11/07/11.

Second order Butterworth low pass filter

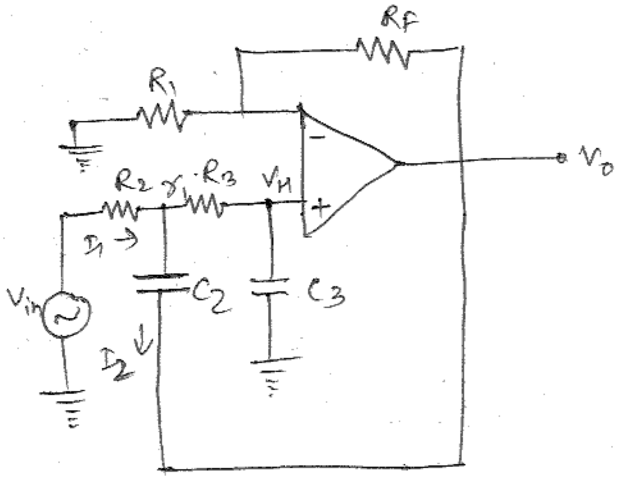

fig ①

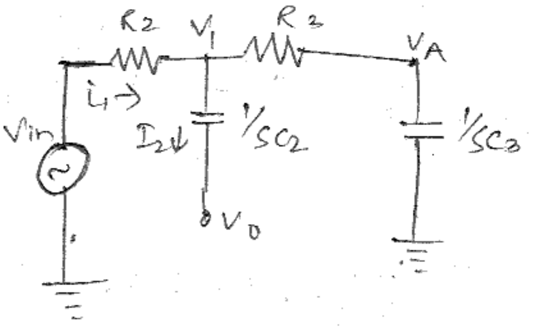

fig ②

Using KCL in fig ②

$I_1 = I_2 + I_3$

$$\frac{V_{in} - V_1}{R_2} = \frac{V_1 - V_o}{1/sC_2} + \frac{V_1 - V_A}{R_3} \quad \text{--- ①}$$

Use potential rules at pt. A

$$V_A = V_1 \left[\frac{1/sC_3}{R_3 + 1/sC_3} \right]$$

$$V_A = \frac{V_1}{sR_3C_3 + 1} \quad \text{--- ②}$$

$$V_1 = V_A (sR_3C_3 + 1) \quad \text{--- ③}$$

sub. eqn ③ in eqn ①

$$\frac{V_{in} - V_A(R_3C_3s + 1)}{R_2} = \frac{V_A(sR_3C_3 + 1) - V_o}{1/sC_2} + \frac{V_A(1 + C_3R_3s) - V_A}{R_3}$$

$$\frac{V_{in}}{R_2} - V_A\frac{(sR_3C_3+1)}{R_2} = sC_2\left(V_A(R_3C_3s+1) - V_0\right) + V_A\frac{(1+R_3C_3s-1)}{R_3}$$

$$\frac{V_{in}}{R_2} + V_0 sC_2 = V_A\left[\frac{1+sR_3C_3}{R_2} + sC_2(1+sR_3C_3) + \frac{1+R_3C_3s}{R_3} - \frac{1}{R_3}\right]$$

$$\frac{V_{in}}{R_2} + V_0 sC_2 = V_A\left[\frac{R_3(1+sR_3C_3) + sC_2R_2C_3(1+R_3C_3s) + R_2(1+R_3C_3s) - R_2}{R_2R_3}\right]$$

$$R_3V_{in} + V_0R_2R_3sC_2 = V_A\left[(1+R_3C_3s)(R_3+sC_2R_2R_3+R_2) - R_2\right]$$

$$V_A = \frac{R_3V_{in} + V_0R_2R_3sC_2}{\left[(1+R_3C_3s)(R_3+R_2R_3sC_2+R_2) - R_2\right]}$$

