BASIC PRINCIPLES OF REMOTE SENSING

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1. Introduction

Remote Sensing as it has been accepted today in the scientific literature is comparatively a young branch of science. But the act of remote sensing is perhaps as old as the origin of life on our planet. Remote sensing is the sensing of an object or a phenomenon from a remote distance. But then, how remote is remote for remote sensing? Consideration of this type is highly relative and depends on the characters of the signals and the sensors, and also on the attenuation properties of the signal transmission channel. One may also like to know whether there can be sensing without physical contact between the sensor and the object. You may say yes, but the real answer to this question is a big NO. This is because of the fact that under all circumstances the objects to be sensed and the sensor are always intimately bathed in an interacting field, namely the gravitational field, the electromagnetic field and / or the pressure field. These fields are not fictitious but are as real as a lump of matter is. Thus, whatever may be the distance between the sensor and the sensed, they are always in contact with each other through the field. What then is the special significance of the contact sensing? In fact, during the so-called contact sensing no true material contact is established since the planetary / surface electrons of the two bodies can not touch each other, being both negatively charged they repel one another and keep themselves at a distance. What happens in reality is that during the so-called contact sensing the fields of both the bodies influence each other so markedly that it results in an appreciable amount of interaction force / pressure, which is sensed or measured. Now, without going any further with the passionate philosophical discussion on what is remote sensing, we may content ourselves saying that practically remote sensing is the science and technology for acquiring information about an object or a phenomenon kept at a distance. Basically it is a non destructive physical technique for the identification and characterization of material objects or phenomena at a distance.

2. Essential Components of Remote Sensing

Essentially remote sensing has three components:

(i) The Signal (from an object or phenomenon)

(ii) The Sensor (from a platform), and

(iii) The Sensing (acquiring knowledge about the object or the phenomenon after analysis of the signals, received by the sensor, at the user's laboratory).

However, the interaction of the signal with the object by which we obtain information about it, and the interaction of the signal with the transmission channel which reduces the signal strength are given due considerations for detail information extraction. Remote sensing is a branch of Physics, namely Reflectance Spectroscopy which has now found extensive applications in almost every field of human activity.

2.1 Natural and Artificial Remote Sensing

Sensing in general and remote sensing in particular can be taken as a measure of life and activity of all living organisms, from microbes to man. Any living organism whose sense organs are well developed can interact with its environment better, live a better life and can protect itself better from its enemies and hostile environments. Taking the example of man, we have five well developed sense organs (natural sensors): eye, ear, nose, skin and tongue along with highly developed sensing systems – the brain and the nervous system and these are called as natural remote sensing.

Seeing is believing. But we human beings can see only through the visible light which forms only a very narrow band out of the extremely broad electromagnetic spectrum. This is because our eye is not sensitive to the wavelengths below the violet and above the red region of the electromagnetic spectrum. Similarly our ear is insensitive to the infrasonic and the ultrasonic frequencies – it can sense only in the audible frequency range. Thus the knowledge about objects obtained through our eyes and ears is but partial. With the help of artificial remote sensing, man merely tries to imitate the already existing remote sensors in us and improve upon them to include wider information channels so that they can be used efficiently to collect detailed information about objects or phenomena.

2.2 Passive and Active Remote Sensing

A remote sensing system that possesses only a sensor and depends on an external (natural) source to irradiate the target to be sensed is called a passive remote sensing system. As for example, in visible light remote sensing system, the sun, an external natural source, irradiates the target and the reflected light from the target is detected by the sensor. An active remote sensing system, on the other hand, possesses both the sensor and the source to irradiate the target. As for example, the radar, which is an active remote sensing system, transmits microwave pulses from its transmitter antenna to irradiate the target and receives the radar returns by its receiver antenna. Signals are carriers of information. So before we try to analyze the signals to get the information on the object from which they have come, we should like to spend some time to study the characters of the signals at some depth. For meeting the requirements of remote sensing, in general, we can recognize the four types of signals such as Disturbance in a force field, Acoustic signal, Particulate signal, and Electromagnetic signal. We would focus on electromagnetic signals only which is major carrier of information in remote sensing process.

2.3 Electromagnetic Signals

The electromagnetic waves generated by oscillating electric charges all travel with a velocity which is the highest signal velocity that can be attained. This high signal velocity of electromagnetic radiation coupled with its low atmospheric attenuation confers a unique positive advantage to the electromagnetic waves to be used as signals in remote sensing in general and in satellite remote sensing in particular.

2.3.1 Generation of Electromagnetic Signals

The electromagnetic waves generated by the oscillation of electric charges or fields can have various frequencies. Thus, the only way these waves distinguish themselves from one another is through their frequencies of oscillation. If we jiggle the charges or fields with higher and higher frequencies, we get a whole spectrum of electromagnetic waves generated. For example, when the frequency of oscillation is of the order of 10^2 /s as is the case in AC generators, electromagnetic waves are generated of the frequency 10^2 Hz which are recognized as electrical disturbances. Increasing the frequency of oscillation to 10^5- 10^6 Hz, as is achieved in the radio transmitter antenna, we get the electromagnetic waves known as the radio broadcast band. Similarly by a TV transmitter antenna we get FM-TV waves when the frequency of oscillation reaches 10^8 Hz. In electronic tubes such as klystrons and magnetrons, charges can be oscillated with a frequency of the order of 10^{10} Hz, and we get microwaves, radar. For still higher frequencies we go over to the jiggling of atomic and molecular electrons. In the range of frequency from 10^{14} to10^{15} Hz we sense the electromagnetic waves as visible light. The frequencies below this range are called infrared and above it, the ultraviolet. Shaking the electrons in the innermost shells of atoms produces electromagnetic waves of frequency of the order of 10^{18} Hz, which are known as X-rays. Increasing the frequency of oscillation to 10^{21} Hz, the nuclei of atoms emit electromagnetic waves in the form of γ-rays. From high energy particle accelerators we can get artificial γ-rays of frequency 10^{24} Hz. At times we also find electromagnetic waves of extremely high frequency, as high as 10^{27} Hz, in cosmic rays. Thus we find that the electromagnetic radiation forms a very broad spectrum varying from very low frequency to very high frequency, or from very long wavelength to very short wavelength. Table 1 shows the electromagnetic spectrum with its broad spectral regions and their rough behavior.

