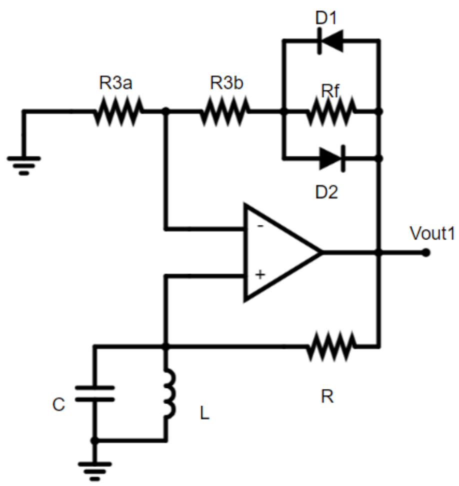
EE204: Analog Circuits
Dept. of Electrical Engineering, IIT Bombay
Autumn Semester 2023

11-10-2023

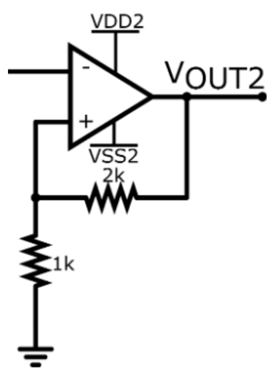
Tutorial 7

Q-1. Consider the oscillator circuit given below:



a. Determine the loop gain A(s)**β**(s), and find the frequency of oscillations.
b. Find the condition on R3a, R3b and Rf for sustained oscillations.

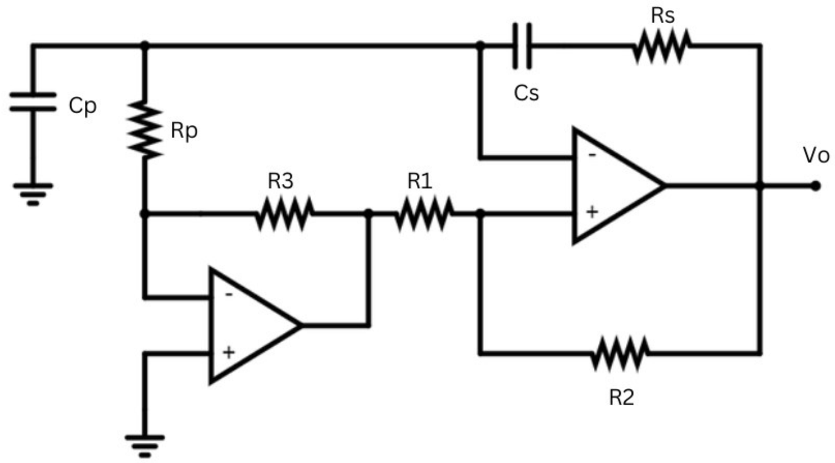
Q-2.
Consider the sine with an amplitude of 5V as the input to the Schmitt trigger circuit shown below:



Sketch the waveforms Vout1 and Vout2 and determine the duty cycles of the outputs if

a. VDD2=15V , VSS2 =-15V
b. VDD2=15V , VSS2 =0V

Q3. Consider the oscillator circuit shown below:



a. Evaluate the loop gain and show that the Barkhausen's condition for this circuit is: (R2/R1)(1 + R3/Rp) = Rs/Rp + Cp/Cs
b. Verify that if we let R2/R1 = Cp/Cs, this condition simplifies to R3 = (R1/R2)Rs.

Q1.

a. $$A(s) = \left(1 + \frac{R_f + R_{3b}}{R_{3a}}\right) = \frac{V_o}{V_i}$$

$$\beta(S) = \frac{V_f}{V_o} = \frac{\frac{1}{R}}{\frac{1}{R} + \frac{1}{SL} + SC}$$

$$= \frac{\frac{1}{R} \cdot SLR \times \frac{1}{LC \cdot R}}{S^2LCR + R + SL \times \frac{1}{LC \cdot R}}$$

$$= \frac{S \cdot \frac{1}{RC}}{S^2 + S \cdot \frac{1}{RC} + \frac{1}{LC}}$$

$\therefore$ Loop gain $$A(S) \cdot \beta(S) = \frac{S \cdot \frac{1}{RC} \cdot \left(1 + \frac{R_f + R_{3b}}{R_{3a}}\right)}{S^2 + \frac{S}{RC} + \frac{1}{LC}}$$