In general

$$V_0 = A_F \cdot V_A.$$

$$V_0 = A_F\frac{\left[R_3V_{in} + V_0R_2R_3sC_2\right]}{\left[(1+R_3C_3s)(R_3+R_2R_3sC_2+R_2) - R_2\right]}$$

$$A_FR_3V_{in} = V_0\left[1 - \frac{A_FR_3R_2sC_2}{(1+R_3s)(R_3+R_2R_3sC_2+R_2) - R_2}\right]$$

$$A_FR_3V_{in} = V_0\left[(1+R_3s)(R_3+R_2R_3sC_2+R_2) - R_2 - A_FR_3R_2sC_2\right]$$

$$\frac{V_0}{V_{in}} = \frac{A_FR_3}{\left[(1+sR_3C_3)(R_3+R_2R_3sC_2+R_2) - R_2 - A_FR_2R_3sC_2\right]}$$

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$$\frac{V_o}{V_{in}} = \frac{A_f R_3}{R_3 + sR_3^2 C_3 + R_3 R_2 C_2 s + s^2 R_3^2 C_3 C_2 R_2 + R_2 + sR_3 R_2 C_3 - R_2 - sR_2 R_3 C_2 A_f}$$

$$= \frac{A_f}{1 + sR_3 C_3 + R_2 C_2 s + s^2 R_3 C_3 C_2 R_2 + sR_2 C_3 - A_f sR_2 C_2}$$

$$\frac{V_o}{V_{in}} = \frac{A_f}{s^2 + \frac{s(R_2 C_3 + R_2 C_2 + R_2 C_3 - A_f R_2 C_2)}{R_3 C_3 C_2 R_2} + \frac{1}{R_3 C_3 R_2 C_2}} \quad \text{— (A)}$$

In general.

$$\frac{V_o(s)}{V_i(s)} = \frac{A}{s^2 + 2\xi \omega_n s + \omega_n^2} \quad \text{— (B)}$$

Comparing A and B.

$$\omega_n^2 = \frac{1}{R_2 R_3 C_2 C_3}$$

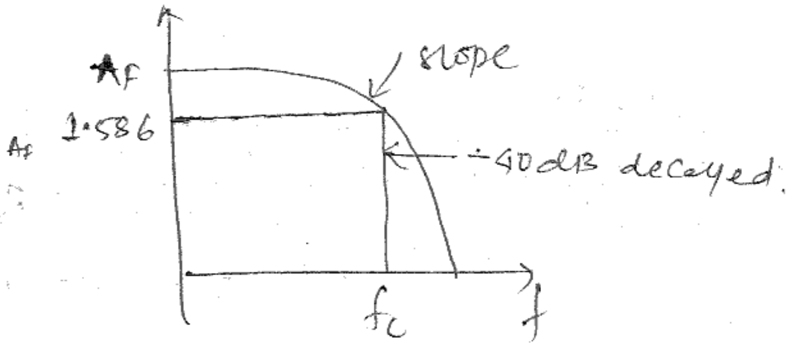
$$\omega_n = \omega_c$$

$$\omega_c^2 = \frac{1}{R_2 R_3 C_2 C_3}$$

$$f_c^2 = \frac{1}{(2\pi)^2 R_2 R_3 C_2 C_3}$$

$$f_c = \frac{1}{\sqrt{(2\pi)^2 R^2 C^2}} \quad \left[\because R_2 = R_3 = R,\ C_2 = C_3 = C\right]$$

$$\therefore \boxed{f_c = \frac{1}{2\pi RC}}$$



$$4\varepsilon_0^2 \omega_n^2 = \left[\frac{s(RC+RC+RC-A_f RC)}{R^2C^2}\right]^2$$

$$4\varepsilon_0^2 \frac{1}{R^2C^2} = \frac{s(4RC-A_f)}{R^2C^2}$$

$$\varepsilon = \sqrt{\frac{s(3RC-A_f)}{2}}$$

$$2\varepsilon\omega_n s = \frac{s\cdot RC(3-A_f)}{RC\cdot RC}$$

$$2\varepsilon\omega_n = (3-A_f)$$

$$2\varepsilon\frac{1}{RC} = \frac{(3-A_f)}{RC}$$

$$\varepsilon = \frac{(3-A_f)}{2}$$

$$\frac{1}{\sqrt{2}} = \frac{3 - A_f}{2}$$

$$\boxed{A_f = 1.586}$$

$= 20\log(1.586)$

$= -40\,dB$ / decade.

