The University Of Sheffield.

Data Provided: Smith Chart,
Useful equations are given at the end of the paper

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2014-15 (2.0 hours)

EEE6220 Electronic Communication Technologies

Answer **THREE** questions. **No marks will be awarded for solutions to a forth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1. Figure 1.1 shows a scenario where Electromagnetic Interference (EMI) is causing problems. The scenario comprises of two systems, the first being a control electronics circuit which is connected to a stepper motor. The second system is a data link between a motor sensor and a data logger, used for transmitting motor performance data.

Each system is connected using a cylindrical wire of 1mm diameter and length 1m. Assume that there is no ground plane under the cables. The distance between centres of the two cables is 3mm.

The control electronics circuit is has a square wave voltage output as shown in Figure 1.2 and has a frequency of f=50kHz. The maximum voltage from the controller is 2.5V and the current flowing between the control electronics and the motor is a maximum of 5A.

The data logger operates over a voltage range of 0-5V and high frequency interference has been observed at the input to the data logger.

The impedances of the various system elements are shown in Figure 1.1.

Assume the self inductances of the cables are negligible.

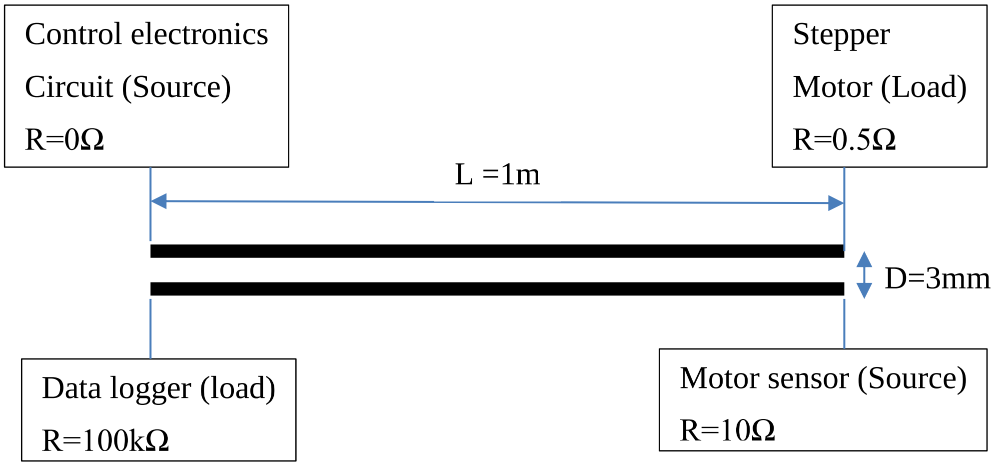


Figure 1.1: System schematic

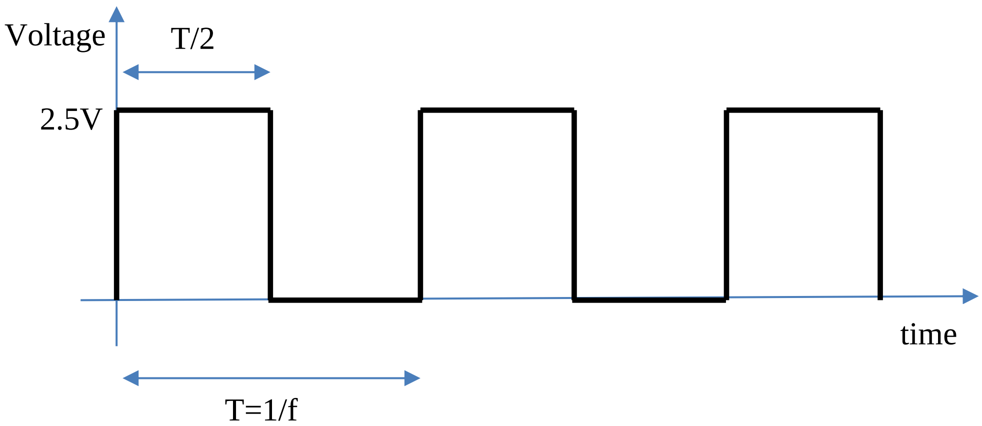


Figure 1.2: Voltage waveform

a

i. Calculate the mutual inductance and capacitance between the two cylindrical cables

ii. Using Fourier analysis calculate the magnitude of the voltage and current at 50kHz at the output of the control electronics circuit.

