Microwave Radiometry

Radiometry is the measurement of electromagnetic radiation. All material (gases, liquids, solids, plasmas) radiate (or emit) via the process of thermal emission. Radiometry can be used to infer the properties of a medium depending on the temperature of the medium and how the medium alters/modifies the thermal emission.

Microwave radiometry: the measurement of thermally-generated radiation in the microwave region of the spectrum.

Radiometric Quantities

**radianc flux or power (W):** radiant energy emitted, transmitted, scattered, or received per unit time.

**radianc flux density or power density (W/m²):** Also called radiant emittance, the radiant flux density emitted by a surface. Also called irradiance, the radiant flux density incident on a surface.

**radianc intensity or radiation intensity (W/sr⁻¹):** radiant power per solid angle.

**radianc or brightness (W/m².sr⁻¹):** radiant power per area per solid angle.

spectral radianc or spectral brightness

\[ [B_\lambda (\lambda)] = W/m^2.sr^{-1}.m^{-1} \]

\[ [B_\lambda (\lambda)] = W/m^2.sr^{-1}.Hz^{-1} \]
What is the Source of Brightness?

Because all matter above zero Kelvin (0 K) contains accelerating electric charges, all matter emits radiation.

Recall the wave/particle duality. Instead of electromagnetic waves, we can also consider electromagnetic radiation in the form of photons. Photons are emitted or absorbed because of discrete energy transitions.

**Transitions**

- Electron jumps to a higher energy level (excited state)
- Electron emitted
- Photon absorbed
- "Spontaneous emission"
- Photon emitted

**Transitions**

- Vibrational
- Rotational
- Translational

In the case of a material that has an infinite number of transitions spaced throughout the spectrum, then the material is called a perfect radiator and a perfect absorber. It will absorb all incident radiation and emit at all frequencies. Such a material is called a blackbody. No blackbodies exist in nature, but some can be approximated as such in certain bands of frequencies.

$$E = \text{photon energy} = hf$$

$$h = \text{Planck constant} = 6.6261 \times 10^{-34} \text{ J s}$$
Blackbody

Thermal emission is described by the Planck law:

$$B_x(f, T) = \frac{2\pi f^3}{c^2} \frac{1}{e^{\frac{h f}{k T}} - 1}$$

where

- $B_x(f, T)$ = spectral brightness, $W \cdot m^{-2} \cdot sr^{-1} \cdot Hz^{-1}$
- $h$ = Planck constant $= 6.63 \times 10^{-34}$ $J \cdot s$
- $f$ = frequency, $Hz$
- $c$ = phase velocity of radiation in a vacuum
  \[ = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3.0 \times 10^8 \text{ m/s} \]
- $k$ = Boltzmann constant $= 1.38 \times 10^{-23}$ $J \cdot K^{-1}$
- $T$ = temperature, $K$

Note that spectral brightness is a function of temperature!
Specifically, $B_x(f, T)$ increases as $f$ and $T$ increase.

Planck law in terms of wavelength:

$$\int_{0}^{\infty} B_x(f, T) df = \text{total power emitted over all frequencies} = \int_{0}^{\infty} B_x(\lambda, T) d\lambda, \quad [B_x(\lambda, T)] = \frac{W}{W \cdot sr \cdot m}$$

To relate $B_x(f, T)$ to $B_\lambda(\lambda, T)$, we must relate $df$ to $d\lambda$.

- $c = \lambda f$, \quad $f = \frac{c}{\lambda}$ \quad $df = -\frac{c}{\lambda^2} d\lambda$

$$\int_{0}^{\infty} B_x(f, T) df = \int_{0}^{\infty} B_x(\lambda, T) \left[- \frac{c}{\lambda^2} d\lambda\right] = \int_{0}^{\infty} B_\lambda(\lambda, T) d\lambda = \int_{0}^{\infty} -B_\lambda(\lambda, T) d\lambda$$

$$B_\lambda(\lambda, T) = \frac{c}{\lambda} B_x(f, T)$$

$$B_\lambda(\lambda, T) = \frac{2\pi c^2}{\lambda^5} \frac{1}{e^{\frac{h c}{\lambda k T}} - 1}$$

Often seen in atmospheric science... why?
6. Thermal Emission

Fig. 6.2: Blackbody emission curves at temperatures typical of the sun and of the earth and atmosphere. (a) The actual value of Planck's function, plotted on a logarithmic vertical axis. The diagonal dashed line corresponds to Wien's law (6.3). (b) Normalized depictions of the same functions as in (a), so that the areas under each curve are equal. Note that the vertical axis in this case is linear.
Figure 2-12. Spectral radiant emittance of a blackbody at various temperatures. Note the change of scale between the two graphs.

Section 4.1 The Origin and Nature of Radiation

FIGURE 4.1 Spectral distribution of radiant energy from a full radiator at a temperature of (a) 6000 K, left-hand vertical and lower horizontal axis, and (b) 300 K, right-hand vertical and upper horizontal axis. About 10% of the energy is emitted at wavelengths longer than those shown in the diagram. If this tail were included, the total area under the curve would be proportional to \( \sigma T^4 \) (W m\(^{-2}\)). \( \lambda_m \) is the wavelength at which the energy per unit wavelength is maximal.