NATIONAL UNIVERSITY OF SINGAPORE

EXAMINATION FOR

(Semester II : 2019/2020)

EE5801 – ELECTROMAGNETIC COMPATIBILITY

April/May 2020 - Time Allowed: 2 Hours

INSTRUCTIONS TO CANDIDATES

1. This paper contains **FOUR (4)** questions and comprises **NINE (9)** 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 respective merits and demerits of the three structures of ventilation holes shown in Figs. Q1.1 – Q1.3.

(10 marks)

Fig. Q1.1

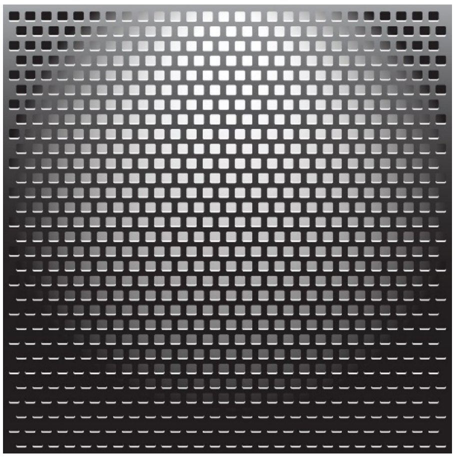

Fig. Q1.2

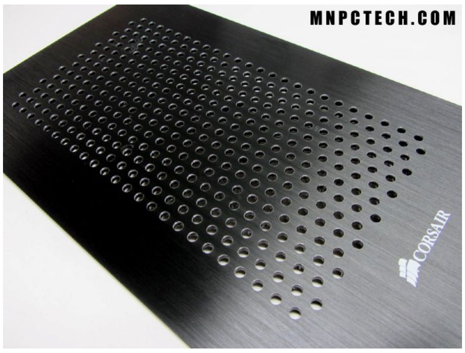

Fig. Q1.3

(b) Discuss the performances (in terms of directivity, radiation pattern, and side lobes) and also their likely applications of the three antennas shown in Figs. Q1.3 – Q1.6.

(10 marks)

Fig. Q1.4

Fig. Q1.5

Fig. Q1.6

Q.2 (a) Explain why grounding strip is better than grounding wire. Furthermore, why should grounding strip be as short as practicable?

(5 marks)

(b) A switchgear is rated to switch 5kA within 50ms. If the circuit has a ground inductance of 2mH, what would be the value of the ground surge it generates?

(5 marks)

(c) An antenna is transmitting 10W of power at 300MHz. The antenna gain is 10dB. What would be the peak electric field strength at a distance of 1km away from the antenna? Is it easy to estimate the peak electric strength at a distance of 1m away from the antenna? If so, what is the value? If not, explain why.

(5 marks)

(d) What is the lowest resonant frequency of a metallic box having dimensions 3m x 2m x 1m?

(5 marks)

(e) 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 5mm, find the degradation in shielding efficiency due to the rectangular hole at 100MHz.

(5 marks)

Q.3 (a) For a 25kV, 60Hz, 500A electric railway system, estimate the maximum distance between ground points such that the maximum voltage induced on a 1m height metal fence situated at 3m away from the traction current (Fig. Q3.1) is less than 60V. (Hints: Use Ampere's law for flux density, and Faraday's law for induced emf. Loop area = L x height)

(10 marks)

