How Far Can Two-way Radios Communicate?

One of the most common questions people ask when they are in the market for a two-way radio or wireless intercom is how far do they communicate? Unfortunately asking this question is along the lines of asking, "How far is up?". There are lots of variables involved and no easy, definitive answer. A brief lesson on radio signal transmission is required to understand the whole range issue.

If you are old enough to remember when AM radio was popular, you may remember listening to radio stations that were hundreds of miles away. For frequencies like these below 2 Megahertz (MHz), these signals follow the Earth's curvature because they are reflected off the atmosphere. So AM radio signals in low-noise environments can be received by radios that are way below the horizon hundreds of miles away.

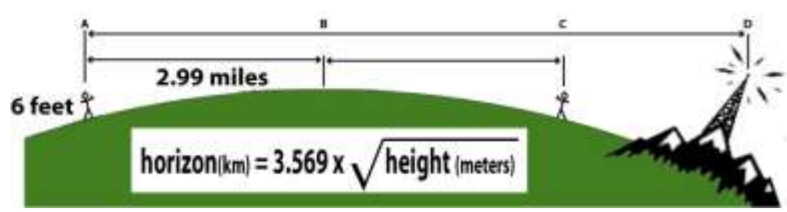
The two-way radios and intercoms available for you to purchase usually fall in the frequency range of 150MHz to 900MHz. Unlike the AM radio waves, radio waves in these frequencies travel in straight lines and as a general rule cannot travel over the horizon or behind solid obstacles.

But as in all general rules, there are exceptions to the rules. Even though these frequencies travel via "line-of-sight" paths, radio signals can travel through many non-metallic objects and be picked up through walls or other obstructions. Even though we can't see between antennas of a transmitter and receiver, this is still considered line-of-sight to the radios. Also, radio waves can be reflected, or bounce off surfaces so the straight line between radios, may not always be so straight.

Knowing that our radio waves travel in straight lines, then to figure out their maximum range for a two way radio, we have to factor in the curvature of the Earth. When you stand on Earth and press the talk button on your radio, the radio waves are going straight and they will eventually just go straight off into space once they pass the horizon. So the distance of the horizon is technically the maximum communication range for a two way radio. But you have to factor in antenna height as well.

To find the line of site distance to the horizon for a given antenna height we use this formula: horizon in kilometers = 3.569 times the square root of the antenna height in meters. Figure 1 illustrates this formula.

So if the antenna height of a radio is at 6 feet, or 1.82880 meters tall, the horizon is 4.83 kilometers, or 2.99 miles away, which is Point B in the illustration. Of course this calculation assumes the receiving antenna is laying directly on the ground so raising the height of it would extend line of site.



Point C in the illustration shows another radio with the antenna at 6 foot so theoretically you should be able to communicate almost 6 miles. So realistically, for two people carrying a handheld two-way radio, the maximum communication distance on flat ground with no obstructions is around 4 to 6 miles.

So you may be wondering why you see radios that have range claims of 25 miles or higher. Technically, they could communicate that far. Point D on Figure 1 shows a tower sitting on top of a mountain. If you are standing on top of this tower, now your antenna height overcomes a whole lot of the Earth's curvature and you can communicate much further.

There are other factors that affect the range of a two-way radio too such as weather, exact frequency used, and obstructions. The radio's power output has a factor too.

Two-Way Radio Power

Another important factor in the distance a two-way radio will communicate is its power output. This power output is measured in watts. You've likely heard an FM radio station say they are broadcasting at 50,000 or 100,000 watts. Well, a handheld business-type two-way radio usually broadcasts at 1-5 watts. A vehicle mobile radio may broadcast anywhere from 5 to 100 watts. The more watts a radio has, the farther it can transmit.

Why is this? When water moves through a pipe it loses pressure along the way. When electricity flows along a wire it loses current. When an object is rolling, it will eventually stop rolling due to friction. Radio waves operate by the same laws of physics as everything else so there will be signal loss along the way. But if you apply more water pressure, more electrical current, or get the rolling object moving faster, you'll get more distance out of all of them. The same is true for a radio signal. Increasing the power in watts at the source helps overcome any "resistance" along the way.

