

**IEEE Std 211-1990**  
(Revision of IEEE Std 211-1977)

# **IEEE Standard Definitions of Terms for Radio Wave Propagation**

Sponsor  
**Wave Propagation Standards Subcommittee  
of the  
IEEE Antennas and Propagation Society**

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**Abstract:** IEEE Std 211-1990, *IEEE Standard Definitions of Terms for Radio Wave Propagation*, identifies terms currently in use in the field of radio wave propagation. Standard definitions for those terms are established.

**Keywords:** Radio wave propagation; glossary; terminology; definitions; dictionary

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## Foreword

(This Foreword is not part of IEEE Std 211-1990, IEEE Standard Definitions of Terms for Radio Wave Propagation.)

This constitutes the second revision to the original ANSI/IEEE Std 211-1969. The early history of ANSI/IEEE Std 211 was described in a Foreword to the first (1977) revision. The work on this second revision started on "tabled" definitions almost as soon as the 1977 version went to press. Chairmen of the Wave Propagation Standards Committee Subcommittee on Definitions have included Kurt Toman, C. H. Liu, John M. Kelso, and George H. Hagn, the current chairman. The primary developers of this second revision are listed in the acknowledgements along with others who materially assisted the work. Within the IEEE, the work has been coordinated with the APS Antenna Standards Committee and the following societies: EMC, COM, and Instrumentation and Measurements. It has also been coordinated with the IEEE Dictionary (SCC10). The current version has been coordinated with the CCIR (International Radio Consultative Committee), the IEC (International Electrotechnical Commission), and with U.S. and Canadian officials of URSI (International Union of Radio Science).

The fields covered include the following where pertinent to electromagnetic wave propagation: radio astronomy, optical waves, gravity waves, plasma waves, ionosphere, magnetosphere, and magneto-hydrodynamic, acoustic, and electrostatic waves.

S.I. (rationalized MKS) units have been used throughout.

As aptly noted in the Foreword to the first revision, "The need for revising a definitions standard transcends its publication date and is essentially continuous." The current revision is one step in the continuous flow of this process.

This standard was prepared by a Wave Propagation Standards Committee (WPSC) Subcommittee on Definitions consisting of:

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The subcommittee, the WPSC, and the APS appreciate the assistance of all those who contributed to this standard.

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# IEEE Standard Definitions of Terms for Radio Wave Propagation

**absorption.** The irreversible conversion of the energy of an electromagnetic wave into another form of energy as a result of wave interaction with matter.

**absorption (frequency) band.** A band of frequencies for which a medium is considered to be an absorbing medium.

**absorption, deviative.** Ionospheric absorption that occurs when the refractive index is appreciably less than unity.

**absorption, ionospheric.** The loss of energy from an electromagnetic wave caused by collisions in the ionosphere, primarily between electrons and neutral species and electrons and ions.

**absorption, non-deviative.** Ionospheric absorption that occurs when the refractive index remains close to unity.

**absorption, polar cap.** The intense absorption of radio waves in polar regions caused by the arrival of high energy solar protons, concentrated in this region by the lines of force of the Earth's magnetic field.

**acoustic-gravity wave.** In the atmosphere, a low-frequency wave whose restoring forces are compressional, gravitational and buoyant.

**albedo.** (1) In astronomy (where the sizes of objects/surfaces are extremely large in comparison to a wavelength), the ratio of the total radiation reflected (scattered) from an object to the total incident power.

(2) In transport theory or particle scattering (where the size of the object is not extremely large), the ratio of the total scattering cross-section to the sum of the scattering and absorption cross-sections.

**Alfvén velocity ( $V_\alpha$ ).** The characteristic velocity of an Alfvén wave, given by:

$$V_\alpha = H_o \left[ \frac{\mu}{\rho} \right]^{1/2}$$

where  $\mu$  is the permeability,  $H_o$  is the static magnetic field strength, and  $\rho$  is the mass density of the conducting fluid.

**Alfvén wave.** In a homogeneous magneto-ionic medium, the magneto-hydrodynamic wave that propagates in the direction of the static magnetic field, with associated electric and magnetic fields and fluid particle velocities oriented perpendicular to the direction of propagation.

**amplitude.** Of a sinusoidally varying quantity, the maximum value of this quantity. *Note:* Sometimes the rms value, rather than the peak value, is used to characterize the amplitude of a sinusoidal oscillation.

**angle of arrival.** Of a wave, the angle between the negative of the propagation vector and a reference direction.

**angle of incidence.** At a point on a surface, the acute angle between the normal to this surface and the direction of propagation of an incident wave.

**angular frequency ( $\omega$ ).** Of a sinusoidal wave,  $2\pi$  times the frequency. The angular frequency is also called the radian frequency.

**antenna temperature.** The temperature of a black body that, when placed around a matched antenna that is similar to the actual antenna but loss-free, produces from this antenna the same available noise power, in a specified frequency range, as the actual antenna in its normal electromagnetic environment.

**antipodal focusing.** Ionospheric focusing observed in the vicinity of the antipodal point.

**atmospheric radio duct.** A layer in the atmosphere within which radio waves propagate with low attenuation.

**atmospherics.** Transient bursts of electromagnetic radiation arising from natural electrical disturbances in the lower atmosphere. *Note:* In the past, the term "static" was used to include atmospherics and other radio noise. The term "sferics" is in current use.

**attenuation, of an electromagnetic wave.** The decrease in amplitude of a field with distance or with changes in the propagation path in excess of the decrease due to a geometrical spreading factor. *See also:* **spreading factor.**

**attenuation constant.** The magnitude of the attenuation vector.

**attenuation vector ( $\vec{\alpha}$ ).** The real part of the propagation vector ( $\vec{\gamma}$ ). The attenuation vector points in the direction of maximum decrease in amplitude.

**aurora.** Collective name of optical, electrical and magnetic phenomena, generally at high latitudes, resulting from direct excitation of the upper atmosphere by energetic particles.

**auroral attenuation.** The attenuation of radio waves propagating through the D and E regions of the ionosphere when additional ionization is produced by an aurora.

**auroral hiss.** Audio-frequency electromagnetic noise associated with auroras.

**auroral zone, auroral oval.** An annular region situated between approximately 60 degrees and 70 degrees geomagnetic latitude, north or south, in which auroras are frequently present.

**backscatter.** The scattering of waves back toward the source.

**bandwidth, coherent; dispersive bandwidth.** *Same as:* **frequency selective bandwidth.**

**bandwidth, frequency selective.** The inverse of the product  $2\pi\sigma_\tau$ , where  $\sigma_\tau$  is the time delay spread.

**Brewster angle.** The angle of incidence of a wave on the planar bounding surface of a lossless medium for which the reflection coefficient for parallel polarization is zero. *Note:* For a lossy medium, the pseudo-Brewster angle is that angle at which the modulus of the reflection coefficient is a minimum.

**brightness of surface.** The power radiated per unit area, per unit bandwidth, per unit solid angle.

**brightness temperature.** Of a region on an extended source at a given wavelength, the temperature of a black-body radiator that has the same brightness.

**characteristic impedance.** Of a transmission line, the ratio of the complex voltage between the conductors to the complex current on the conductors, taken at a common reference plane. These voltages and currents must be associated with waves traveling in the same direction.

**characteristic wave.** A wave that propagates in a homogeneous anisotropic medium with unchanging polarization. *See:* **ordinary wave** and **extraordinary wave.**

**circularly polarized wave.** An electromagnetic wave for which the locus of the tip of the electric field vector is a circle in a plane orthogonal to the wave normal. This circle is traced at a rate equal to the angular frequency of the wave. *See also:* **left-handed polarized wave** and **right-handed polarized wave.**

**coherence.** The correlation between electromagnetic fields at points separated in space or in time or both.

**coherence function [ $R(\Delta\vec{r}, \tau)$ ].** The expected value of the product of a component of the complex field ( $F_x$ ) at a given location ( $\vec{r}$ ) and time  $t$  and the complex conjugate of that field component ( $F_x^*$ ) at a different location ( $\vec{r} + \Delta\vec{r}$ ) and time ( $t + \tau$ ):

$$R(\Delta\vec{r}, \tau) = [F_x(\vec{r}, \tau) F_x^*(\vec{r} + \Delta\vec{r}, t + \tau)]$$

*Notes:* (1) This definition assumes that the statistics of the fields are homogeneous and stationary. (2) The normalized coherence function, also called the mutual coherence function, is the coherence function divided by the expected value of the square of the magnitude of the field.

