An Explanation of

# The citizen's guide to the airwaves


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*"The wireless spectrum belongs to the public, and thus should be made to serve the public."*
Senator Ernest Hollings, former Chairman, Senate Commerce Committee

## Spectrum Basics[3]

To understand spectrum policy, it is useful to understand some basic concepts, including fidelity, waves, frequencies, signals, bandwidth, propagation characteristics, spectrum flexibility, and the difference between spectrum allocation and licensing. Readers may want to skip this section now and refer back to it only if additional background information is desired.

### Fidelity

A slice of spectrum contains a band of frequencies. The wider the band, the more information-carrying capacity it has (it has more "**bandwidth**"). Bandwidth is generally counted in thousands, millions, or billions of hertz.

- **kilohertz** (1,000 Hertz) is written as kHz.
- **megahertz** (1 million Hertz) is written as MHz.
- **gigahertz** (1 billion Hertz) is written as GHz.

Note that convention dictates that kilohertz is abbreviated with a small k but megahertz and gigahertz with a capital M and G respectively.

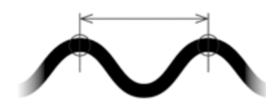
The greater the bandwidth of a communication, the greater its fidelity can be. **Fidelity** means the correspondence between the information at the sending and receiving end of a communication. Today, most wireless communication is low fidelity audio. In the future, high fidelity video could require 5,000 times or more bandwidth.

- 1 kHz — Text (e.g., closed captioned text)
- 10 kHz — Voice (e.g., telephone quality)
- 100 kHz — Music (e.g., CD quality)
- 1,000 kHz — Standard Definition TV (e.g., VCR quality)
- 5,000 kHz — High Definition TV (e.g., movie theater quality)
- 50,000 kHz — Super High Definition TV (e.g., glossy magazine quality)
- 100,000 kHz — 3D Super High Definition TV (e.g., glossy magazine quality 3D)

### Waves, Frequencies, and Information

Electrical energy travels from place to place in one of two ways: it either flows through a wire or wirelessly via spectrum (popularly known as "the airwaves"). When electrical energy varies over time so that it conveys information, it is called a **signal**. Signals can either be analog or digital. **Analog signals** vary gradually between two electrical values; **digital signals** vary instantaneously.

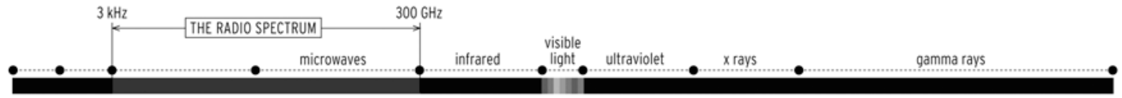
Electrical energy travels wirelessly in the form of waves, the basic information unit of spectrum. A **wavelength** is the distance between the recurring peaks of a wave. The number of times a signal goes through a complete up and down cycle in one second is the signal's **frequency** (measured in **hertz** and abbreviated Hz). For example, a 1 gigahertz signal goes through 1 billion cycles a second.



The electromagnetic spectrum has long wavelengths (low frequency) at one end and short wavelengths (high frequency) at the other end. The length of a wavelength affects a signal's **propagation characteristics**, including its ability to pass through objects.

As a signal passes through objects, it is gradually weakened. Although every object the signal encounters weakens it, some weaken it more than others. The air we breathe, for example, weakens it less than the drops of water in a rainstorm, which in turn weakens it less than a brick wall. This weakening is called **absorption**, and absorption tends to vary by wavelength. Long wavelengths (low frequencies) are less likely to be absorbed by dense objects such as clouds, trees, cars, and homes. This is a key reason that low frequency spectrum, such as the bands assigned to broadcasters, are most valuable.

Spectrum is divided into general bands based on wavelength. The portion of the spectrum valued most highly for communication purposes is the **radio spec-**

