What is RF?

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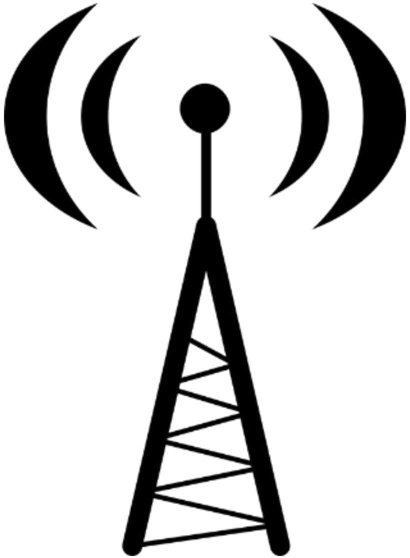
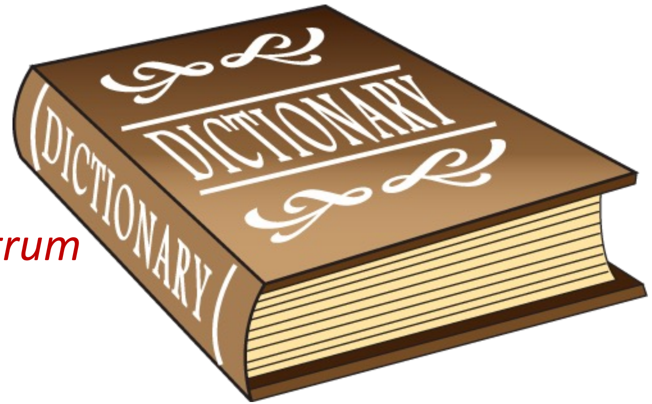


Let’s start with the abbreviation

RF = radio frequency

Definitions

Radio frequency (RF)



- Definition: *That portion of the electromagnetic spectrum from a few kilohertz to just below the frequency of infrared light (~3 kHz to ~300 GHz).*
- Radio frequency also can be defined as a *rate of oscillation within the 3 kHz to 300 GHz range*. More on this later.
- Before too much eyeball glaze factor sets in it might be helpful to talk about frequency, and wavelength, the electromagnetic spectrum, and a few other basics.

Back to basics …

Direct current (DC)

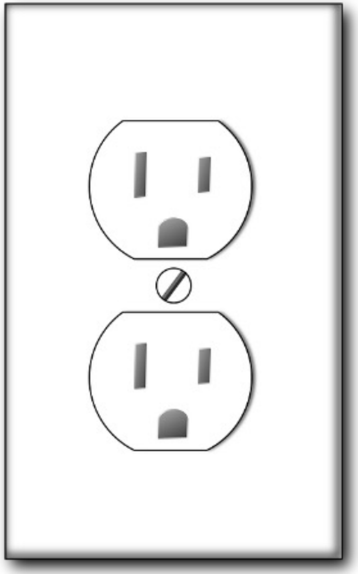
- Direct current, abbreviated DC, is an electric current that is unidirectional, as a result of a voltage source whose output maintains the same polarity. An example is the output of a flashlight battery. DC is not RF, nor is it part of the electromagnetic spectrum.

Back to basics …

Alternating current (AC)

- Alternating current, abbreviated AC, is an electric current that periodically reverses direction and whose instantaneous magnitude varies continuously over time. Examples include super low frequency (SLF) AC from a household electrical outlet and RF signals.
- Yes, RF is a form of AC, but that electrical outlet's AC isn't usually considered a form of RF – even though it is possible to have an RF signal whose frequency is within that range.

