(1) Consider the following circuit and its input waveform $V_i$ shown below.

(a) [5%] Draw the $V_o$ waveform. Assume the operational amplifier is ideal, and without input offset voltage and bias current, i.e., $V_{OS} = 0 \text{ V}$ and $I_B = 0 \text{ mA}$.

(b) [7%] Draw the $V_o$ waveform. Assume the operational amplifier is ideal, except that it has a non-zero input offset voltage, i.e., $V_{OS} = 0.5 \text{ V}$ and $I_B = 0 \text{ mA}$.

(c) [7%] Draw the $V_o$ waveform. Assume the operational amplifier is ideal, except that it has a non-zero input bias current, i.e., $I_B = 0.5 \text{ mA}$ and $V_{OS} = 0 \text{ V}$.

(2) In the following circuit, the current equation for a MOSFET in saturation region is $I_{D} = 0.5k(V_{GS} - V_{T})^2$.

$V_t(nMOS) = -V_t(pMOS) = 2 \text{ V}$, $k(nMOS) = k(pMOS) = 50 \text{ \mu A/V}^2$. $R = 10\Omega$ and $C$ is sufficiently large.

(a) [6%] What are the DC current and transconductance ($g_m$) of Q1 and Q2?

(b) [10%] If $V_{th}(Early \text{ voltage}) = 180 \text{ V}$, what is the small signal voltage gain $v_o/v_i$?

(c) [4%] For what range of output voltage do Q1 and Q2 remain in the saturation region?
(3) Consider the amplifier shown below (Fig. 3). Let $g_{m1} = g_{m2} = 5 \text{ mA/V}$, and $g_{m3} = 2.5 \text{ mA/V}$ when switch is closed. All the MOSFETs are operated in saturation region. Neglect channel length modulation effect.

A. If switch is open, answer the following questions.
   (a) [5%] Small signal DC gain $V_o/V_i = ?$.
   (b) [5%] $-3 \text{ dB bandwidth of } V_o/V_i = ?$

B. If switch is closed, answer the following questions.
   (c) [3%] What kind of feedback topology (shunt-shunt, series-shunt, shunt-series, series-series) is utilized in this amplifier?
   (d) [7%] Small signal DC gain $V_o/V_i = ?$.
   (e) [5%] $-3 \text{ dB bandwidth of } V_o/V_i = ?$

![Fig. 3]
(4) A circuit of sawtooth waveform generator is shown in Fig. 4(a) with a Schmitt trigger followed by an integrator. The limiting levels of the Schmitt trigger are \(+V_z\) and \(-V_D\). The output triangular waveform is shown in Fig. 4(b).

(a) [10%] Find \(V_{TH}\), \(V_{TH}^L\), \(T_1\) and \(T_2\) in terms of \(V_z\), \(V_D\), \(R_1\), \(R_2\), \(R\) and \(C\).

(b) [5%] For \(V_z=6.3\ V\), \(V_D=0.7\ V\), \(R_1/R_2=3/7\) and \(RC=2.1\times10^{-5}\ \text{sec}\), sketch and level the triangular waveform. What is the frequency of oscillation of the circuit?

(5) For the ECL circuit in Fig. 5(a), assume that the base-emitter drop of an ON transistor is 0.8V and cut-in voltage is 0.6V.

(a) [6%] Calculate \(V_{IL}\), \(V_{OL}\), \(V_{IH}\), \(V_{OH}\) and noise margin \(NM_H\) and \(NM_L\) of the OR transfer characteristic as shown in Fig. 5(b). Ignoring the base current when calculating \(V_{OL}\), but using \(\beta=99\) to calculate \(V_{OH}\).

(b) [4%] Recalculate \(V_{IL}\), \(V_{OL}\), \(V_{IH}\), \(V_{OH}\), \(NM_H\) and \(NM_L\) when the 50\(\Omega\) resistor \(R_T\) is replaced by 50k\(\Omega\).

(c) [8%] The NOR transfer characteristic is shown in Fig. 5(c). It has four distinct regions as indicated by segments ab, bc, cd and de. What are the corresponding transistor modes of operation (cut-off, active or saturation) of \(Q_a\), \(Q_b\) and \(Q_c\) for each segment?

(d) [2%] Explain why the ECL circuit employs a negative power supply and the \(V_{CC}\) line is connected to ground?