Radio propagation

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Radio propagation describes how radio waves behave when they are transmitted, or are propagated from one point on the Earth to another.[1] Like light waves, radio waves are affected by the phenomena of reflection, refraction, diffraction, absorption, polarization and scattering.[2]

Radio propagation is affected by the daily changes of water vapor in the troposphere and ionization in the upper atmosphere, due to the Sun. Understanding the effects of varying conditions on radio propagation has many practical applications, from choosing frequencies for international shortwave broadcasters, to designing reliable mobile telephone systems, to radio navigation, to operation of radar systems. Radio propagation is also affected by several other factors determined by its path from point to point. This path can be a direct line of sight path or an over-the-horizon path aided by refraction in the ionosphere. Factors influencing ionospheric radio signal propagation can include sporadic-E, spread-F, solar flares, geomagnetic storms, ionospheric layer tilts, and solar proton events.

Radio waves at different frequencies propagate in different ways. The interaction of radio waves with the ionized regions of the atmosphere makes radio propagation more complex to predict and analyze than in free space. Ionospheric radio propagation has a strong connection to space weather. A sudden ionospheric disturbance or shortwave fadeout is observed when the x-rays associated with a solar flare ionize the ionospheric D-region. Enhanced ionization in that region increases the absorption of radio signals passing through it. During the strongest solar x-ray flares, complete absorption of virtually all ionospherically propagated radio signals in the sunlit hemisphere can occur. These solar flares can disrupt HF radio propagation and affect GPS accuracy.

Predictions of the average propagation conditions were needed and made during the Second world war. A most detailed code developed by Karl Rawer was applied in the german Wehrmacht, and after the war by the French Navy.

Since radio propagation is not fully predictable, such services as emergency locator transmitters, in-flight communication with ocean-crossing aircraft, and some television broadcasting have been moved to communications satellites. A satellite link, though expensive, can offer highly predictable and stable line of sight coverage of a given area.

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Free space propagation

In free space, all electromagnetic waves (radio, light, X-rays, etc) obey the inverse-square law which states that the power density of an electromagnetic wave is proportional to the inverse of the square of the distance from the source [3] or:

$$\rho_P \propto \frac{1}{r^2}.$$

Doubling the distance from a transmitter means that the power density of the radiated wave at that new location is reduced to one-quarter of its previous value.

The power density per surface unit is proportional to the product of the electric and magnetic field strengths. Thus, doubling the propagation path distance from the transmitter reduces each of their received field strengths over a free-space path by one-half.

Modes

Radio frequencies and their primary mode of propagation

Band		Frequency	Wavelength	Propagation via
VLF	Very Low Frequency	3–30 kHz	100–10 km	Guided between the earth and the ionosphere.
LF	Low Frequency	30–300 kHz	10–1 km	Guided between the earth and the D layer of the ionosphere. Surface waves.
MF	Medium Frequency	300–3000 kHz	1000–100 m	Surface waves. E, F layer ionospheric refraction at night, when D layer absorption weakens.
HF	High Frequency (Short Wave)	3–30 MHz	100–10 m	E layer ionospheric refraction. F1, F2 layer ionospheric refraction.

VHF	Very High Frequency	30–300 MHz	10–1 m	Infrequent E ionospheric refraction. Extremely rare F1,F2 layer ionospheric refraction during high sunspot activity up to 80 MHz. Generally direct wave. Sometimes tropospheric ducting.
UHF	Ultra High Frequency	300–3000 MHz	100–10 cm	Direct wave. Sometimes tropospheric ducting.
SHF	Super High Frequency	3–30 GHz	10–1 cm	Direct wave.
EHF	Extremely High Frequency	30–300 GHz	10–1 mm	Direct wave limited by absorption.

Surface modes

Main article: Surface wave

Lower frequencies (between 30 and 3,000 kHz) have the property of following the curvature of the earth via groundwave propagation in the majority of occurrences.

In this mode the radio wave propagates by interacting with the semi-conductive surface of the earth. The wave "clings" to the surface and thus follows the curvature of the earth. Vertical polarization is used to alleviate short circuiting the electric field through the conductivity of the ground. Since the ground is not a perfect electrical conductor, ground waves are attenuated rapidly as they follow the earth's surface. Attenuation is proportional to the frequency making this mode mainly useful for LF and VLF frequencies.