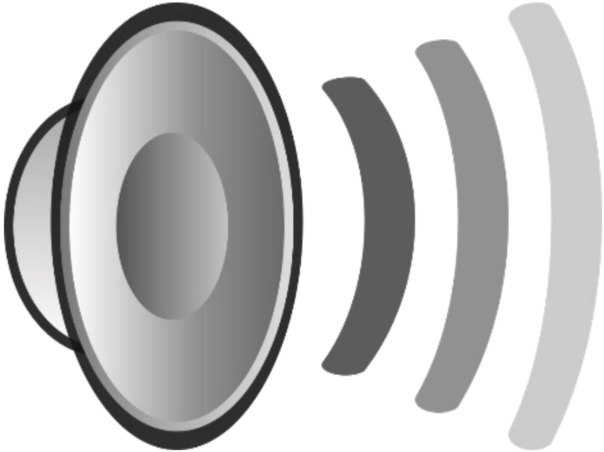
  (*Note: The U.S. and Russia have used SLF signals in the 76 Hz to 82 Hz range for communication with submarines.*)



Back to basics …

What about sound waves?

- In case you were wondering, sound waves are not RF, and they are not part of the electromagnetic spectrum. An RF signal can have the same frequency as a sound wave, though. Most people can hear a 5 kHz audio tone, but no one can hear a 5 kHz RF signal.



What’s frequency?

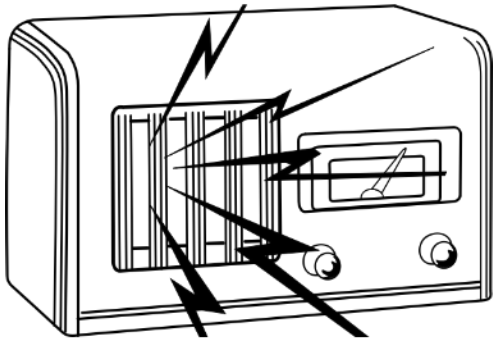
Frequency

- Frequency is the number of times, typically per second, that a repetitive event happens – the previously mentioned rate of oscillation.
- In the case of AC from a North American household electrical outlet, the polarity changes through a complete cycle of values 60 times each second. A sinusoidal AC signal’s polarity changes aren’t instantaneous, but vary continuously (albeit quickly) from one value to another.
- For RF signals, the number of cycles per second can vary from a few thousand times per second (kilohertz) to billions of times per second (gigahertz) and higher!

What’s frequency?

Frequency

- That variation can be measured in terms of parameters such as amplitude and degrees. For example, a full cycle of polarity change comprises 360 degrees, and if that cycle is completed in one second the frequency is said to be one cycle per second or 1 hertz (Hz).
- As noted previously, AC from a North American household electrical outlet has a frequency of 60 cycles per second or 60 Hz.
- A local FM radio station’s transmitted signal might have a frequency of 103,500,000 Hz, or 103.5 megahertz (MHz).



What's frequency?

Frequency is measured in units called hertz:

