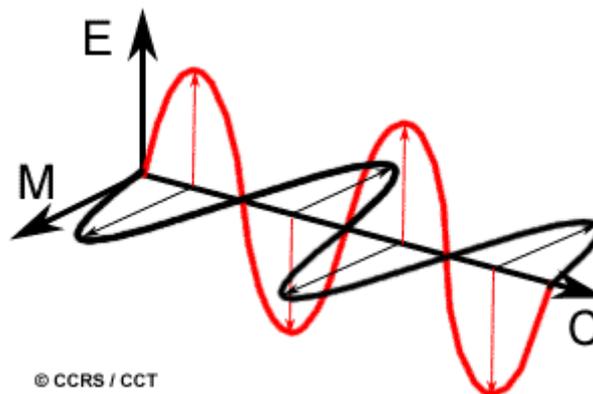## ELECTROMAGNETIC RADIATION (EMR)

The first requirement for remote sensing is to have an energy source to illuminate the target (unless the sensed energy is being emitted by the target). EMR is a dynamic form of energy that propagates as wave motion at a velocity of c = 3 x 10^{10} cm/sec. This energy is in the form of electromagnetic radiation. All electromagnetic radiation has fundamental properties and behaves in predictable ways according to the basics of wave theory. **Electromagnetic radiation** consists of an electrical field (E) which varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling, and a magnetic field (M) oriented at right angles to the electrical field. Both these fields travel at the speed of light (c).

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Two characteristics of electromagnetic radiation are particularly important for understanding remote sensing. These are the **wavelength and frequency.** The wavelength is the length of one wave cycle, which can be measured as the distance between successive wave crests. Wavelength is usually represented by the Greek letter lambda (λ). Wavelength is measured in metres (m) or some factor of metres such as nanometres (nm, 10^{-9} metres), micrometres (μm, 10^{-6} metres) (μm, 10^{-6} metres) or centimetres (cm, 10^{-2} metres). Frequency refers to the number of cycles of a wave passing a fixed point per unit of time. Frequency is normally measured in hertz (Hz), equivalent to one cycle per second, and various multiples of hertz.

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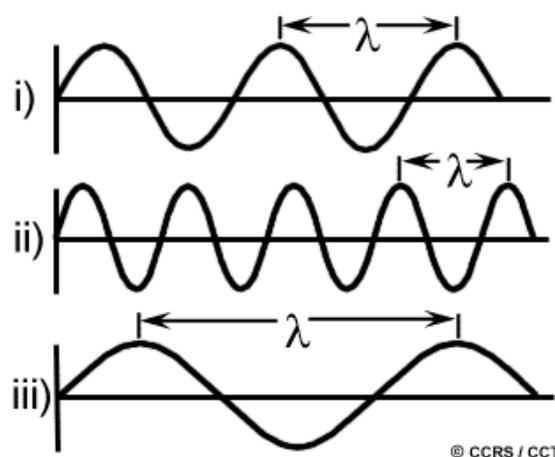
Wavelength and frequency are related by the following formula:

$$c = \lambda v$$

where:

λ = wavelength (m)
v = frequency (cycles per second, Hz)
c = speed of light (3×10^8 m/s)

Therefore, the two are inversely related to each other. The shorter the wavelength, the higher the frequency. The longer the wavelength, the lower the frequency. Understanding the characteristics of electromagnetic radiation in terms of their wavelength and frequency is crucial to understanding the information to be extracted from remote sensing data.

Electromagnetic energy radiates in accordance with the basic wave theory. This theory describes the EM energy as travelling in a harmonic sinusoidal fashion at the velocity of light. Although many characteristics of EM energy are easily described by wave theory, another theory known as particle theory offers insight into how electromagnetic energy interacts with matter. It suggests that EMR is composed of many discrete units called photons/quanta. The energy of photon is

