Exercise 1 (EMI/EMC) (14%)

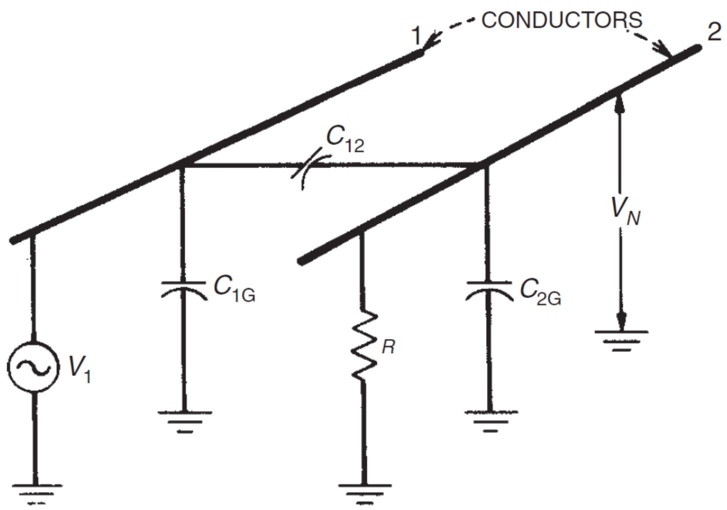


Figure 1. Diagram of two conductors with capacitive coupling

A diagram of two conductors with capacitive coupling is shown in Figure 1. With an assumption that conductors are short compared with a wavelength:

Question A (6%). Draw the equivalent circuit diagram and calculate the noise voltage (V_N) picked up by the second conductor.

Question B (6%). Consider the parasitic capacitances and the noise source given as below:

V_1 (noise source) = 10 Vac @ 100 kHz
C_{12} = 50 pF
C_{1G} = C_{2G} = 150 pF

Calculate V_N if the termination resistance R is:

Question B.1. R = 100 kΩ

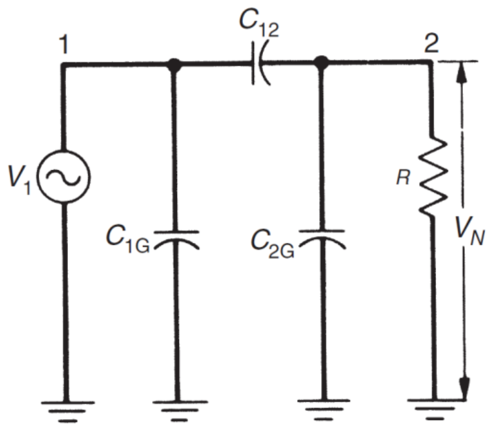
Question B.2. R = 50 Ω

Question C (2%). Based on the calculated noise voltage (V_N) in Part A and the obtained results in Part B, how does the termination resistance R minimizes the noise voltage (V_N) picked by the second conductor?

Solution

Question A.

The equivalent circuit of Figure 1 is: (1%)



EQUIVALENT
CIRCUIT

From the obtained equivalent circuit V_N is calculated from V_1 based on voltage division principle:

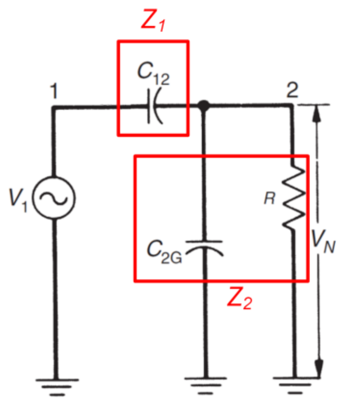
(3%)

$$V_N = \frac{Z_2}{Z_1 + Z_2} V_1$$

$$Z_1 = \frac{1}{j\omega C_{12}}$$

$$Z_2 = \frac{1}{j\omega C_{2G}} \parallel R = \frac{R}{j\omega R C_{2G} + 1}$$

$$\Rightarrow V_N = \frac{\frac{R}{j\omega R C_{2G}+1}}{\frac{R}{j\omega R C_{2G}+1} + \frac{1}{j\omega C_{12}}} V_1 = \frac{j\omega R C_{12}}{j\omega R(C_{12}+C_{2G})+1} V_1$$



EQUIVALENT
CIRCUIT

$$\Rightarrow V_N = \frac{\frac{RC_{12}}{(C_{12}+C_{2G})}}{R + \frac{1}{j\omega(C_{12}+C_{2G})}} V_1$$

Condition 1: $R \ll \frac{1}{j\omega(C_{12}+C_{2G})} \longrightarrow V_N = j\omega R C_{12} V_1$ (1%)

Condition 2: $R \gg \frac{1}{j\omega(C_{12}+C_{2G})} \longrightarrow V_N = \left(\frac{C_{12}}{C_{12}+C_{2G}}\right) V_1$ (1%)

Question B.

In order to calculate the noise voltage picked by second conductor, considering the giving parameter values the following term should be calculated:

$$\frac{1}{j\omega(C_{12}+C_{2G})} \xrightarrow[C_{12}=50\,pF,\,C_{2G}=150\,pF]{\omega=2\pi\times100\times10^3} \left|\frac{1}{j\omega(C_{12}+C_{2G})}\right| \approx 7.96k\Omega \qquad \text{(I)}$$ (2%)

B.1. Considering the calculated the ratio above (I) and termination resistance R = 100 kΩ, then V_N can be estimated following condition 2

$$V_N = \left(\frac{C_{12}}{C_{12}+C_{2G}}\right)V_1 \longrightarrow V_N = \frac{50}{200}\times10 = 2.5V$$ (2%)

B.2. Considering the calculated the ratio above (I) and termination resistance R = 50 Ω, then V_N can be estimated following condition 1

(2%)

$$V_N = j\omega RC_{12}V_1 \longrightarrow |V_N| = 2\times\pi\times100\times10^3\times50\times50\times10^{-12}\times10 = 15.7mV$$

Question C. (2%)

Considering the above calculations, the termination resistance can minimize the noise voltage (V_N) picked by the second conductor if condition 1 is hold.

This means that the termination resistance should be

$$R \ll \frac{1}{j\omega(C_{12}+C_{2G})} \longrightarrow V_N = j\omega RC_{12}V_1$$

From the above relation it is obvious that reducing R can directly reduce V_N as well. Ideally if R is zero, V_N will be zero as well (grounding the second conductor R = 0).