Today LF and VLF are mostly used for time signals, and for military communications, especially with ships and submarines. Early commercial and professional radio services relied exclusively on long wave, low frequencies and ground-wave propagation. To prevent interference with these services, amateur and experimental transmitters were restricted to the higher (HF) frequencies, felt to be useless since their ground-wave range was limited. Upon discovery of the other propagation modes possible at medium wave and short wave frequencies, the advantages of HF for commercial and military purposes became apparent. Amateur experimentation was then confined only to authorized frequency segments in the range.

Direct modes (line-of-sight)

Line-of-sight is the direct propagation of radio waves between antennas that are visible to each other. This is probably the most common of the radio propagation modes at VHF and higher frequencies. Because radio signals can travel through many non-metallic objects, radio can be picked up through walls. This is still line-of-sight propagation. Examples would include propagation between a satellite and a ground antenna or reception of television signals from a local TV transmitter.

Ground plane reflection effects are an important factor in VHF line of sight propagation. The interference between the direct beam line-of-sight and the ground reflected beam often leads to an effective inverse-fourth-power law for ground-plane limited radiation. [Need reference to inverse-fourth-power law + ground plane. Drawings may clarify]

Ionospheric modes (skywave)

Main article: Skywave

Skywave propagation, also referred to as skip, is any of the modes that rely on refraction of radio waves in the ionosphere, which is made up of one or more ionized layers in the upper atmosphere. F2-layer is the most important ionospheric layer for HF propagation, though F1, E, and D-layers also play some role. These layers are directly affected by the sun on a daily cycle, the seasons and the 11-year sunspot cycle determines the utility of these modes. During solar maxima, the whole HF range up to 30 MHz can be used and F2 propagation up to 50 MHz are observed frequently depending upon daily solar flux values. During solar minima, propagation of higher frequencies is generally worse.

Forecasting of skywave modes is of considerable interest to amateur radio operators and commercial marine and aircraft communications, and also to shortwave broadcasters.

Meteor scattering

Meteor scattering relies on reflecting radio waves off the intensely ionized columns of air generated by meteors. While this mode is very short duration, often only from a fraction of second to couple of seconds per event, digital Meteor burst communications allows remote stations to communicate to a station that may be hundreds of miles up to over 1,000 miles (1,600 km) away, without the expense required for a satellite link. This mode is most generally useful on VHF frequencies between 30 and 250 MHz.

Auroral reflection

Intense columns of Auroral ionization at 100 km altitudes within the auroral oval reflect radio waves, perhaps most notably on HF and VHF. The reflection is angle-sensitive - incident ray vs. magnetic field line of the column must be very close to right-angle. Random motions of electrons spiraling around the field lines create a Doppler-spread that broadens the spectra of the emission to more or less noise-like—depending on how high radio frequency is used. The radio-auroras are observed mostly at high latitudes and rarely extend down to middle latitudes. The occurrence of radio-auroras depends on solar activity (flares, coronal holes, CMEs) and annually the events are more numerous during solar cycle maximas. Radio aurora includes the so-called afternoon radio aurora which produces stronger but more distorted signals and after the Harang-minima, the late-night radio aurora (sub-storming phase) returns with variable signal strength and lesser doppler spread. The propagation range for this predominantly back-scatter mode extends up to about 2000 km in east-west plane, but strongest signals are observed most frequently from north at nearby sites on same latitudes.

Rarely, a strong radio-aurora is followed by Auroral-E, which resembles both propagation types in some ways.

Sporadic-E propagation

Sporadic E (Es) propagation can be observed on HF and VHF bands. It must not be confused with ordinary HF E-layer propagation. Sporadic-E at mid-latitudes occurs mostly during summer season, from May to August in the northern hemisphere and from November to February in the southern hemisphere. There is no single cause for this mysterious propagation mode. The reflection takes place in a thin sheet of ionisation around 90 km height. The ionisation patches drift westwards at speeds of few hundred km per hour. There is a weak periodicity noted during the season and typically Es is observed on 1 to 3 successive days and remains absent for a few days to reoccur again. Es do not occur during small hours; the events usually begin at dawn, and there is a peak in the afternoon and a second peak in the evening. Es propagation is usually gone by local midnight.