**collision frequency.** In a plasma, the average number of collisions per second of a charged particle of a given species with particles of another or the same species.

**conductivity ( $\sigma$ ).** A macroscopic material property that relates the conduction current density ( $\vec{J}$ ) to the electric field ( $\vec{E}$ ) in the medium. For a monochromatic wave in a linear medium, that relationship is described by the (phasor) equation:

$$\vec{J} = \bar{\sigma} \cdot \vec{E}$$

where  $\bar{\sigma}$ , the conductivity, is a tensor, generally frequency dependent and  $\vec{J}$  is in phase with  $\vec{E}$ . For an isotropic medium, the tensor conductivity reduces to a scalar conductivity.

**cosmic noise.** Noise-like radio waves originating from extragalactic sources.

**critical frequency, of an ionospheric layer.** The limiting frequency below which a normally incident magneto-ionic wave component is reflected by, and above which it penetrates through, an ionospheric layer.

**cross-polarization.** The polarization orthogonal to a reference polarization. *See: orthogonal polarization.*

**cross-polarization discrimination.** The ratio of the signal level at the output of a receiving antenna, nominally co-polarized with the transmitting antenna, to the output of a receiving antenna of the same gain but nominally orthogonally polarized to the transmitting antenna.

**cross-polarization isolation.** The ratio of the wanted signal level to the unwanted signal level in the same receiver channel when the

transmitting antenna is radiating nominally orthogonally polarized signals at the same frequency and power level.

**cyclotron frequency.** *See: gyro-frequency.*

**cylindrical wave.** A wave whose equiphasic surfaces form a family of coaxial cylinders.

**D layer.** An ionized layer in the D region.

**D region.** The region of the terrestrial ionosphere between about 50 and 90 km altitude. *Note:* The D region is responsible for most of the daytime attenuation of LF, MF and HF radio waves.

**Debye length ( $L_D$ ).** That distance in a plasma over which a free electron may move under its own kinetic energy before it is pulled back by the electrostatic restoring forces of the polarization (ion) cloud surrounding it. Over this distance, a net charge density can exist in an ionized gas. The Debye length is given by:

$$L_D = 6.9 \left[ \frac{T_e}{N_e} \right]^{1/2}$$

where  $T_e$  is the electron temperature, and  $N_e$  is the electron number density.

**decorrelation distance.** The direction-dependent distance over which the mutual coherence function falls to  $1/e$  of its maximum value. Also called correlation length.

**decorrelation time ( $\tau_0$ ).** The time required for the mutual coherence function to decay to  $1/e$  of its maximum value.

**defocusing.** The failure of rays to converge.

**diffracted wave.** An electromagnetic wave generated when an incident wave encounters one or more obstacles or is limited by openings.

**diffraction.** The deviation of the direction of energy flow of a wave, not attributable to reflection and/or refraction, when it passes an obstacle, a restricted aperture, or other inhomogeneities in a medium.

**direct wave.** A wave propagated over an unobstructed ray path from a source to a point.

**direction of polarization.** Of an elliptically polarized wave, the direction of the major axis of the electric vector ellipse.

**direction of propagation.** At any point in a medium, the direction of the time-averaged energy flow. *See: Poynting vector.*

**dispersion (of a wave).** The variation of the phase velocity with frequency.

**dispersion relation.** The functional relationship between the angular frequency,  $\omega$ , and the wave vector,  $\vec{k}$ , for waves in a source-free medium. For a dispersionless medium,  $\vec{k}$  is linearly proportional to  $\omega$ .

**dispersive medium.** A medium where the phase velocity depends on frequency.

**Doppler effect.** For an observer, the apparent change in frequency of a wave when there is relative motion between the source and the observer.

**Doppler spread.** *See: spread, Doppler.*

**ducting.** Guided propagation of radio waves inside a tropospheric radio duct. *See also: atmospheric radio duct and tropospheric duct.*

**E layer.** An ionized layer in the E region. The ionization within the E region is highly correlated with the incident solar flux. Therefore, the normal E layer is present only during daytime.

**E region.** The region of the terrestrial ionosphere between about 90 and 150 km altitude.

**edge diffraction.** Diffraction by a transverse obstacle with a relatively sharp profile, located between the transmission and reception points. Diffraction over a very sharp profile is frequently called knife-edge diffraction.

**effective radius of the earth.** An effective value for the radius of the earth that is used in place of the geometrical radius to correct approximately for atmospheric refraction when the index of refraction changes linearly with height, and the rays propagate nearly

parallel to the earth (with low grazing angles). *Note: Under conditions of standard refraction, the effective radius of the earth is  $8.5 \times 10^6$  meters, or 4/3 the geometrical radius.*

**electric displacement ( $\vec{D}$ ).** *Same as: electric flux density.*

**electric field ( $\vec{E}$ ).** The electric force that acts on a unit electric charge independently of the velocity of that charge.

**electric field strength ( $|\vec{E}|$ ).** The magnitude of the electric field at a point in the field. *Note: This term has sometimes been called the electric field intensity, but such use is deprecated, since intensity connotes power in optics and radiation.*

**electric flux density ( $\vec{D}$ ).** A vector quantity related to the charge displaced within the medium by an electric field. The electric flux density is that function whose divergence is the charge density. *Note: Using phasor notation, the electric flux density is given by:*

$$\vec{D} = \bar{\epsilon} \cdot \vec{E}$$

where  $\vec{D}$  is the electric flux density,  $\bar{\epsilon}$  is the permittivity in the medium, and  $\vec{E}$  is the electric field. In an isotropic medium,  $\epsilon$  is a scalar and  $\vec{D}$  is parallel to  $\vec{E}$ . In an anisotropic medium,  $\bar{\epsilon}$  is a tensor and  $\vec{D}$  and  $\vec{E}$  are not necessarily parallel.

**electrical length.** For a wave of a given frequency, a distance between field points, expressed in wavelengths of the wave in the medium. *Note: The electrical length is sometimes expressed in radians or degrees.*

**electromagnetic field.** A time-varying field, associated with the electric or magnetic forces and described by Maxwell's equations.

**electromagnetic pulse (EMP).** A transient high-intensity electromagnetic field. EMP is commonly associated with nuclear explosions in or near the Earth's atmosphere; however, electromagnetic pulses can arise from other sources, such as lightning.

**electromagnetic spectrum.** The spectrum of electromagnetic radiation, consisting of: gam-

ma rays, wavelengths shorter than 0.006 nm; X rays, 0.006 to 5 nm; ultraviolet rays, 5 nm to 0.4  $\mu\text{m}$ ; visible light, 0.4 to 0.7  $\mu\text{m}$ ; infrared, 0.7  $\mu\text{m}$  to 1 mm; radio, greater than 0.1 mm. *See also: radio spectrum.*

**electromagnetic waves.** Waves characterized by temporal and spatial variations of electric and magnetic fields. Electromagnetic waves are known as radio waves, infrared waves, light waves, etc., depending on the frequency.

**electrostatic wave.** In a plasma, the type of wave whose restoring force is electrostatic. The associated electric field and particle velocity is in the direction of propagation with accompanying charge density fluctuations.

