FREQUENCY, WAVELENGTH & THE EM SPECTRUM

Radio and television broadcasting, radar, shortwave and satellite communications, GPS and mobile phones — they all use electromagnetic (EM) radiation, where energy propagates through space or materials in the form of synchronised oscillating electric and magnetic fields. So too does optical communication, both in space and via glass fibres, and the infra-red remote control you use to change the channels on your TV. When you stand out in the sun, the light that allows you to see and the direct warmth you feel are both EM radiation — as also is the ultra-violet radiation that gives you a tan (and skin cancers).

When you heat up a frozen meal in your microwave oven, you're also making use of EM radiation. And when the dentist or radiologist takes a diagnostic X-ray of some part of your body, they too are using EM radiation. Similarly when a scientist monitors gamma radiation from space (cosmic rays), they're checking yet another type of EM radiation.

All of these types of EM radiation, some of them apparently quite dissimilar, are basically different only in terms of their frequency — or to put in another way, the length of their propagating waves.

As you may know, when early radio pioneers began working with 'wireless' waves, they generally described them in terms of their *wavelength*. Transmissions were said to be on 'long waves', 'medium waves' or 'short waves', and their actual wavelength was given in metres (to the extent that the pioneers were able to measure them).

Nowadays, of course, we tend to describe EM radiation in terms of its *frequency* — in hertz (Hz), kilohertz (kHz), megahertz (MHz) and so on. Only in the microwave region do we still tend to refer to the wavelength as well.

How can you convert between the two? As with any moving waves, the frequency and wavelength are simply related by the velocity of motion:

velocity = frequency x wavelength

And where we have EM radiation propagating through free space or a vacuum, its velocity is well known. It's the so-called *speed of light*, usually labelled c:

c = 299,793,000 +/-300 metres/second (m/s)

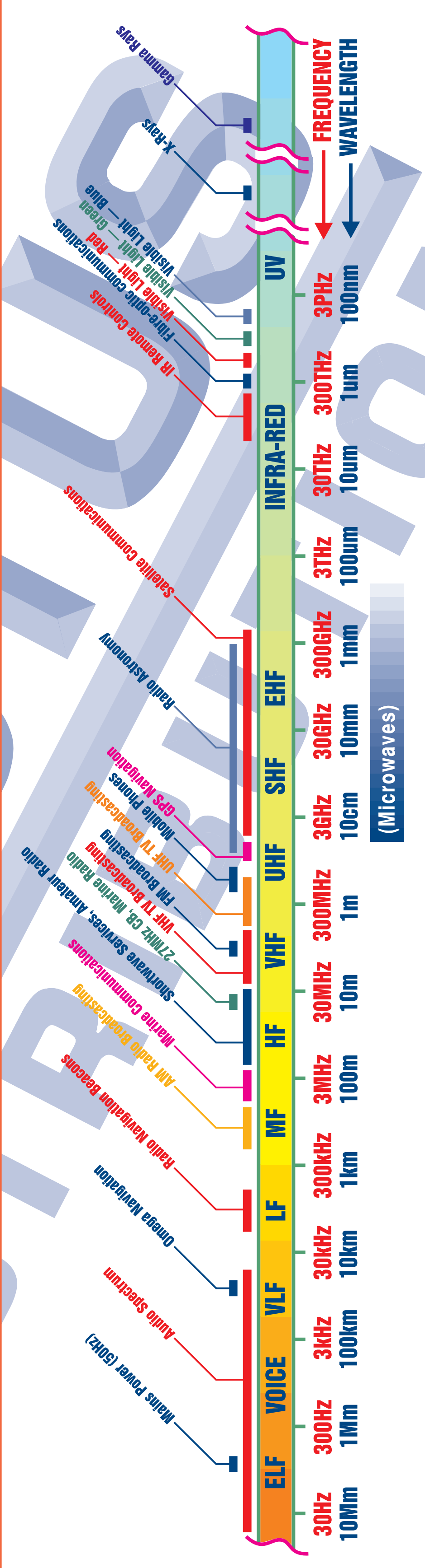
As you can see, this is very close indeed to 300 million metres per second — closer than 0.1%, in fact. So for most purposes, we can be quite accurate enough calling it 300 million (or 3×10^8) m/s.

