Skin Effect

Skin effect

- **Skin effect** is the tendency of an alternating electric current (AC) to become distributed within a conductor such that the current density is largest near the surface of the conductor, and decreases with greater depths in the conductor. The electric current flows mainly at the "skin" of the conductor, between the outer surface and a level called the **skin depth**.

Skin effect

- The skin effect causes the effective resistance of the conductor to increase at higher frequencies where the skin depth is smaller, thus reducing the effective cross-section of the conductor. The skin effect is due to opposing eddy currents induced by the changing magnetic field resulting from the alternating current.
- The AC current density *J* in a conductor decreases exponentially from its value at the surface J_S according to the depth *d* from the surface

$$J = J_S \, e^{-(1+j)d/\delta}$$

- The general formula for the skin depth is

$$\delta = \sqrt{\frac{2\rho}{\omega\mu}} \sqrt{\sqrt{1+(\rho\omega\epsilon)^2}+\rho\omega\epsilon}$$

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$$\delta=\sqrt{\frac{2\rho}{\omega\mu}}\sqrt{\sqrt{1+(\rho\omega\epsilon)^2}+\rho\omega\epsilon}$$

where

ρ = resistivity of the conductor

ω = angular frequency of current = 2π × frequency

$\mu = \mu_r \mu_0$

μ_r = relative magnetic permeability of the conductor

μ_0 = the permeability of free space

$\epsilon = \epsilon_r \epsilon_0$

ϵ_r = relative permittivity of the material

ϵ_0 = the permittivity of free space

At frequencies much below $1/\rho\epsilon$ the quantity inside the large radical is close to unity and the formula is more usually given as:

$$\delta=\sqrt{\frac{2\rho}{\omega\mu}}.$$

This formula is valid at frequencies away from strong atomic or molecular resonances

where would have a large imaginary part) and at frequencies that are much below both the material's plasma frequency (dependent on the density of free electrons in the material) and the reciprocal of the mean time between collisions involving the conduction electrons. In good conductors such as metals all of those conditions are ensured at least up to microwave frequencies, justifying this formula's validity

Material effect on skin depth

- In a good conductor, skin depth is proportional to square root of the resistivity. This means that better conductors have a reduced skin depth. The overall resistance of the better conductor remains lower even with the reduced skin depth. However the better conductor will show a higher ratio between its AC and DC resistance, when compared with a conductor of higher resistivity.
- Skin depth also varies as the inverse square root of the permeability of the conductor. In the case of iron, its conductivity is about 1/7 that of copper. However being ferromagnetic its permeability is about 10,000 times greater.
- This reduces the skin depth for iron to about 1/38 that of copper, about 220 micrometres at 60 Hz.
- The skin effect also reduces the effective thickness of laminations in power transformers, increasing their losses.