Remote Sensing Data Acquisition

Course Outline and subjects

- EM Radiation and its interaction with Matter
- Optical Systems
- Ray Tracing (using Beam Four)
- Microwave Systems

The EM spectrum

The most commonly used wavelengths for remote sensing are based on the frequencies at which the Earth's atmosphere is the most transparent:

0.1 μm — 1 μm — 10 μm — 0.1 mm — 1 mm — 10 mm — 0.1 m → λ

VNIR
Visible and Near Infrared
$\lambda \approx 0.38 \sim 3\mu m$

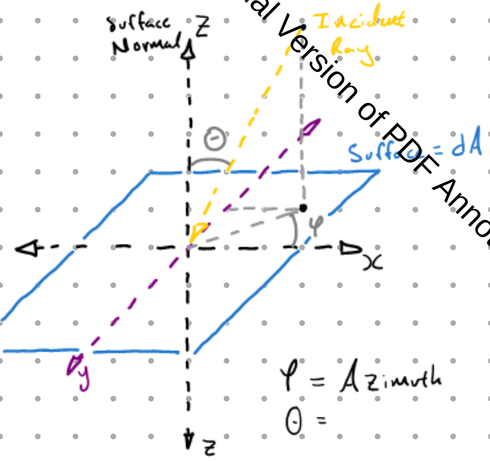
TIR
Thermal Infrared
$\lambda \approx 8 - 15 \mu m$

MW
Microwave Region
$\lambda \approx 1mm \sim 1m$

Wavelength Region	Passive Systems	Active Systems
VNIR - Visible and Near Infrared $\lambda \approx 0.3 \sim 3\mu m$	- Cameras (Analogue) - Electro-Optical Systems (Digital)	- Laser Profiler - LIDAR (Light Detection and Ranging)
TIR - Thermal Infrared $\lambda \approx 8 \sim 15 \mu m$	- TIR Imaging Systems	N/A
Microwave $\lambda \approx 1mm \sim 1m$	- Passive Microwave Radiometer	- RADAR Altimeter (Radio Detection and Ranging) - Microwave Scatterometer Imaging RADAR

Definition of Radiation Quantities

For remote sensing we have to consider radiation in 3D (not using plane waves as one may be familiar with) as such we will make use of polar coordinates and some other reference planes/systems:

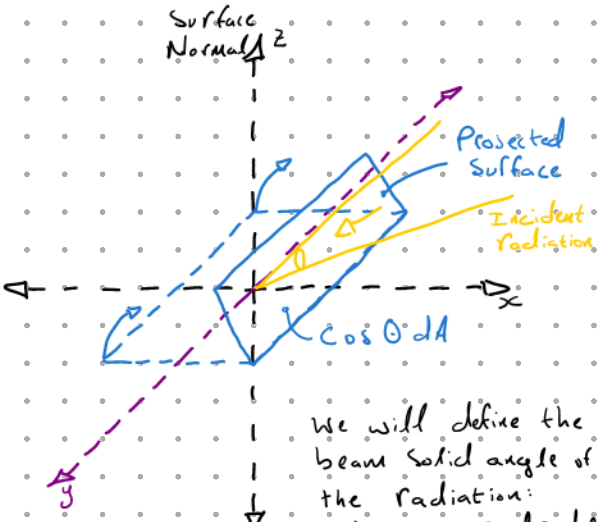


φ = Azimuth

θ =

If the surface is rotated about y from its corner such that the radiation is now normal to the new projected surface.

We can then make some useful definitions.



We will define the beam solid angle of the radiation:

$$d\Omega = \sin\theta \, d\theta \, d\varphi$$

$$L, \text{ Radiance} = \frac{dP}{\cos\theta \, dA \, d\Omega} = \frac{\text{watts}}{\text{metre}^2 \cdot \text{steradian}}$$

In plain words; this the **RADIANCE** of the incident radiation or power in a given solid angle and surface.

