Skin Depth and AC Resistance of a Round Conductor

Skin depth at a frequency and the AC-to-DC resistance ratio of a round conductor from its diameter, resistivity and relative permeability.

Method: Skin depth δ = √(ρ/(πfμ)); exact Bessel-function solution for a round wire; Z/R_dc = (kr/2)J₀(kr)/J₁(kr) with k = (1 − j)/δ (Ramo, Whinnery and Van Duzer, Fields and Waves in Communication Electronics, 3rd ed. (Wiley, 1994))

Input parameters

Unit system: SI

Parameter	Value	Unit
Frequency	50.000	Hz
Conductor diameter	25.000	mm
Resistivity	1.7240e-08	Ω·m
Relative permeability	1.0000	

Calculated results

Parameter	Value	Unit
Skin depth	9.3455	mm
Diameter-to-skin-depth ratio	2.6751	
AC-to-DC resistance ratio	1.0633	

Notes for this case

- Isolated straight round conductor; proximity effect from nearby conductors is extra. Copper at 50 Hz has δ ≈ 9.3 mm, so skin effect matters for large single conductors and busbars.

Formula and method

$$\delta = \sqrt{\frac{\rho}{\pi f \mu_0 \mu_r}}, \quad \frac{R_{ac}}{R_{dc}} = \mathrm{Re}\left[\frac{kr}{2}\frac{J_0(kr)}{J_1(kr)}\right], \quad k = \frac{1-j}{\delta}; \quad \approx \frac{x}{4} + \frac{1}{4} + \frac{3}{16x} \quad (x = d/\delta > 20)$$

Variables

f	Frequency	1/s
d	Conductor diameter	m
ρ	Resistivity	Ω·m
μ_r	Relative permeability	-
δ	Skin depth	m
d/δ	Diameter-to-skin-depth ratio	-
R_{ac}/R_{dc}	AC-to-DC resistance ratio	-
μ_0	Magnetic constant, 1.256 637 062 12 × 10⁻⁶	H/m
k	Complex propagation constant (1 − j)/δ	1/m
r	Conductor radius d/2	m
J_0, J_1	Bessel functions of the first kind	-
x	d/δ	-

Method and standards

Exact Bessel solution (power series), asymptotic form for very large d/δ.

Assumptions and limits

- Isolated round conductor.
- Above d/δ = 20 the three-term asymptotic form r/(2δ) + 1/4 + 3δ/(32r) (with r = d/2) is used; it agrees with the series solution to about 0.002 % at the switch, and closer above it.

References

• Skin depth $\delta = \sqrt{(\rho/(\pi f \mu))}$; exact Bessel-function solution for a round wire
• $Z/R_{dc} = (kr/2)J_0(kr)/J_1(kr)$ with $k = (1 - j)/\delta$ (Ramo, Whinnery and Van Duzer, Fields and Waves in Communication Electronics, 3rd ed. (Wiley, 1994))

Report details

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Results are for engineering estimation. Verify critical designs against the referenced standards and your own data.

This calculator online

https://calc.firecad.com/electrical/cables/skin-depth-ac-resistance

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Reopens the calculator with the inputs of this report.