**elevated duct.** A tropospheric radio duct in which the lower boundary is above the surface of the Earth.

**elevation angle.** Complement of the angle of incidence. *See also: grazing angle.*

**ELF.** Extremely low frequency. 3 Hz to 3 kHz. *See: radio spectrum.*

**elliptically polarized (electromagnetic) wave.** An electromagnetic wave for which the locus of the tip of the electric field vector is an ellipse in a plane orthogonal to the wave normal. This ellipse is traced at the rate equal to the angular frequency of the wave. *See also: left-hand polarized wave; right-hand polarized wave.*

**emissivity.** The ratio of power (per unit surface area, per unit solid angle, per unit bandwidth) radiated by a material body to the power radiated by a black body at the same temperature.

**EMP.** *See: electromagnetic pulse.*

**enhanced solar radiation.** The electromagnetic radiation of the sun under other than quiet conditions. *See also: quiet sun.*

**envelope delay.** The time of propagation of the envelope of a wave between two points provided that the envelope is not significantly distorted. *Same as: group delay. See also: group velocity.*

**equiphase surface.** Any surface over which the field vectors of a wave have the same phase.

**EHF.** *See: extremely high frequency.*

**evanescent field.** An electromagnetic field for which the the phase is everywhere the same (no spatial variation) and the amplitude decays exponentially as one moves away from a boundary. An evanescent field is a special case of an inhomogeneous plane wave.

**extragalactic radio waves.** Radio waves from beyond our galaxy. *See: cosmic noise.*

**extraordinary wave (X wave).** The magneto-ionic wave component in which the electric vector rotates in the opposite sense to that for the ordinary wave component. *See: ordinary wave.*

**extremely high frequency (EHF).** 30 to 300 GHz. *See: radio spectrum.*

**F region.** The region of the terrestrial ionosphere from about 150 km altitude to about 1000 km.

**F1 layer.** The lower of the two ionized layers normally existing in the F region in the day hemisphere.

**F2 layer.** The single ionized layer normally existing in the F region in the night hemisphere and the higher of the two layers normally existing in the F region in the day hemisphere.

**fade depth.** The ratio, generally expressed in decibels, of a reference signal power to the signal power during a fade.

**fade duration.** The time interval during which a signal is below a reference value.

**fading.** The temporal variation of received signal power caused by changes in the transmission medium or path(s).

**fading range.** The ratio of maximum signal to minimum signal during fading, usually expressed in dB. Often the fading range is specified over a range of percentages. For example, the 5% to 95% fading range is the

ratio of the signal exceeded 5% of the time to that exceeded 95% of the time.

**fading rate.** The average number of fades occurring per unit time.

**fade slope.** The time rate of change of the signal power during a fade, expressed in dB/second.

**fading spectrum.** The spatial or temporal frequency spectrum of a fading signal.

**Faraday rotation.** The rotation of the polarization ellipse of an electromagnetic wave as it propagates in a magneto-ionic medium.

**fast wave.** An electromagnetic wave propagating close to a boundary with a phase velocity greater than that of a free wave which would exist in an unbounded medium with the same electromagnetic properties. *See also: slow wave.*

**field strength.** *Same as: radio field strength.*

**focusing.** The concentration of electromagnetic energy into a smaller region of space. *See also: defocusing.*

**forward scattering.** Scattering of an electromagnetic wave into directions that are at acute angles to the average direction of propagation of the original wave.

**FOT.** Initials for the French phrase, "Frequence Optimum de Travail" [Optimum Working Frequency (OWF)]. Applies to ionospheric propagation. *See also: optimum working frequency.* *Note:* The FOT is estimated as 0.85 of the predicted monthly median maximum useable frequency (MUF).

**free space.** Free of obstructions and characterized by the constitutive parameters of a vacuum.

**frequency.** Of a periodic oscillation or wave, the number of identical cycles per second, measured in hertz.

**frequency selective fading.** Fading that affects unequally the different spectral components of a radio signal.

**Fresnel ellipse, ellipsoid.** (1) The locus of points for which the sum of distances from two antennas is an integral number of half wavelengths greater than the length of the direct ray between the two antennas. The antennas are at the focal points of the set of ellipses, ellipsoids.

(2) For a ground-reflected ray, the Fresnel ellipse is the locus of points in the ground plane for which the sum of the distances from the two antennas is an integral number of half wavelengths greater than the length of the specularly reflected ray.

**Fresnel zone.** In general, any surface or region bounded by adjacent Fresnel ellipses or ellipsoids. For instance, any plane through both antennas will intersect Fresnel ellipses and define Fresnel zones in that plane. Any plane normal to the ray path between antennas will define a series of circular (annular) Fresnel zones.

**galactic radio waves.** Radio waves originating in our galaxy.

**gravity wave.** *See: acoustic-gravity wave.*

**grazing angle.** The complement of the angle of incidence for large angles of incidence.

**ground wave.** From a source in the vicinity of the surface of the Earth, a wave that would exist in the vicinity of the surface in the absence of an ionosphere. *Note:* The ground wave can be decomposed into the Norton surface wave and a space wave consisting of the vector sum of a direct wave and a ground-reflected wave.

**group delay.** *Same as: envelope delay.*

**group path length.** For a pulsed signal traveling between two points in a medium, the product of the speed of light in vacuum and the travel time of the pulse between the two points, provided the shape of the pulse is not significantly changed.

**group velocity.** Of a traveling wave, the velocity of propagation of the envelope, provided that the envelope moves without significant change of shape. The magnitude of the group velocity is equal to the reciprocal of the rate of change of phase constant with angular frequency.

**guided wave.** A propagating wave whose energy is concentrated within or near boundaries between media having different electromagnetic properties.

**gyro-frequency ( $f_H$ ).** The lowest natural frequency at which charged particles spiral in a fixed magnetic field. It is given by

$$f_H = q \frac{|\vec{B}|}{2\pi m}$$

where  $q$  is the charge of the particles,  $|\vec{B}|$  is the magnitude of magnetic flux density, and  $m$  is the mass of the particles.

**height gain.** In tropospheric propagation, the ratio of the electromagnetic field modulus at a given point to that of the field at another height, at the same location, selected as a reference height. This ratio is generally expressed in decibels and may have a negative value.

**high frequency (HF).** 3 to 30 MHz. *See: radio spectrum.*

**homogeneous plane wave.** A wave in which the planes of constant amplitude and constant phase are parallel. *Note:* Homogeneous plane waves are sometimes called uniform plane waves.

**horizontally polarized wave.** A linearly polarized wave whose electric field vector is perpendicular to the plane of incidence.

**hydromagnetic wave.** *See: magneto-hydrodynamic wave.* Use of the term hydromagnetic wave is deprecated.

**ideal conductor.** *See: perfect conductor.*

**ideally conducting medium.** *See: perfect conductor.*

**ideal dielectric.** *See: perfect dielectric.*

**impedance, intrinsic.** For a monochromatic (time harmonic) electromagnetic wave propagating in a homogeneous medium, the ratio of the complex amplitude of the electric field to that of the magnetic field. *Note:* The intrinsic impedance of a medium is sometimes referred to as the characteristic impedance of the medium.

**incidence angle.** *See: angle of incidence.*

**incident wave.** A wave that impinges on a discontinuity in refractive index or a medium of different propagation characteristics. The incident wave is the total field in the absence of the discontinuity.

**incoherent scattering.** Scattering produced when an incident wave encounters random fluctuations of complex dielectric constant. The fluctuations may be either discrete or continuous (turbid or turbulent in the case of scattering from atmospheric refractive index fluctuations). The scattered fields exhibit random variations in phase and amplitude.

**inhomogeneous plane wave.** A wave for which the planes of constant amplitude and planes of constant phase are not parallel. Sometimes called a heterogeneous plane wave, but this use is deprecated.

**instantaneous frequency.**  $1/(2\pi)$  times the time rate of change of phase of a wave.

**intrinsic impedance.** *See: impedance, intrinsic.*

**ionogram.** A record showing the group path delay of ionospheric echoes as a function of frequency.

**ionosonde.** A swept-frequency or stepped frequency instrument that transmits radio waves vertically or obliquely to the ionosphere and uses the echoes to form an ionogram.

**ionosphere.** That part of a planetary atmosphere where ions and free electrons are present in quantities sufficient to affect the propagation of radio waves.

