1. For \( V = 18 \text{ V} \), \( R_1 = 39 \text{ k}\Omega \), \( R_2 = 43 \text{ k}\Omega \), and \( R_3 = 11 \text{ k}\Omega \), use Ohm’s Law, voltage division, and current division to solve for \( V_1 \), \( V_2 \), \( I_1 \), \( I_2 \), and \( I_3 \).

\[
V_1 = 18 \cdot \frac{39 \text{ k}\Omega}{39 \text{ k}\Omega + 43 \text{ k}\Omega} = 14.7 \text{ V} \\
V_2 = 18 \cdot \frac{43 \text{ k}\Omega \parallel 11 \text{ k}\Omega}{39 \text{ k}\Omega + 43 \text{ k}\Omega \parallel 11 \text{ k}\Omega} = 3.30 \text{ V} \\
I_1 = \frac{18}{39 \text{ k}\Omega + 43 \text{ k}\Omega \parallel 11 \text{ k}\Omega} = 376.8 \mu\text{A} \\
I_2 = \frac{11 \text{ k}\Omega}{43 \text{ k}\Omega + 11 \text{ k}\Omega} I_1 = 76.8 \mu\text{A} \\
I_3 = \frac{43 \text{ k}\Omega}{43 \text{ k}\Omega + 11 \text{ k}\Omega} I_1 = 300 \mu\text{A}
\]

2. For \( I = 250 \mu\text{A} \), \( R_1 = 100 \text{ k}\Omega \), \( R_2 = 68 \text{ k}\Omega \), and \( R_3 = 82 \text{ k}\Omega \), use Ohm’s Law, voltage division, and current division to solve for \( I_1 \), \( I_2 \), and \( V_3 \).

\[
I_1 = 250 \mu\text{A} \cdot \frac{68 \text{ k}\Omega + 82 \text{ k}\Omega}{100 \text{ k}\Omega + 68 \text{ k}\Omega + 82 \text{ k}\Omega} = 150 \mu\text{A} \\
I_2 = 250 \mu\text{A} \cdot \frac{100 \text{ k}\Omega}{100 \text{ k}\Omega + 68 \text{ k}\Omega + 82 \text{ k}\Omega} = 100 \mu\text{A} \\
V_3 = 100 \mu\text{A} \times 82 \text{ k}\Omega = 8.2 \text{ V}
\]

3. It is given that \( R_1 = 1 \text{ k}\Omega \), \( A_v = 10^{-4} \), \( A_i = 50 \), and \( R_2 = 40 \text{ k}\Omega \).

(a) With \( i_o = 0 \), use superposition to write the equations for \( i_1 \) and \( v_{o(oc)} \). Solve the equations for \( v_{o(oc)} \) as a function of \( v_s \).

\[
i_1 = \frac{v_s - A_v v_o}{R_1} \\
v_{o(oc)} = -A_i i_1 R_2
\]
\[ v_{o(oc)} = \frac{-A_v R_2}{1 - A_v A_i \frac{R_2}{R_1}} v_s = -2500v_s \]

(b) With \( v_o = 0 \), use superposition to write the equations for \( i_1 \) and \( i_{o(scc)} \). Solve the equations for \( i_{o(scc)} \) as a function of \( v_s \).

\[ i_{o(scc)} = -\frac{A_v v_s}{R_1} = -0.05v_s \]

(c) Use the solutions for \( v_{o(oc)} \) and \( i_{o(scc)} \) to show that \( r_{out} = 50k\Omega \).

(d) Show that the Thévenin equivalent circuit seen looking into the output is a voltage source \( v_{o(oc)} = -2500v_s \) in series with a resistance \( r_{out} = 50k\Omega \).

(e) Show that the Norton equivalent circuit seen looking into the output is a current source \( i_{o(scc)} = -0.05v_s \) in parallel with a resistance \( r_{out} = 50k\Omega \).

(f) If a load resistor \( R_L = 20k\Omega \) is connected from the output node to ground, use both the Thévenin and the Norton equivalent circuits to show that \( v_o = -714.3v_s \) for both.

4. It is given that \( R_1 = 10\,\Omega \), \( G_m = 0.5\,\text{S} \), \( R_2 = 5\,\Omega \), \( R_3 = 50\,\Omega \), and \( A_v = 4 \).

