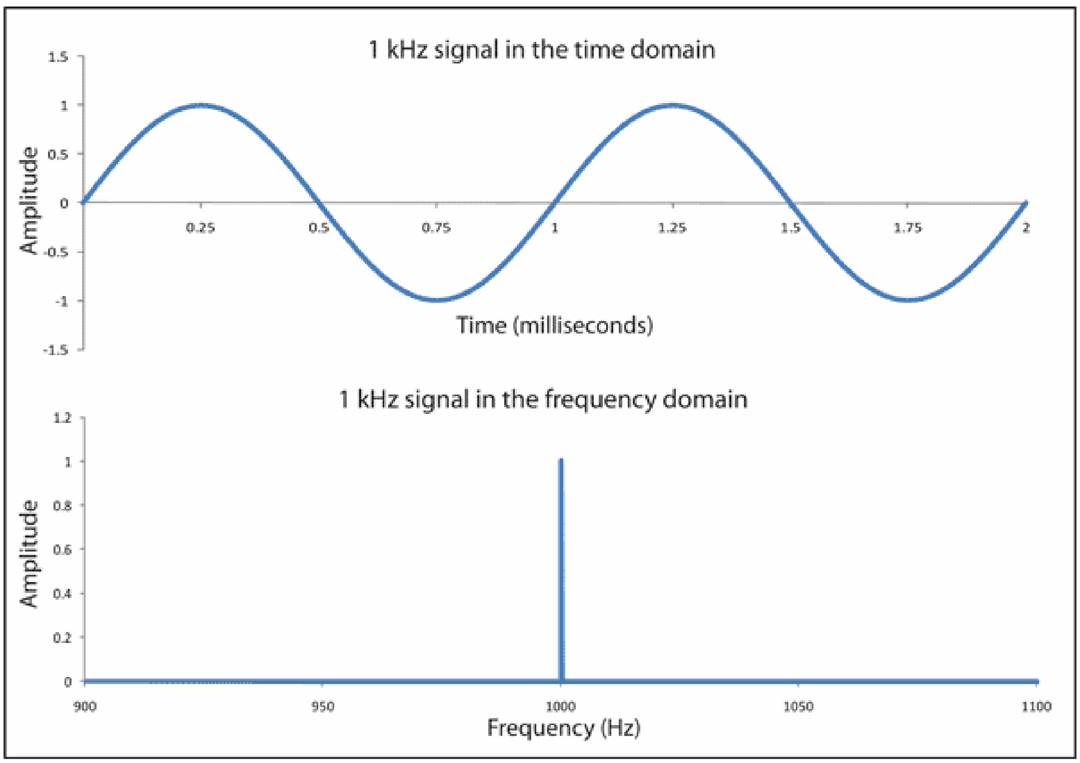
Brass Tacks

An in-depth look at a radio-related topic

Bandwidth

Every so often, the subject of *bandwidth* seems to come up, and judging by the way most hams dismiss its significance, it seems to me that the topic deserves a little mention. Essentially, bandwidth is the ***difference between two frequencies*** that surround a spectrum of concern. A *spectrum* is a (continuous or non-continuous) range of frequencies, for the purposes of this discussion.

Furthermore, to discuss this topic a little more intelligently, it might be better to refer to spectrum and bandwidth in the *frequency domain*. When we visualize sine waves, we tend to think of a graph that shows the amplitude of the wave, as it rises and falls with time, in what we call the *time domain*. The following graphs illustrate both, representing the same signal:



The translation from the time domain to the frequency domain is displayed easily by a *spectrum analyzer*, or mathematically by a *Fourier Transform*, which we won't get into here. As you can see, because a simple sine wave has only a single frequency, it shows up on the analyzer as occupying a single spot, and therefore its bandwidth is

higher frequency – lower frequency = 0 Hz

This simple sine wave cannot convey much information, except that a) it does or doesn't exist at that frequency, and b) what its amplitude is. And this very point alone can be the beginning of some amount of misunderstanding of the concept of bandwidth.