b. $S = j\omega$

$$A(j\omega)\beta(j\omega) = \frac{j\frac{\omega}{RC}}{\left(-\omega^2 + \frac{1}{LC}\right) + j\frac{\omega}{RC}} \cdot \left(1 + \frac{R_f + R_{3b}}{R_{3a}}\right)$$

for phase $0°$

$$\omega_0^2 = \frac{1}{LC} \Rightarrow \omega_0 = \frac{1}{\sqrt{LC}}$$

for $|A(j\omega)\beta(j\omega)| \geq 1$

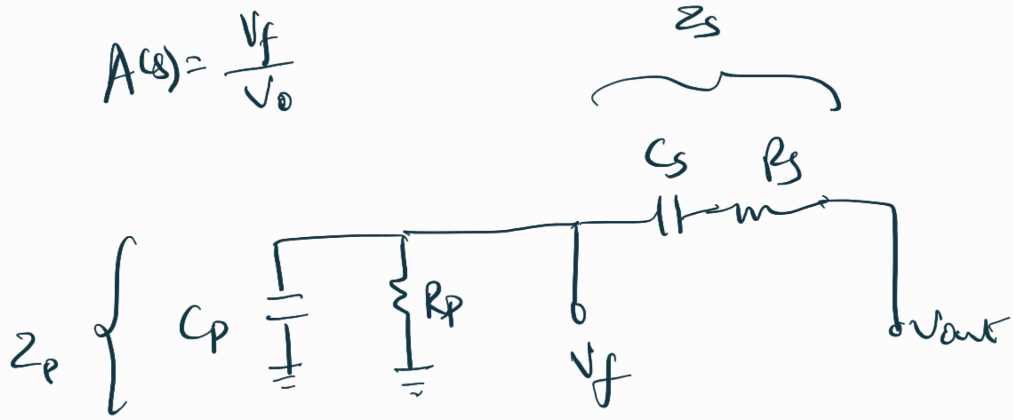
$$\Rightarrow 1 + \frac{R_f + R_{3b}}{} \geq 1$$

R_{3a}

$$\Rightarrow \quad \frac{R_f + R_{3b}}{R_{3a}} \geq 0 \;\rightarrow\; \text{condition for sustained oscillations.}$$

Q3. $\underline{A}(s) \cdot \beta(s)$

$$A(s) = \frac{V_f}{V_o}$$



$$Z_p = \frac{R_p \cdot \frac{1}{sC_p}}{R_p + \frac{1}{sC_p}} \qquad Z_s = R_s + \frac{1}{sC_s}$$

$$V_f = \frac{Z_p}{Z_s + Z_p} \cdot V_{out}$$

$$\beta(s) = \frac{V_f(s)}{V_{out}} = \frac{\frac{R_p}{\cancel{sC_p}}}{\frac{sR_pC_p + 1}{\cancel{sC_p}}} \times \frac{1}{\frac{R_p}{1+sR_pC_p} + R_s + \frac{1}{sC_s}}$$

$$= \frac{R_p}{(\cancel{1+sR_pC_p})} \times \frac{1}{\frac{R_p \cdot s \cdot C_s + R_s(1+sR_pC_p)\cdot sC_s + (1+sR_pC_p)}{(\cancel{1+sR_pC_p})\cdot sC_s}}$$

$$= \frac{s R_p \cdot C_s}{s^2 R_s R_p C_s C_p + s\left(C_s R_p + R_s C_s + R_p C_p\right) + 1}$$