This means that for EM radiation in free space or a vacuum, the frequency and wavelength can be related by this simple expression:

$$300{,}000{,}000 = f \times \lambda$$

Metric multipliers commonly applied to Frequency

Multiplier/unit	Abbrev.	Meaning
microhertz	µHz	Millionths of a hertz (10^{-6}Hz)
millihertz	mHz	Thousandths of a hertz (10^{-3}Hz)
hertz	Hz	Basic unit of frequency (one cycle/second)
kilohertz	kHz	Thousands of hertz (10^{3}Hz)
megahertz	MHz	Millions of hertz (10^{6}Hz)
gigahertz	GHz	Thousands of megahertz (10^{9}Hz)
terahertz	THz	Millions of megahertz (10^{12}Hz)
petahertz	PHz	Thousands of terahertz (10^{15}Hz)



Here's an overview of the electromagnetic spectrum, to give you a broad idea of the frequencies and wavelengths used for many of the common applications of EM energy. For clarity quite a few haven't been shown, though. For example microwave ovens usually operate at 2.4GHz, while radar or 'radiolocation' systems operate at many different frequencies — from about 420MHz right up into the EHF region. There are also many bands allocated for use by radio amateurs, from 1.8MHz right up to 250GHz. The scale here is logarithmic, of course, to cope with the enormous range.

Where **f** is the frequency in hertz, and λ is the wavelength in metres.

For many practical situations, this expression can be simplified even further:

$$300 = f \times \lambda$$

Where both sides have been divided by one million, so the frequency **f** is now in megahertz (MHz), and **c** has become simply 300.

As the propagation velocity of EM radiation in air is very close to that in a vacuum, this same expression also gives quite accurate results for radiation in air. **So in most cases, to find either the frequency or the wavelength, knowing the other, you simply divide the one you know into 300**. Just remember that the wavelength will be in metres, and the frequency in MHz.

It's very easy to remember this. Just remember that a wavelength of one metre corresponds to 300MHz, and that doubling the frequency halves the wavelength and vice-versa. Similarly dividing the frequency by 10 gives 10 times the wavelength, and so on.

So the wavelength at 1MHz becomes 300 metres, for example, while at 30GHz the wavelength has shrunk to 10mm (1m divided by 30,000/300, or 100).

Don't forget, though, that this rule of thumb relating frequency and wavelength really only applies to EM radiation in free space, a vacuum or air. When EM waves are propagating in a dielectric medium like the polyethylene inside a co-axial cable, their velocity (called the *phase velocity*) slows down, by a factor roughly equal to the square root of the medium's **dielectric constant**. So the wavelength of the radiation in these media will also be shorter, by the same factor.

For example in polyethylene, with a dielectric constant of 2.3, the velocity and wavelength both tend to shrink to about 66% of their free-space values ($1/\sqrt{2.3}$).

Finally, you might like to know the meaning of some of the terms often used to describe different regions of the EM spectrum:

ELF:	**extra low frequencies**
VLF:	**very low frequencies**
LF:	**low frequencies**
MF:	**medium frequencies**
HF:	**high frequencies**
RF:	**radio frequencies**
VHF:	**very high frequencies**
UHF:	**ultra high frequencies**
SHF:	**super high frequencies**
EHF:	**extremely high frequencies**
Microwaves:	**frequencies above about 2GHz**

The significance of these terms should become a little clearer if you refer to the diagram on page 1, which gives an overview of the complete EM spectrum. The table also explains the decimal multipliers used to make it easier to handle frequency values varying over this very wide range.