# WAVE PROPAGATION

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Electromagnetic radio waves can propagate in three different ways between the transmitter and the receiver.

1- Ground waves
2- Troposphere waves
3- Sky waves

## Ground waves

The ground wave is the wave strongly influenced by the earth's surface. We can divide the ground wave into three components: the ***surface wave,*** for which the earth's surface serves as a wave conductor; the ***direct wave,*** which is the straightest and the shortest propagation distance between the transmitter and receiver; and the ***earth reflected wave,*** in which the wave first hits the earth surface and is then reflected towards the receiver. See **Fig 3.1.**

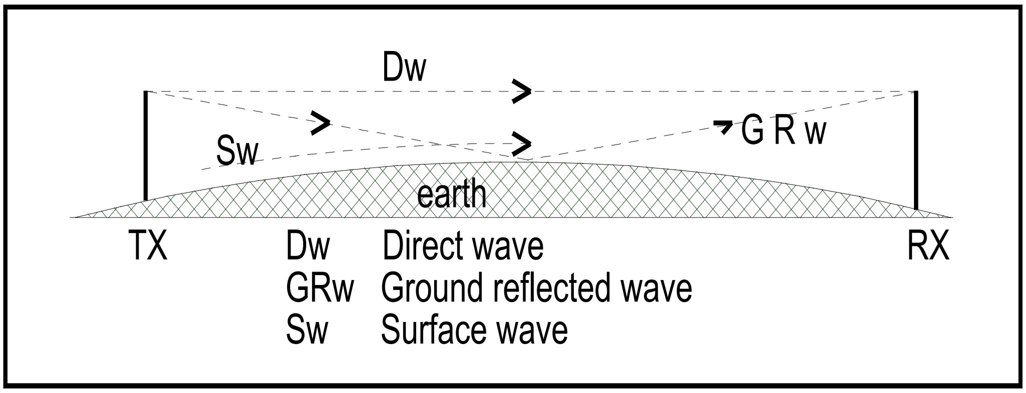


***Fig. 3.1*** *Ground waves can be direct, be ground reflected, or follow the surface.*

### Surface wave

To achieve an optimal propagating result with a surface wave, you must use vertical polarization. That is the reason why long and medium wave radio stations use self-radiating, vertical transmitting masts as their antennas. Long surface waves propagate further than medium waves. Medium waves have a range (depending of the transmitting power) of approximately 200 km by means of ground waves.

The field strength of a ground wave decreases rather quickly with increasing frequency. See **Table 3.1**. The coverage of ground waves does not depend on day and night or seasonal time.

The range of long and medium surface waves is slightly greater than the line of sight distance. They can travel beyond the horizon for some distance. Long and medium waves, traveling tangential with the earth surface, undergo some slow down in velocity at the point where they touch the earth. The decrease in velocity is caused by a partial absorption of the radio wave by the earth. Due of the decrease of velocity, the waves are slightly retarded at the surface, and the traveling path curves beyond the horizon. See **Fig 3.2**.

