15^{th} **July, 2020** **Numericals**

Numerical: Determine the following for the circuit shown in figure 1. Assume $\beta_1 = \beta_2 = 100$

a. Name of the circuit

b. Current flowing through resistors R_{S1}, R_{S2}, R_{C1} and R_{C2}

c. V_{C1}, V_{C2}, V_{CE1}, V_{CE2}

d. differential voltage gain

e. Common mode gain

f. CMRR (in dB)

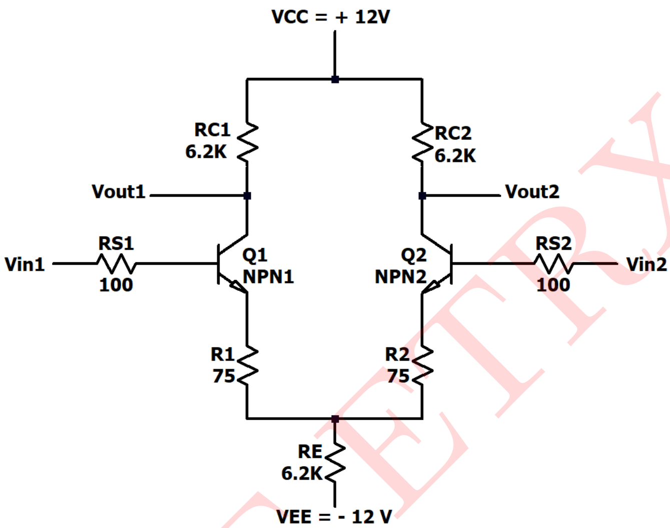

Figure 1: Circuit 1

Solution:

The given circuit is a Dual input Balanced output (DIBO) differential amplifier.

DC ANALYSIS:

Applying KVL to Base - Emitter loop;

$-I_{B1}R_{S1} - V_{BE1} - I_{E1}R_{E1} - 2R_E I_{E1} - V_{EE} = 0$

But $V_{BE1} = V_{BE2} = 0.7V$

And $I_{E1} = (\beta + 1)I_{B1}$

$\therefore -I_{B1}R_{S1} - V_{BE1} - (\beta + 1)I_{B1}R_1 - (2R_E)(\beta + 1)I_{B1} - V_{EE} = 0$

$\therefore -V_{EE} - V_{BE1} = I_{B1}(R_{S1} + (i + \beta_1)(R_1 + 2R_E)$

$$\therefore I_{B1} = \frac{-V_{EE} - V_{BE1}}{R_{S1} + (1 + \beta)(R_1 + 2R_E)} = \frac{12 - 0.7}{100 + (101)(75 + (2 \times 6.2k))} = \mathbf{8.96\mu A}$$

$I_{C1} = \beta \times I_{B1} = 10 \times 8.96 \times 10^{-6} = \mathbf{0.896mA}$ (current flowing across R_{C1})

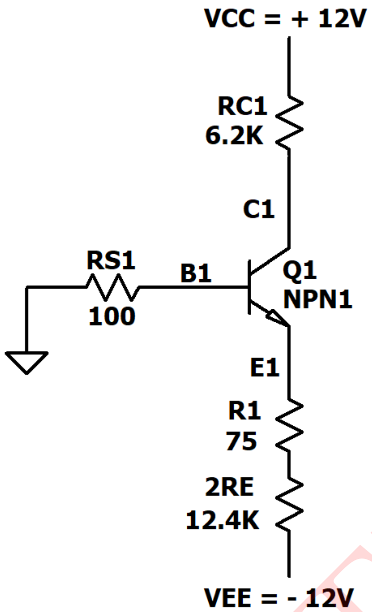

Figure 2: DC ANALYSIS

The DC values are the same for both the transistors

$\therefore I_{B1} = I_{B2} = \mathbf{8.96\mu A}$

$I_{C1} = I_{C2} = 0.896mA$

$\therefore I_{B2} = \mathbf{8.96\mu A}$ (current flowing across R_{S2})

$I_{C2} = \mathbf{0.896mA}$ (current flowing across R_{C2})

Applying KVL to the Common - Emitter loop;