**ionospheric wave.** *See: sky wave.*

**Jansky.** A unit of spectral power flux density:  $10^{-26}$  times one watt per square meter per hertz.

**knife-edge diffraction.** *See: edge diffraction.*

**lateral wave.** A wave excited at and propagated along the interface of two (possibly lossy) dielectric media when the source is in the medium with the larger refractive index.

For sufficiently large distances from the source, the amplitude of the wave varies as the inverse square of the distance measured along the interface.

**leaky wave.** An electromagnetic wave associated with a fast wave guided along a surface. The wave radiates ("leaks") energy continuously as it travels along the surface and thus decreases exponentially in the direction of propagation. *Note:* Leaky waves may be created by periodic as well as uniform, open guiding structures.

**left-hand polarized wave.** A circularly or elliptically polarized electromagnetic wave for which the electric field vector, viewed by an observer (at the source) looking in the direction of propagation, rotates counterclockwise in space. Thus, a left-handed helical antenna radiates a left-handed polarized wave.

**limiting polarization.** The resultant polarization of a wave after it has emerged from a magneto-ionic medium.

**linearly polarized wave.** An electromagnetic wave for which the locus of the tip of the electric field vector is a straight line in a plane orthogonal to the wave normal.

**LOF.** *See:* lowest observed frequency.

**lowest observed frequency (LOF).** In ionospheric sounding, the lowest radio frequency at which echoes can be detected or observed with a particular equipment.

**lowest useful frequency (LUF).** For sky-wave signals in the MF/HF spectrum, the lowest frequency effective under specified conditions for ionospheric propagation of radio waves between two points. *Note:* The lowest useful frequency is a system-dependent parameter and is determined by factors such as ionospheric absorption, transmitter power, antenna gain, receiver characteristics, type of service, and noise conditions.

**low frequency (LF).** 30 to 300 kHz. *See:* radio spectrum.

**LUF.** *See:* lowest useful frequency.

**M-unit.** A unit in terms of which the refractive modulus of the troposphere is expressed. *See also:* refractive modulus. Example: If the refractivity,  $N$ , is such that  $(N + 10^6 h/a) = 400$ , then the refractive modulus is said to be 400 M-units, or 400 M.

**magnetic constant.** *See:* permeability of free space ( $\mu_0$ ).

**magnetic field ( $\vec{H}$ ).** For time harmonic fields in a medium with linear and isotropic magnetic properties, the magnetic flux density divided by the permeability of the medium.

**magnetic field strength ( $|\vec{H}|$ ).** The magnitude of the magnetic field vector  $\vec{H}$ .

**magnetic flux density ( $\vec{B}$ ).** A vector field that acts on moving charges ( $q$ ) such that the force per unit charge ( $\vec{F}$ ) is equal to the vector (cross) product of the velocity  $\vec{v}$  of the particle and  $\vec{B}$  the magnetic flux density:

$$\frac{\vec{F}}{q} = \vec{v} \times \vec{B}$$

**magnetic induction.** Same as magnetic flux density. Use of the term magnetic induction is deprecated.

**magnetic loss angle.** For a pure sinusoidal wave, in a magnetically isotropic medium, the angle defined by the equation

$$f_m = \tan^{-1} \left( \frac{\mu''}{\mu'} \right)$$

where  $\mu''$  and  $\mu'$  are the values of the imaginary part and the real part, respectively, of the complex permeability.

**magnetic storm.** A disturbance of the Earth's magnetic field, generally lasting one or more days, and characterized by significant changes in the strength of this field.

**magnetizing force ( $\vec{H}$ ).** *Same as:* magnetic field.

**magneto-hydrodynamic wave.** A low-frequency wave in an electrically highly conducting fluid (such as a plasma) permeated by a static magnetic field. The restoring forces of the waves are, in general, the combination of a magnetic tensile stress along the magnetic

field lines and the compressive stress between the field lines and the fluid pressure (for example, an Alfvén wave).

**magneto-ionic medium.** An ionized gas that is permeated by a fixed magnetic field.

**magneto-ionic wave component.** At a given frequency, either of the two characteristic plane electromagnetic waves that can travel in a homogeneous magneto-ionic medium without change of polarization. *Note:* These characteristic waves are also called the ordinary and extraordinary wave components.

**magnetopause.** The outer boundary of a planetary magnetic field.

**magnetosphere.** The region of a planetary atmosphere where the magnetic field, as modified by the solar wind, controls the motions of charged particles. *Note:* The Earth's magnetosphere includes part of the F-region of the terrestrial ionosphere up to the magnetopause.

**magneto-telluric current.** A current induced in the Earth by time-varying magnetic fields of external origin.

**magneto-telluric fields.** Electric and magnetic fields induced in the earth by external time-varying sources.

**maximum observed frequency (MOF).** In ionospheric sounding, the highest radio frequency at which echoes can be detected or observed with a particular piece of oblique incidence sounding equipment.

**maximum usable frequency (MUF).** The highest radio frequency that can be used for reliable communication between two points under specified conditions by means of reflection from the regular layers of the ionosphere. *Notes:* (1) Where the MUF is restricted to a particular ionospheric mode of propagation, the values may be quoted together with an indication of that mode. For example, 2F2 MUF represents the MUF for the second reflection from the F2 layer. (2) If the extraordinary wave is involved, then this is noted. For example, 1F2 MUF (x). Absence of a specific reference to a magneto-ionic component implies that the quoted value refers to the

ordinary wave. (3) The ground range for which the MUF applies is indicated in kilometers following the indication of the mode type (for example, 1F2 (4000) MUF).

**mesosphere.** That part of the Earth's atmosphere, located above the stratosphere, in which the temperature decreases with increasing height. The mesosphere extends to an altitude of around 85 km, where the temperature reaches a minimum value.

**mesopause.** The upper boundary of the mesosphere.

**medium frequency (MF).** 300 kHz to 3 MHz. *See:* radio spectrum.

**micropulsation.** Small amplitude fluctuations (usually less than  $10^{-6}$  of the Earth's magnetic field with periods on the order of seconds or minutes. *Note:* These fluctuations usually result from magneto-hydrodynamic waves in the magnetosphere.

**mixing ratio (of water vapor).** The ratio of the mass of water vapor to the mass of dry air in a given volume of air. This ratio is generally expressed in grams per kilogram.

**mode.** A characteristic solution to the wave equation for specified boundary conditions. Other uses of the term mode are common. *See:* mode of propagation, ionospheric.

**mode of propagation, ionospheric.** Representation of a transmission path by the number of hops between the end points of the path, the ionospheric layers producing the ionospheric reflections being indicated for each hop. Example: 1F + 1E represents a hop with an ionospheric reflection in the F region followed by a reflection at the ground, followed, in turn, by a hop with a reflection from the E region.

**modified index of refraction.** In the troposphere, the sum of the refractive index at a given height  $h$  above the mean local surface and the ratio of this height to the geometrical mean radius of the Earth.

**MOF.** *See:* maximum observed frequency.

**MUF.** *See:* maximum usable frequency.

**multipath transmission (propagation).** The propagation phenomenon that results in signals reaching the receiving antenna by two or more paths. When two or more signals arrive simultaneously, wave interference results. The received signal fades if the wave interference is time varying or if one of the terminals is in motion.

**mutual coherence function.** *See: coherence function.*

**N-units.** *See: refractivity.*

**non-deviative absorption.** *See: absorption, non-deviative.*

**Norton surface wave.** A guided electromagnetic wave produced by a source over or on the ground. It is the non-geometrical optics component of the ground wave. *See also: ground wave.*

**O wave.** *Same as: ordinary wave.*

**oblique-incidence ionospheric sounding.** *See: sounding.*

**obstacle gain.** The ratio, in dB, of the electromagnetic field at a point in the vicinity of an obstacle (but not on the obstacle), to the field that would occur in the absence of the obstacle.

