IEEE Standard Definitions of Terms for Radio Waves Propagation

IEEE Antennas and Propagation Society

Sponsored by the
Antennas and Propagation Standards Committee

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USA

IEEE Std 211™-2018
(Revision of IEEE Std 211-1997)

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Abstract: Terms and definitions used in the context of electromagnetic wave propagation relating to the fields of telecommunications, remote sensing, radio astronomy, optical waves, plasma waves, the ionosphere, the magnetosphere, and magnetohydrodynamic, acoustic, and electrostatic waves are supplied.

Keywords: electromagnetic wave propagation, IEEE 211™, terminology

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David G. Michelson, *Vice Chair*

Gary Brown
Nicholas Buris
Gregory Durgin
Francisco Falcone
Everett Farr
Michael Francis
Ramakrishna Janaswamy
Jeffrey Nanzer
Michael Newkirk
Yahya Rahmat-Samii
Tapan Sarkar
Warren Stutzman
Steven Weiss

The following members of the individual balloting committee voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

Gary Brown
Demetrio Bucaneg Jr.
Nicholas Buris
William Bush
William Byrd
William Dorsey
Lars Foged
Jeffrey Fordham
Michael Francis
Randall Groves
Werner Hoelzl
Noriyuki Ikeuchi
Ramakrishna Janaswamy
Donald McPherson
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Eric Mokole
Vikass Monebhurrun
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Michael Newkirk
Iulian Profir
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Walter Struppler
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Jian Yu

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Introduction

This introduction is not part of IEEE Std 211-2018, IEEE Standard Definitions of Terms for Radio Waves Propagation.

This is the fourth revision of the original IEEE Std 211™-1969, following those of 1977, 1990, and 1997. It is indeed true, as noted in previous Introductions, that the “need for revising a definitions standard transcends its publication date and is essentially continuous.” Therefore, as this standard goes to print, work on the fifth revision is already in progress, consisting of adding new terms, refining or deleting old ones, and improving the overall consistency of the standard. This voluntary effort is carried out by the Antennas and Propagation Standards Committee (APS/SC) Subcommittee on Definitions of Terms for Radio Wave Propagation (WG_P211), which meets once a year at the conference sponsored by the IEEE Antennas and Propagation Society. Increasingly, the face to face meeting has been replaced by regular e-mails and conference calls, expanding the opportunity for international participation. The chair of the Subcommittee presenting this revision is Vikass Monebhurrun, who was preceded by David Thiel, who took over from Wolfhard J. Vogel, who took the baton from George H. Hagn, who in turn was preceded by chairs John M. Kelso, C. H. Liu, and Kurt Toman. The individuals with primary responsibility for this fourth revision, as well as those who contributed or made useful comments, are acknowledged below. An invitation is extended to the users of this standard to contribute to the fifth revision whenever they see deficiencies or have ideas for an improvement by communicating with the APS/SC chair via e-mail to vikass.monebhurrun@centralesupelec.fr.

Within the IEEE, the work has been coordinated with the Antennas and Propagation Standards Committee (APS/SC). For the previous revision, it had involved the following societies: EMC, COM, and Instrumentation and Measurements. It was then also coordinated with Study Groups 1, 5, and 6 of the International Telecommunication Union (ITU-R) and the U. S. National Body of the International Electrotechnical Commission (IEC).

The fields covered by this standard include the following where pertinent to electromagnetic wave propagation: radio astronomy, optical waves, plasma waves, ionosphere, magnetosphere, and magnetohydrodynamic, acoustic, and electrostatic waves.

Contents

IEEE Standard Definitions of Terms for Radio Waves Propagation

1. Scope

The standard provides terms and definitions used in the context of electromagnetic wave propagation relating to the fields of telecommunications, sensing, astronomy, optical waves, plasma waves, the ionosphere, the magnetosphere, and magnetohydrodynamic, acoustic, and electrostatic waves. Some obsolete terms and definitions will be removed. The language used for some already existing terms will be refined. The standard will also include some additional terms that are commonly accepted in these fields.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 145™-2013, IEEE Standard for Definitions of Terms for Antennas.[1,2]

3. Definitions

The $e^{j\omega t}$ convention is used throughout this document, where $j^2 = -1$, ω is the radian frequency, and t is time. For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[3]

NOTE—The terms defined in IEEE Std 211-2018 should be considered before applying the definitions in IEEE Std 145™-2013.[4,5]

absorption: The process of converting electromagnetic energy to heat.

absorption band: A band of frequencies for which a medium is considered to be absorbing.

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absorption coefficient (κ_a): (of a medium, nonnegative quantity). The rate of decrease of power density of a wave per unit distance, due to absorption. *See also:* **extinction coefficient (κ_e)**.

NOTE—For inhomogeneous media.

absorption cross-section (σ_a): (of a lossy body). The ratio of power absorbed by the body, P_a, to the power density of an incident plane wave, S_i:

$$\sigma_a = \frac{P_a}{S_i}$$

See also: **extinction cross-section (σ_e)**.

active sounding: The remote sensing of atmospheric or ionospheric parameters by transmission and reception of radio signals.

albedo: **(A)** In astronomy (where the sizes of the 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. **(B)** 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.

amplitude: The maximum or peak value of a waveform. *See also:* **magnitude**.

NOTE—Amplitude is a positive quantity.

angel echoes: Radar returns caused by atmospheric inhomogeneities, refractive index discontinuities, insects, birds, or unknown sources.

NOTE—Originally, when some physical target could not be identified through direct visual observation, echoes from such unknown causes were designated as "angels."

angle of arrival (AoA): (of a wave). The angle between the direction from which the wave arrived and a reference direction.

angle of incidence: At a point on a surface, the angle between the negative of the incident propagation vector and the outward normal to this surface.

angular frequency (ω): (of a sinusoidal wave). 2π times the frequency. *Syn:* **radian frequency**.

angular power spectrum: Constituted by the mean squared magnitudes of the plane wave spectrum of an electromagnetic field as a function of the direction cosines k_x/k and k_y/k, where k is the wavenumber, and k_x and k_y are the x and y components of the propagation vector of the plane wave, respectively. *See also:* **mutual coherence function**.

NOTE—The angular power spectrum and the mutual coherence function are Fourier transform pairs.

anisotropic medium: A medium that is not isotropic, i.e., whose constitutive parameters depend on the polarization and direction of wave propagation of the electric and magnetic fields. *See also:* **isotropic medium**.

anomalous propagation: RF propagation through a non-standard atmosphere.

antenna temperature: The temperature of a blackbody that, when placed around a matched, loss-free antenna similar to the actual antenna, produces the same available noise power, in a specified frequency range, as the actual antenna in its normal electromagnetic environment. *See also:* **blackbody**.

antiferromagnetic material: A material exhibiting strong magnetic arrangements internally but weak macroscopic effects due to the equal and opposite ordering of the neighboring microscopic domains. *See also:* **ferromagnetic material**.

antipodal focusing: Ionospheric focusing sometimes observed in the vicinity of the antipodal point or region.

aperture averaging: The reduction in output signal variation when the size of the antenna is large compared to the decorrelation distance of the incident field across the aperture. *See also:* **angular power spectrum**.

NOTE—The beamwidth of the antenna is much smaller than the angular power spectrum of the incoming wave.

astigmatic ray: A ray in a bundle of rays whose spreading factor has two non-coincident singularities. The wave described by this ray is not focused at a single point in space; rather, it experiences focusing with respect to its principal axes of curvature at two different points in space. *See also:* **spreading factor, ray**.

astigmatism: *See:* **astigmatic ray**.

atmospheric radio frequency (RF) 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 1—In the past, the term *static* was used to include atmospherics and other radio noise. The term *sferics* is in current use.

NOTE 2—Below 1 Hz, noise is primarily of geomagnetic origin; above 1 Hz it is due to lightning.

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

attenuation coefficient: *See:* **attenuation constant**.

attenuation constant (α): The real part of the complex propagation constant. *Syn:* **attenuation coefficient**.

attenuation vector ($\vec{\alpha}$): The imaginary part of the propagation vector, $\vec{k}$. The attenuation vector points in the direction of maximum decrease in magnitude. *See also:* **propagation vector ($\vec{k}$)**.

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 absorption: The increased attenuation of radio waves propagating through the D and E regions of the ionosphere when additional ionization is produced by precipitating charged particles usually associated with the visual aurora.

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

auroral oval: *See:* **auroral zone**.

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

average fade duration: For a specified power or envelope threshold, the average duration of the interval over which the fade drops below this threshold.

axial ratio: (of a polarization ellipse). The ratio of the major to minor axes of a polarization ellipse. Refer also to IEEE Std 145™-2013.

azimuth: The direction of arrival measured along the horizon with respect to some reference direction (e.g., East). In the spherical coordinate system (electromagnetic convention), this corresponds to the bearing angle ϕ .

backscatter: The scattering of waves back toward the source.

backscattering cross-section: Refer also to IEEE Std 145-2013. *See also:* **monostatic cross-section**.

baseband equivalent channel: A complex representation of a band-limited propagation channel where the real part of the channel frequency response has been shifted downward so that it is centered at 0 Hz instead of the carrier frequency. *See also:* **in-phase component, quadrature component**.

Beer-Lambert Law: Also called Beer's Law or Bouger's Law, this law, valid for discrete random media, relates the intensity of an electromagnetic wave at one point to the intensity at another point in the direction of propagation. The intensity decreases exponentially with distance, and the attenuation coefficient is equal to the product of the concentration of particles and the extinction cross-section per particle. Consequently, the application of Beer's Law is restricted to weakly scattering media.

bistatic radar: Radar having receiver and transmitter at different locations. *See also:* **monostatic radar**.

bistatic scattering coefficient: The scattering coefficient when the transmitter and receiver are not collocated. *See also:* **scattering coefficient**.

blackbody: An ideal material that absorbs all incident radiation.

NOTE—Under thermal equilibrium, a blackbody is a perfect emitter with its emissivity and absorptivity equal to unity. The radiation spectrum of a blackbody is given by Planck's radiation law.

Born approximation: A single-scattering approximation in which the exciting field is assumed to be equal to the incident field.

boundary element method (BEM): In electromagnetics, it is often, though not always, synonymous to the method of moments. *Syn:* **method of moments (MoM)**.

NOTE—For the boundary element method, the unknown sources are located on the boundary only, whereas for the method of moments, depending on the formulation, the unknowns may be on the surface or distributed over the entire volume.

