RADIO WAVE PROPAGATION

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INTRODUCTION

What is propagation? What do we mean by propagation? Propagation is a sort of expanding. Radio-wave propagation is a combination of what happens with and to our expanding waves and the behavior of those waves between a transmitter and receiver at the particular moment of transmission. In other words, how do our radio signals travel to reach our radio friend and vice versa?

Is your interest as a ham to talk to distant places with exotic names or just to make contacts with near-by amateurs? Whatever your desire—DXing or rag chewing, or maybe both—it is always useful and interesting to have a general idea of how your radio signal reaches the other station. Propagation is essential to each and every QSO we are making. Having some knowledge of or insight into how all this happens will make your hobby more interesting and enjoyable.

Ten thousands of radio hams make daily contacts worldwide by using various properties of the ionosphere. A good knowledge of propagation modes and behaviors is certainly a bonus. You are better off understanding the physics of the ionosphere and the "magic" of propagation by and through it. Communications are enhanced if we know where signals might come from, which part of the world we can reach at a given time and date, and what is the best frequency to use for that open path. Having an answer to those questions enables experienced DXers to work stations that newcomers only dream of contacting. An insight in propagation and a feeling for conditions are valuable commodities for any radio ham. WARNING and beware! Propagation is fascinating: the more you find out, the more interesting it becomes. You may become addicted to it.

The goal of the forthcoming discussions is to introduce you to the manifold modes of radio wave propagation. You will understand that you will not reach very far only with rectilinear propagating waves, the ones that reach only to the horizon, except with some exceptional and outstanding ***TROPOSPHERE*** properties or other phenomena causing some bending beyond the horizon. So it must be the sky waves that make it possible for us to reach the other side of the globe. In other words, those sky waves must for some reason return to the earth some distant point from our QTH. Fortunately this is true. But why are certain waves refracted back to earth and why do others travel further into outer space? Or why are certain waves more attenuated than others, or even totally absorbed? The answer is, they can meet different ionized layers up there in the sky. This region is named the ***IONOSPHERE***, and it is there that we must look to understand the basic mechanisms of **"*HF PROPAGATION*"**, and under some circumstances, **"VHF PROPAGATION"** as well.

I shall expend lots of words on the phenomena, trying to explain what propagation is. We will approach the subject in all its facets: why, where, when, causes, etc. I shall also attempt to illustrate the fundamental ideas of propagation as much as possible with sketches, drawings, graphics, maps, illustrations of all kinds, tables, animated gifs, presentation wizards, etc. Those presentation wizards may result in a future CD-ROM. From experience, I know that even the smallest or simplest sketch can tell more than hundreds of words and make things a lot easier to understand and imagine. To make this all true we will make use of PC propagation prediction software packets, (substantially PROPLAB-PRO-2) with its different outputs. We shall also discuss and review other prediction software. This will hopefully yield objective teaching. I shall try to give you full updated information about other sources concerning the subject, such as articles in books and magazines, ***W****orld* ***W****ide* ***W****eb* of Internet, and propagation-related software.

The whole subject will be approached in a matter that will be clear and understandable for every radio ham. You will not need a degree as a scientist or a mathematician. Nevertheless, where convenient, we shall sometimes mention a necessary equation or formula to illustrate some aspects of radio wave propagation characteristics or properties.

Last but not least. The following question is raised frequently and continuously: what item or subject must we handle first; what has priority in the explanation process? It is not easy to make a decision, but we will try to our best knowledge to follow a leading thread through the subject matter.

Often some propagation conceptions will be repeated more than once so that we can study them each time a bit more profoundly.

RADIO-WAVES FUNDAMENTALS

Radio waves are electromagnetic radiations; they belong to the same family as infrared, visible light, ultraviolet, X-rays, gamma rays and cosmic rays. All those rays or waves have a given frequency and thereof a given wavelength. Radio waves have the longest wavelength and the lowest frequency of the electromagnetic radiation family **Table 1.1**.

The name *electromagnetic* explains itself. We have two components—an interaction of an electric field and a magnetic field. When we put an oscillating electric charge in a piece of wire (an antenna), that electric charge creates an electric field which will in its turn create an magnetic field and so on: both are inherent to each other. Those two fields sustain themselves as a composite electromagnetic wave, which propagates itself further and further away from its source into space. Both components: the electric and the magnetic are oriented at right angles to each other and 90° to the traveling direction. See **Fig 1.1**. Unlike sound waves, electromagnetic waves need no propagating medium such as air. This property enables electromagnetic waves to travel through the vacuum of space.