iii. Calculate the magnitude of the induced noise voltage at the input to the data logger due to the mutual inductance and mutual capacitance. **(15)**

iv. What is the dominant source of interference (inductance or capacitance)?

b A perfect electrically conducting shield is placed around the cable of the data link to reduce the EMI. Assume the cable does not extend outside the ends of the shield and the shield is connected to ground at both ends. The cut-off frequency of the shield is 10kHz and the shield is cylindrical. **(5)**

Calculate the magnitude of the voltage at the input to the data logger.

2. An FM radio transmitter has been placed 10m from a sensitive medical device making measurements in the 5-10μV range, illustrated in Figure 2.1.

The medical device consists of a low impedance sensor connected to a high impedance data logger. The sensor and data logger are connected using 2 parallel cylindrical wires of diameter 1mm, length 10cm with a vertical wire spacing of 2cm as shown in Figure 2.2. The E-field from the FM transmitter is vertical and propagating towards the cables. A list of specifications are given below. The characteristic impedance of free space is 377Ω.

- FM transmitter power = 30W
- FM transmission frequency = 100MHz
- FM antenna directivity =10cos(θ)
- Medical sensor impedance Z_1=10Ω
- Data logger impedance Z_2= 100kΩ
- Reflections from the ground can be neglected

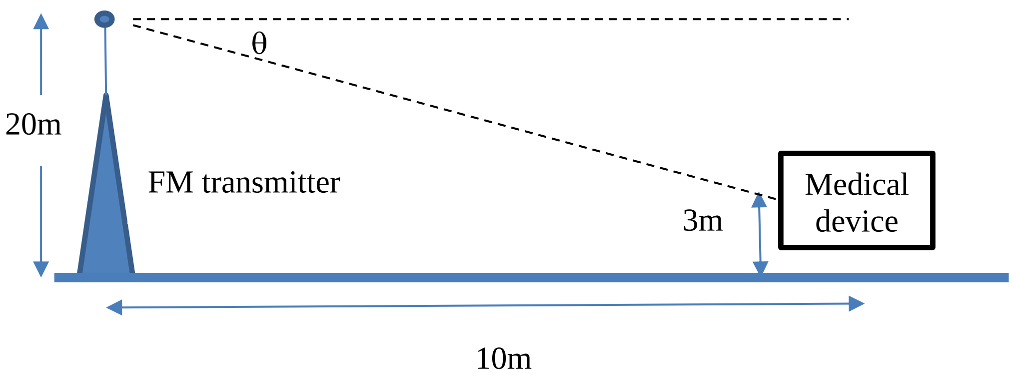


Figure 2.1: Illustration of transmitter and device locations

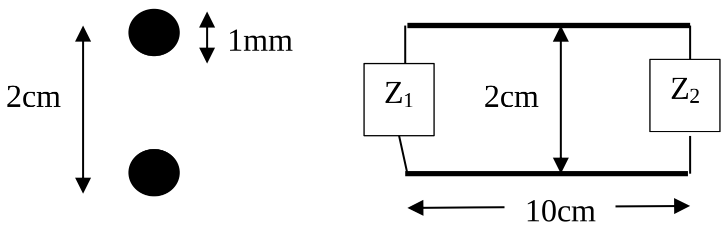


Figure 2.2: Cross section of medical device cables, including circuit diagram

a Estimate the following:-

i. The power density at the medical device due to the FM signal
ii. The magnitude of the E-field at the medical device
iii. The wavelength of the FM signal
iv. The noise voltage at the input to the data logger, Z_2

(12)

b To reduce interference from the FM transmitter an aluminium shield is placed around the medical device. The required Shielding Effectiveness (SE) is 100dB and it can be assumed that the shield has no apertures. Assume the effects of multiple reflections in the shield are negligible.