(a) With \( i_o = 0 \), use superposition to solve for \( v_{o(oc)} \) as a function of \( v_s \).

\[ v_{o(oc)} = \frac{R_3}{R_2 + R_3} v_s + A_v v_s \frac{R_2}{R_2 + R_3} = \frac{R_3 + A_v R_2}{R_2 + R_3} v_s = 1.273v_s \]

(b) With \( v_o = 0 \), use superposition to solve for \( i_{o(scc)} \) as a function of \( v_s \).

\[ i_{o(scc)} = \frac{v_s}{R_2} + \frac{A_v v_s}{R_3} = v_s \left( \frac{1}{R_2} + \frac{A_v}{R_3} \right) = 0.28v_s \]

(c) Solve for \( r_{out} \).

\[ r_{out} = \frac{v_{o(oc)}}{i_{o(scc)}} = 4.545\,\Omega \]

(d) Show that the Thévenin equivalent circuit seen looking into the output is a voltage source \( v_{o(oc)} = 1.273v_s \) in series with a resistance \( r_{out} = 4.545\,\Omega \).

(e) Show that the Norton equivalent circuit seen looking into the output is a current source \( i_{o(scc)} = 0.28v_s \) in parallel with a resistance \( r_{out} = 4.545\,\Omega \).

(f) If a load resistor \( R_L = 5\,\Omega \) is connected from the output node to ground, show \( v_o = 0.667v_s \).

5. It is given that \( g_m = 0.025\,\text{S} \) and \( R_1 = 40\,\text{k\Omega} \).
(a) With the output terminals open-circuited, use superposition of $v_s$ and $g_m v$ to write equations for $v_{O(oc)}$ and $v$. Solve the two equations for $v_{O(oc)}$ as a function of $v_S$.

$$v_{O(oc)} = v_s + g_m v R_1 \quad v = 0 - g_m v R_1 \implies v = 0 \implies v_{O(oc)} = v_s$$

(b) For the output terminals short-circuited, use superposition of $v_s$ and $g_m v$ to write equations for $i_{O(sc)}$ and $v$. Solve the two equations for $i_{O(sc)}$ as a function of $v_S$.

$$i_{O(sc)} = \frac{v_s}{R_1} + g_m v \quad v = v_s - 0 \implies v = v_s \implies i_{O(sc)} = v_s \left( \frac{1}{R_1} + g_m \right) = \frac{v_s}{39.96}$$

(c) Solve for the Thévenin equivalent circuit looking into the output terminals.

$$v_{O(oc)} = v_s \text{ in series with } r_{out} = 39.96 \Omega$$

(d) Solve for the Norton equivalent circuit looking into the output terminals.

$$i_{O(sc)} = \frac{v_s}{39.96} \text{ in parallel with } r_{out} = 39.96 \Omega$$

6. It is given that $\beta = 80$, $R_1 = 75 \, \text{k}\Omega$, and $R_2 = 39 \, \text{k}\Omega$.

(a) With the output terminals open-circuited, use superposition of $v_s$ and $\beta i$ to write equations for $v_{O(oc)}$ and $i$. Solve the two equations for $v_{O(oc)}$ as a function of $v_S$ by eliminating $i$.

$$v_{O(oc)} = 0 - \beta i R_2 \quad i = -\frac{v_s}{R_1} \implies v_{O(oc)} = \frac{\beta R_2}{R_1} v_S = 41.6 v_S \text{ V}$$

(b) With the output terminals short-circuited, use superposition of $v_s$ and $\beta i$ to write equations for $i_{O(sc)}$ and $i$. Solve the two equations for $i_{O(sc)}$ as a function of $v_S$ by eliminating $i$.

$$i_{O(sc)} = 0 - \beta i \quad i = -\frac{v_s}{R_1} \implies i_{O(sc)} = \frac{\beta}{R_1} v_S = 1.067 v_S \text{ mA}$$

(c) Solve for the Thévenin equivalent circuit looking into the output terminals. [$v_{O(oc)} = 41.6v_s \text{ in series with } 39 \, \text{k}\Omega$]

(d) Solve for the Norton equivalent circuit looking into the output terminals. [$i_{O(sc)} = 1.067 \times 10^{-3} v_s \text{ in parallel with } 39 \, \text{k}\Omega$]
7. It is given that \( g_m = 0.002 \text{S} \), \( R_1 = 100 \text{k}\Omega \), and \( R_2 = 1 \text{M}\Omega \).

(a) With the output terminals open-circuited, solve for \( v \) as a function of \( i_S \) and \( v_{O(oc)} \) as a function of \( v \). Solve the two equations for \( v_{O(oc)} \) as a function of \( i_s \) by eliminating \( v \).

\[
v_{O(oc)} = -g_m v R_2 \quad v = i_S R_1 \Rightarrow v_{O(oc)} = -g_m i_S R_2 R_1 = -2 \times 10^8 i_S
\]

(b) With the output terminals short-circuited, solve for \( v \) as a function of \( i_S \) and \( i_{O(sc)} \) as a function of \( v \). Solve the two equations for \( i_{O(sc)} \) as a function of \( i_S \) by eliminating \( v \).

\[
i_{O(sc)} = -g_m v \quad v = i_S R_1 \Rightarrow i_{O(sc)} = -g_m i_S R_1 = -200 i_S
\]

(c) Show that the Thévenin equivalent circuit looking into the output terminals is a voltage source \( v_{O(oc)} = -2 \times 10^8 i_S \) in series with a resistance \( r_{out} = 1 \text{M}\Omega \).