Table 1.1
Electromagnetic Spectrum

Radiation	***Frequency***	***Wavelength***
X-ray	$3 * 10^5$ THz and higher	10 Å and shorter
Ultraviolet	800 THz - $3 * 10^5$ THz	4000 - 10 Å
Visible light	400 THz - 800 THz	8000 - 4000 Å
Infrared	300 GHz - 400 THz	1 mm - 0.0008 mm
Radio wave	10 KHz - 300 GHz	30,000 km - 1 mm
Å = Ångstrome.	THz = Thetahertz.	GHz = Gigahertz.

Wavelength - Velocity - Phase

Radio waves expand from their source with a speed of approximately 300 000 000 meters per second (186 000 miles/sec or 300 000 km/sec). These values are close enough for practical purposes and will be used in these discussions. For those who wishes to be more precise, the speed is 299 792 458 meters per second in vacuum, and slightly slower in any other medium. How much the speed decreases depends on the type or sort of medium. For frequencies from somewhere 30 MHz and lower, we can ignore the very slightly traveling speed decrease through the medium air. From the VHF range and higher, temperature and moisture content of the air medium further decrease speed, but they may increase the communication range (discussed later). In a conducting medium (an antenna wire, for example) the speed is much slower, about 95% of the free-space speed. For example, in a piece of wire shortens the wavelength of a 30 MHz signal to about 9.5 meters instead of 10 meters in space. In a solid insulating medium, the speed can even decrease by 9%.

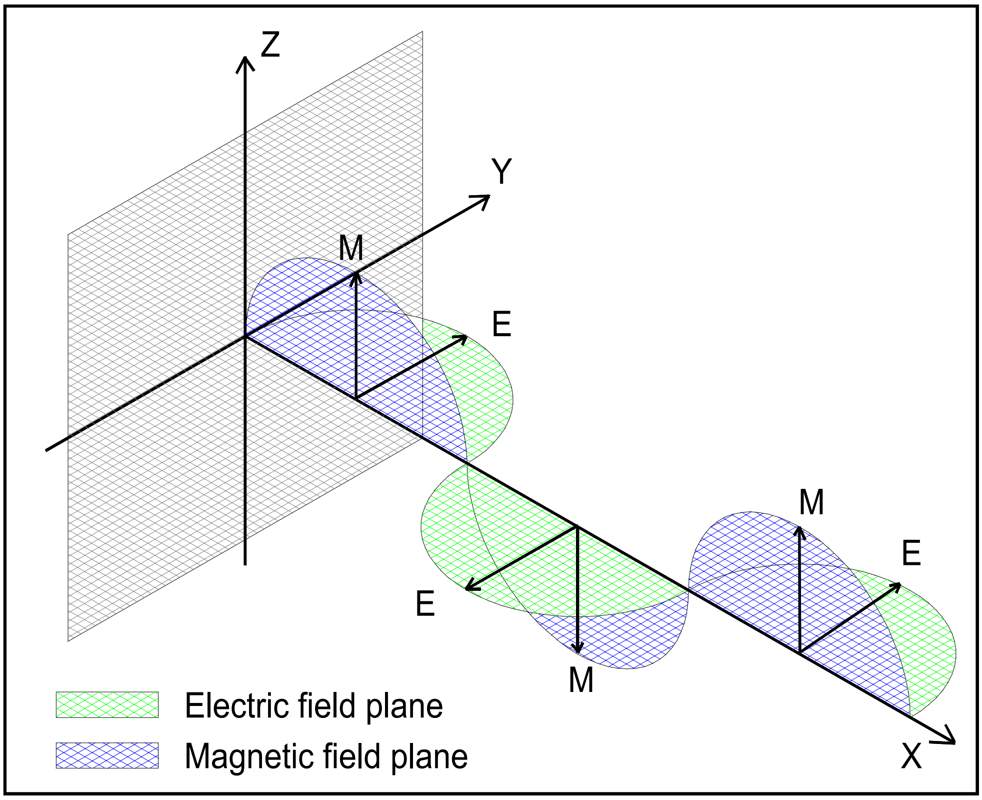

Fig 1.1 *E-field and M-field components of the electromagnetic wave. The polarization of a radio wave is in the same direction, as the plane of the electric field (here illustrated horizontal polarization).*

Radio wave propagation speed is immensely great, so great that we tend to ignore it. Only 0.7 of a second is needed for a radio wave to travel around the world. Suppose the frequency is 30 MHz. Then one cycle or period is completed in 1/30,000,000 second. In this time, the wave is moved only 10 meters. This was also the time that the current needed in our antenna wire to flow for one period. The electromagnetic field 10 meters away from that antenna is caused by the current that was flowing one period earlier in time. The field 20 meters away is caused by the current that was flowing two periods earlier, and so on. Let's suppose that we have a continuous repetition of identical current periods. Then the fields caused by those currents will also be identical. The fields are moving outward from the antenna, so that they become more thinly spread over larger and larger surfaces and their amplitude decreases with distance from the antenna. But in spite of decreasing field strength and amplitude, they do not lose their identity with respect to the instant of the generated period. In other words, they are and remain in phase. With our 30 MHz example, at every interval of 10 meters, measured from the antenna at any given instant, the phase of the wave will remain identical. See **Fig 1.2**. The distance between two of those identical points, having the same phase, is one wavelength long, abbreviated with the Greek letter lambda, λ. Knowing the frequency, the wavelength can be calculated by the following equation (**Eq. 1**). The first version is the precise one, and the other is the practical and most used one.