Table 1: Electromagnetic spectrum with its broad spectral regions and their rough Behavior

Frequency Hz	wavelength	Name of spectral regions	Rough behavior
10^0	300,000 Km	Electrical disturbance/AC	Fields
10^1	30,000 Km	- do -	- do -
10^2	3,000 Km	- do -	- do –
10^3	300 Km	Audio	Waves
10^4	30 Km	- do -	- do –
10^5	3 Km	Radio	- do –
10^6	0.3 Km	- do -	- do –
10^7	30 m	FM – TV	- do –
10^8	3 m	- do -	- do –
10^9	0.3 m	Microwave	- do –
10^{10}	3 cm	- do -	- do –
10^{11}	3 mm	- do -	- do –
10^{12}	0.3 mm	Sub-millimeter / IR	- do –
10^{13}	30 μm	- do -	- do –
10^{14}	3 μm	- do -	- do –
	0.7 μm	Visible	- do –
	0.4 μm	- do -	- do –
10^{15}	0.3 μm	UV	- do –
10^{16}	30 nm	X-rays	- do –
10^{17}	3 nm	- do -	- do –
10^{18}	0.3 nm	- do -	- do –
10^{19}	30 pm	γ- rays (natural)	Particles
10^{20}	3 pm	- do -	- do –
10^{21}	0.3 pm	- do -	- do –
10^{22}	3×10^{-2} pm	γ - rays (artificial)	- do –
10^{23}	3×10^{-3} pm	- do -	- do –
10^{24}	3×10^{-4} pm	- do -	- do -
10^{25}	3×10^{-5} pm	γ -rays (cosmic)	- do –
10^{26}	3×10^{-6} pm	- do -	- do –
10^{27}	3×10^{-7} pm	- do -	- do –

2.3.2 Emission of Electromagnetic Signals from a Material Body (Thermal/Black-body Radiation)

We have already discussed about the fact that a charge oscillating with a certain frequency (i.e., an accelerated charge) radiates electromagnetic waves of the same frequency. Now let us take an example of an electron oscillating in an atom. This is our charged quantum oscillator which is capable of radiating electromagnetic radiation of frequencies characteristic of the oscillator. In an open system, this electromagnetic radiation never comes to thermal equilibrium with the oscillators since as the oscillators gradually lose energy in the form of radiation, their kinetic energy diminishes and hence the jiggling motion slows down. But when these charged quantum oscillators are imprisoned in an isolated cavity having perfectly reflecting walls, then although initially the oscillators lose energy in the way of radiation and thereby decrease their temperature, in course of time the quantum oscillators maintain an equilibrium temperature. This is because the radiation which does not escape from the cavity gets reflected back and forth and fills the cavity. Under this condition the energy lost by the oscillators in radiation is gained by absorbing energy from the radiation field since they are illuminated by it. We may say that in the cavity electromagnetic radiation has attained thermal equilibrium with matter (oscillators). Now if we make a hole in the cavity and look at it when theoretically its temperature is 0^o K, it looks perfectly black. It is for this reason that the cavity is called a black body, and the cavity radiation the black body radiation. We have seen that characteristically the black body is a perfect absorber of electromagnetic radiation and also a perfect emitter. On the contrary, a white body is a non-absorber and non-emitter, it is a perfect reflector. As a matter of fact, in the natural world we do not come across a perfect black body or a white body. Natural bodies show a behavior intermediate between a perfect black body and a perfect white body – the gray body.

2.3.3 Some Characteristics of Black-body Radiation

2.3.3.1 Kirchhoff's Law

Since no real body is a perfect emitter, its emittance is less than that of a black body. Thus the emissivity of a real (gray) body is defined by

$$\varepsilon_g = M_g / M_b \qquad \dots (1.1)$$

where M_g is the emittance of a real (gray) body, and

M_b is the emittance of a black body (perfect radiator).

The emissivity of a black body is $\varepsilon_b = 1$, while the emissivity of a white body $\varepsilon_w = 0$. Between these two limiting values, the grayness of the real radiators can be assessed, usually to two decimal places. For a selective radiator ε varies with wavelength.

2.3.3.2 Planck's Radiation Law

For a radiating body with emissivity ε, the spectral radiant (emittance) is given by Planck's radiation Law as

$$M_\lambda = (\varepsilon\, 8\pi hc / \lambda^5) * 1 / (e^{hc/\lambda\kappa T} - 1), \quad W/(m^2 - \mu m) \qquad \dots (1.2)$$

where ε = emissivity, dimensionless

h = Planck's constant = 6.2559×10^{-34} Js (joule.second)

c = velocity of light = 2.9979×10^8 m/s = 2.9979×10^{14} μm /s

λ= wavelength of radiation

κ= Boltzmann's constant = 1.38×10^{-23} J /K

T = absolute temperature of the radiating body in degree Kelvin (K)

Using the relationship between frequency and wavelength of the electromagnetic radiation

$$\nu = c / \lambda \qquad \dots (1.3)$$

Planck's radiation law (Eqn. 1.2) can also be written in terms of frequency as

$$M_\nu = (\varepsilon\, 8\pi h / c^3) * \nu^3 / (e^{h\nu/\kappa T} - 1), \quad W/(m^2 - Hz) \qquad \dots (1.4)$$

where ν = radiation frequency, Hz

A useful feature of Planck's law is that it enables us to compute the amount of total spectral radiant emittance which falls between two selected wavelengths or frequencies. This can be useful in remote sensor design, and also in the interpretation of remote sensing observations.

2.3.3.3 Stefan – Boltzmann Law

If we integrate M_λ or M_ν over all wavelengths or all frequencies, the total radiant emittance M will be obtained for a radiating body of unit area, i.e.

$$M = \int_o^\infty M_\lambda \, d\lambda = \int_o^\infty M_\nu \, d\nu = (\varepsilon \, 8\pi^5\kappa^4 / h^3c^3) * T^4$$
$$= \varepsilon \, \sigma \, T^4, \quad W/m^2 \qquad \ldots (1.5)$$

where σ is the Stefan – Boltzmann radiation constant, and has the numerical value

$= 5.669 \times 10^{-8}$ $W/(m^2 - K^4)$

Equation (1.5) is known as the Stefan – Boltzmann radiation law.

2.3.3.4 Wien's Displacement Law

To obtain the peak spectral radiant emittance, we differentiate M_λ with respect to λ and set it equal to 0, and the resulting equation is solved for λ_{max}. Thus we get

$$\lambda_{max} = (a / T), \quad \mu m \qquad \ldots (1.6)$$

where $a \cong 3000$ μmK, and T is the absolute temperature of the radiating body.

This shows that as the temperature increases, the peak of M_λ gets displaced towards the shorter wavelengths and the area under the curve increases. Take the examples of the sun and the earth as radiating bodies. For the sun, with a mean surface temperature of 6000 K, $\lambda_{max} \cong 0.5$ μm , and for the earth, with a surface temperature of 300 K, $\lambda_{max} \cong 10$ μm. Thus the wavelength of the maximum radiant emittance from the sun falls within the visible band of the electromagnetic spectrum, whilst that from the earth falls well within the thermal infrared region. We experience the former dominantly as light and the latter as heat.

Another useful parameter, namely the value of emittance at $\lambda = \lambda_{max}$ can be obtained from Planck's radiation law (Eqn. 1.2) by substituting λ by λ_{max} (= a/T as in Eqn. 1.6 above) which yields

$$M_{max} = b \, T^5 \qquad \ldots (1.7)$$

Where $b = 1.29 \times 10^{-5}$ $W/(m^3\text{-}K^5)$. For example, for T = 300 K and a narrow spectral band of 0.1 μm around the peak, the emitted power is about 3.3 W/m^2.