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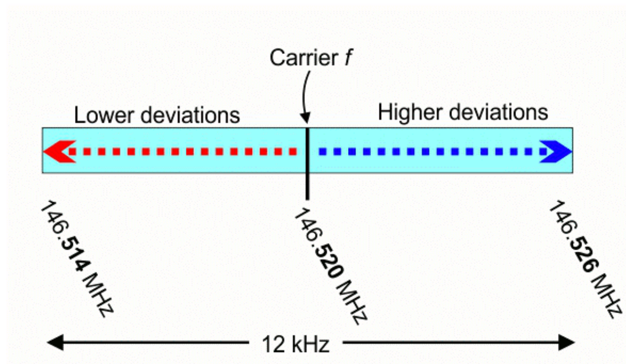
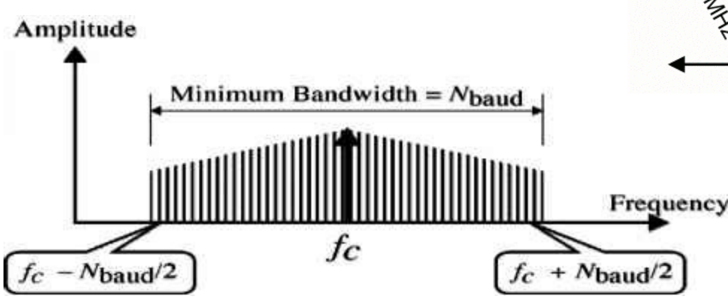
Modulated signal bandwidth

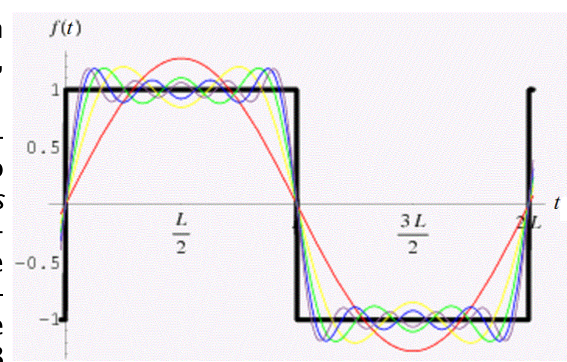
In FM (frequency modulation), the bandwidth is defined by the *deviation*, which relates directly to the *amplitude* (strength) of the modulating signal. In AM (amplitude modulation), the bandwidth is defined by the *modulation*, which relates to the *pitch* (frequency) of the modulating signal (voice or music, for example). It stands to reason that not much information can be conveyed by zero bandwidth, because it takes one or more frequencies to communicate, over and above the carrier signal. The modulated signal that requires perhaps the smallest bandwidth, CW (continuous wave, for transmitting Morse code), is achieved by an on-and-off signal, but still requires around 150 Hz.





ASK signal bandwidth

In digital modes such as ASK (amplitude shift keying) and FSK (frequency shift keying), the bandwidth is defined by *bitrate*. Therefore, the higher the bitrate, the more bandwidth is required to transmit digital information.



A square wave, which defines a string of bits in an ASK signal, in fact, takes up an infinite bandwidth, as seen by the Fourier Series for a square wave.

So, digital signals require a huge amount of bandwidth to preserve the square wave, but our radio equipment will filter out much of the *harmonics* that exceed a specific amplitude threshold. Furthermore, our transmissions can legally be made outside the amateur bands, so long as they're under a specific amplitude level, depending on the frequency. For example, say I'm transmitting SSB on 14.252 MHz, and my PEP (peak envelope power) is 80 watts at the output of my transceiver. It's possible for my transmission to produce a third harmonic at 14.252 MHz x 3 = 42.756 MHz, which is outside the amateur radio service bands. If the harmonic is less than –43 dB of the PEP (80 watts –43 dB = 80 watts ÷ 20,000 = 4 mW), then my transmitted harmonic is legal, according to the rules, even though it's outside the amateur range.

So, when a sine wave is modified in any way, except by amplitude, its bandwidth also changes. The conclusion is that *transmitted information takes up bandwidth*.