Keep in mind that for battery-powered handheld radios more watts is not always a good thing. The higher the wattage, the quicker your batteries run down.

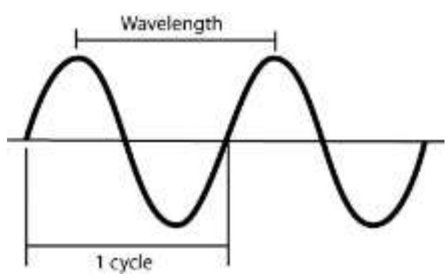
Radio Frequencies

One more factor in determining how far a two-way radio will communicate is the frequency it uses and the environment that frequency is used in.

There are two major formats for most two-way radios. They are Ultra High Frequency (UHF) radio and Very High Frequency (VHF) radio. Neither frequency band is inherently better than the other. They each have their pluses and minuses. Both formats are effective ways to communicate with another person so deciding on the right radio for you depends on your application.

Two-way radios communicate with each other through use of radio waves. Radio waves have different frequencies, and by tuning a radio receiver to a specific frequency you can pick up a specific signal.

Radio waves are transmitted as a series of cycles, one after the other. You will always see the "Hz" abbreviation used to indicate the frequency of a radio. Hertz is equal to one cycle per second.



Radio waves are measured by kilohertz (kHz), which is equal to 1000 cycles per second, or megahertz (MHz), which is equal to 1,000,000 cycles per second--or 1000 kHz. The relationship between these units is like this: 1,000,000 Hertz = 1000 kilohertz = 1 megahertz.

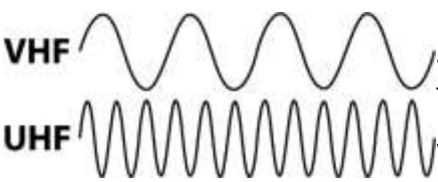
You may also hear the term "wavelength" when you hear about radio waves. This term is from the early days of radio when frequencies were measured in terms of the distance between the peaks of two consecutive cycles of a radio wave instead of the number of cycles per second. Lower frequencies produce a longer wavelength (the width of each cycle gets bigger on lower frequencies).

What is significant about wavelength for two-way radios is that it affects transmission range under certain conditions. A longer wavelength, which corresponds to a lower frequency, as a general rule lets a radio signal travel a greater distance.

Lower frequencies or longer wavelengths also have greater penetrating power. That's one of the reasons they are used for communicating with submarines. VLF (Very Low Frequency) radio waves (330 kHz) are used to penetrate sea water to a depth of approximately 20 meters. So a submarine at shallow depth can use these frequencies.

So from what you read above you may think VHF is always the better choice for a two-way radio no matter where you are using it since it has a lower frequency than UHF and the signal can travel a greater distance. That's not necessarily true. Even though VHF has better penetrating capabilities and can travel farther, that doesn't necessarily make it the better choice for use in buildings. Remember the conversation about wavelength above? Wavelength has a big impact on transmission distance.

To explain this let's assume we are communicating from one side of a metal commercial building to the other. In between these two points is a metal wall with a three foot doorway. Metal is an enemy to radio waves and they typically don't pass through it.



For our example, let's assume that the UHF wavelength the radio uses is about a foot and a half wide and a similar VHF radio is around five feet wide. These are in the ballpark of their normal wavelengths.

When the UHF radio transmits its signal the foot and a half wide wave will pass through the door since the door is wider than the wavelength. The VHF signal will be totally reflected since it is wider than the opening to the door.

Your microwave oven provides an example of this. The glass front door has a metal mesh with very small holes. Microwaves being an extremely high frequency have wavelengths that are only several inches long. The mesh keeps the microwaves trapped in the oven but it allows you to see inside because light waves have a microscopic wavelength.

Just imagine walking through the building carrying a five foot wide pole. You will encounter the same challenges a VHF signal encounters. Now imagine walking through the building with a pole that's only a foot and a half wide like a UHF wave. There are lots fewer doorways you couldn't get through.

The one caveat is that wireless signals will penetrate through drywall, masonry, human bodies, furniture, wall paneling, and other solid objects. All these objects will reduce the signal strength though. The more dense the object, the more it reduces the signal. VHF will penetrate these obstacles better than UHF, but that doesn't necessarily mean that VHF is better for indoor applications as we continue to discuss the reasons why in the UHF section below.

