The University Of Sheffield.

**Data Provided: Supplementary information at end of paper**

**Smith Chart provided with paper**

**DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING**

**Spring Semester 2015-16 (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.** Fig Q1a illustrates a EMC scenario where the source of interference is a circuit placed on a non-conductive table. The source consists of a square wave current source connected to a metallic loop, as shown in Figure Q1b. The current varies from 0A to 1A at a frequency of 50MHz.

A victim circuit, also on a non-conducting table, is 3m away from the source, Figure Q1a. The victim circuit consists of two impedances, $Z_1$ and $Z_2$, connected by a pair of cylindrical wires of diameter, d=1mm. The wires are 50 cm long and are separated by 1cm and can be assumed to be parallel to each other, Figure Q1b.

Assumptions:

- The victim circuit is susceptible to interference over the frequency range 130MHz-170MHz.
- Reflections from the ground can be ignored.
- The electric field produced by the source is parallel to the victim circuit.

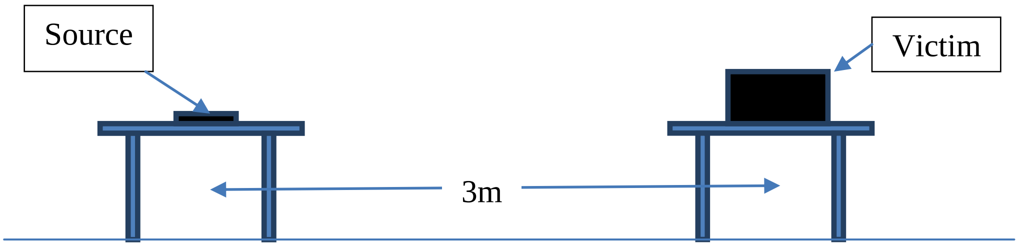
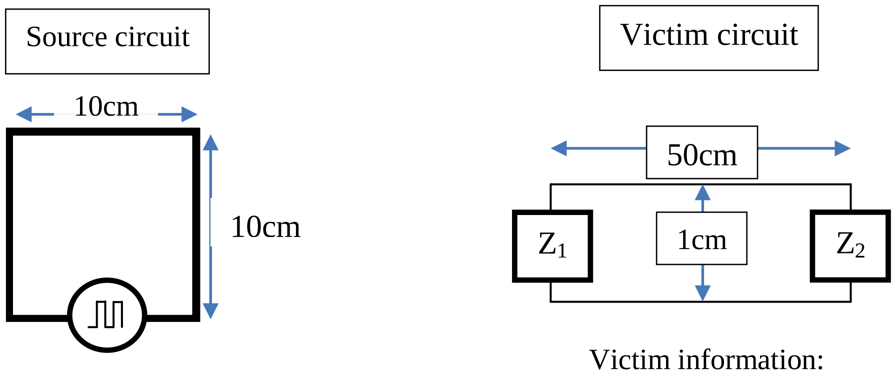



Figure Q1a: EMC scenario




Source information:

Current =0-1A

50MHz square wave

Victim information:

$Z_1$=1MΩ

$Z_2$=10Ω

Wire diameter =1mm

E-Field is parallel to wires

Figure Q1b: Source and victim circuits and information

**a.**

i. Using Fourier analysis calculate the magnitude of the current flowing in the source circuit at the frequency which could cause interference to the victim.

ii. Calculate the magnitude of the electric field at the victim circuit at the frequency which could cause interference to the victim. **(15)**

iii. Calculate the magnitude of the induced voltage across $Z_2$ at the frequency which could cause interference to the victim

**b.** A solution to reducing the interference is to place a metallic shield around the victim. If the required shielding effectiveness is 110dB calculate the minimum shield thickness required assuming the shield is manufactured from aluminium. ($\mu_r$=1, $\sigma_r$=0.6, $\mu_0$=4$\pi$*10$^{-7}$, $\sigma_{cu}$=5.8*10$^{7}$) **(5)**

**2.** Figure Q2 shows the equivalent circuit of two systems where capacitive coupling is occurring. The first system (1) is a high frequency 2-way digital communications link where the source and load of the system are connected by a cylindrical wire of diameter 1mm, spaced 3mm above a ground plane which carries the return current.

The second system (2) consists of a low voltage sinusoidal voltage source connected to an amplifier. The two elements of system 2 are also connected by a cylindrical wire of diameter 1mm spaced 3mm above the ground plane.

The wires of the two systems are separated by 4mm and are 10cm long.

The parameters of the two systems are shown below. Assume inductive coupling can be ignored.