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Repeater bandwidth

In the US, most analog FM repeaters accept and transmit signals that are restricted to specific, set bandwidths. 2-meter repeaters are generally set to one of two band-widths, which are often referred to as *Wide* and *Narrow*. Their nominal values are typically 15 kHz and 6 kHz, re-spectively, for transmit, and 28 kHz and 22 kHz, respec-tively, for receive. In Utah, a Wide transmission is defined as ±5 kHz deviation, resulting in 15 kHz to 18 kHz band-width, and a Narrow transmission is defined as ±2.5 kHz deviation, resulting in 12 kHz to 15 kHz bandwidth.

Because most amateur radio 2-meter and 70-cm repeaters in the US use Wide bandwidth for analog FM, your amateur radio should also be set for Wide. This corresponds to the "25 kHz" or "Wide" setting on your handheld and mobile radios. The "12.5 kHz" setting, therefore, corre-sponds to the "Narrow" setting in the same radios. There are some analog repeater owners across the US who are converting their repeaters to Narrow band, but in Utah, they are all Wide band. Digital repeaters ("digipeaters") typically use Narrow bandwidth (12.5 kHz) for some modes, such as DMR or D-STAR.

At any rate, if you attempt to transmit an analog FM signal with a bandwidth that's different from the receiver bandwidth of the repeater or other station, your demodulated signal will like-ly be heard as a distorted or garbled sound, resembling that of Charlie Brown's teacher or Donald Duck. Furthermore, if you attempt to transmit a Narrow analog signal to a receiver set to accept a Wide FM analog signal, your audio will likely be heard at about ¼ the normal audio level or lower. So, when you hear somebody who's able to hold the repeater, but speaking at a very low audio level, he might simply have his bandwidth setting on Narrow by mistake.

Antenna bandwidth

The bandwidth of an antenna is the frequency range within which it can effectively receive or transmit a signal. Typically, we consider "effective" to mean the range of frequencies for which the antenna presents an SWR of 2.0:1 or lower, known as the *SWR bandwidth*. If the antenna SWR is too high for the desired frequency range, we often use a tuner on HF, or a passive matching (gamma match, beta match, delta match, hairpin match, etc.) system on VHF to low-er the SWR, and reduce the loss due to feed line attenuation. In either case, the SWR bandwidth is determined by the entire *antenna system* (antenna, tuner / match, feed line, connectors, etc.) within the target frequency range. Furthermore, the antenna system can include objects that it *couples* with, such as metal gutters, swing sets, and anything nearby that can conduct electrical energy, thereby also affecting its bandwidth.

There are material and other characteristics that can affect antenna bandwidth. Typically, the thinner the active elements (the conductive parts that actually emit the signal), the lower the bandwidth. Many find themselves having to choose between copper, aluminum, galvanized steel, and stainless steel for antenna element material, and the two metals will differ more in *velocity factor* than they will in bandwidth.

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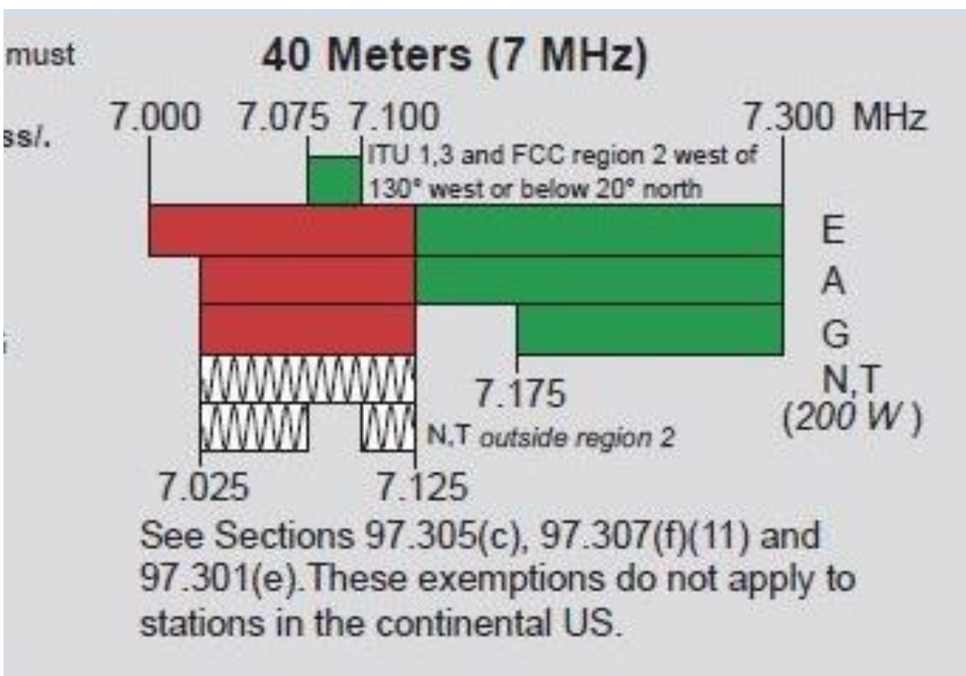
Allocation bandwidth

