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

Calculate the shielding effectiveness of a sheet of 50mm copper foil.
σ = 5.7x107 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.

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

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.

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

$$\boxed{SE = 177dB}$$

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=12mm 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

$$Z_E = \frac{|E|}{|H|} \approx \frac{1}{2 \cdot \pi \cdot f \cdot \varepsilon_0 \cdot r}$$

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:

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

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

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

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

the shielding effectiveness can be calculated to be

$$SE = R(dB) + A(dB) + B(dB) = 20 \cdot \log\left(\frac{Z_H}{4 \cdot Z_M}\right) + 20 \cdot \log\left(e^{t/\delta}\right) + 20 \cdot \log\left|1 - e^{-2 \cdot t/\delta}\right|$$

$$SE = 20 \cdot \log\left(\frac{1.2 \cdot 10^{-3}}{4 \cdot \left(12 \cdot 10^{-6}\right)}\right) + 20 \cdot \log\left(e^{12/2.1}\right) + 20 \cdot \log\left|1 - e^{-2 \cdot \left(12/2.1\right)}\right| = 28\,dB + 50\,dB + \approx 0\,dB$$

$$\boxed{SE = 78dB}$$