$V_{CE1Q} = V_{CC} + V_{EE} - I_{C1Q}(R_{C1} + 2R_E + R_1)$ (where $V_{EE} = 12V$)

$V_{CE1Q} = 12 + 12 - (0.896 \times 10^{-3})(3.2k + 75 + (2 \times 6.2k)) = \mathbf{7.2672V}$

$V_{CE1Q} = V_{CE2Q} = \mathbf{7.2672V}$

Also $V_{C1} = V_{CC} - I_{C1Q}R_C1 = 12 - (0.896 \times 10^{-3})(6.2 \times 10^3) = \mathbf{6.44V}$

$V_{C1} = V_{C2} = \mathbf{6.44V}$

AC ANALYSIS:

$$|A_d| = \frac{\beta R_C}{2(R_S + r_\pi + \beta R_1)}$$

$\beta = \beta_1 = \beta_2 = 100$

And $r_\pi = \dfrac{\beta V_T}{I_{CQ}}$

$$I_{CQ} = I_{C1Q} = I_{C2Q} = \mathbf{0.896mA}$$

$$r_\pi = \frac{100 \times 26 \times 10^{-3}}{0.896 \times 10^{-3}} = \mathbf{2.901k\Omega}$$

$$|A_d| = \frac{100 \times 3.2 \times 10^{3}}{2(100 + 2901 + (100)(75))} = \mathbf{59.04}$$

$$A_{cm} = \frac{R_C}{2R_E} = \frac{6.2k}{2 \times 6.2k} = \mathbf{0.5}$$

$$\text{CMRR} = \frac{A_d}{A_{cm}} = \frac{59.04}{0.5} = \mathbf{118.18}$$

$$\text{CMRR (in dB)} = \mathbf{41.44dB}$$

SIMULATED RESULTS:
Above circuit is simulated in LTspice and the result is as follows:

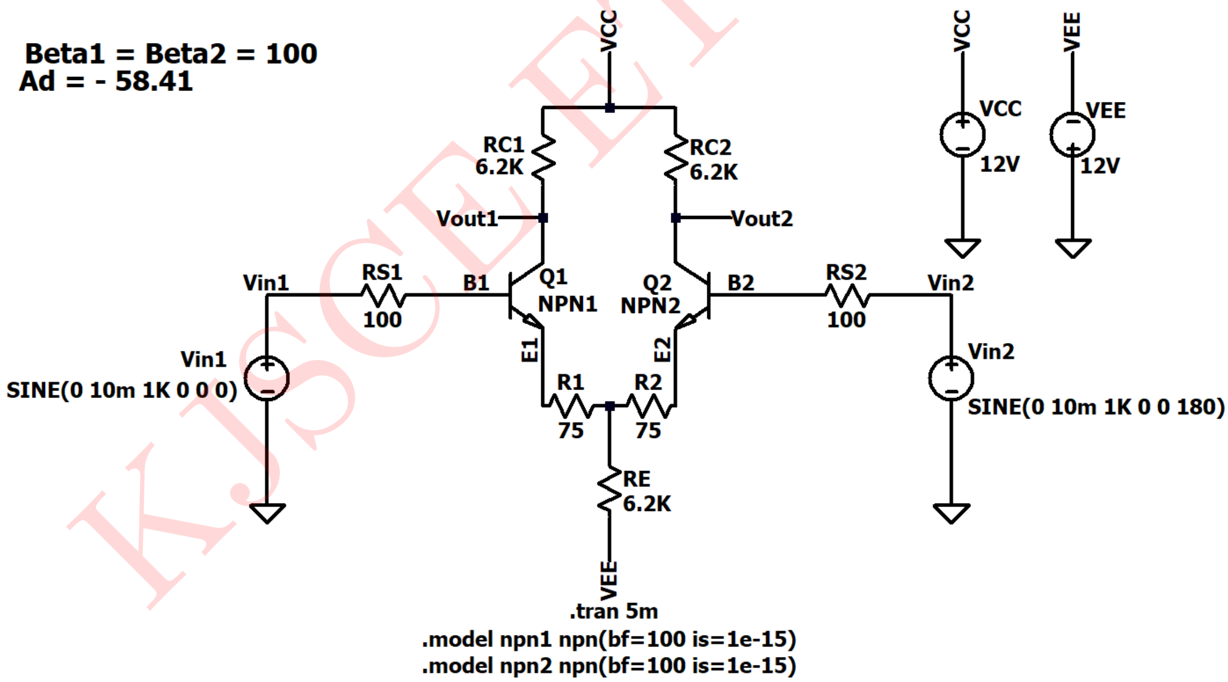

Figure 3: Circuit Schematic

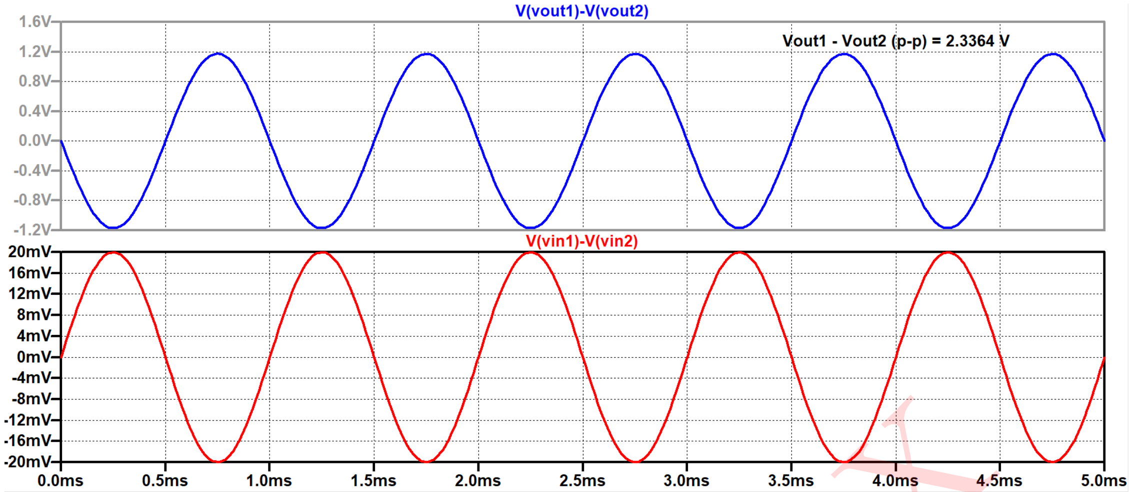

Figure 4: Input output Voltage waveform

Comparison between Theoretical and Simulated values :-

Parameters	Theoritical	Simulated
I_{C1}	0.896mA	0.8957mA
I_{C2}	0.896mA	0.8957mA
V_{C1}	6.44V	6.44V
V_{C2}	6.44V	6.44V
V_{CE1}	7.2672V	7.167V
V_{CE2}	7.2672V	7.167V
Differential voltage gain ($\lvert A_d \rvert$)	59.04	58.41
Common mode voltage gain (A_{cm})	0.5	–
CMRR (in dB)	45.44dB	–

Table 1: Numerical 1

Numerical 2: Consider the given circuit the transistor parameters are
$k_{n1} = k_{n2} = 50\mu A/V^2$, $\lambda_1 = \lambda_2 = 0.02V^{-1}$ and $V_{TN1} = V_{TN2} = 1V$
Determine I_S, I_D1, I_{D2}, V_{D1}, V_{D2}, V_{DS1}, V_{DS2}
Calculate differential mode voltage gain A_d, common mode gain A_{cm} and CMRR (in dB)