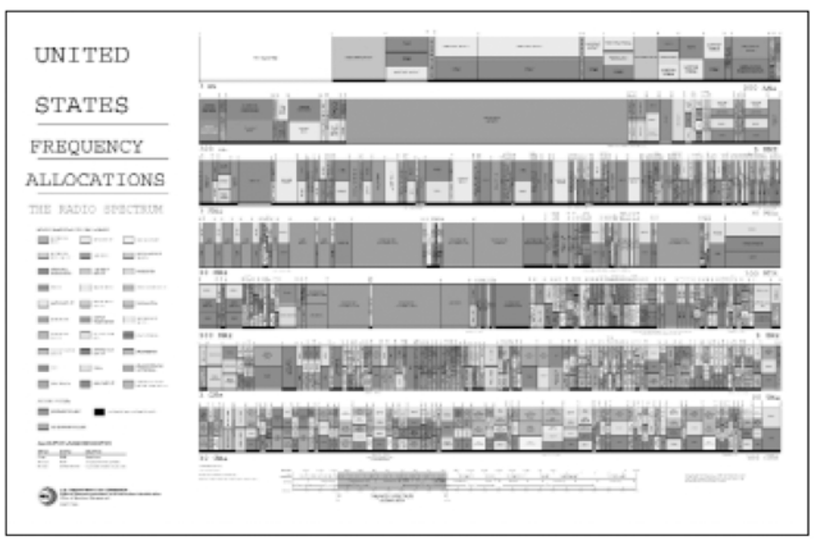



ELECTROMAGNETIC SPECTRUM

**trum**, located from 3 kHz to 300 GHz. Other well-known bands are the **infrared**, **visible light**, **ultraviolet**, **x-ray**, and **gamma ray**. It is illegal to use certain higher bands, such as x-rays, for communication because repeated exposure to x-rays harms human bodies.

## Spectrum Policy

According to United States law, the public owns the spectrum; hence the well-known phrase "the public airwaves." The government manages the spectrum on behalf of the public by **allocating** spectrum for different uses. For example, it allocates frequencies between 174 and 216 MHz for TV broadcasting services (channels 7 to 13) and frequencies between 824 and 849 MHz for mobile telephone services. The United States Department of Commerce graphically depicts these allocations in a chart titled *United States Frequency Allocations*.[4] The chart divides the radio spectrum into more than 500 frequency bands, each of which may be shared by multiple types of allocation. Some users may be designated as **primary** and others as **secondary**. Secondary users may not interfere with primary users.




After the government decides what types of services are allowed in a given band of frequencies, it may **license** use of that band to specific entities such as broadcast companies, mobile telephone companies, police departments, and hospitals.

Allowing a licensee to provide additional services with a license is called **spectrum flexibility**. For example, a licensee restricted to providing mobile telephone service to taxi cab drivers wins spectrum flexibility when it is allowed to provide the service to all Americans, not just taxi cab drivers. Permanent, comprehensive spectrum flexibility is equivalent to **spectrum ownership**, which is illegal under United States law.[5]

The allocation and assignment of radio frequencies is limited by **interference**. Radio interference occurs when radio frequency energy other than a desired signal is present at the receiver. **Harmful interference** occurs when a desired and undesired signal both arrive at a receiver and conflict, such that the receiver can extract less information from the desired signal. It is important to understand that the level of acceptable interference is overwhelmingly a function of the equipment used, since simultaneous transmissions on the same frequency do not literally cancel each other out. High quality receivers can better discriminate between competing signals, thus mitigating the effects of interference. Disputes about interference, like lawsuits about land boundaries, are essentially disputes about who gets access to valuable property. In this case, the property is the information carrying capacity of spectrum.

# Everyday Devices

Today, wireless devices are almost everywhere. It's hard to find a middle-class home in America without at least a dozen wireless devices (see "Licensed and Unlicensed Spectrum").

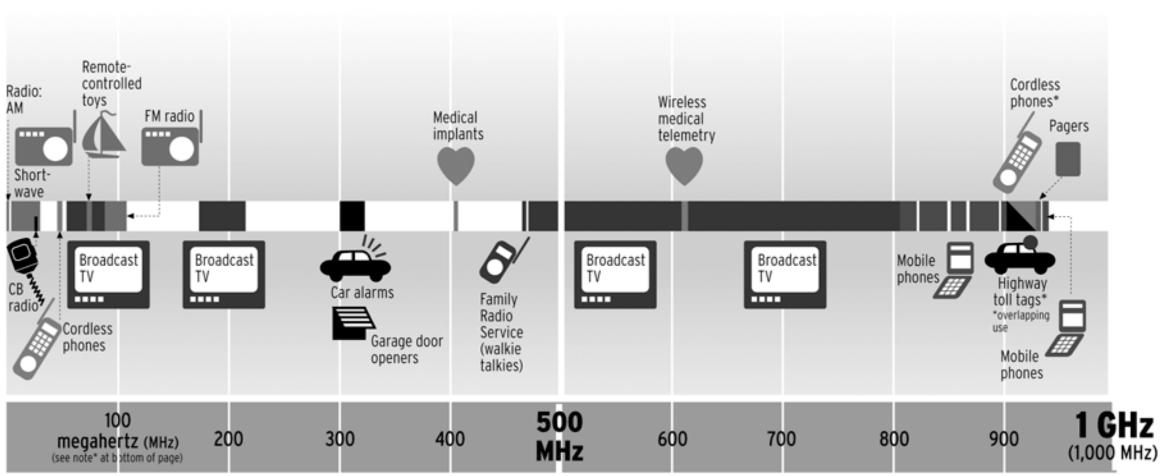
Despite the pervasiveness of everyday devices, they use only a small portion of the spectrum—less than a third of the most valuable spectrum under 3 GHz and less than 2% of the spectrum under 300 GHz.[6] The vast majority of spectrum is used by government or by industry in applications the consumer rarely if ever sees and in devices that consumers cannot purchase (see "Retail and Industrial Spectrum" and "Who Manages Access to the Airwaves?").

