Ch5 PCB Design

2018-2019 2.(b)

(b) The output of a driver is connected to the input of a receiver through two parallel signal lines, as shown in Figure 4 on page 4. The signal frequency is 50 MHz; and the differential-mode (DM) and common-mode (CM) signal currents are as indicated.

(i) Calculate the radiated electric field in dBμV/m due to DM signal current at a distance 3 m from the circuit.

(4 Marks)

(ii) Repeat part (i) for CM signal current.

(4 Marks)

(iii) Based on calculated radiated electric fields in parts (i) and (ii), what conclusion can you draw?

(2 Marks)

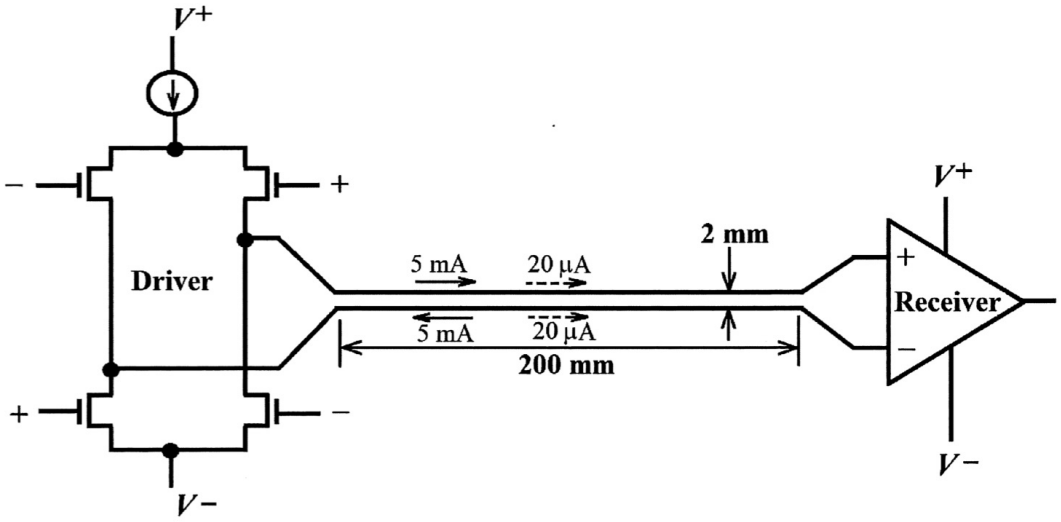


Figure 4

(i) From the figure we can get the loop area is: $A = 0.2m \times 0.002m = 4\times10^{-4} m^2$

Hence the radiated electric field due to DM current is

$$E_{DM} = 2.632\times10^{-14}\left(\frac{f^2 A I_{DM}}{r}\right)$$

$$= 2.632\times10^{-14}\left(\frac{(50\times10^6)^2\times4\times10^{-4}\times5\times10^{-3}}{3m}\right) = 4.387\times10^{-5} V/m = 43.87\,\mu V/m$$

$$= 32.84\ dB\mu V/m$$

(ii) $E_{CM} = 1.26\times10^{-6}\left(\frac{f I_{CM} l}{r}\right) = 1.26\times10^{-6}\left(\frac{50\times10^6\times20\times10^{-6}\times200\times10^{-3}}{3}\right) = 84\,\mu V/m = 38.49\ dB\mu V/m$

(iii) Even common mode current is much lower than DM current, but it produces comparable radiation due to the length of cable

2017 - 2018 3.

3. Figure 4 shows the cross-sectional view of a printed circuit board (PCB) where a clock driver (CD) is powered by a voltage regulator (VR) through the power and ground planes. The substrate between the power and ground planes has relative permittivity $\varepsilon_r = 4.5$ and relative permeability $\mu_r = 1$.

(a) The CD draws its supply current from the VR and the current waveform is shown in Figure 5. Plot the radiated emission spectrum up to 1 GHz from the power delivery path and compare it with the FCC Part 15 Class B limit specified in Table 2. Comment on whether the PCB can be sold in USA's market?

