Ch 2. Grounding

2021 Quiz 2.

2. Figure 2 shows two parallel copper conductors to be connected between a signal source and a load. One of them (S) serves as signal conductor and the other (G) serves as a ground return conductor. The diameter of the conductor is 2.5 mm and the centre-to-centre spacing is 8 mm. The length of each conductor is 120 cm. The two conductors are separated by air. Electrical properties of copper: $\sigma = 5.82 \times 10^7$ S/m and $\mu = 4\pi \times 10^{-7}$ H/m. Free space: $\varepsilon = 8.854 \times 10^{-12}$ F/m.

(a) Draw the equivalent circuit of the two parallel conductors at 150 kHz.

(5 Marks)

(a) Calculate the resistance, inductance and capacitance of the equivalent circuit.

(15 Marks)

(a) The maximum ground impedance must be less than 0.5 Ω to ensure the circuit's functionality. Is the given ground conductor a good ground at 150 kHz?

(5 Marks)

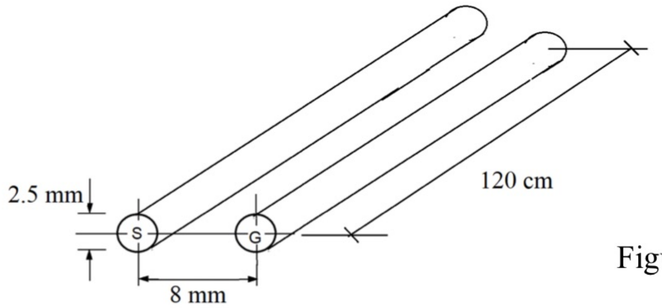
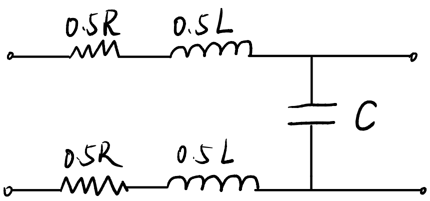


Figure 1

(a) The wavelength at 150 kHz is, $\lambda = \frac{c}{f} = \frac{3 \times 10^8}{150 \times 10^3} = 2 \times 10^3 m$

Since length of conductor (1.2 m) $< \lambda/10$ (200 m), the two parallel conductor can be modelled as lumped circuit.

The equivalent circuit is



(b) @150 kHz, the skin depth $\delta = \frac{1}{\sqrt{\pi f \sigma \mu}} = \frac{1}{\sqrt{\pi 150 \times 10^3 \times 5.82 \times 4\pi}} = 1.7 \times 10^{-4} m$

$\delta < r (1.25 \times 10^{-3} m)$,

$$R = 2 \times \frac{l}{2\pi r \sigma \delta} = \frac{2 \times 1.2}{2\pi \times 1.25 \times 10^{-3} \times 5.82 \times 10^7 \times 1.7 \times 10^{-4}} = 30.88\ m\Omega$$

$$L = 4 \times 10^{-7} \times l \times \ln\left(\frac{D-r}{r}\right) = 4 \times 10^{-7} \times 1.2 \times \ln\left(\frac{8-1.25}{1.25}\right) = 0.81\ \mu H$$

$$C = \frac{\pi \varepsilon_0 l}{\ln\left[\frac{D}{2r} + \sqrt{\left(\frac{D}{2r}\right)^2 - 1}\right]} = \frac{\pi \times 8.854 \times 10^{-12} \times 1.2}{\ln\left(\frac{8}{2.5} + \sqrt{\left(\frac{8}{2.5}\right)^2 - 1}\right)} = 18.23\ pF$$

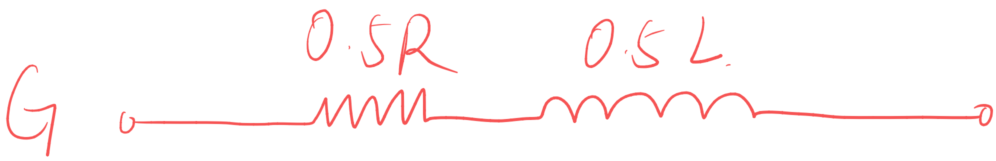
(c) At 150 kHz, the capacitive reactance $= \frac{1}{jwC} = \frac{1}{j \cdot 2\pi \cdot 150\times10^{3} \times 18.23\times10^{-12}} = -j58.20\,k\Omega$

It is significant longer than series resistance and inductance. So its effect can be ignored.