System 1:

- Port one impedance, $R_{S1} = 100\ \Omega$
- Port two impedance, $R_{L1} = 100\ \Omega$
- Voltage waveform: Square wave
- Minimum voltage = 0V
- Maximum voltage = 5V
- Communication data rate = 100Mbit/s
- Assume the probability of a 0V or 5V is equal (i.e. periodic waveform)

System 2:

- Voltage supply resistance, $R_{S2} = 100\ \Omega$
- Amplifier resistance, $R_{L2} = 1\text{M}\ \Omega$
- Assume amplifier is only susceptible to signals with a frequency of 250MHz

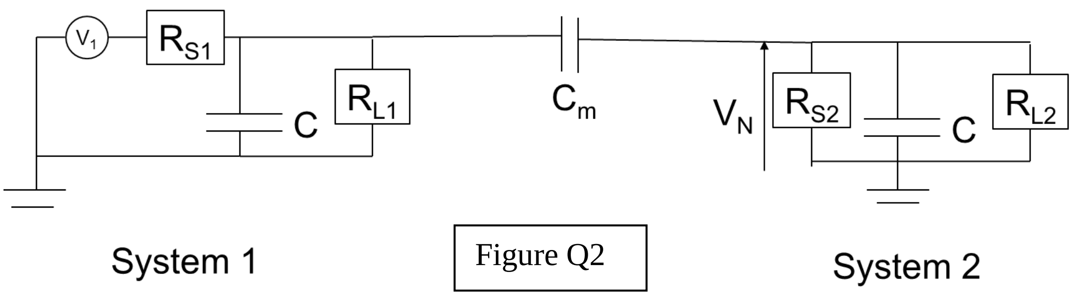



Figure Q2

**a.** Show that the noise voltage $V_N$ is given by the equation below. Assume weak coupling between the two systems and the impedance due to the self capacitance is much higher than the resistance of the systems. **(8)**

$$V_N(\omega) = \frac{R_{L1}}{R_{S1}+R_{L1}} \frac{j\omega\left[\dfrac{C_m}{C_m+C}\right]}{j\omega + \dfrac{R_{S2}+R_{L2}}{R_{S2}R_{L2}(C_m+C)}} V_1(\omega)$$

**b.**
i. Calculate the mutual capacitance, $C_m$, and self capacitance, C.
ii. Using Fourier analysis calculate the source voltage at 250MHz.
iii. Calculate the induced noise voltage across the load, $R_{L2}$, of system 2. **(7)**

**c.** To reduce the EMI at the amplifier a $2^{nd}$ order low pass filter consisting of an inductor and capacitor is used.

i. Sketch a circuit diagram of the filter
ii. If the capacitance of the filter is 5pF what inductance is required to reduce the interference by 40dB? **(5)**

**3. a.** Explain the advantages of using the Smith Chart in network analysis. **(4)**

**b.** A lossless transmission line with a length of 5cm and a characteristic impedance of 50Ω is terminated with a complex load impedance of (80+j30) Ω at a frequency of 1GHz. Use the required transmission line equations to calculate the input impedance, reflection coefficient, insertions and return losses. **(4)**

**c.** A lossless quarter wavelength transformer with Zo=75Ω is terminated by a load impedance of $Z_L$=100Ω. Calculate the impedance and voltage at the sending end when the voltage at the receiving end is 60V. **(5)**

**d.** Using diagrams as necessary, explain how to devise an equivalent circuit of a high frequency inductor. Describe the performance of the inductor as the frequency increases. **(7)**

**4. a.** Explain the difference between the input reflection coefficient and the S11 scattering parameter in a two ports network. **(3)**

**b.** Explain what is meant by internal noise and how it can be generated. Describe the differences between different types of internal noise. **(4)**

**c.** Explain with the aid of diagrams how the Miller's theorem can be used to simplify the equivalent circuit of a high frequency BJT. **(5)**

**d.** Design an amplifier to have a gain of 10dB at 6GHz using a transistor with the following S parameters (Zo=50Ω): S11 = $0.61\angle -70°$, S21 = $2.24\angle 32°$, S12 = 0, S22 = $0.72\angle -83°$. Plot, and use, constant gain circles for Gs=0.5dB, Gs=1.5dB, GL=1.5dB, and GL=2.5dB, where Gs and GL have their usual meanings. **(8)**

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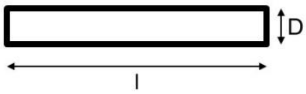
# Supplementary information for EEE6220

## Inductance estimations

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

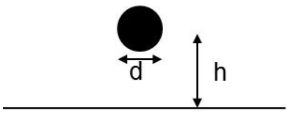

$$L = 2l\left(\ln\left(\frac{4l}{d}\right) - 0.75\right)nH$$

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



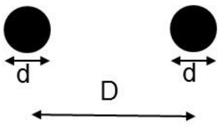

$$L = 4l\left(\ln\left(\frac{2D}{d}\right) - D/l + 0.25\right)nH$$

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



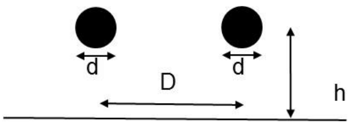

$$L = 2l\ln\left(\frac{4h}{d}\right)nH$$

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




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

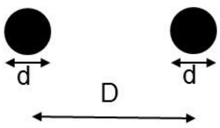
Mutual inductance between two parallel wires length, l(cm), spaced, D(cm) apart height, h(cm) above a ground plane carrying its return current.