2.3.3.5 Radiant Photon Emittance

Dividing M_λ or M_ν by the associated photon energy $E = hc/\lambda = h\nu$, Planck's radiation law (Eqn. 1.2) can be written in terms of the radiant photon flux density. Thus the spectral radiant photon emittance is given by

$$Q_\lambda = (2\pi/ \lambda^4) * [\, 1 / (e^{hc/\lambda\kappa T} - 1) \,] , \quad \text{photons} / (m^3\text{- s}) \qquad \ldots (1.8)$$

Integrating over the whole spectrum thus provides the total photon flux emitted by the radiating body of unit area. The Stefan – Boltzmann law for photon flux thus becomes

$$Q = \int_o^\infty Q_\lambda \, d\lambda = \sigma' \, T^3 \qquad \ldots (1.9)$$

where $\sigma' = 1.52 \text{ X } 10^{15} \text{ m}^2 \text{ s}^{-1} \text{T}^{-3}$. This shows that the rate at which the photons are emitted by a radiating body varies as the third power of its absolute temperature. For example, for T = 300 K, the total number of emitted photons becomes equal to $4 \text{ X } 10^{22}$ photons / (m^2- s).

Thus far we have described the generation of electromagnetic radiation. Among its essential properties, it does not require a material medium to propagate. In empty space it travels with the highest signal velocity

$$c = 2.9979 \text{ X } 10^8 \text{ m/s}$$

In material medium (non-absorbing or partially absorbing, i.e. transparent or translucent) the velocity of electromagnetic wave is less, depending on the refractive index (μ) or the dielectric constant (k) of the medium:

$$v = c / \mu \qquad \ldots (1.10)$$

The dielectric constant of the medium is given by

$$k = \mu^2 \qquad \ldots (1.11)$$

The frequency and wavelength of electromagnetic radiation are related by the formula

$$\nu \lambda = c \qquad \ldots (1.12)$$

The electromagnetic radiation being transverse in character, it can be polarized and its state of polarization can be changed by reflection, refraction, scattering, absorption and emission.

3. Radiation Terminology

For the measurement of light we commonly use photometric unit which is based on the assumption that human eye is the ultimate sensor of radiation, and thus the sensitivity of human eye is the basis for the formulation of these units. In remote sensing, however, sensors other than the human eye are used to detect radiation in many other parts of the electromagnetic spectrum to which the human eye is not sensitive. Thus the useful units for measuring radiation in remote sensing are the radiometric units. Table 2 lists the most important of these radiometric quantities along with their symbols, defining expressions and commonly used units.

Table 2: Radiometric and Photometric Quantities

Quantities	Symbols	Defining equations	Commonly used Units
Radiant energy (Spectral radiant energy)	Q	-	joule (J)
Radiant energy density (Spectral radiant energy density)	W	W = dQ / dV	joule / m^3 (Jm^{-3}) erg / cm^3
Radiant flux / Radiant power (Spectral radiant flux)	Φ	Φ = dQ / dt	watt (joule/sec) (W) erg / sec
Incident flux	Φ_i	$\Phi_i = dQ_i / dt$	watt (W)
Reflected flux	Φ_r	$\Phi_r = dQ_r / dt$	watt (W)
Absorbed flux	Φ_a	$\Phi_a = dQ_a / dt$	watt (W)
Transmitted flux	Φ_t	$\Phi_t = dQ_t / dt$	watt (W)
Radiant flux density at surface:			

Irradiance	E	$E = d\Phi / dA$	watt / m^2	(Wm^{-2})
(Spectral irradiance)			watt / cm^2	($W\ cm^{-2}$)
Radiant exitance / Radiant Emittance	M	$M = d\Phi / dA$	watt / m^2	($W\ m^{-2}$)
(Spectral radiant exitance)			watt / cm^2	($W\ cm^{-2}$)
Radiant intensity	I	$I = d\Phi / d\omega$	watt / steradian	($W\ sr^{-1}$)
(Spectral radiant intensity)				
Radiance	L	$L = dI / (dA\cos\theta)$	watt/(sr. m^2)	($W\ sr^{-1}m^{-2}$)
(Spectral radiance)				
Reflectance	ρ	$\rho = \Phi_r / \Phi_i$	-	-
Transmittance	τ	$\tau = \Phi_t / \Phi_i$	-	-
Absorptance	α	$\alpha = \Phi_a / \Phi_i$	-	-
Hemispherical reflectance	ρ	$\rho = M_r / E$	-	-
(Spectral hemispherical reflectance)				
Hemispherical transmittance	τ	$\tau = M_t / E$	-	-
(Spectral hemispherical transmittance)				
Hemispherical absorptance	α	$\alpha = M_a / E$	-	-
(Spectral hemispherical absorptance)				
Emissivity	ε	$\varepsilon = M / M_{\text{black body}}$	-	-
(Spectral emissivity)				

3.1 Target– Signal Interaction in Optical Region (Visible and Infrared): Radiation Modification

An Overall View

The very fact that electromagnetic radiation incident on a target (object) is partly reflected, partly absorbed and partly transmitted, clearly demonstrates the interaction of electromagnetic radiation with matter. This fact is summarized as

$$\rho_\lambda + \alpha_\lambda + \tau_\lambda = 1 \qquad \ldots (1.13)$$

where ρ_λ is the reflectance or reflectivity

α_λ is the absorptance or absorptivity, and

τ_λ is the transmittance or transmissivity of the object with respect to the electromagnetic radiation (λ) under consideration. The defining equations of the radiometric quantities are given in Table 3. The spectral signatures of various earth surface features give credence to the above interactions.

If the object (target) is opaque to the radiation, as for example, the earth's crust, then $\tau_\lambda = 0$, and under this condition equation (1.13) reduces to

$$\rho_\lambda + \alpha_\lambda = 1, \text{ or } \alpha_\lambda = 1 - \rho_\lambda \qquad \ldots (1.14)$$

Now, applying the concept that an ideal absorber is an ideal radiator (emitter), we identify absorptance with emittance, and write

$$\rho_\lambda + \varepsilon_\lambda = 1 \text{ , or } \quad \varepsilon_\lambda = 1 - \rho_\lambda \qquad \ldots (1.15)$$

This is Kirchhoff's law in a different version which shows that for opaque terrestrial material, the emissivity (absorptivity) and reflectivity (reflectance) are complementary to each other.

Many common terrestrial materials are found to be similar in their thermal emission spectrum in the 8 – 14 μm infrared range with a spectral emissivity between 0.85 – 0.95. Thus for the measurement of temperature of terrestrial materials by remote sensing technique (with the help of an IR thermometer), this 8–14μm band is invariably used where it is assumed that the emissivity of all these materials are similar with an estimated emissivity of about 0.9.

3.2 Interaction of Electromagnetic Radiation with Atmospheric Constituents

Electromagnetic radiation from the sun interacts with the atmospheric constituents and gets absorbed or scattered. Essentially two types of scattering takes place: elastic scattering in which the energy of radiation (ν or λ) is not changed due to the scattering, and inelastic scattering in which the energy of the scattered radiation (ν or λ) is changed (Compton scattering and Raman scattering). Inelastic scattering usually takes place when high energy photons are scattered by free electrons in the ionosphere or by the loosely bound electrons of atoms and molecules in the atmosphere.

As regards the elastic scattering, we recognize three types of such scattering phenomena in the atmosphere : Rayleigh scattering, Mie scattering and non-selective scattering depending on the size of the scatterers in relation to the wavelength of radiation (λ) being scattered. The atmospheric scattering processes are summarized in Table 3.