Eq. 1

$$\lambda_{meters} = \frac{299.7925}{\text{Freq (MHz)}} \qquad \lambda_{meters} = \frac{300}{\text{Freq (MHz)}}$$

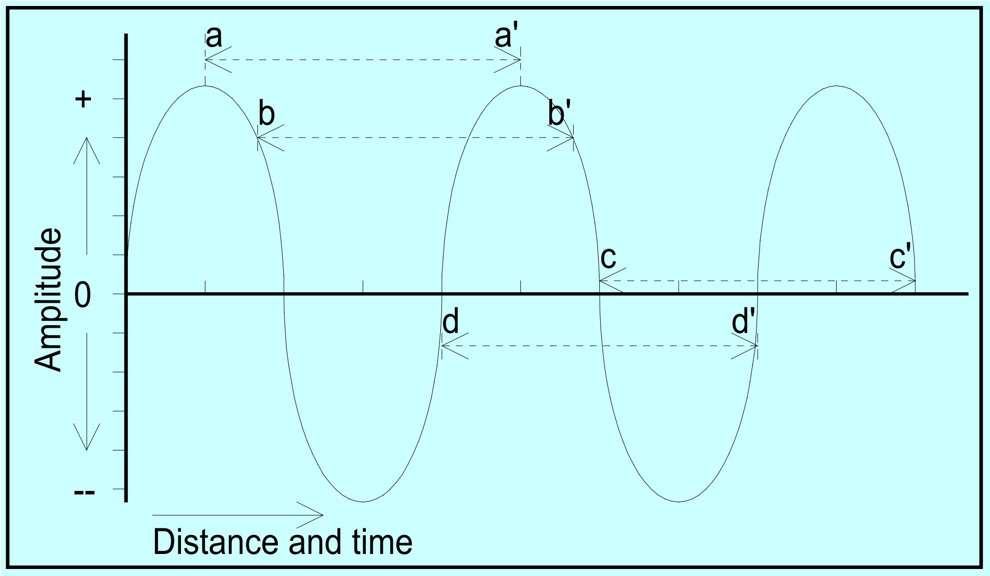

Fig 1.2*. The distances a - a' and b - b' or c - c' and d - d' are exactly the same. They all are exactly one wavelength long.*

Polarization

The direction plane of the *electric field* lines defines the polarization of an electromagnetic wave. If the electric field lines are parallel with the earth surface, we speak about horizontal polarization. When those electrical field lines are perpendicular to the earth surface, we have vertical polarization. However in free space, the reference plane of the earth's surface is lost and the expressions *horizontal* and *vertical* no longer have any meaning. In the ionosphere, our polarization is rotating continually and randomly, and we can speak about *elliptically polarized* waves. Radio waves will be elliptically polarized after their space journey when they hit your antenna.

Despite the changes in radio wave polarization, polarization has meaning and sense right at the electromagnetic source: our antenna and our surrounding ground surface. The antenna construction and type dictate the polarization of our transmitted radio wave. The chosen polarization can play an important role for the best take-off angle (**TOA**) of our waves, especially for frequencies from 10 MHz and lower. For those low frequencies, we often use vertical polarization for the following reason: electric field lines must be perpendicular to a good conductor. When they are parallel with that conductor, they generate infinite currents in the conductor, and our waves would be considerably attenuated. Don't underestimate the earth surface; it can be a very good conductor. A low TOA produces mostly a further and less attenuated signal reach. The TOA range depends on the antenna type and antenna height above the ground in wavelength units. The important role of the antenna for your radio signal propagation will be the subject of a later column in this series.

Field intensity

The field intensity of a wave at a distance from the source can be measured: we call the measurement *field strength*. Field strength measurements are expressed in volts/meter, the voltage developed in a wire of one meter long. If the wire used to make the measurement is longer than 1 meter we must divide our measured result by the factor by which the wire is longer. For example, using a 2-meters wire, we must divide the measured value by two and so on. The voltage is usually low: we are measuring in millivolts or microvolts per meter. For amateur use, it is not necessary to measure the actual field strength, since the equipment needed to this measurement is elaborate and costly. Mostly, we only need to know if an antenna or other equipment adjustment has been beneficial and to what degree. Relative measurements are satisfactory and can be done easily with homebuilt equipment.

