A Rocky Mountain Chapter White Paper: “What is RF?”

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The following is adapted from an article I wrote about understanding the fundamentals of RF, which originally appeared in the December 2011 issue of *Communications Technology*.

The cable industry has since the very first systems in the late 1940s embraced and been based upon RF technology. These days we’ve also embraced the digital world – and a subset of digital technology called Internet Protocol or IP – but RF is still needed in most cable networks to transport digital data to and from devices in our subscribers’ homes. The answer to the question in the title is far more complicated than it initially seems.

A good place to start is with an explanation of the letters R and F, which together are an abbreviation for radio frequency. But what’s radio frequency? Here’s one very high-level perspective: It’s that portion of the electromagnetic spectrum from a few kilohertz (kHz) to about 300 gigahertz (GHz). The Federal Communications Commission, in §15.3(u) of Title 47 of the Code of Federal Regulations, Part 15, includes this definition: “Radio frequency (RF) energy. Electromagnetic energy at any frequency in the radio spectrum between 9 kHz and 3,000,000 MHz.” The radio frequency part of the electromagnetic spectrum is often broken down into two chunks: radio waves and microwaves. Some references define radio waves as those with a frequency starting at about 3 kHz (the beginning of the very low frequency, or VLF band) and extending to 300 megahertz (MHz) – the beginning of the ultra high frequency, or UHF band – with microwaves covering roughly 300 MHz to 300 GHz. The latter is the beginning of the far infrared (FIR) portion of the electromagnetic spectrum. Other references have microwaves starting at frequencies higher than 300 MHz. Indeed, many RF engineers consider the microwave spectrum to be above about 1000 MHz (1 GHz).

Radio frequency also can be defined as a rate of oscillation within the 3 kHz to 300 GHz range. More on this in a moment. Before too much eyeball glaze factor sets in, it might be helpful to talk about frequency, and wavelength, and the electromagnetic spectrum, and…

See, I said this is more complicated than it initially seems. So back to the basics it is.

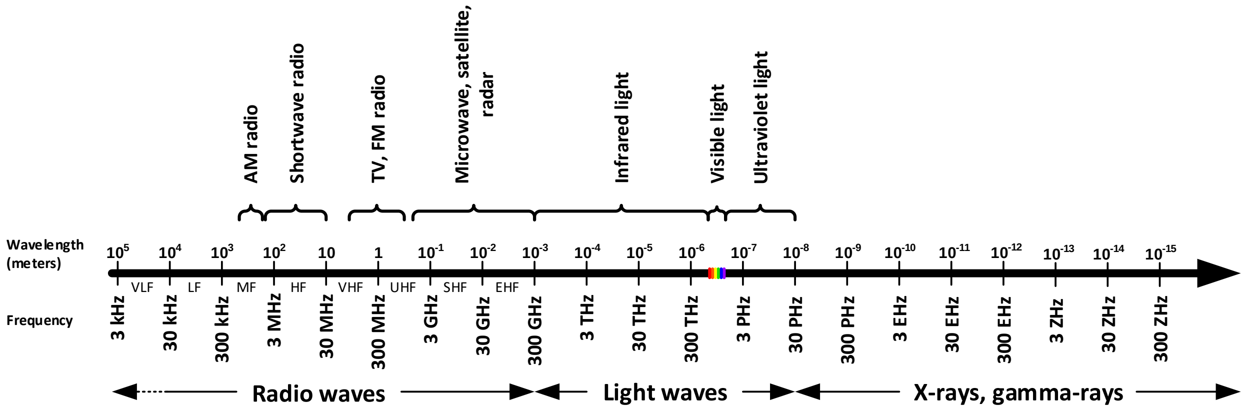
Direct current, abbreviated DC, is an electrical current that is unidirectional, as a result of a voltage source whose output maintains the same polarity. An example is the output of a flashlight battery. DC is not RF, nor is it part of the electromagnetic spectrum. Alternating current, abbreviated AC, is an electrical current that periodically reverses or alternates in direction, as a result of a voltage source whose output periodically reverses or alternates in polarity. 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’s possible to have an RF signal whose frequency is within that range. 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, and most people can hear a 5 kHz audio tone. No one can hear a 5 kHz RF signal.

I've been tossing the word frequency around, but what's frequency? It's 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. 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 one hertz (Hz). As noted previously, AC from a 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 MHz.

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 = 1/frequency in hertz.

Wavelength and frequency are related by the formula $\upsilon = f * \lambda$ where υ is the speed of the wave (speed of light in a vacuum or somewhat slower in a medium such as coaxial cable), f is frequency, and λ is wavelength. The following variations of the formula are used to calculate the relationship between frequency in hertz (f_{Hz}) and wavelength in meters (λ_{meters}) or feet (λ_{feet}) in a vacuum: 299,792,458 meters per second = $f_{Hz} * \lambda_{meters}$ or 983,571,056.43 feet per second = $f_{Hz} * \lambda_{feet}$.

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 is a form of energy comprising oscillating electric 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. The wave-like behavior allows electromagnetic radiation to be categorized based on wavelength. Going from electromagnetic radiation's longest wavelengths and lowest frequencies to the shortest wavelengths and highest frequencies, the list looks like this: radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays. See the following figure.



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 signal level meters and spectrum analyzers.

RF energy propagates through free space at the speed of light and is 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 electrical current (think electrons) that travels on or near the surface of the conductor, a phenomenon known as skin effect.

An RF signal can convey information if one or more characteristics of that signal are varied: amplitude, frequency, or phase. 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. As some of my data colleagues say, "it's like magic."