Table 3: Atmospheric scattering processes

Scattering Process	**Wavelength dependence**	**Approximate particle size (μm)**	**Kind of particles**
Rayleigh	λ^{-4}	<< 0.1	Air molecules
Mie	λ^0 to λ^{-4}	0.1 to 10	Smoke, fumes, haze
Nonselective	λ^0	> 10	Dust, fog, cloud

3.2.1 Rayleigh Scattering

Rayleigh scatterers have size << λ. Mostly molecules of the atmosphere satisfy this condition. In Rayleigh scattering the volume scattering coefficient σ_λ is given by

$$\sigma_\lambda = [(4\pi^2 NV^2) / \lambda^4] * [(\mu^2 - \mu_o^2)^2 / (\mu^2 + \mu_o^2)^2] \cong \text{const.}/\lambda^4 \qquad \ldots (1.16)$$

where N = number of particles per cm^3

V = volume of scattering particles

λ = wavelength of radiation

μ= refractive index of the particles, and

μ_o = refractive index of the medium

Rayleigh scattering causes the sky to appear blue. Since the scattering coefficient is inversely proportional to the fourth power of the wavelength, radiation in the shorter blue wavelengths is scattered much more strongly than radiation in the red wavelengths. The red of the sunset is also caused by Rayleigh scattering. As the sun approaches the horizon and its rays follow a longer path through the denser atmosphere, the shorter wavelength radiation is comparatively strongly scattered out of the line of sight, leaving only the radiation in longer wavelengths, red and orange, to reach our eyes. Because of Rayleigh scattering, multispectral remote sensing data from the blue portion of the spectrum is of relatively limited usefulness. In case of aerial photography, special filters are used to filter out the scattered blue radiation due to haze present in the atmosphere.

3.2.2 Mie Scattering

Mie scatterers have size $\approx \lambda$. Water vapor and fine dust particles in the atmosphere satisfy this condition. As a general case, in which there is a continuous particle size distribution, the Mie scattering coefficient is given by

$$\sigma_\lambda = 10^5 \pi \int_{a1}^{a2} N(a)\, K(a,\mu)\, a^2\, da \qquad \ldots (1.17)$$

where σ_λ = Mie scattering coefficient at wavelength λ

$N(a)$ = number of particles in interval of radius a and a+da

$K(a,\mu)$ = scattering coefficient (cross section) as a function of spherical particles of radius a and the refractive index of the particles μ

Mie scattering may or may not be strongly wavelength dependent, depending upon the wavelength characteristics of the scattering cross sections. In remote sensing, Mie scattering usually manifests itself as a general deterioration of multispectral images across the optical spectrum under conditions of heavy atmospheric haze.

3.3 Target- Signal Interaction Mechanisms

The radiation-matter interaction mechanisms across the electromagnetic spectrum are summarized in Table 4. Examples of remote sensing applications of each spectral regions are also given in this table. Needless to say that a good understanding on the interaction of radiation with terrestrial matter is essential for extracting correct information from remote sensing data analysis.

Table 4: Radiation-matter interaction mechanisms across the electromagnetic spectrum

Spectral Region	Main Interaction mechanism	Fields of Remote Sensing Application
γ-rays X-rays	Atomic processes	Mapping of radio-active materials
UV	Electronic processes	Presence of H and He in atmosphere
VIS, NIR	Electronic and vibrational Molecular processes	Surface chemical composition, vegetation cover, biological properties
MIR	Vibrational, vibration-rotational molecular processes	Surface chemical composition, atmospheric chemical composition
Thermal IR	Thermal emission, vibrational and rotational processes	Surface heat capacity, surface temperature, atmospheric temperature, atmospheric and surface constituents
Microwave	Rotational processes, thermal emission, scattering, conduction	Atmospheric constituents, surface temperature, surface physical properties, atmospheric precipitation
Radio Frequency	Scattering, conduction, ionospheric effects	Surface physical properties, surface sounding, ionospheric sounding

3.4 Electromagnetic Signals Useful for Satellite Remote Sensing (the Atmospheric Windows)

The wave bands, narrow or broad, for which the transmission percentage is very high are the spectral regions that are least attenuated by the atmospheric constituents. These spectral regions are called the atmospheric windows, and these channels play important role in remote sensing of the earth resources from satellite platforms. Some of these identified atmospheric windows are given below in Table 5. From it is seen that the spectral bands of the solar spectrum which are attenuated due to absorption by the water vapour and other atmospheric gases, though can not be used in satellite remote sensing of terrestrial surface features yet they are considered extremely useful for monitoring these absorbing atmospheric gases.

Table 5: Atmospheric Windows for terrestrial surface monitoring from space-borne observation platforms

Spectral regions	Spectral bands
VIS (Visible)	0.4 - 0.7 μm
NIR (Near infrared)	0.7 - 1.1 μm
SWIR (Short wave infrared)	1.1 - 1.35 μm 1.4 - 1.8 μm 2.0 - 2.5 μm
MWIR (Mid wave infrared)	3.0 - 4.0 μm 4.5 - 5.0 μm
TIR (Thermal infrared)	8.0 - 9.5 μm 10 - 14 μm
Microwave	0.1 - 100 cm

Spectral bands for remote sensing are chosen from the entire spectrum of the electromagnetic spectrum so that they can be used for monitoring thematic earth surface features and phenomena.

4. Sensors and Sensor Platforms

4.1 Sensor Materials

The sensor or detector transforms the energy of the incoming radiation into a form of recordable information. It is found that no single sensor material is equally sensitive to the entire range of electromagnetic spectrum. Therefore, different sensor materials are used for the construction of detectors in different wavelength ranges. In general, there are two types of electromagnetic signal detectors, namely optical film detectors and opto-electronic detectors.

Sensor materials in the film detectors are silver bromide grains. Usually black and white, true color and infrared false color films are in use. Black and white and true color films are sensitive to the visible band of the electromagnetic spectrum (0.4 – 0.7 μm). Spectral sensitivity curves of these photographic films are found to attain a maximum around 0.69 μm and then falls to a very small value at 0.7μm. It is because of this that all panchromatic films operate within 0.4 – 0.7 μm spectral band. However, spectral sensitizing procedures can be applied to the emulsions of black and white films so that they can be made sensitive to near infrared radiation up to wavelength of approximately 0.9 μm. The sensitivity of the false color film is increased up to 0.9 μm including a short but highly reflective part of the near infrared spectrum (0.7 – 0.9 μm).

Opto-electronic detectors are classified into two types on the basis of the physical processes by which radiant energy is converted to electrical outputs. They are thermal detectors (sensitive to temperature changes) and quantum detectors (sensitive to changes in the incident photon flux).

Typical thermal detectors are: thermocouples /thermopiles and thermister bolometers. In thermocouples and thermopiles, change in voltage takes place due to the change in temperature between thermoelectric junctions. In thermister bolometers change in resistance takes place due to the change of temperature of the sensor materials. Thermister bolometers usually use carbon or germanium resistors with resistance change of 4 % per degree. Thermal detectors are slow, have low sensitivity and their response is independent of the wavelength of the electromagnetic radiation.

