

Electromagnetics

Curated undergraduate study track (not accredited, no external exam). Original explanations and practice only, following the reviewed course handout.

Opening the circuit box

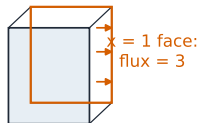
- Circuits hide the fields; this course computes them.
- Every field answer two ways: Gauss vs integration, Ampere vs Biot-Savart, every wave at a limit.

Vector tools: symmetry picks the surface

- 1 **Box** $F = (3x^2, 0, 0)$: $\text{div } 6x$; cube flux 3 by volume integral AND by the two x -faces - identical.
- 2 **Curl** $F = (-y, x, 0)$: **curl** $(0, 0, 2)$; unit-circle circulation $2\pi = 2 \times \text{area}$ - Stokes verified.
- 3 **Rule** No symmetry: integrate directly; the theorem checks the bookkeeping, never the physics.

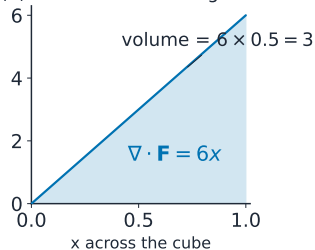
Two routes, one number

(1) surface route: flux = 3



$x = 0$ face: 0; other four: parallel to $\mathbf{F}$

(2) volume route: integral = 3

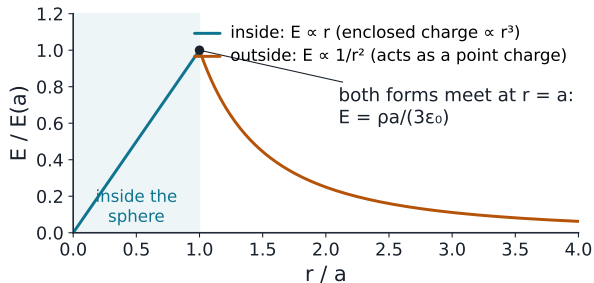


Face flux 3 equals volume integral 6 times $0.5 = 3$ - the **divergence** theorem as bookkeeping on a unit cube.

Electrostatics: Gauss with boundary checks

- 1 **Sphere** Inside grows as r , outside falls as $1/r^2$; the two agree at the boundary - the check that earns the marks.
- 2 **Coax** text:
- 3 **Images** A charge near a grounded plane: mirror $-q$; induced total $-q$; force $q^2/4\pi\epsilon(2h)^2$.

The sphere, both regions

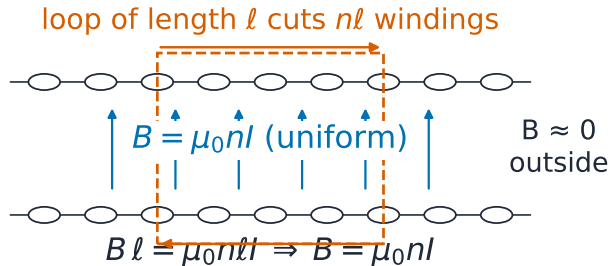


E grows as r inside, falls as $1/r$ squared outside, and both formulas meet at the surface: 753 V/m.

Magnetostatics: Ampere first, Biot-Savart when it fails

- 1 **Solenoid** 1000 turns/m at 2 A: $B = 2.51 \text{ mT}$ inside, ~ 0 outside.
- 2 **Toroid** text:
- 3 **Force** Loop near a wire: near side attracts 18 μN , far side repels 5.1; net toward the wire.

One line instead of a page

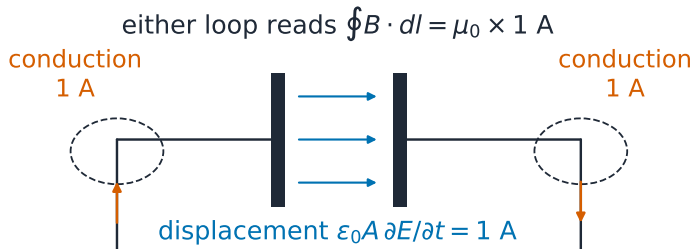


The rectangular Amperian loop cuts $n\ell$ windings: $B = \mu_0 n I$ inside, zero outside.