(8)

Calculate the minimum thickness of the aluminium shield needed to meet the SE requirement. (μ_r=1, σ_r=0.6, μ_r=4π*10^{-7}, σ_{cu}=5.8*10^{7})

3. **a.** Explain briefly how the Smith chart can be used to solve transmission line problems. **(2)**

b. A lossless transmission line with a length of 3cm and a characteristic impedance of 50Ω is terminated with a complex load impedance of (80+j30)Ω at a frequency of 3GHz. Use the required transmission line equations to calculate the input impedance, input reflection coefficient, and the voltage standing wave ratio. **(4)**

c. Design a quarter wave matching transformer to match a 40Ω load to a75Ω line. Plot the voltage standing wave ratio (VSWR) for $0 \leq (f/f_o) \leq 2$, where f_o is the frequency at which the line is 0.25λ long. **(6)**

d. Using diagrams as necessary, explain how to devise an equivalent circuit of a high frequency resistor. Describe the performance of the resistor as the frequency increases. **(8)**

4. **a.** Explain briefly what are the two basic components of a Signal Flow Diagram (SFD). **(2)**

b. Explain what is meant by the Inter-Modulation Distortion (IMD) **(4)**

c. Calculate the scattering parameters of the two ports network shown in Figure 1 assuming a characteristic impedance of 50Ω for each port. What value of gain/attenuation is provided from this network?

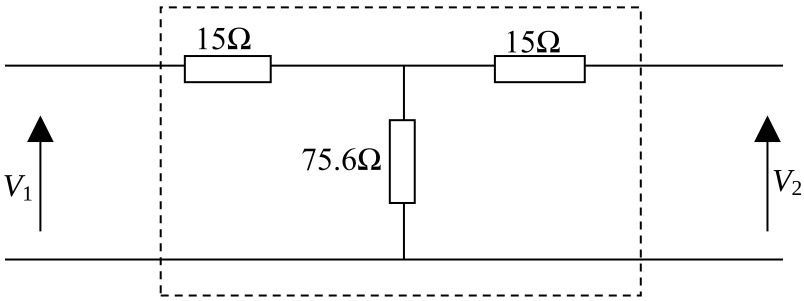


Figure 1

(6)

d. An amplifier has the following scattering and noise parameters

F [GHz]	S_{11}	S_{21}	S_{12}	S_{22}
4.0	$0.6\angle -60°$	$1.9\angle 81°$	$0.05\angle 26°$	$0.5\angle -60°$

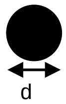
$Z_o = 50\Omega$ $R_N = 20\Omega$ $NF_{min} = 1.6dB$ $\Gamma_{opt} = 0.62\angle 100°$

Design an amplifier having a noise figure of 2 dB with the maximum gain that is compatible with this noise figure. **(8)**

Supplementary information

Inductance estimations

Self inductance of a wire length, l (cm), diameter, d(cm)

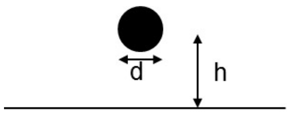


$$L = 2l\left(\ln\left(\frac{4l}{d}\right) - 0.75\right) nH$$

Self inductance of a return circuit of length, l(cm), diameter, d(cm) and distance apart, D(cm) for D/l<<1

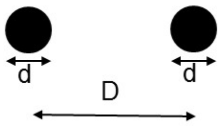
$$L = 4l\left(\ln\left(\frac{2D}{d}\right) - D/l + 0.25\right) nH$$

Self inductance of a wire length, l (cm), diameter, d(cm), a height, h(cm), above a ground plane carrying the return current



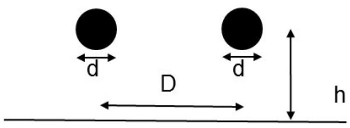
$$L = 2l\ln\left(\frac{4h}{d}\right) nH$$

Mutual inductance between two wires length, l (cm), distance apart, D(cm), for D/l<<1



$$M = 2l\left(\ln\left(\frac{2l}{D}\right) - 1 + D/l\right) nH$$

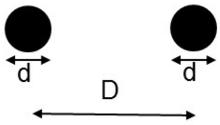
Mutual inductance between two parallel wires length, l(cm), spaced, D(cm) apart height, h(cm) above a ground plane carrying its return current.



