Consider a three-phase inverter below supplying a wye-connected load with series connected resistance of 4 Ω and inductance of 2 mH in each phase. Given the line-to-line voltage waveforms below and the α-phase line-to-ground voltage waveform, sketch the α-phase line-to-neutral voltage $v_{as}$. 

![Diagram of a three-phase inverter supplying a wye-connected load with series connected resistance and inductance in each phase. The line-to-line voltage waveforms and the α-phase line-to-ground voltage waveform are shown.]
Problem A2  Power/Machinery  Code #________

For the buck-boost converter depicted in the figure below assume that:

1) The converter is operating in the steady-state condition.
2) All of the components are ideal.

Given $V_{in} = 100$ V and inductor current $i_L$ as sketched in the second figure,

a) (50 pts) find output voltage $V_o$, and

b) (25 pts) find $I_{max}$ if load $R$ is $\frac{100}{3}$ $\Omega$, and

c) (25 pts) plot $i_s$ (switch current).
Problem A-3

Using the Newton-Raphson method, perform two (2) iteration/updates of the following set of equations:

\[ 0 = y - \sin x \]
\[ 0 = y - e^x \]

Use \( x = 1 \) and \( y = 1 \) as initial conditions.
A C400 multiratio CT, with characteristics as shown below, is to be used to protect a line with a maximum 3-phase fault current of 3,000 A primary and a minimum fault current of 450 A primary. The maximum load on the feeder is 120 A. Phase overcurrent relays are connected to the CT secondaries and the lead burden is 0.15Ω.

Assume the following relay burden for the various relay taps:

<table>
<thead>
<tr>
<th>Tap</th>
<th>Relay Burden</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At tap</td>
</tr>
<tr>
<td>1.0</td>
<td>2.42</td>
</tr>
<tr>
<td>1.5</td>
<td>2.51</td>
</tr>
<tr>
<td>2.0</td>
<td>2.65</td>
</tr>
<tr>
<td>2.5</td>
<td>2.74</td>
</tr>
<tr>
<td>5.0</td>
<td>2.85</td>
</tr>
<tr>
<td>7.0</td>
<td>2.90</td>
</tr>
<tr>
<td>10.0</td>
<td>3.00</td>
</tr>
<tr>
<td>12.0</td>
<td>3.46</td>
</tr>
</tbody>
</table>

Assume that the 300:5 CT ratio is used:

(a) (15 pts) Select a relay tap so that the relay pickup is 125% above the maximum load.

(b) (15 pts) Determine the minimum primary current to just operate the relays

(c) (45 pts) Determine if the CTs will perform satisfactorily for the maximum fault current.
The circuit below was designed so that a 5V relay could be used with a 2.5V source to reduce power consumption. The relay coil must have at least 3.5 volts applied to energize, but will stay latched as long as the coil voltage is > 1.5 volts. When switch S1 closes, C1 charges to almost 2.5 volts, so that when pin 1 of the IC reaches its threshold, pin 5 connects to pin 6, and a momentary pulse of $2.5V + V_{C1} \approx 5$ volts is applied to engage the relay.

(a) If the 5V relay normally draws 90mA, calculate the power it normally consumes. (20%)

(b) How much power will the relay consume with the circuit above, after $C_1$ discharges? Assume that $V_D = 0.7$ volts. (40%)

(c) What will the peak current be through the analog switch? (Look at both the charging and discharging case of $C_1$.) (20%)

(d) What is the purpose of $D_2$? (20%)
In this problem, you will design a flyback converter. It must operate in discontinuous conduction mode for input voltages ranging 300 V to 800 V, and the primary-side duty ratio must not exceed 45%. The output voltage is 24 V and the output current is 1 A. The maximum reflected voltage (that is, the voltage seen on the primary when the output diode is conducting) is 200 V.

a. Sketch the circuit. Include all protection elements.
b. Find the turns ratio.
c. Find the duty ratio of the MOSFET at minimum input voltage that satisfies all criteria (including the turns ratio found in part b).
d. If the switching frequency is 30 kHz, find the primary inductance that satisfies all criteria at minimum input voltage (including parts b and c).
e. Given this design of the coupled inductor, find the duty ratio of the MOSFET at maximum input voltage.
The RF amplifier shown below operates in Class F. That is, tank circuit $L_1C_1$ is designed to resonate at the desired fundamental frequency $\omega_0$. The third harmonic $3\omega_0$ is blocked by resonant circuit $L_3C_3$. Coupling capacitor $C_B$ is chosen such that the total $Z_L$ is a short to ground at the second harmonic $2\omega_0$.

(a) Write the equation for $Z_L(2\omega_0)$. Set this equation equal to 0 and solve for $C_B$ in terms of $C_1$ and $C_3$. [Hint: A useful relationship is $L_3C_3 = 1/(9\omega_0^2)$.] (90%)

(b) With this circuit, the output is nearly sinusoidal at $\omega_0$, while the waveform at the collector is almost rectangular. What is the purpose of making an amplifier like this? (10%)
The transistor below uses negative feedback to set the bias point and control AC gain.

(a) Is the feedback element $R_F$ sampling voltage or current? Is current or voltage being compared at the input of the amplifier? (10%)

(b) Using the simplified transistor model shown, draw the small-signal equivalent circuit. Derive the equation for the voltage gain $V_o/V_i$. (80%)

(c) Knowing that, in theory, this gain is equal to $A_f = A/(1+A\beta)$, where $A$ = the gain without feedback and $\beta$ = the feedback factor, what is your expression for loop gain $A\beta$? State any assumptions you might make. (10%)
A silicon dioxide film of total thickness 0.8 μm is grown after a two-step thermal oxidation process on a <100> wafer in wet oxygen. The linear growth rate constant (B/A) and the parabolic growth rate constant (B) in this process condition are 2.895 μm/hr and 0.529 μm²/hr, respectively.

How long does it take to grow the initial oxide films and the additional oxide films in each step? The final thickness after the step 1 becomes the initial thickness of the step 2. Assume that the initial thickness in the step 1 is zero. Fill out the three answers in the table based on the formula below.

\[
\tau = \frac{X_i^2}{B} + \frac{X_i}{B/A}, \quad t = \frac{X_o^2}{B} + \frac{X_o}{B/A} - \tau
\]

<table>
<thead>
<tr>
<th></th>
<th>Initial thickness</th>
<th>Final thickness</th>
<th>Time for initial thickness</th>
<th>Time for additional thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>0.0 μm</td>
<td>0.4 μm (after step 1)</td>
<td>(0.0) hour</td>
<td>(________) hour</td>
</tr>
<tr>
<td>Step 2</td>
<td>0.4 μm</td>
<td>0.8 μm (after step 2)</td>
<td>(________) hour</td>
<td>(________) hour</td>
</tr>
</tbody>
</table>
Problem: A11    Area: Waves, Devices & Optics

Given is the structure below:

1m long, narrow, flat enclosure

1m long cable

PCB: 80 x 5 cm, 1 mm from the metallic enclosure

Source: 10 mV, 50-Ohm source

The inductance of the connection of the cable shield to the enclosure is 10nH

1) Identify the antenna structure
2) Identify which current will determine the far field radiation strength
3) Give an equivalent circuit that allows to approximately calculate the far field radiation.
4) Give an estimate of the real part of the antenna impedance at resonance
5) Calculate the current that drives the far field
6) Estimate the far field strength in 10 m distance, using

$$E = \frac{\sqrt{3OPG}}{R}$$

With:

E: Maximal E-field strength [V/m]
P: Power radiated [W]
G: Gain, assume 1
R: Distance [m]
An elliptically polarized electromagnetic plane wave is propagating through free space in the +z direction at a frequency of 2 GHz. The axial ratio is 2.5 and the tilt angle is $12.5^\circ$ with respect to the positive $x$ axis. At some instant of time, $t_0$, the $x$ component of the electric field is $5.39 \, \mu V/\, m$. The electric field has a maximum magnitude of $22 \times 10^{-6}$ Volts per meter. Find all possible values of the $y$ component of the electric field in units of $\mu V/m$ at the same instant of time, $t_0$. If you believe there are no possible values of the $y$ component, explain why there are no possible values. Otherwise find all possible answers to at least three significant digits.
Consider a negative unity-feedback control system with the open-loop transfer function

\[ G(s) = K \frac{(s + 5)^2}{(s^2 - 2s + 2)(s^2 + 2s + 2)}. \]

(a) Construct the root-locus diagram for \( K > 0 \). Determine all the important features like asymptotes, break-away and/or break-in points, imaginary-axis crossings, angles of departure and/or arrival. (90%)

(b) Determine the values of \( K \) such that the closed-loop system is stable. (10%)
Consider the following system with a sampling period of 1/2 second.

Design the simplest controller $D(z)$, such that the 2% settling-time is about 4 seconds, and the maximum percent-overshoot for the unit-step input is between 15% and 20%.
Pole-locations for Constant Damping Coefficients

The relationship of the zero-pole configuration with the auxiliary angle $\alpha$ is given in the following figures.

Maximum-Overshoot for Constant Damping Coefficients

$z = R(z) + jX(z) = e^{\sqrt{\zeta^2 - \zeta^2 \gamma}}$
A time-varying control system is described by

\[
\dot{x}(t) = \begin{bmatrix}
-e^{-t} & 0 \\
0 & -1 - \cos(t)
\end{bmatrix} x(t),
\]

where \( x \) is the state variable. Determine \( x(t) \) for \( t \geq 0 \), when \( x(0) = \begin{bmatrix} 10 \\ 20 \end{bmatrix}^T \).
A control system is described by

\[
\dot{x}(t) = \begin{bmatrix}
-4 & 0 & -29 & -7 \\
1 & -1 & 8 & 1 \\
0 & 0 & 0 & 0 \\
0 & 0 & -3 & -4
\end{bmatrix} x(t) + \begin{bmatrix}
-5 \\
2 \\
0 \\
0
\end{bmatrix} u(t),
\]

where \(u, x,\) and \(y\) are the input, the state, and the output variables, respectively. Obtain its Kalman decomposition that separates the controllable, uncontrollable, observable, and unobservable portions. Clearly mark the portions on the decomposed system.
Like they say in the movies – the following is based on a true story:

When I was in graduate school, one of my instructors told me he had made a fortune on the following idea:

Given signal $x(t)$, pass it through a linear, time-invariant (LTI) filter with impulse response $h(t)$, and a frequency response $H(f)$. Call the output of this filter $y(t)$.

Digitize $y(t)$ using one of the new-fangled devices called an analog-to-digital converter. Yes, when I was in graduate school, A/Ds were new and exotic devices, the local deli served Mammoth steak sandwiches, and the U.S. did not have universal health care.

Store the output of the analog-to digital converter on a hard disk drive (yes, they were new too, and very expensive, stored very little data, and were huge).

Read the digital signal off the disk drive and put it through a digital-to-analog converter. Call this output $z(t)$. But here’s the trick that made him all the money – read the signal out in the time-reversed order. This is sometimes called a LIFO (last in first out) buffer. Another way to think of this is $z(t) = y(-t)$.

Pass $z(t)$ through a filter that is identical to the original one, with an impulse response of $h(t)$ and a frequency response of $H(f)$. Call the output of this filter $a(t)$.

Pass $a(t)$ through another LIFO buffer, to produce $b(t) = a(-t)$.

My professor claimed that if you put all this in a box, with $x(t)$ as the input, and $b(t)$ as the output, that it looks like a LTI filter. He also claimed this filter had a very interesting phase response.

Answer both of the following questions for full credit. Use the following two pages of the exam for your answers, and to show your work.

A) Was my professor correct, that the system with $x(t)$ as an input, and $b(t)$ as an output is a linear, time-invariant, device? (If you want a Ph.D., you should never believe anything a professor says, unless you can prove it yourself from first principles.)

B) If this system is LTI, what is the frequency response? Find both the amplitude and phase response, and express both as a function of $H(f)$. If the system is not LTI, write “NO NEED TO ANSWER PART B”.

This page left blank intentionally, to allow students additional room to write their answer.
This page left blank intentionally, to allow students additional room to write their answer.
Problem A-22

Communications

When an analog sinusoid, \( x_a(t) = A \cos(\Omega_c t) \), is sampled with a sampling frequency slightly above the Nyquist frequency, that is, \( \Omega_s = 2(\Omega_c + \varepsilon) \), where \( 0 < \varepsilon \ll \Omega_c \), then two interesting things happen: a) the sampled signal has a frequency somewhat offset from that of the original signal and b) it has a slowly varying envelope. Determine the offset frequency, \( \Omega_o \), and the envelope frequency, \( \Omega_e \), of the sampled waveform (in radians per second).

Hint: \( X_s(j\Omega) = \frac{1}{T} \sum_{k=-\infty}^{\infty} X_a(j(\Omega - k\Omega_s)) \) where \( X_a(j\Omega) \) is the Fourier Transform of \( x_a(t) \).
Assume that a message signal \( m(t) \) has a bandwidth \( W \) and power \( P_m \). It is transmitted via a double sideband suppressed carrier (DSB-SC) modulated signal \( X_c(t) \) with the carrier frequency \( f_c \) and gain \( A_c \). It is corrupted by an Additive White Gaussian Noise (AWGN) \( n(t) \) having a two-sided power spectrum density \( N_0/2 \). The receiver uses a pre-detection filter and a coherent demodulation and the output signal is denoted \( Y_o(t) \). Assume that all filters are ideal.

1. Express the modulated signal \( X_c(t) \) in terms of the message and carrier signal. Is this modulation linear or nonlinear?

2. Draw a block diagram of the receiver including the pre-detection filter. Specify filter parameters by labeling the type of filter, center frequency and bandwidth;

3. Sketch the spectrum of the noise at the output of the pre-detection filter;

4. Derive an expression for the demodulated output \( Y_o(t) \).

5. Find the output signal to noise ratio (SNR) in terms of \( W, N_0, A_c, \) and \( P_m \).
A random process is defined as \( x(t) = A \cos(\omega_0 t + \theta) \), where \( A \) and \( \omega_0 \) are constants, and \( \theta \) is uniformly distributed on \([0, 2\pi)\). The mean, variance, and autocorrelation of \( x(t) \) are defined as

\[
\begin{align*}
\mu_x(t) &= E[x(t)] \\
\sigma_x^2(t) &= E[|x(t) - \mu_x(t)|^2], \\
R_{xx}(t, t + \tau) &= E[x(t) \cdot x^*(t + \tau)].
\end{align*}
\]

where the operator \( E[\cdot] \) is the expectation with respect to \( \theta \). The superscript \( * \) denotes conjugate. Note that \( \cos a \cdot \cos b = [\cos(a + b) + \cos(a - b)]/2 \).

1. Derive the mean, variance, and autocorrelation function of \( x(t) \).

2. Is the random process wide sense stationary (WSS)? Why? If so, derive its power spectrum density function \( S_{xx}(f) \) (defined as the Fourier transform of the autocorrelation function).

3. Now assume that \( \theta \) is a constant and \( A \) is Gaussian distributed with zero mean and variance \( \sigma^2 \). All other parameters remain the same. Re-derive the mean, variance and autocorrelation of \( x(t) \). Is this random process WSS?