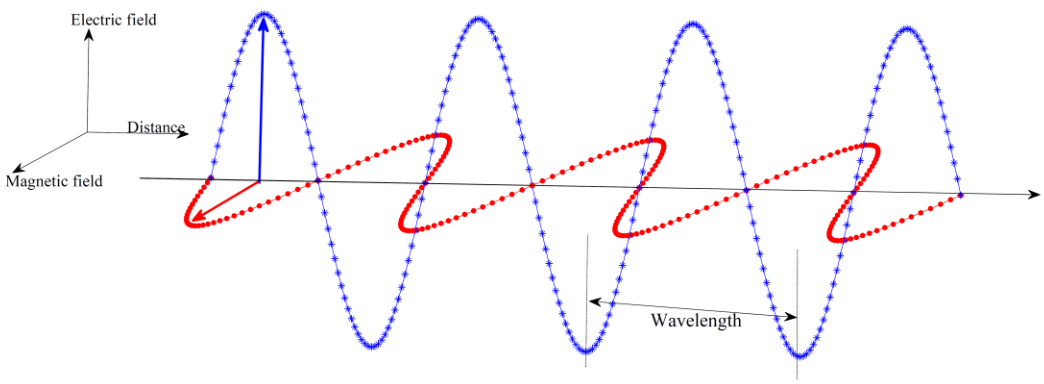

Fig.1. Electromagnetic wave

Examples of different forms of electromagnetic energy: Light, heat etc.

EM energy can be described in terms of its velocity, wavelength and frequency.

All EM waves travel at the speed of light, c, which is approximately equal to 3×10^8 m/s.

Wavelength λ of EM wave is the distance from any point on one wave to the same position on the next wave (e.g., distance between two successive peaks). The wavelengths commonly used in remote sensing are very small. It is normally expressed in micrometers (μm). 1 μm is equal to 1×10^{-6} m.

Frequency f is the number of waves passing a fixed point per unit time. It is expressed in Hertz (Hz).

The three attributes are related by

$$c = \lambda f \tag{1}$$

which implies that wavelength and frequency are inversely related since c is a constant. Longer wavelengths have smaller frequency compared to shorter wavelengths.

Engineers use frequency attribute to indicate radio and radar regions. However, in remote sensing EM waves are categorized in terms of their wavelength location in the EMR spectrum.

Another important theory about the electromagnetic radiation is the particle theory, which suggests that electromagnetic radiation is composed of discrete units called photons or quanta.

3. Electro-Magnetic Radiation (EMR) spectrum

Distribution of the continuum of radiant energy can be plotted as a function of wavelength (or frequency) and is known as the electromagnetic radiation (EMR) spectrum. EMR spectrum is divided into regions or intervals of different wavelengths and such regions are denoted by different names. However, there is no strict dividing line between one spectral region and its adjacent one. Different regions in EMR spectrum are indicated in Fig. 2.