$$M = l\ln\left(1 + \left(\frac{2h}{D}\right)^2\right) nH$$

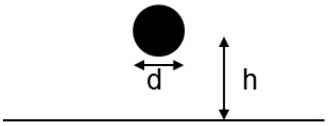
Capacitance estimations

Capacitance between two parallel wires of length, l(cm), diameter, d(cm), separated by, D(cm)



$$C = \frac{0.0885\pi l}{\cosh^{-1}\left(\frac{D}{d}\right)}\, pF$$

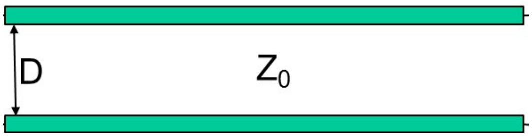
Capacitance between a wire of length, l(cm), diameter, d(cm), height, h(cm) above a conducting surface



$$C = \frac{2*0.0885\pi l}{\cosh^{-1}\left(\frac{2h}{d}\right)}\, pF$$

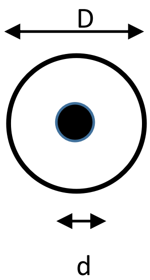
Characteristic impedance

The characteristic impedance of two cylindrical wires, diameter d(cm) spaced, D(cm) apart.



$$Z_0 = 120\ln\left(\frac{2D}{d}\right)\Omega$$

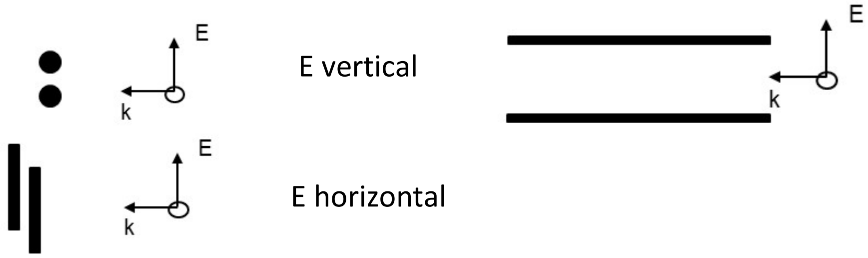
The characteristic impedance of a coaxial cable of inner conductor diameter, d(cm), and outer conductor diameter, D(cm)



$$Z_0 = \frac{138}{\sqrt{\varepsilon_r}}\log\left(\frac{D}{d}\right)$$

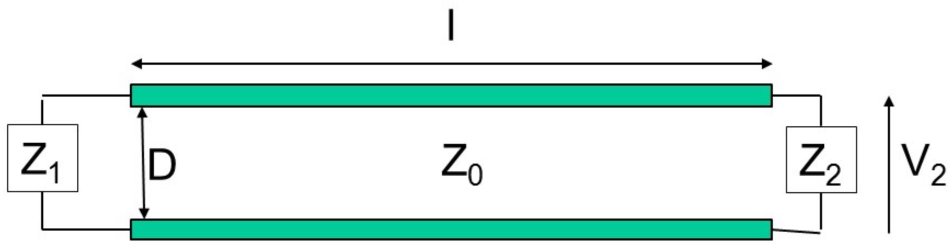
Plane wave to transmission line coupling

For a two wire transmission line, with the E-field and propagation direction shown below, the induced voltage across Z_2 is given by the equations below (assuming plane wave illumination). D(m) is the vertical wire separation, l(m) is the length of the cables



Propagating towards the line

Propagating along the line



$$\frac{V_2}{E} = \frac{Z_2 D\left(Z_0\left[1-\cos(\beta l)\right] + jZ_1\sin(\beta l)\right)}{(Z_0Z_1 + Z_0Z_2)\cos(\beta l) - j\left(Z_0^2 + Z_1Z_2\right)\sin(\beta l)}$$

E vertical, travelling towards the line

$$\frac{V_2}{E} = \frac{Z_2 D(Z_0 - Z_1)\left[\left(1-\cos(2\beta l) + j\sin(2\beta l)\right)\right]}{2(Z_0Z_1 + Z_0Z_2)\cos(\beta l) - j\left(Z_0^2 + Z_1Z_2\right)\sin(\beta l)}$$

E vertical, travelling along the line

$$\frac{V_2}{E} = \frac{Z_2\left[-2j\sin\left(\frac{\beta D}{2}\right)\left[Z_0\sin(\beta l) + jZ_1\left(1-\cos(\beta l)\right)\right]\right]}{\beta(Z_0Z_1 + Z_0Z_2)\cos(\beta l) - j\left(Z_0^2 + Z_1Z_2\right)\sin(\beta l)}$$