4.2 Quantum Detectors

Quantum detectors are of three types. They are:

Photo-emissive detectors (photocells and photomultipliers use alkali metal surface coatings such as cesium, silver-oxygen-cesium composite)

Photo-conductive detectors (photosensitive semiconductors whose conductivity increases with incident photon flux), and Photo-voltaic detectors (here modification takes place in the electrical properties of a semiconductor p-n junction such as backward bias current on being irradiated with light)

In the wavelength region < 1 μm, quantum detectors like photo-multipliers and Si-photodiodes are found quite efficient and do not need cooling devices. However, for satellite platforms the photo-multipliers are found less suitable because of its accompanying high voltage power supplies that increase the weight of the payload substantially. In 1 to 3 μm wavelength region, Ge-photodiode, Ge-photo-conductor, InSb photodiode, InAs photodiode and HgCdTe photodiode can be used for sensor materials. However, these sensors are to be kept cooled as their electrical characteristics change with increase in their temperature. In the thermal wavelength region (10 to 14 μm), HgCdTe photo-conductors and PbSnTe photodiodes can be used as sensor materials with effective cooling systems. For the microwave region of the electromagnetic spectrum, the sensor or detector invariably used is the microwave antenna.

4.3 Sensor Systems

In a sensor system the sensor material is integrated into its appropriate circuitry and housing to detect and process the input signals and give out the corresponding outputs for further analysis to generate information on the target surface from which the signals are received. Sensor systems are of two types : non-imaging sensor system and imaging sensor system.

Non-imaging sensor system include sounders and altimeters for measurement of high accuracy locations and topographic profiles, spectrometer and spectroradiometer for measurement of high spectral resolution along track lines or swath, and radiometers, scatterometers and polarimeters for high accuracy intensity measurements and polarization changes measurements along track lines or wide swath.

Imaging sensor systems are again of two types: framing systems and scanning systems. In framing systems images of the targets are taken frame by frame. These include imagers like photographic film cameras and return beam videcon. The scanning systems include across track scanners and along track (push broom) scanners. Imagers and scanning altimeters / sounders are used for three dimensional topographic mapping. Multispectral scanners / thematic mappers are used for limited spectral resolution with high spatial resolution mapping. Imaging spectrometers are meant for high spectral and spatial resolutions. Imaging radiometers and imaging scatterometers (microwave) are used for high accuracy intensity measurement with moderate imaging resolution and wide coverage. Brief descriptions of some of the important framing and scanning systems mentioned above are presented in the following paragraphs.

4.4 Framing Systems

4.4.1 Large Format Camera (LFC)

This high performance photographic film camera was used for the first time in Space Shuttle flight mission of October, 1984. Large format camera has an achromatic lens (in the wavelength range of 0.4 to 0.9 μm) of focal length 305 mm. Its format is 230 X 460 mm and exposure range is 3 to 24 ms. The camera is flown with the long dimension of its format in the flight direction to obtain the necessary stereo coverage for the topographic map compilation. The magazine capacity of the large format camera is 1200 m of film for 2400 frames.

4.4.2 Hasselblad Camera

This was the multi-band camera flown on Apollo-9 flight mission of March,1969 to obtain the first multi-band pictures of earth from space in the NASA program. It had in the assembly four Hasselblad cameras with filters in the green, yellow, red and deep red regions of the electromagnetic spectrum. It was this Hasselblad camera with infrared ektachrom film which was used to obtain the first historic aerial photograph of the coconut plantation of Kerala in India in late nineteen sixties. The analysis of the coconut crown intensity showed its strong relationship with the coconut production by the plants. Investigating the cause of low crown crown intensity it was found that such plants were affected by a viral disease attributed to the coconut root wilt virus which was confirmed from electron microscopic studies. The clear practical demonstration of the fact that the onset of a disease could be identified by the near-infrared aerial photography, much before its visual symptoms become apparent, gave a strong boost to the development of remote sensing program of the Indian Space Research Organization, Department of Space, Government of India.

4.4.3 Return Beam Vidicon (RBV)

Return beam vidicon is a framing system which is an electron imager and works like a television camera. When the shutter is opened and closed, its optical system frames an image on a photoconducting plate and retained as a varying charge distribution just like a photographic a photographic camera frames the image on a photochemical film. The pixels of the image receiving higher intensity of light becomes more conducting, meaning thereby that more of the electrons from their corresponding backside pixels move to the front side. Thus the backside pixels of the photoconducting plate becomes positively charged to different amounts. Now a fine electron beam from the electron gun is allowed to scan the pixels line by line. Thus while the electron beam neutralizes the pixels of the photoconductor from the backside, a part of the beam, now weaker than the forward scanning beam, returns back to a detector carrying the image describing signals. The strength of these feeble signals is increased in an electron multiplier and final signals are digitized and recorded as the image output. These electronically processed image data are amenable to rapid transmission from sensor platform to a ground receiving station. Being a framing device, the return beam vidicon collects a full frame data practically instantaneously. Alternately, the images may be recorded on a magnetic tape for replay at a later time when the sensor platform is within the range of a ground receiving station.

Landsat-1 and -2 carried three RBVs with spectral filters to record green (0.475 – 0.575 μm), red (0.580 – 0.680 μm), and photographic infrared (0.698 – 0.830 μm) images of the same area on the ground. During image processing these data are taken as due to blue, green and red bands to develop the false color image of the scene. Landsat-3 carried two RBVs operating in the panchromatic band (0.505 – 0.750 μm) to obtain higher resolution (24m) compared to its MSS ground resolution (79m). Moreover, each of these two RBVs has a covered adjacent ground area of 99X99Km with 15Km sidelap. Successive pairs of RBV images also have a 17Km forward overlap. Thus two pairs of RBV images cover an area of 181X183 Km which is equivalent to the area corresponding to the MSS scene (185X185 Km). The time sequence of RBV scene acquisition was kept at 25 seconds, because of the driver for the framing sequence of the multi-spectral scanner of the Landsat series of remote sensing satellites.

4.5 Scanning Systems

4.5.1 Across Track Multispectral Scanner (MSS)

This form of imaging is used in Landsat series of satellites. The scanning system employs a single detector per band of the multispectral signal. It has an electrical motor, to the axel of which is attached a solid metal cylinder whose free end is cut at 45 degrees to the axis of its rotation and highly polished to act as a scanning mirror. The field of view (FOV) is restricted by an aperture so that the mirror will receive signals in almost nadir view from 2000 ground resolution cells that makes one scan line. The signal received by the rotating scanning mirror from a ground resolution cell (corresponding to GIFOV) is a white one and contains spectral information in different bands. This white beam is reflected by the mirror in the flight direction (parallel to the ground) and is allowed to pass through a monochromator / spectroscope which splits the composite beam into its color components. The detectors with their designed apertures are so placed that they now receive the spectral information from the ground resolution cells in the specified bandwidths of various color components of the white signal. The current produced in the sensor material (Si- photodiodes etc.) by the different bands of the electromagnetic spectrum are digitized and transmitted to the ground receiving stations or stored in magnetic tapes till a ground receiving station is within its range for transmission / reception. Since the rotating mirror scans the swath line by line perpendicular to the track (flight direction), the scanner is called across-track scanner.

The dwell time of the scanner is computed by the formula:
Dwell Time = (Scan rate per line) / (Number of ground resolution cells per line)
The Spatial Resolution of the Scanner = Ground Resolution Cell = GIFOV

4.5.2 Along Track Multispectral Scanner / Push Broom Scanner

In this type of scanner, the scan direction is along the track (direction of flight) and hence the name along track scanner. It is also called push broom scanner because the detectors are analogous to the bristles of a push broom sweeping a path on the floor.