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

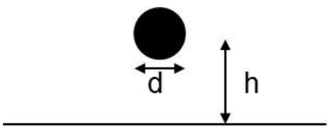
## Capacitance estimations

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




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

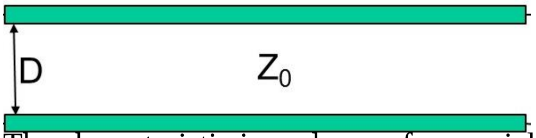
Capacitance between a wire of length, l(cm), diameter, d(cm), height, h(cm) above a conducting surface




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

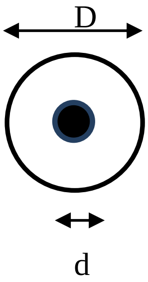
## Characteristic impedance

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




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

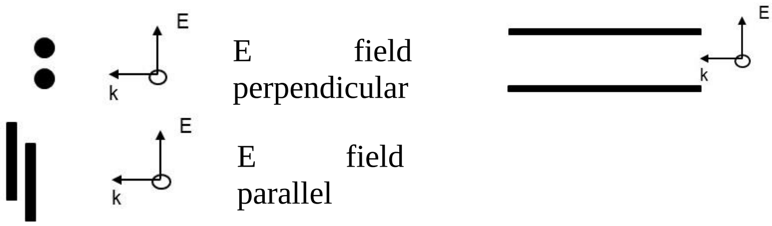
The characteristic impedance of a coaxial cable of inner conductor diameter, d(cm), and outer conductor diameter, D(cm)




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

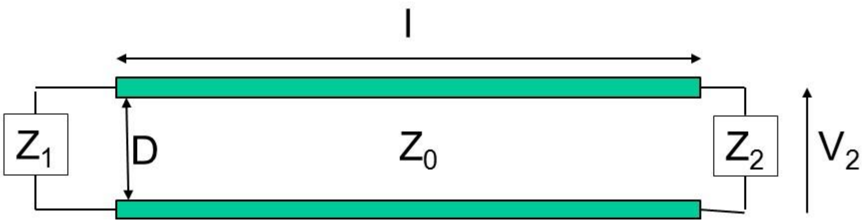
## Plane wave to transmission line coupling

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




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

E perpendicular, travelling towards the line

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

E perpendicular, travelling along the line

$$\frac{V_2}{E} = \frac{-2jZ_2\sin\left(\frac{\beta D}{2}\right)\left[Z_0\sin(\beta l) + jZ_1\left(1-\cos(\beta l)\right)\right]}{\beta\left[\left(Z_0Z_1 + Z_1Z_2\right)\cos(\beta l) - j\left(Z_0^2 + Z_1Z_2\right)\sin(\beta l)\right]}$$

E parallel, travelling towards the line

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

## Fourier series

For a periodic waveform the Fourier series is given by

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

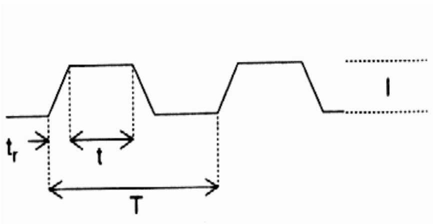
*where*

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

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

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

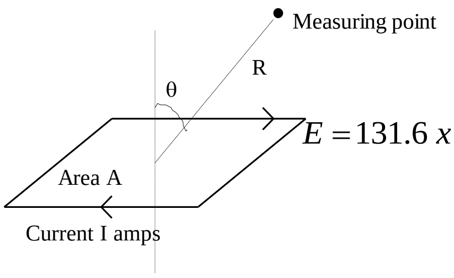
For a trapezoidal waveform of amplitude I the envelope of the frequency spectrum is given below




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

## Radiated emissions

The radiation from an electrically short loop is given by




$$E = 131.6 \, x 10^{-16} \frac{\left( f^2 A I \right)}{R} \sin\theta \quad volts/m$$

where f (Hz) is the frequency, A ($m^2$) is the area of the loop, I(A) is the sinusoidal time varying current flowing in the loop, R(m) is the distance from the centre of the loop of the measurement point and θ(radians) is the angle from the vertical axis.

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

$$E = 4\pi * 10^{-7} \frac{fLI}{R} \sin(\theta) \quad \text{V/m}$$

where f (Hz) is the frequency, L(m) is the length of the monopole I(A) is the common mode current flowing in the monopole, R(m) is the distance from the centre of the loop of the measurement point and θ(radians) is the angle from the vertical axis.

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

$$E = \frac{1}{R}\sqrt{30 P_t D_t(\theta,\phi)} \quad \text{V/m}$$

## Screening/Shielding

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

$$SE = A + R + B$$

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

*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

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

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

$$C_L = \frac{g_L S_{22}^*}{1-(1-g_L)|S_{22}|^2}$$

$$r_L = \frac{\sqrt{1-g_L}\,(1-|S_{22}|^2)}{1-(1-g_L)|S_{22}|^2}$$

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