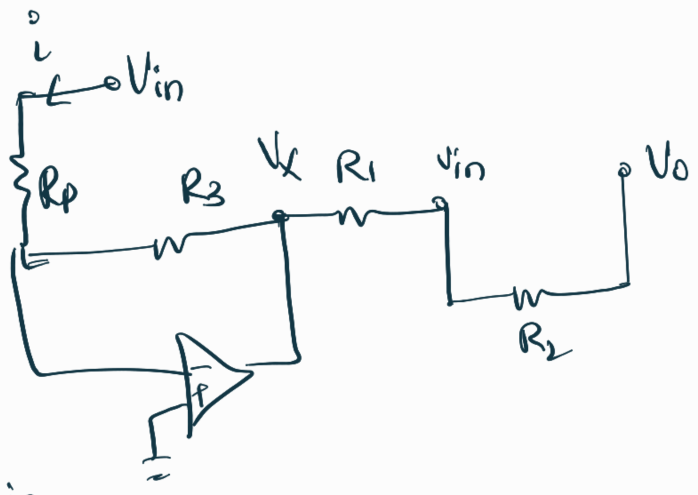
$$= \frac{j\omega \cdot R_p C_s}{\left(1 - \omega^2 R_s R_p C_s C_p\right) + j\omega\left(C_s R_p + R_s C_s + R_p C_p\right)}$$

$$\omega_0 = \frac{1}{\sqrt{R_s R_p C_s C_p}}$$

at ω_0

$$= \frac{1}{\dfrac{C_s R_p + R_s C_s + R_p C_p}{R_p C_s}} = \underline{\frac{1}{1 + \dfrac{R_s}{R_p} + \dfrac{C_p}{C_s}}}$$

$$A(s) = ? = \frac{V_o}{V_{in}}$$



$$i = \frac{V_{in}}{R_p}$$

$$0 - \left(\frac{V_{in}}{R_p}\right) \cdot R_3 = V_x$$

$$V_{in} = \left(V_o + \frac{V_{in}}{R_p} \cdot R_3\right) \cdot \frac{R_1}{R_1 + R_2}$$

$-V_x$

$\Rightarrow V_o = \left(V_x + V_{in} \cdot R_3\right) \left(\quad 1 \quad \right) \quad V_{in} \; R_p$

$$V_{in} = \left(V_0 + \frac{\cdots}{R_p} \cdots 3\right)\cdot\left(\frac{\cdots}{1+R_2/R_1}\right) - V_{in}\cdot\frac{R_3}{R_p}$$

$$V_{in}\left(1+\frac{R_3}{R_p}\right)\cdot\left(1+\frac{R_2}{R_1}\right) - V_{in}\left(\frac{R_3}{R_p}\right) = V_0$$

$$\Rightarrow \quad \frac{V_0}{V_{in}} = 1 + \frac{R_2}{R_1}\left(1+\frac{R_3}{R_p}\right)$$

$$\Rightarrow \quad A.\beta = 1$$

$$\Rightarrow \left[1 + \frac{R_2}{R_1}\left(1+\frac{R_3}{R_p}\right)\right]\left[\frac{1}{1+\frac{R_S}{R_p}+\frac{C_p}{C_S}}\right] = 1$$

$$\Rightarrow \quad \frac{R_2}{R_1}\left(1+\frac{R_3}{R_p}\right) = \frac{R_S}{R_p} + \frac{C_p}{C_S}$$

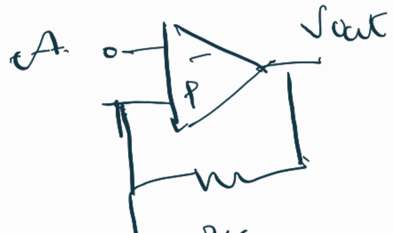
b.

$$\frac{R_3}{\cancel{R_p}}\cdot\frac{R_2}{R_1} = \frac{R_S}{\cancel{R_p}}$$

$$R_3 = \left(\frac{R_1}{R_2}\right)\cdot R_S$$

Q2. If initially high

$$V_{HT} = V_f = V_{out_{max}}\left(\frac{1k}{\underset{+1k}{2k}}\right)$$



$$= V_{DD}$$

$= \frac{VDD}{3}$

1K

If $V_{in} \geq V_{HT}$

then O/P goes low.