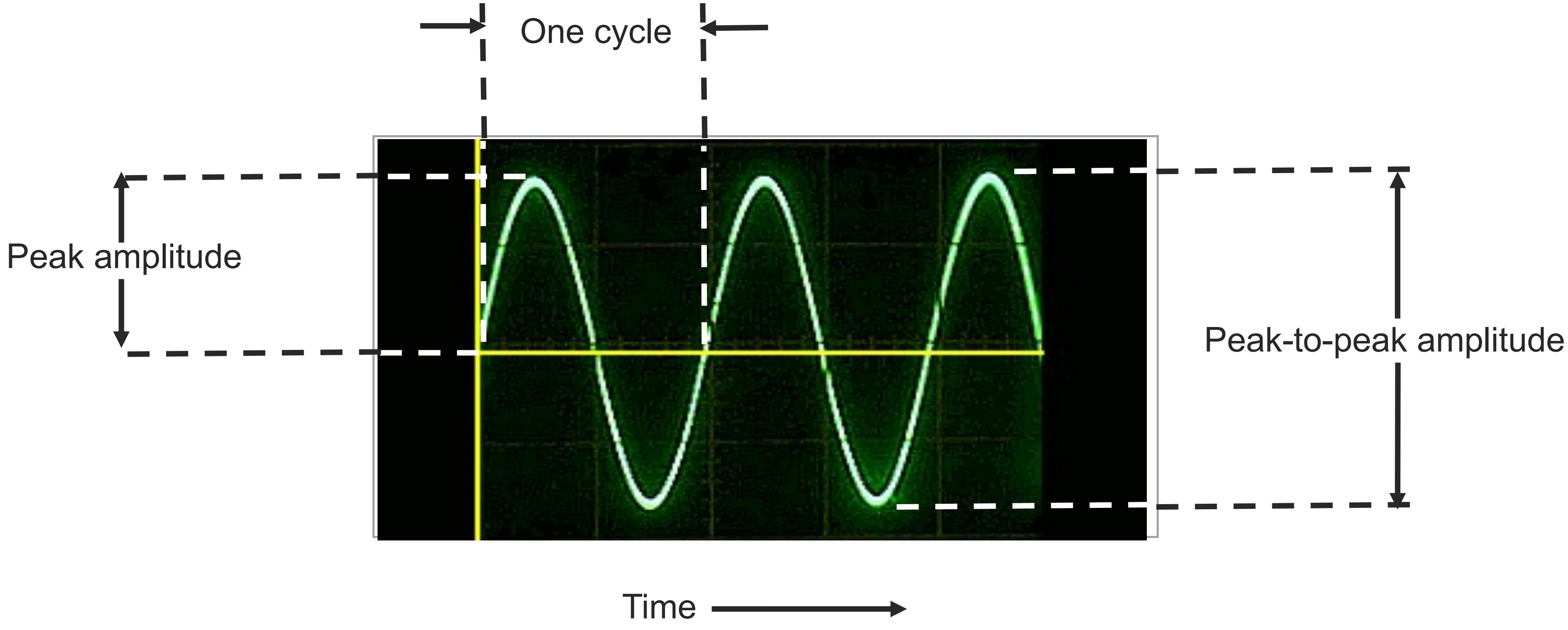
- Cycles per second = hertz (Hz)
  - 1 cycle per second = 1 Hz = 1 hertz (Hz)
  - 1,000 cycles per second = 1,000 Hz = 1 kilohertz (kHz)
  - 1 million cycles per second = 1,000,000 Hz = 1 megahertz (MHz)
  - 1 billion cycles per second = 1,000,000,000 Hz = 1 gigahertz (GHz)
  - 1 trillion cycles per second = 1,000,000,000,000 Hz = 1 terahertz (THz)

An electromagnetic signal can be represented as a sine wave

Sine wave and wavelength

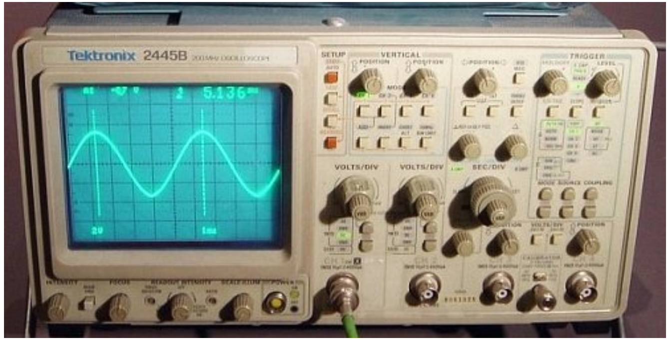
- If one plots a sinusoidal AC waveform on a graph of amplitude in the vertical axis versus time in the horizontal axis, the result is the classic sine wave.
- One way to characterize a sinusoidal AC waveform is by its wavelength, which is a measure of the distance between the same points on adjacent cycles, for instance, from one cycle's peak to an adjacent cycle's peak.
- Another definition of wavelength is the distance that a wave travels through some medium in the period of a single cycle, where period in seconds = 1/frequency in hertz.

Sine wave in the time domain



Time and frequency domains

- An oscilloscope shows a signal in the time domain – amplitude (vertical axis) versus time (horizontal axis).
- A spectrum analyzer displays a signal in the frequency domain – amplitude (vertical axis) versus frequency (horizontal axis).



Sine wave on oscilloscope

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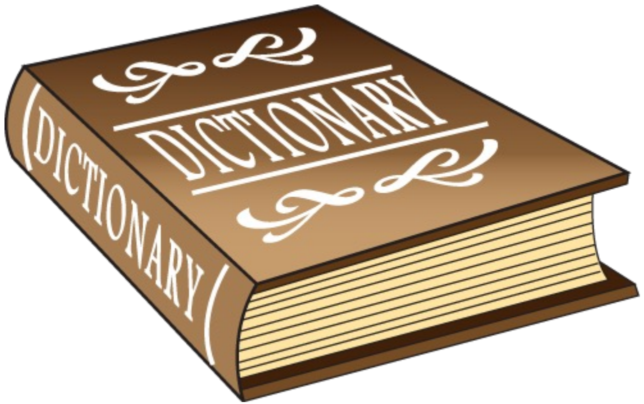
Sine wave on spectrum analyzer

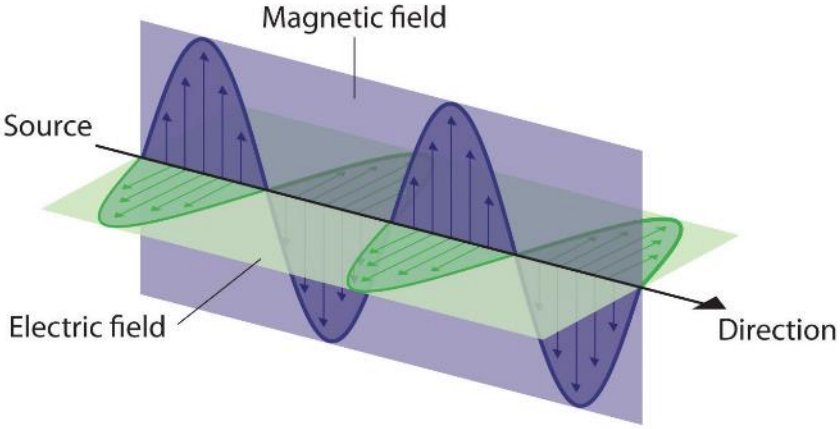
Let’s get back to some definitions



NASA defines the electromagnetic spectrum as “the full range of frequencies, from radio waves to gamma rays…” and Wikipedia says it’s the “range of all possible frequencies of electromagnetic radiation.”

Electromagnetic radiation

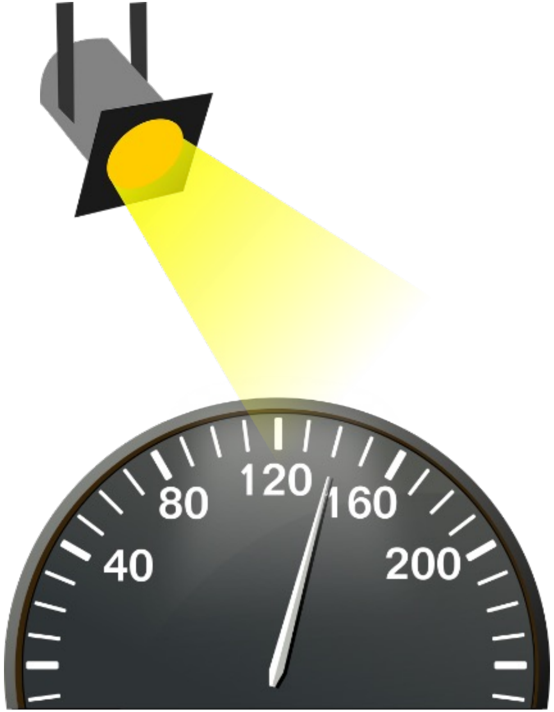
Electromagnetic radiation is a form of energy comprising oscillating electric fields and magnetic fields (the electric and magnetic components are orthogonal, or perpendicular to each other, and also are orthogonal to the direction of propagation), and which exhibits wave-like behavior as it zips along through space at the speed of light.