$$Q = hc / \lambda = h v$$

Where, Q is the energy of quantum,
   h = Planck's constant

The Electromagnetic Spectrum

The electromagnetic spectrum defines the entire region of wavelengths. Normally, the spectrum is divided into arbitrary regions with a beginning and an ending wavelength. This interval is commonly referred to as a spectral band, channel or region. The spectral regions are normally called UV, visible, near IR, middle IR, thermal IR and microwave. Below the UV region are the short wavelengths of gamma waves measured in nanometers (nm) and above the microwave region are the long wavelengths of radio waves measured in meters. However, these two wavelength regions are rarely used in terrestrial remote sensing because the earth's atmosphere absorbs the energy in these wavelength regions. The **electromagnetic spectrum** ranges from the shorter wavelengths (including gamma and x-rays) to the longer wavelengths (including microwaves and broadcast radio waves). There are several regions of the electromagnetic spectrum which are useful for remote sensing. The light which our eyes - our "remote sensors" - can detect is part of the **visible spectrum**. It is important to recognize how small the visible portion is relative to the rest of the spectrum. There is a lot of radiation around us which is "invisible" to our eyes, but can be detected by other remote sensing instruments and used to our advantage. The visible wavelengths cover a range from approximately 0.4 to 0.7 μm. The longest visible wavelength is red and the shortest is violet. Common wavelengths of what we perceive as particular colours from the visible portion of

the spectrum are listed below. It is important to note that this is the only portion of the spectrum we can associate with the concept of **colours**.
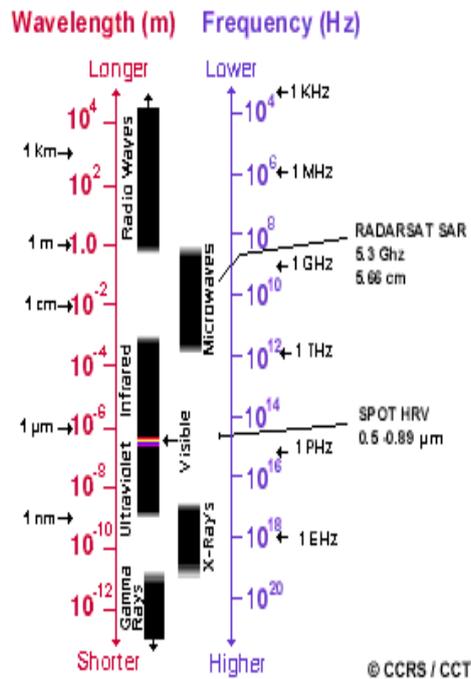

The **ultraviolet or UV** portion of the spectrum has the shortest wavelengths which are practical for remote sensing. This radiation is just beyond the violet portion of the visible wavelengths, hence its name. Some Earth surface materials, primarily rocks and minerals, fluoresce or emit visible light when illuminated by UV radiation.
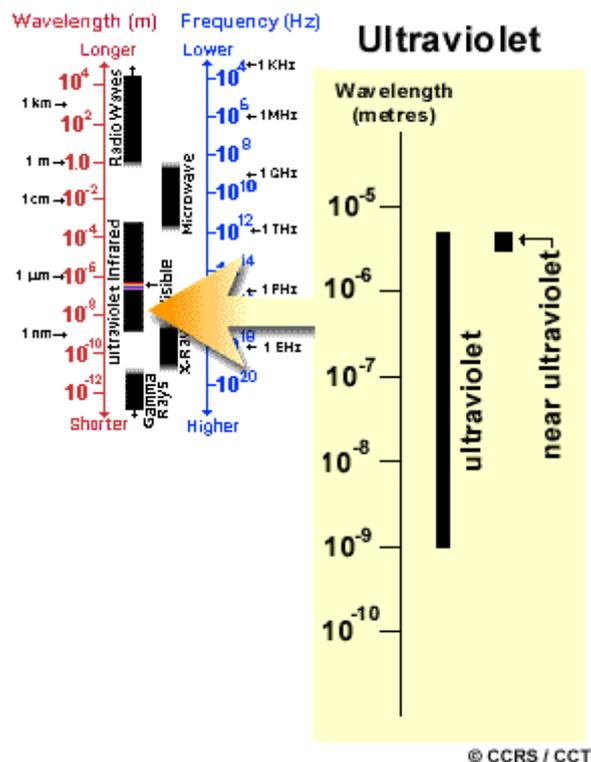
Blue, **green**, and **red** are the **primary colours** or wavelengths of the **visible spectrum**. They are defined as such because no single primary colour can be created from the other two, but all other colours can be formed by combining blue, green, and red in various proportions. Although we see sunlight as a uniform or homogeneous colour, it is actually composed of various wavelengths of radiation in primarily the ultraviolet, visible and infrared portions of the spectrum. The visible portion of this radiation can be shown in its component colours when sunlight is passed through a **prism**, which bends the light in differing amounts according to wavelength.

