**ECE 614 Final Exam - Prof. E.H. Newman**
**June 6, 2007**

Print First, Last Name: Solutions

The following general comments pertain to this exam:

1. **Print** your name (First, Last) on every sheet of this exam.
2. This is a 5 Problem, in class 1 hour and 48 min. exam.
3. You are permitted to use Paul's text, the UniPrint class notes, plus one addition 8.5xin. sheet of paper with your notes, formulas, etc. However, you may not use copies (handwritten or machine) of the Homework or old exam problems.
4. If you don't understand the problem, **ask a question**.
5. **Work neatly**, include a minimum description of the basic steps, and **erase or cross out unused work**. Work each problem on a separate sheet of paper, and **underline or box final answers**. If you need to use the rear side of the page write the word ``OVER" in large letters on the front.

Problem 1: ________/20

Problem 2: ________/20

Problem 3: ________/20

Problem 4: ________/20

Problem 5: ________/20

Total: ________/100

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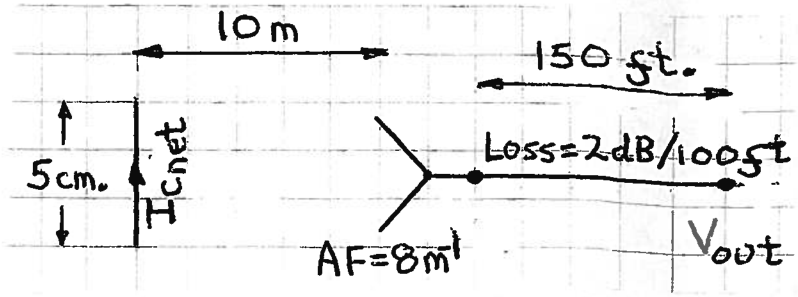
Problem 1: (20%)

The radiation from a product is dominated by common mode current on a T-line of length 5 cm. If the output voltage at 1 GHz in the setup shown is $V_{out}$ = 60 dBμV, find the magnitude of the T-line net common mode current in amps. Assume far zone fields.




- Step 1: Find $E_{inc}(\text{dB}\mu\text{V/m}) = AF(\text{dB}) + V_{out}(\text{dB}\mu\text{V}) + CL(\text{dB})$

- $AF(\text{dB}) = 20\log_{10}(AF) = 20\log_{10}(8) = 18.1\ \text{dB}$
- $CL(\text{dB}) = (150\text{ft.})(2\text{dB}/100\text{ft.}) = 3\ \text{dB}$

$\therefore E_{inc} = 18.1 + 60 + 3 = 81.1\ \text{dB}\mu\text{V/m}$ ← Convert absolute

$$= 10^{81.1/20} = 11350\ \mu\text{V/m} = 0.01135\ \text{V/m}$$

- Step 2: Find $I_{Cnet}$ from $E_C = C L I_{Cnet}/r$ (mag.)

- $\lambda_0 = \dfrac{300}{f_{MHz}} = \dfrac{300}{1000} = 0.3\ \text{m} \rightarrow \beta_0 = \dfrac{2\pi}{\lambda_0} = \dfrac{2\pi}{0.3} = 20.9\ \text{m}^{-1}$
- $C = \dfrac{\beta_0 \eta_0}{4\pi} = \dfrac{(20.9)(377)}{4\pi} = 627$

$$\therefore I_{Cnet} = \frac{rE_{inc}}{CL} = \frac{(10)(0.01135)}{(627)(0.05)} = \underline{\underline{0.00362\ \text{A}}} = \underline{\underline{-48.8\ \text{dBA}}}$$

