Problem M.1  

A round-rotor, three-phase synchronous generator is rated for 60 Hz, 7.2 kV, 25 MVA. Because of field heating limits, excitation voltage $E_a$ is limited to 6.0 kV. Because of stator copper loss, output apparent power is limited to 25 MVA. Synchronous reactance is 1.3 $\Omega$. The generator is connected to a three-phase, 60 Hz, 7.2 kV bus. Useful equations:

$$P_a = \frac{V_a E_a}{X_s} \sin \delta$$

$$Q_a = \frac{V_a E_a}{X_s} \cos \delta - \frac{V_a^2}{X_s}$$

a. Determine the maximum VAR output for this machine if operated as a synchronous condenser. Also find the torque angle and line current magnitude.

b. Determine the minimum excitation voltage and corresponding torque angle to generate 15 MW. Compute the VAR consumption at this operating point and the line current magnitude. Is this a valid operating point within ratings?
The separately excited dc generator depicted in the figure below has the following parameters:

\[ \omega_m = 200 \text{ rad/s} \quad V_f = 12 \text{ V} \quad R_f = 1 \text{ } \Omega \quad R_a = 0.5 \text{ } \Omega \]

When \( R_{fx} \) is set to be 11 \( \Omega \), the no-load terminal voltage of the generator appears to be 100 V.

When a load resistance of 3 \( \Omega \) is connected to the generator and \( R_{fx} \) is adjusted to a new value, the terminal voltage of the generator appears to be 102 V. Find the new value for \( R_{fx} \).
1. Draw the per unit diagram of the system below using a 25MVA, 138kV base in the zone of the transmission line.

![Diagram of electrical system]

You may find the following equation useful:

\[
Z_{pu}^{new} = Z_{pu}^{old} \left( \frac{V_{old}}{V_{base}} \right)^2 \left( \frac{S_{new}}{S_{base}} \right)
\]
A three-phase load draws 200 kW at a power factor of 0.85 lagging from a 440 V line. Find the rating (in kVAR) of a capacitor bank installed in parallel with the load needed to raise the power factor to 0.95 lagging.
Determine the Thevenin Voltage and resistance for the circuit below and calculate the maximum power it can deliver.
For the following ideal transformer circuit, find:

a. The phasor node voltages $V_1$, $V_2$ and $V_3$ if $V_s = 10/0^\circ V$.

b. The impedance seen by the source $V_s$. 
Consider the op-amp circuit shown.

a) Assuming the op-amp is ideal, find $V_o$ in terms of $V_A$ and $V_B$.

(50%)

Answer: $V_o =$

b) Now suppose the op-amp is non-ideal with an input offset voltage of zero, an input bias current of 300nA (flowing into the input terminals), and an input offset current of zero. Find $V_o$ under these conditions if $V_A = V_B = 0$.

(50%)

Answer: $V_o =$
Consider the junction between two transmission lines TL1 and TL2. TL1 has a characteristic impedance $Z_{01}$, and length $\ell_1$, and is fed by a unit step source matched to the characteristic impedance of the line. TL2 has characteristic impedance $Z_{02}$, and length $\ell_2$, and has a matched load. These two transmission line sections are cascaded together. Define a reflection coefficient $\rho_{21}$ at the junction as the ratio of the reflected wave $v_i^-$ to the incident wave $v_i^+$ on TL1, and a transmission coefficient $\tau_{21}$ as the ratio of the outgoing wave $v_2^+$ on TL2 to the incoming wave $v_i^+$ from TL1. Then solve for the reflection and transmission coefficients in terms of the line parameters $Z_{01}$ and $Z_{02}$. What is the relationship between the reflection coefficient and the transmission coefficient? For what case can the transmitted voltage be greater than the reflection coefficient? Does this violate any conservation law? What conservation law must be satisfied.
Problem #M11  Area: Waves & Devices Code #

A slab of crystalline gallium arsenic (GaAs) is doped such that the Fermi level with respect to the middle of the bandgap is -0.1293 eV. The slab is 5 cm in length and 10 mm² in cross-sectional area. \( T = 300 \text{ K} \). Important physical constants are:

- Boltzmann's constant: \( k = 1.38 \times 10^{-23} \text{ J/K} = 8.62 \times 10^{-5} \text{ eV/K} \)
- Planck's constant: \( h = 4.14 \times 10^{-15} \text{ eV-s} \)
- Electronic charge: \( q = 1.60 \times 10^{-19} \text{ C} \)
- Carrier Mobilities: \( \mu_n = 9200 \text{ cm}^2/\text{V-s} \quad \mu_p = 400 \text{ cm}^2/\text{V-s} \)
- Bandgap Energy of Si: \( E_g = 1.42 \text{ eV} \)
- Intrinsic Carrier Concentration: \( n_i = 2.10 \times 10^6 \text{ cm}^{-3} \text{ at 300 K} \)

(a) Is the material n-type, p-type, or intrinsic? Circle the correct choice and justify your answer with a statement (reason).

- **n-type**
- **p-type**
- **intrinsic**

(b) Assume that the doping is done with silicon (Si) and no other dopant. Noting that Si is a column IV material, Ga is a column III material, and P is a column V material, what conditions, if any, are needed regarding the Si dopants? Circle the correct choice.

- Si on Ga site
- Si on As site
- Si on either Ga and As sites
- Si as an interstitial
- Insufficient Information

(c) Calculate the equilibrium minority and majority carrier concentrations.

(d) Calculate the sample resistivity, i.e. \( \rho \).

