ORIGINAL

NATIONAL UNIVERSITY OF SINGAPORE

EXAMINATION FOR

(Semester II : 2021/2022)

EE5801 – ELECTROMAGNETIC COMPATIBILITY

April/May 2022 - 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. One A4 size help sheet (printed both sides) is allowed.

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 $= 1.38 \times 10^{-23}$ J/K

6. Smith Charts are available on request.

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

8. You may make use of the formulae given in page 2.

	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) For two cables as shown in Fig. Q1(a), show that the magnetic field at a point P(x, 0) is inversely proportional to x^2 and proportional to d, when x >> d. Discuss on its significance.

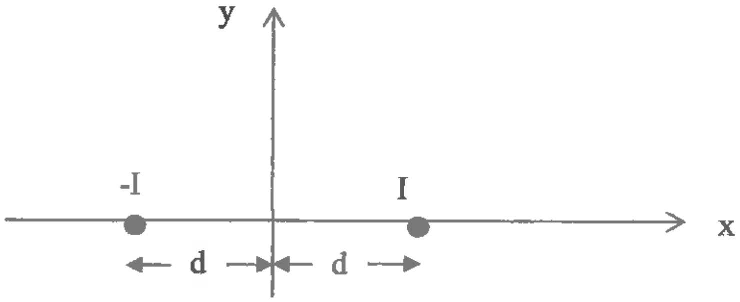

Fig. Q1(a)

(10 marks)

(b) For an aperture on a metallic screen as shown in Fig. Q1(b), a student deduces that the cutoff wavelength is $\lambda_c = 2a = 20$cm. Recalculate the cutoff frequency and cutoff wavelength using the formula below. Are the values the same? Why?

$$k_z^2 + (\frac{m\pi}{a})^2 + (\frac{n\pi}{b})^2 = \omega^2\mu\varepsilon$$

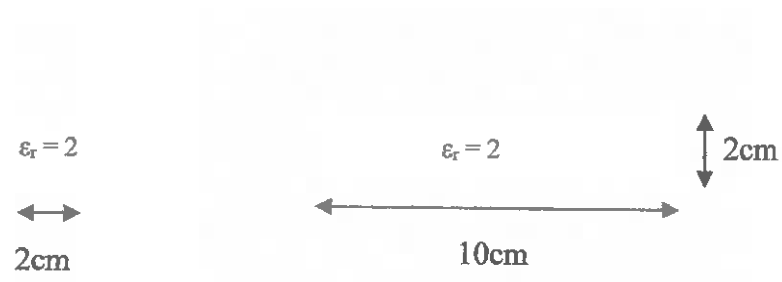

Fig. Q1(b)

(10 marks)

(c) An omnidirectional antenna is radiating a power P in free space. Show that the rms electric field strength at a distance d away is given by

$$E = \frac{\sqrt{30P}}{d}$$

(5 marks)

Q.2 (a) Fig. Q2(a) shows that cavity wall current distribution of a TM_{110} resonance. Sketch the current distribution of a TM_{210} resonance on the top cavity wall, and indicate the positions of one radiating slot and one non-radiating slot

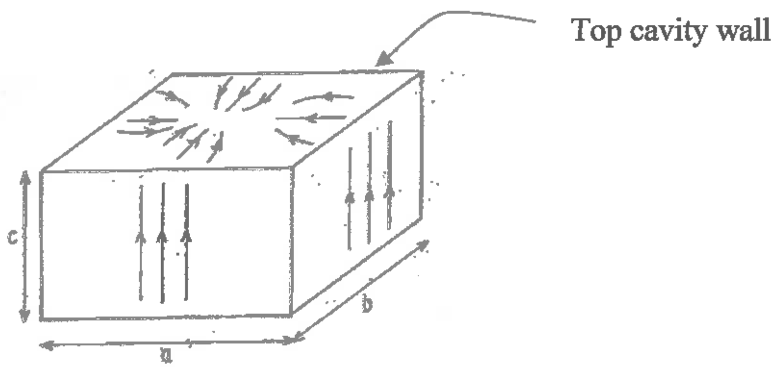

Fig. Q2(a)

(5 marks)

(b) Briefly explain why there is no risk of mobile phone emission inducing significant EMI voltage on a nearby cable.

(5 marks)

(c) Some internationally recommended DC bonding resistances are: (i) for ESD: 1Ω, (ii) for lightning protection: 2.5mΩ, (iii) for RF grounding: 2.5mΩ. Briefly explain the rationales behind these recommendations.

(5 marks)

(d) A equipment is DC-operated and draws its input from a AC/DC converter. Explain why there can still be conducted and radiated EMI from this equipment.

(5 marks)

(e) Briefly explain why it is undesirable to use a receiver bandwidth larger than necessary.

(5 marks)

Q.3 (a) The mutual inductance per unit length of two (equal radii) cables separated by a distance d and at (equal) height h above a ground plane and when 2h >> d:

$$l_m = \frac{\mu_o \mu_r}{4\pi} \ln[1 + \left(\frac{2h}{d}\right)^2]$$

Two cables are buried in earth with the following parameters: conductivity = 10S/m, relative permeability = 1, relative permittivity = 4. Find the induced voltage on the second (telecommunication) cable when a fault occurs at the first (50Hz, 230kV power) cable with a fault current of 63kA. The lengths of the cables are 300m. The cable separation is 1m.

(20 marks)

(b) Discuss on how this induced voltage could be reduced.

(5 marks)

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 10kHz low-impedance source located 0.01m 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 copper with $\varepsilon = \varepsilon_o$, $\sigma = 5.6\text{x}10^7$ S/m. Material 3 is air.

Find the required thickness t of material 2 in order to achieve a 60dB shielding efficiency. Discuss/comment on the result if the source is at 50Hz.

(25 marks)

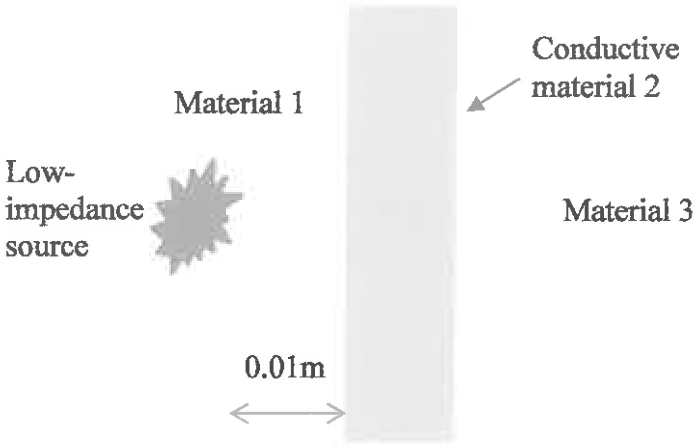

Fig. Q4

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