(d) Show that the Norton equivalent circuit looking into the output terminals is a current source \( i_{O(sc)} = -200 i_S \) in parallel with a resistance \( r_{out} = 1 \text{M}\Omega \).

8. It is given that \( R_1 = 3 \text{k}\Omega \), \( R_2 = 2 \text{k}\Omega \), and \( g_m = 0.1 \). This problem illustrates two solutions for the input resistance to the circuit. In one solution, the source is a voltage source. In the other it is a current source.

(a) Use superposition of \( v_S \) and \( g_m v_1 \) to solve for \( i_S \).

\[
i_S = \frac{v_S}{R_1 + R_2} - g_m v_1 \frac{R_2}{R_1 + R_2}
\]

(b) Use superposition of \( v_S \) and \( g_m v_1 \) to solve for \( v_1 \).

\[
v_1 = \frac{v_S R_1}{R_1 + R_2} - g_m v_1 R_1 \| R_2 \Rightarrow v_1 = v_S \frac{R_1}{R_1 + R_2} \times \frac{1}{1 + g_m R_1 \| R_2}
\]

(c) Solve the two equations for \( i_S \) as a function of \( v_S \) by eliminating \( v_1 \).

\[
i_S = \frac{v_S}{R_1 + R_2} \left( 1 - \frac{g_m R_2}{R_1 + R_2} \frac{R_1}{1 + g_m R_1 \| R_2} \right) = \frac{v_S}{R_1 + R_2} \left( 1 - \frac{g_m R_1 \| R_2}{R_1 + R_2} \right)
\]

\[
i_S = \frac{v_S}{R_1 + R_2} \frac{1}{1 + g_m R_1 \| R_2} = \frac{605 \text{k}\Omega}{605 \text{k}\Omega}
\]

(d) Solve for the input resistance to the circuit.

\[
r_{in} = \frac{v_S}{i_S} = 605 \text{k}\Omega
\]
(e) Replace $v_S$ with an independent current source $i_S$. Repeat the problem to solve for $r_{in}$. Which solution is simpler?

$$v_S = i_S (R_1 + R_2) + g_m v_1 R_2 \quad v_1 = i_S R_1 \implies v_S = i_S (R_1 + R_2 + g_m R_1 R_2)$$

$$r_{in} = \frac{v_S}{i_S} = R_1 + R_2 + g_m R_1 R_2 = 605 \, \text{kΩ}$$

9. The figure shows an amplifier equivalent circuit. It is given that $A_i = 0.99$, $R_S = 1 \, \text{kΩ}$, $R_1 = 25 \, \Omega$, $R_2 = 100 \, \Omega$, and $R_3 = 30 \, \text{kΩ}$.

(a) With $R_L = \infty$, use superposition of $v_s$ and $A_i i_\alpha$ to show that $v_{o(oc)}$ and $i_\alpha$ are given by

$$v_{o(oc)} = v_s \frac{R_2}{R_S + R_1 + R_2} - A_i i_\alpha \left( R_3 + \frac{R_1}{R_S + R_1 + R_2} R_2 \right)$$

$$= \frac{v_s}{11.25} - 29702.2 i_\alpha$$

$$i_\alpha = \frac{v_s}{R_S + R_1 + R_2 + A_i i_\alpha} \frac{R_S + R_2}{R_S + R_1 + R_2}$$

$$= \frac{v_s}{1125} + \frac{i_\alpha}{1.03306}$$

(b) Solve the equations to show that $v_{o(oc)} = -824.97 v_s$.

(c) With $R_L = 0$, use superposition of $v_s$ and $A_i i_\alpha$ to show that $i_{o(sc)}$ and $i_\alpha$ are given by

$$i_{o(sc)} = \frac{v_s}{R_S + R_1 + R_2 \| R_3 R_2 + R_3} - A_i i_\alpha \left( 1 - \frac{R_S}{R_S + R_1 + R_2 \| R_3} \frac{R_2}{R_2 + R_3} \right)$$

$$= \frac{v_s}{338525} - \frac{i_\alpha}{1.01309}$$

$$i_\alpha = \frac{v_s}{R_S + R_1 + R_2 \| R_3 + A_i i_\alpha R_S}{R_S + R_1 + R_2 \| R_3}$$

$$= \frac{v_s}{1124.67} - \frac{i_\alpha}{1.13603}$$

(d) Solve the equations to show that $i_{o(sc)} = -v_s / 136.486$.

