NATIONAL UNIVERSITY OF SINGAPORE

EXAMINATION FOR

(Semester II : 2015/2016)

EE5801 – ELECTROMAGNETIC COMPATIBILITY

April/May 2016 - 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. 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 = 1.38×10^{-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.

Q.1 (a) The SWR of an antenna, measured with a 50 Ω system, is 1.5. What are the possible values of antenna input impedance?

(5 marks)

(b) State the relationship between the third order intercept and 1-dB compression point of an amplifier.

(5 marks)

(c) A student connected the output of an antenna to a receiver via a 10-m length, 3-dB attenuation coaxial cable. The receiver output signal strength he measured is 10 dBm and the noise floor is -40 dBm. The noise figure of the receiver is 4 dB and the gain of the receiver is 20 dB. He thus concludes that the signal output of the antenna is 10 – 20 + 3 = -7 dBm, and that the noise power at the antenna output is -40 – 20 – 3 – 4 = -67 dBm. Is he correct? Explain (no numerical working is needed).

(5 marks)

(d) A transmitter is transmitting 1 kW of RF power at 100 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)

(e) 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)

Q.2 A receiver system is having the following parameters; Central frequency $F = 3$ GHz; Bandwidth $B = 10$ MHz; Receiving antenna gain $G_A = 30$ dB; Antenna efficiency $\eta = 0.9$; Antenna physical temperature $T_p = 300$ K; Antenna background temperature $T_b = 200$ K; Transmission line (connecting antenna to RF front end) loss $L_T = 1.5$ dB; LNA gain $G_{LNA} = 20$ dB; LNA noise figure $F_{LNA} = 1.5$ dB; RF amplifier gain $G_{RF} = 30$ dB; RF amplifier noise figure $F_{RF} = 3$ dB; RF mixer loss $L_M = 6$ dB; IF amplifier gain $G_{IF} = 20$ dB; IF amplifier noise figure $F_{IF} = 3$ dB; Baseband mixer noise figure $L_B = 6$ dB; Baseband amplifier gain $G_{BB} = 30$ dB, Baseband amplifier noise figure $F_{BB} = 3$ dB. Signal output from the antenna $Si = -80$ dBm. Find:

(a) The antenna noise temperature. (5 marks)

(b) The receiver (excluding antenna and transmission line)'s gain. (5 marks)

(c) The receiver (excluding antenna)'s noise temperature. (5 marks)

(d) The total system noise temperature. (5 marks)

(e) The output signal to noise ratio. (5 marks)

Q.3 Fig. 3.1 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 = 2 mm, w = 1 mm, and the thickness of the trace s = 100 μm:

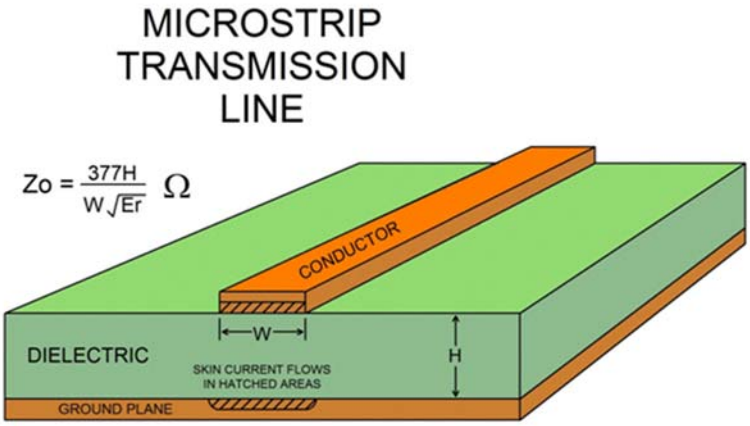

Fig. 3.1

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

Compute the resistance per unit length at 100 MHz (2 marks)

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

Fig. 3.2 shows a pair of PCB traces 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, 100 MHz digital pulse train (rise time 1 ns) propagating on the culprit trace using the simple mutual capacitance model as suggested in Fig. 3.2. The parameters are: H = 2 mm, L = 2 cm, d = 3 mm, s = 100 μm, w = 1 mm, $\varepsilon_r = 2.54$.

(5 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.

