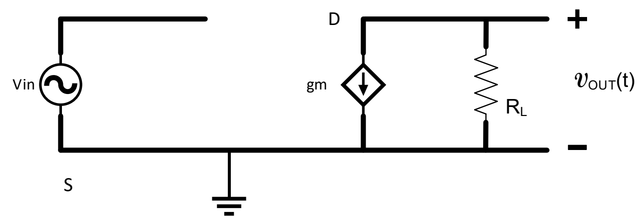
SOLUTIONS:

Problem 1:

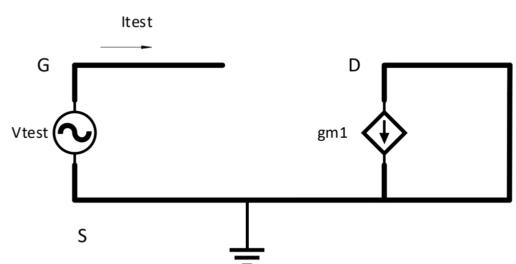
a) The small signal equivalent signal is shown below:



Note that the output resistance was simplified $\frac{1}{g_0}||R_L \approx R_L$

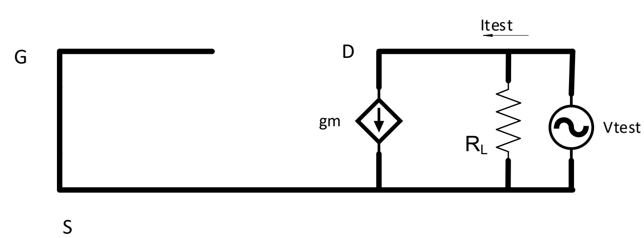
$$-g_m V_{gs} = V_{ds}\frac{1}{R_L} \rightarrow \frac{V_{ds}}{V_{gs}} = \frac{V_{out}}{V_{in}} = -g_m * R_L$$

b) The small signal equivalent signal is shown below:



There is no current flowing in the input terminal (due to the open circuit). $R_{in} = \infty$

c) The small signal equivalent signal is shown below:



Since $V_{in} = 0$, $V_T = I_T * R_L \rightarrow R_{out} = \frac{V_T}{I_T} = R_L$

Problem 2:

a) $g_m V_{gs} = V_{ds} \frac{1}{R_L} \rightarrow \frac{V_{ds}}{V_{gs}} = \frac{V_{out}}{V_{in}} = g_m * R_L$

b) $I_T = I_T * g_m \rightarrow R_{in} = \frac{V_T}{I_T} = g_m^{-1}$

c) $V_T = I_T * R_L \rightarrow R_{out} = \frac{V_T}{I_T} = R_L$

Problem 3:

a) $g_m(V_{in} - V_{out}) = V_{out} \frac{1}{R_L} \rightarrow \frac{V_{out}}{V_{in}} = \frac{g_m}{\frac{1}{R_L} + gm} \approx 1$

b) $R_{in} = \frac{V_T}{I_T} = \infty$

c) $I_T = V_T * \frac{1}{R_L} + V_T * g_m \approx V_T * g_m \rightarrow R_{out} = \frac{V_T}{I_T} = g_m^{-1}$

Problem 4:

$$I_{DSQ} = \frac{\mu C_{ox}}{2} \frac{W}{L} (V_{GS} - V_T)^2 = \frac{350\mu}{2} \frac{W}{L} (1 - 0.5)^2 = 43.75\left(\frac{W}{L}\right) \mu$$

$$A_v = \frac{V_{out}}{V_{in}} = -g_m * R_L = -10 \rightarrow gm = \frac{10}{20\ k} = 0.5\ m$$

$$g_m = \frac{2I_{DSQ}}{V_{GS} - V_T} \rightarrow 0.5\ m = \frac{2 * 43.75\left(\frac{W}{L}\right) \mu}{1 - 0.5} \rightarrow \frac{W}{L} = 2.86$$