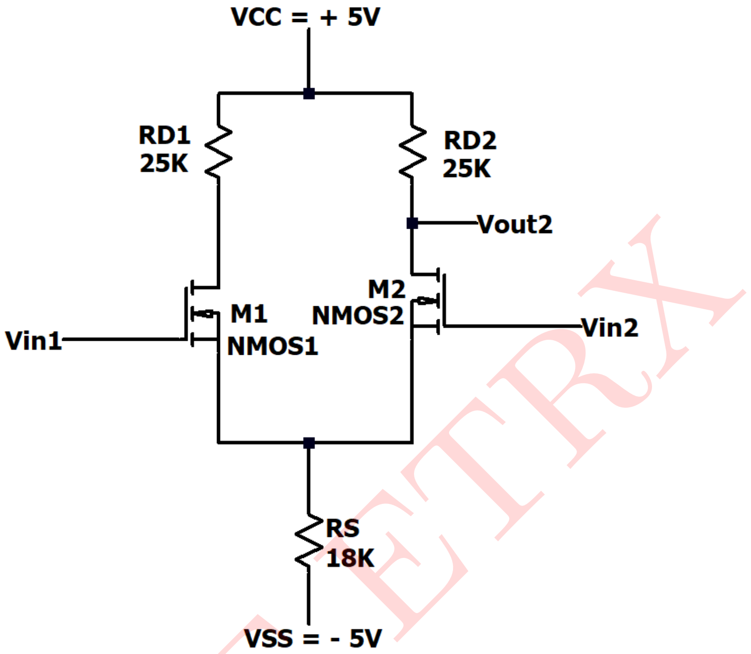

Figure 5: Circuit 2

Solution:

The given circuit is a Dual input Unbalanced output (DIUO) differential amplifier.

DC ANALYSIS:

Since both the transistors are identical we consider only one transistor

Applying KVL to Gate - Source loop;

$-V_{GS1} - I_{S1}(2R_S) - V_{SS} = 0$

But $I_{D1} = I_{S1}$

$\therefore V_{GS1} = 5 - I_{D1}(2 \times 18 \times 10^3) = 5 - I_{D1}(36 \times 10^3)$ 1

Applying KVL to the Drain - Source loop;

$V_{DD} - I_{D1}R_{D1} - V_{DS1} - I_{S1}2R_S - V_{SS} = 0$

$I_{D1} = I_{S1}$

$\therefore V_{DS1} = V_{DD} - V_{SS} - I_{D1}(R_{D1} + 2R_S) = 5 - (-5) - I_{D1}(25k + 36k) = 10 - I_{D1}(61 \times 10^3)$ 2

Also we know that,

$$I_{D1} = k_{n1}(V_{GS1} - V_{TN1})^2(1 + \lambda_1 V_{DS1})$$

$$= 50 \times 10^{-6}(5 - I_{D1}(36 \times 10^3) - 1)^2 \times (1 + 0.02(10 - (61 \times 10^3)I_{D1}))$$

$$= 50 \times 10^{-6}(4 - I_{D1}(36 \times 10^3))^2 \times (1 + 0.2 - I_{D1}(10^3)(1.22))$$
$$= 50 \times 10^{-6}(4 - I_{D1}(36 \times 10^3))^2 \times (1.2 - (1.22 \times 10^3 \times I_{D1}))$$

$$= 50 \times 10^{-6}(16 - 288 \times 10^3 I_{D1} + (1296 \times 10^6 \times I_{D1}^2)) \times (1.2 - 1.22 \times 10^3 I_{D1})$$

$$= 50 \times 10^{-6}(19.2 - (345.6 \times 10^3 I_{D1}) + (1555.2)(10^6)(I_{D1}^2) - (19.52 \times 10^3 I_{D1})$$

$$+(351.36 \times 10^6 I_{D1}^2) - (1581.12 \times 10^9 I_{D1}^3))$$

$$= 960\times10^{-6} - 17.28 I_{D1} + 77.76\times10^3 I_{D1}^2 - 0.976 I_{D1} + (17.568\times10^3 I_{D1}^2) - (79.256\times10^6)(I_{D1}^3)$$

$$= 960 \times 10^{-6} - 18.256 I_{D1} + (95.328 \times I_{D1}^2 \times 10^3) - 79.056 \times 10^6 I_{D1}^3$$

So, $79.056 \times 10^6 (I_{D1}^3) - (95.328 I_{D1}^2)(10^3) + (19.256 I_{D1}) - (960 \times 10^{-6}) = 0$