$V_o = A(V_+ - V_{ip})$

if V_o is VDD

$V_+ = \frac{VDD}{3}$

if V_o is VSS

$V_+ = \frac{V_{SS}}{3}$

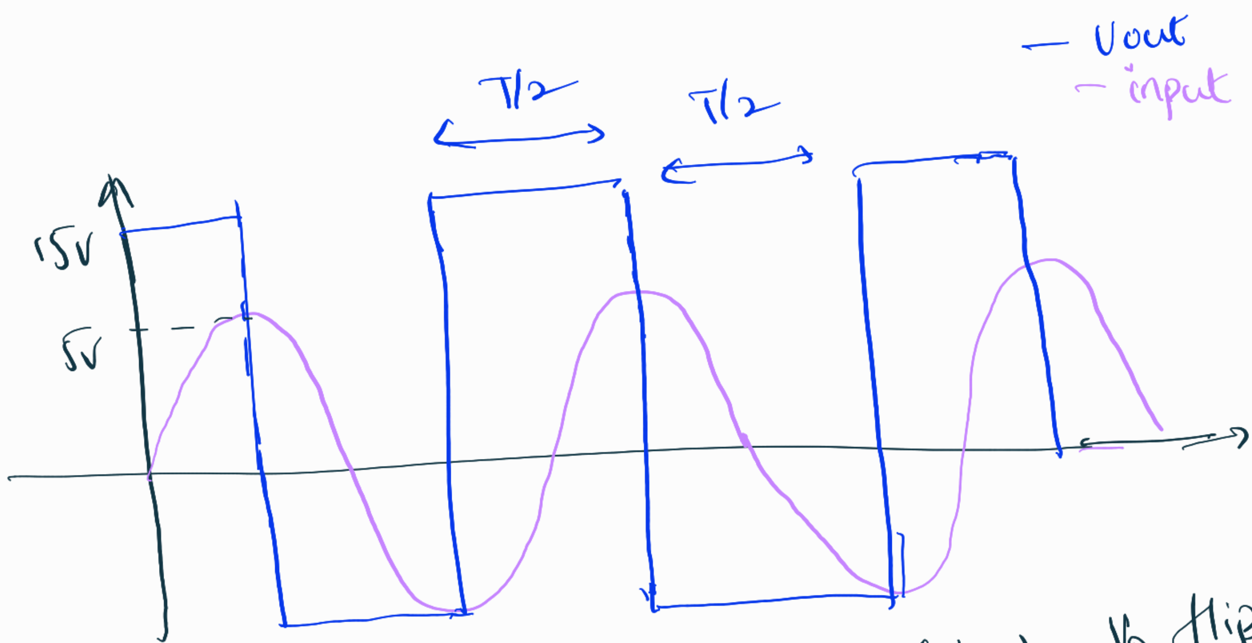
when V_o is low

$$V_{LT} = V_+ = VSS\left(\frac{1}{1+2}\right) = \frac{VSS}{3}$$

when $V_{in} \leq V_{LT}$

then Vout goes high

a:

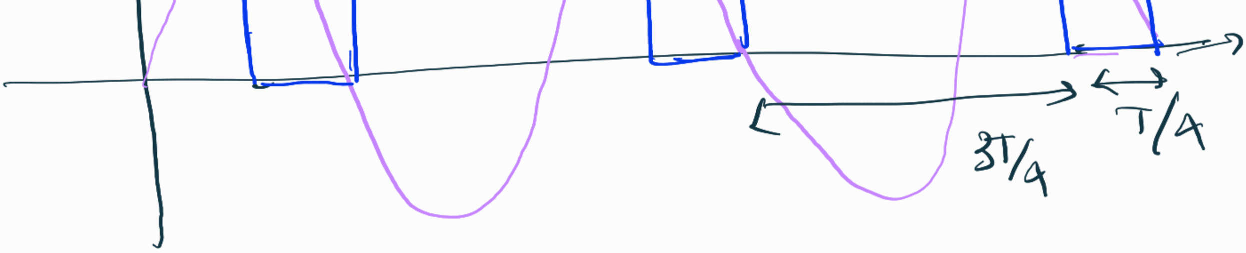


Starting Op is high, when $V_{ip} \geq V_+ \left(\frac{VDD}{3}\right)$ V_o flips

then when $V_{ip} \leq V_+ \left(\frac{VSS}{3}\right)$ V_o flips again.

duty cycle: $\frac{T/2}{T/2 + T/2} = 0.5$

b.



when o/p is low, $V_+ = VSS/3$

if $v_{ip} \le \frac{VSS}{3}$, it becomes high again

$V_{ip} \le 0$

then when $V_{ip} \ge \frac{VDD}{3}$ o/p becomes low again

duty cycle $\frac{\frac{3T}{4}}{\frac{3T}{4} + \frac{T}{4}} = 0.75$