We can further define the **IRRADIANCE**, E, as the incident power per unit area:

$$E = \int_0^{\pi/2}\int_0^{2\pi} L_{in} \cos\theta \, . \, d\Omega = \frac{\text{Watts}}{\text{metre}^2}$$

Then we can consider the radiated power from the surface due to the incident power:

$$M, \text{ Radiant Excitance} = \int_0^{\pi/2}\int_0^{2\pi} L_{out} \cos\theta \, d\Omega \xrightarrow{\text{For isotropic radiation this simplifies}} M = \pi L$$

Thermal Radiation

Everything above 0K (−273.15°C) emits thermal radiation we can use our new definitions of radiometric quantities to account for radiation dependent on wavelength:

Note: IR is the most commonly used radiation for remote sensing.

$$\Delta L = L_\lambda \cdot \Delta\lambda$$

where:

L_λ = Spectral Radiance $\left(\frac{\text{Watts}}{m^3 \cdot s}\right)$

$$\therefore L = \int_{\lambda_1}^{\lambda_2} L_\lambda \, . \, d\lambda$$

ΔL = Change in radiance

$\Delta\lambda$ = Change in wavelength

Thermal Radiation - Black body Radiation

Formally a black body is defined as an object in thermal equilibrium, absorbing all radiation incident upon it. (often approximated as a cavity)

Black bodies and the radiation they emit tends to be a quite a good approximation of the spectral radiance emitted by any given object.

Radiation of black bodies is governed by Planck's Formula:

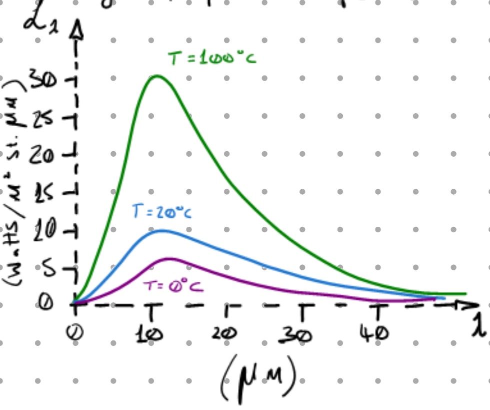
$$L_\lambda = \frac{2hc^2}{\lambda^5} \cdot \frac{1}{\exp\left(\frac{hc}{\lambda k_B T}\right) - 1}$$

h, Planck's Constant = 6.626×10^{-34} J.s

k_B, Boltzmann's Constant = 1.38×10^{-23} J/K

c, Speed of light = 3×10^8 m/s

Rough Graph of Spectral Radiance



At sufficiently long wavelengths (different for each temperature) the Rayleigh-Jeans approximation can be used:

$$L_\lambda \approx \frac{2 k_B T \cdot c}{\lambda^4}$$

By integrating the planck formula by wavelength the total radiance can be obtained;

$$L = \int_0^\infty L_\lambda \cdot d\lambda = \frac{2\pi^4 k_B^2}{15 \cdot c^2 \cdot h^3} \cdot T^4$$

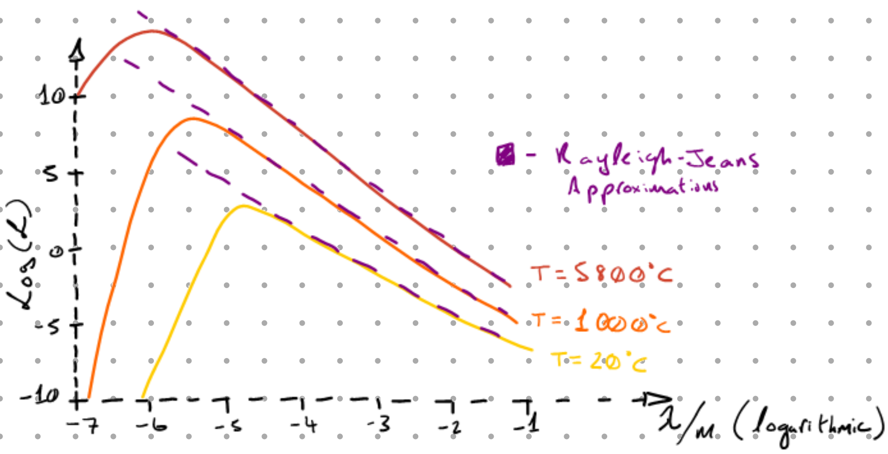
Since the radiator is isotropic the total radiant excitance gives Stefan's Law:

$$M = \pi L = \frac{2\pi^5 k_B^2}{15 \cdot c^2 \cdot h^3} \cdot T^4 \quad \therefore M = \sigma T^4$$

(Stefan's Law)

σ, Stefan-Boltzmann Constant = $5.64 \times 10^{-8} \frac{\text{watts}}{\text{m}^2 \cdot \text{K}^4}$