(e) Answer the following multiple-choice questions. Circle the one best answer.

- The crystal structure of semiconductor GaAs is ???

  - **simple cubic**
  - **diamond**
  - **zincblende**

- The correct units for the diffusion coefficient are ???

  - \((1/\Omega)\)
  - \((\Omega \cdot \text{cm})^{-1}\)
  - \((\Omega/\text{cm})^{-1}\)
  - \((\text{cm}^2/\text{s})\)
  - \((\text{cm}^2/\text{V-s})\)

- As \( T \) increases, the intrinsic carrier concentration of a semiconductor ???

  - **increases**
  - **decreases**
  - **stays the same**
A uniform plane wave propagating in air given by
\[ \vec{E}_i(x) = 600 \pi e^{-j40\pi x - j30\pi z} \hat{y} \text{ (V/m)} \]
is incident on a perfectly conducting plane located at \( x = 0 \). Find the electric and magnetic field vectors of the reflected wave \( \vec{E}_r(x) \) and \( \vec{H}_r(x) \).
A discrete-time control system is described by

\[
\begin{bmatrix}
Y_1(z) \\
Y_2(z)
\end{bmatrix} =
\begin{bmatrix}
z - 0.3 & z + 0.3 \\
z^2 - 0.6z + 0.05 & z - 0.1 \\
0 & z + 0.3 \\
z - 0.2
\end{bmatrix}
\begin{bmatrix}
U_1(z) \\
U_2(z)
\end{bmatrix},
\]

where \( U_1 = Z[u_1] \), \( U_2 = Z[u_2] \), \( Y_1 = Z[y_1] \), and \( Y_2 = Z[y_2] \) are the two input and the two output variables, respectively. Obtain a state-space representation of the system with minimal number of state variables.
Use the Routh-Hurwitz test to find the range of $K$ for which the following characteristic equation is stable.

\[ s^4 + 5s^3 + 2s^2 + 4s + K = 0 \]
Find the complex exponential Fourier Series coefficients for

\[ x(t) = \text{sgn}\{\text{sgn}[10 \cos(2\pi 10t) + 5\sqrt{2}]\} + 10 \]

Where \(\text{sgn}(\cdot)\) is the signum function, defined as

\[ \text{sgn}(y) = \begin{cases} 
-1 & \text{for } y < 0 \\
0 & \text{for } y = 0 \\
+1 & \text{for } y > 0 
\end{cases} \]

Show your work for full credit. If you think it is impossible to find the Fourier Series coefficients for \(x(t)\), explain why it is impossible.
Let 
\[ x[n] = \begin{cases} 1 & n = 0, 1, 2, 3, 4 \\ 0 & \text{elsewhere} \end{cases} \quad \text{and} \quad h[n] = \begin{cases} 1 & n = 0, 1, 2, 3 \\ 0 & \text{elsewhere} \end{cases} \]

We wish to compute the linear convolution of \( x[n] \) and \( h[n] \) using circular convolution from finite sequences \( x[n] \) and \( h[n] \) derived from \( x[n] \) and \( h[n] \).

a) From the non-zero lengths of \( x[n] \) and \( h[n] \) find the minimum finite length, \( N \) of \( x[n] \) and \( h[n] \) to accomplish our goal.

b) Write the finite sequences \( x[n] \) and \( h[n] \) with the minimum \( N \) from part (a)

c) Perform the linear convolution of \( x[n] \) and \( h[n] \) and the \( N \)-point circular convolution of \( x[n] \) and \( h[n] \) from part (b) and show that the output is the same.
A message signal \( m(t) \) with a bandwidth \( W \) of 8 kHz is the input to a narrowband frequency modulator that uses a carrier frequency of 100 kHz. The narrowband FM output of this modulator \( x_1(t) \) is to be converted to wideband FM. \( x_1(t) \) is the input to a \( \times 2000 \) frequency multiplier. The output of the frequency multiplier, \( x_2(t) \), is the input to a mixer which contains a local oscillator operating at 195 MHz. The output of the mixer \( x_c(t) \) is wideband FM with a deviation ratio \( D = 20 \) and with a carrier frequency less than 300 MHz.

a) What is the carrier frequency for the signal \( x_2(t) \)?
(10%)

Answer: \( f_2 = \) 

b) What is the carrier frequency for the output \( x_c(t) \)?
(15%)

Answer: \( f_c = \) 

c) What is the deviation ratio \( D_2 \) for the signal \( x_2(t) \)?
(10%)

Answer: \( D_2 = \) 

d) What is the approximate bandwidth of the signal \( x_2(t) \)?
(15%)

Answer: \( B_2 = \) 

e) What is the deviation ratio \( D_1 \) for the signal \( x_1(t) \)?
(15%)

Answer: \( D_1 = \) 

f) What is the approximate bandwidth of the signal \( x_1(t) \)?
(15%)

Answer: \( B_1 = \) 

g) What must be the center frequency and bandwidth of the bandpass filter?
(20%)

Answer: Center frequency = 
Bandwidth = 
Figure 1 shows three baseband signal pulses.

1. Prove or disprove that the pulses are pair-wise orthogonal.

2. If there are orthogonal pairs, what value of $T$ ensures that they are orthonormal?

3. Sketch the signals $x(t) = P_1(t) - P_2(t) + P_3(t)$ and $y(t) = P_1(t) + P_2(t)$. Clearly mark all relevant values on the horizontal axis and vertical axis.

Figure 1: Baseband signal pulses.