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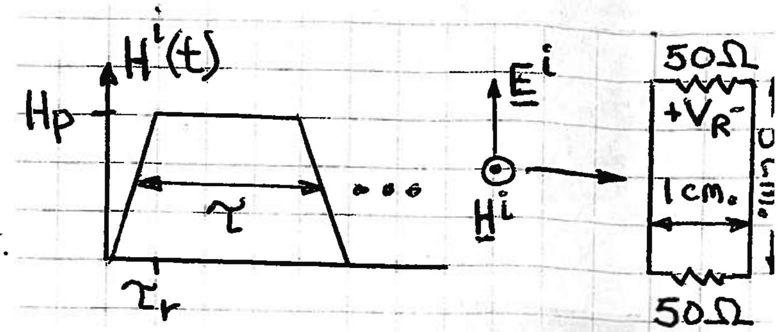
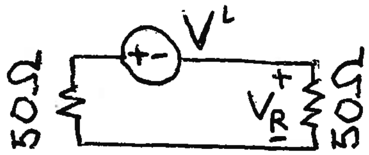
Problem 2: (20%)

A T-line of length 5 cm. and separation 1 cm. is illuminated by a 10 MHz trapezoidal pulse field of duty cycle 0.1 and rise and fall time $\tau_r = 0.1$ nsec. Find $H_P$ = the peak amplitude of the trapezoidal pulse magnetic field such that the **asymptotic envelope** induced voltage at 100 MHz is $V_R = 0.3$ V. Assume the pol. and T-line orientation shown.




- Step 1: Find $H^i(100\,\text{MHz})$ such that $V_R(100\,\text{MHz}) = 0.3$ V

• For the pol. shown, there is only magnetic field pickup




• Mag. $V^i = \omega\mu_0 H^i A$ and $V_R = V^i/2 = 0.3$ V

$$\therefore H^i = \frac{2V_R}{\omega\mu_0 A} = \frac{2(0.3)}{(2\pi 10^8)(4\pi 10^{-7})(0.05\times 0.01)} = \underline{1.52 \text{ A/m at } 100\,\text{MHz}}$$

- Step 2: Find $H_P$ such that $H^i(100\,\text{MHz}) = 1.52$ A/m

• Trap. $H^i(f) = [2H_P D][\text{sinc}(f/f_1)][\text{sinc}(f/f_2)]$  $f = 100$ MHz

• $T = 1/f_0 = 1/10^7 = 10^{-7}$ sec. $\rightarrow \tau = DT = 0.1\times 10^{-7} = 10^{-8}$ sec.

• $f_1 = \frac{1}{\pi\tau} = \frac{1}{\pi 10^{-8}} = 31.8\,\text{MHz} < f \rightarrow \text{sinc}(f/f_1) \doteq \frac{f_1}{f} = \frac{31.8}{100} = 0.318$

asym. env.

• $f_2 = \frac{1}{\pi\tau_r} = \frac{1}{\pi 10^{-10}} = 3.18\,\text{GHz} > f \rightarrow \text{sinc}(f/f_2) \doteq 1$

$$H^i(f = 100\,\text{MHz}) = [2H_P(0.1)][0.318][1] = 1.52 \rightarrow \underline{\underline{H_P = 23.9 \text{ A/m}}}$$

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Problem 3: (20%)

A non-magnetic ($\mu = \mu_0 = 4\pi \times 10^{-7}$ H/m) planar slab of thickness $T = 2$ mm has a plane wave shielding effectiveness of $SE = 10^5$ at $f = 1$ MHz. If the thickness of the slab is doubled, the shielding effectiveness increases to $SE' = 10^8$. Find the conductivity, $\sigma$, of the slab.

Step 1: Find the skin depth $\delta = 1/\sqrt{\pi f \mu \sigma}$

- Changing T changes $AL = e^{T/\delta}$ and $AL' = e^{2T/\delta} = AL^2$

$$SE = RL \cdot AL \quad \& \quad SE' = RL \cdot AL' = RL \cdot AL^2$$

$$= \left(\frac{SE'}{AL^2}\right) AL = \frac{SE'}{AL} \longrightarrow AL = \frac{SE'}{SE} = \frac{10^8}{10^5} = 10^3$$

$\therefore e^{T/\delta} = 10^3 \longrightarrow T/\delta = \ln(10^3) = 6.91$

$\therefore \delta = T/6.91 = 2\times10^{-3}/6.91 = \underline{2.89\times10^{-4}\text{ m}}$