(e) Solve for $r_{out} = v_{o(oc)}/i_{o(sc)}$. [$r_{out} = 112.597 \, \text{kΩ}$]

(f) With $R_L = 10 \, \text{kΩ}$, solve for $v_o$. [$v_o = -67.2913v_s$]
10. For the circuit shown, it is given that \( i_s = 4 \text{ mA} \), \( R_1 = 2 \text{ k}\Omega \), \( R_2 = 1 \text{ k}\Omega \), \( R_3 = 9 \text{ k}\Omega \), and \( g_m = 0.005 \text{ S} \).

(a) Use superposition to solve for \( v_{oc} \). Express your answer in symbolic form.

\[ v_1 = i_s [R_1 \parallel (R_2 + R_3)] + g_m v_1 \frac{R_2}{R_1 + R_2 + R_3} \]

\[ = i_s \frac{R_1}{R_1 \parallel (R_2 + R_3)} - g_m v_1 \frac{R_2}{R_1 + R_2 + R_3} \]

\[ v_{oc} = i_s \frac{R_1}{R_1 + R_2 + R_3} - g_m v_1 \frac{R_2}{R_1 + R_2 + R_3} \]

(b) Use superposition to solve for \( i_{oc} \). Express your answer in symbolic form.

\[ v_1 = (i_s + g_m v_1) R_1 \parallel R_2 = i_s \frac{R_1 \parallel R_2}{1 - g_m R_1 \parallel R_2} \]

\[ i_{oc} = i_s \frac{R_1}{R_1 + R_2} - g_m v_1 \frac{R_2}{R_1 + R_2} \]

(c) Solve for the Thévenin equivalent circuit seen looking into the output terminal. Express your answer in numerical form.

\[ v_{th} = v_{oc} = -144 \text{ V} \]

\[ R_{th} = \frac{v_{oc}}{i_{oc}} = -3150 \text{ } \Omega \]

(d) Solve for the Norton equivalent circuit seen looking into the output terminal. Express your answer in numerical form.

\[ i_{nor} = i_{oc} = 4.571 \text{ mA} \]

\[ R_{nor} = \frac{v_{oc}}{i_{oc}} = -3150 \text{ } \Omega \]

(e) If a load resistor \( R_L = 9 \text{ k}\Omega \) is connected to the output, what is the load voltage?

\[ v_L = v_{th} \frac{R_L}{R_{th} + R_L} = i_{nor} R_{nor} \parallel R_L = 57.6 \text{ V} \]

11.
(a) For the circuit of figure (a), show that
\[
    \begin{align*}
    i_b &= (1 - \alpha) i_e' \\
    i_e' &= \frac{v_{tb} - v_e}{(1 - \alpha) R_{tb} + r_e} \\
    i_0 &= \frac{v_e - v_c}{r_0} \\
    i_c &= \alpha i_e' + i_0 \\
    i_e &= i_e' + i_0
    \end{align*}
\]

(b) For the circuit of figure (b), show that $i_e', i_e$, and $i_c$ are the same as those in figure (a) provided $r_e'$ is given by
\[
r_e' = (1 - \alpha) R_{tb} + r_e
\]

(a) For the circuit of figure (a), use superposition of $v_c$, $\alpha i_e'$, $v_{tb}$, and $v_{te}$ to show that
\[
    i_c = \frac{v_c}{r_0 + r_e' || R_{te}} + \alpha i_e' - \frac{v_{tb}}{r_e' + R_{te} || r_0} + \frac{R_{te}}{r_0 + r_e' || R_{te}} \frac{v_{te}}{r_0 + r_e' || R_{te}} - \frac{v_{te}}{r_0 + r_e' || R_{te}} \frac{r_e'}{r_e' + r_0}
\]
\[
    i_e' = \frac{v_{tb}}{r_e' + R_{te} || r_0} - \frac{v_{te}}{r_0 + r_e' || r_0} - \frac{v_{te}}{r_0 + r_e' || R_{te}} + \frac{v_{te}}{r_0 + r_e' || R_{te}} \frac{R_{te}}{r_e' + r_0}
\]

(b) Substitute the $i_e'$ into the $i_c$ equation to show that
\[
    i_c = \frac{v_{tb}}{r_e' + R_{te} || r_0} \left( \alpha - \frac{R_{te}}{r_e' + R_{te} || r_0} \right) - \frac{v_{te}}{r_e' + R_{te} || r_0} \frac{\alpha r_0 + r_e'}{r_0 + r_e'} + \frac{v_c}{r_0 + r_e' || R_{te}} \left( 1 - \frac{\alpha R_{te}}{r_e' + R_{te}} \right)
\]