(10 Marks)

(b) If the length and width of the PCB are 15 cm and 10 cm, respectively; what are the expected board resonant frequencies below 1 GHz?

(7 Marks)

(c) What are the harmonics of the current waveform below 1 GHz that may exhibit significant radiated emission due to the board resonance?

(3 Marks)

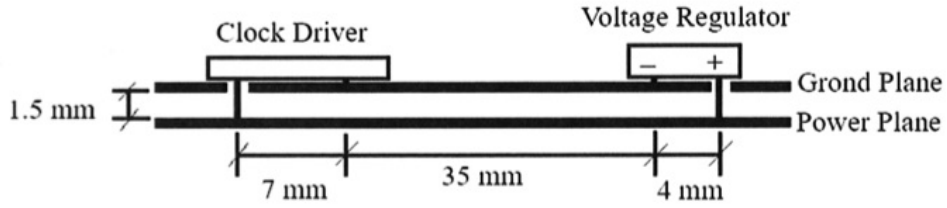


Figure 4

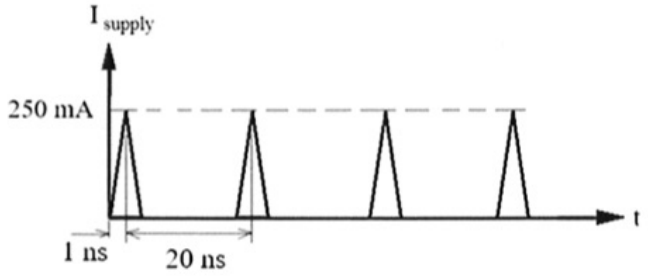


Figure 5

Table 2

Frequency (MHz)	Limit at 3 m (dBμV/m)
30 – 88	40
88 – 216	43.5
216 – 960	46
>960	54

2017-2018 contd.

(a) The fundamental frequency f_1 is : $f_1 = \frac{1}{T} = \frac{1}{20\times10^{-9}} = 50\ MHz$.

$$|I_n| = \frac{2I\tau}{T}\left[\frac{\sin\left(\frac{n\pi\tau}{T}\right)}{\frac{n\pi\tau}{T}}\right]^2$$

$$= \frac{2\times250\times10^{-3}\times1}{20}\left[\frac{\sin(0.157n)}{0.157\cdot n}\right]^2$$

$$= 2.5\times10^{-2}\left[\frac{\sin(0.157n)}{0.157n}\right)^2$$

$$\Rightarrow I_1 = 24.795\ mA$$

The loop area is : $(7+35+4)\times1.5 = 69\times10^{-6}\ m^2$

$$E_{Dm}\ (50MHz\ @3m) = 2.632\times10^{-14}\left(\frac{(50\times10^6)^2\times69\times10^{-6}\times24.795\times10^{-3}}{3}\right)$$

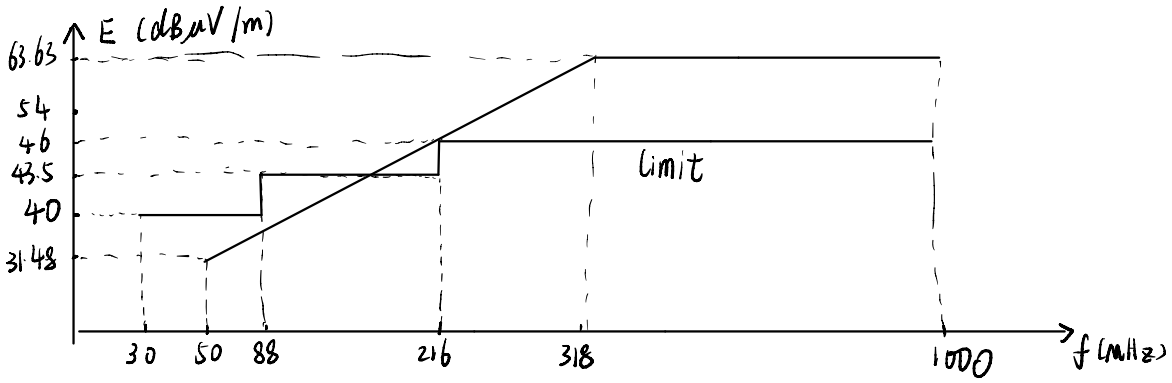
$$= 37.50\ \mu V/m$$

$$= 31.48\ dB\mu V/m$$

The corner frequency : $f_c = \frac{1}{\pi t_r} = \frac{1}{10^{-9}\pi} = 318.31\ MHz$