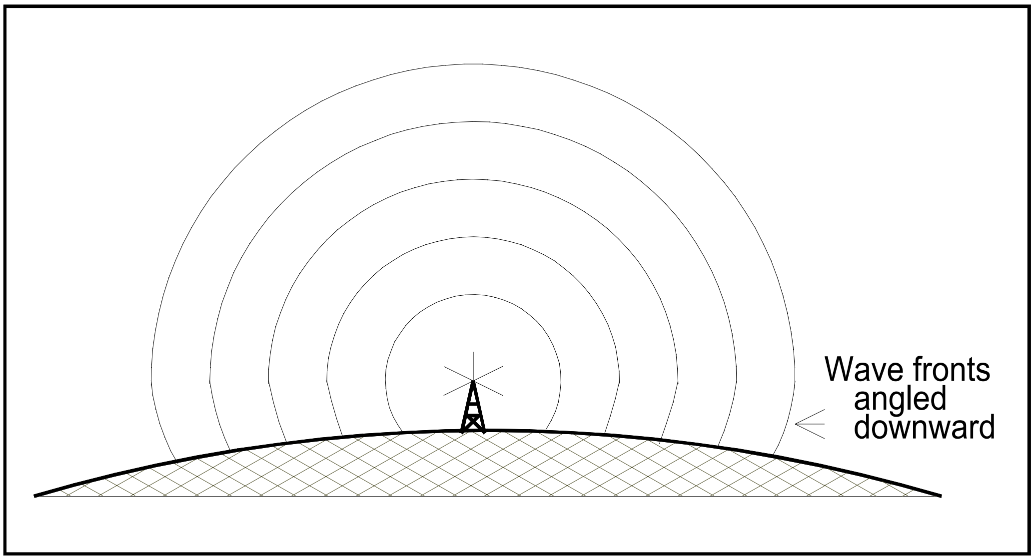


***Fig 3.2** The surface-following property is caused by retarding the velocity of the wave at the surface boundary. The retarding due to the earth's absorption will angle the wave fronts downwards.*

**Table 3.1**

| ***Frequency**.* | ***Approximately Maximum reach with ground wave.*** |
|---|---|
| 1.85 MHz | 150 km |
| 3.5 MHz | 100 km |
| 7 MHz | 60 km |
| 14 MHz | 40 km |
| 21 MHz | 30 km |
| 28 MHz | 20 km |

## Direct and earth reflected wave

When radio waves travel from the transmitter antenna toward the receiver antenna in a straight line, both antennas are within each other's horizon view. For this situation, we speak about direct waves. As well, the wave can reach the horizon-view receiving antenna by an earth-reflected path. In this case, the traveling distance, and therefore the traveling time, will be slightly longer. The direct and the earth-reflected signals will be phase shifted relative to each other. Depending on the phase shift, in or out phase, the resulting signal may be stronger or weaker than with only direct waves.

The in-view horizon of both antennas is the straight line between them, not between one antenna and the earth's horizon. See **Fig 3.4.** The maximum line of sight distance between two elevated antennas is equal to the sum of their distances to the horizon. Literally, this is not completely true on frequencies above 30 MHz. Measured distances of coverage soon made it clear that VHF waves were actually being scattered and bent in several ways. This property permitted reliable communication beyond visual distances between two stations. The reachable distance is increased by approximately one-third. (See further information on this phenomenon when we cover tropospheric waves.) The radio horizon distance can be calculated by the following equation (**Eq. 3.1**) in miles or kilometers.

**Eq. 3.1**

| | |
|---|---|
| $D = 1.415\sqrt{H}$ | $D = 4.124\sqrt{H}$ |
| D = miles | D = kilometers |
| H = feet | H = meters |

The above equations were used to compute the data in **Table 3.2**. Be aware that the formula and table are for one radio horizon distance. To calculate the total reachable distance for two antennas, you must make the sum of the two radio horizon distances. As an example: one station has an antenna height of 60 feet and another station has an antenna height of 40 feet. Together, they give a total workable distance of (10.96 + 12.19) about 32 miles. But remember that, in many cases, the terrain can be far from ideal. Your radio energy can be absorbed, reflected, or scattered in many ways, and these factors may add or subtract from your calculated distance. The formula and the table must be used as only a guide for estimating the potential coverage radius.

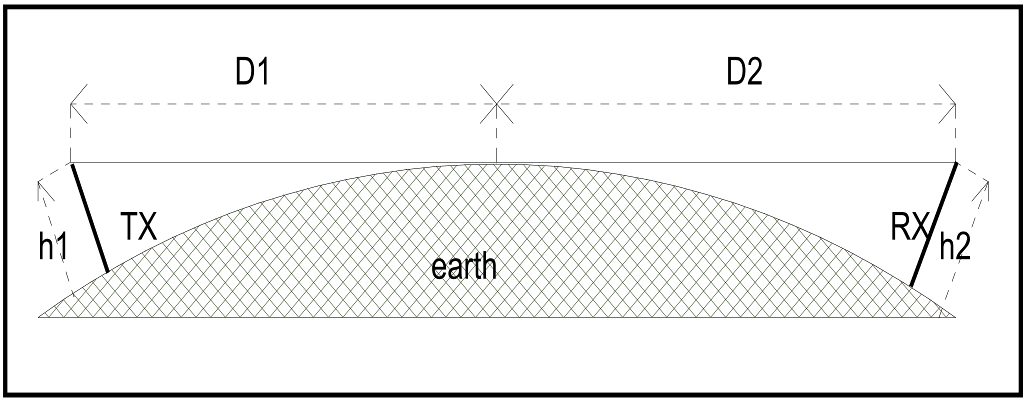


***Fig 3.4***. *The maximum line-of-sight distance between two elevated antennas is equal to the sum of their distances to the horizon. Total reachable distance is equal to the sum of D1 and D2.*

Transmitting or receiving from a hill or mountaintop can increase your working distance remarkably. Concerning this increase of working range, I had the opportunity to perform some tests. In August, 2000, my two daughters give me a hot air balloon flight as a present for my early retirement, a very nice present indeed. On the flight, I not only took along my camera, but also my 2-meter handheld transceiver. QSOs were easy to make within a range of 100 km (60 miles) with only a rubber duck antenna and a half-watt output power. I could even open a repeater station at a distance of 135 km (80 miles) away, all this from a height of 2,500 feet (762 meters).

Radios contacts between ground stations and airplanes or hot air balloons, or between two vehicles in the air such as planes or balloons, are made mostly by direct and earth-reflected waves when using VHF and higher frequencies. Only contacts with satellites are purely direct-wave contacts.

For HF frequencies, the electrical characteristics of the area between antennas play an important role with ground waves. The ground conductivity in S/m and the dielectric constant ($\varepsilon_r$) dictate the final field strength. The conductivity can vary from a high value of 5 (sea water) down to $3 * 10^{-5}$ S/m (very dry sand soil). The dielectric constant ($\varepsilon_r$) can vary from a high value of 80 (sea water) down to 4 (very dry sand soil). Salt water has an "amplification" factor of 30 to 50 times greater than fresh water. When we have the favorable conditions of wide areas of salt water between antennas, we often speak of salt-water gain.

Therefore, maritime stations and coastal stations have a much greater ground-wave reach, even at frequencies as low as 2 MHz, than inland stations. MF and LF waves follow the earth's curve to some extent, but are also highly absorbed by the earth's surface. The absorption is more severe with horizontally polarized waves, because the electrical field component is parallel to the earth's surface and looses energy by induced current in the ground.

| Antenna Height | | Reachable Distance | |
|---|---|---|---|
| feet | meter | Miles | km |
| 5 | 1.52 | 3.16 | 5.09 |
| 10 | 3.04 | 4.47 | 7.20 |
| 20 | 6.09 | 6.33 | 10.18 |
| 30 | 9.14 | 7.75 | 12.47 |
| 40 | 12.19 | 8.95 | 14.40 |
| 50 | 15.24 | 10.01 | 16.10 |
| 60 | 18.28 | 10.96 | 17.64 |
| 70 | 21.33 | 11.84 | 19.05 |
| 80 | 24.38 | 12.66 | 20.36 |
| 90 | 27.43 | 13.42 | 21.60 |
| 100 | 30.48 | 14.15 | 22.77 |
| 200 | 60.96 | 20.01 | 32.20 |
| 300 | 91.44 | 24.51 | 39.43 |
| 400 | 121.92 | 28.30 | 45.53 |
| 500 | 152.4 | 31.64 | 50.91 |
| 600 | 182.88 | 34.66 | 55.77 |
| 700 | 213.36 | 37.44 | 60.24 |
| 800 | 243.84 | 40.02 | 64.40 |
| 1000 | 304.8 | 44.75 | 72.00 |
| 2000 | 609.6 | 63.28 | 101.82 |
| 3000 | 914.4 | 77.50 | 124.70 |
| 4000 | 1219.2 | 89.49 | 143.99 |
| 6000 | 1828.8 | 109.61 | 176.36 |
| 7000 | 2133.6 | 118.39 | 190.49 |
| 8000 | 2438.4 | 126.56 | 203.64 |
| 9000 | 2743.2 | 134.24 | 215.99 |
| 10000 | 3048 | 141.50 | 227.67 |
| 20000 | 6096 | 200.11 | 321.98 |