(c) Show that the circuit of figure (b) gives the same value for $i_c$ provided
\[
    i_c = G_{mb} v_{tb} - G_{me} v_{te} + \frac{v_c}{r_{ic}} \\
    G_{mb} = \frac{1}{r_e' + R_{te} || r_0} \left( \alpha - \frac{R_{te}}{R_{te} + r_0} \right) \\
    G_{me} = \frac{1}{R_{te} + r_e' || r_0} \frac{\alpha r_0 + r_e'}{r_0 + r_e'} \\
    r_{ic} = \frac{r_0 + r_e' || R_{te}}{r_e' + R_{te}}
\]
(d) If $\beta$ is sufficiently large, show that $G_{mb} = G_{me} = G_m$, where $G_m$ is given by

$$G_m = \frac{1}{r_e' + R_{te}}$$

13.

(a) For the circuit of figure (a), use superposition of $v_{tb}$, $i_e$, and $\alpha i_e'$, to show that

$$v_e = v_{tb} \frac{r_0 + R_{te}}{r_e' + r_0 + R_{te}} - i_e \left[ r_e' \left( r_0 + R_{te} \right) \right] - \alpha i_e' \frac{R_{te} r_e'}{R_{te} + r_0 + r_e'}$$

$$i_e' = \frac{v_{tb} - v_e}{r_e'}$$

(b) Eliminate $i_e'$ between the equations to show that

$$v_e \left( 1 - \frac{\alpha R_{te}}{R_{te} + r_0 + r_e'} \right) = v_{tb} \frac{r_0 + (1 - \alpha) R_{te}}{r_0 + r_e' + R_{te}} - i_e \left[ r_e' \left( r_0 + R_{te} \right) \right]$$

(c) Show that the above equation simplifies to

$$v_e = v_{tb} \frac{r_0 + (1 - \alpha) R_{te}}{r_0 + r_e' + (1 - \alpha) R_{te}} - i_e \frac{r_e' \left( r_0 + R_{te} \right)}{r_e' + r_0 + (1 - \alpha) R_{te}}$$

(d) Show that the circuit of figure (b) gives the same value for $v_2$ provided

$$v_{e(oc)} = v_{tb} \frac{r_0 + (1 - \alpha) R_{te}}{r_0 + r_e' + (1 - \alpha) R_{te}} \quad r_{ie} = \frac{r_e' \left( r_0 + R_{te} \right)}{r_e' + r_0 + (1 - \alpha) R_{te}}$$

(e) If $r_0$ is sufficiently large, show that the above answers reduce to

$$v_{e(oc)} = v_{tb} \quad r_{ie} = r_e'$$
14. (a) For the circuit of figure (a), use superposition of $v_{te}$, $i_b$, and $\beta i_b$ to show that

$$v_b = v_{te} \frac{r_0 + R_{tc}}{R_{te} + r_0 + R_{tc}} + i_b \left[ r_\pi + R_{te} \| (r_0 + R_{tc}) \right] + \beta i_b \frac{r_0 R_{te}}{r_0 + R_{te} + R_{tc}}$$

(b) Show that the equation for $v_b$ simplifies to

$$v_b = v_{te} \frac{r_0 + R_{tc}}{r_0 + R_{te} + R_{tc}} + i_b \left[ r_\pi + R_{te} \frac{1 + \beta}{r_0 + R_{te} + R_{tc}} \right]$$

(c) Show that the circuit of figure (b) gives the same value for $v_b$ provided

$$v_{b(oc)} = v_{te} \frac{r_0 + R_{tc}}{r_0 + R_{te} + R_{tc}} \quad r_{ib} = r_\pi + R_{te} \frac{1 + \beta}{r_0 + R_{te} + R_{tc}}$$

(d) If $r_0$ is sufficiently large, show that the above answers reduce to

$$v_{b(oc)} = v_{te} \quad r_{ib} = r_\pi + (1 + \beta) R_{te}$$

15. A diode has the parameters $I_S = 10\text{fA}$, $n = 2$, and $V_T = 25\text{mV}$.

(a) Calculate $r_d$ for $V_D = 0.6\text{V}$.

$$r_d = \frac{nV_T}{I_D + I_S} = \frac{nV_T e^{-V_D/nV_T}}{I_S} = 30.72 \text{M}\Omega$$

(b) Calculate $r_d$ for $V_D = 0$.

$$r_d = \frac{nV_T}{I_S} = 5 \times 10^{12} \text{}\Omega$$

(c) At what voltage does $r_d$ exceed $10^{15} \text{\Omega}$?

$$V_D = nV_T \ln \left( \frac{nV_T}{I_S r_d} \right) = -0.265 \text{V}$$
16. A diode current-controlled attenuator circuit is shown. It is given that \( R = 20 \, \text{k}\Omega \). The diode parameters are \( n = 2 \) and \( V_T = 0.025 \, \text{V} \).

![Diode Current-Controlled Attenuator Circuit Diagram]

(a) Calculate the bias current which will provide a small-signal attenuation of 20 dB, i.e. \( v_o/v_s = 0.1 \).

\[
I = \frac{2nV_T}{R} \left[ \left( \frac{v_o}{v_s} \right)^{-1} - 1 \right] = 45 \, \mu\text{A}
\]

(b) If the current is halved, what is the new attenuation? (-14.8 dB). (c) If the current is doubled, what is the new attenuation? (-25.6 dB)

17. A diode has the current \( I_{D_1} = 1 \, \text{mA} \) for \( V_{D_1} = 0.55 \, \text{V} \) and \( I_{D_2} = 2 \, \text{mA} \) for \( V_{D_2} = 0.58 \, \text{V} \). If \( I_S \ll I_{D_1} \), determine the ideality factor or emission coefficient \( n \) and the saturation current \( I_S \).

\[
n = \frac{V_{D_2} - V_{D_1}}{V_T \ln (I_{D_2}/I_{D_1})} = 1.73
\]

\[
I_S = \frac{I_{D_1}}{\exp (V_{D_1}/nV_T)} = \frac{I_{D_2}}{\exp (V_{D_2}/nV_T)} = 3.03 \, \text{nA}
\]

18. The diagram shows a zener diode regulator. It is given that \( V_1 = 35 \, \text{V} \). The diode has the zener voltage \( V_Z = 24 \, \text{V} \). The load resistance varies between the limits \( 500 \, \Omega \leq R_L \leq 10 \, \text{k}\Omega \).

![Zener Diode Regulator Diagram]

(a) Calculate \( R_1 \) if \( I_Z \) is to have a value that is no smaller than 10 mA. Note that \( I_1 \) is a constant once \( R_1 \) is determined and \( I_1 = I_Z + I_L \). Thus the minimum value of \( I_Z \) occurs when \( I_L \) is a maximum (when \( R_L \) is a minimum) because this makes \( I_Z \) have the smallest value.

\[
R_1 = \frac{35 \, \text{V} - 24 \, \text{V}}{0.01 \, \text{A} + 24 \, \text{V}/500 \, \Omega} = 190 \, \Omega
\]

(b) What is the power dissipation in \( R_1 \) and the maximum power dissipation in the zener diode? Note that \( I_1 \) is a constant and \( I_1 = I_Z + I_L \). Thus the maximum dissipation in the zener diode occurs when \( I_L \) is its smallest value because this makes \( I_Z \) have the largest value.

\[
P_1 = \frac{(35 \, \text{V} - 24 \, \text{V})^2}{190 \, \Omega} = 0.637 \, \text{W}
\]

\[
P_{Z_{\text{max}}} = 24 \, \text{V} \left( \frac{35 \, \text{V} - 24 \, \text{V}}{190 \, \Omega} - \frac{24 \, \text{V}}{10 \, \text{k}\Omega} \right) = 1.33 \, \text{W}
\]

19. Calculate the values of \( \beta \) and \( I_S \) for the transistor shown if \( V_{CB} = V_{BE} = 0.7 \, \text{V} \), \( I_B = 0.2 \, \text{mA} \), and \( I_E = 10 \, \text{mA} \).
20. Calculate the values of $\beta$ and $I_S$ for the transistor shown if $V_{EB} = V_{BC} = 0.7 \, V$, $I_B = 50 \, \mu A$, and $I_C = 2.5 \, mA$.

$$\beta = \frac{10 \, mA - 0.2 \, mA}{0.2 \, mA} = 49 \quad I_S = \frac{9.8 \times 10^{-3}}{\exp(0.7/0.025)} = 6.78 \times 10^{-15} \, A$$

21. Calculate the collector, emitter, and base currents if $V^+ = 3.3 \, V$, $V_{EE} = -3.3 \, V$, $V_{BE} = 0.7 \, V$, $R_E = 47 \, k\Omega$, and $\beta = 90$.

$$I_E = \frac{-0.7 \, V - (-3.3 \, V)}{47 \, k\Omega} = 55.3 \, \mu A \quad I_B = \frac{55.3 \, \mu A}{91} = 0.608 \, \mu A \quad I_C = I_E - I_B = 54.7 \, \mu A$$

