1(a)

\[ V_{\text{out}} = 0 \text{V} \] since \( C_2 \) is large.

\[ I_A = 10^{-12} \text{A} \quad \beta = 100 \]

\[ I_B = \frac{10 - (V_B - 0)}{500k} = \frac{10^{12} A}{100} e^{\frac{V_B - 0}{26mV}} \]

\[ V_B = V_{BE} = 0.555 \text{V} \]

\[ V_C = 2.444 \text{V} \]

(b)

(c) \[ A_V = -g_m \cdot R \quad g_m = \frac{V_C}{V_\text{out}} \]

\[ I_C = 10 - \frac{V_C}{4k} = 10^{-12} A \cdot e^{\frac{V_B - 0}{26mV}} \]

\[ V_C = 2.444 \text{V} \]

\[ g_m = 2.90604 \]

\[ A_V = -g_m \left( \frac{4k}{2k} \right) \]

\[ A_V = -96.87 \left[ \frac{\text{V}}{V_\text{out}} \right] \]

(d) \[ V_{\text{in}} = 200mV \cdot \sin(wt + \theta) \]

\[ V_{\text{out}} = A_V \cdot V_{\text{in}} \]

\[ V_{\text{out}} = -19.374 \sin(wt + \theta) \text{[V]} \]
2 (a) for saturation \( V_{dd} < V_T \) \( V_{gs} \geq V_T \)
\( V_T = 0.5 \quad V_N = 0 \quad V_f = 2 \)
\( 2 - \frac{V_d}{V_T} < (V_f = 0.5) \)
\( V_{dd} > 1.5 \quad V_f = -2 \)

\[ I_{ds} = \frac{V_T^2 + 0.5}{R_i} = 100 \mu A \left( \frac{12}{2} \right) \left( \frac{1}{2} \right) (2 - 0.5)^2 \]
so \( V_f = -0.5 V \)
or \( V_d > -V_T \)

\[ R_i = 6.67 k \Omega \]

(b) \( R_{i max} = 6.67 k \Omega \)
then \( R_i = \frac{1}{3} R_{i max} = 2.22 k \Omega \)

saturation?
\[ I_d = \frac{V_T^2 - V_d}{2.22 k} = 100 \mu A \left( \frac{12}{2} \right) \left( \frac{1}{2} \right) (2 - 0.5)^2 \]
\( V_d = 2.5 V \)
\( V_d > -V_T \)

we have saturation

\[ A_v = -\frac{g_m}{R_{out}} = \left( 100 \mu A \left( \frac{12}{2} \right) \left( \frac{1}{2} \right) (2 - 0.5) \right) \cdot 2.22 k \]

\[ A_v = -2 \left[ \frac{V}{V} \right] \]

(c) \( V_d = V_{out} = 2.5 V \)
\( a - pa + b \)
\( V_{in} = 0.001 \sin (5000t + 75^\circ) \)

\[ V_{out} = 2.5 - 0.002 \sin (5000t + 75^\circ) \]
\[ V_{in} = V_m \cos(\omega t + \phi) \]

\[ M_2 = \text{saturation} \]
\[ M_1 = \text{saturation (given)} \]

then \[ I_{D1} = I_{D2} \]

\[ A_v = \frac{V_{out}}{V_{in}} = \frac{-g_m}{g_m} \]

\[ g_m, V_{in} = -g_m \cdot V_{out} \]

\[ V_{out} = -\frac{g_m}{g_m} \cdot V_m \cos(\omega t + \phi) \]

\[ V_{DD} = 5 \text{V} \quad V_{SS} = -2 \text{V} \]
\[ \frac{W_1}{L_1} = \frac{15 \mu}{2 \mu} \quad \frac{W_2}{L_2} = \frac{4.5 \mu}{1 \mu} \quad \mu_{n} = 100 \mu \text{A}/\text{V}^2 \quad \mu_{p} = 30 \mu \text{A}/\text{V}^2 \quad V_{TH} = 0.5 \text{V} \quad V_{TP} = -0.5 \text{V} \]