Speed of light in a vacuum

From the *National Institute of Standards and Technology*[1]:

c_0 = 299,792,458 meters per second



A little number crunching gives us other values:

- 983,571,056.43 feet per second
- 186,282.397 miles per second
- 670,616,629.39 miles per hour

Note 1: http://physics.nist.gov/cgi-bin/cuu/Value?c

A closer look at electromagnetic signals

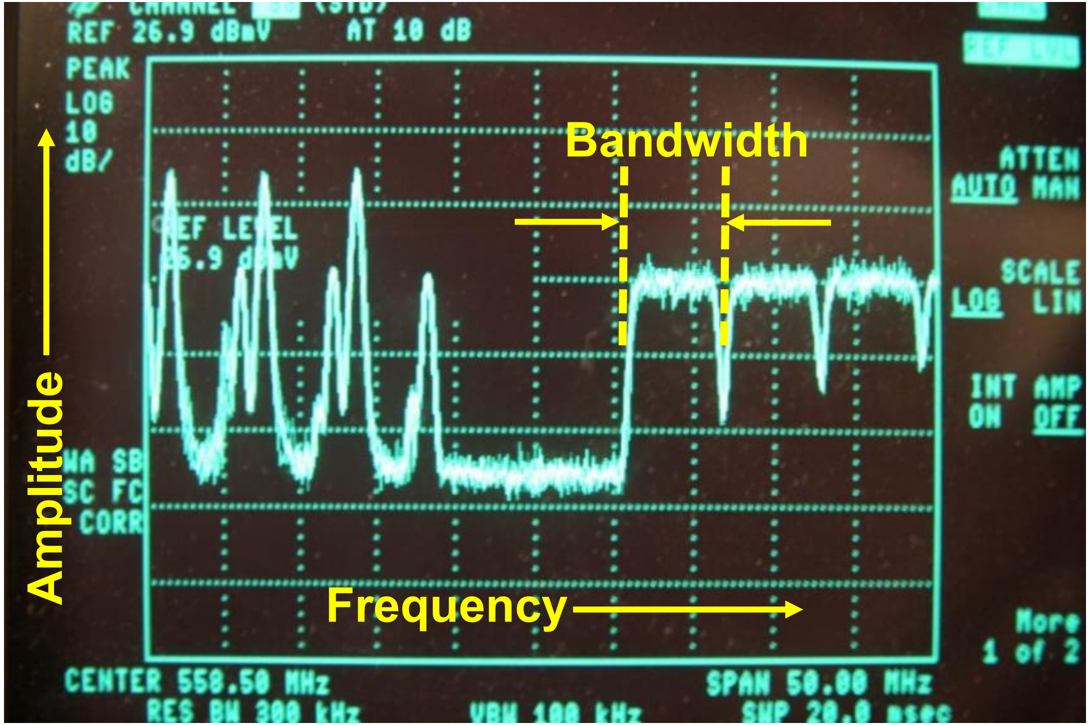
Electromagnetic signals can be visualized as waves, similar to the ripples that occur when one tosses a rock into a pond of water. Recapping some definitions (and adding a new one) …

- Frequency - The number of times (typically per second) that a repetitive event happens; that is, the rate of oscillation of an electromagnetic signal. Frequency is measured in units of hertz, abbreviated Hz, which is the number of cycles or waves per second.
- Wavelength – A measure of the distance between the same points on adjacent cycles, for instance, from one cycle's peak to an adjacent cycle's peak.
- Amplitude – The signal level, or more specifically, the power of an electromagnetic signal.
- Bandwidth – The amount (width) of spectrum, measured in units of Hz, that an electromagnetic signal occupies.