(3 marks)

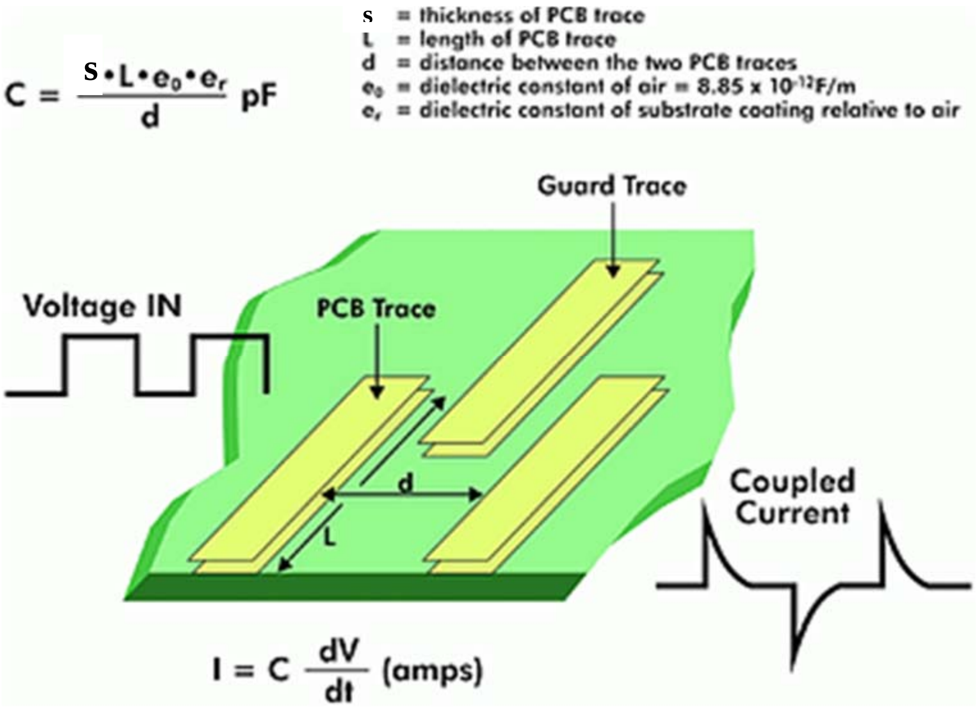

Fig. 3.2

Q.4 Fig. 4.1 shows a portable mobile EMI shielded room made with conductive clothing material X of the following specifications:

Thickness = 3 mm
Relative permeability $\varepsilon_r = 3$
Relative permeability $\mu_r = 1$
The frequency-dependence conductivity is given in Fig. 4.2.

Estimate in dB, at 1 GHz, the followings against plane wave EMI. 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. (5 marks)
ii) The absorption loss of the material. (2 marks)
iii) The shielding effectiveness of the material. (2 marks)

Observing the small difference between the conductivity at 50 Hz (650 S/m) and at 1 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.

(5 marks)

Fig. 4.1

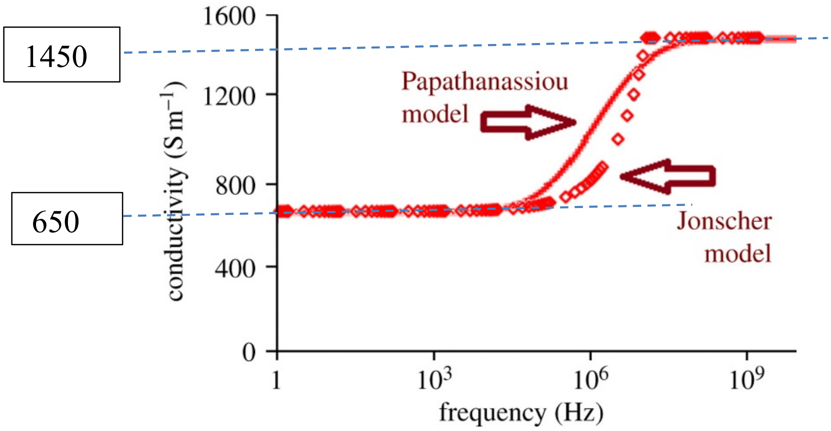

Fig. 4.2

Fig. 4.3 shows a metallic shielded box made of copper plates with conductivity = 5.8 x 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 = 1, and relative permeability = 1.

The goal of the shielded box is to provide a 50 dB shielding in the frequency band of 10 MHz to 10 GHz. Is the goal achievable?

(2 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 50 dB? If not, suggest a method in achieving it.

(5 marks)

Suggest a method in extending the usable frequency. (2 marks)

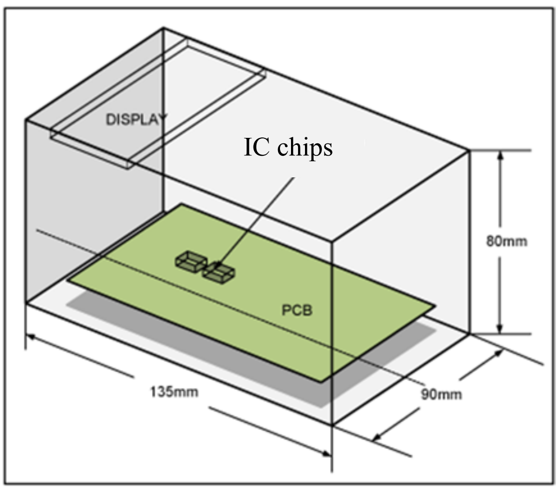

Fig. 4-3

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