NATIONAL UNIVERSITY OF SINGAPORE

EXAMINATION FOR

(Semester II : 2020/2021)

EE5801 – ELECTROMAGNETIC COMPATIBILITY

April/May 2021 - Time Allowed: 2 Hours

INSTRUCTIONS TO CANDIDATES

1. This paper contains **FOUR (4)** questions and comprises **FIVE (5)** printed pages including this cover page.

2. Candidates are required to answer all **FOUR (4)** questions.

3. All questions carry equal marks.

4. This is a **CLOSED BOOK** examination with authorized materials only. Allowed to bring in one A4 size help sheet."

5. Take: $\mu_0 = 4\pi \times 10^{-7}$ H/m
   $\varepsilon_0 = 8.852 \times 10^{-12}$ F/m
   c : velocity of light $= 3 \times 10^{8}$ m/s
   η_0 : free space intrinsic impedance $= 120\pi\ \Omega$
   k = Boltzmann's constant = 1.38×10^{-23} J/K

6. Smith Charts are available on request.

7. All symbols not specifically defined in this examination paper carry their normally accepted meanings.

	Any Medium	Lossless Medium ($\sigma = 0$)	Low-loss Medium ($\varepsilon''/\varepsilon' \ll 1$)	Good Conductor ($\varepsilon''/\varepsilon' \gg 1$)	Units
$\alpha =$	$\omega\left[\frac{\mu\varepsilon'}{2}\left[\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}-1\right]\right]^{1/2}$	0	$\frac{\sigma}{2}\sqrt{\frac{\mu}{\varepsilon}}$	$\sqrt{\pi f \mu \sigma}$	(Np/m)
$\beta =$	$\omega\left[\frac{\mu\varepsilon'}{2}\left[\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}+1\right]\right]^{1/2}$	$\omega\sqrt{\mu\varepsilon}$	$\omega\sqrt{\mu\varepsilon}$	$\sqrt{\pi f \mu \sigma}$	(rad/m)
$\eta_c =$	$\sqrt{\frac{\mu}{\varepsilon'}}\left(1-j\frac{\varepsilon''}{\varepsilon'}\right)^{-1/2}$	$\sqrt{\frac{\mu}{\varepsilon}}$	$\sqrt{\frac{\mu}{\varepsilon}}$	$(1+j)\frac{\alpha}{\sigma}$	(Ω)
$u_p =$	ω/β	$1/\sqrt{\mu\varepsilon}$	$1/\sqrt{\mu\varepsilon}$	$\sqrt{4\pi f/\mu\sigma}$	(m/s)
$\lambda =$	$2\pi/\beta = u_p/f$	u_p/f	u_p/f	u_p/f	(m)

Notes: $\varepsilon' = \varepsilon$; $\varepsilon'' = \sigma/\omega$; in free space, $\varepsilon = \varepsilon_0$, $\mu = \mu_0$; in practice, a material is considered a low-loss medium if $\varepsilon''/\varepsilon' = \sigma/\omega\varepsilon < 0.01$ and a good conducting medium if $\varepsilon''/\varepsilon' > 100$.

Q.1 (a) Discuss the various issues associated with EMI shielding at very low frequencies (kHz and below) and very high frequencies (GHz and above).

(10 marks)

(b) Discuss the various issues associated with cable-to-cable coupling in EMI management.

(10 marks)

(c) Explain why grounding strip is better than grounding wire. Furthermore, why should grounding strip be as short as practicable?

(5 marks)

Q.2 (a) What are the five lowest resonant modes and frequencies of a metal box of dimensions 0.5m x 0.3m x 0.2m.

(5 marks)

(b) A rectangular hole of dimensions 0.5m x 0.2m is needed on a solid metallic shield box for ventilation purposes. Assuming that the box wall has thickness of 3mm, find the degradation in shielding efficiency due to the rectangular hole at 150MHz.

(5 marks)

(c) An antenna is transmitting 10W of power at 200MHz. The antenna gain is 6dBi. What would be the peak electric field strength at a distance of 0.5km away from the antenna? Is it easy to estimate the peak electric strength at a distance of 0.5m away from the antenna? If so, what is the value? If not, explain why.

(5 marks)

(d) A switchgear is rated to switch 5kA within 10ms. If the circuit has a ground inductance of 5mH, what would be the value of the ground surge it generates?

(5 marks)

(e) A rectangular loop of dimensions 0.5m x 0.2m is placed at a distance of 1m away from a long straight cable. If the current in the cable is increased from 500 A DC to 2000 A DC in 2 sec, find the maximum induced voltage in the rectangular loop.

(5 marks)

Q.3 (a) A passenger with a cardiac pacemaker is standing at a distance of 5m away from the third rail of a railway system. His cardiac pacemaker has an internal loop area of approximately 2 cm^2. Determine the voltage induced when a train is pulling out from the station and the third rail current is increasing from 500A to 2000A in 2sec.