Violet: 0.4 - 0.446 µm

Blue: 0.446 - 0.500 µm

Green: 0.500 - 0.578 µm

Yellow: 0.578 - 0.592 µm

Orange: 0.592 - 0.620 µm

Red: 0.620 - 0.7 µm
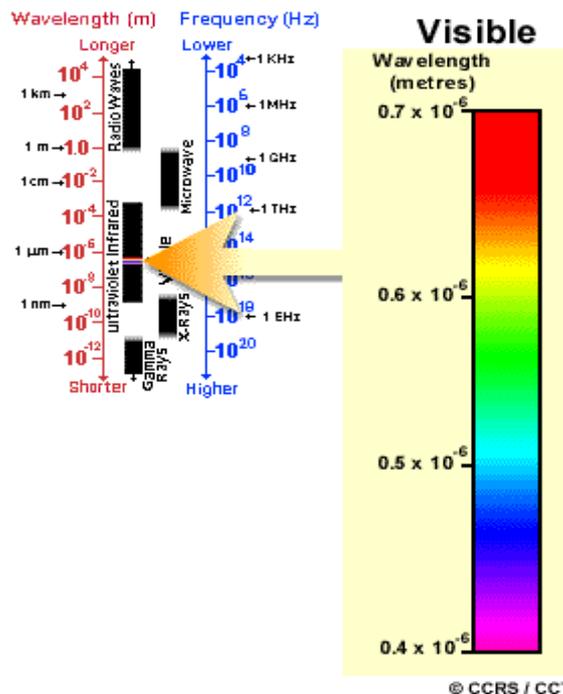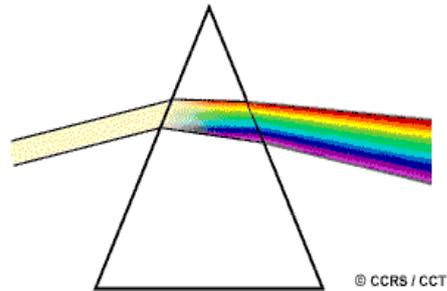
The next portion of the spectrum of interest is the infrared (IR) region which covers the wavelength range from approximately 0.7 µm to 100 µm - more than 100 times as wide as the visible portion! The infrared region can be divided into two categories based on their radiation properties - the **reflected IR**, and the emitted or **thermal IR**. Radiation in the reflected IR region is used for remote sensing purposes in ways very similar to radiation in the visible portion. The reflected IR covers wavelengths from approximately 0.7 µm to 3.0 µm. The thermal IR region is quite different than the visible and reflected IR portions, as this energy is essentially the radiation that is emitted from the Earth's surface in the form of heat. The thermal IR covers wavelengths from approximately 3.0 µm to 100 µm.

Infrared
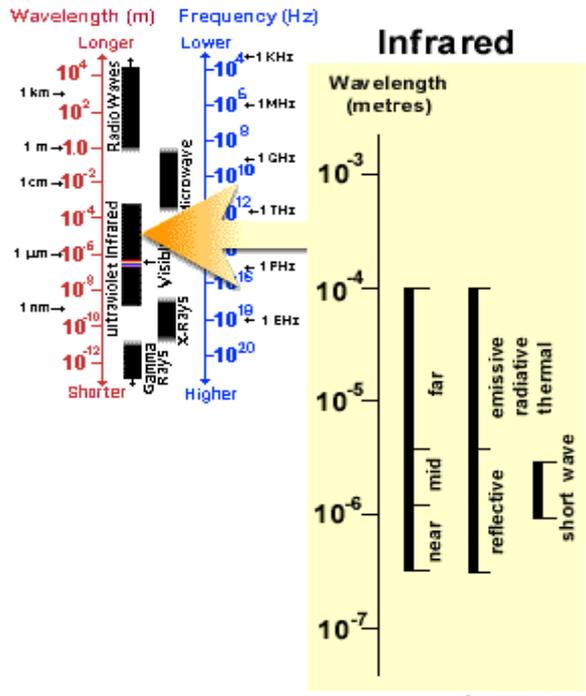
The portion of the spectrum of more recent interest to remote sensing is the **microwave region** from about 1 mm to 1 m. This covers the longest wavelengths used for remote sensing. The shorter wavelengths have properties similar to the thermal infrared region while the longer wavelengths approach the wavelengths used for radio broadcasts. Because of the special nature of this region and it is important in remote sensing.