An analogy: frequency, wavelength and amplitude

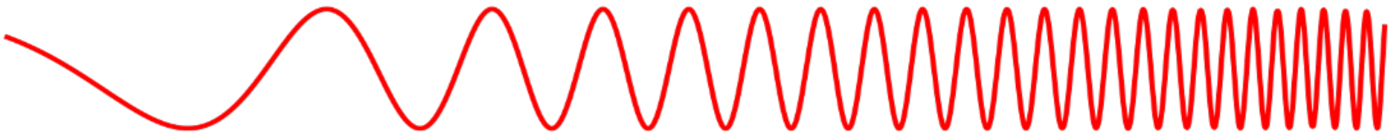
Throw a rock in the water, then count the number of waves per second (frequency) that go by a wooden post sticking out of the water. Next, measure the distance between adjacent peaks or valleys (wavelength). Finally, measure the height of the waves (amplitude).

Spectrum analyzer display of RF signals



Electromagnetic radiation

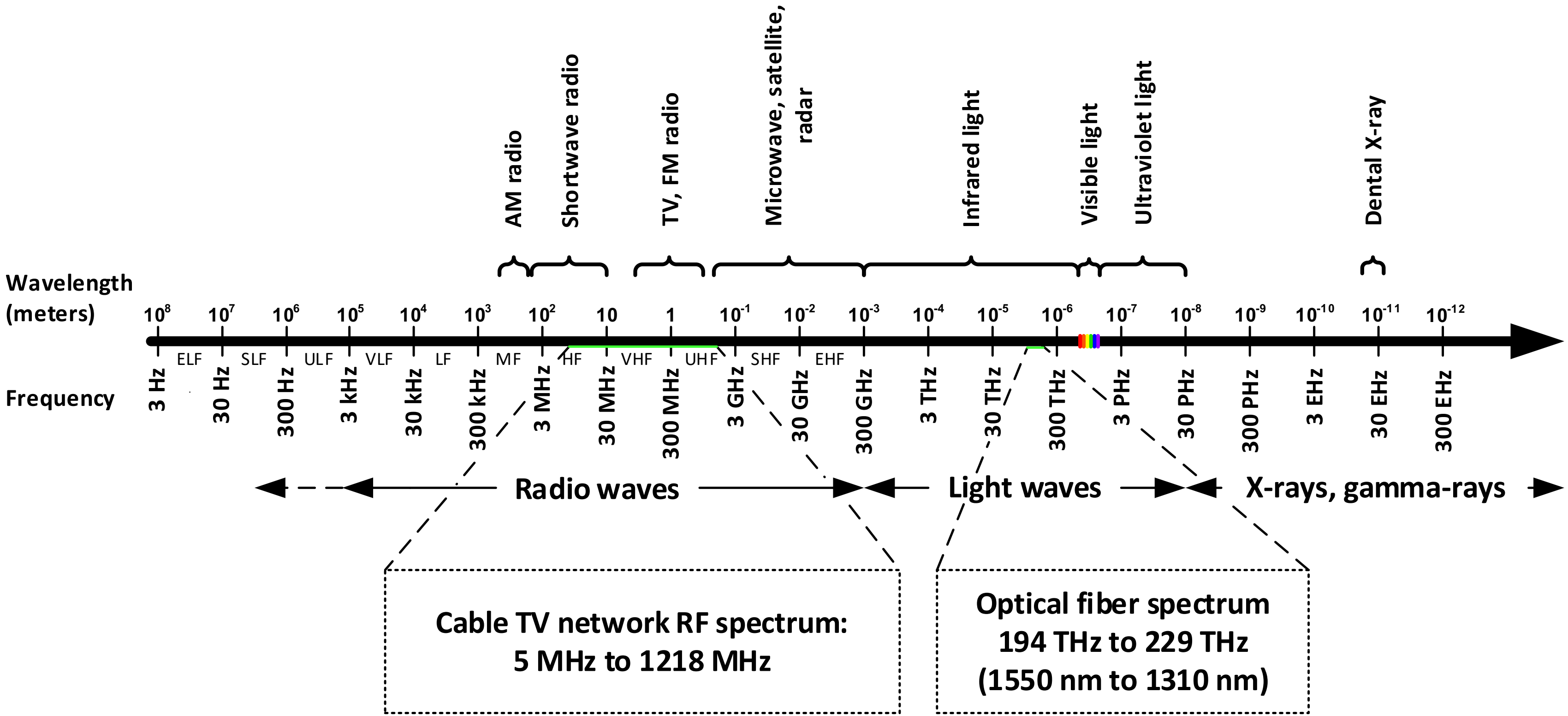
The wave-like behavior allows electromagnetic radiation to be categorized based on wavelength. Going from electromagnetic radiation's longest wavelengths (lowest frequencies) to the shortest wavelengths (highest frequencies), the list looks like this: radio waves, microwaves, infrared light, visible light, ultraviolet light, X-rays, and gamma rays.