Step 2: Find $\sigma$ knowing $\delta$, $f$, and $\mu = \mu_0$

- $\delta^2 = \dfrac{1}{\pi f \mu_0 \sigma} \longrightarrow \sigma = \dfrac{1}{\pi f \mu_0 \delta^2}$

or $\sigma = \left[\pi(10^6)(4\pi\times10^{-7})(2.89\times10^{-4})^2\right]^{-1} = \underline{\underline{3.03\times10^6 \text{ mho/m}}}$

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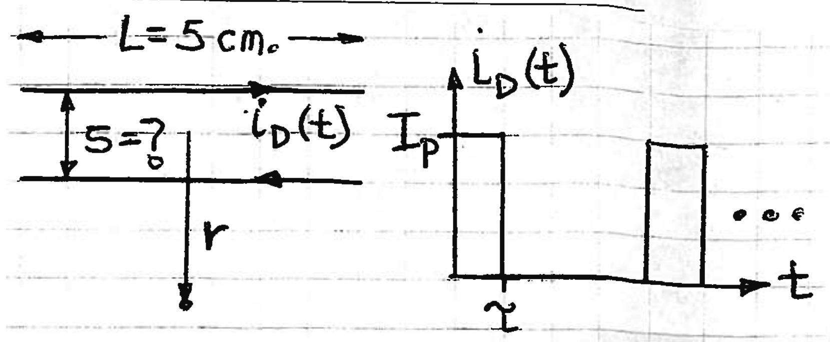
Problem 4: (20%)

A T-line of length $L = 5$ cm carries a pure differential mode 1 MHz rectangular pulse current of peak amplitude $I_p = 2$ mA and pulse width $\tau = 0.1\mu\text{sec}$. Find the line separation, $s$, such that the asymptotic envelope electric field at range $r = 20$ m and frequency 50 MHz is 0.01 $\mu$V/m.




- Step 1: Find $I_D(f = 50\,\text{MHz}) = \left[2 I_p D\right]\left[\text{sinc}(f/f_1)\right]$

• Period $T = \frac{1}{f_0} = \frac{1}{10^6} = 10^{-6}\,\text{sec}, \rightarrow D = \frac{\tau}{T} = \frac{10^{-7}}{10^{-6}} = 0.1$

• $f_1 = \frac{1}{\pi\tau} = \frac{1}{\pi 10^{-7}} = 3.18\,\text{MHz} < f = 50\,\text{MHz}$

$\therefore$ Asym, Env, $\text{sinc}\underbrace{(f/f_1)}_{>1} = \frac{f_1}{f} = \frac{3.18}{50} = 0.0636$

• $I_D(f = 50\,\text{MHz}) = \left[(2)(0.002)(0.1)\right]\left[0.0636\right] = \underline{2.544 \times 10^{-5}\,\text{A}}$

- Step 2: Find $E_{1D}(f) \overset{\text{mag.}}{=} C L \frac{s}{r}\sqrt{\frac{1}{r^2} + \beta^2}$

• $\lambda = \frac{300}{f_{MHz}} = \frac{300}{50} = 6\,\text{m} \rightarrow \beta = \frac{2\pi}{\lambda} = \frac{2\pi}{6} = 1.047\,\text{m}^{-1}$

• $C = \frac{\beta \eta_0}{4\pi} = \frac{(1.047)(377)}{4\pi} = 31.4$

$\therefore E_{1D}(f) = (31.4)(0.05)\left(\frac{s}{20}\right)\sqrt{\frac{1}{20^2} + 1.047^2} = \underline{0.08235}$

- Step 3: $E_D(f) = I_D(f)\, E_{1D}(f) = 10^{-8}$ V/m

$\therefore \left[2.544 \times 10^{-5}\right]\left[0.0823 s\right] = 10^{-8} \rightarrow s = \frac{10^{-8}}{(2.544 \times 10^{-5})(0.0823)} = \underline{\underline{4.78\,\text{mm}}}$