Bragg angles: When an incident plane wave is diffracted by a periodic structure into discrete directions, the angles these directions of travel make with respect to the normal of the mean boundary.

Bragg resonant scattering: Originally described the scattering in discrete directions by spatially periodic boundaries or constitutive parameter(s), where the scattering directions are determined by the resonance condition in which two source-to-scatter-to-receiver path lengths differ by an integer multiple of 2π radians. This same physical mechanism has been found to apply to some randomly rough planar interfaces and random fluctuations of spatially continuous constitutive parameter(s). In these cases, there is a continuum of scattering angles provided there is either a continuous surface roughness or a continuous constitutive parameter fluctuation spectrum that satisfies the proper Bragg resonance condition.

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: *See:* **spectral brightness**.

brightness temperature: For a region or an extended source at a given wavelength, the temperature of an equivalent blackbody radiator that has the same brightness.

caustic: A point in space where geometric or ray optics theory predicts infinite field strength.

channel: A means to transfer a signal.

channel hardening: Property of channels whereby additional received signals mitigate deep fades.

channel matrix: A collection of channels that describes propagating signal flow from M transmission points to N reception points, and describes a time- and/or frequency-varying channel at the carrier frequency. *See also:* **multiple-input, multiple-output (MIMO)**.

characteristic impedance: **(A)** For 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 for a single transverse electromagnetic (TEM) propagating wave. **(B)** For a wave guide, the ratio of the complex transverse electric field component at any point in the wave guide to the complex magnetic field component measured perpendicular to the electric field at the same point in the wave guide for a single propagating wave guide mode. **(C)** For an unbounded homogeneous medium, the ratio of the complex transverse electric field component at any point to the complex magnetic field component measured perpendicular to the electric field at the same point.

NOTE—For a linearly polarized transverse electromagnetic (TEM) wave propagating in the z-direction of an isotropic medium, E_x/H_y is the characteristic impedance.

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

circularly polarized wave: An electromagnetic wave for which the locus of the tip of the instantaneous 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 with a left-hand or right-hand sense of rotation. *See also:* **left-hand circularly polarized (LHCP) wave**; **right-hand circularly polarized (RHCP) wave**.

classical maximum usable frequency: *See:* **maximum usable frequency (MUF)**.

NOTE—The use of "classical maximum usable frequency" is deprecated.

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

coherence bandwidth: The bandwidth over which the autocovariance of the signal amplitudes at two extreme frequencies reduces from 1 to 0.5 or some other specified level. It is inversely proportional to the channel delay spread. *See also:* **time delay spread (σ_τ)**.

coherence distance: The distance over which the field strength is correlated to the level of exp(−1). It is inversely proportional to the **wave number spread**.

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 $(t+\tau)$:

$$R(\Delta\vec{r},\tau) = E\left\{F_x(\vec{r},t)F_x^*(\vec{r}+\Delta\vec{r},t+\tau)\right\}$$

NOTE 1—This definition assumes that the statistics of the field are homogeneous and stationary.

NOTE 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.

coherence length: The distance between two wave fronts of an electromagnetic wave, measured in the direction of propagation, over which the phase of these wave fronts remains sufficiently correlated to result in observable interference between them.

coherence time (τ_0 **)**: The time over which the mutual coherence function has decreased to $1/e$ at a given location.

coherent bandwidth: *See:* **frequency selective bandwidth**.

coherent field: In situations where the magnitude, phase, and/or vector direction of an electromagnetic field are random variables, the result of averaging the field over all random characteristics. Also called the mean or average field.

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

completely polarized wave: A wave with no randomly polarized content.

conductivity (σ **)**: A macroscopic material property that relates the conduction current density $\vec{J}$ to the electric field $\vec{E}$ in the medium.

NOTE 1—For a monochromatic wave in a linear medium, that relationship is described by the (phasor) equation:

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

where

$\overline{\overline{\sigma}}$ is a tensor, generally frequency dependent
$\vec{J}$ is in phase with $\vec{E}$

NOTE 2—For an isotropic medium, the tensor conductivity reduces to a scalar conductivity σ, in which case $\vec{J} = \sigma\vec{E}$.

constitutive parameters: The permittivity and permeability of a medium. *See also:* **permeability (** μ **)**; **permittivity (** ε **)**.

co-polarization: The polarization parallel to a reference polarization. Refer also to IEEE Std 145-2013. *See also:* **parallel polarization**.

corner reflector: **(A)** (antenna). A reflecting object consisting of two or three mutually intersecting conducting flat surfaces. **(B)** (radar). Dihedral or trihedral mutually intersecting conducting surfaces designed to return electromagnetic radiation toward its source. Also used as calibration devices. Refer also to IEEE Std 145-2013.

NOTE—Two (dihedral) forms of corner reflectors are frequently used in antennas; three (trihedral) forms are more often used as radar targets.

correlation length: The direction-dependent distance over which the mutual coherence function for fields or the covariance function for statistical properties of a medium or surface decreases to $1/e$ of its maximum value.

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

creeping wave: A wave propagating along a smooth convex conducting surface that has diffracted into the shadow region.

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

cross-polarization: The polarization orthogonal to a reference polarization. Refer also to IEEE Std 145-2013. *See also:* **orthogonal polarization**.

cross-polarization discrimination: The ratio of the power 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 power to the unwanted power 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 (f_H)**.

cylindrical wave: A wave whose equiphase surfaces form a family of coaxial cylinders.

D region: The region of the terrestrial ionosphere between about 50 km and 90 km altitude.

NOTE—The D region is responsible for most of the daytime attenuation of LF, MF, and HF radio waves, and it forms the upper boundary of the Earth-ionosphere waveguide for VLF 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, L_D, is given by:

$$L_D = 6.9\sqrt{\frac{T_e}{N_e}}$$

where

T_e is the electron temperature in K
N_e is the electron number density in cm^{-3}

defocusing: The failure of rays to converge.

degree of polarization: The fraction of the total power in a wave that is completely polarized.

NOTE—Sometimes the definition is further restricted to a given polarization state, as in degree of linear polarization.

delay spread: *See:* **time delay spread (σ_τ)**.

depolarization: A process by which the polarization state of a wave is altered.

diamagnetic material: A material that is weakly repelled by a magnetic field that is applied on it. Diamagnetic materials are not magnetized in the absence of an applied static magnetic field and have a small negative magnetic susceptibility. All materials exhibit some degree of diamagnetism, but in magnetic materials the diamagnetic effects are very weak in comparison to other effects.

dielectric constant: *See:* **relative complex permittivity (ε_r)**.

diffracted wave: An electromagnetic wave that has been modified by an obstacle or spatial inhomogeneity in the medium by means other than reflection or refraction.

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

diffuse field: For random media, the non-coherent component of the scattered field.

NOTE—The diffuse electromagnetic field has a zero average value, (i.e., it is a zero-mean process).

diffuse intensity: Power density associated with the diffuse field.

diffuse reflection: *See:* **diffuse scattering**.

diffuse scattering: The generation of non-coherent (diffuse) fields caused by scattering of an incident electromagnetic wave by a random rough surface or a medium randomly varying with time and/or space.

diffusion approximation: For wave propagation in lossy media, it corresponds to neglecting the displacement current.

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. *See also:* **elliptically polarized wave**.

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

Dirichlet boundary condition: A boundary condition applied to the solution of a partial differential equation in which the function is specified on the boundary.

NOTE—When applied to the wave equation for electromagnetic fields, it requires continuity of the tangential field components across the boundary.

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

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

dispersive bandwidth: *See:* **frequency selective bandwidth**.

dispersive medium: A medium in which one or more of the constitutive parameters vary with frequency.

NOTE—As a result, the phase velocity of propagating waves in a dispersive medium depends on frequency.

displacement current: The time rate of change of the electric flux density.

distorted Born approximation: *See:* **extended Born approximation**.

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 (σ_λ): The spreading in the frequency domain of the power spectrum of a wave.

NOTE—The Doppler spread is inversely related to the coherence time (τ_0):

$$\sigma_\lambda = \frac{1}{\left(2\pi\tau_0\right)}$$

ducting: Guided propagation of radio waves inside an atmospheric or tropospheric radio frequency (RF) duct. *See also:* **atmospheric radio frequency (RF) 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 km 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 medium: The replacement of an inhomogeneous medium by an equivalent homogeneous medium having complex constitutive parameters derived from the propagation of the coherent (i.e., mean) field in the actual medium. The equivalent medium describes only the coherent field.

effective radius of the Earth: An effective value for the radius of the Earth that is used in place of the actual radius to correct approximately for standard atmospheric refraction. *See also:* **k-factor**; **refractive index gradient**.

NOTE—Under conditions of standard refraction, the effective radius of the Earth is 8.5×10^6 m, or 4/3 the geometrical radius.

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

eikonal: A function that describes the phase propagation of a time harmonic field.

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

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

electric field integral equation: An integrodifferential equation having the form of a Fredholm integral equation of the first kind for the electric current surface density along the surface S of a perfect electric conductor induced by an incident electric field.

NOTE—The tangential component of the incident electric field acts as the source for the current, hence the name.

electric field strength ($\left|\vec{E}\right|$): The magnitude of the electric field vector $\vec{E}$. The units of electric field strength are in volts per meter. *See also:* **field strength**.

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. *Syn:* **electric displacement**.

NOTE—Using phasor notation, the electric flux density is given by:

$$\vec{D} = \overline{\overline{\varepsilon}} \cdot \vec{E}$$

where

$\vec{D}$ is the electric flux density
$\overline{\overline{\varepsilon}}$ is the permittivity of the medium
$\vec{E}$ is the electric field

In an isotropic medium, permittivity is a scalar and $\vec{D}$ is parallel to $\vec{E}$. In an anisotropic medium, permittivity is a tensor and $\vec{D}$ and $\vec{E}$ are not necessarily parallel. The units of electric flux density are in coulombs per meter squared. *See also:* **permittivity**.

electrical length: For a wave of a given frequency, a distance between field points, expressed in wavelengths of the wave in the medium. *See also:* **phase path length**.

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): An intense transient electromagnetic field.

NOTE—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, as shown in Table 1. *See also:* **radio spectrum**.