\[ V_{OUT} \Rightarrow I_{D1} = I_{D2} \]

\[ 100 \mu \text{A} \cdot \frac{\frac{15}{2}(1)(0.5)}{(0+2)-0.5} = 30 \mu \text{A} \cdot \frac{4.5}{1}(1)(0.9645+0.5) \]

\[ V_{OUT} = 0.9645 \text{ [V]} \]

\[ g_m = \mu_n \text{Cox} \cdot \frac{W}{L} \cdot (V_{GS}-V_{T}) \]
\[ g_{m1} = 100 \mu \text{A} \cdot \frac{15}{2}(1)(0.5+2)-0.5 \quad g_{m1} = 0.001125 \]
\[ \frac{g_{m1}}{g_{m2}} = 2.357 \]
\[ g_{m2} = -30 \mu \text{A} \cdot \frac{4.5}{1}(0.9645+0.5) \quad g_{m2} = 0.0004773 \]

\[ V_{OUT} = -2.357 \cdot V_m \cos(\omega t + \phi) \]

\[ V_{OUT} = 0.9645 - 2.357 \cdot V_m \cos(\omega t + \phi) \]
AC

\[ V(t) \]

\[ V_{DD} = 5 \text{V} \]

\[ V_{DD} = 5 \text{V} \]

\[ V_{BS} = -2 \text{V} \]

\[ V_{IN} \]

\[ 70k \parallel 10k \parallel 2k \]

\[ 2k \parallel 4k \parallel 10 \]

\[ V_{EE} = 8 \text{V} \]

\[ V_{out} \]

\[ V_{out} = 0 \text{V} \]

DC

\[ l_A = \frac{V_B}{10k} \]

\[ l_B = \frac{V_{BE}}{100} \]

\[ l_E = \frac{V_E}{100} \]

\[ l_C = \frac{V_C}{2k} = 10^{-12} \cdot \frac{V_{BE}}{26mV} \]

\[ V_{IN} = 0 \text{V} \]

\[ V_{EE} = 8 \text{V} \]

\[ V_{out} = 0 \text{V} \]

E)

\[ l_B = \frac{V_B}{10k} \]

\[ l_B = \frac{V_{BE}}{100} \]

\[ l_E = \frac{V_E}{100} \]

\[ l_C = \frac{V_C}{2k} = 10^{-12} \cdot \frac{V_{BE}}{26mV} \]

\[ V_{out} = 0 \text{V} \]

F)

\[ l_C = \frac{V_C}{2k} = 10^{-12} \cdot \frac{V_{BE}}{26mV} \]

\[ V_{out} = 0 \text{V} \]
j) \[ V_{out} = (V_{be} \cdot g_m) \left( \frac{2K}{114K} \right) \quad V_{be} = V_{in} \]
\[ A_v = \frac{V_{out}}{V_{in}} = -g_m \left( \frac{2K}{114K} \right) \quad g_m = \frac{V_t}{V_t} \quad L = \frac{32 - V_t}{2K} \quad V_t = 26mV \]
\[ g_m = 0.082595 \]
\[ A_v = -110.127 \frac{V}{V} \]

h) \[ V_{in} = 200mV \]
\[ V_{in} = 0.2 \sin (\omega t + \phi) \]
\[ V_{out} = A_v \cdot V_{in} \]
\[ V_{out} = -22.025 \sin (\omega t + \phi) \]