E horizontal, travelling towards the line

$$\beta = \frac{2\pi}{\lambda} = \frac{2\pi f}{c}$$

λ is the wavelength

Fourier series

For a periodic waveform the Fourier series is given by

$$f(t) = A_o + \sum_{n=1}^{\infty}\left(A_n \cos\omega_n t + B_n \sin\omega_n t\right)$$

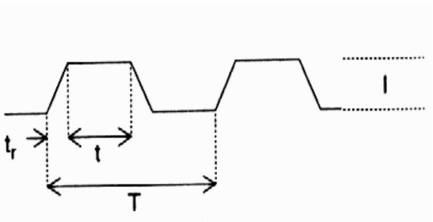
where

$$A_o = \frac{1}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} f(t)dt$$

$$A_n = \frac{2}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} f(t)\cos\omega_n t\, dt$$

$$B_n = \frac{2}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} f(t)\sin\omega_n t\, dt$$

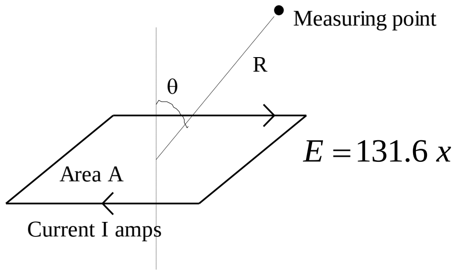
For a trapezoidal waveform of amplitude I the envelope of the frequency spectrum is given below



$$I(n) = 2I\left(\frac{(t+t_r)}{T}\right)\left(\frac{\sin n\pi\left(\frac{(t+t_r)}{T}\right)}{n\pi\left(\frac{(t+t_r)}{T}\right)}\right)\left(\frac{\sin n\pi\left(\frac{t_r}{T}\right)}{n\pi\left(\frac{t_r}{T}\right)}\right)$$

Radiated emissions

The radiation from an electrically short loop is given by



$$E = 131.6\ x10^{-16}\frac{\left(f^2 A I\right)}{R}\sin\theta \quad volts/m$$

The radiation from an electrically short monopole above a large ground plane is

$$E = 4\pi.10^{-7}.\frac{\left(f.L.I_{CM}\right)}{R}\sin(\theta) \quad V/m$$

The electric field a distance, R, away from a radiating source, where P_t is the transmitting power and $D_t(\theta,\phi)$ is the angular dependent directivity, is given by.

$$E = \frac{1}{R}\sqrt{30P_t D_t\left(\theta,\phi\right)}$$

Screening/Shielding

For a shield of thickness, d(m), frequency, f(Hz), conductivity, σ (S/m), and permeability μ. The Shielding Effectiveness (SE), in dB, can be calculated using the following equations.

$$SE = A + R + B$$

Absorption loss $$A = 8.69\left(\frac{d}{\delta}\right) \qquad \delta = \frac{1}{\sqrt{\pi.f.\mu.\sigma}}$$

Reflection loss

Plane wave source $$R = 168 - 10.\log_{10}\left(\left(\frac{\mu_r}{\sigma_r}\right).f\right)$$

E-field source $$R = 322 - 10.\log_{10}\left(\left(\frac{\mu_r}{\sigma_r}\right).f^3 r^2\right)$$

H-field source $$R = 14.6 - 10.\log_{10}\left(\left(\frac{\mu_r}{\sigma_r}\right).f^{-1} r^2\right)$$

Multiple reflection loss $$B = 20.\log_{10}\left(1 - e^{-2\sqrt{2}(d/\delta)}\right)$$

You may find the following information useful:

The constant gain and noise figure circles can be plotted using the following set of equations

$$C_S = \frac{g_S S_{11}^*}{1-(1-g_S)|S_{11}|^2}$$

$$r_S = \frac{\sqrt{1-g_S}\,(1-|S_{11}|^2)}{1-(1-g_S)|S_{11}|^2}$$

$$C_{NF} = \frac{\Gamma_{opt}}{(N+1)}$$

$$r_{NF} = \frac{\sqrt{N(N+1-|\Gamma_{opt}|^2)}}{(N+1)}$$

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