$$\Delta E = 40\log\frac{f_c}{f_1} = 32.15\ dB$$

$$E_{Dm}(318.3\ MHz\ @3m) = 31.48\ dB\mu V/m + 32.15\ dB = 63.63\ dB\mu V/m$$



Hence the PCD can't be sold in USA's market. It has exceeded the limit and failed to comply with FCC part 15 class B.

(b) $f_{mn} = \frac{150\sqrt{(\frac{m}{L})^2+(\frac{n}{W})^2}}{\sqrt{\varepsilon_r \mu_r}}$ MHz

$= \frac{150\sqrt{(\frac{m}{0.15})^2+(\frac{n}{0.1})^2}}{\sqrt{4.5}}$

$= 70.71\sqrt{(\frac{m}{0.15})^2+(\frac{n}{0.1})^2}$

$m=0$, $n=1,2,3,4\ldots$

$f_{01} = 707.1$ MHz

$f_{02} = 1.41$ GHz > 1GHz

$m=1$, $n=0,1,2,\ldots$

$f_{10} = 471.4$ MHz

$f_{11} = 849.83$ MHz

$f_{12} = 1.49$ GHz > 1GHz

$m=2$, $n=0,1,2\ldots$

$f_{20} = 942.8$ MHz

$f_{21} = 1.18$ GHz > 1GHz

$m=3$, $n=0,1,2\ldots$

$f_{30} = 1.41$ GHz > 1GHz

Therefore, the expected board resonant frequencies are:

707 MHz, 471.4 MHz, 849.83 MHz

(c) The harmonic frequency below 1GHz :

$f_1 = 50$ MHz

$f_2 = 100$ MHz

$f_3 = 150$ MHz

$\vdots$

$f_{19} = 950$ MHz

Because of the board resonance, $f_{14} = 700$ MHz, $f_9 = 450$ MHz, $f_{17} = 850$ MHz may exhibit significant radiated emission.

2016-2017 2(b)

(b) A computer is connected to a USB hub through a 1.5 m long USB cable, as shown in Figure 4. A radio frequency (RF) receiver with a tuning range of 30 MHz to 60 MHz, is located at 5 m away from the cable. It has been demonstrated that if any unwanted external field strength at the receiver's antenna is higher than 60 dBμV/m, the receiver will not be able to receive the wanted signal properly. In order to prevent possible interference from the USB cable's common mode radiation, what is the maximum allowable common-mode current on the USB cable (in dB μA) from 30 MHz to 60 MHz? It is assumed that the common-mode current on the USB cable is nearly constant along its length. The common mode radiation from the power cord can be ignored.

(10 Marks)

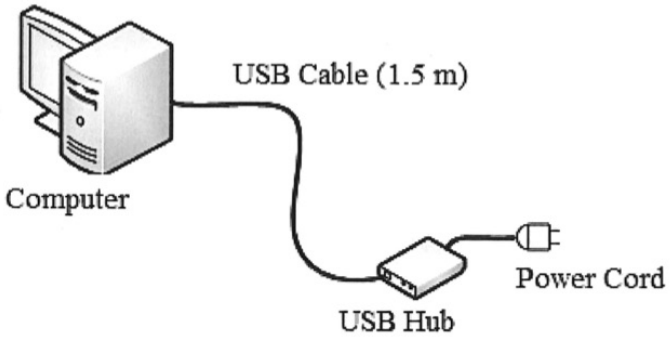


Figure 4

Since $E_{cm} \propto f$, when $f = 60\ MHz$, assuming that $E_{cm} = 60\ dB\mu V/m$
$= 10^3\ \mu V/m$