- For DC: \[ V_{gs} \geq V_t \quad \omega t = 0 \]
- \[ V_{gd} < V_t \quad \text{check} \]

\[ I_D = \frac{12 - V_{out}}{15k} = 100\mu A \cdot \frac{10k}{15k} \cdot (2-1)^2 \]
\[ V_{out} = V_D = 10.125 \text{ V} \]
\[ \text{so} \quad (V_{gd} = (0 - 10.125)) < (V_t = 1) \quad \text{saturation} \]
\[ I_D = \frac{12 - 10.125}{15k} \quad I_D = 125\mu A \]
\[ A_v = -g_m R_{out} \]
\[ A_v = -2.1 \cdot 10^2 \cdot R \quad = \frac{2.125\mu A \cdot 15k}{-2+1} \]
\[ A_v = -3.75 \frac{V}{V} \]
\[ V_D = 10.125 \frac{V}{V} \]
\[ V_{in} = 1kHz, 25mVp \]

\[ V_{out} = 0.125 \sin (2000 \pi t) \] [V]

\[ g_m = \mu C_0 \frac{W}{L} (V_{gs} - V_T) \]

\[ g_m = \frac{1}{2 \mu C_0 \frac{W}{L} \cdot V_{1mA}} \]

\[ g_m = \frac{I_{eq}}{V_e} - \frac{1}{g_m} = \frac{26mV}{1mA} = 26 \Omega \]
\[ y_i = \frac{dI_i}{dV_i} \quad y_{12} = \frac{dI_1}{dV_2} \quad y_{21} = \frac{dI_2}{dV_1} \quad y_{22} = \frac{dI_2}{dV_2} \]

\[ I_1 = V_1^2 V_2^2 \quad I_2 = 0.1 e^{0.2 V_1 V_2} \]

\[ y_{11} = 2V_1 V_2^2 \quad y_{12} = 2 V_1^2 V_2 \quad y_{21} = 0.02 V_1 e^{0.2 V_1 V_2} \quad y_{22} = 0.02 V_1 e^{0.2 e^{0.2 V_1 V_2}} \]

\[ V_{1a} = 5V \quad V_{2a} = 1V \]

\[ y_{11} = 10 \quad y_{12} = 50 \quad y_{21} = 0.0344 \quad y_{22} = 0.3718 \]

\[ I_{1a} = V_{1a} V_{2a} = 25A \quad I_{2a} = 0.1 e^{0.2 V_{1a} V_{2a}} = 271.8 mA \]

\[ i_i = y_i V_i + y_{ip} V_p = 110 mA_{\text{rms}} \]

\[ i_2 = y_{p2} V_p + y_{p3} V_1 = 0.598 mA_{\text{rms}} \]
(a)

\[ R_{FET} = \frac{1}{\mu C_{ox} \frac{W}{L} (V_{gs} - V_{th})} \]

\[ R_{FET} = \frac{1}{100 \times 10^6 \left(\frac{12}{1}\right)(2-1)} \]

\[ R_{FET} = 833.33 \text{ } \Omega \]

\[ A_v \text{ for non-inverting amplifier} = 1 + \frac{R_F}{R_{FET}} \]

\[ A_v = 1 + \frac{R_F}{833.33} \left[ \frac{V_{out}}{V} \right] \]

(b)

\[ 1.5 < V_{xx} < 4 \]

\[ R_{FET} (V_{xx} = 1.5) = \frac{1}{100 \times 10^6 \left(\frac{12}{1}\right)(1.5-1)} \]

\[ R_{FET} = 1666.67 \text{ } \Omega \]

\[ A_v (V_{xx} = 1.5) = 1 + \frac{R_F}{1666.67} \]

\[ R_{FET} (V_{xx} = 4) = \frac{1}{100 \times 10^6 \left(\frac{12}{1}\right)(4-1)} \]

\[ R_{FET} = 277.77 \]

\[ A_v (V_{xx} = 4) = 1 + \frac{R_F}{277.77} \]

If \( R_F \) is large, then \( A_v (V_{xx} = 1.5) \approx \frac{1}{6} \)