Wave attenuation and absorption

As radio waves travel away from their source, whether in the near vacuum of outer space or within the earth's atmosphere, they weaken by *free-space attenuation*. The dispersal of radio energy itself results in the main attenuation. This attenuation increases rapidly with distance, because the power density weakens inversely with the square of the distance traveled. See **Fig 1.3**. For example, suppose that you measure the power level of a stable signal at 1 km from its source and compare it with the power level measured at a distance of 6 km from that same source. You would find that the more distant signal has a 0.009 times power-level (nearly one-hundredth), an attenuation of 20 dB. The power is measured in Watt / m^2, so if we have a power density at 1 km distance of 16 mW / m^2, then at a distance of 2 km we have 4 mW / m^2 and at 3 km distance it will be 1 mW / m^2. The relationship between power density and field intensity is similar to that for power and voltage. The field intensity of the wave varies inversely with the distance from the source. The field intensity is measured in volt / meter, so if we have a field strength at 1 km of 100 mV / m, then at a distance of 2 km we have 50 mV / m and at 3 km distance it will be 25 mV /m, and so on.

Relationship of field strength and power intensity is this: 1mv / m = 2.65 mW / m^2, with a free space impedance of 377 Ω.

Free-space attenuation is a major factor in signal strength diminutions, but our radio signals undergo a variety of other losses as well. The phenomena of *refraction, diffraction and reflection*, that allow us long distance propagation, attenuate as well and can even absorb our radio energy. Radio waves are attenuated when they pass through the ionosphere or when their traveling course is altered by the ionosphere properties. This last phenomenon allows us useful long-distance propagation, but a price has to be paid. This can vary from slight losses to total absorption. Circumstances can be so severe that our radio signals become too weak for decent communication. These topics will be covered soon in more detail.

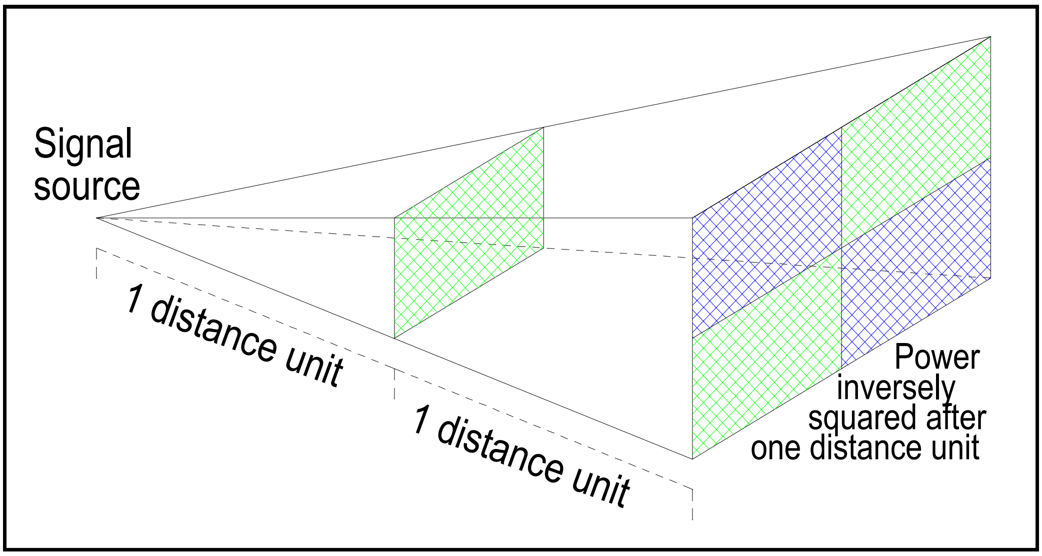

Fig 1.3 *The power of a propagating wave disperses inversely squared after one traveled distance unit. Each of the five in one color filled rectangles in the sketch (in reality a spherical section) has the same surface area.*

Radio energy is also lost when our waves travel through media other than a vacuum. Radio waves propagate through the atmosphere and solid materials by activating the electrons. Those electrons re-radiate the energy at the same frequency, but the re-radiation is not always an efficient or lossless process. Part of the energy is transformed into heat and retrained by the pass-through medium: absorption occurs. How much of the pass-through energy is lost or absorbed, depends on the characteristics and density of the medium and on the frequency of the signal. Attenuation in the atmosphere is minor from 10 MHz to 3 GHz; higher frequencies can give rather high absorption, due to water vapor and oxygen molecules. **–30-**

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