A series-connected dc motor is depicted in the below figure.

1) The motor operates in the steady state condition so inductors are to be neglected.
2) Electromechanical energy conversion in the armature is assumed to be ideal.
3) Armature reaction is negligible.
4) Back emf can be described as $E_a = K * I_f * \omega_m$ where $K=5$.
5) Armature winding resistance $R_a = 1.3 \ \Omega$
6) $R_f = 4 \times R_f$ where $R_f$ is added externally to adjust the field current. $R_f$ is the field winding resistance.
7) Developed torque $T = 256 \ \text{Nm}$.
8) Mechanical speed $\omega_m = 20 \ \text{rad/s}$

![Diagram of a series-connected dc motor]

a) Find armature current $I_a$ and field current $I_f$ (50 points).
b) Find back emf $E_a$ (25 points).
c) Find $R_f$ (25 points).
A synchronous motor with parameters

\[ \text{poles} = 4 \quad L_{sf} = 100 \text{ mH} \quad X_s = 0.2 \Omega \quad R_s = 0 \Omega \]

is operating at 60-Hz. The scope plot at the right shows one electrical cycle of the \( a \)-phase armature line-to-neutral voltage and current.

Find the armature current phasor \( \hat{I}_a \) and back-emf phasor \( \hat{E}_{sf} \). Calculate the mechanical speed of the rotor in RPM. Compute the electromechanical torque. Sketch the phasor diagram.
Three identical single-phase two-winding transformers, each rated at 50-MVA 39.84 kV/8.66 kV with leakage reactance $X_{eq} = 3.2 \, \Omega$ per phase referred to the HV winding are to be connected in a three-phase bank. The HV side is connected in a wye and the LV winding in a delta. Winding resistances and exciting current may be neglected. A three-phase source is connected to the HV end of the transformer while a rated load is operating at rated voltage at 0.8 power factor lagging on the LV side of the bank.

(a) (5 pts) What is the three-phase bank's MVA rating?

(b) (5 pts) What are the voltage ratings (HV and LV sides) of the three-phase bank?

(c) (10 pts) Working in per units and using base quantities of your own choice, determine the line-line voltage at the source. Neglect the transformer phase shift.
The figure below shows the one-line diagram of a 3-phase power system. The 3-phase power and line-line voltage ratings are also given below:

- **Gen G1:** 400 MVA, 11 kV, $X = 0.2$ pu
- **Gen G2:** 600 MVA, 15 kV, $X = 0.16$ pu
- **Motor M:** 800 MVA, 20 kV, $X = 0.18$ pu
- **Line 1-2:** Series reactance $X = 120 \, \Omega$ per phase
- **Line 2-3:** Series reactance $X = 120 \, \Omega$ per phase
- **Line 2-4:** Series reactance $X = 120 \, \Omega$ per phase
- **T1:** 3-phase, 500 MVA, $12.5 \, \text{kV}_{\text{Y}}/345 \, \text{kV}_{\text{Y}}, X = 0.12$ pu
- **T2:** 3-phase, 600 MVA, $20 \, \text{kV}_{\text{Y}}/345 \, \text{kV}_{\text{Y}}, X = 0.11$ pu
- **T3:** 3-phase, 1000 MVA, $20 \, \text{kV}_{\text{Y}}/345 \, \text{kV}_{\text{Y}}, X = 0.1$ pu

Using a system base of 100 MVA and 12.5 kV in the circuit of G1, draw the impedance diagram for the power system marking all impedances in per unit.
Given source voltage $v_t = \begin{cases} 
0 \text{ V} & t < 0 \\
12 \text{ V} & t \geq 0
\end{cases}$

Determine capacitance voltage

$v = \ldots \ldots \quad \text{V} \quad t > 0$
Redraw the following circuit in frequency domain and determine Thevenin Voltage, $V_{Th}$ and impedance, $Z_{Th}$ for it. Assume $v_s = 20 \cos (120\pi + 60^\circ)$. 
The circuit shown below is a common-source MOSFET amplifier.

(a) Using the given transistor model and assuming the capacitors ($C_i$ and $C_o$) are short circuits at the frequency of interest, draw the small-signal (ac) equivalent circuit, label all elements.

(b) Derive the voltage gain: $A_v = \frac{v_o}{v_i}$

(c) Derive the expression for the input resistance $R_i$ seen by the source $v_i$.
A 3.3 volt precision reference diode is used with an op-amp to generate a stable 13.2 volt source. This requires that the reference diode current be very close to 1ma.

\[
V^+ = 10 \text{ V}
\]

\[
V_0 = 13.2 \text{ V}
\]

(a) Choose suitable standard values from Table D.1 that will work for \( R_2 \) and \( R_3 \).

<table>
<thead>
<tr>
<th>Table D.1</th>
<th>Standard resistance values (( \times 10^3 ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>13</td>
<td>22</td>
</tr>
<tr>
<td>15</td>
<td>24</td>
</tr>
</tbody>
</table>

(b) If the transistors are matched, calculate the value needed for \( R_1 \). State any assumptions you make.
Two concentric metallic spheres form a capacitor. The inner sphere has an outer radius of \( a \) and is maintained at a potential of \( V_0 \). The outer sphere has an inner radius of \( b \) and is maintained at a potential of \( V = 0 \). The medium between the two spheres is free space (\( \varepsilon = \varepsilon_0 \)). In spherical coordinates the electric field components are \( E_r \), \( E_\theta \) and \( E_\phi \). With the aid of Gauss’s law:

1. Evaluate all three electric field components at an observation point \( r \), where \( a < r < b \).
2. Relate the surface charge density, \( \rho_s \), on the inner sphere to the potential value \( V_0 \).
In the transmission line problem shown below, there is an incident wave indicated by $V_1^+$. Find the reflected wave, $V_1^-$, and the transmitted wave, indicated by $V_2^-$, in terms of the line impedances, phase lengths of the lines, and $V_1^+$. Let $\theta_2 = \pi/2$ and $\theta_3 = \pi$. The input line and the output line (with the transmitted wave) may be considered infinitely long. The following quantities may be helpful in the solution: $Z_{in2}$, $Z_{in3}$, $V_1(0)$, $V_2(-\theta_2)$, and $V_2(0)$.
Important physical constants are:

Boltzmann's constant: \( k = 8.62 \times 10^{-5} \text{ eV/K} \)
Electronic charge: \( q = 1.60 \times 10^{-19} \text{ C} \)
Planck's constant: \( h = 4.14 \times 10^{-15} \text{ eV-s} \)
Speed of Light \( c = 2.998 \times 10^{10} \text{ cm/s} \)
Carrier Mobilities of Ge \( \mu_n = 3600 \text{ cm}^2/\text{V-s} \)
\( \mu_p = 650 \text{ cm}^2/\text{V-s} \)
Carrier Mobilities of Si \( \mu_n = 1350 \text{ cm}^2/\text{V-s} \)
\( \mu_p = 480 \text{ cm}^2/\text{V-s} \)
Intrinsic Carrier Concentration of Ge \( n_i = 2.5 \times 10^{13} \text{ cm}^{-3} \text{ at 300 K} \)
Intrinsic Carrier Concentration of Si \( n_i = 1.5 \times 10^{10} \text{ cm}^{-3} \text{ at 300 K} \)

(a) Calculate the resistivity of intrinsic Ge at room temperature.

(b) Calculate the resistivity of intrinsic Si at room temperature.

(c) What is the relationship between the energy gap \( E_g \) for Ge and Si?
(Fill the blank \(<, =, \text{ or } >\)?

\[ E_{g, \text{Ge}} \quad \_\_\_\_\_ \quad E_{g, \text{Si}} \]

(d) Calculate the ratio of the electron diffusion coefficient for Ge to that of Si.

\[ D_{n, \text{Ge}} / D_{n, \text{Si}} = \]

(e) The Ge sample is doped with \( 1 \times 10^{12} \) ionized phosphorus atoms per \( \text{cm}^3 \). Recall that germanium is a column IV material and that phosphorus is a column V material. If \( T = 300 \text{ K} \), determine if the sample is n-type, p-type or intrinsic. Circle the best choice and justify the answer.

\[ \_\_\_\_\_\_\_\_ \quad \_\_\_\_\_\_\_\_ \quad \_\_\_\_\_\_\_\_ \]

(f) The Si sample is doped with \( 1 \times 10^{12} \) ionized phosphorus atoms per \( \text{cm}^3 \). Recall that silicon is a column IV material and that phosphorus is a column V material. If \( T = 300 \text{ K} \), determine if the sample is n-type, p-type or intrinsic. Circle the best choice and justify the answer.