As \( V_{xx} \) increases, the gain increases as well.
10 pts

120) \[ \text{RFET} = \frac{1}{\frac{W}{L} \mu \text{Cox} (V_{\text{gs}} - V_T)} = 3.33 \text{K}\Omega = 3.33k \]

\[ I = \frac{V_{\text{in}}}{\text{RFET}} \quad V_{\text{out}} = V_{\text{in}} + I \left( \frac{1}{V_{\text{ok}} + 1 \times 10^{-6} \text{s}} \right)^{-1} \]

\[ V_{\text{out}} = \frac{V_{\text{in}}}{1 + \frac{1}{\text{RFET} \left( V_{\text{ok}} + 1 \times 10^{-6} \right)}} \]

\[ V_{\text{out}} = \frac{\text{RFET}/V_{\text{ok}} + 1 \times 10^{-6} \text{RFET} \cdot 5 + 1}{V_{\text{in}} \frac{\text{RFET}/V_{\text{ok}} + 1 \times 10^{-6} \text{RFET} \cdot 5}{\text{RFET}/V_{\text{ok}} + 1 \times 10^{-6} \text{RFET} \cdot 5}} \]

b) see attached graphs

c) \[ -\frac{1}{1 \times 10^{-6} V_{\text{ok}}} \quad \text{poles} = -2.5 \]

\[ \text{zeros} = -\frac{1}{1 \times 10^{-6} \left( \frac{1}{V_{\text{ok}}} + 1/\text{RFET} \right)} \]

see attached plot
b) $I_D = 100E-6 \frac{g}{20} (2-1)^2 = 4E-5 A$

$V_D = 5 - 4E-5 \cdot 100K = 4V$  \hspace{1cm} \text{Saturation}$V_{GS} = V_T$  \hspace{1cm} $V_{OS} = V_{GS} - V_T$

$V_{out} = 0V$

$c) \quad g_0 = \lambda \cdot I_D q \quad \lambda = \frac{1}{100} \quad g_0 = 4E-7 \quad R_0 = 2.5E6$

$g_m = \frac{2 \cdot I_D q}{V_{GS} - V_T} = 8E-5 \quad AV = -g_m (\frac{1}{100K} + \frac{1}{100K} + \frac{1}{50K})^{-1} = -2.6$

d) $-20mV \cdot -2.6 = -52mV$

$V_{out} = -52mV \cdot \sin (\omega t + \theta)$
(a) (10 points)

(b) 

Guess Saturation

\[ I_D = \frac{100\mu A}{2} \left( \frac{10}{40k} \right) \left( \frac{1}{2} \right) \left( 0 - V_D - 1 \right)^2 \]

\[ I_D = \frac{V_D + 2}{40k} \]

\[ V_D = -1.2 \text{ V} \]

\[ I_D = 20 \mu A \]

\[ V_{gs} > V_T \quad V_s = -2 + 40k \cdot 20 \mu A \quad V_s = -1.2 \text{ V} \]

\[ V_{gd} = -3 < V_T \quad \checkmark \]

\[ V_{gs} = 1.2 > V_T \quad \checkmark \quad \text{saturation} \]

\[ V_D = 3 \text{ V} \]

\[ V_{out} = 0 \text{ V} \]

(c) \[ V_{out} = -g_m V_s \left( 100k || 50k \right) \]

\[ V_{gs} = V_{in} - (g_m V_s \cdot 20k) \]

\[ V_{gs} = \frac{V_{in}}{1 + g_m 20k} \]

\[ \frac{V_{out}}{V_{in}} = -\frac{g_m}{1 + g_m 20k} \left( 100k || 50k \right) \]

\[ g_m = \frac{\mu C}{2} (V_{gs} - V_T) \]

\[ g_m = 104 \mu A \cdot \left( \frac{10}{40k} \right) \cdot (1.2 - 1) \]

\[ g_m = 2 \times 10^{-4} \]

\[ A_V = -1.333 \] \[ \frac{V}{V} \]