The FCC has defined bands of frequencies for use by operators holding each license class and operation mode. We say that these bands have been *allocated* according to the operating privileges and modes defined by each license class. In a sense, each segment of continuous frequencies constitutes a sub-band, and the difference between the highest and lowest frequency of each sub-band defines its bandwidth. But when discussing the entire bandwidth of a nominal band, we often refer to the entire range, which is the difference between the highest and lowest frequency in the entire band, and therefore includes all the sub-bands.

For example, amateurs have privileges in the frequency range surrounding 7.200 MHz, whose wavelength is approximately 300 / 7.2 = 41.6 meters. The rounded number "40" is a *nominal* value (meaning *by name only*), so although none of the wavelengths within the amateur 40 Meter band are actually 40 meters (300 / 40 = 7.5 MHz), we simply refer to the band by the name *40 Meters*.



Within the 40 Meter band are sub-bands that are defined by license privilege and mode. The frequency range from 7.175 MHz to 7.300 MHz, for example, is allocated for operation only for *phone* (voice), *image* (analog photos and video), and *CW* (Morse code) operation by those holding a General class or higher license. Some sub-bands are further restricted per location. For example, amateurs operating in the segment from 7.075 MHz to 7.100 MHz are permitted if they transmit from ITU Region 1, Region 3, or Region 2 west of 130˚ W longitude or south of 20˚ N latitude. For us Americans, that means only if we're in Hawaii or Alaska.

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Transceiver bandwidth

It probably goes without saying, that you should acquire a transceiver that's capable of both receiving and transmitting your desired bands. Many hams purchase an "HF" rig that can transmit not only HF signals, but 6 Meters as well. Some go as far as purchasing what's known as a *shack-in-a-box*, or a transceiver that can transmit at least HF, 6 Meters, 2 Meters, and 70 cm signals.

Another bandwidth concern to consider when purchasing an HF transceiver is *coverage*. Most modern rigs support what's known as *general coverage*, meaning it can receive all the frequencies in the HF band, whether they're amateur or not, something that's important to SWLers (shortwave listeners). So, one more thing to watch for, if general coverage is important to you.

Amplifier bandwidth

Like any other amateur equipment, amplifiers operate most effectively within a specific frequency range. Typically, HF amplifiers support the entire 1.8 MHz to 30.0 MHz spectrum, but some do not support operation under 3.5 MHz, so close attention to their specifications is advised, as it is for any piece of amateur hardware.

Audio bandwidth

Those of us who enjoy high-fidelity sound understand the human limitation of hearing between 20 Hz and 20 kHz. However, in an effort to conserve spectrum space, our amateur radio equipment that captures, modulates, transmits, receives, and demodulates audio uses much less than that to effectively perform communication. In fact, the typical audio range of most amateur equipment is designed to cover little more than 300 Hz to 3000 Hz, with perhaps the microphone often being the component of largest bandwidth.

Most repeaters require a (CTCSS) tone from your radio, to activate its re-transmit function. This tone is a simple sine wave between 67 Hz and 255 Hz, and is called a *sub-audible* tone, even though it's within the human audio range, because it (along with any signal below 300 Hz) is filtered out in the receiver during demodulation, sparing the listener from hearing it.

Instrumentation bandwidth

When considering the purchase or use of equipment, bandwidth must often be taken into account, especially to determine whether your tool will support the frequency range required. For example I purchased a RigExpert AA-170 antenna analyzer to aid in my DIY (do-it-yourself) adventures, because I felt it provided the greatest benefit for my investment. The analyzer supports all HF bands, 6 Meters, and 2 Meters, but not 1.25 Meters (220 MHz), so when I needed to build a match for a 220 MHz antenna, I had no way of testing it until I could borrow somebody else's analyzer.