**optimum working frequency (OWF).** The frequency that is exceeded by the operational MUF on a given skywave path at a given time, during 90% of a specified period, usually a month. The OWF frequently is estimated as 0.85 times the median value of the MUF for the specified time period. The OWF is also called the FOT.

**ordinary wave (O wave).** That characteristic magneto-ionic wave component deviating the least, in most of its propagation characteristics, from those expected for a wave in a non-magnetized plasma of the same density. *Note:* For vertical incidence, the ordinary wave is reflected near the height at which the plasma frequency is equal to the wave frequency when the effects of collisions are negligible.

**orthogonal polarization.** (1). For linear polarization, the (linear) polarization perpendicular to the reference (linear) polarization.

(2) For circular polarization, the (circular) polarization with the opposite sense of rotation.

(3) For elliptical polarization, the polarization state with the same axial ratio, opposite rotation sense and major axis perpendicular to the reference polarization.

**parallel polarization.** The polarization of a wave for which the electric field vector lies parallel to the plane of incidence. *Note:* Sometimes called vertical or transverse magnetic (TM) polarization, in optics it is called "p" polarization.

**Pedersen ray.** The upper ionospheric ray in oblique-incidence propagation.

**penetration depth.** For a given frequency, the depth at which the electric field strength of an incident plane wave, penetrating into a lossy medium, is reduced to  $1/e$  of its value just beneath the surface of the lossy medium. *Note:* The penetration depth, also called the skin depth, is equal to the reciprocal of the attenuation constant in the lossy medium.

**penetration frequency, oblique incidence propagation.** For a given angle of incidence, the lowest frequency that just penetrates the ionosphere.

**penetration frequency, vertical incidence propagation.** *See: critical frequency.*

**perfect conductor; ideal conductor; perfectly conducting medium; ideally conducting medium.** A medium for which the conductivity is infinite. In a perfect conductor, the total electric and magnetic fields are identically zero regardless of the exciting source.

**perfect dielectric.** A dielectric medium in which the conductive and dielectric losses are identically zero. *Also: ideal dielectric.*

**perfectly conducting medium.** *See: perfect conductor.*

**permeability, complex ( $\mu$ ).** A macroscopic material property of a medium that relates the magnetic flux density,  $\vec{B}$ , to the magnetic field,  $\vec{H}$ , in the medium. For a monochromatic wave in a linear medium, that relationship is

described by the (phasor) equation:

$$\vec{B} = \vec{\mu} \cdot \vec{H}$$

where  $\mu'$ , the complex permeability, is a tensor that is generally frequency dependent. For an isotropic medium, the tensor reduces to a complex scalar:

$$\mu = \mu' - j\mu''$$

where  $\bar{\mu}$  is the real part of the permeability and  $\mu''$  accounts for losses.

**permeability of free space ( $\mu_0$ ).** A scalar constant such that, in vacuum, its product with the magnetic field  $\vec{H}$  is equal to the magnetic flux density  $\vec{B}$ :

$$\vec{B} = \mu_0 \vec{H}$$

The numerical value of  $\mu_0$  is  $4\pi \times 10^{-7}$  henry/meter.

**permeability, relative complex.** The complex permeability of a medium normalized to the free space permeability.

**permittivity, complex ( $\epsilon$ ).** A macroscopic material property of the medium that relates the electric field,  $\vec{E}$  to the electric flux density,  $\vec{D}$ , in the medium. For a monochromatic wave in a linear medium, that relationship is described by the (phasor) equation:

$$\vec{D} = \vec{\epsilon} \cdot \vec{E}$$

where  $\bar{\epsilon}$ , the complex permittivity, is a complex-valued tensor, generally frequency dependent. For an isotropic medium, the tensor reduces to a complex scalar:

$$\epsilon = \epsilon' - j\epsilon''$$

where  $\epsilon'$  is the real part of the permittivity and  $\epsilon''$  accounts for losses.

**permittivity, free space ( $\epsilon_0$ ).** A scalar constant such that in vacuum, the product of  $\epsilon_0$  and the electric field,  $\vec{E}$ , is equal to the electric flux density.

$$\vec{D} = \epsilon_0 \vec{E}$$

The numerical value for  $\epsilon_0$  is  $8.854 \times 10^{-12}$  farad/meter.

**permittivity, relative complex ( $\epsilon_r$ ).** The complex permittivity, of a medium normalized to the free space permittivity,  $\epsilon_0$ .

**perpendicular polarization.** The polarization of a wave for which the electric field vector lies perpendicular to the plane of incidence. *Note:* Sometimes called horizontal or transverse electric (TE) polarization; in optics, such a wave is said to be "s" polarized.

**phase constant ( $\beta$ ).** The magnitude of the phase vector.

**phase path.** For a monochromatic electromagnetic wave, the product of the phase constant and the physical path length. *Note:* In a slowly varying spatially inhomogeneous medium, the phase path length equals the line integral of the real part of the phase vector along the ray path.

**phase vector ( $\vec{\beta}$ ).** Of a propagating wave, the vector in the direction of the wave normal, whose magnitude is the phase constant. *See:* **wave normal**.

**phase velocity ( $v_p$ ).** Of a monochromatic uniform plane wave, the velocity of an equiphase surface along the wave normal.

**phasor notation.** For monochromatic fields, the complex notation used in the expressions for field quantities with the exponential time factor  $\exp(j\omega t)$ . For example, for plane waves

$$\vec{e}(\vec{r}, t) = \text{Re} \{ \vec{E}(\vec{r}, \omega) \exp(-j\vec{k} \cdot \vec{r}) \exp(j\omega t) \}$$

where  $\vec{e}(\vec{r}, t)$  is the instantaneous electric field,  $\text{Re}$  indicates the real part, and  $\vec{E}(\vec{r}, \omega) \exp(-j\vec{k} \cdot \vec{r})$  is the phasor notation for the electric field.

**photo-ionization.** Ionization of atoms or molecules caused by electromagnetic radiation such as ultraviolet radiation or X rays.

**plane of incidence.** The plane containing the normal to the surface of a boundary and the phase vector,  $\vec{\beta}$ , of the incident wave.

**plane wave.** A wave whose equiphase surfaces form a family of parallel planes.

**plane wave exponential factor.** The factor  $\exp(-j\vec{k} \cdot \vec{r})$  in the phasor expression for plane wave fields, where  $\vec{k}$  is the wave vector and  $\vec{r}$  is the position vector.

**plane wave, uniform.** A plane wave in which the planes of constant phase and amplitude are parallel. *Same as: homogeneous plane wave.*

**plasma.** A macroscopically neutral assembly of charged and possibly also uncharged particles. *Note:* A plasma is said to be cold if the thermal effects of charged particles on dynamic processes in the plasma can be neglected for the particular problem involved. It is said to be hot (or warm) if the thermal effects are not negligible.

**plasma frequency ( $f_N$ ).** A natural frequency of oscillation of charged particles in a plasma given by:

$$(f_N)^2 = (2\pi)^{-2} \frac{Nq^2}{m\epsilon_0}$$

where  $q$  is the charge per particle,  $m$  is the particle mass,  $N$  is the particle number density, and  $\epsilon_0$  the permittivity of free space. *Note:* For electrons, with  $f_N$  in hertz and  $N$  in electrons per cubic meter:

$$(f_N)^2 = 80.6 N$$

**plasmopause.** The outer boundary of the plasmasphere, characterized by a steep decrease of the plasma density.

**plasma sheath.** A layer of charged particles, of substantially one sign, that accumulates around a body in a plasma.

**plasmasphere.** The ionized region of the topside ionosphere, toroidal in shape, that encircles the Earth around the equator and that follows the rotation of the Earth. *Note:* In the equatorial plane, the plasmasphere extends to a distance of 3 to 7 Earth radii, depending on local time and geomagnetic activity.

**plasma waves.** Electrostatic waves associated with a "warm" plasma, giving rise to density and velocity fluctuations.

**polar cap.** Polar region bounded by the auroral zone.

**polar cap absorption, (PCA).** The intense absorption of radio waves in the polar cap caused by the arrival of high-energy solar protons, concentrated in this region by the lines of force of the Earth's magnetic field.

