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Electromagnetics Interview Questions

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Electrostatics

1. What does Gauss's law state, and when does it give the field directly?

The net electric flux through any closed surface equals the free charge enclosed: $\oint \mathbf{D} \cdot d\mathbf{S} = Q_{enc}$. It is always true, but it gives the field directly only when symmetry (spherical, cylindrical or planar) makes D constant and normal over a chosen surface. Otherwise the integral cannot be solved for D.

2. Why is the electric field zero inside a conductor in electrostatics, and why is it normal to the surface?

Free charges move until the net field inside vanishes, so the conductor is an equipotential. A tangential field at the surface would push charge along it, so in equilibrium only the normal component remains, equal to ρ_s/ϵ. This holds for static conditions only.

3. A parallel-plate capacitor has plates of area 0.01 m² separated by 1 mm, filled with a dielectric of relative permittivity 4. Find its capacitance.

Using $C = \epsilon_0 \epsilon_r A/d$ with $\epsilon_r = 4$, $A = 0.01$ m² and $d = 1$ mm gives $C = 3.54 \times 10^{-10}$ F, about 354 pF. The dielectric multiplies the air-filled value by 4. This ignores fringing at the plate edges.

WORKING

1. $C = \epsilon_0 \epsilon_r A/d$
2. $C = 8.854 \times 10^{-12} \times 4 \times 0.01/10^{-3}$
3. $C = 3.54 \times 10^{-10}$ F

Magnetostatics, magnetic circuits and inductance

4. What does Ampere's circuital law state, and where is it used to find the field?

The line integral of $\mathbf{H}$ round any closed path equals the current enclosed: $\oint \mathbf{H} \cdot d\mathbf{l} = I_{enc}$. For steady currents it is the magnetic counterpart of Gauss's law, and it gives H directly when symmetry holds, as for a long straight wire, a solenoid or a toroid.

5. Why does a small air gap dominate the reluctance of a magnetic circuit?

The reluctance per unit length of air is about μ_r times that of iron, and μ_r is in the hundreds or thousands. A gap of a millimetre can therefore match a core path of hundreds of millimetres. Most of the mmf drops across the gap, which lowers the inductance but makes it more linear and delays saturation.

6. A toroidal iron core has a mean length of 0.4 m, a cross-section of 4 cm² and a relative permeability of 1000. It has a 1 mm air gap and a 500-turn winding carrying 1 A. Find the flux, ignoring leakage and fringing.

The core reluctance is about 7.96×10^5 A/Wb and the 1 mm gap adds 1.99×10^6 A/Wb, so the gap dominates. Dividing the mmf of 500 A by the total 2.79×10^6 A/Wb gives a flux of about 180 µWb (0.18 mWb).

WORKING

1. Core: $R_c = l/(\mu_0 \mu_r A) = 0.4/(4\pi \times 10^{-7} \times 1000 \times 4 \times 10^{-4}) = 7.96 \times 10^5$ A/Wb
2. Gap: $R_g = 10^{-3}/(4\pi \times 10^{-7} \times 4 \times 10^{-4}) = 1.99 \times 10^6$ A/Wb
3. Total $R = 2.79 \times 10^6$ A/Wb, and mmf $= NI = 500$ A
4. $\phi = 500/(2.79 \times 10^6) = 1.8 \times 10^{-4}$ Wb

Maxwell's equations

7. What is displacement current, and why did it have to be added to Ampere's law?

It is the term $\partial \mathbf{D}/\partial t$ added to give $\nabla \times \mathbf{H} = \mathbf{J} + \partial \mathbf{D}/\partial t$. It lets a changing electric field act like a current, so the total current stays continuous through a capacitor gap. It also couples the electric and magnetic fields, which is what allows a travelling wave.

8. What is the difference between conduction current and displacement current?

Conduction current is the drift of free charges, $J = \sigma E$, and it dissipates power. Displacement current is $\partial D/\partial t$ and needs no charge to move, so it exists in vacuum. For sinusoidal fields their magnitudes are in the ratio $\sigma/\omega\epsilon$, which decides whether a medium acts as a conductor or a dielectric.

9. A uniform plane wave in free space has a peak electric field of 100 V/m. Find its average power density.

For a plane wave in free space the average power density is $E_0^2/(2\eta_0)$, with $\eta_0 \approx 377\ \Omega$. The factor 2 comes from averaging over a cycle. With a peak field of 100 V/m this gives about 13.3 W/m².

WORKING

1. $\langle S \rangle = E_0^2/(2\eta_0)$
2. $\eta_0 \approx 377\ \Omega$
3. $\langle S \rangle = 10^4/754 = 13.3$ W/m²

Plane waves

10. Find the skin depth of copper (conductivity 5.8×10^7 S/m, non-magnetic) at 1 MHz.

For a good conductor $\delta = 1/\sqrt{\pi f \mu \sigma}$, which gives about 66 µm for copper at 1 MHz. This is the depth at which the field amplitude has fallen to 1/e of its surface value.

