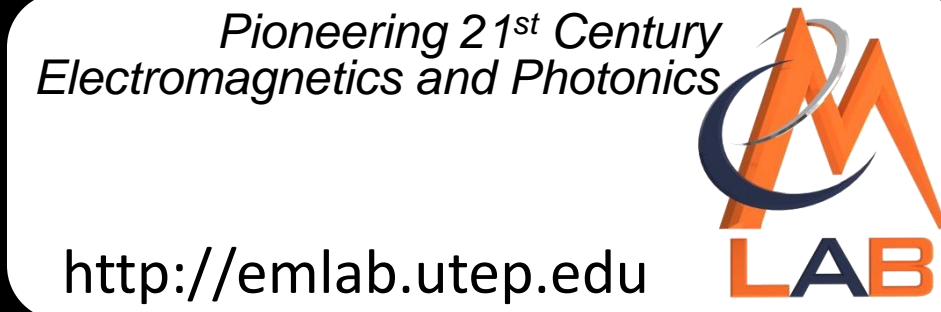




ELECTROMAGNETIC MATERIAL PARAMETERS & RELATIONS



FUNDAMENTAL PARAMETERS

These parameters are fundamental to Maxwell's equations, but it is difficult to conclude their effect on fields and waves.

Electrical Permittivity, ϵ
 $\epsilon \equiv$ permittivity $\epsilon = \epsilon_0 \epsilon_r$
 $\epsilon_0 \equiv$ free space permittivity
 $\epsilon_r \equiv$ relative permittivity (dielectric constant) $\epsilon_r \geq 1$
 $\epsilon_0 = 8.8541878176 \times 10^{-12}$ F/m

Magnetic Permeability, μ
 $\mu \equiv$ permeability $\mu = \mu_0 \mu_r$
 $\mu_0 \equiv$ free space permeability
 $\mu_r \equiv$ relative permeability $\mu_r \geq 1$
 $\mu_0 = 1.2566370614 \times 10^{-6}$ H/m

Electrical Conductivity, σ
 $\sigma \equiv$ conductivity (1/ $\Omega \cdot m$)

Two Sets of Electrical Properties

Real permittivity ϵ and real conductivity σ $\tilde{\epsilon} = \epsilon' - j\epsilon'' = \epsilon + \sigma/j\omega$
 or
 Complex permittivity $\tilde{\epsilon}$ $\epsilon' = \epsilon$ $\epsilon'' = \sigma/\omega$

Frequency, Velocity, and Wavelength

$f \equiv$ ordinary frequency (Hz) Wave velocity
 $\omega = 2\pi f \equiv$ angular frequency (s^{-1}) $c_0 = 1/\sqrt{\mu_0 \epsilon_0}$
 $\lambda_0 \equiv$ free space wavelength $v = c_0/n_0$
 $\lambda = \lambda_0/n_0 \equiv$ wavelength inside medium
 $c_0 = f\lambda_0 = 299,792,458$ (m/w) \equiv speed of light in vacuum

MEANINGFUL PARAMETERS

These parameters isolate specific information about fields and waves into single quantities. They are more intuitive than the fundamental parameters.

Refractive Index, n
 The ordinary refractive index n_0 is the factor by which the phase of a wave slows down inside of a medium.
 The extinction coefficient κ quantifies growth or decay of a wave due to gain or loss, respectively.
 $E(z) = e^{-jk_0nz} = \underbrace{e^{-jk_0n_0z}}_{\text{speed/oscillation}} e^{-k_0\kappa z}_{\text{growth/decay}}$
 For non-magnetic materials:
 $\epsilon_r = n^2$ $\eta = \frac{\eta_0}{n}$

Impedance, η
 $\eta = \eta' + j\eta'' = |\eta| \angle \theta_\eta = \sqrt{\frac{\mu}{\epsilon}}$
 Impedance η quantifies the relationship between the electric field E and magnetic field H due to the coupling in Maxwell's equations.
 $\eta = E_0/H_0$

$\eta_0 = \sqrt{\mu_0/\epsilon_0} = 376.73031346177 \Omega \equiv$ free space impedance

$\eta' \equiv$ resistive component $|\eta| \equiv$ amplitude relation between E_0 and H_0
 $\eta'' \equiv$ reactive component $\theta_\eta \equiv$ phase relation between E_0 and H_0

Propagation Constant, γ
 $\gamma = \alpha + j\beta = jk_0n$
 $E(z) = e^{-\gamma z} = e^{-\alpha z} e^{-j\beta z}$
growth/decay speed/oscillation

Loss Parameters
 The absorption coefficient α_p describes decay of power. $P(z) = P_0 e^{-\alpha_p z}$
 $\alpha_p = 2\alpha$
 The loss tangent $\tan \delta$ describes decay of power.
 $P(z) = P_0 e^{-\delta k_0 n_0 z}$

$\alpha \equiv$ attenuation coefficient (m^{-1}) $\delta = 2\kappa/n_0 = \frac{2\alpha}{k_0 n_0}$
 $\beta = \frac{2\pi}{\lambda} = k_0 n \equiv$ wave number (m^{-1})