Development of charge-coupled device (CCD) has contributed to the successful design of the along track scanner. In this the sensor elements consist of an array of silicon photodiodes arranged in a line. There are as many silicon photodiodes as there are ground resolution cells (corresponding to IFOV) accommodated within the restricted FOV of the sensor optics. Each silicon photodiode, in turn, is coupled to a tiny charge storage cell in an array of integrated circuit MOS (metal oxide semiconductor) device forming a charge coupled device (CCD). When light from a ground resolution cell strikes a photodiode in the array, it generates a small current proportional to the intensity of light falling on it and the current charges the storage cell placed behind the diode. The charged cells form a part of an electronic shift register which can be activated to read out the charge stored in the cells in a sequential fashion. The output signals are correlated with the shift pulses, and digitized to reconstitute the image.

Because of the linear array of the sensor elements in this type of imaging / scanning system, it is also called linear imaging self scanning (LISS) system. SPOT satellites and IRS series of satellites extensively use this type of payloads for scanning purposes.

For multispectral scanning, the along track scanner accommodates one line of detector array for each spectral band. However, IRS satellites use as many cameras as there are spectral bands each with a characteristic filter and a linear array of CCD detectors.

The spatial resolution of the sensor = ground resolution cell = GIFOV
The dwell time for the along track scanner is given by
Dwell time = (ground resolution cell dimension) / (velocity of sensor platform)

Under identical setup, it is found that the dwell time of along track scanner is far greater than the dwell time of the across track scanner. The increased dwell time of the along track scanner which provides higher signal intensity from ground resolution cells provides two important improvements for incorporation in the scanner system, namely to minimize the detector size corresponding to a smaller GIFOV producing higher spatial resolution and to narrow down the spectral bandwidth, thereby increasing the spectral resolution.

4.5.3 Side Viewing / Side Looking Scanner

The across track and along track scanners described above are used in passive remote sensing in visible, infrared and microwave regions of the electromagnetic spectrum. These scanners always receive signals in the nadir view. However, if the user demands (on payment basis) to observe a dynamic scene frequently, then there is provision in SPOT and IRS satellites to steer the cameras to look off-nadir at the required scene, some days before to some days after the normal nadir viewing date.

But scanners of active remote sensing, like the scanners used for radar remote sensing, in their normal mode of scanning look to the sides and not to the nadir for technical reasons which will be described later. Therefore such scanners are called side looking airborne radar (SLAR). The most sought after, sophisticatedly designed synthetic aperture radar (SAR) belongs to the side looking scanner system.

4.6 Scale, Resolution and Mapping Units

4.6.1 Scale

Remote sensing information is scale dependent. Images can be described in terms of scale which is determined by the effective focal length of the optics of the remote sensing device, altitude from which image is acquired and the magnification factor employed in reproducing the image.

Normally we talk about small scale, intermediate scale and large scale while describing an image. These scales are quantitatively specified in the following manner:

Small scale	(> 1: 500,000),	1cm = 5 Km or more
Intermediate scale	(1: 50,000 to 1: 500,000),	1cm = 0.5 to 5 Km
Large scale	(< 1: 50,000)	1cm = 0.5 Km or less

Thus large scale images provide more detailed information than the small scale images. For achieving optimum land use planning at different levels the following scales are often recommended:

1. National level	1: 1,000,000
2. State level	1: 250,000
3. District level	1: 50,000
4. Farm / Micro-watershed / Village / Command area level	1: 4,000 to 1: 8,000

These scales are equally applicable for images of visible, infrared and microwave remote sensing.

With regard to photo scale (S) of the aerial or satellite imageries, it is computed as the ratio of the photo distance (d) to the ground distance (D) between any two known points, i.e.

$$S = d / D = \text{(photo distance)} / \text{(ground distance)}$$

For a photograph taken in the nadir view, the image scale is a function of the focal length of the camera used to acquire the image, the flying height of the sensor platform above the ground and the magnification factor (M) employed in reproducing the image, i.e.

$$\text{Image Scale} = Mf / H = \text{(magnification factor) (camera focal length)} / \text{(flying height above terrain)}$$

However, it is observed that the image scale of the photograph of a landscape may vary from point to point because of displacements caused by the topography.

4.6.2 Resolution

An image can be described not only in terms of its scale, as mentioned earlier, but also in terms of its resolution. In remote sensing we basically need three different types of information to be acquired such as spatial information, spectral information and radiometric (intensity) information. Accordingly the sensor systems or the instruments vary in principles of detection and construction. For obtaining spatial information we use imagers, altimeters and sounders. Spectral information can be acquired by spectrometers and intensity (radiometric) information by radiometers and scatterometers. A suitable modification of the remote sensing equipment helps to acquire two of the three types of information at a time. For example, with an imaging spectrometer one can obtain spatial as well as spectral information from a target. Spectral and radiometric information can be gathered by a spectroradiometer. An imaging radiometer collects not only spatial information but also the radiometric information. Acquisition of all the three types of information from a target is possible by the multispectral scanner and the multispectral push broom imager. It summarizes the information needed for remote sensing analysis and the types of sensor systems or instruments used to acquire such information.

As already mentioned, remote sensing information is not only scale dependent but also resolution dependent. Four types of resolutions are considered in remote sensing work. They are: Spatial resolution, Spectral resolution, Radiometric resolution and Temporal resolution.

4.6.2.1 Spatial Resolution

It is the minimum distance between two objects that a sensor can record distinctly. Description of spatial resolution may be placed into one of the following four categories:

- the geometric properties of the imaging system
- the ability to distinguish between point targets
- the ability to measure the periodicity of repetitive targets and
- the ability to measure spectral properties of small finite objects

The geometric properties of the imaging system is usually described by the ground projected instantaneous field of view (GIFOV). However, a GIFOV value is not in all cases a true indication of the size of the smallest object that can be detected. An object of sufficient contrast with respect to its background can change the overall radiance of a given pixel so that the object becomes detectable. Because of this, features smaller than 80 m, such as railway lines and low-order drainage patterns are detectable on Landsat images. Conversely, on Landsat imagery, objects of medium to low contrast may only be detectable if they are of the size 250 m or more.

For measurements based on the distinguishability between two point targets, Rayleigh criterion is used. According to Rayleigh, the two objects are just resolvable if the maximum (center) of the diffraction pattern of one falls on the first minimum of the diffraction pattern of the other. Consequently the smallest angle resolvable is

$$\theta_m = 1.22 \ (\lambda / D) \ \text{radians} \qquad \ldots (1.18)$$

where λ and D are the wavelength of light and diameter of the lens respectively. In remote sensing terminology, θ_m is called the instantaneous field of view (IFOV).

Measures of resolution using periodicity of repetitive targets are expressed in line pairs / cm. Resolution employing spectral properties of the target is the effective resolution element (ERE). This measure of spectral resolution is of interest because of the increasing importance of automated classification procedures which are highly dependent upon the fidelity of the spectral measurements recorded by the sensor system.