Long wavelength = low frequency

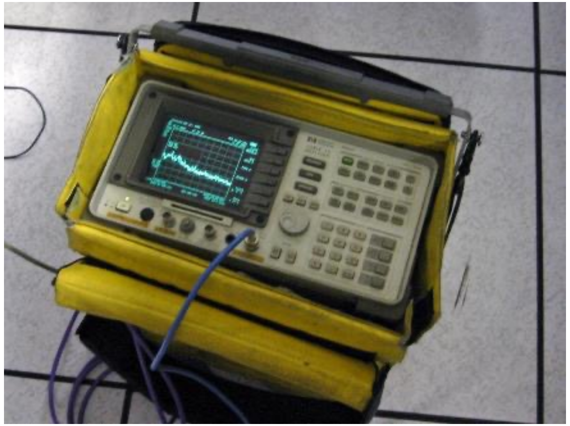
Short wavelength = high frequency

Electromagnetic spectrum



Measuring RF

- Unlike the visible light portion of the electromagnetic spectrum, RF can’t be seen. Its presence and various characteristics such as frequency, wavelength, and amplitude can be detected and measured with specialized test equipment. Examples of that test equipment include power meters, signal level meters, frequency counters, and spectrum analyzers.

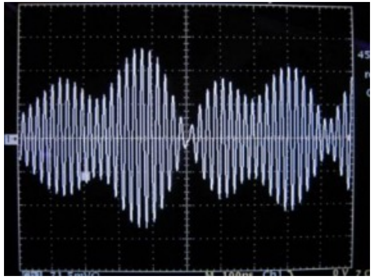


More RF stuff

- RF signals propagate through free space at the speed of light and are made of photons. “Wait a minute,” you say, “I thought photons are what light is made of.” That’s true, because light’s a form of electromagnetic radiation. But so are radio waves, microwaves, infrared, ultraviolet, X-rays, and gamma rays.
  - The energy per photon is low at long wavelength electromagnetic radiation such as RF, and high at short wavelength electromagnetic radiation such as gamma rays.
- From an abstract point of view RF is really, really low frequency light, or light is really, really high frequency RF.
- Making things a bit more interesting: RF energy coupled to a conductor produces electric current (think electrons) that travels on or near the surface of the conductor, a phenomenon known as skin effect.
- Our cable networks use radio frequencies from 5 MHz to >1,000 MHz (1 GHz)
- RF signals in conductors such as coaxial cable are high frequency alternating current

Wrapping up

- An RF signal can convey information if one or more characteristics of that signal are varied: amplitude, frequency, or phase. That's called modulation, something we'll talk about next time.
- We can't see or hear RF, but we can see and hear pictures and sound that it carries. RF can be transmitted via a conductor such as coaxial cable, and it can be transmitted over-the-air or through the vacuum of space. It can be used to cook food or heat a cup of coffee. Pretty cool, this thing we call RF: "It's a bit like magic."



64-QAM signal in the time domain

Q&A