Table 1—Electromagnetic spectrum

Spectral region	Wavelength
Gamma rays	< 0.006 nm
X-rays	0.006 nm to 5 nm
Ultraviolet rays	5 nm to 0.4 µm

Table continues

Table 1—Electromagnetic spectrum *(continued)*

Spectral region	Wavelength
Visible light	0.4 μm to 0.7 μm
Infrared	0.7 μm to 0.1 mm
Radio	> 0.1 mm

electromagnetic waves: Waves characterized by temporal and spatial variations of electric and magnetic fields. Radio waves, infrared waves, light waves, etc., are all electromagnetic waves.

electrostatic wave: *See:* **longitudinal wave**.

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. May also refer to the angle of radiation measured above the horizon from a source. *See also:* **grazing angle**.

ELF: *See:* **extremely low frequency**.

elliptically polarized 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 in radians equal to the angular frequency of the wave. *See also:* **left-hand circularly polarized (LHCP) wave**; **right-hand circularly polarized (RHCP) wave**.

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

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

enhanced backscatter: Stronger than expected backscattered signal due to resonant surface or internal waves in the target region.

envelope: The real-valued amplitude of a modulated signal. *See also:* **field strength**.

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

equiphase surface: Any surface over which the field vectors of a time harmonic wave have the same phase.

Ergodic hypothesis: For stationary random processes, the equivalence of spatial or temporal average with ensemble average.

Es layer: *See:* **sporadic E layer**.

evanescent field: An electromagnetic field for which, as one moves away from a boundary, the phase is spatially invariant and the magnitude decays exponentially.

NOTE 1—An evanescent field is a special case of an inhomogeneous plane wave.

NOTE 2—Fields in a waveguide beyond cutoff are evanescent.

evaporation duct: A class of surface ducts that is caused by turbulent mixing at the air-earth interface, causing a rapid decrease in water vapor pressure (and relative humidity) as a function of height above the surface.

exciting field: The total field responsible for the waves scattered by a particle or elemental surface area. In the case of single scattering, the exciting field consists solely of the incident field. In the multiple scattering case, the exciting field consists of the incident field plus the fields scattered by and among all other particles or elemental surface areas. *See also:* **incident field**.

extended Born approximation: The extended Born approximation takes the exciting field to be the incident field after propagating through the average medium. *Syn:* **distorted Born approximation**.

extended Huygen's-Fresnel principle: An integral relationship between a scalar wave over one plane in an extended random medium and the wave over a parallel plane located a distance away. In this formulation, the random effects are explicitly represented by the change in log amplitude and phase of a spherical wave propagating between the two planes.

extinction: The decrease of power flux density of an electromagnetic wave due to absorption and scattering.

extinction coefficient (κ_e): (of a medium). The rate of decrease of power density of a wave, per unit distance, due to absorption and scattering.

extinction cross-section (σ_e): (of a body). The ratio of power absorbed P_a and scattered P_s by the body to the power density of an incident plane wave, S_i:

$$\sigma_e = \frac{\left(P_a + P_s\right)}{S_i} = \sigma_a + \sigma_{ts}$$

where

σ_a is the absorption cross-section of the body
σ_{ts} is the total scattering cross-section of the body

extinction matrix ($\overline{\overline{\kappa}}_e$): (of a medium). Vector analog of extinction coefficient for polarized waves propagating in an anisotropic medium.

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

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

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

extremely low frequency (ELF): 3 Hz to 30 Hz. *See also:* **radio spectrum**.

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

NOTE 1—The daytime F region is characterized by an F1 layer and an F2 layer, and at night the lower (F1) layer merges with the upper (F2) layer.

NOTE 2—The maximum (or peak) of the F2 layer normally occurs in the 300 km to 600 km altitude range.

fade depth: The ratio, usually expressed in decibels, of a reference signal power to the received signal power during a fade.

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

fade slope: The time rate of change of the received signal power during a fade, expressed in decibels per second.

fading: The temporal and/or spatial variation of received signal power caused by changes in the transmission medium or path(s) with time and/or receiver location.

fading range: The ratio of maximum received signal to minimum received 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.

far field region: That region of the field of an antenna where the angular field distribution is essentially independent of the distance from a specified point in the antenna's region. Refer also to IEEE Std 145-2013.

Faraday rotation: The rotation of the polarization ellipse of an electromagnetic wave as it propagates in a gyrotropic medium such as a plasma in the presence of a finite magnetic field, in a ferrite, or in some dielectric crystals.

NOTE—A gyrotropic material is one in which the permittivity tensor, $\overline{\overline{\varepsilon}}$, or the permeability tensor, $\overline{\overline{\mu}}$, is antisymmetric such that $\varepsilon_{ij} = -\varepsilon_{ji}$ or $\mu_{ij} = -\mu_{ji}$, respectively.

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

ferromagnetic material: A material that responds strongly to the magnetic field that is applied on it. Ferromagnetic materials have a large positive magnetic susceptibility. Due to the random orientations of their internal magnetic domains, they can start as not being magnetized, but they retain their magnetization after an external magnetic field has been applied on them (i.e., they turn into permanent magnets after an external magnetic field has been applied on them).

field strength: *See:* **radio field strength**.

finite difference frequency domain (FDFD): A numerical technique for solving partial differential equations by first Fourier transforming the time variable of the equation from the time domain to the frequency domain. Then the resultant partial equation is discretized and solved using the finite difference method.

finite difference time domain (FDTD): A numerical technique for solving a partial differential equation involving time and space variables. The solution is implemented sequentially in the time domain.

finite element frequency domain (FEFD): A numerical technique for solving partial differential equations by first Fourier transforming the time variable of the equation to the frequency domain and then using the finite element method.

finite element time domain (FETD): A numerical technique for solving a partial differential equation directly in the time domain. Discretization of the time variable can be accomplished by the finite difference scheme or by the Galerkin method. *See also:* **finite difference time domain**.

NOTE—This method differs from the finite difference time domain (FDTD) method in that the space variable is made discrete by the finite element method rather than the finite difference method.

finite integral technique (FIT): A numerical technique for solving Maxwell's equations expressed in their integral form.

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

Foldy's approximation: The approximate solution for the propagation constant of the mean field in a random medium based on the scattering properties of a single particle.

Foldy-Twersky theory: *See:* **Foldy's approximation**.

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

Fraunhofer region: *Syn:* **far field region**.

free space: Space that is free of obstructions and characterized by the constitutive parameters of a vacuum.

free space permeability (μ_0): A scalar constant such that, in vacuum, its product with the magnetic field $\vec{H}$ is equal to the magnetic flux density:

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

The numerical value of μ_0 in SI units is $4\pi \times 10^{-7}$ H/m.

free space permittivity (ε_0): A scalar constant such that in vacuum, the product of ε_0 and the electric field, $\vec{E}$, is equal to the electric flux density:

$$\vec{D} = \varepsilon_0 \vec{E}$$

The numerical value for ε_0 in SI units is 8.854×10^{-12} F/m.

frequency: (of a periodic oscillation or wave). The number of identical cycles per second, measured in Hertz.

frequency selective bandwidth: The inverse of the product $2\pi\sigma_t$, where σ_t is the time delay spread. *Syn:* **coherent bandwidth**; **dispersive bandwidth**.

frequency selective fading: Fading which affects unequally the different spectral components of a radio signal.

Fresnel coefficients: (for reflection and transmission). The ratio of the value of the parallel or perpendicular polarization component of the electric field of a reflected or transmitted plane wave to that of the corresponding component of the incident plane wave, evaluated at an infinite planar interface separating two homogeneous media. *Syn:* **reflection coefficient**; **reflection factor**.

Fresnel ellipse: 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 ellipsoid: 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 ellipsoids.

Fresnel emissivity: The emissivity of an infinite planar interface between two homogeneous media.

Fresnel region: *Syn:* **radiating near-field region**.

Fresnel zone: *Syn:* **near-field region**.

Friis transmission formula: Under ideal conditions of impedance and polarization match, the Friis transmission formula relates the power at the output terminals of a receiving antenna due to radiated power from a distant transmitting antenna when the two antennas are operating in each other's far field and in free space according to the following relationship:

$$\frac{P_r}{P_t} = A_r A_t \left(\frac{1}{\lambda d}\right)^2 = A_r G_t \left(\frac{1}{4\pi d^2}\right) = G_r G_t \left(\frac{\lambda}{4\pi d}\right)^2$$

where

P_r is the received power
P_t is the transmitted power
A_r is the effective area of the receiving antenna
A_t is the effective area of the transmitting antenna
λ is the wavelength
d is the separation distance between the antennas
G_r is the gain of the receiving antenna given by $G_r = \frac{4\pi A_r}{\lambda^2}$
G_t is the gain of the transmitting antenna given by $G_t = \frac{4\pi A_t}{\lambda^2}$

Gain here refers to the corresponding antenna gains in the anticipated transmit and receive directions.

NOTE 1—Additional terms should be included to account for impedance and polarization mismatch.

NOTE 2—In the second form, the Friis transmission formula does not show an explicit dependence on the wavelength.

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

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. *See also:* **F region**.

galactic radio waves: Radio waves originating in our galaxy.

Gaussian curvature: The product of the two principle radii of wave front curvature, as measured at a specific point along perpendicular directions. In ray theory, the spreading factor is related to the Gaussian curvature of a wave.

geometric optics: The infinitesimal-wavelength limit of processes involved in scattering or propagation, in which case ray-optics apply.

geometric theory of diffraction (GTD): The theory of geometric optics modified to allow for rays propagating into shadow regions. Also includes the development of ray constructs for scattering from edges and removal of "infinities" in optical focusing predictions in inhomogeneous media.

grazing angle: The angle that a ray or propagation vector of a wave makes with the tangent plane at the point of reflection. *See also:* **elevation angle**.

Green's function: The impulse response of an inhomogeneous differential equation defined on a domain, with specified initial conditions or boundary conditions.

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—Above the surface 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. A ground wave can also be a lateral wave if both the transmitter and the receiver are in the denser lossy medium like the sea.

group delay: *See:* **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:

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

where

q is the charge of the particles
$\left|\vec{B}\right|$ is the magnitude of magnetic flux density
m is the mass of the particles

For a linear medium, the gyro-frequency is the same as cyclotron frequency.

height gain: The variation in electromagnetic field strength above a surface, expressed as gain relative to a fixed reference height.

NOTE 1—This ratio is generally expressed in decibels and may have a negative value.

NOTE 2—The reference height may be at the Earth's surface.

NOTE 3—The separation distances are such that the transmitting and receiving antennas are in each other's far field in free space.

HF: *See:* **high frequency**.

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

homogeneous dense medium: Medium in which the refractive index is significantly different from that of a vacuum. *See also:* **sparse medium**.

homogeneous Helmholtz equation: The wave equation for the electromagnetic potential, Φ, given by:

$$\left(\nabla^2 + k^2\right)\Phi = 0$$

where

k is the wave number in the medium
∇^2 is the Laplacian operator

The homogeneous Helmholtz equation is also an equation satisfied by the scalar components of the electric/magnetic fields.

NOTE—Sometimes k^2 is replaced by $-\gamma^2$, where γ is the propagation constant.

homogeneous medium: A medium whose properties are spatially invariant.

homogeneous plane wave: A wave in which the planes of constant magnitude 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 or parallel to the Earth's surface in radio propagation. Same as S-polarization in optics; perpendicular polarization in physics. *See also:* **transverse electric (TE) wave**.

Huygen's principle: A principle proposed by Christian Huygen in 1678 which states that:

—Each point on the wave front of a light disturbance can be considered to be a new source of secondary spherical waves, and

—The wave front at any other point in space can be found by constructing the envelopes of the secondary wavelets.

Hyper Rayleigh fading: A fading distribution that is observed when two homogeneous plane waves with uniformly distributed, independent phases are superimposed upon a diffuse collection of waves. *See:* **two-wave with diffuse power (TWDP) fading**.

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

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

improper mode: A mode of propagation that cannot be excited by a physical source in the absence of other modes.

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

incident field: That component of the exciting field identical to the field that would have been present in the absence of all particles, surfaces, and volumes. *See also:* **exciting field**.

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 or medium.

incoherent field: *See:* **diffuse field**.

incoherent scattering: Scattering produced when the wave of an exciting field encounters random fluctuations of complex permittivity or permeability. 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 magnitude and thus constitute a zero mean process.

index of refraction (*n*): The speed of light in a vacuum divided by the velocity of wave propagation in the medium. In a lossless, linear, isotropic dielectric, this is usually given by:

$$n = \sqrt{\varepsilon_r \mu_r}$$

where

ε_r is the relative permittivity of the medium
μ_r is the relative permeability of the medium

inhomogeneous dense medium: A medium having discrete or continuous spatial variations in its permittivity or permeability, such that multiple scattering must be considered. *See also:* **sparse medium**.

inhomogeneous medium: A medium whose properties are not spatially invariant.

inhomogeneous plane wave: A wave for which the planes of constant magnitude and planes of constant phase are not parallel. Sometimes called a non-uniform plane wave or non-homogenenous plane wave or a heterogeneous plane wave, but this last term use is deprecated.

in-phase component: The real part of a phasor representation of a time harmonic field.

instantaneous frequency: 1/(2π) times the rate of change of phase of a wave.

instantaneous Poynting vector $\left[\vec{P}(t,\vec{r})\right]$: (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.

integrated precipitable water vapor: The equivalent liquid water height (in centimeters) of a vertical column of water vapor in the atmosphere with 1 cm^2 horizontal cross-section.

intrinsic impedance: For a monochromatic (time harmonic) electromagnetic wave propagating in an unbounded homogeneous isotropic 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.

invariant imbedding: A mathematical technique that can be employed to treat radiative transfer problems in the presence of inhomogeneous profiles of absorption and temperature. In it, a boundary-value problem is converted to an initial value problem that incorporates the boundary conditions in the equations themselves. The equations are in the form of first-order ordinary differential equations and can be solved by standard methods of initial value problems.

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

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

isotropic medium: A medium whose constitutive parameters do not depend on the polarization and direction of wave propagation of the electric and magnetic fields. *See also:* **anisotropic medium**.

isotropic scatterer: A non-physical scatterer that scatters equally in all directions.

Jansky: The SI unit of spectral power flux density: 10^{-26} times one watt per square meter per Hertz.

junction frequency (JF): The frequency at which the traces seen on an oblique-incidence ionogram corresponding to the low-angle ray and to the high-angle ray, respectively, for a given mode, merge together.

NOTE—The high-angle ray is also called the Pederson ray.

k-factor: A scaling factor used to adjust the radius of the Earth in a simplified method to approximate the effects of refraction in spherical propagation calculations. *See also:* **effective radius of the Earth**; **refractive index gradient**.

NOTE—Although K has occasionally been used to represent the Earth scaling factor, k is the recommended choice.

K-factor: In a Rician (also Ricean or Rice) fading channel, the K-factor is the ratio of the power contained in the single, dominant homogeneous plane wave component (the steady part) and in the diffuse wave component (the fluctuating part). K is also a parameter of the Rician distribution. *See also:* **Rician fading**.

Kirchhoff approximation: When used in computing electromagnetic scattering from surfaces, this approximation assumes that the surface is locally planar and the field on the surface is equal to the field that would have existed had the surface been a plane tangent to the actual surface at that point.

NOTE 1—Valid when the local radius of curvature is much greater than a wavelength and multiple scattering can be neglected.

NOTE 2—Not valid in shadow regions.

Kirchhoff's theory of diffraction: A scalar wave theory, valid when the diffracting aperture has dimensions that are large relative to the wavelength. The diffracted field at any point is found by evaluating an integral involving the field and its derivative over the aperture only, and these quantities are assumed to be the same as they would be were the aperture infinitely large in both directions.

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

Lambert-Beer Law: *See:* **Beer-Lambert Law**.

Lambertian surface: A surface with a cosine dependence of the scattered power on both the incident and scattering angles and, hence, a cosine squared dependence on angle in the backscatter direction.

large-scale fading: Fluctuations in average field strength due to changes in the amount of power scattered, reflected, or diffracted to an area. *See also:* **shadow fading**.

lateral wave: A wave, not predicted by geometrical optics, excited at and propagated along the interface of two (possibly lossy) dielectric media. For sufficiently large distances from the source, the magnitude of the field varies as the inverse square of the distance measured along the interface.

NOTE—Lateral wave is similar to the component of the radio ground wave when the geometrical-optical component is separated out and the source is located in the denser lossy medium.

leaky wave: An electromagnetic wave associated with a fast wave guided along a surface. The wave radiates (or leaks) energy continuously as it travels along the surface and, thus, decreases exponentially in the direction of propagation. Over a limited region, it may increase with height above the surface.

NOTE—Leaky waves may be created by periodic as well as uniform, open guiding structures.

left-hand circularly polarized (LHCP) wave: A circularly or an elliptically polarized electromagnetic wave for which the electric field vector, when viewed with the wave approaching the observer, rotates clockwise in space.

NOTE 1—This definition is consistent with observing a counterclockwise rotation when the electric field vector is viewed in the direction of propagation.

NOTE 2—A left-handed helical antenna radiates a left-hand circularly polarized wave.

level crossing rate: The number of times per second that a field drops below the specified power or envelope threshold.

LF: *See:* **low frequency (LF)**.

limb sounding: A technique for making observations of planetary atmospheres wherein satellite-borne sensors are oriented in a direction tangent to the spherical atmospheric layer of interest, to afford the longest path length and highest vertical resolution through the atmosphere.

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.

locally homogeneous medium: A medium in which the changes in electrical properties are small when measured over a distance of a wavelength.

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

lognormal fading: Large-scale fading that follows a Gaussian probability function when plotted on a dB scale (decibel scale).

longitudinal 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.

Lorenz-Mie scattering: *See:* **Mie scattering**.

line of sight (LOS): The direct path from the source to the receiver.

loss tangent: (of a material). The ratio of the imaginary part to the real part of the complex permittivity.

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

lowest observed frequency (LOF): In ionospheric sounding, LOF is the lowest frequency for which signals transmitted from a sounder and propagated via the ionosphere are observed on the ionogram, regardless of the precise propagation path involved.

NOTE—The LOF is a function of the ionosonde's transmit power, antenna gain, and receiver noise environment.

lowest usable frequency (LUF): The lowest frequency that would permit acceptable performance of a radio circuit by signal propagation via the ionosphere between given terminals at a given time under specified working conditions.

NOTE 1—The LUF 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.

NOTE 2—LUF is sometimes referred to as lowest usable high frequency.

NOTE 3—The use of lowest useful frequency for LUF is deprecated.

LUF: *See:* **lowest usable frequency (LUF)**.

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 integral equation: A Fredholm integral equation of the second kind for the electric current density induced on the surface S of a perfect electric conductor by an incident electric field.

NOTE—The tangential component of the incident magnetic field acts as the source for the current, hence, the name.

magnetic field strength ($|\vec{H}|$): The magnitude of the magnetic field vector $\vec{H}$. The units of magnetic field strength are in amperes per meter. *Syn:* **magnetizing force**.

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 the magnetic flux density ($\vec{B}$):

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

The units of magnetic flux density are in volt seconds per meter squared.

magnetic induction: *See:* **magnetic flux density**.

NOTE—The use of "magnetic induction" is deprecated.

magnetic loss angle: For a pure sinusoidal wave in a medium with complex permeability μ, the angle defined by the equation:

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

where

μ'' is the imaginary part of the complex permeability
μ' is the real part of the complex permeability

magnetic material: A material whose internal structure allows for strong effects when an external magnetic field is applied on it. All materials lose their ability to be magnetic when heated above a critical temperature, their Curie temperature.

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.

magnetic susceptibility: A quantity describing the degree to which a material is magnetized by a magnetic field that is applied on it. The magnetization of a material is proportional to the magnetic field applied to it.

magnetizing force: *See:* **magnetic field strength**.

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

magneto-ionic wave: At a given frequency, either of the two characteristic electromagnetic plane waves that can travel in a homogeneous magneto-ionic medium without change of polarization. *See also:* **extraordinary wave**; **ordinary wave**.

NOTE—These characteristic waves are also called the ordinary and extraordinary waves.

magnetopause: The transition region between the planetary and the interplanetary magnetic fields.

magnetosphere: The region of a planetary atmosphere where the planetary magnetic field, as modified by the solar wind and the interplanetary magnetic field, 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 in the Earth associated with time-varying geomagnetic fields.

magneto-telluric fields: Electric and magnetic fields induced in the Earth by external time-varying sources that are usually of ionospheric origin.

magnitude: The real number indicating the maximum or peak absolute value of a varying quantity. *See also:* **amplitude**.

maximum observed frequency (MOF): In oblique-incidence ionospheric sounding, the MOF is the highest frequency for which the signals transmitted from a sounder are observed on the ionogram, regardless of the propagation path involved.

maximum usable frequency (MUF): The highest frequency by which a radio wave can propagate between given terminals, on a specified occasion, by ionospheric refraction alone.