Maximum observed frequency (MOF) for Es is found to be lurking around 30 MHz on most days during the summer season, but sometimes MOF may shoot up to 100 MHz or even more in ten minutes to decline slowly during the next few hours. The peak-phase includes oscillation of MOF with periodicity of approximately 5...10 minutes. The propagation range for Es single-hop is typically 1000 to 2000 km, but with multi-hop, double range is observed. The signals are very strong but also with slow deep fading.

Thomas F. Giella, retired meteorologist, space plasma physicist and an Amateur Radio Operator (NZ4O), cites the following from his professional research:

Just as the E layer is the main refraction medium for medium frequency (300–3000 kHz) signal propagation within approximately 5000 km (3000 mi), so is a Sporadic-E (Es) cloud. Sporadic-E (Es) clouds occur at approximately 100 km (60 mi) in altitude and generally move from ESE to WNW. Like Stratosphere level warming and Troposphere level temperature and moisture discontinuities, Sporadic-E (Es) clouds can depending on the circumstances absorb, block or refract medium, high and very high frequency RF signals in an unpredictable manner.

The main source for "high latitude" Sporadic E (Es) clouds is geomagnetic storming induced radio aurora activity.

The main source for "mid latitude" Sporadic-E (Es) clouds is wind shear produced by internal buoyancy/gravity waves (IBGW's), that create traveling ionosphere disturbances (TID's), most of which are produced by severe thunderstorm cell complexes with overshooting tops that penetrate into the Stratosphere. Another tie in between Sporadic-E (Es) and a severe thunderstorm is the Elve.

The main sources for "low latitude" Sporadic-E (Es) clouds is wind shear produced by internal buoyancy/gravity waves (IBGW's), that create traveling ionosphere disturbances, most of which are produced by severe thunderstorm cell complexes tied to tropical cyclones. High electron content in the Equatorial Ring Current also plays a role.

The forecasting of Sporadic-E (Es) clouds has long been considered to be impossible. However it is possible to identify certain troposphere level meteorological conditions that can lead to the formation of Sporadic E (Es) clouds. One is as mentioned above the severe thunderstorm cell complex.

Sporadic-E (Es) clouds have been observed to initially occur within approximately 150 km (90 mi) to the right of a severe thunderstorm cell complex in the northern hemisphere, with the opposite being observed in the southern hemisphere. To complicate matters is the fact that Sporadic-E (Es) clouds that initially form to the right of a severe thunderstorm complex in the northern hemisphere, then move from ESE-WNW and end up to the left of the severe thunderstorm complex in the northern hemisphere. So one has to look for Sporadic-E (Es) clouds on either side of a severe thunderstorm cell complex. Things get even more complicated when two severe thunderstorm cell complexes exist approximately 1000–2000 miles apart.

Not all thunderstorm cell complexes reach severe levels and not all severe thunderstorm cell complexes produce Sporadic-E (Es). This is where knowledge in tropospheric physics and weather analyses/forecasting is necessary.

Some of the key elements in identifying which severe thunderstorm cell complexes have the potential to produce Sporadic-E (Es) via wind shear, from internal buoyancy/gravity waves, that produce traveling ionosphere disturbances include:

1.) Negative tilted mid and upper level long wave troughs.

2.) Approximate 150 knot (170 mph, 280 km/h) jet stream jet maxes that produce divergence and therefore create a sucking vacuum effect above thunderstorm cells, that assist thunderstorm cells in reaching and penetrating the tropopause into the stratosphere.

3.) 500 mb (50 kPa) temperatures of −20 °C or colder, which produce numerous positive and negative lightning bolts and inter-related Sprites and Elves.

4.) Approximate 150–175 knot (170–200 mph) updrafts within thunderstorm cells complexes that create overshooting tops that penetrate the Tropopause into the Stratosphere (See definition #20 on Stratospheric Warming), launching upwardly propagating internal buoyancy/gravity waves, which create traveling ionosphere disturbances and then wind shear.

Tropospheric modes

Tropospheric scattering

At VHF and higher frequencies, small variation (turbulence) in the density of the atmosphere at a height of around 6 miles (10 km) can scatter some of the normally line-of-sight beam of radio frequency energy back toward the ground, allowing over-the-horizon communication between stations as far as 500 miles (800 km) apart. The military developed the White Alice communications system covering all of Alaska, using this tropospheric scattering principle.

