The following equations are for drain current in a nMOSFET. They may be useful in your answering the following questions.

\[ I_D(\text{triode}) = k_n(W/L)_n ((V_{GS} - V_{tn})V_{DS} - 0.5V_{DS}^2) \]
\[ I_D(\text{saturated}) = 0.5k_n(W/L)_n (V_{GS} - V_{tn})^2(1 + \lambda V_{DS}) \]

where \( k_n = \mu_n C_{ox} \). \( V_{tn} \) is threshold voltage. The subscript \( n \) denotes a n-type MOSFET. \( \lambda = 1/V_A \) is the channel length modulation factor.

1. In the following circuit (Fig. 1), \( Q_2 = Q_3 \) (matched), \( V_{tn} \) (threshold voltage) = \( |V_{tp}| = 1 \text{V} \);
\( \mu_n C_{ox} = 2\mu_p C_{ox} = 20 \mu_A/\text{V}^2 \), \( (W/L)_n = 100/10 \); \( V_{An} \) (Early voltage) = \( |V_{An}| = 40 \text{V} \). Neglect the Early effect for DC analysis and when evaluating the transconductance \( g_m \).

(a) Find \( R \) to obtain \( I_R = 200 \mu_A \). (4%)
(b) For the circuit to have maximum small signal voltage gain, find the DC bias \( V_i \), the DC output current \( I_{D1} \), the mode of operation of \( Q_1 \) and \( Q_2 \), and the small-signal voltage gain of this amplifier. (2%)
(c) If the DC bias \( V_i = 2 \text{V} \), find the DC output current \( I_{D1} \), the DC output voltage \( V_o \), the \( Q_1 \) and \( Q_2 \) operation mode. (4%)

2. In the following TTL gate (Fig. 2), assume all transistors are identical. \( V_{BE(\text{active})} = 0.7 \text{V} \), \( V_{BE(\text{saturation})} = 0.8 \text{V} \), \( V_{CE(\text{saturation})} = 0.1 \text{V} \), \( \beta_F = 100 \), \( \beta_R = 0.1 \). fan-out = 1.

(a) Specify which region (forward-active, reverse-active, off, saturation) each transistor is in when \( V_{in} \) is logic "1". (4%)
(b) Specify which region each transistor is in when \( V_{in} \) is logic "0" (4%)
(c) At the instant when \( V_{in} \) switches from "1" to "0", specify which region the transistor \( Q_1 \) and \( Q_6 \) are in. (2%)
(d) If \( Q_6 \) is removed (i.e., \( R_2 \) and \( R_5 \) connected to ground directly), sketch \( V_o \) versus \( V_{in} \) and specify the voltages at the breakpoints. (8%)
(3) The following four circuits have errors. Please briefly point out the error in each circuit and redraw the correct circuit. (15%) 

(a) BJT Current Mirror

(b) BJT CE-CB Cascade Amplifier

(c) BJT Differential Amplifier

(d) BJT CE Amplifier

(4) Assuming the Op-Amp is ideal in the following circuit with +5V and -5V output saturation levels.

(a) Sketch and level the transfer characteristic of \( v_o \) versus \( v_i \) (6%) 
(b) For a 100mV-amplitude sine-wave input having zero average, what will be the waveform of \( v_o \)? (4%)
(5) In Fig. 5, the Op-Amp is ideal but with the input offset voltage $V_{os}$. The power supply voltages of the Op-Amp are $+5V$ and $-5V$.

(a) Assume that $V_1=0.5V$, $V_2=1V$ and $V_{os}=0V$. If the switch $S$ is closed, calculate $V_o$. (5%)
(b) The same as in (a) but with the switch $S$ open and negligible switch transients, calculate $V_o$. (5%)
(c) The same as in (a) but with $V_{os}=+5mV$, calculate $V_o$. (5%)

(6) In the following circuit, the transfer function of the basic amplifier $A$ is

$$A = \frac{200}{1 + j\frac{5}{10} \text{kHz}}$$

The feedback factor $\beta$ is 0.01. Calculate the upper 3dB frequency and the phase margin of the feedback amplifier. (20%)