On solving we get,

$I_{D1} = 9.669 \times 10{-}4A$ or

$I_{D1} = 7.808 \times 10^{-5} A$ or

$I_{D1} = 16.083 \times 10^{-4} A$

When $I_{D1} = 9.669 \times 10^{-4} A$

$V_{GS1} = 5 - (9.669 \times 10^{-4})(36 \times 10^3) = -\mathbf{29.8V}$

When $I_{D1} = 78.08 \mu A$

$V_{GS1} = 5 - (78.08 \times 10^{-6})(36 \times 10^3) = \mathbf{2.189V}$

When $I_{D1} = 16.083 \times 10^{-4} A$

$V_{GS1} = 5 - (16.083 \times 10^{-4})(36 \times 10^3) = -\mathbf{52.898V}$

V_{GS1} can not be negative and $V_{GS} > V_{TN}$

$V_{GS1} = \mathbf{2.189V}$

And $I_{D1} = \mathbf{78.08\mu A}$

$I_{D1} = I_{D2} = \mathbf{78.08\mu A}$

$I_S = I_{D1} = \mathbf{78.08\mu A}$

$V_{GS1} = V_{GS2} = \mathbf{2.189V}$

$V_{DS1} = V_{DS2} = 10 - (78.08 \times 61 \times 10^{-3}) = \mathbf{5.237V}$

AC ANALYSIS:

$$g_{m1} = 2k_{n1}(V_{GS1} - V_{TN1})(1 + \lambda V_{DS1}) = 2 \times 50 \times 10^{-6}(2.189 - 1)(1 + (0.02)(5.237))$$

$$= \mathbf{0.131mA/V}$$

$$r_{d1} = \frac{1}{\lambda I_{D1}} = \frac{1}{0.02 \times 78.08 \times 10^{-6}} = \mathbf{640.368k\Omega}$$

As both transistors are identical,

$$g_{m1} = g_{m2} = \mathbf{0.131mA/V}$$

$$r_{d1} = r_{d2} = \mathbf{640.368k\Omega}$$

Differential mode gain:

$$|A_d| = \frac{g_m(r_d \ || \ R_D)}{2} = \frac{0.131 \times 10^{-3}(640.368k \ || \ 25k)}{2} = \mathbf{1.57}$$

Common mode voltage gain:

$$A_{cm} = \frac{g_m(r_d \ || \ R_D)}{1 + 2g_m R_S} = \frac{0.131 \times 10^{-3}(640.386k \ || \ 25k)}{1 + 2(0.121 \times 10^{-3} \times 18 \times 10^3)} = \mathbf{0.549}$$

$$\text{CMRR} = \frac{A_d}{A_{cm}} = \mathbf{2.859}$$

$$\text{CMRR (in dB)} = \mathbf{9.1265dB}$$

SIMULATED RESULTS:
Above circuit is simulated in LTspice and the result is as follows:

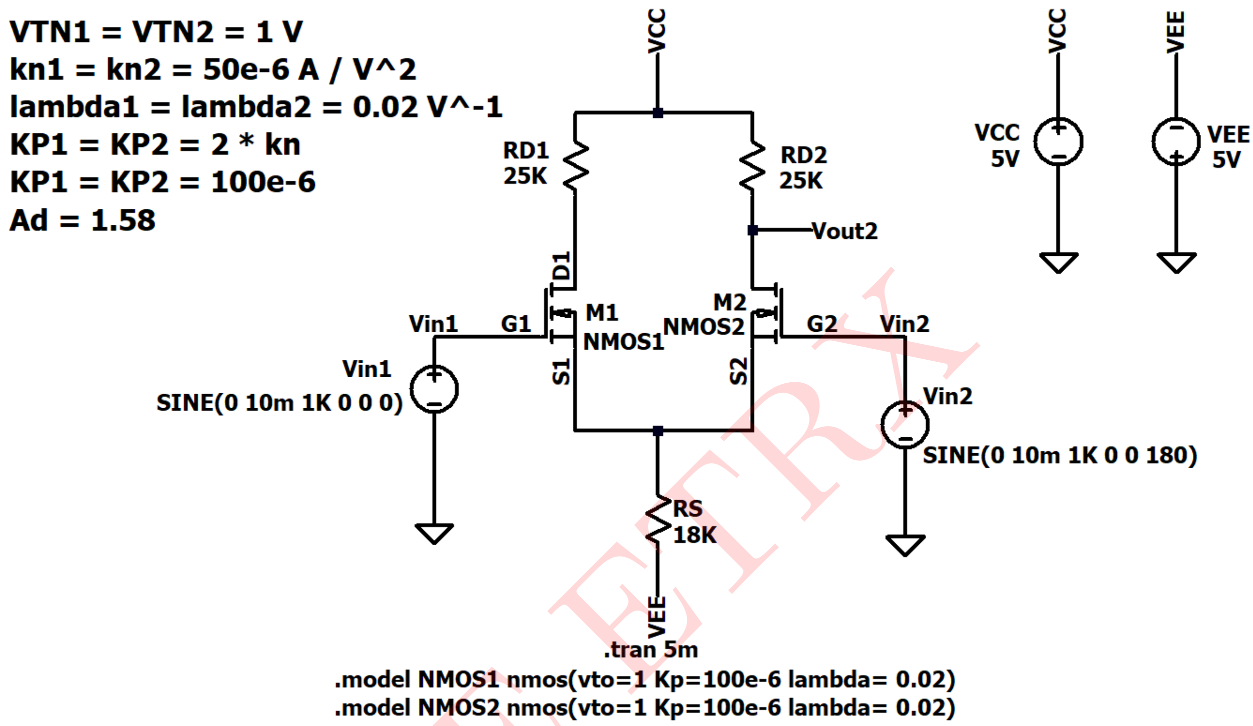

Figure 6: Circuit Schematic

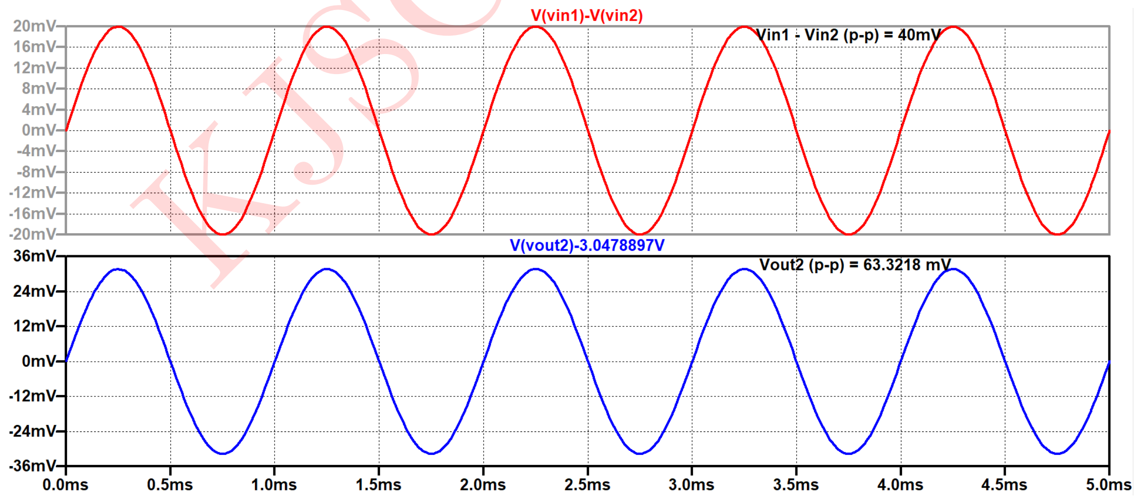

Figure 7: Input output Voltage waveform

Comparison between Theoretical and Simulated values :-

Parameters	Simulated	Theoretical
I_{D1}	$78.08\mu A$	$78.08\mu A$
I_{D2}	$78.08\mu A$	$78.08\mu A$
I_S	$78.08\mu A$	$78.08\mu A$
V_{GS1}	2.188V	2.189V
V_{GS2}	2.188V	2.189V
V_{DS1}	5.2368V	5.237V
V_{DS2}	5.2368V	5.237V
Differential voltage gain ($\lvert A_d \rvert$)	1.58	1.57
Common mode voltage gain (A_{cm})	–	0.549
CMRR (in dB)	–	9.1265dB