$$E_{cm} = 1.26 \times 10^{-6} \left(\frac{f I_{cm} l}{r}\right) V/m$$

$$= 1.26 \times 10^{-6} \times \frac{60 \times 10^6 I_{cm} \times 1.5\,m}{5\,m}$$

$$= 10^{-3}\ V/m$$

$$\Rightarrow I_{cm} = \frac{E_{cm}}{1.26 \times 10^{-6}} \cdot \frac{r}{f l}$$

$$= \frac{10^{-3}}{1.26 \times 10^{-6}} \times \frac{5}{60 \times 10^6 \times 1.5}$$

$$= 44.09\ \mu A$$

$$= 32.89\ dB\mu A$$

Therefore, the maximum allowable common-mode current on the USB cable is 32.89 dBμA.

2015 - 2016 3.

3. Figure 2(a) shows the cross-sectional view of a printed circuit board (PCB) where a memory chip is connected to a voltage regulator through the power and ground planes. The substrate between the power and ground planes has a relative permittivity $\varepsilon_r = 4.2$ and relative permeability $\mu_r = 1$.

(a) When the memory chip is in operation, it draws the current from the voltage regulator and the current waveform is shown in Figure 2(b). Will the PCB comply with FCC Part 15 Class B limit given in Table 3 on page 4? Justify your answer by plotting the radiated emission spectrum up to 1 GHz against the limit line.

(10 Marks)

(b) If the length and width of the PCB are 20 cm and 10 cm, respectively; what are the expected board resonant frequencies below 1 GHz for the PCB?

(7 Marks)

(c) Which harmonics of the current waveform shown in Figure 2(b) below 1 GHz are expected to exhibit significant emission level due to the board resonance?

(3 Marks)

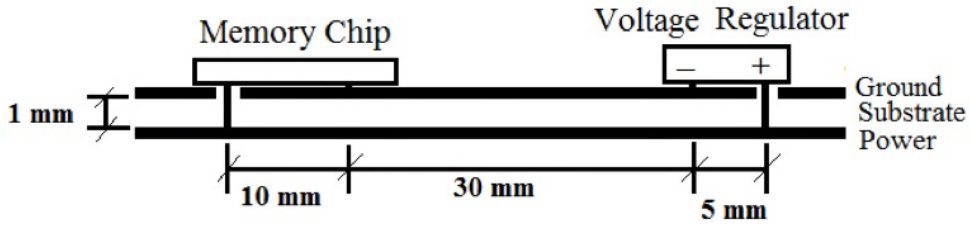


Figure 2(a)

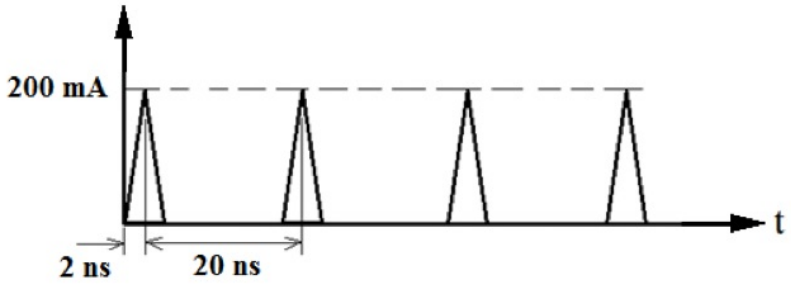


Figure 2(b)

Table 3

Frequency (MHz)	Limit at 3 m (dBμV/m)
30 - 88	40
88 - 216	43.5
216- 960	46
>960	54

(a) From figure 2(a), we know that the loop area is $A = (10+30+5) \times 1 = 45 \times 10^{-6}\ m^2$

The fundamental frequency $f_1 = \frac{1}{T} = \frac{1}{20 \times 10^{-9}} = 50\ MHz$

$$|I_n| = \frac{2I\tau_r}{T}\left[\frac{\sin(\frac{n\pi\tau_r}{T})}{\frac{n\pi\tau_r}{T}}\right]^2 A$$

$$\Rightarrow |I_1| = \frac{2 \times 200 \times 10^{-3} \times 2}{20}\left[\frac{\sin(\frac{2}{20}\pi)}{\frac{\pi \times 2}{20}}\right]^2 = 38.70\ mA$$

$$E_{DM}(50\ MHz\ @\ 3\ m) = 2.632 \times 10^{-14}\left(\frac{(50\times10^6)^2 \times 45 \times 10^{-6} \times 38.7 \times 10^{-3}}{3}\right)$$