**polarization.** Of an electromagnetic wave, the locus of the tip of the electric field vector observed in a plane orthogonal to the wave normal. *See: linearly, circularly, and elliptically polarized waves. See also: parallel and perpendicular polarization.*

**polarization coupling loss.** That part of the transmission loss due to the mismatch between the polarization of the transmitted wave and the propagation medium or between the polarization of the incident waves and the polarization of the receiving antenna, or both.

**power density.** Of a traveling wave, the time average of the Poynting vector.

**power flux density.** *Same as: power density.*

**power reflectance.** *Same as: power reflection coefficient.* Use of the term "power reflectance" is deprecated.

**power reflection coefficient; power reflection factor.** The ratio of the power flux densities of the reflected and incident waves in the corresponding directions of propagation, at a point close to a reflecting surface.

**Poynting vector, instantaneous  $\vec{P}(t, \vec{r})$ .** Of an electromagnetic wave, the vector product of the instantaneous electric and magnetic field vectors. The integral of  $\vec{P}(t, \vec{r})$  over a surface is the instantaneous electromagnetic power flow through the surface.

**Poynting vector, time-averaged ( $\vec{S}$ ).** Of a periodic electromagnetic wave, the time average of the instantaneous Poynting vector over the wave period. For time harmonic waves, it is equal to  $(1/2) \text{Re}(\vec{E} \times \vec{H}^*)$ , where  $\text{Re}$  indicates the real part,  $\vec{E}$  and  $\vec{H}$  are the electric and magnetic field vectors in phasor notation, and \* indicates the complex conjugate.

**precipitation scatter.** Tropospheric scattering caused by precipitating rain, hail, or snow particles.

**propagation constant ( $\beta$ ).** The magnitude of the phase vector.

**propagation vector ( $\vec{\gamma}$ ).** For a traveling time-harmonic wave, the complex vector whose real part is the attenuation vector and whose imaginary part is the phase vector. *See also: wave vector.*

**quiet sun.** The sun in the absence of any unusual electromagnetic activity.

**radian frequency.** *See: angular frequency.*

**radar astronomy.** The branch of astronomy uses radar to study astronomical objects.

**radio astronomy.** The branch of astronomy dealing with the reception and analysis of radio waves from extraterrestrial sources.

**radio field strength.** The electric or magnetic field strength at a radio frequency.

**radio frequency.** A frequency in the radio spectrum.

**radio horizon.** The locus of points at which the direct rays from a point source of radio waves are tangent to the surface of the Earth. *Note:* In general, the radio and geometric horizons differ because of atmospheric refraction.

**radio interferometer.** A type of radio telescope that uses two or more physically separated collecting elements in order to achieve high angular resolution of the brightness temperature distribution of a radio source.

**radio source.** In radio astronomy, a celestial object or region that emits radio waves.

**radio spectrum.** The radio frequency portion of the electromagnetic spectrum. The frequency ranges are: ultra low frequency (ULF), lower than 3 Hz; extremely low frequency (ELF), 3 Hz to 3 kHz; very low frequency (VLF), 3 to 30 kHz; low frequency (LF), 30 to 300 kHz; medium frequency (MF), 300 kHz to 3 MHz; high frequency (HF),

3 to 30 MHz; very high frequency (VHF), 30 to 300 MHz; ultra high frequency (UHF), 300 MHz to 3 GHz; super high frequency (SHF), 3 to 30 GHz; extremely high frequency (EHF), 30 to 300 GHz; Submillimeter, 300 GHz to 1 THz.

**radio telescope.** An instrument used to detect and collect radio emissions from an object or region in space.

**radio wave.** An electromagnetic wave of radio frequency. Current usage includes frequencies up to 1 THz.

**radio wave propagation.** The transfer of energy by electromagnetic radiation at radio frequencies.

**rain rate; rainfall rate.** A measure of the volume of water collected per unit area per unit time due to rain. The common unit is millimeters per hour. *Note:* Precipitation rate may refer to other hydrometeors such as snow, in which case the common units are either millimeters per hour or equivalent rainfall rate in millimeters per hour.

**random medium.** A medium in which the spatial variations of permittivity, discrete and/or continuous, are best described in terms of statistical measures.

**random surface.** A boundary surface, between two different but otherwise homogeneous media, whose height fluctuations are best described in terms of statistical measures.

**range of a radio system.** The maximum distance for which a radiowave transmitting system, with specified installation and operating conditions, produces a usable field strength at a specified radio receiver installation.

**ray.** The path of a wave packet or energy flow in a homogeneous or a slowly varying medium. *Notes:* (1) Energy transport (per unit area) is generally associated with bundles of rays. (2) In isotropic, slowly varying, media the ray path is identical to the path of the wave normal, but this may not be the case in anisotropic media.

**Rayleigh criterion.** A criterion that characterizes the roughness of a surface with respect to the reflection of an electromagnetic wave. The degree of roughness is expressed in terms of the quantity:

$$\frac{h \cos \theta}{\lambda}$$

where  $h$  is the rms height of the surface irregularities,  $\theta$  is the angle of incidence with respect to the mean surface, and  $\lambda$  is the wavelength. The surface is considered specular (smooth) if

$$\frac{h \cos \theta}{\lambda} < \frac{1}{100}$$

The surface is considered rough if

$$\frac{h \cos \theta}{\lambda} > \frac{1}{10}$$

**reciprocity.** In wave propagation, the invariance of the complex amplitudes of the received signals to the interchange in location of transmitter and receiver. *Note:* Reciprocity applies provided that the transmission medium is isotropic and that the antennas remain in place with only their transmit and receive functions interchanged.

**reference atmosphere for refraction.** *See:* **standard atmosphere for refraction.**

**reflectance.** Usage deprecated. *See:* **power reflection coefficient.**

**reflected wave.** For two media, separated by a planar interface, that part of the incident wave which is returned to the first medium. The direction of propagation of the reflected wave is given by Snell's Law.

**reflection, specular.** The process by which part of a wave, incident on a plane surface, is returned to the original medium in accordance with Snell's Law.

**reflection (diffuse).** *See:* **scattering, diffuse.**

**reflection coefficient (or factor).** The ratio of the phasor value of a given component of the electric or magnetic field of a reflected wave to that of the corresponding component of the incident wave, at a point close to a specularly reflecting surface.

**refracted wave.** For two media, separated by an infinite planar boundary, that part of the incident wave that travels from the first medium into the second medium. The direction of propagation of the refracted wave is given by Snell's Law. Also called: **transmitted wave.**

**refractive index (M).** The ratio of the phase velocity in free space to that in the medium. *Note:* The refractive index is the real part of the complex refractive index.

**refractive index, complex.** A dimensionless complex quantity, characteristic of a medium and so defined that its real part is the ratio of the phase velocity in free space to the phase velocity in the medium. The product of the imaginary part of the refractive index and the free space propagation constant is the attenuation constant in the medium.

**refractive modulus.** In the troposphere, the excess over unity of the modified index of refraction, expressed in millionths. It is represented by  $M$ , and is given by the equation:

$$M = (n + h/a - 1)10^6$$

where  $a$  is the mean geometrical radius of the Earth, and  $n$  is the refractive index at a height,  $h$ , above the local surface.

**refractivity.** The amount by which the real part of the refractive index exceeds unity. Refractivity is often measured in parts per million called N-units.

**refractivity profile.** The height dependence of refractivity in the atmosphere.

**refractometer.** An instrument used to measure the refractive index of the atmosphere.

**relative humidity with respect to water (ice).** The ratio, expressed as a percentage, of the water vapor pressure in moist air to the saturation vapor pressure with respect to a plane pure water (ice) surface at the same temperature.

**resonance.** (1) In an oscillating system, the rapid increase or decrease of the oscillation

amplitude as the excitation frequency approaches one of the natural frequencies of the system.