Maxwell: the displacement current closes the loop

- 1 **Capacitor** Charging at 1 A: no conduction between plates, yet $\epsilon_0 A dE/dt = dQ/dt$ supplies exactly the missing ampere.
- 2 **Sliding rod** EMF $Blv = 0.64$ V; force $BIl = 0.051$ N; mechanical power 0.205 W $= I^2 R$ - energy conserved.
- 3 **Continuity** $\nabla \cdot J + \nabla \cdot \epsilon_0 \dot{E} = 0$ even where $\nabla \cdot J = -\partial\rho/\partial t$: charge conservation built in.

The missing ampere

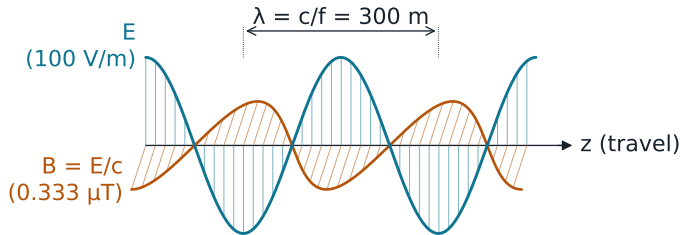


The capacitor charging at 1 A: **displacement current** carries the loop between the plates, numerically equal.

Plane waves: the trio and the impedance

- 1 Numbers** 100 V/m at 1 MHz: $B = 0.333 \text{ uT}$, $\lambda = 300 \text{ m}$, $S = 26.5 \text{ W/m}^2$ - and $S = EB/\mu_0$ agrees.
- 2 Boundary** Into $\epsilon_r 9$: $\Gamma = -0.5$, SWR 3; reflected 0.25+ transmitted 0.75 = 1 - power conserved.
- 3 Shield** 1 kHz into 1 mm aluminium: 0.37 skin depths, 31% attenuation; 12.4 mm needed for 100x.

E, B and 377 ohms

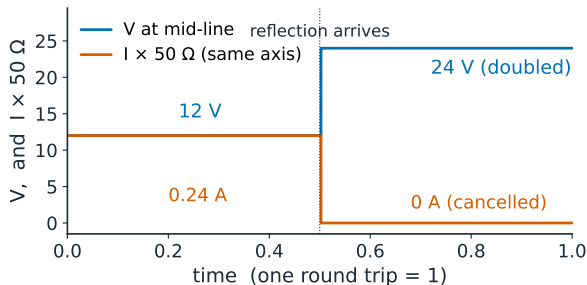


In phase, at right angles, $B = E/c$ - and the power density $S = E$ squared over 377.

Transmission lines: Z_0 , bounces, matching

- 1 **Coax** 250 nH/m, 100 pF/m: $Z_0 = 50 \text{ ohm}$, $v_p = 2/3 c$ - the standard cable from two numbers.
- 2 **Bounce** 75-ohm line, 300-ohm load: $\Gamma = 0.6$; one round trip settles at the DC divider 12 V - the bounces converge to circuit theory.
- 3 **Match** 112.5 ohm to 50 ohm: $Z_Q = 75 \text{ ohm}$, 5.56 cm at 900 MHz; Γ at the junction zero.

The open doubles the voltage

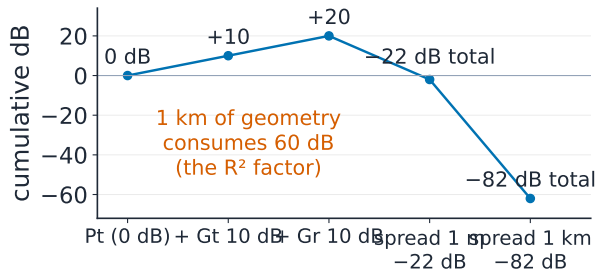


12 V in, reflection +12 V out: 24 V at the load and zero current - the open-circuit signature.

Guides and antennas: cutoff and the link budget

- 1 **WR-90** text:
- 2 **Limits** text:
- 3 **Budget** Satellite 12 GHz, 38,000 km: 205.6 dB path loss, -110.6 dBW received, 25 dB margin over a 135.6 dBW floor.

Geometry decides the last term



Two 10-dBi antennas: minus 22 dB at 1 m, minus 82 dB at 1 km - the R-squared factor eats 60 dB.

Check yourself

- Sphere: E at the surface from inside vs outside? (Equal - $\rho a / 3 \epsilon_0$.)
- Wave: 100 V/m gives B of? (0.333 μT .)
- Line: L' 250 nH/m, C' 100 pF/m gives Z_0 ? (50 ohm.)