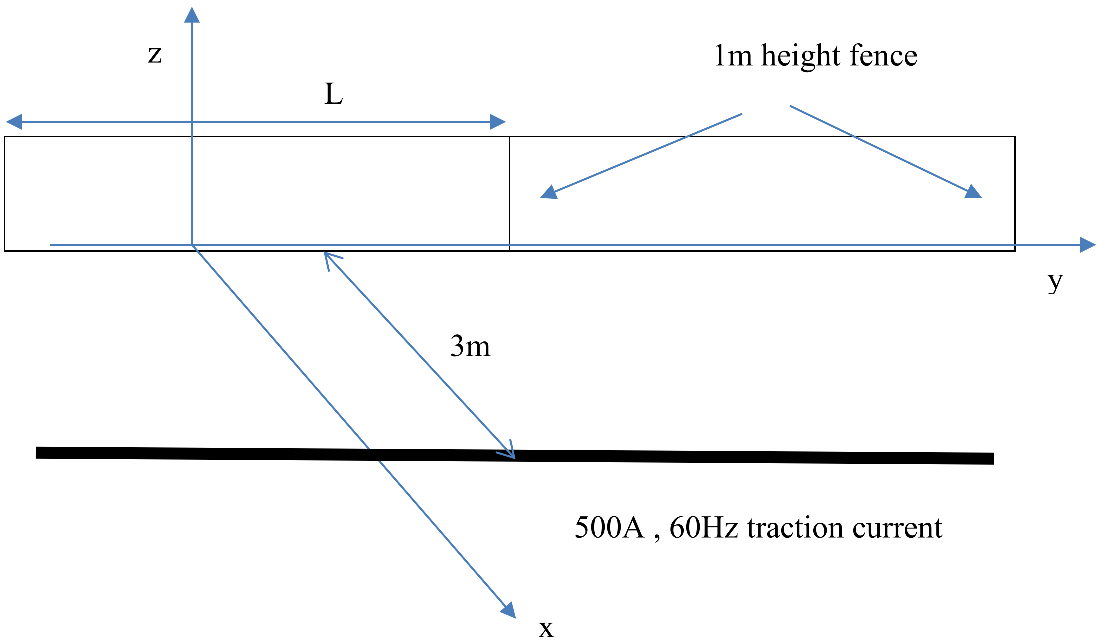

Fig. Q3.1

(b) Find the capacitive couplings between a pair of power cable and a pair of unshielded untwisted communication cable separated at a distance of 4cm. The parameters and equations are given below. The length of cable run is 5km. You may also make use of information given in Fig. Q3.2. State all assumptions made.

(10 marks)

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

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

Capacitive coupling:

$$V_V = V_C \frac{Z_V}{\frac{1}{j\omega C_{CV}\ell} + Z_V}, \qquad \frac{1}{Z_V} = \frac{1}{Z_{V1}} + j\omega C_V \ell + \frac{1}{Z_{V2}}$$