$$A_f = 1 + \frac{R_f}{R_1}$$

$$1.586 = 1 + \frac{R_f}{R_1}$$

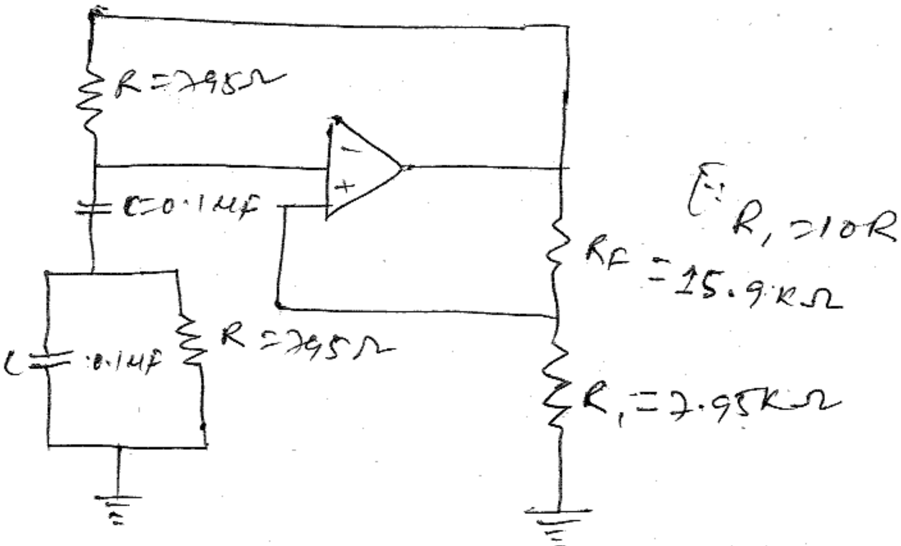
$$\therefore \boxed{R_f = 0.586 R_1}$$

15/07/11.

~~Procedure~~ Design procedure for second order low pass filter (LPF).

1) choose the cut-off frequency.
2) select $R_2 = R_3 = R$, and $C_2 = C_3 = C$
3) Select $A_f = 1.586$, $R_f = 0.586 R_1$.
4) select $R_1 \leq 1\,M\Omega$

Q] Use ± 15V. power supply and IC 741. Design wein Bridge oscillator for 2KHz freq. Assume C = 0.1μF.



$R_f = 2R_1$

f = 2KHz

C = 0.1μF

$f = \frac{1}{2\pi RC}$

$R = \frac{1}{2\pi f C} = 795\,\Omega$

R = 795Ω

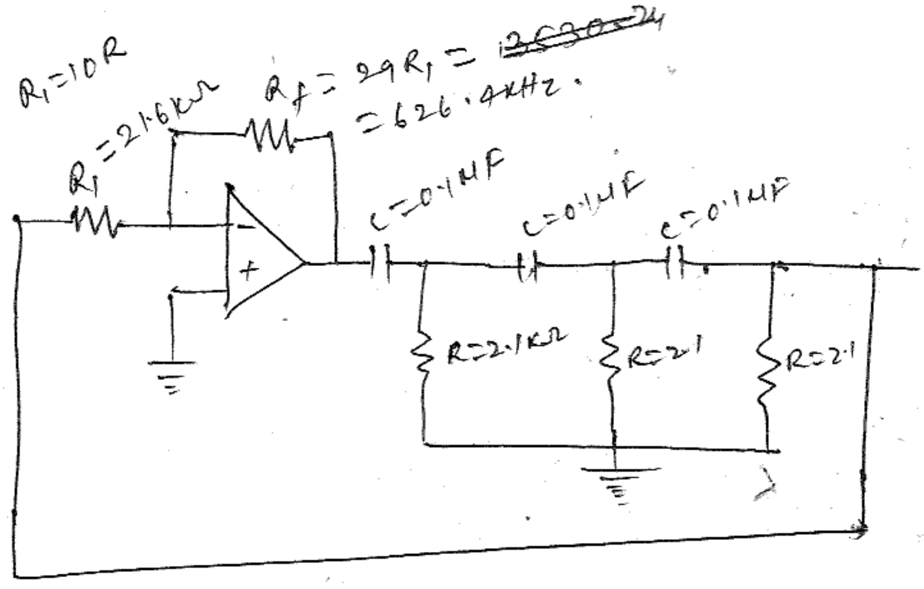
Q2] Design a phase shift oscillator, oscillates at 300Hz. and C = 0.1μF