Problem 5:

a)

$$y_{11} = \frac{dI_1}{dV_1} = V_2{}^3, \qquad y_{12} = \frac{dI_1}{dV_2} = 3V_1V_2{}^2$$

$$y_{21} = \frac{dI_2}{dV_1} = 0.01V_1V_2e^{0.2V_1^2V_2}, \qquad y_{22} = \frac{dI_2}{dV_2} = 0.05V_1{}^2e^{0.2V_1^2V_2}$$

b)

$$y_{11} = 1^3 = 1\frac{A}{V}, \qquad y_{12} = 3(5)(1)^2 = 15\frac{A}{V}$$

$$y_{21} = 0.01(5)(1)e^{0.2(5^2)1} = 7.42\frac{A}{V}, \qquad y_{22} = 0.05(5^2)e^{0.2(5^2)1} = 185.52\frac{A}{V}$$

c)

$$I_{1Q} = V_1V_2^3 = 5(1^3) = 5\ A$$

$$I_{2Q} = 0.25e^{0.2V_1^2V_2} = 0.25e^{0.2(5^2)1} = 37.1\ A$$

d)

$$i_1 = 1(1mV_{RMS}) + 15(2mV_{RMS}) = 31\ mI_{RMS}$$

$$i_2 = 7.42(1mV_{RMS}) + 185.52(2mV_{RMS}) \quad = 378.46\ mI_{RMS}$$

Problem 6:

The transistor is in saturation. V_{DS} = 4 + 2 = 6V & $V_{GS} – V_T$= 0 + 2 – 0.5 = 1.5 V

$$I_{DS} = \frac{\mu C_{ox}}{2}\frac{W}{L}(V_{GS} - V_T)^2 = \frac{350\mu}{2}\frac{12}{4}(2-0.5)^2 = 1.18125\ mA$$

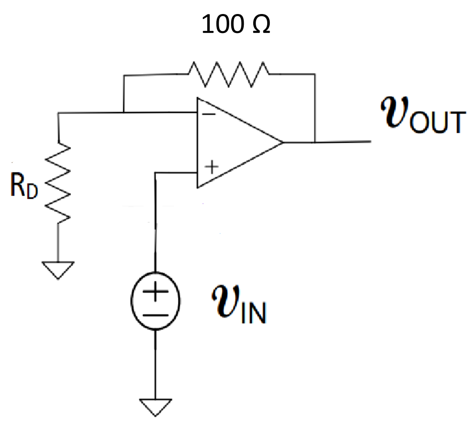
$$g_m = \frac{2I_{DSQ}}{V_{GS} - V_T} = \frac{2 * 1.18125\ m}{2 - 0.5} = 1.575\ m$$

$$V_{OUT} = I_f * R_f = g_m * v_{in} * R_f = 1.575m * 25\ mV * 1.25\ k = 49.22\ mV$$

V_{OUT} is sinusoidal 1 KHz signal with 0-P amplitude of 49.22 mV

Problem 7:

a.) Small signal equivalent circuit



$$R_D = \frac{V_t}{I_{DQ}} = \frac{25.85mV}{1mA} = 25.85\ \Omega$$

$$A_v = 1 + \frac{100\ \Omega}{R_D} = 1 + \frac{100\ \Omega}{25.85\ \Omega} = 4.87\ V/V$$

b.) $R_D = \frac{25.85mV}{10mA} = 2.59\ \Omega$

$$A_v = 1 + \frac{100\ \Omega}{2.59\ \Omega} = 39.68\ V/V$$

Problem 8:

Code:

```
`timescale 1ns/1ps
module add_mul (A,B,S,F);
input[3:0]      A,B;
input           S;
output[7:0]     F;

assign F = S ? A * B : A + B;
endmodule
```

Test bench:

```
`timescale 1ns/1ps
module add_mul_tb();
 reg[3:0]       A,B;
 reg            S;
 wire[7:0]      F;

add_mul a_m(A,B,S,F);

initial begin
 A = 10;
 B = 2;
 S = 0;
end

always #10 S = -S;
always #20 A = A + 1;
always #30 B = B + 1;

endmodule
```

Waveform: