ECE342 Sample Test 1 (100 pts max, Closed Book & Notes, 1 Crib Sheet, Laptop Maple)

Name: Solution **Box #** ____________

1) **18 Points** (**Decibel Conversions**) Make the usual assumption that the signal appears across a 50 Ω load, and that all ac voltage amplitudes are in rms volts and all ac current amplitudes are in rms amperes. Remember that "dBm" is the same as "dBmw".

Note: Remember in MAPLE $\log_{10} = \log10(\ )$

a) Convert 5 kV to dBμV

$$20\log\left(\frac{5kV}{1\mu V}\right) = 193.98$$

193.98 dBμV

b) Convert 50 nV to dBμV

$$20\log\left(\frac{50nV}{1\mu V}\right) = -26.02$$

-26.02 dBμV

c) Convert 10 dBm to dBμV

$$10 = 10\log\left(\frac{V^2/50}{1mW}\right) \Rightarrow V = 0.707V$$

$$dB\mu V = 20\log\left(\frac{0.707V}{1\mu V}\right) = 116.99$$

116.99 dBμV

d) Convert 50 mW to dBm

$$10\log\left(\frac{50mW}{1mW}\right) = 16.99$$

16.99 dBm

e) Convert 100 V to dBm

$$10\log\left(\frac{100^2/50}{1mW}\right) = 53.01$$

53.01 dBm

f) Convert 1 mA to dBm

$$10\log\left(\frac{(1mA)^2 50}{1mW}\right) = -13.01$$

-13.01 dBm

g) Convert -200 dBμV to dBm

$$-200 = 20\log(V_x/1\mu V) \Rightarrow V_x = 10^{-16}\ V$$

$$dBm = 10\log((V_x^2/50)/1mW) = -306.99$$

-306.99 dBm

h) Convert +200 dBμV to units of volts

$$200 = 20\log(V_x/1\mu V) \Rightarrow V_x = 10kV$$

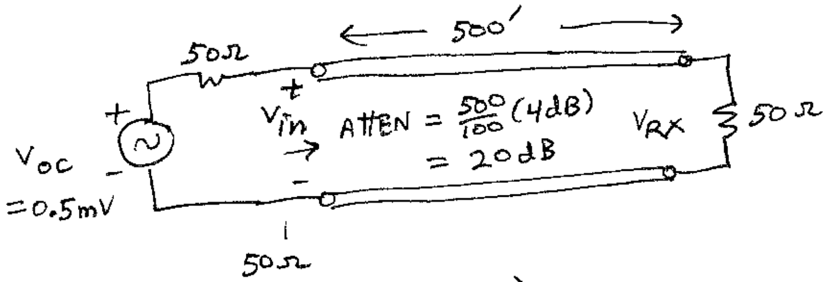
10,000 V

i) Convert +200 dBm to units of volts

$$200 = 10\log\left(\frac{V_x^2/50}{1mW}\right) \Rightarrow V_x = 2.236\times10^9$$

2,236,067,977 V = 2.236 GV

2) **10 points** **(Application of Decibels)** A 50 Ω, 200 MHz sinusoidal source is connected to a 50 Ω receiver using 500 feet of standard "RG58/U 50-ohm" coaxial cable that exhibits a 4 dB/100 feet loss at 200 MHz. If the internal Thevenin Equivalent (open circuit) voltage of the 50 Ω source is measured to have an rms amplitude of 0.5 mV, find the voltage in dBμV at the **receiver** terminals? *Recall I have mentioned in class that "standard 50-ohm coaxial cable" has the property that if it is terminated in 50 ohms, its input impedance will be 50 ohms, regardless of its length. This interesting property of a transmission line will be studied later in this class.*



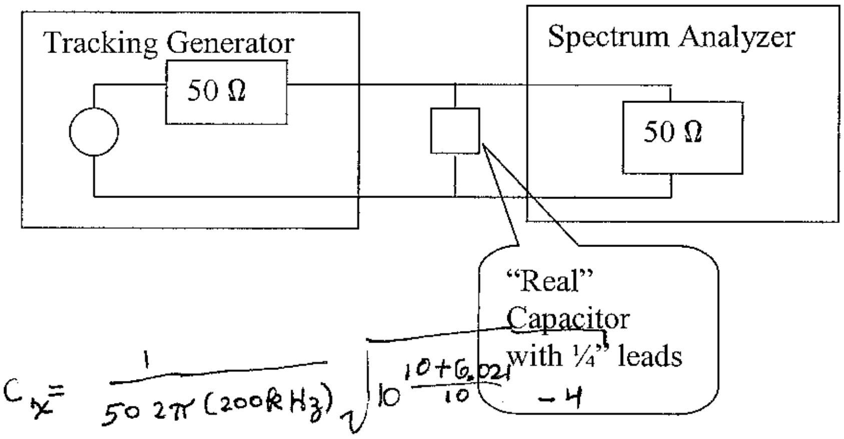
$$V_{in} = V_{oc}\left(\frac{50}{50+50}\right) = 0.25\,mV$$

$$V_{in\,dB\mu V} = 20\log\left(\frac{0.25mV}{1\mu V}\right) = 47.96\ dB\mu V$$

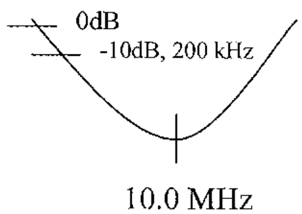
$$V_{Rx} = +47.96 - 20 = 27.96\ dB\mu V$$

Vrcvr = 27.96 dBμV

3) **10 points** **(Real Capacitor Modeling - Lab 1)**
Using the same spectrum analyzer / tracking generator apparatus that we used in the laboratory, a capacitor with 0.25 inch leads is found to have a frequency response curve that has a sharp dip (minimum value) at 10 MHz, and an attenuation of 10 dB at 200 kHz. Determine its series L-C model.



Spectrum Analyzer Display



$$C_x = \frac{1}{50\,2\pi(200kHz)\sqrt{10^{\frac{10+6.021}{10}}-4}}$$

$$\Rightarrow C_x = 95.5\,nF$$

$$F_{res} = 10\,MHz = \frac{1}{2\pi\sqrt{L_x C_x}}$$

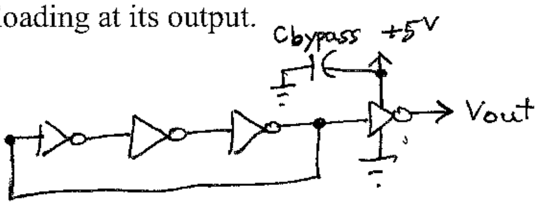
$$\Rightarrow L_x = 2.65\,nH$$

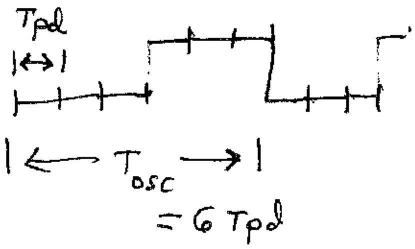
Cseries = 95.5 nF
Lseries = 2.65 nH

(Include appropriate units in your answers!)

4) **<u>14 points</u> (Ring Oscillator - Lab 2)**

A. Draw the 74HC04 "three-inverter" ring oscillator circuit that you built in Lab 2 in the space below. Recall that we used three inverters in the ring with a fourth inverter as an isolating "output buffer". This output buffer was used to avoid capacitive loading (slowing down) of one of the three inverters in the ring, and thus making the frequency of oscillation independent of the amount of capacitive loading at its output.





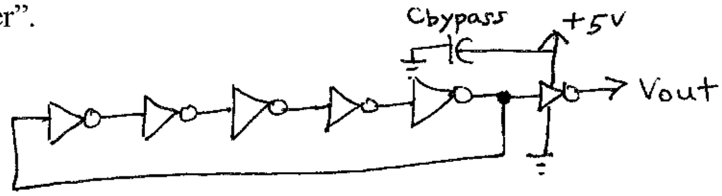
B. If the oscillator of Part A is found to oscillate at a frequency of 33.333 MHz, determine the propagation delay of each individual inverter, just as you did in this lab experiment, assuming that all inverters have the same propagation delay, Tpd.

$$6\,T_{pd} = \frac{1}{33.33\,MHz} = T_{osc}$$

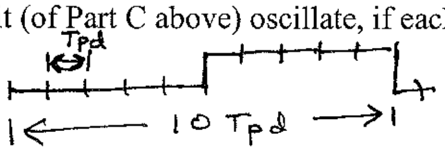
$$\Rightarrow T_{pd} = 5ns$$

Tpd = <u>5</u> ns

C. Now draw the circuit of a similar 5-inverter 74HC04 ring oscillator, using a sixth inverter as an isolating "buffer".



D. At what frequency will this 5-inverter ring oscillator circuit (of Part C above) oscillate, if each inverter has a Tpd = 10 ns?

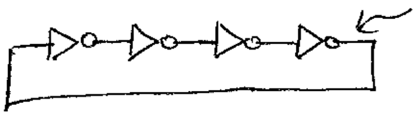


$$T_{osc} = 2(5)(10ns) = 100ns$$

$$f_{osc} = \frac{1}{T_{osc}} = \frac{1}{100ns} = 10\,MHz$$

f= <u>10</u> MHz

E. Would 4 inverters connected in a ring oscillate? <u>Explain your answer</u>.
Hint: Explain by drawing the proposed circuit, then postulating a logic change at one of the inverter outputs, and then tracking this change around the ring to see if it leads to oscillation, just as I did in the lab handout when explaining the operation of the 3-ring oscillator.



IF initially Low, after 4 Tpd elapses the output <u>stays</u> <u>low</u>!

$\Rightarrow$ <u>No Oscillation</u>

F. Explain how harmonic radiation, and also ac noise on the dc power bus, was reduced in the "three-inverter" ring oscillator circuit of Part A.

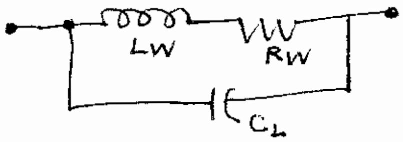
AC "bypass capacitor" was connected across "Vcc" and "Ground" dc power pins of 74HC04 IC. This "shorted out" (diverted to ground) the RF noise on the power bus, thereby reducing radiation from the power bus wires.

G. Explain why the saying "*bigger is not always better*" is especially true when choosing the value of a dc power bus "bypass" capacitor in a digital system design. (Do this in the context of what you have learned in the first two ECE342 laboratory experiments that you have now completed. ***NOTE***: *Be sure to mention something about "self-resonant frequency" in your answer*!)

Bigger capacitors have larger "self-resonant" frequencies above which they stop acting like capacitors and start acting like inductors! ⇒ They do <u>NOT</u> divert to ground noise frequencies greater than their self-resonant freq!

5) **(12 Points) Simplified Lumped Parameter Model of a "Real Inductor"**

(a) Draw the equivalent lumped circuit model of a "real" inductor. Your model must consist of an interconnection of three components: the lumped winding resistance R_w, its self-inductance L_w, and the combined effects of inter-turn capacitance and the lead capacitance, C_L. (You may assume that the particular real inductor under discussion has $R_w = 5\ \Omega$, $L_w = 50\ \mu H$, and $C_L = 50$ pF.)



(b) At very low frequencies, this "real" inductor acts approximately like:
(1) A resistor of value R_w (2) An inductor of value L_w (3) a capacitor of value C_L

(c) At very high frequencies, this "real" inductor acts approximately like:
(1) A resistor of value R_w (2) An inductor of value L_w (3) a capacitor of value C_L

(d) At intermediate frequencies, this "real" inductor acts approximately like:
(1) A resistor of value R_w (2) An inductor of value L_w (3) a capacitor of value C_L

(e) From this equivalent model, write an approximate expression (in terms of R_w, L_w) for the frequency (in Hertz) above which this "real" inductor changes its behavior (from its low frequency behavior to its intermediate frequency behavior.) Then calculate this frequency using the component values given above.

Freq at which $R_W = |j\omega L_W| \Rightarrow \omega = \frac{R_W}{L_W} \Rightarrow \boxed{f = \frac{R_W}{2\pi L_W}}$

$f = \frac{5\Omega}{2\pi\, 50\times10^{-6} H} = \underline{15.9\,kHz}$

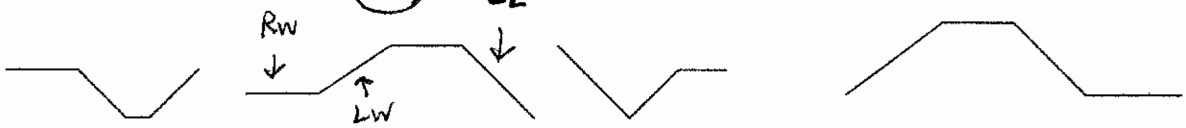
(f) From this equivalent model, write an approximate expression (in terms of L_w, and C_L) for the frequency (in Hertz) above which this "real" inductor changes from its intermediate frequency behavior to its high frequency behavior? Then calculate this frequency using the component values given above.

Freq at which $\frac{1}{j\omega L_W} + j\omega C_L = 0 \Rightarrow \omega = \frac{1}{\sqrt{L_W C_L}} \Rightarrow \boxed{f = \frac{1}{2\pi\sqrt{L_W C_L}}}$

$f = \frac{1}{2\pi\sqrt{50\times10^{-6}\cdot 50\times10^{-12}}} = \underline{3.18\,MHz}$

(g) If this "real inductor" is connected to the tracking generator/spectrum analyzer (replacing the "real capacitor" in the circuit of Problem 3), which *approximate* spectrum analyzer display shown below would you expect? (Recall that we are assuming a real inductor that is modeled by $R_w = 5\ \Omega$, $L_w = 50\ \mu H$, and $C_L = 50$ pF.)

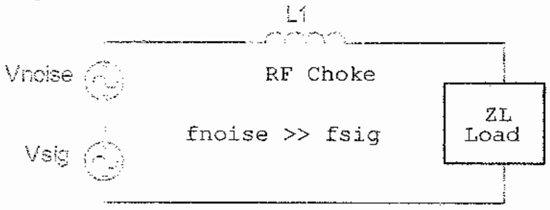
(a) (b) (c) (d)



(h) When blocking high frequency noise in a signal line using a series inductor (the inductor is often called an "RF Choke"), should the magnitude of the *load impedance* be _?_ the magnitude of the impedance of the *series inductor* at the noise frequency? Explain your answer in the space below:

(1) much higher than (2) about the same as (3) much lower than

Voltage Division Ratio $\left.\right\}$ $\dfrac{Z_L}{Z_L + j\omega_{noise} L_1}$ Must be ≈ 0 To Keep V_{noise} from reaching Load



$\Rightarrow |Z_L| << |j\omega_{noise} L_1|$

6) **(10 Points) Vector Manipulations**
Two vectors are given by **A** = **ix** + 2**iy** – 3**iz** and **B** = 2**ix** – **iy** + **iz**, and they are placed "tail-to-tail".

(a) Find a unit vector that is perpendicular to the plane containing the vectors A and B

$$\hat{i}_N = \frac{\vec{A} \times \vec{B}}{|\vec{A} \times \vec{B}|} = \frac{\begin{vmatrix} \hat{i}_x & \hat{i}_y & \hat{i}_z \\ 1 & 2 & -3 \\ 2 & -1 & 1 \end{vmatrix}}{|\vec{A} \times \vec{B}|} = \frac{\hat{i}_x(2-3) - \hat{i}_y(1-(-6)) + \hat{i}_z(-1-4)}{|\vec{A} \times \vec{B}|}$$

$$\hat{i}_N = \frac{-1\hat{i}_x - 7\hat{i}_y - 5\hat{i}_z}{\sqrt{1^2 + 7^2 + 5^2}} = \boxed{-0.1301\,\hat{i}_x - 0.9113\,\hat{i}_y - 0.6509\,\hat{i}_z}$$

(Check: Observe that $\hat{i}_N \cdot \vec{A} = 0$ and $\hat{i}_N \cdot \vec{B} = 0$)

(b) Find the smallest angle between these two vectors.

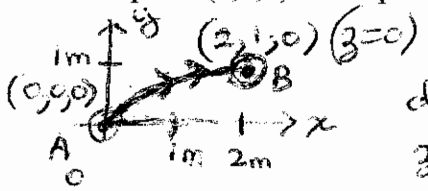
$$\vec{A} \cdot \vec{B} = |\vec{A}| \cdot |\vec{B}| \cdot \cos\theta$$

$$\theta = \arccos\left[\frac{\vec{A} \cdot \vec{B}}{|\vec{A}| \cdot |\vec{B}|}\right] = \arccos\left[\frac{1 \cdot 2 + 2(-1) + (-3)(1)}{\sqrt{1^2+2^2+3^2}\,\sqrt{2^2+1^2+1^2}}\right]$$

$$\theta = \arccos\left[\frac{-3}{\sqrt{14}\,\sqrt{6}}\right] = \boxed{109.1^\circ}$$

7) **(9 Points) Line, surface and volume integration**

a) In the electric field intensity in a region of space is given by $E = yi_x + xi_y$ V/m, find the work done in carrying a 1 C test charge from the point (0,0,0) to the point (2m, 1m, 0m) over the path $x = 2y^2$ in the z = 0 plane.



$$W = \int_{(2,1,0)}^{(0,0,0)} \vec{E} \cdot d\vec{\ell}$$

$d\vec{\ell} = dx\,\hat{i}_x + dy\,\hat{i}_y + dz\,\hat{i}_z$

$z = 0 \Rightarrow dz = 0$

$x = 2y^2 \Rightarrow dx = 4y\,dy$

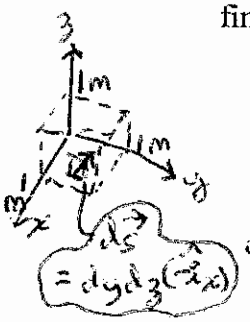
$\Rightarrow d\vec{\ell} = 4y\,dy\,\hat{i}_x + dy\,\hat{i}_y$

$$W = \int_{y=1}^{0} (4y^2 dy + \underbrace{x}_{=2y^2} dy) = \int_{y=1}^{0} 6y^2 dy$$

$$W = \left[\frac{6y^3}{3}\right]_1^0 = \boxed{-2J}$$

Negative work is done since $\vec{E}$ pushes the +1C charge from A to B! ($V_{BA} = 2V$)

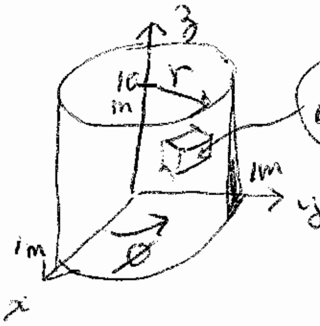
b) Consider a cube whose sides lie in the z = 0, z = 1 m, x = 0, x = 1 m, y = 0, and y = 1 m planes. If the conduction current density in this region of space is given by $J = 2x^2yi_x + zi_y + yi_z$ A/m², find the amount of current ***entering the cube*** through the ***x = 1 m side*** of the cube.



$d\vec{s} = dy\,dz\,(-\hat{i}_x)$ in the x = 1 plane, $\vec{J}\big|_{x=1} = 2y\,\hat{i}_x + z\,\hat{i}_y + y\,\hat{i}_z$

$$\int_{y=0}^{y=1}\int_{z=0}^{z=1} \vec{J} \cdot d\vec{s} = \int_0^1 \int_0^1 -2y\,dz\,dy = \left[-2\frac{y^2}{2}\right]_0^1 = \boxed{-1\ A}$$

c) A cylinder is defined in cylindrical coordinates as the intersection of the planes z = 0, z = 10 m, and r = 1 m. Find the charge contained within this cylinder if the volume charge density in this region is given by ρ = (2r + 3) C/m³.



$dv = r\,d\phi\,dr\,dz$

$$Q = \int_{z=0}^{10m}\int_{\phi=0}^{2\pi}\int_{r=0}^{1m} \underbrace{(2r+3)}_{\rho}\ \underbrace{(r\,dr\,d\phi\,dz)}_{dv}$$

$$Q = 10(2\pi)\left[\frac{2r^3}{3} + \frac{3r^2}{2}\right]_0^1 = \boxed{136.14\ C}$$

8) <u>24 points</u> (Maxwell's Equations)

A. Use symmetry and Ampere's Circuital Law to find an expression for the **H** field set up by a time-varying current i(t) = 10sin(1000t) A flowing in an infinitely long wire along the z axis, flowing in the +z direction. Apply Ampere's Law around the circular contour "C" that is centered on the z axis and of radius "r" as shown below. Express **H** in cylindrical coordinates.

