Frequency Spectrum

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The frequency spectrum

The Electromagnetic frequency spectrum is represented in Figure 1 in terms of the wavelength.

In this Figure is also shown the portion of spectrum where the transmission characteristics of optical fibers are best utilized.

Waveguides used in optical communication systems and in integrated optics are generally operated in this frequency range.

Another part of the spectrum intensively used is that corresponding to radio wavelengths, as detailed in Table 1

Electromagnetic wave spectrum

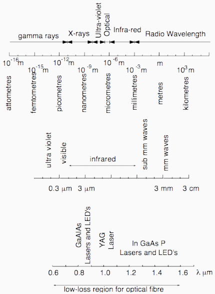

Figure 1: Electromagnetic wave spectrum.

Table 1: Radio frequency band designations and use.

Frequency	*Wavelength*	*Band designation*	*Typical service*
30-300 Hz 300-3000 Hz	10-1 Mm 1000-100 km	ELF extremely low frequency	
3-30 kHz	100-10 km	VLF very low frequency	Navigation, sonar
30-300 kHz	10-1 km	LF low frequency	Radio beacons, navigational aids
300-3000 kHz	1 km-100 m	MF medium frequency	AM broadcasting, maritime radio, Coast Guard communication, direction finding
3-30 MHz	100-10 m	HF high frequency	Telephone, telegraph, facsimile; shortwave international broadcasting; amateur radio; citizen's band; ship to coast and ship to aircraft communication
30-300 MHz	10-1 m	VHF very high frequency	Television, FM broadcast, air traffic control, police, taxicab mobile radio, navigational aids
300-3000 MHz	1 m-10 cm	UHF ultra high frequency	Television, radioprobes, satellite communication, surveillance radar, navigational aids
3-30 GHz	10-1 cm	SHF super high frequency	Airborne radar, satellite communication, common carrier land mobile communication, microwave links
30-300 GHz	1 cm- 1 mm	EHF extremely high frequency	Experimental, Radar, vehicular anti-collision radar

Electromagnetic communications can take place in free–space or with guided waves.

Waveguides operating at microwave and millimeter waves are of particular interest for their wide range of applications.

The frequency band designations employed in the microwave range are reported in Table 2.

Table 2: Microwave frequency band designations.

Frequency	Wavelength	IEEE radar band designation	
		old	new
1-2 GHz	30-15 cm	L	D
2-3 GHz	15-10 cm	S	E
3-4 GHz	10-7.5 cm	S	F
4-6 GHz	7.5-5 cm	C	G
6-8 GHz	5-3.75 cm	C	H
8-10 GHz	3.75-3 cm	X	I
10-12.4 GHz	3-2.42 cm	X	J
12.4-18 GHz	2.42-1.67 cm	Ku	J
18-20 GHz	1.67-1.5 cm	K	J
20-26.5 GHz	1.5-1.13 cm	K	K
26.5-40 GHz	1.13 cm-7.5 mm	Ka	K
40-300 GHz	7.5-1.0 mm	mm	

wavenumber concept

The wavenumber concept is perhaps more fundamental in electromagnetic wave theory than either of the more popular concepts of wavelength and frequency.

The corresponding values of wavenumber k and frequency f are obtained from the wavelength λ by the following relationships

$$f = \frac{c}{\lambda} \qquad \lambda = \frac{2\pi}{k} \tag{1}$$

where c is the free–space velocity of light,

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 2.997925 \times 10^8 \mathrm{m/s} \approx 3 \times 10^8 \mathrm{m/s} \tag{2}$$

and

$$
\begin{aligned}
\mu_0 &= 4\pi \times 10^{-7} \, henry/metre && \left(\frac{V \cdot s}{A \cdot m}\right) \\
\varepsilon_0 &= \frac{1}{36\pi} \times 10^{-9} \, farad/metre && \left(\frac{A \cdot s}{V \cdot m}\right)
\end{aligned}
\tag{3}
$$

where

μ_0 is the magnetic permeability

ε_0 the dielectric permittivity of free–space.

Guided waves

Waveguides may operate up to optical frequencies.

For communication purposes, since it is generally desirable to employ as large a bandwidth as possible, it is advantageous to use the higher frequencies now available.

Up to the millimetric range this is an added bonus, as circuit dimensions become smaller as frequency increases, thus allowing a saving of space and sometimes a reduction of costs when higher frequencies are used.

Atmospheric attenuation

Atmospheric attenuation

As frequency increases so does the average atmospheric attenuation, as shown in Figure 2

This fact, together with problems related to electromagnetic interference, prevents the use of free–space as a transmitting media for very large amounts of data.

Atmospheric attenuation is also important for many applications; for example, by choosing frequencies for which the atmosphere is opaque, one prevents detection of satellite–to–satellite communications by ground–based receivers.

Similarly, terrestrial systems desiring to prevent signal overshoot in range may operate at a frequency of high atmospheric absorption

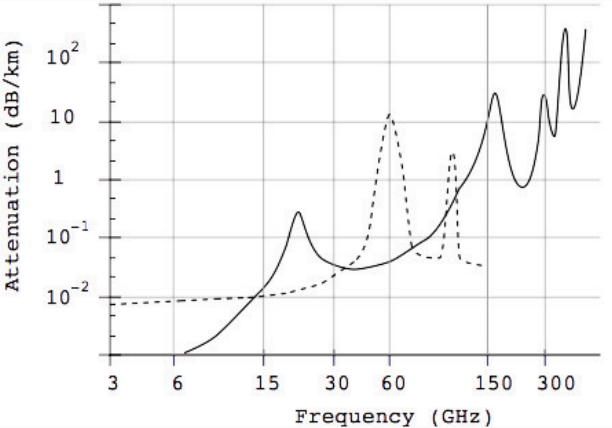

Figure 2: Attenuation by oxygen (dotted line) and water vapour (continuous line) at sea level. The water content is 7.5 g/m^3 and the temperature is $T = 20^\circ C$.

Speed of light frequency and wavelength

The frequency f, the wavelength λ and the speed of light c are also related by the important relation

$$c = f\lambda \tag{4}$$

As an example compute the wavelength of a gps receiver with $f = 1575.42\,\mathrm{MHz}$

The code clf.wxm computes wavelength from frequency.

```
/* [wxMaxima batch file version 1] [ DO NOT EDIT BY HAND! ]*/
/* [ Created with wxMaxima version 11.08.0 ] */

/* [wxMaxima: input   start ] */
kill(all)$
print("-----------------------------------------------")$
print("Program name: clf")$
print("-----------------------------------------------")$

print("Computing the wavelength for a given frequency")$
Mega : 10^6$
print("speed of light c")$
c_light: 2.99792458 * 10^8;
print("Frequency f")$
freq : 1575.42 * Mega ;
print("wavelength in meters")$
%lambda : c_light/freq;
print("in cm")$
lambdacm : %lambda*100 ;
print("-----------------------------------------------")$
print("wavenumber")$
k : 2.0 * float(%pi)/%lambda$
print('k," = ",k)$
print("end")$
/* [wxMaxima: input   end   ] */

/* Maxima can't load/batch files which end with a comment! */
"Created with wxMaxima"$
```