(2) Of a travelling wave, the change in amplitude as the frequency of the wave approaches or coincides with a natural frequency of the medium (for example, a plasma frequency).

**right-handed polarized wave.** A circularly or an elliptically polarized electromagnetic wave for the electric field vector, viewed by an observer (at the source) looking in the direction of propagation, rotates clockwise in space. Thus, a right-handed helical antenna radiates a right-hand polarized wave.

**rough surface.** An irregular surface separating two media. *See: Rayleigh criterion.*

**scattered wave.** An electromagnetic wave that results when an incident wave encounters:  
a) one or more discrete scattering objects,  
b) a rough boundary between two media, or  
c) continuous irregularities in the complex permittivity of a medium.

**scattering.** A process in which the energy of a travelling wave is dispersed in a direction by means other than reflection and refraction.

**scattering coefficient.** (1) The scattering cross-section per unit illuminated area of a surface expressed in square meters per square meter and usually designated  $\sigma^0$ .

(2) The scattering cross-section per unit volume of a medium containing discrete scatterers or random variations of refractive index. It is expressed in meters squared per cubic meter and is often designated  $\sigma_v$ . *Note:* The scattering coefficient may be monostatic (backscatter) when the transmitter and receiver are co-located, or bistatic, when they are not.

**scattering cross-section.** The projected area required to intercept and isotropically radiate the same power as a scatterer (target) scatters toward the receiver. The scattering cross-section is calculated from the relationship:

$$\sigma = \lim_{R \rightarrow \infty} \left[ 4\pi R^2 \frac{(|\vec{E}_s|^2)}{(|\vec{E}_i|^2)} \right]$$

where  $R$  is the distance between the scatterer and the receiver,  $(|\vec{E}_s|^2)$  is the mean of the squared amplitude of the scattered electric field at the receiver,  $(|\vec{E}_i|^2)$  is the mean of the squared amplitude of the incident electric field at the scatterer, and the incident field is assumed to be planar over the extent of the target.

**scintillation.** The phenomenon of fluctuation of the amplitude of a wave caused by irregular changes in the transmission path or paths with time. *See also: fading.* *Note:* The term scintillation is sometimes used to describe fluctuations of phase and angle of arrival.

**selective fading.** *See: frequency selective fading.*

**sferics.** *See: atmospherics.*

**shadow region.** The region in space that, because of an intervening obstacle, cannot be reached by an incident ray.

**SHF.** *See: super high frequency.*

**short-wave fade-out.** *See: sudden ionospheric disturbance (SID).*

**signal decorrelation time.** *Same as: decorrelation time.*

**silent zone.** Part of the skip zone at a distance greater than the range of the ground wave.

**skin depth.** *Same as: penetration depth.*

**skip distance.** For a given frequency, the minimum distance at which the sky wave is returned to the earth. *Note:* That given frequency is the maximum usable frequency for the skip distance.

**skip distance focusing.** Ionospheric focusing observed in the vicinity of the skip distance.

**skip zone.** An area of the surface of the Earth surrounding a transmission point bounded by the skip distance in each direction.

**sky wave.** A radio wave propagated obliquely toward, and returned from, the ionosphere. *Note:* This term has sometimes been called an

ionospheric wave, but the term "ionospheric wave" is intended to connote internal waves in ionospheric plasmas.

**slow wave.** An electromagnetic wave propagating close to a boundary with a phase velocity less than that which would exist in an unbounded medium having the same electro-magnetic properties. *See also: fast wave.*

**solar activity.** The emission of electromagnetic radiation and particles from the sun, including slowly variable components and transient components caused by phenomena such as solar flares.

**solar activity center.** A region on the sun in which are located the sources of variable electromagnetic radiation and corpuscular radiation.

**solar activity index.** A number characterizing solar activity, such as: international relative sunspot number, twelve-month running mean sunspot number, monthly mean solar radio-noise flux.

**solar cycle.** The magnitude of slowly varying components of solar activity as a function of time. The solar cycle has a period of approximately 11 years. *Note:* The cycle is not symmetrical. It rises to a maximum in approximately 4 years and declines to a minimum in approximately 7 years.

**sounding, active.** Remote sensing of atmospheric or ionospheric parameters by transmission and reflection of radio signals. Radio systems used in this manner are called sounders.

**spectral power density.** Power per unit bandwidth, in watts per Hertz.

**spectral power flux density.** The power density per unit bandwidth in watts per square meter per Hertz.

**spectrum, angular.** An electromagnetic field, that is source-free in the homogeneous half space  $z > 0$ , can be represented in this half space by a superposition of plane waves. The complex amplitude of these plane waves, as a function of their direction cosines, constitute

the angular spectrum. *Notes:* (1) The direction cosines are defined by  $k_x/k$  and  $k_y/k$  where  $k_x$  and  $k_y$  are the  $x$  and  $y$  components of the wave vector  $k$ . (2) The angular spectrum is the Fourier transform of the field in the plane  $z = 0$  or any other plane  $z = \text{constant} > 0$ .

**spectrum, angular power.** The mean squared amplitudes of the plane wave spectrum of an electromagnetic field as a function of the direction cosines  $k_x/k$  and  $k_y/k$  constitute the angular power spectrum. *Note:* The angular power spectrum and the mutual coherence function are Fourier transform pairs.

**spherical diffraction (propagation).** Trans-horizon propagation due to diffraction by the spherical surface of the Earth, or more generally by any rounded obstacle that is extremely large in relation to the wavelength.

**spherical wave.** A wave with equiphase surfaces that form a family of concentric spheres.

**sporadic E layer (Es layer).** An ionospheric layer of the E region that is thin, transient, and of limited extent.

**sporadic ionization.** Ionization of the upper atmosphere, irregularly distributed in space and time, and abnormally high relative to the average ionization level of the region in which it is produced.

**spread F.** A phenomenon observed on ionograms displaying a wide range of delays of echo pulses, near the F region critical frequencies.

**spread, delay.** *See: time delay spread.*

**spread, Doppler ( $\sigma_\lambda$ ).** The Doppler spread of a propagation channel is the spreading in the frequency domain of the power spectrum of a transmitted monochromatic wave. *Note:* The Doppler spread is inversely related to the decorrelation time ( $\tau_o$ ):

$$\sigma_\lambda = (2\pi\tau_o)^{-1}$$

**spread, time delay ( $\sigma_\tau$ ).** Time delay spread is a measure of the differential propagation times due to multipath propagation. Specifically, it is

the rms width of the signal received when a very narrow pulse has been transmitted. *Note:* The time delay spread is inversely proportional to the frequency selective bandwidth ( $f_{\tau}$ ):

$$\sigma_{\tau} = (2\pi f_{\tau})^{-1}$$

**spreading factor.** For propagation in isotropic unbounded media, that amplitude factor that accounts for geometric spreading of the field intensity. *Note:* In the far field region of plane, cylindrical, and spherical waves, this factor is 1,  $r^{-1/2}$  and  $r^{-1}$  respectively, where  $r$  is the distance from the source to the observation point.

**standard atmosphere for refraction.** An atmosphere for which the refractivity is determined by the equation:

$$N(h) = 315 \exp(-0.136 h)$$

where  $h$  is the altitude in kilometers above mean sea level. *Note:* The standard atmosphere for refraction is almost identical to the standard radio atmosphere up to a height of one kilometer.

**standard propagation.** The propagation of radio waves over a smooth, spherical earth of uniform dielectric constant and conductivity, under conditions of standard refraction in the atmosphere.

**standard radio atmosphere.** An atmosphere whose vertical refractivity gradient is equal to the standard refractive index gradient.

**standard radio horizon.** The radio horizon corresponding to propagation through the standard radio atmosphere.

**standard refraction (radio waves).** The refraction that would occur in an atmosphere in which the refractive index decreases uniformly with height above the earth at the rate of  $39 \times 10^{-9}$  per meter. Standard refraction may be included in propagation calculations by using an effective earth radius of  $8.5 \times 10^6$  meters or  $4/3$  the geometrical radius of the earth.