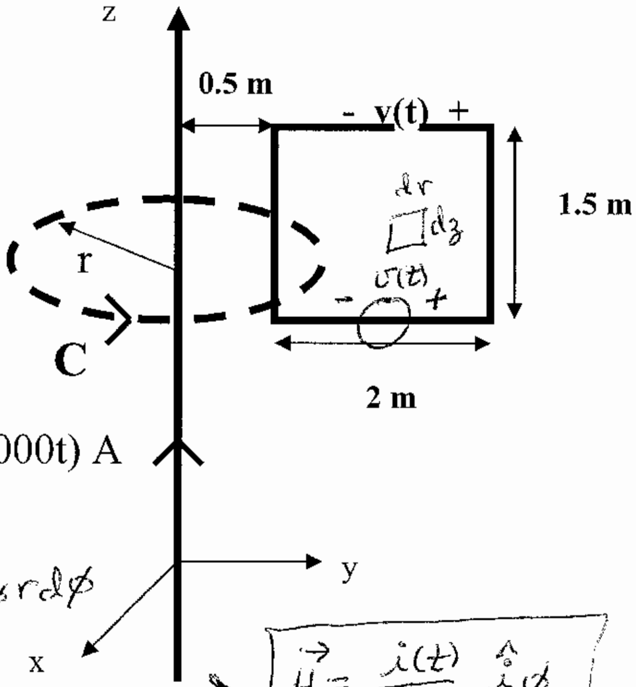
$$\oint_C \vec{H}\cdot d\vec{l} = I_{enclosed} = i(t) + \cancel{\frac{d}{dt}\int_S \vec{D}\cdot d\vec{s}}^{\,\rightarrow 0}$$

(No time-varying $\vec{D}$ field is in the vicinity)

From symmetry considerations,

$$\vec{H} = H_\phi(r)\hat{i}_\phi$$

($\vec{H}$ depends only on distance away from the wire, "r", and it is purely in the ϕ direction.)



i(t) = 10sin(1000t) A

$$\therefore \quad d\vec{l} = r\,d\phi\,\hat{i}_\phi$$

$$\oint_C \vec{H}\cdot d\vec{l} = \oint_C H_\phi\hat{i}_\phi \cdot r\,d\phi\,\hat{i}_\phi = \int_{\phi=0}^{2\pi} H_\phi r\,d\phi$$

$$= H_\phi \int_{\phi=0}^{2\pi} r\,d\phi = H_\phi(2\pi r) = i(t)$$

$$\Rightarrow \boxed{\vec{H} = \frac{i(t)}{2\pi r}\hat{i}_\phi}$$

B. Assuming that the material surrounding the wire is air (recall the permeability of free space is $\mu_0 = 4\pi x 10^{-7}$ H/m), use Faraday's Law of Induction to find the voltage, v(t), induced around the rectangular loop that lies in the x = 0 plane, taking note of the pre-assigned voltage polarity signs!

$$B = \mu_0 H = \frac{\mu_0\, i(t)}{2\pi r}\hat{i}_\phi$$

Because of the assigned polarity of $v(t)$, which is <u>opposite</u> the right-hand convention.

$$v(t) = +\frac{d}{dt}\int_S \vec{B}\cdot d\vec{s} \quad \text{where } d\vec{s} = dr\,dz\,\hat{i}_\phi$$

$$= +\frac{d}{dt}\int_{z=0}^{1.5m}\int_{r=0.5m}^{2.5m} \frac{\mu_0\, i(t)}{2\pi r}\,dr\,dz = +\frac{d}{dt}\left[\frac{1.5\mu_0\, i(t)}{2\pi}\ln(r)\Big|_{0.5m}^{2.5m}\right]$$

$i(t) = 10\sin(1000t)$

$$= \frac{+1000(10)\cos(1000t)(1.5\mu_0)}{2\pi}\ln\left(\frac{2.5}{0.5}\right) = \boxed{4.83\cos(1000t)\ \text{mV}}$$