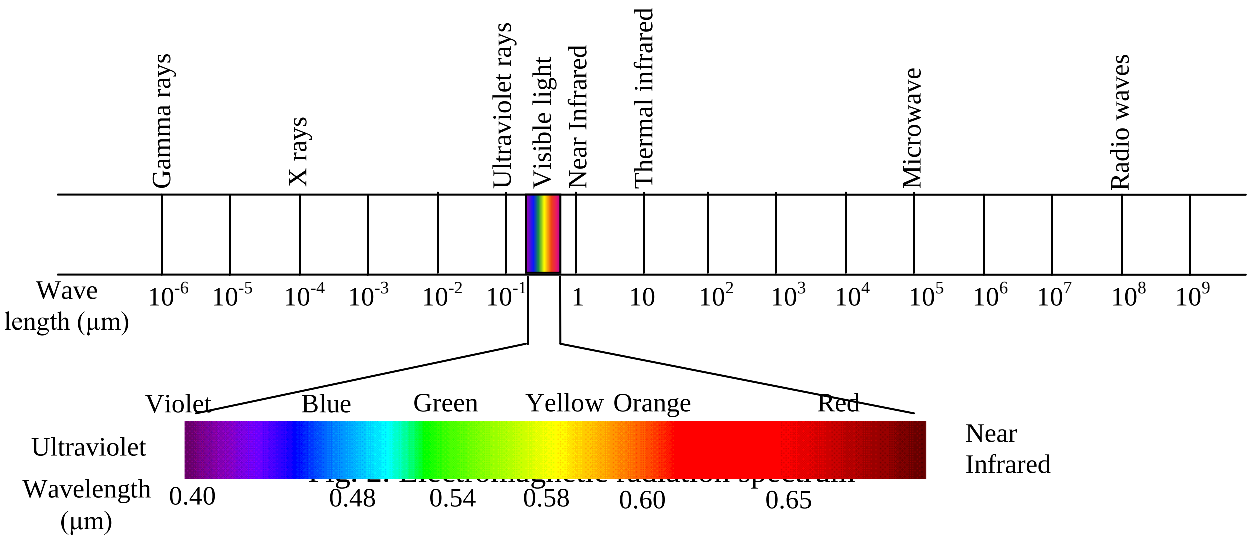

Fig. 2. Electromagnetic radiation spectrum

The EM spectrum ranges from gamma rays with very short wavelengths to radio waves with very long wavelengths. The EM spectrum is shown in a logarithmic scale in order to portray shorter wavelengths.

The visible region (human eye is sensitive to this region) occupies a very small region in the range between 0.4 and 0.7 µm. The approximate range of color “blue” is 0.4 – 0.5 µm, “green” is 0.5-0.6 µm and “red” is 0.6-0.7 µm. Ultraviolet (UV) region adjoins the blue end of the visible region and infrared (IR) region adjoins the red end.

The infrared (IR) region, spanning between 0.7 and 100 µm, has four subintervals of special interest for remote sensing:

(1) Reflected IR (0.7 - 3.0 µm)

(2) Film responsive subset, the photographic IR (0.7 - 0.9 μm)

(3) and (4) Thermal bands at (3 - 5 μm) and (8 - 14 μm).

Longer wavelength intervals beyond this region are referred in units ranging from 0.1 to 100 cm. The microwave region spreads across 0.1 to 100 cm, which includes all the intervals used by radar systems. The radar systems generate their own active radiation and direct it towards the targets of interest. The details of various regions and the corresponding wavelengths are given in Table 1.

Table 1. Spectrum of electromagnetic radiation

Region	Wavelength (μm)	Remarks
Gamma rays	$< 3\times10^{-5}$	Not available for remote sensing. Incoming radiation is absorbed by the atmosphere
X-ray	3×10^{-5} - 3×10^{-3}	Not available for remote sensing since it is absorbed by atmosphere
Ultraviolet (UV) rays	0.03 - 0.4	Wavelengths less than 0.3 are absorbed by the ozone layer in the upper atmosphere. Wavelengths between 0.3- 0.4 μm are transmitted and termed as “Photographic UV band”.
Visible	0.4 - 0.7	Detectable with film and photodetectors.
Infrared (IR)	0.7 - 100	Atmospheric windows exist which allows maximum transmission. Portion between 0.7 and 0.9 μm is called photographic IR band, since it is detectable with film. Two principal atmospheric windows exist in the thermal IR region (3 - 5 μm and 8 - 14 μm).
Microwave	10^3 - 10^6	Can penetrate rain, fog and clouds. Both active and passive remote sensing is possible. Radar uses wavelength in this range.
Radio	$> 10^6$	Have the longest wavelength. Used for remote sensing by some radars.

Energy in the gamma rays, X-rays and most of the UV rays are absorbed by the Earth’s atmosphere and hence not used in remote sensing. Most of the remote sensing systems operate in visible, infrared (IR) and microwave regions of the spectrum. Some systems use the long wave portion of the UV spectrum also.