Tropospheric ducting

Sudden changes in the atmosphere's vertical moisture content and temperature profiles can on random occasions make microwave and UHF & VHF signals propagate hundreds of kilometers up to about 2,000 kilometers (1,300 mi)—and for ducting mode even farther—beyond the normal radio-horizon. The inversion layer is mostly observed over high pressure regions, but there are several tropospheric weather conditions which create these randomly occurring propagation modes. Inversion layer's altitude for non-ducting is typically found between 100 meters (300 ft) to about 1 kilometer (3,000 ft) and for ducting about 500 meters to 3 kilometers (1,600 to 10,000 ft), and the duration of the events are typically from several hours up to several days. Higher frequencies experience the most dramatic increase of signal strengths, while on low-VHF and HF the effect is negligible. Propagation path attenuation may be below free-space loss. Some of the lesser inversion types related to warm ground and cooler air moisture content occur regularly at certain times of the year and time of day. A typical example could be the late summer, early morning tropospheric enhancements that bring in signals from distances up to few hundred kilometers for a couple of hours, until undone by the Sun's warming effect.

Tropospheric delay

This is a source of error in radio ranging techniques, such as in GPS.

Rain scattering

Rain scattering is purely a microwave propagation mode and is best observed around 10 GHz, but extends down to a few gigahertz—the limit being the size of the scattering particle size vs. wavelength. This mode scatters signals mostly forwards and backwards when using horizontal polarization and side-scattering with vertical polarization. Forward-scattering typically yields propagation ranges of 800 km. Scattering from snowflakes and ice pellets also occurs, but scattering from ice without watery surface is less effective. The most common application for this phenomenon is microwave rain radar, but rain scatter propagation can be a nuisance causing unwanted signals to intermittently propagate where they are not anticipated or desired. Similar reflections may also occur from insects though at lower altitudes and shorter range. Rain also causes attenuation of point-to-point and satellite microwave links. Attenuation values up to 30 dB have been observed on 30 GHz during heavy tropical rain.

Aeroplane scattering

Aeroplane scattering (or most often reflection) is observed on VHF through microwaves and besides back-scattering, yields momentary propagation up to 500 km even in a mountain-type terrain. The most common back-scatter application is air-traffic radar and bistatic forward-scatter guided-missile and aeroplane detecting trip-wire radar and the US space radar.

Lightning scattering

Lightning scattering has sometimes been observed on VHF and UHF over distance of about 500 km. The hot lightning channel scatters radiowaves for a fraction of a second. The RF noise burst from the lightning makes the initial part of the open channel unusable and the ionisation disappears soon because of combination at low altitude high atmospheric pressure. Although the hot lightning channel is briefly observable with microwave radar, this mode has no practical use for communications.

Other effects

Diffraction

Knife-Edge diffraction is the propagation mode where radio waves are bent around sharp edges. For example, this mode is used to send radio signals over a mountain range when a line-of-sight path is not available. However, the angle cannot be too sharp or the signal will not diffract. The diffraction mode requires increased signal strength, so higher power or better antennas will be needed than for an equivalent line-of-sight path.

Diffraction depends on the relationship between the wavelength and the size of the obstacle. In other words, the size of the obstacle in wavelengths. Lower frequencies diffract around large smooth obstacles such as hills more easily. For example, in many cases where VHF (or higher frequency) communication is not possible due to shadowing by a hill, one finds that it is still possible to communicate using the upper part of the HF band where the surface wave is of little use.

Diffraction phenomena by small obstacles are also important at high frequencies. Signals for urban cellular telephony tend to be dominated by ground-plane effects as they travel over the rooftops of the urban environment. They then diffract over roof edges into the street, where multipath propagation, absorption and diffraction phenomena dominate.

Absorption

Low-frequency radio waves travel easily through brick and stone and VLF even penetrates sea-water. As the frequency rises, absorption effects become more important. At microwave or higher frequencies, absorption by molecular resonance in the atmosphere (mostly water, H_2O and oxygen, O_2) is a major factor in radio propagation. For example, in the 58–60 GHz band, there is a major absorption peak which makes this band useless for long-distance use. This phenomenon was first discovered during radar research during World War II. Beyond around 400 GHz, the Earth's atmosphere blocks some segments of spectra while still passes some—this is true up to UV light, which is blocked by ozone, but visible light and some of the NIR is transmitted.

Heavy rain and snow also affect microwave reception.