***Table 3.2***

## Troposphere Waves

All our radio communications involve propagation through the lowest region of the earth's atmosphere. For at least a part of the signal path, the waves have to travel through the troposphere. In this environment, our radio waves will be influenced by different phenomena, such as refraction, scattering, and ducting. These tropospheric conditions are rarely significant below 30 MHz, but from 50 MHz upward, they play a very important role. Most of the long distance communications on VHF, UHF, and microwave frequencies are the result of troposphere propagation properties. These troposphere properties are much more dependent on the weather than on solar activity and geomagnetic indices.

Communications in the VHF range and higher are also possible beyond the line-of-sight limit, as already mentioned. Only in the vacuum of space will our radio waves essentially travel in straight lines, but in terrestrial environments, even in our troposphere, conditions are different. In the troposphere, we have phenomena that cause signal refractions, such as sub-layers in the air with dropping temperatures, pressures, and humidity levels. The properties change with increasing altitude and result in different refraction indices. The troposphere can refract and bend our waves in a way comparable to what the ionized layers do in the ionosphere. Naturally, we have both average and exceptional conditions. Under average conditions, refractions toward earth are sufficient to extend the radio horizon by a factor of 1.15 to 1.3 times over the in-sight horizon. When exceptional and unusual conditions exits, troposphere refraction can extend that range significantly. For VHF frequencies and higher, do not under-estimate the role played by antenna height as an added factor in extended-range communications.

For example, with an antenna height of 100 feet (30.5 meters) the range is 14 miles (22.7 kilometers), and with a height of 3000 feet (914 meters) the range is 77.5 miles (125 kilometers). These ranges presume that we have no exceptional conditions or high terrain (meaning that there are no obstructions, such as mountain ranges or massive building complexes, along the path).

### Tropospheric propagation possibilities

Other troposphere events can remarkably extend our VHF communications. I will not go in detail at this moment, since VHF, UHF and microwave propagation modes and possibilities will be handled in a separate column in this series. But I shall just mention a few of the possibilities: tropospheric scatter, rain scatter, ducting temperature inversion conditions, warm and cold fronts, etc. Most propagation modes at very high frequencies are totally different matters compared with the modes of propagation at lower frequencies in the ionosphere environment.

## Sky Waves

Ground and tropospheric wave propagation modes are confined to the earth's lower atmosphere. "Sky waves" is a term used to describe propagation modes that use the earth's ionosphere. We mentioned already in an earlier column a few subjects that are relevant to the study of sky waves, such as the ionosphere, ionization density, electron densities, refraction, MUF, etc. The time has come to study this very interesting and intriguing propagation mode. Sky wave propagation is dictated by the ionosphere's properties, and those properties again are dictated by solar phenomena and to some extend by the earth's magnetic field. Sky wave propagation therefore has continually changing and variable aspects: **diurnal**, **seasona**l, **geographica**l and **cyclical**. In a word, ionospheric propagation is a complex matter, but it is also both understandable and predictable. We shall attack and solve the mystery of sky wave propagation in forthcoming columns. **–30-**

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