An **everyday device** is defined as one that could easily be purchased by a consumer at a mass market retail store such as Sears, Target, Best Buy, Circuit City, or Wal-Mart.

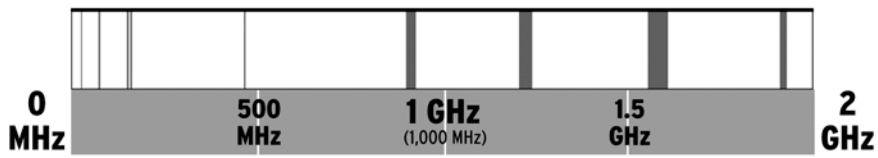
The line between everyday and other uses is not always easy to draw. We omitted wireless devices that may now be pervasive but which consumers cannot purchase at retail stores. These include the radar guns police use to catch speeding drivers; the traffic light cameras that catch drivers who don't stop at red lights; the automatic door openers used at the entrance of some retail stores; radar detectors at the entrances of airports and office buildings; and the handheld devices used by FedEx and UPS to digitize signatures and complete orders when delivering packages to your door.

There are also many everyday wireless devices that are not in the radio band (0-300 GHz). These include the infrared remote controls that today come with most consumer electronics products. Infrared remote controls require a short line-of-sight link to consumer electronics equipment. In the future, radio frequency remotes using Bluetooth and Wi-Fi (both at the 2.4 GHz band) are expected to replace many of the early infrared remotes.

In putting together our list of spectrum bands with everyday devices, we have overlooked the distinction between primary and secondary services. Many spectrum bands are allocated to multiple services. If there is a conflict with a secondary service, the primary service gets priority use of a band. Some everyday devices, such as broadcast television and mobile telephone service, are primary devices.




FREQUENCY ASSIGNMENTS USED BY EVERYDAY DEVICES




# Citizen's Access Spectrum

Citizen access spectrum includes unlicensed, amateur, and personal radio services. Citizens can use citizen access spectrum without paying a fee or seeking the approval of a licensee. Whereas the ability to use other frequency bands is based on *exclusive licensing*, access to these bands is *open* and *shared*. These "citizen access" bands are either shared by consumer devices operating on an unlicensed basis (e.g., the unlicensed band at 2.4 GHz is shared by tens of millions of cordless phones, microwave ovens, wireless local area networks, such as Wi-Fi, and other devices), or shared by individual citizens (e.g., amateur radio operators) who qualify for an individual license.

The citizen access bar has two major differences with the everyday devices bar. First, it excludes services such as broadcast radio, broadcast TV, medical telemetry, and mobile telephone service that require some type of payment for spectrum use. Mobile telephone and medical telemetry service requires consumers to pay with money. Broadcast radio and TV require consumers to pay with time spent watching ads (the ad watching pays for the programming).

Second, it includes services that are not everyday uses because they are not readily available at retail stores, even though they can be used without a government license or fee to a private entity. This includes equipment to use some of the amateur bands, which requires additional effort on the part of the consumer to locate and use.

In putting together our list of spectrum bands with citizen's access, we have included bands that are not exclusively or even primarily for citizen's access. This tends to overstate the amount of spectrum allocated for citizen's access. For example, the Air Force uses the same spectrum band as garage door openers. The two applications can co-exist because garage door openers are low-power devices and are designed not to activate when an Air Force plane flies overhead.

# Valuing Spectrum: Propagation Characteristics

In real estate, there is a famous saying that the value of a piece of real estate is determined by "location, location, location." With regards to spectrum, the equivalent phrase would be "frequency, frequency, frequency." Different frequencies have different propagation characteristics that have a huge impact on their market value. As a rule of thumb, the economic value of spectrum increases with its permeability (its ability to penetrate objects). This is reflected in the value chart, which shows that lower frequencies (longer wavelengths) are more valuable. The 1% of frequencies below 3 GHz are worth more than the 99% of frequencies from 3 GHz to 300 GHz.

We have divided the spectrum up into four zones: the permeable zone, the semi-permeable zone, the long line-of-sight zone, and the short line-of-site zone. As a rule of thumb, the permeability of a radio signal decreases as the frequency increases. [7]

FM radio (at 88 MHz) is an example of an application in the permeable zone. You can use your FM radio almost anywhere in your house without worrying that walls will block signal reception. A major attraction of modern mobile phones (which use bands between 800 MHz and 2 GHz) is their promise of anywhere, anytime accessibility.