Effective resolution element (ERE) is defined as the size of an area for which a single radiance value can be assigned with reasonable assurance that the response is within 5% of the value representing the actual relative radiance.

Spatial resolution of a system must be appropriate if one is to discern and analyze the phenomena of interest, namely the detection and identification of objects and their analysis. To move from detection to identification, the spatial resolution must improve by about 3 times. To pass from identification to analysis, a further improvement in spatial resolution of 10 or more times may be needed.

4.6.2.2 Spectral Resolution

For a remote sensing instrument, spectral resolution is determined by the bandwidth of the channels used. High spectral resolution is achieved by narrow bandwidths which are collectively likely to provide more accurate spectral signature for discrete objects than by broad bandwidths. However, narrow band instruments tend to acquire data with low signal-to-noise ratio lowering the system’s radiometric resolution. This problem may be eliminated if relatively long dwell times are used during scanning / imaging.

4.6.2.3 Radiometric Resolution

Radiometric resolution is determined by the number of discrete levels into which a signal strength maybe divided (quantization). However, the maximum number of practically possible quantizing levels for a sensr system depends on the signal-to-noise ratio and the confidence level that can be assigned when discriminating between the levels.

With a given spectral resolution, increasing the number of quantizing levels or improving the radiometric resolution will improve discrimination between scene objects. It is found that the number of quantizing levels has a decided effect upon the ability to resolve spectral radiance that is related to plant-canopy status. Interdependency between spatial, spectral and radiometric resolutions for each remote sensing instrument affects the various compromises and tradeoffs.

4.6.2.4 Temporal Resolution

Temporal resolution is related to the time interval between two successive visits of a particular scene by the remote sensing satellite. Smaller the revisit time the better is the temporal resolution of the sensor system of the remote sensing satellite. High temporal resolution satellites are more suitable for monitoring dynamic surface features or processes like the growth and development of agricultural crops, floods and so on. To monitor changes with time, temporal resolution is also an important consideration when determining the resolution characteristics of a sensor system. For agricultural applications, the use of time as a discriminant parameter may allow crops over large areas to be identified with sensors possessing spatial and spectral resolutions that are too coarse to identify them on the basis of the spectral and morphological characteristics alone.

4.6.3 Mapping Units

Minimum size of an area which can be recognized over a map is taken as 3mm X 3mm. Thus this area is taken as the minimum mapping unit. If the scale of the map is 1: 50,000, then the length of the mapping unit can be calculated as

1 mm on the map = 50,000 mm on the ground
3 mm on the map = 150,000 mm on the ground = 150 m on the ground

Therefore, the minimum mapping unit is 150m X 150m.

Similarly when we process the remote sensing digital data, the smallest area of a land surface feature which can be visually recognized on the screen is 3 X 3 pixels. Thus if the ground resolution cell of the satellite sensor is 80m (as in case of Landsat MSS), then the smallest classifiable area becomes 240m X 240m. In this case, as the smallest classification distance (namely 240m) is more (coarser) than the minimum mapping unit, therefore, we can not use Landsat MSS data to undertake mapping of land surface features in the scakle of 1: 50,000. For mapping on a specific scale, it is advisable to use remote sensing data that provides a smaller value of the smallest classification distance (3 pixels) than the minimum mapping unit. In the present example, Landsat TM data (ground resolution 30m X 3 = 90m) or IRS LISS-II data (ground resolution 36.25m X 3 = 108.75m) or IRS LISS-III data (ground resolution 23.5m X 3 = 70.5m) can be used for mapping land surface features on a map with 1: 50,000 scale.

5. Remote Sensor Platforms

Essentially three different types of platforms are used to mount the remote sensors wherefrom they collect information on earth’s surface features and record / transmit the information to an earth receiving station for their further analysis and interpretation. These sensor platforms are:

Ground Observation Platform
Airborne Observation Platform, and
Space-borne Observation Platform

5.1 Ground Observation Platform

Ground observation platforms are necessary to develop the scientific understanding on the signal-object and signal-sensor interactions. These studies, both at laboratory and field levels, help in the design and development of sensors for the identification and characterization of the characteristic land surface features. Important ground observation platforms include – handheld platform, cherry picker, towers and portable masts. Portable handheld photographic cameras and spectroradiometers are used for laboratory and field experiments to collect the ground truth. In cherry pickers automatic recording sensors can be placed at a height of about 15m from the ground. Towers can be raised for placing the sensors at a greater height for observation. Towers can be dismantled and moved from place to place. Portable masts mounted on vehicles can be used to support cameras and other sensors for testing and collection of reflectance data from field sites.

5.2 Airborne Observation Platform

Airborne observation platforms are important to test the stability performance of the sensors before they are flown in the space-borne observation platforms. Important airborne observation platforms include – balloons, drones (short sky spy), aircraft and high altitude sounding rockets.

5.2.1 Balloon Platform

Balloons are used for remote sensing observations (aerial photography) and nature conservation studies. Balloons developed by the Socie'te' Europe'anne de Propulsion can carry the payloads upto altitudes of 30Km. It consists of a rigid circular base plate for supporting the entire sensor system which is protected by an insulating and shockproof light casing. It is roll stabilized and temperature controlled. Essential equipment carried by the balloon includes – camera, multispectral photometer, power supply units and remote control system. The sensor system is brought back to earth by tearing the carrying balloon through remote control.

5.2.2 Airborne High Altitude Photography

Special aircraft carrying large format cameras on vibrationless platforms are traditionally used to acquire aerial photographs of land surface features. While low altitude aerial photography results in large scale images providing detailed information on the terrain, the high altitude, smaller scale images offer advantage to cover a larger study area with a fewer photographs.

NASA acquired aerial photographs of the United States from U-2 and RB-57 reconnaissance aircraft at altitudes of 18 Km above the terrain on film of 23 X 23 cm format. Each photograph covered 839 square kilometers at a scale of 1: 120,000. Black and white, normal color and infrared color films were used in these missions.

The National High Altitude Photography (NHAP) program (1978), coordinated by the US Geological Survey, started to acquire coverage of the United States with a uniform scale and format. From aircraft at an altitude of 12 Km, two cameras (23 X 23 cm format) acquired black and white and infrared color photographs. The black and white photographs were acquired with the camera of 152 mm focal length to produce photographs at 1: 80,000 scale which cover 338 square kilometers per frame. The infrared color photographs were acquired with a camera of 210 mm focal length to produce photographs at 1: 58,000 scale covering 178 square kilometers per frame.

5.2.3 Airborne Mulitspectral Scanners

Aircraft platforms offer an economical method of testing the remote sensors under development. Thus photographic cameras, electronic imagers, across-track and along-track scanners, and radar and microwave scanners have been tested over ground truth sites from aircraft platforms in many countries, especially in the NASA programmes.

NASA U-2 aircraft acquired images using a Daedalus across-track multispectral (10 bands between 0.38 – 1.10 μm) scanner. Similarly the M-7 airborne scanner having 12 spectral bands covering ultraviolet, visible and infrared regions, was also tested. Signals from the scanners were monitored and controlled in flight at the operator console and were recorded in analog form by a wide-band magnetic tape recorder. The recorded signals were later digitized and reformatted on the ground for digital image processing and information extraction.