See also

Main article: *List of radio propagation terms*

- Diversity scheme
- Earth bulge
- Electromagnetic radiation
- Fading
- Fresnel zone
- Free space
- Inversion (meteorology)
- Kennelly–Heaviside layer
- Near and far field
- Radio frequency
- Radio horizon
- Radio propagation model
- Rayleigh fading
- Ray tracing (physics)
- Schumann resonance
- Skip (radio)
- Skip zone
- Skywave
- Tropospheric propagation
- TV and FM DX

References

1. ^ H. P. Westman et al., (ed), *Reference Data for Radio Engineers, Fifth Edition*, 1968, Howard W. Sams and Co., no ISBN, Library of Congress Card No. 43-14665 page 26-1
2. ^ Demetrius T Paris and F. Kenneth Hurd, *Basic Electromagnetic Theory*, McGraw Hill, New New York 1969 ISBN -0 048470-8, Chapter 8
3. ^ Westman *Reference data* page 26-19

- Larry D. Wolfgang et al., (ed), *The ARRL Handbook for Radio Amateurs, Sixty-Eighth Edition* , (1991), ARRL, Newington CT USA ISBN 0-87259-168-9

Further reading

- Lucien Boithais: *Radio Wave Propagation*. McGraw-Hill Book Company, New York. 1987. ISBN 0-07-006433-4
- Karl Rawer:*Wave Propagatiom im the Ionosphere*.Kluwer Acad.Publ.,Dordrecht 1993. ISBN 0-7923-0775-5

External links

Wikimedia Commons has media related to: ***Radio propagation***

- Online Propagation Tools, HF Solar Data, and HF Propagation Tutorials
- DXing.info - Propagation links
- Solar Cycle 24 and VHF Aurora Website (www.solarcycle24.com)
- Ionospheric Prediction Service - Australia
- Unusual HF Propagation Phenomena. 13 Apr 2009 Includes useful recordings each type. Retrieved 9 Oct 2009.
- HF Radio Propagation Software for Firefox - Propfire Firefox plug for monitoring radio propagation, website utility to display HF radio propagation status and article on understanding HF radio propagation forecasting
- RadioWORKS A radio wave propagation and antenna length calculator
- SWDXER ¨The SWDXER¨ - with general SWL information and radio antenna tips.
- Space Weather and Radio Propagation Resource Center Live data and images of space weather and radio propagation.
- ARRL Propagation Page The American Radio Relay League page on radio propagation.
- The Basics of Radio Wave Propagation A resource by Edwin C. Jones (AE4TM), MD, PhD, Department of Physics and Astronomy, University of Tennessee.
- "NZ4O 160 Meter Propagation Theory Notes". *A website dedicated to layman level explanations of "seemingly" mysterious 160 meter (MF/HF) propagation occurrences*. http://www.wcflunatall.com/nz4o5.htm.
- Dynamic Radio Propagation Data Constantly updated radio propagation data pulled from various sources.

The following external references provide practical examples of radio propagation concepts as demonstrated using software built on the VOACAP model.

- High Frequency radio propagation de-mystified.
- Is High Frequency radio propagation reciprocal?
- How does noise affect radio signals?

The following external link is designed for use by cell phones and mobile devices that can display content using Wireless Markup Language and the Wireless Application Protocol:

- WAP/WML Space Weather and Radio Propagation Resources Space weather and radio propagation resources.

Radio spectrum

ELF	SLF	ULF	VLF	LF	MF	HF	VHF	UHF	SHF	EHF
3 Hz	30 Hz	300 Hz	3 kHz	30 kHz	300 kHz	3 MHz	30 MHz	300 MHz	3 GHz	30 GHz
30 Hz	300 Hz	3 kHz	30 kHz	300 kHz	3 MHz	30 MHz	300 MHz	3 GHz	30 GHz	300 GHz

Electromagnetic spectrum

← *shorter wavelengths* *longer wavelengths* →

Gamma rays · **X-rays** · **Ultraviolet** · **Visible** · **Infrared** · **Terahertz radiation** · **Microwave** · **Radio**

Visible (optical)	Violet · Blue · Green · Yellow · Orange · Red
Microwaves	W band · V band · Q band · K_a band · K band · K_u band · X band · S band · C band · L band
Radio	EHF · SHF · UHF · VHF · HF · MF · LF · VLF · ULF · SLF · ELF
Wavelength types	Microwave · Shortwave · Medium wave · Longwave