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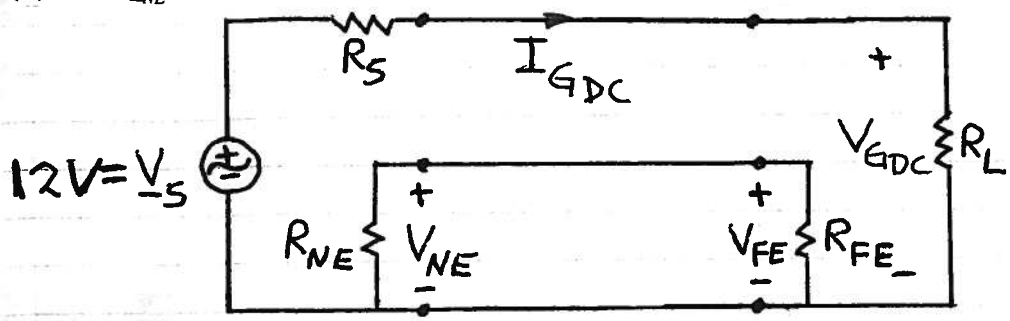
Problem 5: (20%)

At 1 MHz and with $\underline{V}_S = 12$ V, the following measurements were made for the coupled T-lines:

Open Circuit Test: $\underline{V}_{NE}\big|_{R_{FE}=\infty} = j0.5$ V and Short Circuit Test: $\underline{V}_{NE}\big|_{R_{FE}=0} = j0.2$ V

(a) Find the low frequency mutual inductance and mutual capacitance, $(L_m, C_m)$, between the T-lines.

(b) Find $\underline{V}_{NE}$ = the low frequency near end voltage **at 10 MHz.**




$R_S = 50\Omega$

$R_L = 150\Omega$

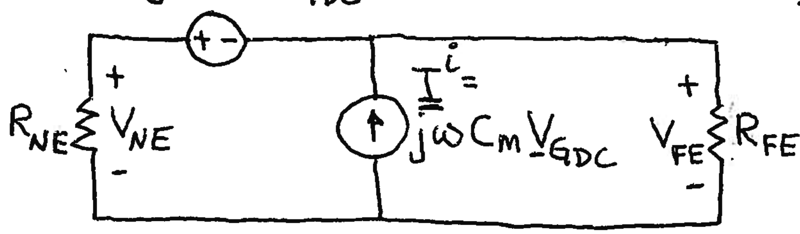
$R_{NE} = 25\Omega$

$R_{FE} = 75\Omega$

(a) The low freq. receptor circuit

(15)

$\underline{V}^i = j\omega L_m \underline{I}_{GDC}$




- $\underline{I}_{GDC} = \dfrac{\underline{V}_S}{R_S + R_L} = \dfrac{12}{50+150} = 0.06\,A$

- $\underline{V}_{GDC} = \dfrac{R_L}{R_S + R_L}\underline{V}_S = \dfrac{150}{50+150}12 = 9V$

- O.C. Test: $V_{NE}\Big|_{R_{FE}=\infty} = R_{NE}\underline{I}^i = j0.5 \rightarrow \underline{I}^i = \dfrac{j0.5}{R_{NE}} = \dfrac{j0.5}{25} = j0.02\,A$

- S.C. Test: $V_{NE}\Big|_{R_{FE}=0} = \underline{V}^i = j0.2V$

- $L_m = \dfrac{\underline{V}^i}{j\omega \underline{I}_{GDC}} = \dfrac{j0.2}{j2\pi 10^6 (0.06)} = 0.5305\,\mu H$

- $C_m = \dfrac{\underline{I}^i}{j\omega \underline{V}_{GDC}} = \dfrac{j0.02}{j2\pi 10^6 (9)} = 0.3537\,nF$

(b) Since $\underline{V}^i$ & $\underline{I}^i \propto f$, increasing $f$ by a factor of 10 will increase $\underline{V}^i$ & $\underline{I}^i$ by a factor of 10

(5)

- $\underline{V}_{NE} = \dfrac{R_{NE}}{R_{NE}+R_{FE}}\underline{V}^i + \dfrac{R_{FE}R_{NE}}{R_{FE}+R_{NE}}\underline{I}^i = \underbrace{\dfrac{25}{25+75}(j2)}_{j0.5} + \underbrace{\dfrac{25\cdot 75}{25+75}(j0.2)}_{j3.75} = j4.25V$