

Exercise 1: Calculating Shielding Effectiveness of Copper Foil [far field]

Calculate the shielding effectiveness of a sheet of 50mm copper foil.

$\sigma = 5.7 \times 10^7$ S/m, at 200 MHz

We start by calculating the skin depth in copper at 200MHz

$$\delta_{Cu} = \frac{1}{\sqrt{\pi \cdot f \cdot \mu \cdot \sigma}} = \frac{1}{\sqrt{\pi \cdot (2 \cdot 10^8) \cdot (4 \cdot \pi \cdot 10^{-7}) \cdot (5.7 \cdot 10^7)}} = 4.7 \mu m$$

From here, absorption loss can be easily calculated as

$$A(dB) \approx 8.7 \cdot \left(\frac{t}{\delta} \right) = 8.7 \cdot \left(\frac{50 \mu m}{4.7 \mu m} \right) = 92 dB$$

To calculate reflection loss, we need to determine the intrinsic impedance of the material (copper) at 200MHz.

$$|Z_{M@200MHz}| = \sqrt{\frac{2 \cdot \pi \cdot f \cdot \mu}{\sigma}} = \sqrt{\frac{2 \cdot \pi \cdot (2 \cdot 10^8) \cdot (4 \cdot \pi \cdot 10^{-7})}{5.7 \cdot 10^7}} = 5.3 \cdot 10^{-3} \text{ ohms}$$

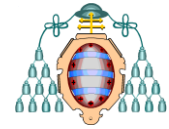
which allows us to easily calculate reflection loss from

$$R(dB) \approx 20 \cdot \log \left(\frac{Z_0}{4 \cdot Z_M} \right) = 20 \cdot \log \left(\frac{377}{4 \cdot (5.3 \cdot 10^{-3})} \right) = 85 dB$$

The overall shielding effectiveness is the sum of the reflection loss and the absorption loss.

$$SE = R(dB) + A(dB) = 85 + 92$$

$SE = 177dB$



Exercise 2: Shielding a Low-Frequency Magnetic [near field]

A transformer generating primarily a magnetic field is located 15 cm from a shielding structure. The shielding structure is made from a $t=12\text{mm}$ thick sheet of copper. Estimate the shielding effectiveness of this structure at 1.0 kHz.

The impedance in the near-field of an electric dipole source can be expressed as

$$Z_E = \frac{|E|}{|H|} \approx \frac{1}{2 \cdot \pi \cdot f \cdot \epsilon_0 \cdot r}$$

whereas that in the near field of a magnetic dipole source is

$$Z_H = \frac{|E|}{|H|} \approx 2 \cdot \pi \cdot f \cdot \mu_0 \cdot r$$

By modelling the transformer as a magnetic dipole source, we can quickly estimate the wave impedance at the position of the shield to be:

$$Z_H \approx 2 \cdot \pi \cdot f \cdot \mu_0 \cdot r = 2 \cdot \pi \cdot (1.0 \cdot 10^3) \cdot (4 \cdot \pi \cdot 10^{-7}) \cdot (0.15) = 1.2 \cdot 10^{-3} \text{ ohm}$$

Since the intrinsic impedance and the skin depth of the material (copper) at 1kHz are

$$|Z_{M@1kHz}| = \sqrt{\frac{2 \cdot \pi \cdot f \cdot \mu}{\sigma}} = \sqrt{\frac{2 \cdot \pi \cdot (1.0 \cdot 10^3) \cdot (4 \cdot \pi \cdot 10^{-7})}{5.7 \cdot 10^7}} = 12 \cdot 10^{-6} \text{ ohms}$$

$$\delta_M = \frac{1}{\sqrt{\pi \cdot f \cdot \mu \cdot \sigma}} = \frac{1}{\sqrt{\pi \cdot (1.0 \cdot 10^3) \cdot (4 \cdot \pi \cdot 10^{-7}) \cdot (5.7 \cdot 10^7)}} = 2.1 \text{ mm}$$

the shielding effectiveness can be calculated to be

$$SE = R(\text{dB}) + A(\text{dB}) + B(\text{dB}) = 20 \cdot \log\left(\frac{Z_H}{4 \cdot Z_M}\right) + 20 \cdot \log\left(e^{\frac{t}{\delta}}\right) + 20 \cdot \log\left|1 - e^{-\frac{t}{\delta}}\right|$$

$$SE = 20 \cdot \log\left(\frac{1.2 \cdot 10^{-3}}{4 \cdot (12 \cdot 10^{-6})}\right) + 20 \cdot \log\left(e^{\frac{12}{2.1}}\right) + 20 \cdot \log\left|1 - e^{-\frac{12}{2.1}}\right| = 28 \text{ dB} + 50 \text{ dB} + \approx 0 \text{ dB}$$

$SE = 78 \text{ dB}$