NOTE 1—Where the MUF is restricted to a particular ionospheric propagation mode, the values may be quoted together with an indication of that mode (e.g., 1E MUF, 2F2 MUF).

NOTE 2—If the extraordinary component of the wave is involved, then this is noted [e.g., 1F2 MUF (X)]. Absence of a specific response to the magneto-ionic component implies that the quoted value relates to the ordinary wave.

NOTE 3—It is sometimes useful to quote the ground range for which the MUF applies. This is indicated in kilometers following the indication of the mode type [e.g., 1F2 (4000) MUF (X)].

Maxwell-Garnett mixing: Approximate permittivity that results from a medium containing a sparse array of small spherical dielectric inclusions.

mean (effective) radiating temperature: For a non-isothermal body or medium:

—The temperature that would give rise to the same total brightness as the actual medium, or

—The temperature that would give rise to the same spectral brightness as the actual medium.

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

mesopause: The upper boundary of the mesosphere.

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.

method of images: A class of ray tracing algorithms loosely based on image theory.

method of moments (MoM): A technique for expressing an integral equation that relates the source to the field as a system of simultaneous linear equations where: 1) the coefficients of the system are expressed in terms of the Green's functions, and 2) the source is expressed as the linear combination of orthogonal basis functions. *See also:* **boundary element method (BEM)**.

MF: *See:* **medium frequency (MF)**.

micropulsation: Small magnitude fluctuations (usually much less than 10^{-6} of the Earth's magnetic field) with periods on the order of seconds or minutes ($f < 1$ Hz).

NOTE—Micropulsations usually result from current fluctuations in the E region.

Mie scattering: Scattering by spherical particles whose diameters are comparable to or greater than a wavelength. *Syn:* **Lorenz-Mie scattering**.

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.

mixing rules: Various theoretical and often empirical models to predict the effective medium constitutive parameters.

mode of propagation: A form of propagation of guided waves where the transverse field pattern is invariant with range (i.e., as in a waveguide). One of possibly many, if not infinite, distinct wave solutions in a medium bounded by a waveguide, whose bounds may be at infinity.

NOTE—Inappropriate uses of the term mode are common. For example, alternative use of the term mode may refer to reflection, refraction, scattering, or diffraction.

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.

modified refractivity (M): In the troposphere, the excess over unity of the modified index of refraction, expressed in millionths:

$$M = (n + \frac{h}{a} - 1) \times 10^6$$

where

a is the mean geometrical radius of the Earth
n is the refractive index at a height, h, above the local surface and $h/a \ll 1$

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

monostatic cross-section: The scattering cross-section of a target in the retro-direction. Refer also to IEEE Std 145-2013.

monostatic radar: A radar where the transmit and receive antennas are collocated.

Monte Carlo method: Applied to propagation and scattering processes, it simulates such processes by repeatedly calculating outcomes using random sampling from the processes' parameter space. It is useful when a problem is too large to solve by other means.

Mueller matrix: The matrix that relates the Stokes vector of the scattered wave to the Stokes vector of the incident wave. *Syn:* **Stokes matrix**.

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

multipath 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.

multipath transmission: *See:* **multipath propagation**.

multiple-input, multiple-output (MIMO): A communications system that has multiple points of transmission and multiple points of reception.

multiple-input, single-output (MISO): A communications system with multiple points of transmission and a single point of reception.

multiple scatter: A calculation of wave scattering from a surface or a collection of particles for which the field exciting each surface element or particle consists of the incident field plus the fields scattered by all the other surface elements or particles in their many interactions. A full multiple scattering solution is an exact solution to the problem.

M-unit: *See:* **modified refractivity**.

mutual coherence function: The normalized coherence function. *See also:* **coherence function**.

near field region: That part of space between the antenna and the far field region.

Neumann boundary condition: A boundary condition encountered in boundary value problems governed by integral equations or partial (ordinary) differential equations, in which the derivative of the function, applied normal to the boundary (end points) is specified at the boundary (end points).

Norton surface wave: The propagating electromagnetic wave produced by a source over or on the ground. The Norton wave consists of the total field minus the geometrical-optics field.

NOTE 1—It is important to note that it is not a surface wave and in this case the fields decay as $1/(r^2)$.

NOTE 2—The Norton surface wave does not satisfy Maxwell's equations.

N-unit (N): A measurement of refractivity, usually in parts per million, given by:

$$N = (n-1)\times 10^6$$

where

n is the refractive index

See also: **refractivity**.

O wave: *See:* **ordinary wave**.

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

obstacle gain: The ratio, usually expressed in dB, of the electromagnetic field at a point in the vicinity of the geometrical shadow of an obstacle to the field which would occur in the absence of the obstacle.

operational maximum usable frequency (MUF): The highest frequency that would permit acceptable performance of a radio circuit by signal propagation via the ionosphere between given terminals at a given time under specified working conditions. *See also:* **maximum usable frequency (MUF)**.

NOTE 1—Acceptable performance may, for example, be quoted in terms of the maximum allowable bit error rate or required signal-to-noise ratio.

NOTE 2—Specified working conditions may include such factors as antenna type, transmitter power, class of emission, and required information rate.

optical depth: The value of the integral of the extinction coefficient over a specified path.

optimum working frequency (OWF or FOT): The frequency that is exceeded by the operational maximum usable frequency (MUF) during 90% of the specified period, usually a month.

NOTE—The acronym FOT is the French abbreviation of "frequence optimale de travail."

ordinary 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. *Syn:* **O wave**.

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: For a given wave, the unique polarization state containing no components of the given wave's polarization. Refer also to IEEE Std 145-2013.

NOTE 1—For linear polarization, the (linear) polarization perpendicular to the reference (linear) polarization.

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

NOTE 3—For elliptical polarization, the polarization with the same axial ratio, opposite rotation sense, and major axis perpendicular to that of the reference polarization.

parabolic approximation: *See:* **parabolic equation**.

parabolic equation: Results when the Helmholtz equation is approximated to emphasize preferred propagation in the axial direction, leading to a differential equation of parabolic form. *Syn:* **parabolic approximation**.

parallel polarization: The polarization of a wave for which the electric field vector lies parallel to the plane of incidence. *Syn:* **transverse magnetic polarization; vertical polarization**. Refer also to IEEE Std 145-2013.

Sometimes called vertical or transverse magnetic (TM) polarization. In optics, it is called “p” polarization. In radio propagation, *H* is parallel to the ground.

paramagnetic material: A material that is weakly attracted by a magnetic field that is applied on it. Paramagnetic materials are not magnetized in the absence of an applied magnetic field and have a small positive magnetic susceptibility.

paraxial approximation: An approximation in which the waves are constrained to travel predominantly in one direction.

partially polarized wave: A wave with some randomly polarized content.

particle size distribution: The probability density function describing the size distribution of particles in a medium.

partition-based path loss model: A description of propagation losses that assumes free space $1/r^2$ losses, where r is the distance between transmitter and receiver, and additional factors for each type of obstruction.

path loss: The loss in power density experienced by a wave as it traverses the path between the transmitter and receiver.

path loss exponent: The exponent of the transmitter to receiver distance in the path loss exponent model. *See also:* **path loss exponent model**.

path loss exponent model: A simple model where the path loss is a function of the line of sight distance between transmitter and receiver raised to some exponent.

NOTE—The path loss model of unbounded free space has an exponent of 2.

Pederson ray: The upper ionospheric ray in oblique-incidence propagation. *See also:* **junction frequency (JF)**.

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. *Syn:* **skin depth**.

NOTE—The penetration depth, also called the skin depth, is equal to the reciprocal of the attenuation constant in the lossy medium.

penetration frequency: **(A)** (oblique incidence propagation). For a given angle of incidence, the lowest frequency that just penetrates the ionosphere. **(B)** (vertical incidence propagation).

percent polarized: The degree of polarization expressed in percent. *See also:* **degree of polarization**.

perfect conductor: 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. *Syn:* **ideal conductor**; **perfectly conducting medium**.

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

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

permeability (μ): 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:

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

where

$\overline{\overline{\mu}}$ is a tensor that is generally frequency dependent

For an isotropic medium, the tensor reduces to a complex scalar:

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

where

μ' is the real part of the permeability
μ'' is the imaginary part, which accounts for losses

permittivity (ε): A macroscopic material property of the medium that relates the electric flux density, $\vec{D}$, 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:

$$\vec{D} = \overline{\overline{\varepsilon}} \times \vec{E}$$

where

$\overline{\overline{\varepsilon}}$ is the complex permittivity, is a tensor that is generally frequency dependent

For a homogeneous isotropic medium, the tensor reduces to a complex scalar:

$$\varepsilon = \varepsilon' - j\varepsilon''$$

where

ε' is the real part of the permittivity
ε'' is the imaginary part, which accounts for losses

perpendicular polarization: The polarization of a wave for which the electric field vector is perpendicular to the plane of incidence. Refer also to IEEE Std 145-2013.

NOTE—Sometimes called horizontal or transverse electric (TE) polarization; in optics, such a wave is said to be “s” polarized.

perturbation technique: An approximate analytical method, the accuracy of which is based on the smallness of one or more characteristics of the medium or interface.

phase constant (β): The imaginary part of the complex propagation constant. *See also:* **propagation constant**.

phase function matrix: The matrix that results when the elements of the Mueller matrix are averaged over all scatterer orientations. The phase function matrix relates the average scattered Stokes vector to the incident Stokes vector.

phase path length: For a monochromatic electromagnetic wave, the product of the phase constant and the physical path length. *See also:* **electrical length**.

NOTE—In a slowly varying spatially inhomogeneous medium, the path length equals the line integral of the real part of the phase constant along the ray path.

phase vector ($\vec{\beta}$ **)**: The real part of the propagation vector, $\vec{k}$. *See also:* **propagation vector**.

NOTE—The phase vector points in the direction of maximum rate of change of the phase.

phase velocity: The velocity at which the equiphase planes of a propagating wave travel.