In our example above, we assumed you had a metal wall with an opening. If you reverse this and you have a three foot metal object in front of the transmitting radio, then VHF would win. Since the object is three foot wide it will totally block the UHF signal whereas the VHF signal will get around it. Lower frequencies such as VHF diffract around large smooth obstacles more easily, and they also travel more easily through brick and stone.

For most applications, lower radio frequencies are better for longer range. A broadcasting TV station illustrates this. A typical VHF station operates at about 100,000 watts and has a coverage radius range of about 60 miles. A UHF station with a 60-mile coverage radius requires transmitting at 3,000,000 watts.

So there is no clear choice for which is better, VHF or UHF. There is a lot of "black magic" to radio technology so it's not always easy to tell which will work better for your application. To help you decide on the best technology for you, more detail about each one is below.

UHF Radio

The UHF radio band for commercial radios is between 400 to 512 MHz and is used for two-way radios, GPS, Bluetooth, and WiFi.

There are more available channels with UHF so in more populated areas UHF may be less likely to have interference from other systems. The range of UHF is also not as far as VHF under most conditions, but this reduced range may be a positive in some cases. Since UHF has lower range, there is less chance of distant radios interfering with your signal.

While VHF may be better at penetrating physical barriers like walls that doesn't mean it will give you greater coverage in a building. The shorter wavelength of UHF means that it can find its way through more spaces in your building as we discussed above. In the walking around with a pole example we gave you, the UHF signal has fewer obstacles that totally block it.

To highlight the differences in indoor range, below is an excerpt from a brochure of a leading two-way radio maker on the predicted range of one of their lines of handheld VHF and UHF two-way radios:

> "Coverage estimates: At full power, line-of-sight, no obstructions the range is approximately 4+ miles. Indoor coverage at VHF is approximately 270,000 sqft and 300,000 sqft at UHF. Expect about 20 floors vertical coverage at VHF and up to 30 floors at UHF. Note: Range and coverage are estimates and are not guaranteed."

The greater wavelength of VHF makes it more difficult for it to bounce its way through walls, buildings and rugged landscape. Therefore range will be reduced for VHF radios in these environments. That may not necessarily be a problem if the range needed is only a few hundred feet. You can also add an external antenna to an indoor VHF base station that will reduce or eliminate some of the problems encountered.

One of the downsides to UHF is that the FCC requires you to get a license to operate in these frequencies, although many frequencies in the VHF business band also require a license too. If you choose a radio in the VHF MURS frequencies you can operate it without a license (discussed below).

One other advantage of the short wavelength that is produced by the higher UHF frequency is that the antenna on the radio can be shorter than an equivalent VHF radio. That can make it more convenient to carry around as a portable radio, although most manufacturers find a way to make the antennas shorter on their VHF portable radios.

VHF Radio

FM radio, two-way radios, and television broadcasts operate using VHF. The VHF radio band specifically for commercial radios is between 130 -174 MHz.

Both UHF and VHF radios are prone to line of sight factors, but VHF a little more so. The waves make it through trees and rugged landscapes, but not always as well as UHF frequencies do. However, if a VHF wave and a UHF wave were transmitted over an area without barriers, the VHF wave would travel almost twice as far. This makes VHF easier to broadcast over a long range.

If you are working mostly outdoors, a VHF radio is probably the best choice, especially if you are using a base station radio indoors and you add the external antenna. The higher you can place the antenna, the further you can transmit and receive. One exception to using a VHF radio outdoors is if you are using it in a heavily wooded area. Under these conditions a UHF radio may be able to transmit better though the trees. One benefit of VHF wireless radios is that battery life is almost always better than for similar UHF units. For handheld radios this is a plus.

In summary, if you are planning on using your two-way radios mainly inside buildings, then UHF is likely the best solution for you, but in lots of applications, VHF could still work fine since it doesn't have to transmit far. If you are mainly using your two-way radios for communication outside, then VHF would be a good choice, unless the area you are covering is heavily wooded or there are lots of buildings in the way of the radio signal.