22. An npn transistor is operated in the active mode with a base current of $3 \, \mu A$. It is found that $I_C = 240 \, \mu A$ for $V_{CE} = 5 \, V$ and $I_C = 265 \, \mu A$ for $V_{CE} = 10 \, V$. What are the values of $\beta_0$ and $V_A$ for this transistor? [$\beta_0 = 71.7$, $V_A = 43.1 \, V$]

23. A BJT has the parameters $\beta_0 = 75$, $V_A = 100 \, V$, and $V_{CE} = 10 \, V$.

(a) Calculate $I_C$ for $r_\pi = 10 \, k\Omega$.

$$I_B = \frac{V_T}{r_\pi} = 2.5 \, \mu A \quad I_C = \beta_0 \left(1 + \frac{V_{CE}}{V_A}\right) I_B = 0.2063 \, mA$$
(b) Calculate the values of \( g_m \) and \( r_0 \).

\[
g_m = \frac{I_C}{V_T} = \frac{1}{121.2} \quad r_0 = \frac{V_A + V_{CE}}{I_C} = 533.3 \, \text{k}\Omega
\]

(c) Calculate \( \alpha \) and \( r_e \).

\[
\alpha = \frac{\beta}{1 + \beta} = \frac{\beta_0 \left(1 + \frac{V_{CE}}{V_A}\right)}{1 + \beta_0 \left(1 + \frac{V_{CE}}{V_A}\right)} = 0.9880
\]

\[
r_e = \frac{V_T}{I_E} \text{ or } \frac{V_T}{(1 + \beta) I_B} \text{ or } \frac{r_\pi}{1 + \beta_0 \left(1 + \frac{V_{CE}}{V_A}\right)} = 119.8 \, \Omega
\]

24. The output characteristics of a BJT are shown.  
(a) Determine \( \beta_0 \) and \( V_A \).  \([\beta_0 = 120, V_A = 30 \, \text{V}]\)  
(b) Calculate \( \beta \) at \( i_B = 4 \, \text{\mu A} \) and \( V_{CE} = 5 \, \text{V} \).  \([135] \)  
(c) Calculate \( \beta \) at \( i_B = 8 \, \text{\mu A} \) and \( V_{CE} = 15 \, \text{V} \).  \([225] \)

25. (a) Calculate the drain current in an NMOS transistor if \( K = 125 \, \text{\mu A/V}^2 \), \( V_{TO} = -2 \, \text{V} \), \( \lambda = 0 \), \( V_{GS} = 0 \, \text{V} \), and \( V_{DS} = 6 \, \text{V} \).  \([0.5 \, \text{mA}]\)  
(b) Repeat assuming \( \lambda = 0.025 \, \text{V}^{-1} \).  \([0.575 \, \text{mA}]\)

26. An n-channel MOSFET has \( K = 125 \, \text{\mu A/V}^2 \), \( V_{TO} = 1 \, \text{V} \), and \( \lambda = 0.02 \, \text{V}^{-1} \). At what drain current will the MOSFET no longer be able to provide any voltage gain when connected as a common-source amplifier? Note, the maximum gain is denoted by \( \mu_F \) and it is given by \( \mu_F = g_m r_0 \). The object here is to determine the maximum \( I_D \) such that \( \mu_F \leq 1 \). This will require you to select \( V_{DS} \) that minimizes \( \mu_F \) before solving for \( I_D \).  \([1.25 \, \text{A}]\)

27. A common-source amplifier has the drain load resistance \( R_D = 60 \, \text{k}\Omega \) and a power supply voltage \( V^+ = 18 \, \text{V} \). At what Q-point will \( r_{out} = 50 \, \text{k}\Omega \) if the transistor has \( \lambda = 0.02 \, \text{V}^{-1} \)? Use the relations \( r_0 = \left(\lambda^{-1} + V_{DS}\right) / I_D \), \( V_{DS} = 18 - I_D R_D \), and \( r_{out} = r_0 \| R_D \).  \([0.189 \, \text{mA}, 6.67 \, \text{V}]\)
28. The drain current in an n-channel JFET is given by \( i_D = I_{DSS} (1 - v_{GS}/V_P)^2 \) for \( v_{GS} > V_P \) and \( i_D = 0 \) for \( v_{GS} \leq V_P \), where \( I_{DSS} = I_{DSS0} (1 + \lambda v_{DS}) \). For the n-channel JFET, \( V_P < 0 \). Show that the expression for the JFET current can be represented in exactly the same form as that of the MOSFET using the substitution \( V_{TO} = V_P \) and \( K = I_{DSS}/V_P^2 \).