$f = \frac{1}{2\pi\sqrt{6}RC}$

$R = \frac{1 \times 10^6}{2 \times 3.14 \times \sqrt{6} \times 300 \times 0.1}$

$R = \frac{106}{461.48} = 2166.9\,\Omega$

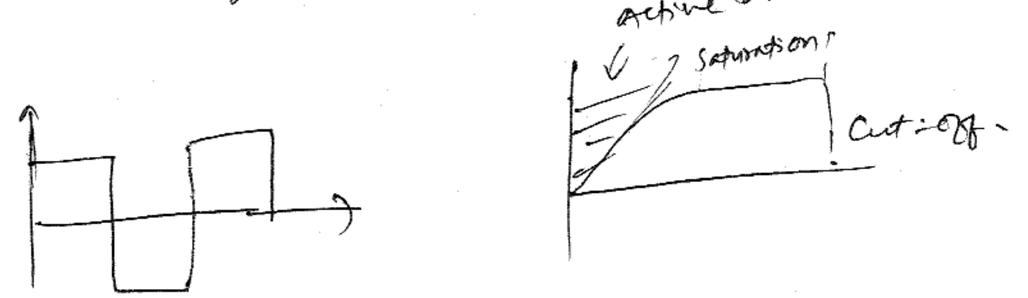
R = 2.167 KΩ



RC phase shift oscillator

COMPARATOR :

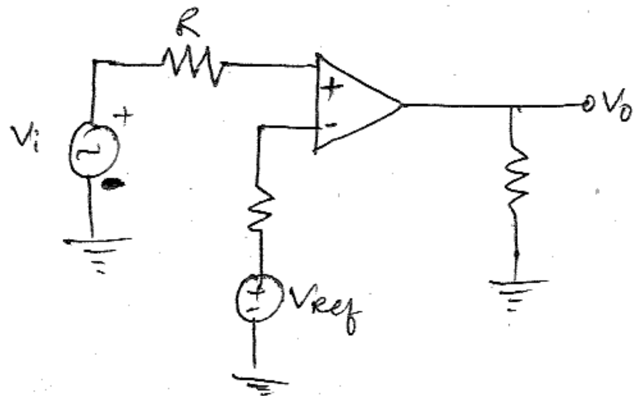
Inverting — Non-inverting

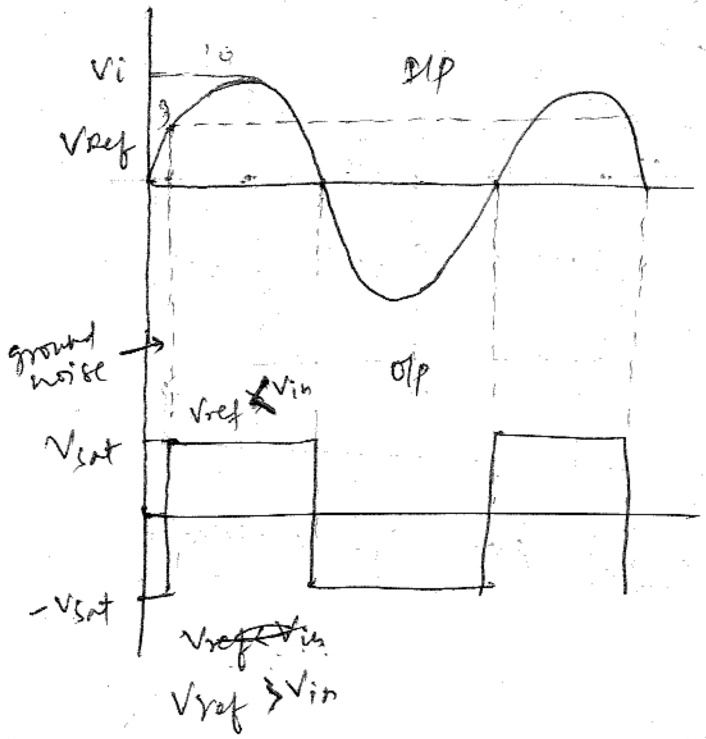


Non-linear

if $V_{ref} > V_{in}$

Non-Inverting Comparator





Inverting.