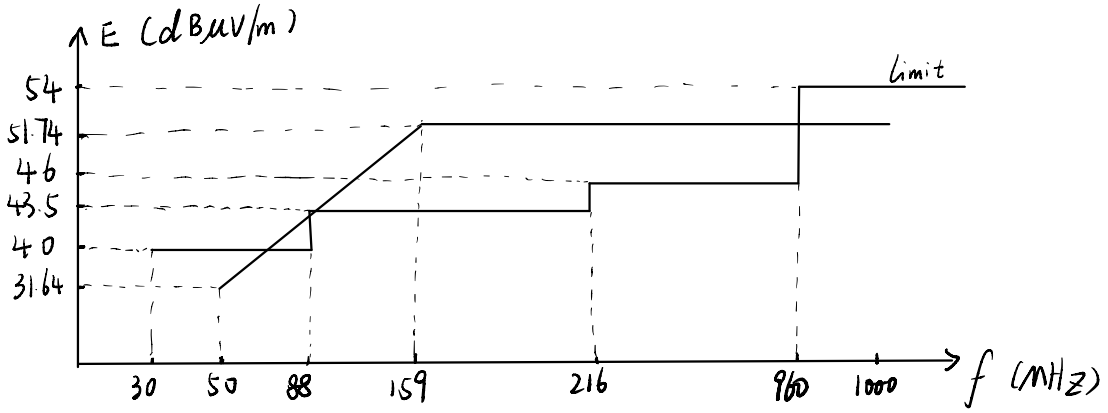
$$= 38.20\ \mu V/m$$

$$= 31.64\ dB\mu V/m$$

The corner frequency $f_c = \frac{1}{\pi\tau_r} = \frac{1}{\pi \times 2 \times 10^{-9}} = 159\ MHz$

$$\Delta E = 40 \log \frac{f_c}{f_1} = 20.10\ dB$$

$E_{DM}(159\ MHz\ @3m) = 31.64\ dB\mu V/m + 20.10\ dB = 51.74\ dB\mu V/m$



It's shown clearly above that this PCB failed to comply with FCC Part 15 class B.

(b) The board resonance frequency is

$$f_{mn} = \frac{150\sqrt{(\frac{m}{L})^2+(\frac{n}{W})^2}}{\sqrt{\mu_r \varepsilon_r}} \text{ MHz}$$

for this PCB $f_{mn} = \frac{150}{\sqrt{1\times 4.2}}\sqrt{(\frac{m}{0.2})^2+(\frac{n}{0.1})^2}$ MHz

$$= 73.19\sqrt{(\frac{m}{0.2})^2+(\frac{n}{0.1})^2} \text{ MHz}$$

$m=0$, $n=1,2,3\ldots$

$f_{01} = 731.9$ MHz

$f_{02} = 1.46$ GHz >1GHz

$m=1$, $n=0,1,2\ldots$

$f_{10} = 365.95$ MHz

$f_{11} = 818.29$ MHz

$f_{12} = 1.51$ GHz >1GHz

$m=2$, $n=0,1,2\ldots$

$f_{20} = 731.9$ MHz

$f_{21} = 1.04$ GHz >1GHz

$m=3$, $n=0,1,2\ldots$

$f_{30} = 1.10$GHz >1GHz

Therefore, the expected board resonant frequencies below 1 GHz are:
365.95 MHz, 731.9 MHz, 818.29 MHz

(c) Harmonics of the current wave below 1GHz are:

$f_1 = 50$ MHz

$f_2 = 100$ MHz

$\vdots$

$f_{19} = 950$ MHz

The 7th (350 MHz), 15th (750 MHz) and 16th (800 MHz) harmonics are expected to exhibit significant emission level due to the board resonance.