4. Energy sources and radiation principles

4.1 Solar radiation

Primary source of energy that illuminates different features on the earth surface is the Sun. Solar radiation (also called insolation) arrives at the Earth at wavelengths determined by the photosphere temperature of the sun (peaking near 5,600 °C).

Although the Sun produces electromagnetic radiation in a wide range of wavelengths, the amount of energy it produces is not uniform across all wavelengths.

Fig.3. shows the solar irradiance (power of electromagnetic radiation per unit area incident on a surface) distribution of the Sun. Almost 99% of the solar energy is within the wavelength range of 0.28-4.96 μm. Within this range, 43% is radiated in the visible wavelength region between 0.4-0.7 μm. The maximum energy (*E*) is available at 0.48 μm wave length, which is in the visible green region.

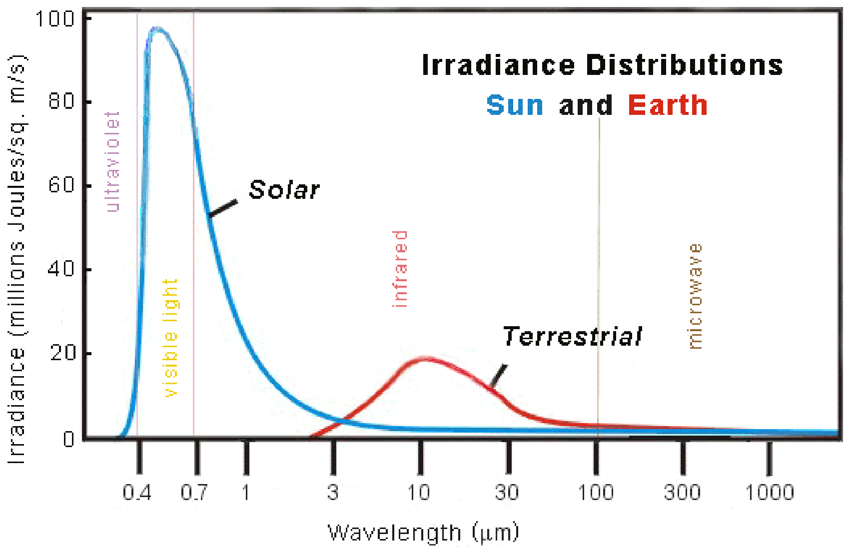

Fig.3. Irradiance distribution of the Sun and Earth (http://www.csulb.edu)

Using the particle theory, the energy of a quantum (Q) is considered to be proportional to the frequency. The relationship can be represented as shown below.

$$Q = h\,f \qquad (2)$$

where h is the Plank's constant (6.626 x 10^{-34} J Sec) and f is the frequency.

Using the relationship between c, λ and f (Eq.1), the above equation can be written as follows

$$Q = h\,c\,/\,\lambda \qquad (3)$$

The energy per unit quantum is thus inversely proportional to the wavelength. Shorter wavelengths are associated with higher energy compared to the longer wavelengths. For example, longer wavelength electromagnetic radiations like microwave radiations are associated with lower energy compared to the IR regions and are difficult to sense in remote sensing. For operating with long wavelength radiations, the coverage area should be large enough to obtain a detectable signal.

4.2 Radiation from the Earth

Other than the solar radiation, the Earth and the terrestrial objects also are the sources of electromagnetic radiation. All matter at temperature above absolute zero (0^oK or -273^oC) emits electromagnetic radiations continuously. The amount of radiation from such objects is a function of the temperature of the object as shown below.

$$M = \sigma\,T^4 \qquad (4)$$

This is known as Stefan-Boltzmann law. M is the total radiant exitance from the source (Watts / m^2), σ is the Stefan-Boltzmann constant (5.6697 x 10^{-8} Watts $m^{-2}k^{-4}$) and T is the absolute temperature of the emitting material in Kelvin.