Microwaves

Band	Wavelength	Frequency (GHz)
P-band	30-100 cm	0.3 – 1
L-band	15-30 cm	1 – 2
S-band	7.5-15 cm	2 – 4
C-band	3.75-7.5 cm	4 – 8
X-band	2.4-3.75 cm	8 – 12.5
Ku-band	1.67-2.4 cm	12.5 – 18
K-band	1.1-1.67 cm	18 – 26.5
Ka-band	0.75 - 1.1 cm	26.5 – 40
millimetre band		
sub-millimetre band		

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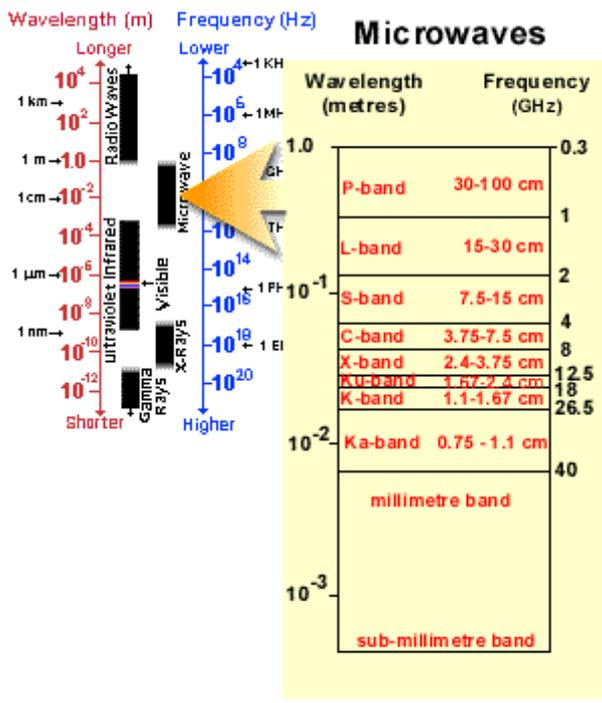
Table: Principal Divisions of the Electromagnetic Spectrum

Wavelength	Description
Gamma rays	Gamma rays
X-rays	X-rays
Ultraviolet (UV) region 0.30 µm - 0.38 µm (1µm = 10⁻⁶m)	This region is beyond the violet portion of the visible wavelength, and hence its name. Some earth's surface material primarily rocks and minerals emit visible UV radiation. However UV radiation is largely scattered by earth's atmosphere and hence not used in field of remote sensing.
Visible Spectrum 0.4 µm - 0.7 µm Violet 0.4 µm -0.446 µm Blue 0.446 µm -0.5 µm Green 0.5 µm - 0.578 µm Yellow 0.578 µm - 0.592 µm Orange 0.592 µm - 0.62 µm Red 0.62 µm -0.7 µm	This is the light, which our eyes can detect. This is the only portion of the spectrum that can be associated with the concept of color. Blue Green and Red are the three primary colors of the visible spectrum. They are defined as such because no single primary color can be created from the other two, but all other colors can be formed by combining the three in various proportions. The color of an object is defined by the color of the light it reflects.
Infrared (IR) Spectrum 0.7 µm – 100 µm	Wavelengths longer than the red portion of the visible spectrum are designated as the infrared spectrum. British Astronomer William Herschel discovered this in 1800. The infrared region can be divided into two categories based on their radiation properties. Reflected IR (.7 µm - 3.0 µm) is used for remote sensing. Thermal IR (3 µm - 35 µm) is the radiation emitted from earth's surface in the form of heat and used for remote sensing.
Microwave Region 1 mm - 1 m	This is the longest wavelength used in remote sensing. The shortest wavelengths in this range have properties similar to thermal infrared region. The main advantage of this spectrum is its ability to penetrate through clouds.
Radio Waves (>1 m)	This is the longest portion of the spectrum mostly used for commercial broadcast and meteorology.