5.3 Space-borne Observation Platforms

Essentially these are satellite platforms. Two types of satellite platforms are well recognized, they are: manned satellite platform and unmanned satellite platform.

5.3.1 Manned Satellite Platforms

Manned satellite platforms are used as the last step, for rigorous testing of the remote sensors on board so that they can be finally incorporated in the unmanned satellites. Crew in the manned satellites operates the sensors as per the program schedule.

5.3.2 Unmanned Satellite Platforms

Landsat series, SPOT series and IRS series of remote sensing satellites, the NOAA series of meteorological satellites, the entire constellation of the GPS satellites and the GOES and INSAT series of geostationary environmental, communication, television broadcast, weather and earth observation satellites all belong to this unmanned satellite category. We may add to this list the unmanned satellites launched by Russia, Canada, European Space Agency, China and Japan to indicate the current state of development in space technology to tackle our problems from global perspective.

These satellites are space observatories which provide suitable environment in which the payload can operate, the power to permit it to perform, the means of communicating the sensor acquired data and spacecraft status to the ground stations, and a capability of receiving and acting upon commands related to the spacecraft control and operation. The environment of the space-borne observation platform is considered as both structural and physical and includes such factors as the framing mount for the payload and functional support systems, the means of maintaining the thermal levels of the payload within allowable limits, and the ability to maintain the orbital location of the spacecraft so that the sensors look at their targets from an acceptable and known perspective. The torso of the observatory is the sensory ring which mounts most of the observatory subsystems that functionally support the payload. The satellite mainframe subsystems designed to meet these support functions include: the structure subsystem, orbit control subsystem, attitude control subsystem, attitude measurement subsystem, power subsystem, thermal control subsystem, and the telemetry storage and telecommand subsystems.

5.4 Ground Systems

Ground communication stations are the radio telemetry links between satellites and the earth. They fall into two general categories: (1) those having the sole function of receiving the sensor and attitude data from the satellites and (2) those which, in addition to receiving the sensor and attitude data, can receive satellite house keeping data and transmit commands.

5.5 Satellite Launch Vehicle

Rocket-vehicles are used for launching the satellites. The type of rocket used for Landsat launches was of Mc Donnell-Douglas Delta-900 series. This was a two-stage rocket that is thrust-augmented with a modified Thorbooster, using nine Thiokol solid propellant strap-on engines. The French launch vehicle is an Ariane Rocket. Russian launch vehicles use cryo-engines. The Indian satellite launch vehicles are of PSLV and GSLV types.

5.6 Remote Sensing Satellite Orbits

A space-borne remote sensing platform is placed and stabilized (by special orbit maneuvers) in an orbit in which it moves. From geometrical characteristics point of view, the orbits of of the space-borne platform can be circular, elliptic, parabolic or hyperbolic. Although the operational orbits for terrestrial remote sensing are supposed to be circular, it is difficult in practice to establish and maintain an exactly circular orbit. Therefore, the so-called nominally circular orbits are slightly elliptical in form. Parabolic and hyperbolic orbits are not used for terrestrial remote sensing. However, they are used primarily in extraterrestrial flights for sending us information on the extraterrestrial objects.

From the point of view of periodicity of satellite movement, orbits can be classified as geo-synchronous (geo-stationary) and sun-synchronous.

5.6.1 Geosynchronous Orbit

It is an important special case of the circular orbit class which is achieved by placing the satellite at an altitude (35,786, 103 Km) such that it revolves in synchrony with the earth, namely from west to east at an angular velocity equal to the earth’s rotation rate. The geosynchronous orbit maintains the satellite over a narrow longitude band over the equator. When this band shrinks to a line the orbit is called geostationary. These orbits are most frequently used for communication / television broadcast satellites. They are also used for meteorological and other applications. Insat series of satellites launched by Indian Space Research Organization, Department of Space, Government of India belong to this class of satellites.

5.6.2 Sunsynchronous Orbit

If the orbit precession exactly compensates for the earth’s revolution around the sun, the orbit is called sunsynchronous. It is an important case of elliptical orbit class in which the orbital plane is near polar (> 85 degrees from the equatorial plane) and the altitude is such that the satellite passes over all places on earth having the same latitude twice daily revolving in the same mode (ascending or descending) at the same local sun time. Here solar incidence angle which is held almost constant over the samelatitude finds potential applications in earth resource survey and management. All remote sensing satellites like Landsat, SPOT and IRS belong to this class of satellites. With sunsynchronous satellites, remote sensing observations of a particular scene (location) can only be made at one fixed time in nadir view during a predetermined date which eliminates multitemporal observations within the its revisit period.

5.6.3 Shuttle Orbit

Shuttle orbits range from 200 to 300 kilometers above the surface of the earth at an inclination of 30^o to 60^o to the equatorial plane. Payloads are mounted on the cargo bay. Space shuttles are the manned space observation platforms. Space stations launched by the United States of America and Russia to carry out important physico-chemical and biological experiments and to develop some hightech materials are also placed in these orbits so that the crew can carry food items and ferry the scientists to-and-fro between the earth and the space station.

5.6.4 Coverage

Coverage represents the areas of the earth which are observed by the satellite in one repeat cycle. For polar (near polar for technical reasons) orbits, it is given as the maximum north and south latitudes. An important aspect of the remote sensing mission design of satellite is to provide coverage of a particular geographic area on some schedule. Coverage has two elements: (1) the nadir trace or ground track of the satellite, and (2) the sensor view area or swath. The ground track is determined by the satellite orbit while the swath is determined not only by the orbit but also by the field of view and the look direction of the sensor relative to the nadir. Landsat, SPOT and IRS series of satellites essentially provide coverage through nadir traces. However, SPOT and the some recent IRS series of satellites have been provided with tiltable mirrors to sweep off-nadir traces involving programs pointing sequences.

5.6.5 Passes

If one observes the pass sequence of the satellite nadir trace then one finds a daily shift through N days when on the Nth day the nadir trace over a particular location exactly coincides. Thus the temporal resolution of the satellite is N days. The characteristic number of passes and the temporal resolution of different satellite systems are presented in Table 6.

Table 6: Characteristics of some remote sensing satellites

Satellite	Altitude (Km)	Orbits /day	Repetivity (days)	Ground Resolution	Radiometri Resolution
Landsat 1, 2, 3	918	14	18	79 m	128MSS 4,5,6 64 MSS 7
Landsat 4, 5	705	14.5	16	30 m TM	256 TM 120 m TM 6
SPOT 1, 2	832		26	20 m MS	256 10 m PAN
IRS-1A,1B	904	14	22	72.5 m LISS- I 36.25m LISS-II	128 LISS-I 128 LISS-II
IRS-1C	817		24	5.8m PAN	188 m WiFS
IRS-P3	817		24	188 m	188 m WiFS 580-1000m MOS
IRS-1D	821		24	5.8m PAN	23.5m LISS-III 70.5m LISS-III MIR 188m WiFS

5.6.6 Pointing Accuracy

The attitude of the sensor platform is affected by the rotational drifts about the roll, pitch and yaw axes which in turn affect the location accuracy of the sensor. It is for this reason that for every satellite configuration, the minimum tolerable roll, pitch and yaw drift angles are decided earlier. The satellite is regularly monitored for these parameters by the ground tracking stations during its passes and corrections are applied accordingly.

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