Since the Earth's ambient temperature is about 300 K, it emits electromagnetic radiations, which is maximum in the wavelength region of 9.7 μm, as shown in Fig.3. This is considered as thermal IR radiation. This thermal IR emission from the Earth can be sensed using scanners and radiometers.

According to the Stefan-Boltzmann law, the radiant exitance increases rapidly with the temperature. However, this law is applicable for objects that behave as a blackbody.

4.3 Blackbody Radiation

A blackbody is a hypothetical, ideal radiator. It absorbs and reemits the entire energy incident upon it.

Total energy emitted by a black body varies with temperature as given in Eq. 4. The total energy is distributed over different wavelengths, which is called the spectral distribution or spectral curve here. Area under the spectral curve gives the total radiant exitance *M.*

In addition to the total energy, the spectral distribution also varies with the temperature. Fig. 4 shows the spectral distribution of the energy radiated from black bodies at different temperatures. The figure represents the Stefan-Boltzman's law graphically. As the temperature increases, area under the curve, and hence the total radiant exitance increases.

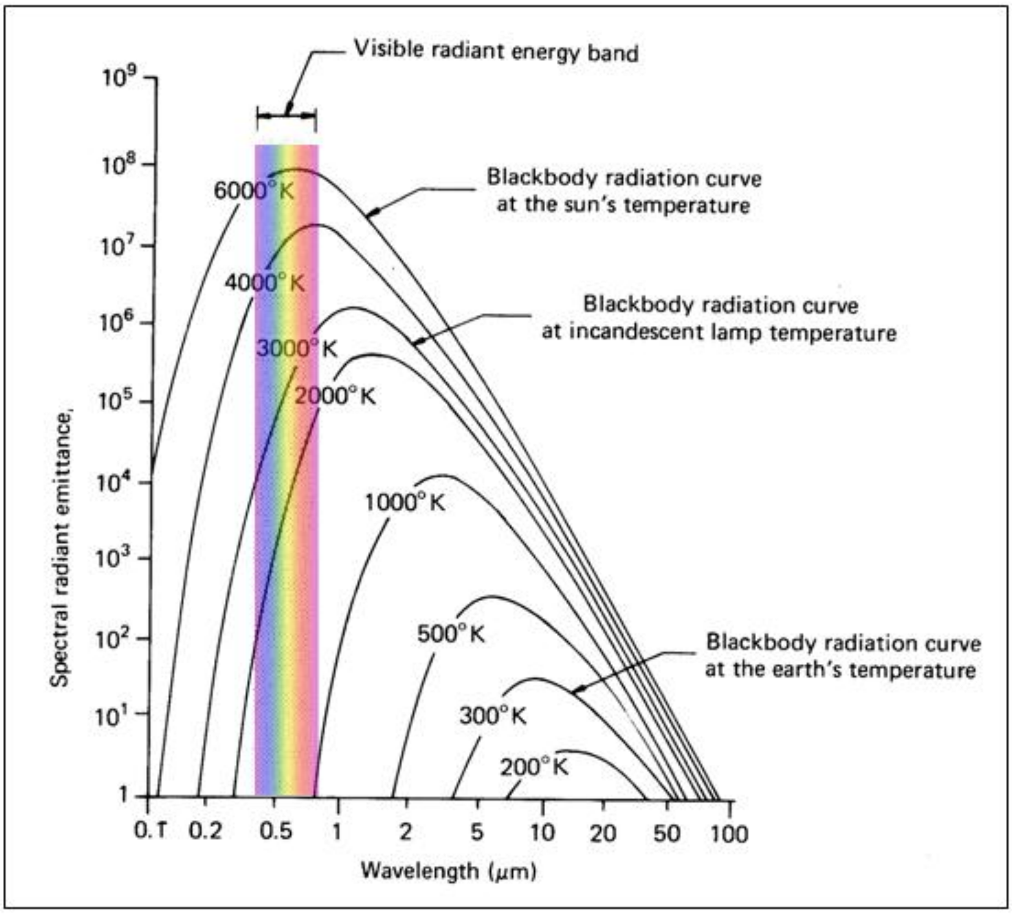

Figure 4. Spectral energy distribution of blackbody at various temperatures

From Fig. 4, it can be observed that the peak of the radiant exitance varies with wavelength. As the temperature increases, the peak shifts towards the left. This is explained by the Wien's displacement law. It states that the dominant wavelength at which a black body radiates λ_m is inversely proportional to the absolute temperature of the black body (in *K*) and is represented as given below.