NOTE—The minimum phase velocity is in the direction of the wave normal.

phasor notation: For monochromatic fields, the complex notation used in the expressions for field quantities with the exponential time factor $e^{j\omega t}$. For example, for plane waves:

$$\vec{\varepsilon}(\vec{r},t) = \mathrm{Re}\left\{\vec{E}(\vec{r},\omega)e^{j\omega t}\right\}$$

where

$\vec{\varepsilon}(\vec{r},t)$ is the instantaneous electric field
Re indicates the real part
$\vec{E}(\vec{r},\omega)$ is the phasor notation for the electric field

photo-ionization: Ionization of atoms or molecules caused by infrared, visible, or ultraviolet photons.

physical optics approximation: Estimates the field scattered by a body by considering only the interaction of the incident wave with the local geometry of the body at every point illuminated by the incident wave. The physical optics approximation is the Kirchhoff approximation in the illuminated part of the body and zero in its shadow.

Planck's radiation law: Defines the emission spectrum of a blackbody in terms of its physical temperature. Planck's radiation law for the brightness, B_ν, of a blackbody is as follows:

$$B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{\exp(h\nu / k_B T) - 1}$$

where

h is Planck's constant
ν is the frequency
k_B is Boltzmann's constant
c is the speed of light in vacuum
T is the temperature in K

plane of incidence: The plane containing the normal to the surface of a boundary and the direction of propagation of the incident wave.

plane wave: A wave whose equiphase surfaces form a family of parallel planes. Refer also to IEEE Std 145-2013. *See also:* **homogeneous plane wave**; **inhomogeneous plane wave**.

plane wave decomposition: Representation of the total field as the weighted sum of plane wave components each traveling in different directions. *See:* **plane wave spectrum**; **angular power spectrum**.

plane wave propagation factor: The factor $e^{-j\vec{k}\cdot\vec{r}}$ in the phasor expression for plane wave fields, where $\vec{k}$ is the propagation vector (a constant) and $\vec{r}$ is the position vector.

plane wave spectrum: *See:* **angular power spectrum**.

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. A plasma 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:

$$\left(f_N\right)^2 = \left(2\pi\right)^{-2} \frac{Nq^2}{m\varepsilon_0}$$

where

q is the charge per particle
m is the particle mass
N is the particle number density
ε_0 is the permittivity of free space

NOTE—For electrons, with f_N in Hertz and N in electrons per cubic meter:

$$\left(f_N\right)^2 = 80.6N$$

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

plasma waves: Electrostatic waves associated with a “warm” plasma, giving rise to density and velocity fluctuations.

plasmapause: The outer boundary of the plasmasphere, characterized by a steep decrease of the plasma density.

plasmasphere: That ionized region of the topside ionosphere that encircles the Earth around the equator and 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.

Poincaré sphere: A tool for graphically displaying the polarization state of a monochromatic wave. For a fully polarized wave, each point on the sphere’s surface defines a unique polarization state, with axial ratio and tilt angle mapping into latitude and longitude, respectively. Refer also to IEEE Std 145-2013.

polar cap: Polar region bounded by the auroral zone.

polar cap absorption (PCA): The intense absorption of radio waves in the 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.

polarimetry: The study of electromagnetic propagation, scattering, and emission that considers the complete polarization state of any arbitrarily polarized wave.

polarization: (of an electromagnetic wave). The locus of the tip of the electric field vector observed over time at a fixed point in space in a plane orthogonal to the wave normal. *See also*: **circularly polarized wave; elliptically polarized wave; linearly polarized wave; parallel polarization; perpendicular polarization**.

NOTE 1—Elliptical polarization is the most general case.

NOTE 2—The polarization of an electromagnetic wave is defined by the tilt angle, the axial ratio, and the sign of the axial ratio, which expresses the sense of rotation of the polarization ellipse.

polarization coupling loss: That part of the transmission loss due to the mismatch between the polarization of the incoming wave and the polarization of the receiving antenna.

power density: (of a traveling wave). *Syn:* **power flux density**; **time-averaged Poynting vector**. *See also:* **spectral power density**; **spectral power flux density**.

power flux density: *See:* **power density**.

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

NOTE—The use of "power reflectance" is deprecated.

power reflection coefficient: The squared magnitude of the electric field reflection coefficient. *Syn:* **power reflection factor**.

NOTE—The power reflection coefficient represents unambiguously the reflected power only in cases where the incident and reflected fields are not coupled (e.g., in single mode transmission lines).

power reflection factor: *See:* **power reflection coefficient**.

Poynting vector: *See:* **instantaneous Poynting vector**; **time-averaged Poynting vector**.

precipitation scatter: Electromagnetic scattering caused by precipitating rain, hail, or snow particles.

propagating mode: Refers to a mode where the imaginary part of the propagation constant is much greater than the real part, (i.e., the mode is not cut-off as in a metallic wave guide).

propagation constant (γ): The complex scalar γ in expressions for one-dimensional wave propagation using the exponential factor $e^{-\gamma z}$.

$$\gamma = jk = \alpha + j\beta$$

where

α is the attenuation
β is the phase constant
k is the wave number

See also: **plane wave propagation factor; propagation vector**.

propagation delay: The time required for energy to propagate between two specified points, determined by multiplying the group velocity of the wave by the distance between the two points projected onto the direction of propagation.

propagation factor: For RF, the magnitude of the ratio of the field strength at a particular location to the field strength obtained in free-space at the same location.

propagation vector ($\vec{k}$ **)**: The complex vector $\vec{k}$ in expressions for wave propagation using the exponential factor $e^{-j\vec{k}\cdot\vec{r}}$ is:

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

where

$\vec{\beta}$ is the phase vector
$\vec{\alpha}$ is the attenuation vector
$\vec{r}$ is a position vector

proper mode: A propagation mode that can be excited by a physical source.

quadrature component: The imaginary part of a phasor representation of a time harmonic field.

NOTE—The in-phase and the quadrature components for a causal system are related by the Hilbert Transform.

quasi-crystalline approximation: A formulation used to determine the coherent mean field of a wave propagating in a non-tenuous (dense) random medium; a higher order approximation to Foldy's approximation.

radar astronomy: That branch of astronomy that uses radar to study astronomical objects.

radar backscattering cross-section: Radar scattering cross-section as determined for coincident transmitter and receiver locations. *See also:* **scattering cross-section**.

radar cross-section (RCS): *See:* **scattering cross-section**.

radar reflectivity: A measure of backscattering from an inhomogeneous medium, defined as radar cross-section (RCS) per unit volume. Frequently used in radar measurements of meteorological phenomena.

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

radiating near field region: That portion of the near field region of an antenna between the far field and the reactive portion of the near field region, wherein the angular field distribution is dependent upon the distance from the antenna. Refer also to IEEE Std 145-2013.

radiation condition: A condition implying that at large distances from a source, only outgoing waves can exist.

radiative transfer theory: A heuristic formulation for the calculation of the scattered specific intensity based on the conservation of energy.

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. *Syn:* **field strength**.

radio frequency (RF): A frequency in the radio spectrum. *See also:* **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 designations, ranges, and International Telecommunication Union (ITU) band designations are shown in the following table.

Frequency designation	Frequency range	ITU band designation
Extremely Low Frequency (ELF)	3 Hz to 30 Hz	1
Super Low Frequency (SLF)	30 Hz to 300 Hz	2
Ultra Low Frequency (ULF)	300 Hz to 3 kHz	3
Very Low Frequency (VLF)	3 kHz to 30 kHz	4
Low Frequency (LF)	30 kHz to 300 kHz	5
Medium Frequency (MF)	300 kHz to 3 MHz	6
High Frequency (HF)	3 MHz to 30 MHz	7
Very High Frequency (VHF)	30 MHz to 300 MHz	8
Ultra High Frequency (UHF)	300 MHz to 3 GHz	9
Super High Frequency (SHF)	3 GHz to 30 GHz	10
Extremely High Frequency (EHF)	30 GHz to 300 GHz	11
Submillimeter, Terahertz or Tremendously High Frequency (THF)	300 GHz to 3 THz	12

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 3 THz. *See also:* **radio spectrum**.

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

rain 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. *Syn:* **rainfall rate**.

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.

rainfall rate: *See:* **rain rate**.

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.

randomly polarized: Electromagnetic radiation in which the direction of the electric field vector changes randomly in time and/or space.

range of a radio system: The maximum distance for which a radio wave transmitting system, with specified installation and operating conditions, produces a usable signal 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.

NOTE 1—Energy transport (per unit area) is generally associated with bundles of rays.

NOTE 2—In isotropic but 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.

ray shooting: A class of ray tracing algorithms that track field strength and phase based on the spreading factors of individual rays. *See also:* **spreading factor**.

ray tracing: An algorithm for finding the trajectories of waves using the high-frequency approximations of geometrical optics. *See also:* **ray**; **geometric optics**.

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
θ is the angle of incidence with respect to the mean surface
λ is the wavelength

The surface is considered specular (smooth) if:

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

The surface is considered rough if:

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

Rayleigh fading: Signal level variations observed when the received signal is composed of numerous scattered waves with a complex Gaussian distribution. The amplitude of the resultant signal follows a Rayleigh distribution.

Rayleigh hypothesis: The Rayleigh hypothesis is an assumption that only outgoing waves exist everywhere above a rough interface, including the trough regions.

Rayleigh scattering: Scattering by dielectric particles much smaller than a wavelength. For the special case of spherical particles in the Rayleigh scattering limit, the scattering cross-section is inversely proportional to the fourth power of the wavelength and directly proportional to the sixth power of the particle diameter.

reactive near field region: That portion of the near field region immediately surrounding the antenna wherein the reactive field predominates. Refer also to IEEE Std 145-2013.

reciprocity: In wave propagation, the invariance of the complex amplitudes of the received signals to the interchange in location of transmitter and receiver, but not the antennas.

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: *See:* **power reflection coefficient**.

NOTE—The use of "reflectance" is deprecated.

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

reflection coefficient: *See:* **Fresnel coefficients**.

reflection factor: *See:* **Fresnel coefficients**.

reflectivity: The ratio of reflected to incident power densities of a plane wave incident on a surface and equal to the square of the magnitude of the reflection coefficient.

refracted wave: For two media, that part of the incident wave that travels from the first medium into the second medium. *Syn:* **transmitted wave**.

NOTE—For planar interfaces, the direction of propagation of the refracted wave is given by Snell's law.

refractive index: A dimensionless complex quantity, characteristic of a medium and so defined that its real part, called the refractive index, n, 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 index gradient: The change of the atmospheric refractive index with height. Refraction may be included in propagation calculations by using an effective Earth radius of k times the geometrical radius of the Earth (6375 km) and straight line propagation. The refraction types of the atmosphere and their corresponding refractive index gradients are shown in the table below. *See also:* **k-factor**.