**standard refractive index gradient (standard N gradient).** A standard value of vertical gradient of refractivity, namely 39 N/km, used in

studies of the refraction of radio waves in the troposphere. *Note:* This value corresponds, approximately, to the median value of the gradient in the first kilometer of altitude in temperate regions.

**standard refractive index modulus gradient (standard M gradient).** The value of vertical gradient of refractive modulus that corresponds to the standard refractivity gradient (+117 M units per kilometer).

**standing wave.** A wave in which, for any component of the field, the ratio of its instantaneous value at one point to that at any other point does not vary with time. A pure standing wave results from the interference of two oppositely directed traveling waves of the same frequency and amplitude.

**stratopause.** The upper boundary of the stratosphere.

**stratosphere.** That part of the Earth's atmosphere located above the troposphere, in which the temperature remains constant or increases slightly with increasing height. The stratosphere extends to a height of around 50 km.

**sub-refraction.** Refraction for which the vertical gradient of refractivity is greater (less negative) than the standard gradient of refractivity.

**sudden ionospheric disturbance (SID).** An ionospheric disturbance with a duration of a few minutes to a few hours, characterized by the sudden increase in the ionization of the D region in the daylight hemisphere as a result of a solar flare.

**super high frequency (SHF).** 3 to 30 GHz. *See:* radio spectrum.

**super-refraction.** Refraction for which the vertical gradient of refractivity is less (more negative) than the standard gradient of refractivity.

**surface duct.** An atmospheric radio duct for which the lower boundary is the Earth's surface.

**surface impedance.** For a monochromatic electromagnetic wave incident on a surface separating two media, the complex ratio of the total orthogonal electric to magnetic field components tangent to the surface. The surface impedance is taken as having a positive real part.

**surface, specular.** A planar interface separating two media.

**surface wave.** A wave guided by an interface between two different media. A surface wave is generally characterized as a slow wave having a magnitude that exponentially decreases with distance from the interface.

**system loss ( $L_s$ ).** Of a radio system, the ratio of the input power to the terminals of the transmitting antenna to the available output power at the terminals of the receiving antenna. Usually expressed in dB as a positive number.

**TEM wave.** *See:* transverse electromagnetic wave.

**temperature inversion (in the troposphere).** An increase of temperature with height in the troposphere.

**thermosphere.** That part of the Earth's atmosphere located above the mesosphere in which temperature increases and then remains constant with increasing height and from which there is virtually no further escape of particles to free space. The thermosphere extends to an altitude of 500 to 600 km.

**topside ionospheric sounding.** Vertical incidence ionospheric sounding made from an artificial Earth satellite above the height of the maximum electron density of the F region.

**total electron content (TEC).** The total number of free electrons in a tube (generally with a vertical axis) of unit transverse cross-section passing through the ionosphere.

**transhorizon tropospheric propagation.** Tropospheric propagation between two points close to the ground, the reception point being beyond the radio horizon of the transmission point. Transhorizon propagation includes a variety

of possible propagation mechanisms such as diffraction, scattering, refraction and reflection. *See also:* tropospheric scatter propagation.

**transmission loss (L).** Of a radio system, the ratio of the power radiated from the transmitting antenna to the resultant power that would be available from a loss-free (but otherwise identical) receiving antenna.

**transmitted wave.** (1) For a wave incident upon the boundary surface between two media, that part of the wave that enters the second medium from the first medium. *See:* refracted wave.

(2) The wave launched by a transmitting antenna.

**transverse electric (TE) wave.** An electromagnetic wave in which the electric field vector is everywhere perpendicular to the direction of propagation.

**transverse electromagnetic (TEM) wave.** An electromagnetic wave in which both the electric and magnetic field vectors are everywhere perpendicular to the direction of propagation.

**transverse magnetic (TM) wave.** An electromagnetic wave in which the magnetic field vector is everywhere perpendicular to the direction of propagation.

**traveling ionospheric disturbance (TID).** A localized disturbance in the electron density distribution propagating in the ionosphere.

**tropopause.** The upper boundary of the troposphere.

**troposphere.** The lower part of the Earth's atmosphere, situated immediately above the surface of the Earth and in which the temperature decreases with increasing altitude except in certain local temperature inversion layers. The troposphere extends to an altitude of around 9 km at the poles and 17 km at the equator.

**tropospheric radio duct.** *See:* atmospheric duct.

**tropospheric layer.** An elevated portion of the troposphere having radio propagation properties that are clearly distinguished from those of the surrounding atmosphere. Horizontal dimensions are generally in excess of 100 km, and vertical dimensions are of the order of 1 km.

**tropospheric propagation.** Propagation within the troposphere.

**troposcatter.** *See:* tropospheric scatter propagation.

**tropospheric scatter propagation (troposcatter).** Propagation of radio waves through the atmosphere caused by scattering from inhomogeneities in the refractive index of the troposphere. *Note:* Troposcatter enables propagation beyond the radio horizon.

**tropospheric wave.** A radio wave that propagates in the troposphere.

**turbulence.** Random movements within a liquid or gaseous medium inducing heterogeneous values of certain characteristics of the medium.

**turbulence, scale of.** A length representative of the average size of the irregularities of a specified property of a medium subject to turbulence.

**ultra-high frequency (UHF).** 300 MHz to 3 GHz. *See:* radio spectrum.

**uniform plane wave.** *See:* homogeneous plane wave.

**vertical polarization.** *Same as:* parallel polarization.

**very high frequency (VHF).** 30 to 300 MHz. *See:* radio spectrum.

**virtual height.** The apparent height of reflection of a radio wave from an ionized layer. It is determined from the time interval between the transmitted pulse and the ionospheric echo at vertical incidence, assuming that the velocity of propagation is the velocity of light (in vacuum) over the entire path.

**very low frequency (VLF).** 3 to 30 kHz. *See:* radio spectrum.

**volume scattering.** Scattering from inhomogeneities distributed throughout a volume. The inhomogeneities can be discrete particles or structures, or spatial variations in a continuous refractive index.

**waveguide.** Metallic or dielectric structures, usually uniform in the longitudinal direction, that are capable of guiding waves.

**wave interference.** The variation of wave amplitude with distance or time, caused by the superposition of two or more waves of the same (or very nearly the same) frequency. *Note:* If the waves have very nearly the same frequency, they are said to "beat with each other."

**wavelength.** Of a monochromatic wave, the distance between two points of corresponding phase of two consecutive cycles in the direction of the wave normal. The wavelength,  $\lambda$  is related to the magnitude of the phase velocity,  $v_p$ , and the frequency,  $f$ , by the equation:

$$\lambda = v_p / f$$

**wave normal.** Of a traveling wave, the direction normal to an equiphase surface taken in the direction of increasing phase. *See:* direction of propagation.

**wave tilt.** Of a monochromatic electromagnetic wave propagating near the interface between two media, the complex ratio of the electric (or magnetic) field component that is tangent to the interface to that which is normal to the interface, both field components lying in the plane of propagation. *Note:* Wave tilt is generally associated with ground wave propagation over the Earth's surface.

**wave vector.** The complex vector  $\vec{k}$  in expressions for wave propagation using the exponential factor  $\exp[-j(\vec{k} \cdot \vec{r})]$ .

$$\vec{k} = \vec{\beta} - j\vec{\alpha}$$

where  $\vec{\beta}$  is the phase vector,  $\vec{\alpha}$  is the attenuation vector, and  $\vec{\gamma} = j\vec{k}$  is the propagation vector.

**whistler.** A form of radio noise in the ELF/VLF portion of the spectrum, usually originating from lightning strokes and characterized by a whistling tone of decreasing pitch that may last for several seconds. *Note:* Propagation of this noise is in the **whistler mode**, which is strongly guided along the Earth's magnetic field.

**whistler mode.** The propagation mode of any right-hand polarized electromagnetic wave propagating along a magnetic field line in a plasma at a frequency less than the electron gyrofrequency but greater than the ion gyrofrequency.

**X wave.** *Same as:* extraordinary wave.