Satellite radio service (at 2.320 GHz) is an example of an application in the semi-permeable zone. When you drive through an urban area with large buildings, your car's satellite radio may lose its signal but not its FM radio signal. Similarly, your mobile telephone (which uses frequencies as high as 1.99 GHz, on the edge of the semi-permeable zone) may be unusable while your FM radio continues to work perfectly.

Satellite TV service (at 12.2 GHz) is an example of an application in the long line-of-sight zone. The TV signal can go 22,000 miles between the satellite and your receiver as long as nothing is in-between. A tree or even a heavy rainstorm will block the signal.

Presently, we know of no widely used consumer devices in the short line-of-sight radio frequency zone. But consumer remote controls thrive in an environment that only allows short line-of-sight optical links. Many remote controls use infrared frequencies, which are located directly above the short line-of-sight frequencies. A standard called IrDA (which stands for Infrared Data Association) uses infrared signals to connect computer equipment such as personal digital assistants, keyboards, mice, and printers over distances less than 3 feet. The short communication distance and difficulty penetrating walls is considered a plus because it enhances security and allows many computer devices in the same room to reuse the same frequency.

In reality, we have greatly oversimplified the ways in which propagation characteristics vary over frequency. For example, antenna size increases with lower frequencies. At frequencies below 50 MHz, antenna size (such as your large AM radio antenna) can become an inconvenience.[8]

At frequencies below 30 MHz, signals bounce off the ionosphere, thus allowing terrestrial signals to transmit thousands of miles. The U.S. government broadcasting service, Voice of America, takes advantage of these low frequencies to transmit thousands of miles into countries with unfriendly regimes.

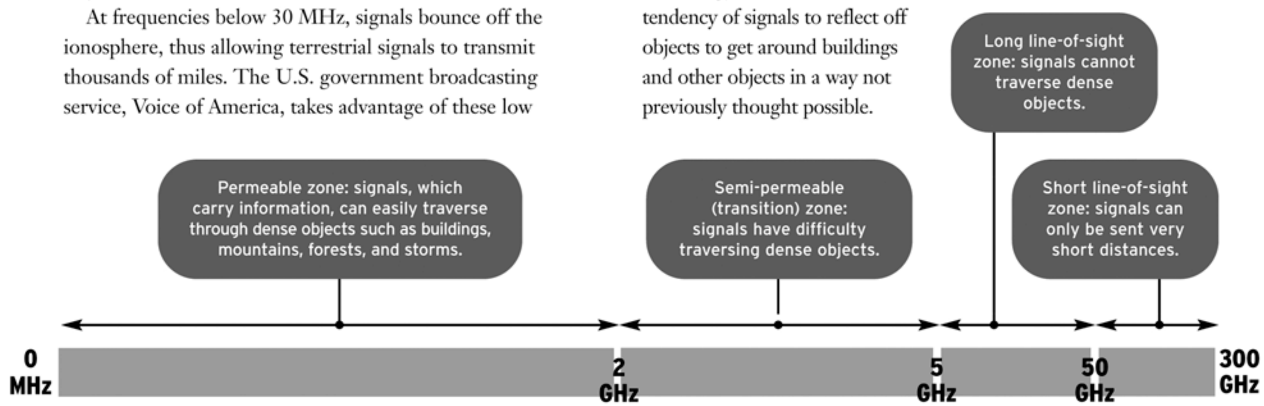
At frequencies above 30 MHz, signals need a higher tower to transmit long distances terrestrially. These permeable signals may be able to penetrate foliage, weather, and buildings, but they cannot penetrate the solid earth. Since the surface of the earth is curved, the distance a signal can travel is a direct function of the height of the tower from which it is transmitted.

There are also some oddball frequencies. Atmospheric oxygen, for example, absorbs signals transmitted at around 60 GHz.

At frequencies above 300 GHz other propagation characteristics come to the fore. Too much human exposure to ultraviolet rays can cause skin cancer (this is why doctors recommend modest exposure to harsh sun). And even relatively short exposure to x-rays can cause cancer and destruction of animal tissue.

Even below 300 GHz, high power signals can heat water (think of a microwave oven heating meat), which is a reason that high frequencies must operate either at lower power levels or with transmitters reasonably distant from humans.[9]

Many weaknesses in propagation characteristics can be addressed via technology. For example, signals attenuate rapidly with distance from the transmitter. The rate at which signals attenuate increases with a signal's frequency. But this can be compensated for by increasing the power levels at which signals are transmitted.[10] Similarly, new smart receivers and transmitters can make much more efficient use of spectrum than dumb equipment. A new smart technology called BLAST uses the tendency of signals to reflect off objects to get around buildings and other objects in a way not previously thought possible.




PROPAGATION CHARACTERISTICS