Spectral Radiance ∝ Rayleigh-Jeans



The peaks of any given temperature can be found using Wien's displacement law:

$$\lambda_{max} = \frac{A}{T} = \frac{2.898 \times 10^{-3}\ \text{K} \cdot \text{m}}{T}$$

Earth's average surface temp:

$$\lambda = \frac{2.898 \times 10^{-3}\ \text{K} \cdot \text{m}}{273\ \text{K}} \approx 9.9\ \mu\text{m}$$

Emissivity and Brightness Temperature

We can even better approximate from the black body by introducing emissivity of materials:

$$\mathcal{L}_{\lambda,\varepsilon} = \varepsilon(\lambda)\cdot\mathcal{L}_\lambda$$

Brightness temperature, T_b, is the equivalent blackbody temperature required to give the same spectral radiance as a given non black body object with emissivity, ε:

$$\varepsilon\,\mathcal{L}_\lambda(\lambda, T) = \mathcal{L}_\lambda(\lambda, T_b)$$

$$\underbrace{\Rightarrow T_B = \varepsilon T}_{\text{From Rayleigh-Jeans approx.}}$$

$$\underbrace{T_B = \frac{hc}{k_B\lambda}\frac{1}{\ln\left(1+\frac{\exp\left(\frac{hc}{\lambda k_B T}\right)-1}{\varepsilon}\right)}}_{\text{Actual formula}}$$

Solar Radiation

Solar Radiant Excitance, $M_s = \sigma T^4 = 6.35\times10^7\ \mathrm{W/m^2}$

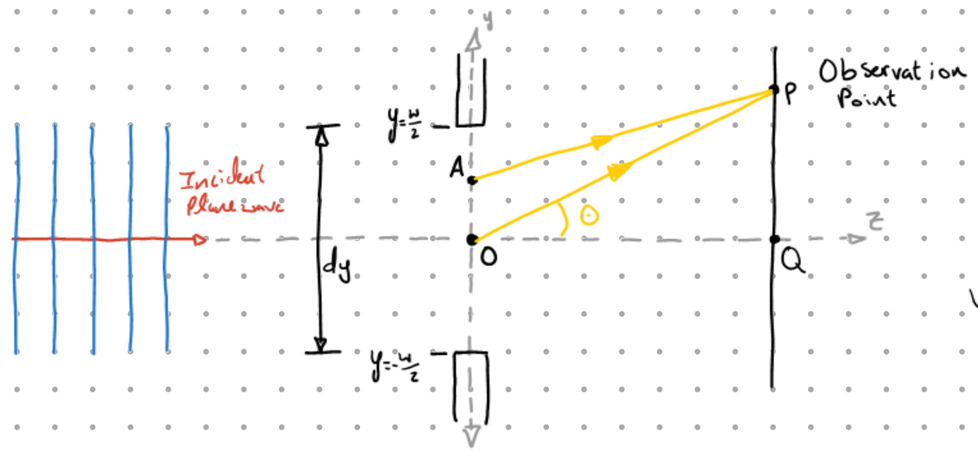
Total Solar Power Radiated, $P_s = 4\pi r_s^2 M_s = 3.87\times10^{26}$ Watts

Sun's Mean Irradiance (extra-atmosphere), $E_s = \dfrac{P}{4\pi D_{s-e}^2} = 1.37\times10^3\ \mathrm{W/m^2}$

Solid Angle Subtended by the Sun, $\Delta\Omega_s = \dfrac{\pi r_s^2}{D_{s-e}^2} = 6.76\times10^{-5}$ sr

Sun's Radiance, $\mathcal{L}_s = \dfrac{E_s}{\Delta\Omega_s} = \dfrac{\sigma T_s^4}{\pi} = 2.02\times10^7\ \mathrm{W/m^2\,sr}$

Diffraction



The complex amplitude at P is proportional:

$$A_p \propto \exp(jk\sin(\theta))\,dy$$

With total amplitude given by:

$$a(\theta) = \int_{-w/2}^{w/2}\exp(jk\sin\theta)\,dy$$

If we define $f(y)$ as the amplitude transmitted to the observation surface we obtain a form of integral (fourier) transform:

$$a(\theta) = \int_{-\infty}^{\infty} f(y)\cdot\exp(jky\sin\theta)\,dy = \int_{-\infty}^{\infty} f(y)\,e^{jky\sin\theta}\,dy$$

Fraunhofer Diffraction Integral

Diffraction Cont...