Table 2: Numerical 2

Numerical 3: For the amplifier shown in figure 1, find

i. I_{D1}, I_{D2}

ii. DC values of V_{o1}, V_{o2}

iii. Single ended output gain $\left(\frac{V_{o1}}{V_1 - V_2}\right)$

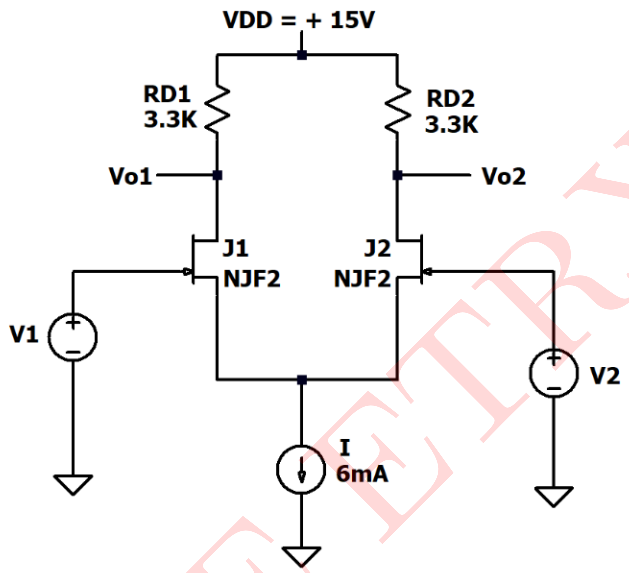

Figure 8: Circuit 3

Solution:

The given circuit is a differential amplifier using JFET.

i. $I_{D1} = I_{D2} = \frac{I}{2} = \frac{6mA}{2} = \mathbf{3mA}$

ii. DC values of $V_{o1} = V_{o2} = V_{DD} - I_D R_D$

where $I_D = I_{D1} = I_{D2}$

$V_{o1} = V_{o2} = 15 - (3 \times 10^{-3})(3.3 \times 10^{3}) = \mathbf{5.1V}$

$\left(\frac{V_{o1}}{V_1 - V_2}\right)$ means that the output is taken from Drain D_1 of transistor M_1

We assume that $V_{o2} > V_{o1}$

The circuit will be a Dual input Unbalanced output configuration.

$$A_d = \frac{V_{o1}}{V_1 - V_2} = \frac{-g_m R_D}{2}$$

We know that for JFET, $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$

so, $\dfrac{I_D}{I_{DSS}} = \left(1 - \dfrac{V_{GS}}{V_P}\right)^2$

$\therefore 1 - \dfrac{V_{GS}}{V_P} = \sqrt{\dfrac{I_D}{I_{DSS}}}$

So, $g_m = \dfrac{2I_{DSS}}{|V_P|}\left(1 - \dfrac{V_{GS}}{V_P}\right) = \dfrac{2I_{DSS}}{|V_P|}\sqrt{\dfrac{I_D}{I_{DSS}}} = \dfrac{2 \times 12 \times 10^{-3}}{25}\sqrt{\dfrac{3 \times 10^{-3}}{12 \times 10^{-3}}} = \mathbf{4.8mA/V}$

$A_d = \dfrac{V_{o1}}{V_1 - V_2} = \dfrac{-g_m R_D}{2} = \dfrac{(-4.8 \times 10^{-}3)(3.3 \times 19^3)}{2} = -\mathbf{7.92}$

SIMULATED RESULTS:

Above circuit is simulated in LTspice and the result is as follows:

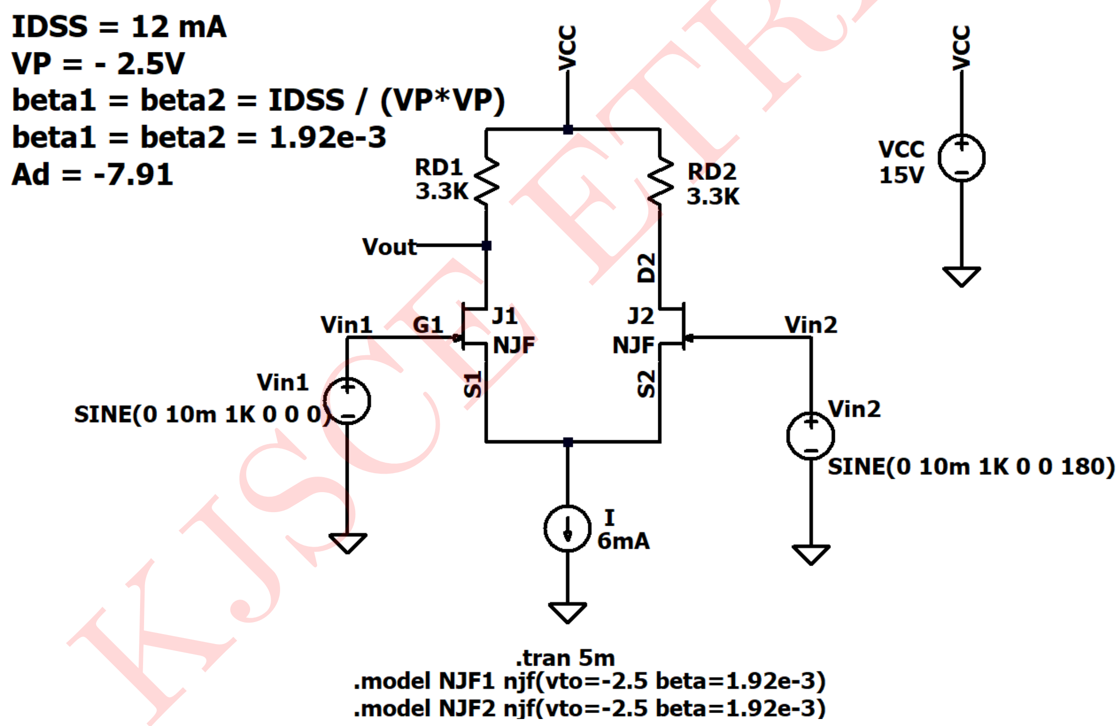

Figure 9: Circuit Schematic

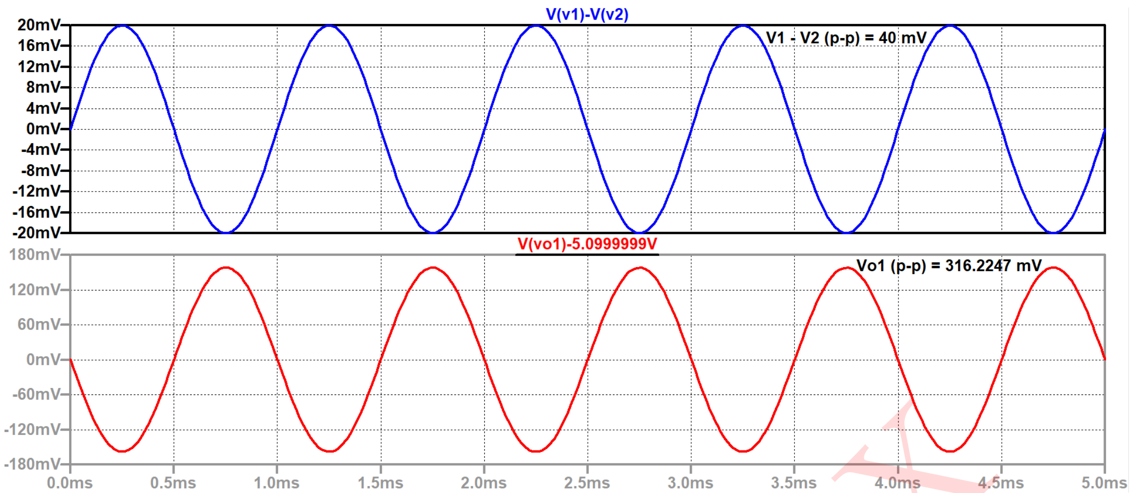

Figure 10: Input output Voltage waveform

Comparison between Theoretical and Simulated values :-

Parameters	Simulated	Theoretical
I_{D1}, I_{D2}	3mA	3mA
V_{D1}, V_{D2}	5.1V	5.1V
Differential voltage gain (A_d)	-7.91	-7.92

Table 3: Numerical 3

****