$$\lambda_m = A / T \qquad (5)$$

where *A* is a constant, which is equal to 2898 $\mu m\ K$. The Sun's temperature is around 6000 K, and from the figure it can be observed that the visible part of the electromagnetic energy (0.4-0.7 μm) dominates in the radiance exitance from the Sun.

5. Remote sensing using electromagnetic radiation

As solar energy travels through atmosphere to reach the Earth, the atmosphere absorbs or backscatters a fraction of it and transmits only the remainder. Wavelength regions, through which most of the energy is transmitted through atmosphere are referred as atmospheric windows. In Fig. 5 (Short, 1999), EMR spectrum is shown identifying different regions with specific names starting from visible region to microwave regions. In the microwave region, different radar bands are also shown such as κ, X, C, L and P.

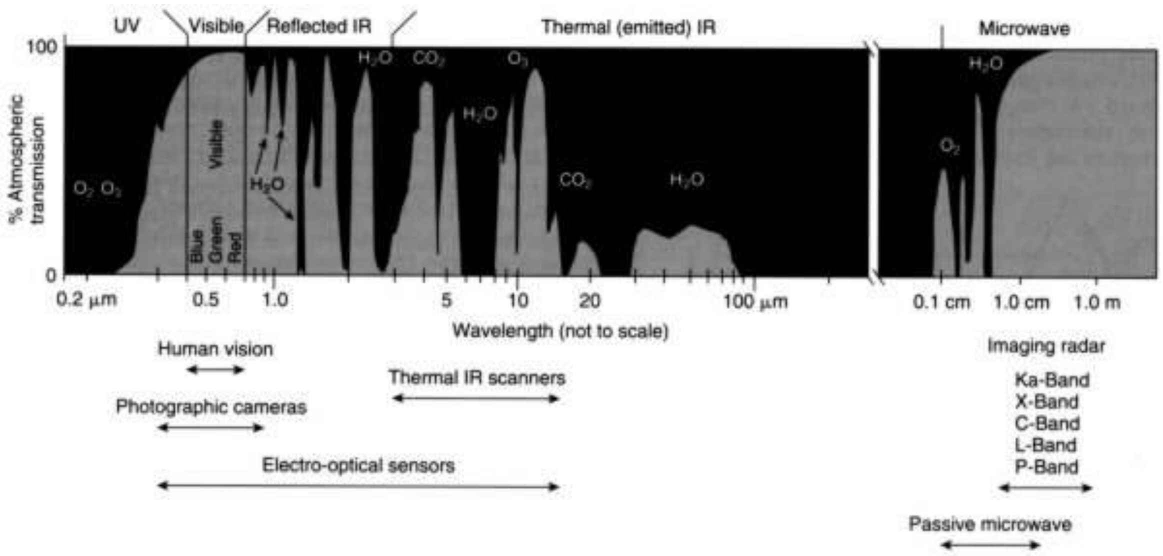

Figure 5. Atmospheric windows in the EMR spectrum

(Source: http://www.geog.ucsb.edu/~jeff/115a/remote_sensing/thermal/thermalirinfo.html)

In Fig. 5, blue (or shaded) zones mark minimal passage of incoming and/or outgoing radiation, whereas white areas denote atmospheric windows. Various constituents of atmosphere at different wavelengths are mainly responsible for atmospheric absorption or back scatter at those wavelengths.

Most remote sensing instruments on air or space platforms operate in one or more of these windows by making their measurements with detectors tuned to specific wavelengths that pass through the atmosphere.