(5 marks)

(b) The harmonic emission of a power cable is given in Fig. Q3. Find the induced inductive voltage at the third harmonic frequency on a pair of unshielded untwisted communication cable separated at a distance of 10cm. The parameters and equations are given below. The length of cable run is 1km. State all assumptions made.

(20 marks)

Power cable:
Frequency: 50Hz
Rating: 1kVA, 400V
Source impedance = 40ohm
Load impedance = 40ohm
Radius of each wire = 2mm
Separation between wires = 12mm

Communication cable:
Source impedance = 75ohm
Load impedance = 600ohm
Radius of each wire = 0.5mm
Separation between wires = 3mm

Inductive coupling:

$$V_V = V_C \frac{Z_{V2}(j\omega L_{CV}\ell)}{(Z_{V1} + Z_{V2} + j\omega L_V \ell)Z_{C2}}$$

$$L_{CV} = \frac{\mu_r \mu_o}{2\pi} \ln\left(\frac{D_{14} D_{23}}{D_{13} D_{24}}\right) H/m$$

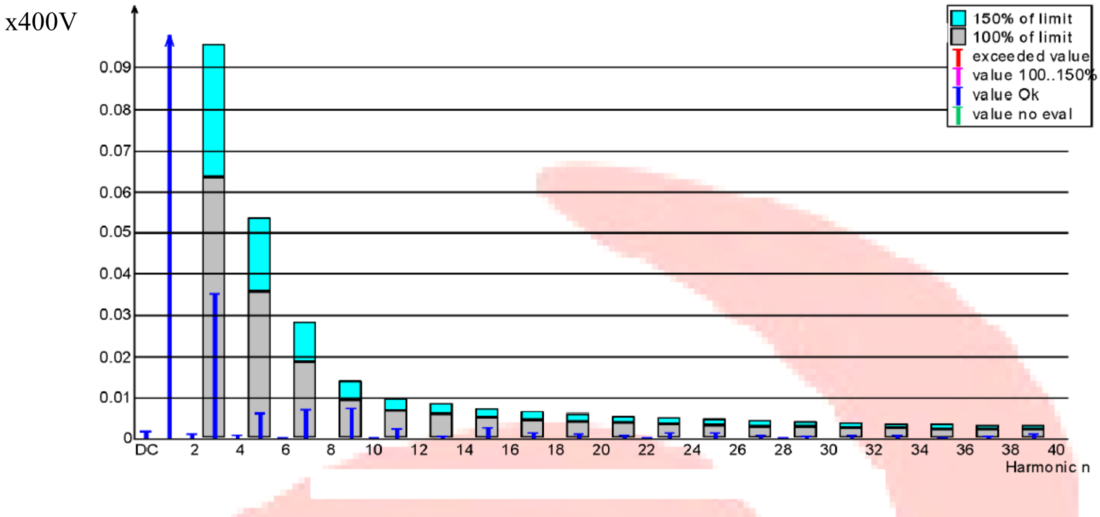

Fig. Q3

Q.4 The shielding efficiency of a solid shielding material arranged as in Fig. Q4 is given as: $\tau_1\tau_2 e^{-\gamma t}/(1 - e^{-2\gamma t}\Gamma_2^2)$, where τ_1 is the transmission coefficient at the first interface (between material 1 and material 2), τ_2 is the transmission coefficient at the second interface (between material 2 and material 3), Γ_2 is the reflection coefficient at the second interface, t is the thickness of material 2, and γ is the complex propagation constant of material 2.

Material 1 is air. However, the source is a 1MHz low-impedance source located 0.1m away from the interface. The wave impedance of a low-impedance source is given as: $240\pi^2(r/\lambda_o)e^{-j\pi/2}$ ohm, where r is the distance of the source to the interface, λ_o is the free space wavelength of the source. Material 2 is a conductive material with $\varepsilon = \varepsilon_o$, σ = 10S/m. Material 3 is air.

Find the required thickness t of material 2 in order to achieve a 30dB shielding efficiency.

(25 marks)

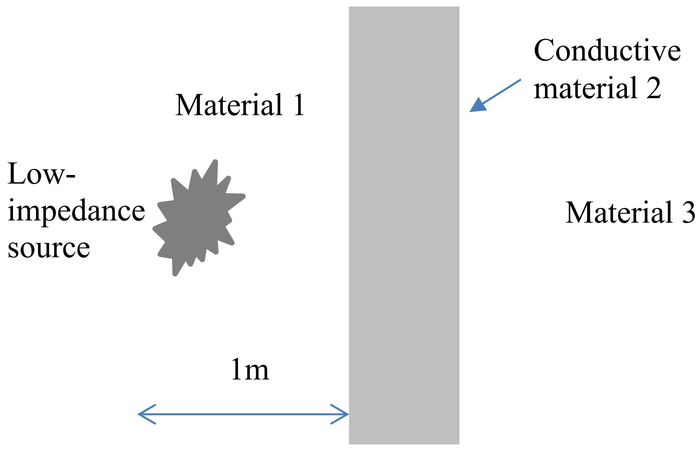

Fig. Q4

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