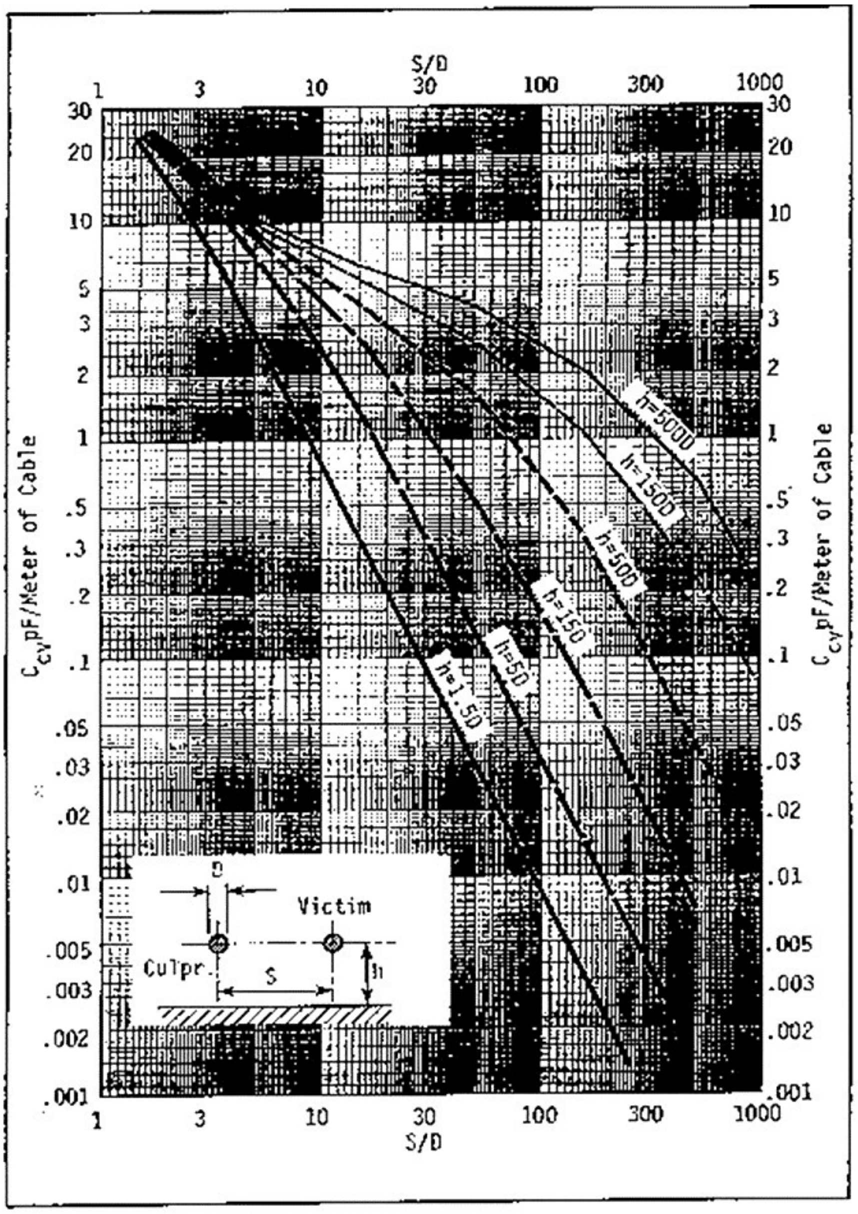

Fig. Q3.2

If the signaling circuit is operating on TTL (Fig. Q3.3), is the current cable arrangement acceptable? Assuming that the culprit voltage may rise when there is a lightning ground surge, what would be the maximum culprit voltage the circuit can tolerate?

(5 marks)

