

IEEE Standard Definitions of Terms for Radio Wave Propagation

Sponsor

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

Reaffirmed 11 September 2003

Approved 9 December 1997

IEEE 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, terminology

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

Copyright © 1998 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 1998. Printed in the United States of America.

ISBN 0-7381-0223-7

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Board. Members of the committees serve voluntarily and without compensation. They are not necessarily members of the Institute. The standards developed within IEEE represent a consensus of the broad expertise on the subject within the Institute as well as those activities outside of IEEE that have expressed an interest in participating in the development of the standard.

Use of an IEEE Standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of all concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE Standards Board
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08855-1331
USA

Note: Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents for which a license may be required by an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; (508) 750-8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Introduction

(This introduction is not part of IEEE Std 211-1997, IEEE Standard Definitions of Terms for Radio Wave Propagation.)

This is the third revision of the original IEEE Std 211-1969, following those of 1977 and 1990. It is indeed true, as noted in previous Forewords, 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 fourth 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 Wave Propagation Standards Committee (WPSC) Subcommittee on Definitions, which meets once or twice a year at conferences sponsored by the IEEE Antennas and Propagation Society and occasionally at college campuses. Increasingly, the meetings have been replaced by e-mail, expanding the opportunity for international participation, although substantial contributions also continue to be made on postcards. The chair of the Subcommittee presenting this revision is 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. Both George H. Hagn, the Subcommittee Chair responsible for the second revision, and Walter A. (Bud) Flood, Chair of the WPSC during most of this revision cycle, have been extremely supportive of the current Subcommittee Chair, thus preserving the momentum of the revision effort and adding greatly to its substance. The individuals with primary responsibility for this third 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 fourth revision whenever they see deficiencies or have ideas for an improvement by communicating with the WPSC chair via e-mail to Wolf_Vogel@mail.utexas.edu.

Within the IEEE, the work has been coordinated with the APS Antenna Standards Committee and the following societies: EMC, COM, and Instrumentation and Measurements. It has also been coordinated with 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.

This standard was prepared by the Wave Propagation Standards Committee (WPSC) Subcommittee on Definitions. The Subcommittee was composed of the following membership:

Wolfhard J. Vogel, *Chair*

Gary S. Brown
Walter A. Flood

George H. Hagn*
Warren L. Stutzman
David Thiel

Fawwaz Ulaby
James R. Wait

*Immediate past Chair

Major contributions were made by:

Weng Chew

Robert D. Hunsucker
William A. Luther

Ernest K. Smith

Useful comments were made by:

Julius Goldhirsh
Kevin A. Hughes

Akira Ishimaru
Hao Ling

Glenn S. Smith
Glenn Stumpff

The Wave Propagation Standards Committee (WPSC) of the IEEE Antennas and Propagation Society (IEEE-APS) balloted this standard and had the following membership at the time of approval:

Gary S. Brown
John F. Cavanagh
Warren L. Flock
Walter A. Flood*

George H. Hagn
Motohisa Kanda
Ernest K. Smith
Glenn S. Smith
Warren S. Stutzman

David Thiel
Fawwaz Ulaby
Wolfhard J. Vogel
James R. Wait

*Immediate past Chair

When the IEEE Standards Board approved this standard on 9 December 1997, it had the following membership:

Donald C. Loughry, *Chair*

Richard J. Holleman, *Vice Chair*

Andrew G. Salem, *Secretary*

Clyde R. Camp
Stephen L. Diamond
Harold E. Epstein
Donald C. Fleckenstein
Jay Forster*
Thomas F. Garrity
Donald N. Heirman
Jim Isaak
Ben C. Johnson

Lowell Johnson
Robert Kennelly
E. G. "Al" Kiener
Joseph L. Koepfinger*
Stephen R. Lambert
Lawrence V. McCall
L. Bruce McClung
Marco W. Migliaro

Louis-François Pau
Gerald H. Peterson
John W. Pope
Jose R. Ramos
Ronald H. Reimer
Ingo Rütisch
John S. Ryan
Chee Kiow Tan
Howard L. Wolfman

*Member Emeritus

Also included are the following nonvoting IEEE Standards Board liaisons:

Satish K. Aggarwal
Alan H. Cookson

Kim Breitfelder
IEEE Standards Project Editor

IEEE Standard Definitions of Terms for Radio Wave Propagation

absorption: The process of converting electromagnetic energy to heat.

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

absorption coefficient (κ_a): (of a medium). The rate of decrease of power density of a wave per unit distance, due to absorption. For a homogeneous medium with relative complex permittivity ϵ_r and the permeability of free space μ_0 :

$$\kappa_a = -4\pi \text{Im}\{\sqrt{\epsilon_r}\}/\lambda_0$$

where

λ_0 is the free-space wavelength

$\exp(+j\omega t)$ is the time factor

Note: For inhomogeneous media *See also:* **extinction coefficient**.

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 :

$$\sigma_a = P_a/S_i$$

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

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

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

adiabatic atmosphere of refraction: *See:* **refractive index gradient**.