WORKING

1. For a good conductor, $\delta = 1/\sqrt{\pi f \mu \sigma}$
2. $\pi f \mu \sigma = \pi \times 10^6 \times 4\pi \times 10^{-7} \times 5.8 \times 10^7 = 2.29 \times 10^8$
3. $\delta = 1/\sqrt{2.29 \times 10^8} = 6.6 \times 10^{-5}$ m

11. What is the difference between linear and circular polarisation?

A linearly polarised wave has two orthogonal field components in phase (or 180 degrees apart), so the tip of the electric field traces a line. Circular polarisation needs equal amplitudes and a 90 degree phase difference, so the tip traces a circle, with the handedness set by which component leads and the direction of travel. Any other combination is elliptical.

12. Why does a wave reflect at the boundary between two media at normal incidence?

The two media have different intrinsic impedances, and the tangential E and H must both be continuous across the boundary. A transmitted wave alone cannot satisfy both unless the impedances are equal, so a reflected wave appears, with $\Gamma = (\eta_2 - \eta_1)/(\eta_2 + \eta_1)$.

Transmission lines

13. What is the characteristic impedance of a transmission line?

It is the ratio of voltage to current for a single wave travelling in one direction on the line: $Z_0 = \sqrt{(R + j\omega L)/(G + j\omega C)}$, which becomes $\sqrt{L/C}$ for a lossless line. It depends on the line's geometry and dielectric, not on its length, and it is not what an ohmmeter reads.

14. Why does a wire need transmission-line treatment only when its length is comparable to the wavelength?

Circuit theory assumes the voltage and current are the same along the whole wire. That holds when the signal's delay along the wire is a small part of its period, roughly when the length is below one tenth of the wavelength. Beyond that, voltage and current vary with position and travel as waves.

15. Why can a quarter-wave section match a real load to a line, and what limits it?

A quarter-wave line of impedance Z_t gives $Z_{in} = Z_t^2/Z_L$. Choosing $Z_t = \sqrt{Z_0 R_L}$ makes the input impedance equal Z_0, so nothing reflects towards the source. It is exact only at the design frequency, where the section is a quarter wavelength, so the match is narrow-band.

16. A 100 ohm resistive load is connected to a lossless 50 ohm line. Find the VSWR.

The VSWR is 2. The reflection coefficient is $\Gamma = (100 - 50)/(100 + 50) = 1/3$, so $\mathrm{VSWR} = (1 + 1/3)/(1 - 1/3) = 2$. For a resistive load on a lossless line this equals the larger of Z_L/Z_0 and Z_0/Z_L, here $100/50$.

WORKING

1. $\Gamma = (Z_L - Z_0)/(Z_L + Z_0) = (100 - 50)/(100 + 50) = 1/3$
2. $\mathrm{VSWR} = (1 + |\Gamma|)/(1 - |\Gamma|)$
3. $\mathrm{VSWR} = (4/3)/(2/3) = 2$

Waveguides and optical fibres

17. Why does a rectangular waveguide pass signals only above a cut-off frequency?

Below cut-off the guided phase constant $\beta = \sqrt{k^2 - k_c^2}$ becomes imaginary, so the field decays along the guide instead of travelling. The cut-off wavenumber k_c is fixed by the cross-section and the mode, so the guide acts as a high-pass filter, and the dominant TE10 mode has the lowest cut-off.

18. Find the cut-off frequency of the dominant mode of an air-filled rectangular waveguide whose broad wall is 2.286 cm wide.

The dominant mode is TE10, whose cut-off for an air-filled guide is $f_c = c/(2a)$. With $a = 2.286$ cm this gives $f_c = 3 \times 10^8 / 0.04572 \approx 6.56$ GHz, so the guide carries the TE10 mode only above that frequency.

WORKING

1. The dominant mode is TE10, so $f_c = c/(2a)$
2. $f_c = 3 \times 10^8/(2 \times 0.02286)$
3. $f_c = 6.56 \times 10^9$ Hz

19. What is the difference between single-mode and multimode optical fibre?

Single-mode fibre has a core of about 8 to 10 µm and a V-number below 2.405, so only one mode propagates and there is no modal dispersion. Multimode fibre has a core of 50 µm or more and carries many modes, whose different delays limit the bandwidth and distance. Single-mode suits long links.

Antennas and antenna arrays

20. What is the difference between the directivity and the gain of an antenna?

Directivity is the ratio of the peak radiation intensity to that of an isotropic source radiating the same total power. Gain uses the power fed to the antenna instead, so $G = \eta D$ with η the radiation efficiency. Gain never exceeds directivity, and the two are equal for a lossless antenna.

21. Why is the half-wave dipole so widely used?

At exactly half a wavelength its input impedance is about $73 + j42.5\ \Omega$. Cut slightly shorter (about 0.47 to 0.48 wavelength), it resonates with a resistance near 70 ohms, close to the impedance of common feed lines, so matching is easy. Its length is practical, and it has a directivity of about 1.64 (2.15 dBi) with a simple doughnut-shaped pattern.

22. Why does received power in free space fall with the square of distance and also depend on wavelength?

The Friis equation $P_r = P_t G_t G_r (\lambda/4\pi d)^2$ shows both. The $1/d^2$ comes from the radiated power spreading over a sphere. The λ^2 comes from the receiving antenna's effective aperture, which shrinks as frequency rises for a given gain. The loss is spreading, not absorption.

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