Refraction types	**Refractive index gradients**		
	dN/dh **(N-Units/km)**	***dM/dh*** **(M-Units/km)**	**k-factor**
Homogeneous	0	157	1
Adiabatic	–23	134	1.2
Standard	–39.2	118	4/3
Sub-refractive	> –39.2	> 118	< 4/3
Extreme sub-refractive	> 0	> 157	< 1
Super-refractive	< –39.2	< 118	> 4/3
Ducting threshold	–157	0	∞
Ducting	< –157	< 0	∞

refractivity: The amount by which the real part of the refractive index, n, exceeds unity. Refractivity is often measured in parts per million, called N-units, where $N = (n-1)\times 10^6$.

refractivity profile: The height dependence of refractivity in the atmosphere. *See also:* **refractive index gradient**.

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

relative complex permeability (μ_r): The complex permeability of a medium normalized to the permeability of free space μ_0.

relative complex permittivity (ε_r): The complex permittivity of a medium normalized to the free space permittivity ε_0.

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: **(A)** (in an oscillating system). The rapid increase or decrease of the oscillation magnitude as the excitation frequency approaches one of the natural frequencies of the system. **(B)** (of a traveling wave). The change in magnitude as the frequency of the wave approaches or coincides with a natural frequency of the medium (e.g., a plasma frequency).

Rician fading: Signal level variations when the received signal is composed of numerous scattered waves in the presence of a dominant steady wave. The amplitude of the resultant signal follows a Rician (also Ricean or Rice) distribution.

right-hand circularly polarized (RHCP) wave: A circularly or an elliptically polarized electromagnetic wave for which the electric field vector, when viewed with the wave approaching the observer, rotates counter-clockwise in space.

NOTE 1—This definition is consistent with observing a clockwise rotation when the electric field vector is viewed in the direction of propagation.

NOTE 2—A right-handed helical antenna radiates a right-hand circularly polarized wave.

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

Rytov approximation: A mathematical approximation for a scalar wave propagating through an inhomogeneous medium in which the unknown field is expressed as $\exp\{X(r)\}$ and various levels of approximation are developed; the lowest order one is based on an assumed slow spatial variability of $X(r)$, (i.e., $grad[\mathrm{X}] = 0$).

scalar approximation: The reduction of the vector representation of an electromagnetic field to a scalar description by assuming that the field is identically polarized at every point in space.

NOTE—It usually means that cross-polarization effects are ignored.

scalar radiative transfer: A radiative transfer theory in which the vector nature of the fields is ignored. *Syn:* **scalar radiative transport**.

scalar radiative transport: *See:* **scalar radiative transfer**.

scalar solutions: Solutions of Maxwell's equations where cross-polarization effects are disregarded, i.e., coupling between transverse electric (TE) and transverse magnetic (TM) fields is ignored.

scalar wave equation: *See:* **homogeneous Helmholtz equation**.

scattered wave: An electromagnetic wave that results when an incident wave encounters the following:

—One or more discrete scattering objects

—A rough boundary between two media

—Continuous irregularities in the complex constitutive parameters of a medium

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

scattering coefficient: The scattering cross-section, σ_{pq} per unit illuminated area of a surface, A, expressed in square meters per square meter:

$$\sigma^0_{pq} = \frac{d\sigma_{pq}}{dA}$$

Where p and q are polarization indices.

See also: **scattering cross-section**.

NOTE—This definition applies to either monostatic (transmitter and receiver collocated) or bistatic (transceiver and receiver separated) situations.

scattering cross-section: The projected area required to intercept and isotropically radiate the same power that a scatterer (target) scatters toward the receiver. The scattering cross-section, σ_{pq}, is given by the relationship:

$$\sigma_{pq} = \lim_{R \to \infty} \left[4\pi R^2 \frac{\left\langle \left| \vec{E}^s_p \right|^2 \right\rangle}{\left\langle \left| \vec{E}^i_q \right|^2 \right\rangle} \right]$$

where

R is the distance between the scatterer and the receiver
$\vec{E}^s_p$ is the p-polarized component of the scattered electric field at the receiver
$\vec{E}^i_q$ is a q-polarized incident electric field at the scatterer

The incident field is assumed to be planar over the extent of the target.

scattering matrix: A 2 × 2 complex matrix that characterizes the polarized field scattered by a given object.

scattering pattern: *See:* **scattering phase function**.

scattering phase function: The angular power spectrum of a scatterer when illuminated by a plane wave. *Syn:* **scattering pattern**.

scintillation: Fluctuation of the amplitude of a received signal caused by atmospheric turbulence, i.e., 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.

scintillation index: The normalized intensity variance caused by atmospheric turbulence, i.e., ratio of the second moment to the first moment squared of the intensity.

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

sense of polarization: For an elliptical or circularly polarized field vector, the sense of rotation of the extremity of the field vector when the point of observation in space is fixed. Refer also to IEEE Std 145-2013.

NOTE 1—The Right Hand rule convention is where the rotation of the electric field vector and the propagation direction point like the fingers and the thumb, respectively, of the right hand.

NOTE 2—Any plane wave of frequency f propagating along a direction can be described as an elliptically polarized wave where the electric field in the plane transverse to the direction of propagation traces an ellipse with an average angular frequency $\omega = 2\pi f$. Linear and circular polarizations are special cases.

NOTE 3—In time harmonic (phasor) field analyzes a wave propagating along the +z axis with electric field $E = E_o \times (\mathbf{x} - j\mathbf{y})^{-jkz}$, where **x** and **y** are the unit vectors along the x and the y axis, respectively, is right hand circularly polarized (RHCP).

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

shadow fading: Fluctuations in the strength of a received signal due to the presence of obstructions much larger than a wavelength along the propagation path between transmitter and receiver.

shadow region: The region in space that, because of an intervening obstacle, cannot be reached by an incident geometric-optic ray. However, it can be reached by a diffracted ray.

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

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

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

single-input, multiple-output (SIMO) channel: A channel with a single point of transmission and multiple points of reception. *See also:* **channel matrix**.

single-input, single-output (SISO) channel: A channel with a single point of transmission and a single point of reception. *See also:* **channel matrix**.

single scatter approximation: An approximation used in the calculation of wave scattering by a surface, volume or a collection of particles. In this approximation, the field that excites the surface element or particle, the exciting field, is assumed to be the same field that would have been present in the absence of all other surface or volume elements or particles, (i.e., the exciting field is equal to the incident field). *See also:* **Born approximation**.

skin depth: *See:* **penetration depth**.

skip distance: For a given frequency, the minimum distance at which the sky wave is returned to the Earth.

NOTE—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 all directions.

sky radiometric temperature: The observed brightness temperature of the sky, caused by emissions from the Earth's atmosphere as well as cosmic and galactic radiation.

sky wave: A radio wave propagated obliquely toward, and returned from, the ionosphere.

NOTE—This term has sometimes been called an ionospheric wave but that term 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 electromagnetic properties. *See also:* **fast wave**.

small-perturbation method: An approximate technique for estimating the scattering from a perturbed boundary or from perturbations in the constitutive parameter(s) of a medium applicable when the perturbation is small compared to a reference parameter or scale such as the wavelength in the boundary case.

small-scale fading: Spatial fluctuations in fields within a limited area that are solely due to constructive and destructive interference between scattered replicas of the propagating wave.

Snell's law: The relationship between angles of incidence, reflection, and transmission, and material constitutive parameters, for a plane wave incident on a planar boundary between media of differing electromagnetic constitutive parameters. Often expressed as:

$$\theta_i = \theta_r$$

and

$$n_i \sin\theta_i = n_t \sin\theta_t$$

where

θ_i is the angle of incidence
θ_r is the angle of reflection
θ_t is the angle of transmission
n_i is the real part of the refractive index of the material in which the wave is incident
n_t is the real part of the refractive index of the other material

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

solar activity center: A region on the sun containing the sources of variable electromagnetic and corpuscular radiation.

solar activity index: A number characterizing solar activity. Examples are international relative sunspot number, 12-month running mean sunspot number, and 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 (though it may vary by almost a factor of two with cycles as short as 8 years and as long as 15 years having been observed).

NOTE—The cycle is not symmetrical. It rises to a maximum in approximately 4 years and declines to a minimum in approximately 7 years.

solitary wave: A propagating wave disturbance where the effects of media dispersion and non-linearity compensate one another to produce a self-preserving wave shape. *Syn:* **soliton**.

soliton: *See:* **solitary wave**.

sparse medium: A medium with a low volume fraction of discrete objects, typically less than 1%. In such a medium, multiple scattering is negligibly small. *See also:* **homogeneous dense medium**; **inhomogeneous dense medium**.

specific intensity (*I*): A positive real quantity, I; in general a function of position, r; direction, s; frequency, f; and time, t; representing the quantity of power, dP, flowing outward through an elemental area, dA, at a particular location, r, within an elemental solid angle, $d\Omega$, containing a particular direction, s, within a frequency interval, $(f, f + df)$, represented as:

$$dP = I(r, s, f, t) s dA d\Omega df$$

speckle: The random distribution of intensity in space.

spectral brightness: (of an object). The total power radiated by an object per unit solid angle per unit projected area per unit bandwidth.

NOTE—In radiative transfer theory it is called the spectral specific intensity. In infrared radiometry it is called the spectral radiance.

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.

specular reflection: The process by which all or part of a wave, incident on a smooth surface, is returned to the original medium, in accordance with Snell's law of reflection.

specular surface: **(A)** A surface, smooth enough that all energy is reflected from it or transmitted across it in those directions specified by Snell's law. **(B)** A planar interface separating two media.

spherical diffraction (propagation): Transhorizon 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 propagation function: The function given by:

$$f(r) = \frac{e^{-jkr}}{r}$$

where

r is the range from the source
jk is the propagation constant of the medium

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

sporadic E layer: An ionospheric layer of the E region that is thin, transient, and of limited geographical extent. *Syn:* **Es layer**.

NOTE—An equatorial sporadic E layer occurs regularly during the day in association with the equatorial electrojet.

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.

NOTE 1—The echoes usually are spread in the frequency and virtual height domains on an ionogram.