(d) \[ V_{in} = 200 \text{ mV} \]

\[ V_{out} = A_V \cdot V_{in} \]

\[ V_{in} = V_{in} \sin (\omega t + \theta) \]

\[ V_{out} = -0.2667 \sin (\omega t + \theta) \]
10 points

\[ A_v = -8 \]

\[ A_v = \frac{2 \cdot 1 \cdot 10 \cdot R_{out}}{V_{gs} + V_T} \]

\[ A_v = -8 = \frac{2 \cdot 1 \cdot 10 \cdot 10K}{-2 + 1} \]

\[ I_{DQ} = 0.4mA \]

\[ 0.4mA = 100 \frac{4A}{V^2} \cdot \frac{W}{L} \cdot \frac{1}{2} \cdot (V_{qs} - 1)^2 \quad V_{qs} = (0+2) \]

\[ \frac{W}{L} = 8 \]

\[ I_{e} \cdot W = 8 \mu \]

\[ L = 1 \mu \]

Check saturation

\[ V_{d} = 4 - 10K \cdot I_{DQ} \quad V_{d} = 0V \]

\[ V_{d} = (0-0) < 1 \]

\[ V_{qs} = 0+2 \geq 1 \quad \checkmark \text{saturation} \]

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\[ A_v = -B = \frac{V_{out}}{V_{in}} \]

\[ V_{out} = -2K \cdot g_m \cdot V_{be} \quad V_{be} = V_{in} \]

\[ g_m = \frac{I_c}{V_T} \quad \frac{V_{out}}{V_{in}} = -8 = \frac{-2K \cdot I_c}{26mV} \]

\[ I_c = 0.104mA \]

\[ I_B = \frac{I_c}{100} = \frac{10 - V_{be}}{R} \]

\[ I_B \quad V_{be} = 0.6 \]

then \[ R = 9M\Omega \]

\[ J_{s}A_B = 7.882 \times 10^{-15} \]
Verilog Code – 7 points

```verilog
module Serial_2 Parallel(D_in, D_out, CLK, RST_n, EN_n);
    input CLK;
    input D_in;
    input RST_n;
    input EN_n;
    output reg [7:0] D_out;

    always @(posedgeCLK)
    begin
        case(RST_n)
            0: begin//reset data (active low)
                D_out <= 8'b00000000;
            end
        1: begin //do nothing
            end
        endcase
    case(EN_n)
        0: begin //enable (active low)
            D_out = (D_out << 1) | D_in;
        end
        1: begin //do nothing
            end
        endcase
    end
endmodule
```

Verilog Test Bench simulation code – 6 points

```verilog
`timescale 1ns/1ps

module Serial_2 Parallel_tb();
    reg D_in_t;
    reg CLK_t;
    reg EN_t;
    reg EN_n;
    wire [7:0] D_out_t;

    Serial_2 Parallel test(D_in_t, D_out_t, CLK_t, RST_n_t, EN_n_t);

    always #10 CLK_t <= ~CLK_t;
    initial begin
        D_in_t = 0, CLK_t = 0, EN_n_t = 1, RST_n_t = 1; // start in complete disabled state
        #20 EN_n_t = 0; // data has been reset
        #20 EN_n_t = 1; // device enabled
        #20 D_in_t = 1; // Data
        #20 D_in_t = 0;
        #20 D_in_t = 0;
        #20 D_in_t = 1;
        #20 D_in_t = 1;
        #20 D_in_t = 1;
        #20 D_in_t = 1; // 8 bits sent
        #20 D_in_t = 0; // send 2 more to show operation
        #20 D_in_t = 1;
        #20 EN_n_t = 1; // disable
        #20 EN_n_t = 0; // should not appear in D_out
        #20 EN_n_t = 1; // reenable
        #20 EN_n_t = 0; // show RST works
        #20 RST_n_t = 1;
    end
endmodule
```
Test Bench Waveform – 7 points

NOTE: operation of data shifting, reset and enable location