ORIGINAL

NATIONAL UNIVERSITY OF SINGAPORE

EXAMINATION FOR

(Semester II : 2017/2018)

EE5801 – ELECTROMAGNETIC COMPATIBILITY

April/May 2018 - Time Allowed: 2 Hours

INSTRUCTIONS TO CANDIDATES

1. This paper contains **FOUR (4)** questions and comprises **EIGHT (8)** 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. You are allowed to bring into the examination hall a single A4-size formula sheet filled on both sides with any handwritten material of your choice. You may refer to this sheet during the examination.

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.

	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) A TV transmitter is transmitting 1 kW of RF power at 200 MHz. The transmitting antenna gain is 15 dB. What would be the power output of a 20-dB gain receiving antenna at a distance of 10 km away from the transmitter?

(5 marks)

(b) Two horn antennas, both operating in the same frequency band, have different aperture sizes. Discuss the differences in gains and radiation patterns of these two horn antennas.

(5 marks)

(c) An airport Long Range Radar (LORAD) operating at 3 GHz carrier frequency is transmitting at 100 W via a 30 dB antenna. The transmitted square-wave modulated pulse has a pulse width of 1 μs and Pulse Repetition Frequency (PRF) of 1 kHz. The antenna is revolving at a rate of 2 revolutions per second. What is the peak electric field due to this transmission at a distance of 1 km away?

(5 marks)

Explain why this peak electric field could not be measured using a field strength meter (Fig. 1.1).

(5 marks)

Fig. 1.1 Field strength meter

Explain why is this measurement also could not be easily accomplished with a spectrum analyzer (Fig. 1.2).

(5 marks)

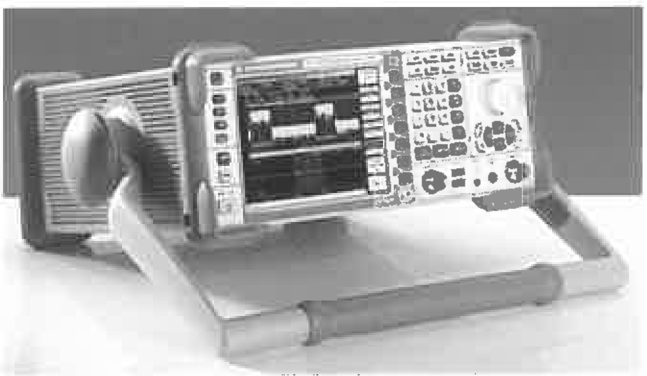


Fig. 1.2 Spectrum analyzer

Q.2 Fig. 2.1 shows a simple PCB trace. At DC, the current flows uniformly across the copper strip (conductivity $\sigma = 5.8\text{x}10^7$) as well as the ground plane. However, as frequencies increases, the current tends to concentrate in the shaded area due to *skin effect*, where skin depth $\delta = 1/\sqrt{(\pi f \mu \sigma)}$. Given that H = 3 mm, w = 2 mm, and the thickness of the trace s = 100 μm:

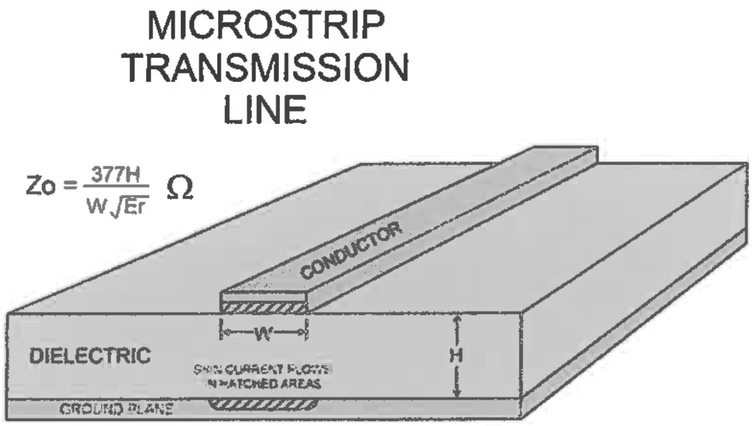


Fig. 2.1

Compute the resistance per unit length of the PCB trace at DC. (2 marks)

Compute the resistance per unit length at 1 GHz. (4 marks)

Comment on the difference and the implication to designer. (2 marks)

Fig. 2.2 shows a pair of PCB traces constructed on the same substrate as in Fig. 2.1, separated by a distance d. It is clear that coupling between traces is common for high-speed digital transmission as illustrated. Estimate the peak induced current on the victim trace due to a 5 volts, 1 GHz digital pulse train (rise time 10 picossecond) propagating on the culprit trace using the simple mutual capacitance model as suggested in Fig. 2.2. The parameters are: H = 3 mm, L = 2 cm, d = 4 mm, s = 100 μm, w = 2 mm, $\varepsilon_r = 2.54$.

(4 marks)

What would the peak induced current be if the mutual capacitance model is modified to replace the trace thickness s by the skin depth δ?

(2 marks)

Why is the modified model more accurate? (2 marks)

Comment on the results. (2 marks)

One common way to reduce the capacitive coupling as shown is to introduce a ground trace in between the two traces as shown in Fig. 3.2. However, a student argues that now the culprit trace is coupled to the victim trace via two series capacitances, C_1 from the culprit to ground trace and C_2 from the ground trace to victim. He further argues that as C_1 and C_2 are much higher than the original capacitance C due to the closer separations between traces, the new coupling capacitance C_{new} would be higher than C, even after taking into account the reduction factor caused by the series connection ($1/C_{new} = 1/C_1 + 1/C_2$). Thus, the arrangement not only does not help, rather, it aggravate the situation. Comment on the student's arguments and point out his mistake/omission, if any.

(5 marks)

Does the ground trace help in reducing the inductive coupling? Explain with justifications.

(2 marks)

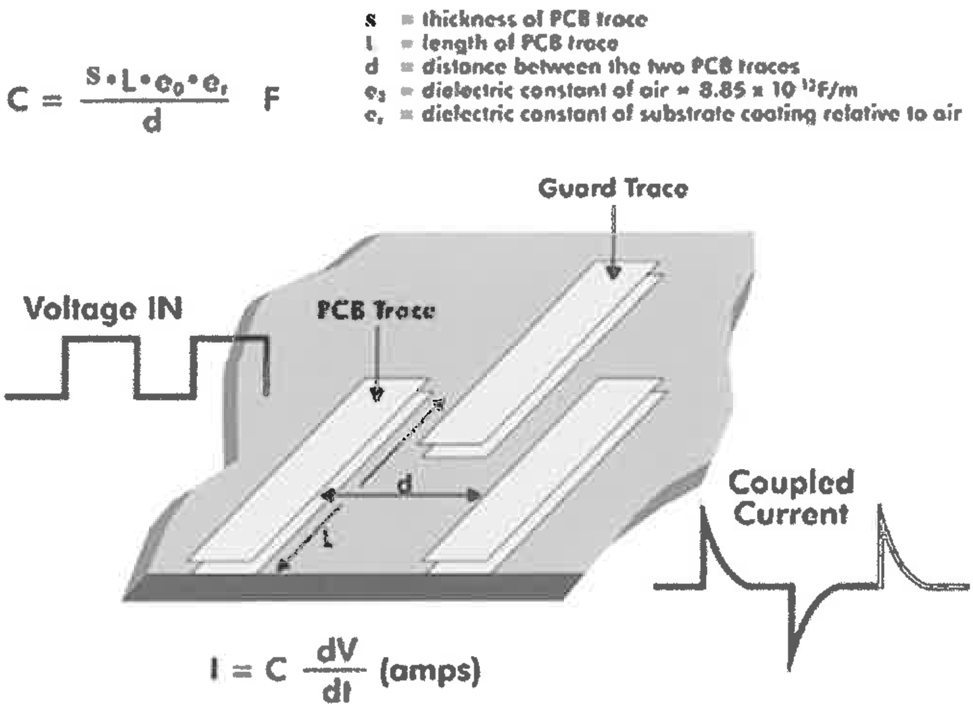


Fig. 2.2

Q.3 Fig. 3.1 shows a portable mobile EMI shielded room made with conductive clothing material X of the following specifications:

Thickness = 2 mm
Relative permeability $\varepsilon_r = 3$
Relative permeability $\mu_r = 1$
The frequency-dependence conductivity is given in Fig. 3.2.

Assuming plane wave incident, estimate the followings at 3 GHz. You may assume that the material is a good conductor and that the skin depth is given by $\delta = 1/\sqrt{(\pi f \mu \sigma)}$.

i) The reflection loss of the material. (10 marks)
ii) The absorption loss of the material. (5 marks)
iii) The shielding effectiveness of the material. (5 marks)

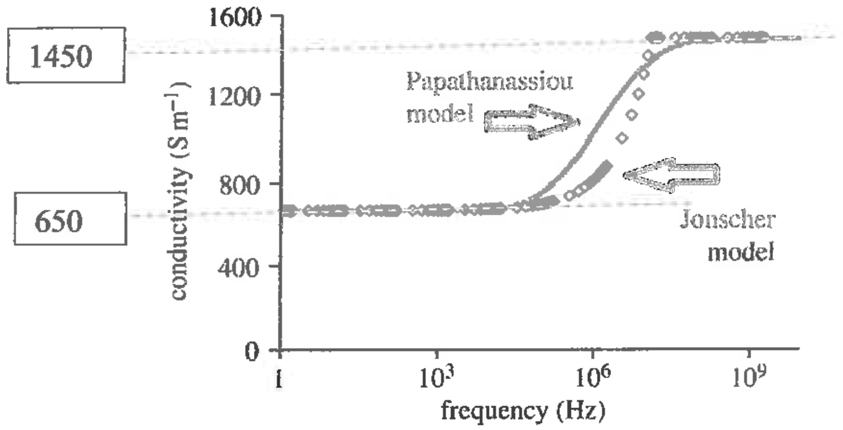
Observing the small difference between the conductivity at 50 Hz (650 S/m) and at 3 GHz (1450 S/m), a student deduced the followings at 50 Hz:

Wave impedance = $7.8 \times 10^{-4} e^{j\pi/4}\ \Omega$
Reflection loss = -107 dB
Absorption loss = 0 dB
Total shielding effectiveness = -107 dB

and concluded that material X is equally good and the shielded room can be used at frequency as low as 50 Hz. Comment on the student's postulation with justifications. (Note: You may assume the student's calculations at 50 Hz are correct and there is no need to re-calculate them.)

(5 marks)

Fig. 3.1



1450
650
1600
1200
800
400
0
conductivity (S m⁻¹)
Papathanassiou model
Jonscher model
1
10³
10⁶
10⁹
frequency (Hz)

Fig. 3.2

Q.4 Fig. 4 shows a metallic shielded box made of copper plates with conductivity = 5.8×10^7, relative permittivity = 1, relative permeability = 1 and thickness = 1 mm. The glass display panel has dimensions of 90 mm x 30 mm x 1 mm, and conductivity = 0, relative permittivity = 2, and relative permeability = 1.

The goal of the shielded box is to provide a 30 dB shielding in the frequency band of 10 MHz to 10 GHz. Is the goal achievable? Explain with justifications.

(5 marks)

What is the upper usable frequency (f_u) for this box? (2 marks)

What is the shielding efficiency at 0.9 f_u? Can it achieve the goal of 30 dB? If not, suggest a method in achieving the 30 dB shielding at $0.9f_u$. You may make use of the following formula, or otherwise:

$$\alpha = \omega_c\sqrt{\mu\varepsilon}\sqrt{1-(\frac{f}{f_c})^2} \qquad for\ f < f_c$$

where α is the attenuation constant, $\omega_c = 2\pi f_c$, and f_c is the cutoff frequency of a wavwguide.

(10 marks)

Suggest a more practical method in extending the usable frequency and achieving the shielding objective. Only a descriptive answer is needed. Detailed design is not needed.

(5 marks)

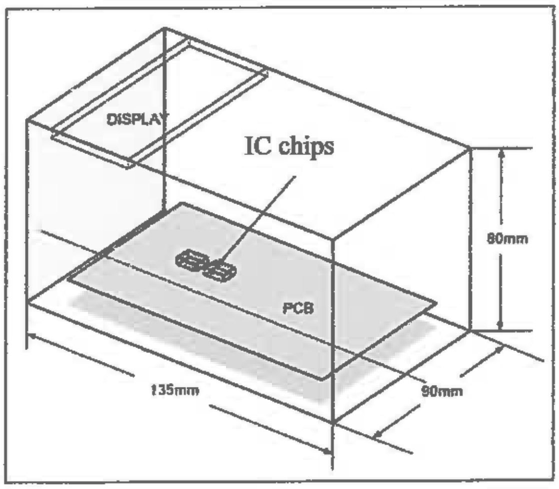


Fig. 4

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