

# IEEE Standard Definitions of Terms for Radio Wave Propagation

IEEE Antennas and Propagation Society

Sponsored by the  
Antennas and Propagation Standards Committee

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

# IEEE Standard Definitions of Terms for Radio Wave Propagation

Sponsor

**Antennas and Propagation Standards Committee**  
of the  
**IEEE Antennas and Propagation Society**

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**IEEE-SA Standards Board**

**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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## Introduction

This introduction is not part of IEEE Std 211-2018, IEEE Standard Definitions of Terms for Radio Wave 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 Increasingly, the face to face meeting has been replaced by regular e-mails and conference calls, expanding the opportunity for international participation.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 Monebhurrn, 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.monebhurrn@centralesupelec.fr](mailto:vikass.monebhurrn@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.

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# IEEE Standard Definitions of Terms for Radio Wave 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.<sup>1,2</sup>

## 3. Definitions

The  $e^{j\omega t}$  convention is used throughout this document, where  $j^2 = -1$ ,  $\omega$  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.<sup>3</sup>

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

**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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<sup>2</sup>IEEE publications are available from The Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

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<sup>4</sup>Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

<sup>5</sup>Information on references can be found in [Clause 2](#).

**absorption coefficient ( $\kappa_a$ ):** (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 ( $\kappa_e$ ).**

NOTE—For inhomogeneous media.

**absorption cross-section ( $\sigma_a$ ):** (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 ( $\sigma_e$ ).**

**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 ( $\omega$ ):** (of a sinusoidal wave).  $2\pi$  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 ( $\alpha$ ):** 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  $\phi$ .

**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 Bouguer'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  $2\pi$  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 ( $\sigma_\tau$ ).*

**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  $(t + \tau)$ :

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

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** ( $\tau_0$ ): 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** ( $\sigma$ ): 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:

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

where

$\overset{=}{\sigma}$  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  $\sigma$ , in which case  $\vec{J} = \sigma \vec{E}$ .

**constitutive parameters**: The permittivity and permeability of a medium. *See also: permeability* ( $\mu$ ); **permittivity** ( $\epsilon$ ).

**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  $\text{cm}^{-3}$

**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 ( $\sigma_\tau$ ).*

**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 ( $\epsilon_r$ ).*

**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 inhomogeneities 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,  $\omega$ , 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  $\omega$ .

**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 ( $\sigma_\lambda$ ):** The spreading in the frequency domain of the power spectrum of a wave.

NOTE—The Doppler spread is inversely related to the coherence time ( $\tau_0$ ):

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

**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  $8.5 \times 10^6$  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.