Electromagnetics

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

Opening the circuit box

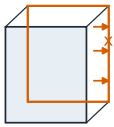
- Circuits hide the fields; this course computes them.
- Every field answer two ways: Gauss vs integration, Ampere vs Biot-Savart, every wave at a limit.

Vector tools: symmetry picks the surface

1. **Box** F = (3x^2,0,0): 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 2pi = 2 x area - Stokes verified.
3. **Rule** No symmetry: integrate directly; the theorem checks the bookkeeping, never the physics.

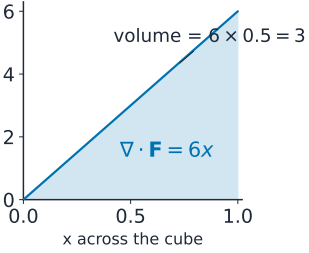
Two routes, one number

(1) surface route: flux = 3



x = 0 face: 0; other four: parallel to F

(2) volume route: integral = 3

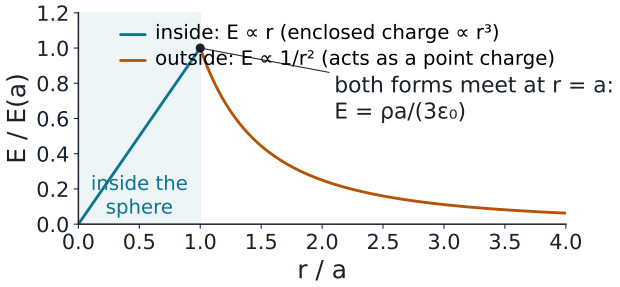


Face flux 3 equals volume integral 6 times 0.5 = 3 - the **divergence** theorem as bookkeeping on a unit cube.

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 eps (2h)^2.

The sphere, both regions

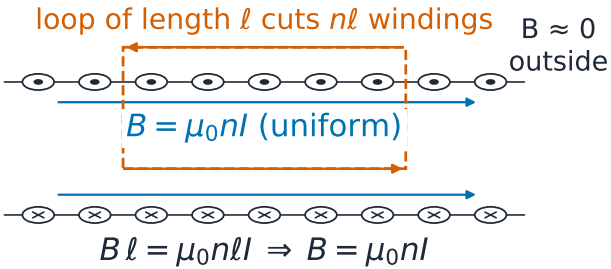


E grows as r inside, falls as $1/r$ squared outside, and both formulas meet at the surface: 753 V/m.

Magnetostatics: Ampere first, Biot-Savart when it fails

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

One line instead of a page

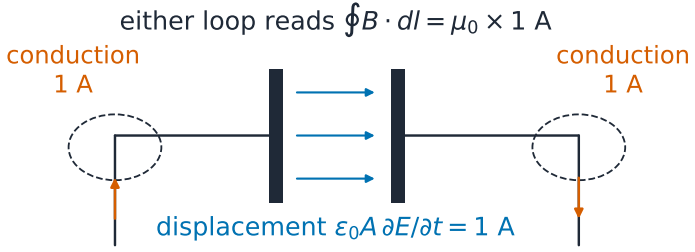


The rectangular Amperian loop cuts n-I windings: B = mu0 n I inside, zero outside.

Maxwell: the displacement current closes the loop

1. **Capacitor** Charging at 1 A: no conduction between plates, yet $\varepsilon_0 A\, dE/dt = dQ/dt$ supplies exactly the missing ampere.
2. **Sliding rod** EMF Blv = 0.64 V; force BI l = 0.051 N; mechanical power 0.205 W = I^2 R - energy conserved.
3. **Continuity** $\nabla \cdot J + \nabla \cdot \varepsilon_0 \dot{E} = 0$ even where $\nabla \cdot J = -\partial\rho/\partial t$: charge conservation built in.

The missing ampere

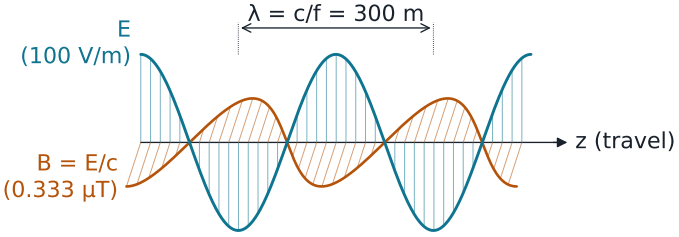


The capacitor charging at 1 A: **displacement current** carries the loop between the plates, numerically equal.

Plane waves: the trio and the impedance

1. **Numbers** 100 V/m at 1 MHz: $B = 0.333$ uT, $\lambda = 300$ m, $S = 26.5$ W/m^2 - and $S = EB/\mu_0$ agrees.
2. **Boundary** Into ε_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

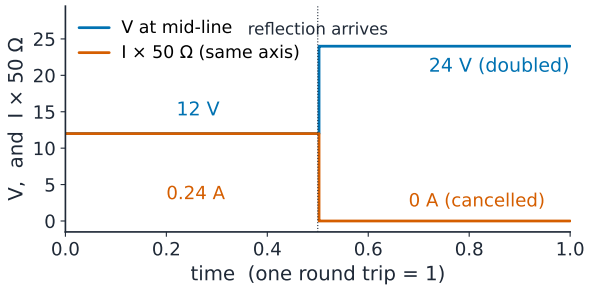


In phase, at right angles, B = E/c - and the power density S = E squared over 377.

Transmission lines: Z0, bounces, matching

1. **Coax** 250 nH/m, 100 pF/m: $Z_0 = 50$ 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: $Z_Q = 75$ ohm, 5.56 cm at 900 MHz; Γ at the junction zero.

The open doubles the voltage

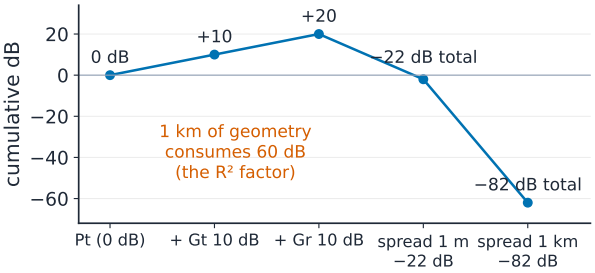


12 V in, reflection +12 V out: 24 V at the load and zero current - the open-circuit signature.

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 - ρ a / 3 eps.)
- Wave: 100 V/m gives B of? (0.333 uT.)
- Line: L' 250 nH/m, C' 100 pF/m gives Z_0? (50 ohm.)