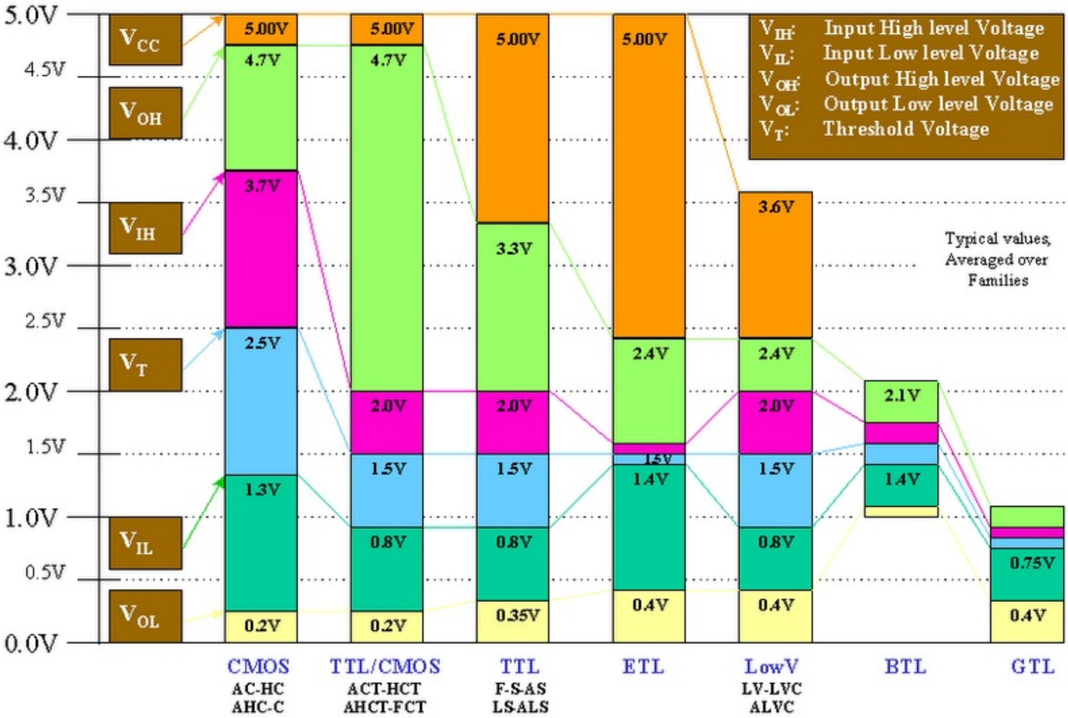

Fig. Q3.3

Q.4 (a) Explain why the plunger shown in Fig. Q4.1 must be of non-conductive material.

(5 marks)

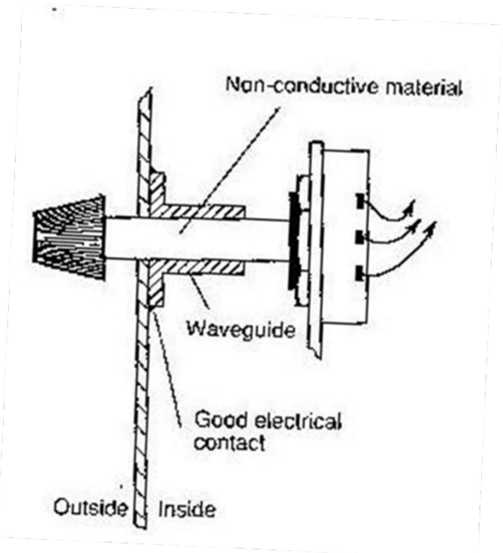

Fig. Q4.1

(b) The shielding efficiency of a solid shielding material arranged as in Fig. Q4.2 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 100kHz low-impedance source located 0.5m 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 $\varepsilon = \varepsilon_o$, $\sigma = 100$S/m.

Material 3 is air.

Find the required thickness t of material 2 in order to achieve a 20dB shielding efficiency.

(20 marks)

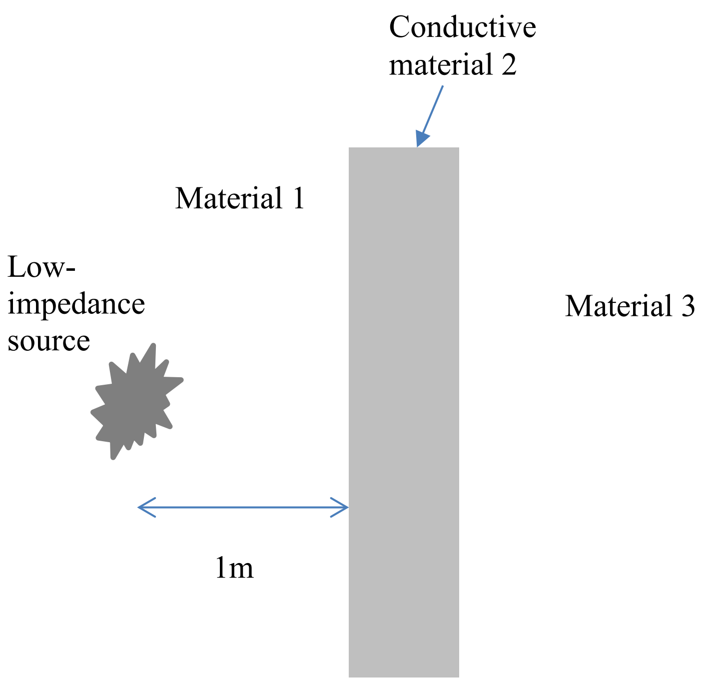

Fig. Q4.2

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