[redacted]

Symbols and Constants

$\vec{F}$	force	W	energy
Q	charge	I	current
ρ_V	volume charge density	$\vec{j}$	current density
$\vec{E}$	electric field	$\vec{H}$	magnetic field
$\vec{D}$	displacement field	$\vec{B}$	magnetic flux density field
$\vec{P}$	polarization field	$\vec{M}$	magnetization field
V	electric potential	$\vec{A}$	vector potential
Φ	electric or magnetic flux	$\vec{S}$	Poynting vector
ϵ_R	dielectric constant	μ_R	relative permeability
ϵ_0	8.854×10^{-12} F/m	μ_0	$4\pi \times 10^{-7}$ H/m

Mathematics

cylinders	volume $= \pi a^2 L$	cross-section πa^2
	$dV = \rho\, d\rho d\phi dz$	cross-section $dS = \rho\, d\rho d\phi$
spheres	volume $= (4/3)\pi a^3$	area $= 4\pi a^2$
	$dV = r^2 \sin\theta dr d\theta d\phi$	$dS = r^2 \sin\theta d\theta d\phi$

Electrostatics

Coulomb's law

$$\vec{F}_2 = \frac{Q_1 Q_2}{4\pi\epsilon_0 R^2}\vec{a}_{12} \qquad \vec{F} = Q\vec{E}$$

point charge

$$\vec{E}(\vec{r}) = \frac{Q(\vec{r}-\vec{r}\,')}{4\pi\epsilon_0 \left|\vec{r}-\vec{r}\,'\right|^3} \qquad V(\vec{r}) = \frac{Q}{4\pi\epsilon_0 \left|\vec{r}-\vec{r}\,'\right|}$$

charge density

$$\vec{E}(\vec{r}) = \int_V \frac{\rho_V}{4\pi\epsilon_0}\frac{(\vec{r}-\vec{r}\,')}{\left|\vec{r}-\vec{r}\,'\right|^3} dV' \qquad V(\vec{r}) = \int_V \frac{\rho_V}{4\pi\epsilon_0 \left|\vec{r}-\vec{r}\,'\right|} dV'$$

electric flux

$$\Phi = \epsilon_0 \int_S \vec{E} \cdot d\vec{S}$$

Guass's law

$$\epsilon_0 \oint_S \vec{E} \cdot d\vec{S} = Q_{\text{encl}} = \int_V \rho_V \, dV$$

$$\oint \vec{D} \cdot d\vec{S} = Q_{\text{encl}}^{\text{free}} = \int_V \rho_V^{\text{free}} \, dV$$

$$\oint \vec{P} \cdot d\vec{S} = -Q_{\text{encl}}^{\text{bound}} = -\int_V \rho_V^{\text{bound}} \, dV$$

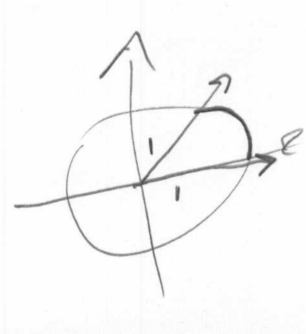
relating $\vec{E}$ to V	$\vec{E} = -\vec{\nabla} V$	$V_{AB} = -\int_B^A \vec{E} \cdot d\vec{l}$
capacitance	$C = Q/V$	$C = \frac{\epsilon_0 \epsilon_R A}{d}$ (parallel plate cap.)
linear dielectrics	$\vec{D} = \epsilon_0 \epsilon_R \vec{E}$	
Poisson's equation	$\nabla^2 V = -\rho_V / \epsilon_0 \epsilon_R$	
Laplace's equation	$\nabla^2 V = 0$	
boundary conditions	E_T and D_N continuous across the boundary	
electric field energy	$W_E = \frac{1}{2} \int_V \epsilon_0 \left\vert \vec{E} \right\vert^2 dV$	$W_E = QV$