29. (a) Write the bias equation and solve for \( I_C \) and \( V_{CB} \) for the values \( V^+ = 18 \text{ V}, R_E = 1 \text{ k} \Omega, R_1 = 130 \text{ k} \Omega, R_2 = 36 \text{ k} \Omega, R_C = 2.4 \text{ k} \Omega, V_{BE} = 0.7 \text{ V}, \) and \( \beta = 99 \). (b) Is the BJT biased in the active mode? \( [I_C = 2.474 \text{ mA}, V_{CB} = 8.863 \text{ V}] \)

![Diagram of a BJT circuit](image)

30. Add a second npn transistor to the circuit of problem 29 as shown below. (a) Show that \( I_{C1} \) does not change. (b) Show that \( V_{BB2} = V^+ - I_{C1} R_C \) and \( R_{BB2} = R_C \). (c) For \( R_3 = 1 \text{ k} \Omega, \) and the same \( V_{BE} \) and \( \beta \) as in problem 29, write the bias equation for the second transistor and solve for \( I_{E2} \). (c) Solve for \( V_{CB} \) for both transistors and verify they are in the active mode. \([I_{E2} = 11.10 \text{ mA}, V_{CB2} = 6.204 \text{ V}, V_{CB1} = 8.597 \text{ V}]\)

![Diagram of a BJT circuit with a second transistor](image)

31. (a) Show that
\[
V_{BB} = V^+ \frac{R_2}{R_1 + R_2 + R_C} - I_C \frac{R_C}{R_C + R_1 + R_2} \times R_2 \quad R_{BB} = (R_1 + R_C) || R_2
\]
\[
V_{CC} = V^+ \frac{R_1 + R_2}{R_C + R_1 + R_2} - I_B \frac{R_2}{R_C + R_1 + R_2} \times R_C \quad R_{CC} = R_C || (R_1 + R_2)
\]
(b) For \( \beta = 99 \) and \( \beta = \infty \) and \( R_1 = 10 \text{ k} \Omega, R_2 = 47 \text{ k} \Omega, R_C = 1.5 \text{ k} \Omega, R_E = 2 \text{ k} \Omega, V_{BE} = 0.7 \text{ V, and } V^+ = 9 \text{ V,} \) write the bias equation and solve for \( I_C \) and \( V_{CB} \). Verify that the BJT is biased in the active mode. \([\beta = 99: I_C = 1.968 \text{ mA and } V_{CB} = 1.194 \text{ V, } \beta = \infty: I_C = 2.025 \text{ mA, } V_{CB} = 1.019 \text{ V}]\)
32. For $K = 1.78\, mA/V^2$, $V_{TO} = 1.5\, V$, $V^+ = 18\, V$, $R_1 = 110\, k\Omega$, $R_2 = 68\, k\Omega$, $R_D = 0$, and $R_S = 1\, k\Omega$, write the bias equation, solve for $I_D$, and verify that the MOSFET is biased in the saturation region, i.e. its active mode. [$I_D = 3.897\, mA$, $V_{DS} = 14.10\, V$, $V_{GS} - V_{TO} = 1.480\, V$]

33. Add a resistor $R_3$ from gate to source for the circuit in problem 32. (a) Show that

$$V_{GG} = V^+ \frac{R_2}{R_1 + R_2} \frac{(R_3 + R_S)}{(R_3 + R_S)} + I_S \frac{R_S}{R_S + R_3 + R_1} \frac{R_1}{R_2}$$

$$R_{GG} = R_1 \frac{R_2}{R_2} \frac{(R_3 + R_S)}{(R_3 + R_S)}$$

$$V_{SS} = \frac{V^+}{R_1 + R_2} \frac{R_2}{R_2 + R_3 + R_S} \frac{R_1}{R_1} \frac{R_2}{R_2 + R_3 + R_S} \frac{R_S}{R_S}$$

$$R_{SS} = \frac{(R_1 + R_2) + R_3}{R_1 + R_2} \frac{R_3 + R_S}{R_3 + R_S}$$

(b) For $R_3 = 20\, k\Omega$, write the bias equation, solve for $I_D$, and verify that the MOSFET is biased in the saturation region. [$I_D = 0.492\, mA$, $V_{DS} = 17.41\, V$, $V_{GS} - V_{TO} = 0.526\, V$]

34. Add a resistor $R_4$ from drain to source for the circuit in problem 32. Show that

$$V_{SS} = V^+ \frac{R_S}{R_D + R_4 + R_S} - I_D \frac{R_D}{R_D + R_4 + R_S} \frac{R_S}{R_D}$$

$$R_{SS} = R_S \frac{(R_4 + R_D)}{(R_4 + R_D)}$$

$$V_{DD} = V^+ \frac{R_4 + R_S}{R_D + R_4 + R_S} + I_S \frac{R_S}{R_D + R_4 + R_S} \frac{R_D}{R_D + R_4 + R_S}$$

$$R_{DD} = R_D \frac{(R_4 + R_S)}{(R_4 + R_S)}$$