NOTE 2—Spread F commonly occurs at night at low latitudes (e.g., near the magnetic dip equator) and at high latitudes.

spreading factor: For propagation in isotropic unbounded media, the 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.

spreading loss: The decrease in power or power density due to divergence of the outward energy flow of cylindrical and spherical waves.

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

$$N(h) = 315e^{-0.136h}$$

where

h is the altitude in kilometers above mean sea level

Syn: **reference atmosphere for refraction**. *See also:* **refractive index gradient**.

NOTE—The standard atmosphere for refraction is almost identical to the standard radio atmosphere up to a height of one kilometer.

standard M gradient: *See:* **refractive index gradient**.

standard maximum usable frequency: *See:* **maximum usable frequency (MUF)**.

NOTE—The use of "standard maximum usable frequency" is deprecated.

standard N gradient: *See:* **standard refractive index gradient**.

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. *See also:* **refractive index gradient**.

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

standard radio horizon: The radio horizon corresponding to propagation through the standard radio atmosphere. *See also:* **refractive index gradient**.

standard refraction: *See:* **refractive index gradient**.

standard refractive index gradient: A standard value of vertical gradient of refractivity, namely 39.2 N-Units/km, used in studies of the refraction of radio waves in the troposphere. *Syn:* **standard N gradient**. *See also:* **refractive index gradient**.

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: *See:* **refractive index gradient**.

standing wave: A wave formed by the interference of two oppositely traveling plane waves having the same frequency and polarization.

stationary phase approximation: A technique for evaluating or estimating integrals whose integrands have rapid variations in phase everywhere except near stationary phase points.

stationary phase point: Point in space near which the phase of a function is slowly varying.

statistically homogeneous: Having statistical characteristics that are independent of the specific locations at which those characteristics are measured.

statistically isotropic: Having statistical characteristics that are independent of the directions along which those characteristics are measured.

Stokes matrix: *See:* **Mueller matrix**.

Stokes parameters: Elements of the Stokes vector. *See also:* **Stokes vector**.

Stokes vector: A 4 × 1 vector of real numbers called the Stokes parameters, which represent the polarization state of a propagating wave:

$$I = \frac{1}{2\eta}\begin{bmatrix} |E_v|^2 + |E_h|^2 \\ |E_v|^2 - |E_h|^2 \\ 2\,\mathrm{Re}\left\{E_v E_h^*\right\} \\ 2\,\mathrm{Im}\left\{E_v E_h^*\right\} \end{bmatrix}$$

where

E_v is the vertical electric field component of the wave
E_h is the horizontal electric field component of the wave
η is the intrinsic impedance of the medium
* indicates the complex conjugate

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.

structure constant (C_n^2): A measure of the turbulent fluctuations of the refractive index of the atmosphere.

submillimeter: 300 GHz to 3 THz. *See also:* **radio spectrum**.

sub-refractive atmosphere: *See:* **refractive index gradient**.

sudden ionospheric disturbance (SID): An ionospheric disturbance with a duration of from 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 electromagnetic radiation from a solar flare.

NOTE—This effect is sometimes called the MŠgel-Delinger effect.

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

super low frequency (SLF): 30 GHz to 300 Hz. *See also:* **radio spectrum**.

super-refractive atmosphere: *See:* **refractive index gradient**.

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 locally planar boundary, 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 wave: A wave propagating along the interface boundary(ies) of layers of different media.

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 decibels as a positive number.

T matrix: Relates the scattered field to the exciting field.

tangent-plane approximation: *See:* **Kirchhoff approximation**.

target: Source of scattering being intended or non-intended.

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

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

tenuous medium: A medium in which the spatial variations of constitutive parameters, either continuous or discrete, are small relative to their mean values.

thermodynamic equilibrium: A situation in which the net thermal radiation exchanged by members of a system is zero.

thermosphere: That part of the Earth's atmosphere located above the mesosphere in which temperature increases and then remains constant with increasing height. The thermosphere extends to an altitude of 500 km to 600 km.

NOTE—From the thermosphere and below there is virtually no escape of particles to free space.

thin phase screen approximation: An approximation in which the cumulative effects of phase distortion take place in an equivalent thin layer and amplitude effects are neglected.

three-wave fading: A type of fading resulting from three homogeneous plane waves with uniformly distributed, independent phases.

tilt angle of polarization: Angle of major axis of the polarization ellipse relative to the horizontal.

time-averaged Poynting vector ($\vec{S}$): For a periodic electromagnetic wave, it is the time average of the instantaneous Poynting vector over the wave period. For time harmonic waves, it is equal to:

$$\frac{1}{2}\operatorname{Re}(\vec{E}\times\vec{H}^{*})$$

where

Re indicates the real part
$\vec{E}$ is the electric field vector in phasor notation
$\vec{H}$ is the magnetic field vector in phasor notation
* indicates the complex conjugate

time delay spread (σ_τ): A measure of the differential propagation times due to multipath propagation. Specifically, time delay spread 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_τ:

$$\sigma_\tau = \frac{1}{2\pi f_\tau}$$

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.

NOTE—The units for TEC are 10^{16} electrons/m^2 (or 1012 electrons/cm^2).

total scattering cross-section: The average over 4π steradians of the bistatic scattering cross-section for a specific illumination, given by:

$$\sigma_t = \frac{1}{4\pi}\int_{\Omega}\sigma\, d\Omega$$

transhorizon tropospheric propagation: Tropospheric propagation between two points, 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, ducting, refraction, and reflection. *See also:* **tropospheric scatter propagation**.

transmission coefficient: *See:* **Fresnel coefficients**.

transmission factor: *See:* **Fresnel coefficients**.

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.

transmissivity: **(A)** (of a boundary). The ratio of the normal component of the power density transmitted across the boundary between two media to the normal component of the incident power density. **(B)** (of a layer). The ratio of the normal component of the power density transmitted through the layer to the normal component of the incident power density.

transmissivity matrix: A 4 × 4 matrix of dimensionless real numbers, which, when multiplied by the Stokes vector incident upon a boundary or through a medium, yields the Stokes vector that is propagated across that boundary or medium. *See also:* **Mueller matrix**.

transmitted wave: The wave launched by a transmitting antenna. *See also:* **refracted wave**.

transverse electric (TE) wave: For waves propagating in homogeneous space, an electromagnetic wave whose electric field is perpendicular to the direction of propagation. For waves incident on a scatterer, the wave whose electric field is perpendicular to the plane of incidence.

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) polarization: *See:* **parallel polarization**.

transverse magnetic (TM) wave: For waves propagating in homogeneous space, an electromagnetic wave whose magnetic field is perpendicular to the direction of propagation. For waves incident on a scatterer, the wave whose magnetic field is perpendicular to the plane of incidence.

trapping: A feature of a ducting environment wherein the modified refractivity gradient in height (dM/dz) has a negative value.

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

NOTE—A TID is the signature in the ionosphere of an atmospheric gravity wave (AGW) in the neutral thermosphere.

tropopause: The upper boundary of the troposphere.

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

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 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 on the order of 1 km.

tropospheric propagation: Propagation within the troposphere.

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

tropospheric scatter propagation: Propagation of radio waves through the atmosphere caused by scattering from inhomogeneities in the refractive index of the troposphere. *Syn:* **troposcatter**.

NOTE—Troposcatter enables propagation beyond the radio horizon.

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

tube shooting: A class of ray-launching algorithms based on a bundle of rays that define the edges of a tube. *See also:* **spreading factor**.

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

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

two-frequency mutual coherence function: The correlation between two fields at two frequencies measured at the same point in space and time.

two-wave fading: A type of fading resulting from two homogeneous plane waves with uniformly distributed, independent phases.

two-wave with diffuse power (TWDP) fading: A type of fading resulting from two homogeneous plane waves with uniformly distributed, independent phases superimposed upon (over) a diffuse collection of waves. *See also:* **Hyper Rayleigh fading**.

UHF: *See:* **ultra high frequency**.

ULF: *See:* **ultra low frequency**.

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

ultra low frequency (ULF): 300 Hz to 3000 Hz. *See also:* **radio spectrum**.

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

unpolarized: *See:* **randomly polarized**.

vector radiative transport: An attempt to incorporate the vector nature of electromagnetic waves into the energy conserving transport theory. *See also:* **radiative transfer theory**.

vertical polarization: *See:* **parallel polarization**.

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

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

VHF: *See:* **very high frequency (VHF)**.

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.

VLF: *See:* **very low frequency (VLF)**.

volume fraction: The ratio of the volume of inclusions to the total volume (inclusions plus host material).

volume mixing ratio: The ratio defined by $N(z)/N(\mathrm{air})$ where $N(z)$ is the number density (number of molecules per unit volume) of a particular species and $N(\mathrm{air})$ is the number density of air.

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

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."

wave normal: (of a traveling wave). The direction normal to an equiphase surface taken in the direction of increasing phase. *See also:* **direction of propagation**.

wave number (*k*): 2π divided by the wavelength in the medium.

wave number spectrum: (of a quantity). The spatial to wave number Fourier Transform of a spatially varying quantity.

NOTE 1—In a wireless link, where the channel represents the transfer function of signals between Tx and Rx and varies with position, the "channel wavenumber spectrum" refers to the spatial Fourier Transform of the autocorrelation of said channel.

NOTE 2—It is often encountered in analyses of spatially varying problems much like the "frequency spectrum" is encountered in the analysis of time varying problems.

wave number spread: The rms width of the wave number spectrum. *See also:* **wave number spectrum**.

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: *See:* **propagation vector**.

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

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, λ, is related to the magnitude of the phase velocity, v_p, and the frequency, f, by the equation:

$$\lambda = \frac{v_p}{f}$$

whispering-gallery mode: A surface electromagnetic wave guided by curved boundaries.

whistler: A form of radio energy in the extremely low frequency/very low frequency portion of the spectrum, usually originating from lightning strokes and characterized by a whistling tone of decreasing pitch that may last for several seconds. *See also:* **whistler mode**.

NOTE—Propagation of this energy is in the whistler mode, which is strongly guided along the Earth's magnetic field.

whistler mode: The propagation mode of any right-hand circularly 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: *See:* **extraordinary wave**.

Zenneck wave: A transverse evanescent wave associated with the Brewster's angle occurring at the zeros of the transverse magnetic reflection coefficient. The Zenneck wave has exponential attenuation in both vertical and horizontal directions because it occurs only when the medium over which it propagates (such as the earth) has loss (nonzero conductivity). Hence the Brewster's angle is complex.

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