$Z_G = 0.5R + jw(0.5L) = 0.015 + j\,2\pi \times 150kHz \times 0.405\times10^{-6}H = (0.015 + j0.382)\Omega$

$|Z_G| = 0.382\Omega < 0.5\Omega$

it can be considered as a good ground.



2016-2017. 2.(a)

2. (a) Figure 3 on page 3 shows a two-wire cable to be used for connecting the output of an amplifier and a sensor, one of the wires serves as the signal conductor and the other as ground return conductor. The operating frequency of the amplifier with the sensor is 1 MHz. The design engineer has found a standard two-wire cable from a supplier and the technical specifications are given in Table 1 on page 3. For the sensor to function properly, the impedance of the ground return path shall not exceed 0.5 Ω. Ignore the capacitance between the two wires, do you think the selected standard cable will work for the given circuit. Justify your answer with calculation. Conductivity and permeability of the copper wire are 5.82×10^{7} S/m and $4\pi \times 10^{-7}$, respectively.

(10 Marks)

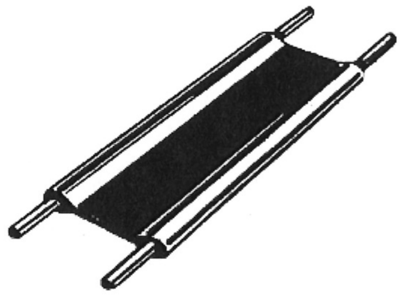


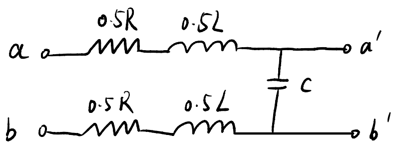
Figure 3

Table 1

Copper wire diameter	1 mm
Centre-to-centre separation between wires	5 mm
Length of the two-wire cable	100 mm

(a). At 1MHz, the wavelength λ is $\lambda = \frac{3\times10^{8}}{10^{6}} = 300\,(m)$

The length of conductor $(0.1\,m) < \frac{\lambda}{10}\,(30\,m)$, the lump circuit model can be applied.



@1MHz, the skin depth is $\delta = \frac{1}{\sqrt{\pi f \sigma \mu}} = \frac{1}{\sqrt{\pi\times10^{6}\times5.82\times4\pi}} = 6.60\times10^{-5}\,m$

Since the radius of wire $(0.5\,mm) > \delta$. The skin effect exists.

$$0.5R = \frac{l}{2\pi r \sigma \delta} = \frac{100\times10^{-3}\,m}{2\pi\times0.5\times10^{-3}\times5.82\times10^{7}\times6.60\times10^{-5}} = 8.29\,m\Omega$$

$$L = 4\times10^{-7}\times l\times\ln\left(\frac{D-r}{r}\right) = 4\times10^{-7}\times100\times10^{-3}\times\ln\left(\frac{5-0.5}{0.5}\right) = 87.89\,nH$$

$0.5L = 43.945\,nH$

Since the capacitance between the two wires can be ignored, the impedance of the ground return path is

$$Z_G = 8.29\,m\Omega + j\omega\times43.945\,nH = (0.00829 + j0.276)\,\Omega$$

$|Z_G| \approx 0.276\,\Omega < 0.5\,\Omega$, Hence, the selected cable will work.