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 periodically varying quantity. *Note:* Sometimes the term complex amplitude is used to denote a phasor. *See also:* **magnitude.**

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: (of a wave). The angle between the negative of the propagation vector and a reference direction.

angle of incidence: At a point on a surface, the 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. *Synonym:* **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 . *Note:* The angular power spectrum and the mutual coherence function are Fourier transform pairs. *See also:* **mutual coherence function.**

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.

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.**

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. *Note:* The beamwidth of the antenna is much smaller than the angular spectrum of the incoming wave. *See also:* **angular spectrum.**

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

atmospherics: Transient bursts of electromagnetic radiation arising from natural electrical disturbances in the lower atmosphere. *Notes:* 1. In the past, the term *static* was used to include atmospherics and other radio noise. The term *sferics* is in current use. 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 magnitude of the attenuation vector. *Synonym:* **attenuation coefficient.** *See also:* **propagation vector.**

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.**

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. *Synonym:* **auroral oval.**

backscatter: The scattering of waves back toward the source.

backscattering cross-section: *See:* **monostatic cross-section.**

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 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.

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.

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 example, 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 polarized wave; right-hand polarized wave.**

classical maximum usable frequency*: *See:* **maximum usable frequency.**

*Deprecated

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

coherence function $[R(\vec{\Delta r}, \tau)]$: 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 ($\vec{r} + \vec{\Delta r}$) and time ($t + \tau$):

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

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

coherence length: The distance between two wavefronts of an electromagnetic wave, measured in the direction of propagation, over which the phase of these wavefronts 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 (J) to the electric field ($\vec{E}$) in the medium. *Note:* For a monochromatic wave in a linear medium, that relationship is described by the (phasor) equation:

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

where

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

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

constitutive parameters: The permittivity and permeability of a medium. *See also:* **permeability; permittivity.**

corner reflector: **(A) (antenna).** A reflecting object consisting of two or three mutually intersecting conducting flat surfaces. *Note:* Dihedral forms of corner reflectors are frequently used in antennas; trihedral forms are more often used as radar targets. **(B) (radar).** Two (dihedral) or three (trihedral) mutually intersecting conducting surfaces designed to return electromagnetic radiation towards its source. Also used as calibration devices.

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 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. *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.**

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

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

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

where

T_e is the electron temperature

N_e is the electron number density

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.**

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

deviative absorption: Occurs when the refractive index is appreciably less than unity (i.e., when the radio ray path is in the process of being bent or “deviated” away from the normal). *Contrast:* **non-deviative absorption.**

dielectric constant*: Relative permittivity (possibly complex).

*Deprecated

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: 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.

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.*

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

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

dispersive bandwidth: *See: frequency selective bandwidth.*

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 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 decorrelation time (τ_0):

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

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.

ducting: Guided propagation of radio waves inside an atmospheric or tropospheric radio duct. *See also: atmospheric radio duct.*

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 atmospheric refraction. *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.*

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.

electrical length: For a wave of a given frequency, a distance between fieldpoints, expressed in wavelengths of the wave in the medium. *Note:* The electrical length is sometimes expressed in radians or degrees. *See also:* **phase path length**.

electric displacement: *See:* **electric flux density**.

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 density and its spatial derivative along the surface S of a perfect electric conductor. *Note:* The tangential component of the incident electric field acts as the source for the current, hence the name. The equation is as follows:

$$\hat{n} \times \vec{E}^i = \frac{j}{\omega \epsilon_0} \hat{n} \times \int_{S_0} \{k_0^2 J_S g - (\nabla_{S_0} \cdot \vec{J}_S) \nabla_0 g\} dS_0$$

where

- $\hat{n}$ is unit normal to S
- $\vec{E}^i$ is incident electric field
- j is $\sqrt{-1}$
- k_0^2 is $\omega^2 \mu_0 \epsilon_0$
- $\exp(j\omega t)$ is time convention
- g is $\exp[-jk_0|\vec{r} - \vec{r}_0|]/4\pi|\vec{r} - \vec{r}_0|$
- ∇_0 is gradient evaluated on the surface
- ∇_{S_0} is gradient in the direction tangential to the surface

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

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

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

where

- $\vec{D}$ is the electric flux density
- $\bar{\epsilon}$ is the permittivity in the medium
- $\vec{E}$ is the electric field

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

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 the following table:

Spectral region	Wavelength
Gamma rays	$< 0.006 \text{ nm}$
X-rays	$0.006\text{--}5 \text{ nm}$
Ultraviolet rays	$5 \text{ nm--}0.4 \mu\text{m}$
Visible light	$0.4\text{--}0.7 \mu\text{m}$
Infrared	$0.7 \mu\text{m--}0.1 \text{ mm}$
Radio	$> 0.1 \text{ mm}$

See also: **radio spectrum.**

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

electrostatic wave: *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 polarized wave; right-hand polarized 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 delay: The time of propagation of the envelope of a wave between two points provided that the envelope is not significantly distorted. *Synonym:* **group delay.** *See also:* **group velocity.**

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