Other test instruments, for which frequency and bandwidth support are important, include a watt (power) meter, SWR meter, VNA (vector network analyzer), logic probe, spectrum analyzer, and maybe even an oscilloscope. More than once I've known hams who have purchased an inexpensive watt meter, only to find later that their instruments don't support the frequency range they actually needed.

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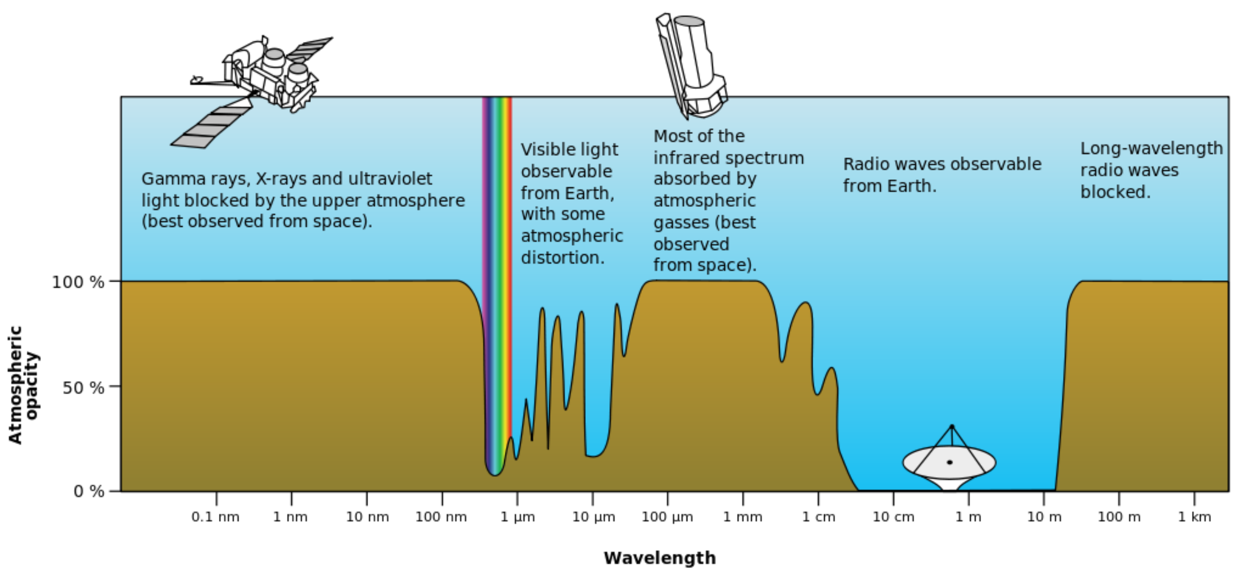
Bandwidth of transmission line components

In specifications of coax (coaxial cable) and associated connectors, even those seemingly RF-friendly items operate effectively only within specific frequency limits, mostly defined by attenuation for each model. For example, RG-58 starts exhibiting 10 dB and greater loss over 500 MHz, whereas LMR-400 doesn't exhibit 10 dB loss until 3000 MHz (3 GHz).

Coax connectors realize similar bandwidth limitations, such that PL-259 / SO-239 connectors work well for HF and VHF applications, but N-type and SMA connectors fare better (lower insertion loss) at UHF frequencies.

Atmospheric bandwidth

In spite of how clear the sky appears on sunny days and starry nights, even the atmosphere has bandwidth. And because our atmosphere is made of a variety of layers, its bandwidth is not confined to a single band, but multiple bands, due to *electromagnetic opacity*.



Summary

Bandwidth is the difference between the highest and lowest frequency in a set of one or more continuous frequency ranges. An often overlooked parameter, bandwidth is an important consideration for radio operation, instrumentation function, and equipment purchases, and if ignored, can spell failure to perform. For amateur radio concerns, just about every piece of hardware that can conduct electrical or RF (radio frequency) energy, and even the air, can perform their intended function only within specifically designed frequency ranges.

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