Magnetostatics

law of Biot-Savart	$\vec{H}(\vec{r}) = \oint \frac{I\, d\vec{l} \times \vec{a}_R}{4\pi R^2}$	$\vec{H}(\vec{r}) = \int_V \frac{\vec{j} \times \vec{a}_R}{4\pi R^2} dV$
	where $\vec{a}_R$ points from a current element to $\vec{r}$	
magnetic flux	$\Phi = \mu_0 \int_S \vec{H} \cdot d\vec{S}$	
Ampere's law	$\oint_{\text{loop}} \vec{H} \cdot d\vec{l} = I_{\text{encl}} = \int_S \vec{j} \cdot d\vec{S}$	
vector potential	$\vec{A}(\vec{r}) = \mu_0 \int_V \frac{\vec{j}}{4\pi \left\vert \vec{r} - \vec{r}\,' \right\vert} dV'$	$\vec{B} = \vec{\nabla} \times \vec{A}$
self-inductance	$L = N\Phi/I$ (from linked flux)	$L = \frac{2W_H}{I^2}$ (from energy)
linear materials	$\vec{B} = \mu_0 \mu_R \vec{H}$	
boundary conditions	H_T and B_N continuous across the boundary	
magnetic field energy	$W_H = \frac{1}{2} \int_V \mu_0 \left\vert \vec{H} \right\vert^2 dV$	

$d\theta = \frac{\theta}{2\pi} \cdot \cancel{2\pi}$

$2\pi r$



$\frac{\theta}{\cancel{2\pi}} \cdot \cancel{2\pi} r$

Electromagnetics

Maxwell's equations $\vec{\nabla} \cdot \vec{D} = \rho_V$ $\quad \vec{\nabla} \cdot \vec{B} = 0$

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad \vec{\nabla} \times \vec{H} = \vec{j} + \frac{\partial \vec{D}}{\partial t}$$

Faraday's law $\quad \text{emf} = -\frac{d}{dt}\int_S \vec{B} \cdot d\vec{S}$

EM plane wave $\quad \vec{E} = \vec{E}_0 e^{j(\omega t - kz)} \qquad \vec{H} = \vec{H}_0 e^{j(\omega t - kz)}$

$$\left|\vec{H}_0\right| = \left|\vec{E}_0\right| / \eta \qquad \eta = \sqrt{(\mu_0 \mu_R)/(\epsilon_0 \epsilon_R)}$$

Poynting vector $\quad \vec{S} = \Re\vec{E} \times \Re\vec{H}$

time-averaged $\vec{S}$ $\quad \left\langle \vec{S} \right\rangle = \frac{\left|\vec{E}_0\right|^2}{2\eta}$

EM wave at a boundary $\quad \Gamma = \frac{E_{0r}}{E_{0i}} = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} \qquad \tau = \frac{E_{0t}}{E_{0i}} = \frac{2\eta_2}{\eta_2 + \eta_1} = \Gamma + 1$

Transmission lines

propagation constant $\quad \gamma = \sqrt{(R + j\omega L)(G + j\omega C)} = \alpha + j\beta$

characteristic impedance $\quad Z_0 = \sqrt{(R + j\omega L)/(G + j\omega C)}$

wavelength and velocity $\quad \lambda = 2\pi/\beta \qquad v_p = \omega/\beta$

refl. and trans. coeffs. $\quad \Gamma = \frac{V_{\text{refl}}}{V_{\text{inc}}} = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad \tau = \frac{V_{\text{trans}}}{V_{\text{inc}}} = \frac{2Z_L}{Z_L + Z_0} = \Gamma + 1$

standing wave ratio $\quad \text{SWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$

$\Gamma = 0.5$

input impedance $\quad Z_{\text{in}} = Z_0 \frac{Z_L + jZ_0 \tan(\beta l)}{Z_0 + jZ_L \tan(\beta l)} \qquad l \geq 0$

$$Z_{\text{in}} = Z_0 \frac{1 + \Gamma e^{-j2\beta l}}{1 - \Gamma e^{-j2\beta l}} \qquad l \geq 0$$

quarter wave transformer $\quad Z_{\text{in}} = Z_Q^2 / Z_L$