\[ \_\_\_\_\_\_\_\_ \quad \_\_\_\_\_\_\_\_ \quad \_\_\_\_\_\_\_\_ \]
A constant uniform surface current of $\mathbf{J}$, $\text{A/m}^2$, flows on the plane $z = 0$. If the magnetic field is given by

$$
\mathbf{H} = \begin{cases} 
2\hat{x} + 3\hat{y} \text{ A/m} & z > 0 \\
4\hat{x} - 4\hat{y} \text{ A/m} & z < 0 
\end{cases}
$$

What is the value of the surface current?
Problem M-21 (Page 1 of 2) Communications/Signal Processing Code # ________

Answer all four parts of this problem (A through D) for full credit. Show all work and justify your answers for full credit.

You enter a laboratory, and find 4 black boxes laying on a table. The boxes are described below:

Box 1 - Single Input, Single Output, Amplifier. Input voltage: \( x(t) \). Output voltage: \( y(t) \). Input / Output Equation \( y(t) = 10 \times x(t) \)

Box 2 - Dual Input, Single Output, Subtractor. Input voltage \( x_1(t) \) and \( x_2(t) \). Output voltage \( y(t) \). Input / Output Equation \( y(t) = x_1(t) - x_2(t) \)

Box 3 - Power Supply. Produces a constant 10 volts on output.

Box 4 - Oscillator. Produces a 1 volt, 10 Hz, sinewave on output.

A) Using some, or all, of these boxes, draw a block diagram of a single input, single output, system which is **Linear and Time Invariant**. If you think it's impossible to construct such a system from these boxes, explain why it's impossible.

B) Using some, or all, of these boxes, draw a block diagram of a single input, single output, system which is **Non-Linear and Time Invariant**. If you think it's impossible to construct such a system from these boxes, explain why it's impossible.
C) Using some, or all, of these boxes, draw a block diagram of a single input, single output, system which is **Linear and Time Varying**. If you think it's impossible to construct such a system from these boxes, explain why it's impossible.

D) Using some, or all, of these boxes, draw a block diagram of a single input, single output, system which is **Non-Linear and Time Varying**. If you think it's impossible to construct such a system from these boxes, explain why it's impossible.
A sequence, \( x(n) \), has the z-transform

\[
X(z) = \frac{z^{-4}}{(z - 0.3)(z + 0.4)(z - 0.2)}
\]

and region of convergence, \( 0.4 < |z| \).

a) What type of sequence, (e.g. right-handed, left-handed, or two-sided) is \( x(n) \)?

b) Write the contour integral (but, don’t solve it yet) that gives \( x(n) \) from its z-transform and region of convergence.

c) Draw a diagram in the z-plane showing the contour, C, and the poles of the function being integrated in part b).

d) What two cases, that is, what two ranges of \( n \) do you need to consider when you solve the integral of part b)?

   case 1:

   case 2:

e) Now, consider the case where the range of \( n \) includes \(+\infty\). Evaluate the integral of part b) using the residue method. Express your answer using some version of the unit step function, \( u(n) \).

f) Now consider the case where the range of \( n \) includes \(-\infty\). If necessary, to simplify your calculations, you may want to make the change of variables, \( v = \frac{1}{z} \), in the contour integral of part b) and evaluate it using the residue method.

g) Combining the results of e) and f) what is \( x(n) \)?
Consider the multiplexing system shown above, where \( f_i = 6 \text{ kHz} \), \( f_2 = 22 \text{ kHz} \), \( f_c = 1000 \text{ kHz} \), and \( A \) is a positive constant. Assume that the messages have the spectra shown:

a) What type of subcarrier modulation is used?

b) What type of multiplexing is used?

c) What type of RF modulation is used?

d) Sketch the baseband spectrum, \(|X_b(f)|\). Label the frequency axis carefully.

\[ |X_b(f)| \]

\[ f'(\text{Hz}) \]

e) What is the bandwidth of the output signal, \( x_c(t) \)?

\[ B = \]
A set of symbols $S = \{a, b, c, d, e\}$ is found in a discrete source with the probability of occurrence being $P = \{0.1, 0.15, 0.30, 0.16, 0.29\}$.

1. What is the self-information of each symbol?

2. What is the entropy of the discrete source?

3. Use Huffman Coding to encode the symbols.

4. Compute the average coding length of the resulting Huffman code and compare it with the entropy.