Electronics Handbook
2nd Year Electrical Engineering

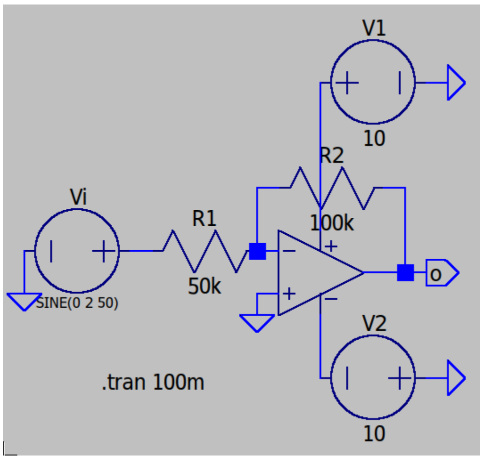
Eng. Abdalrahman Shaban Mohamed

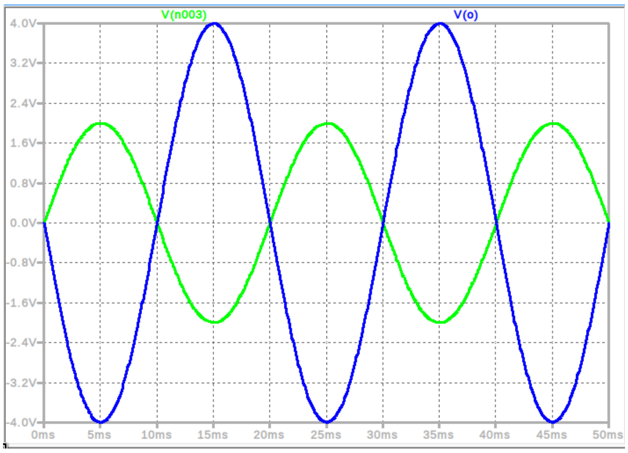
Contents

Chapter 1

Operational Amplifier (Linear Applications)

1.1 Inverting



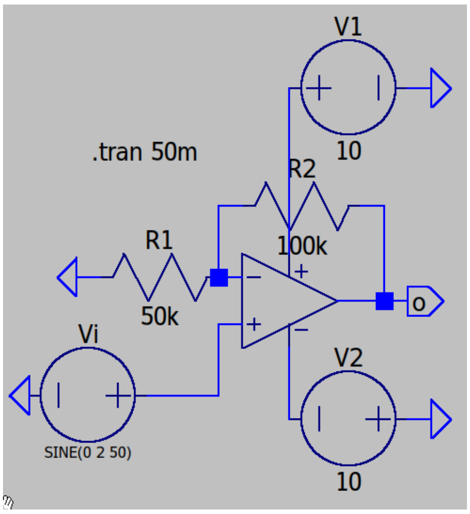


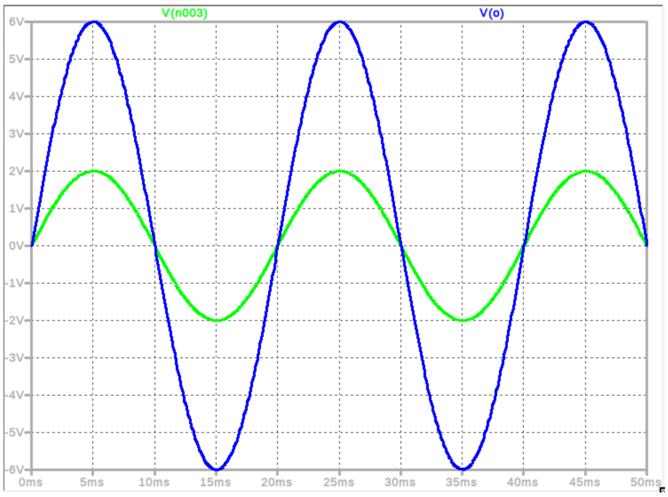
$$
\begin{aligned}
I_{\mathrm{R1}} &= I_{\mathrm{R2}} \\
\frac{V_i - 0}{R_1} &= \frac{0 - V_0}{R_2} \\
R_2 V_i &= -R_1 V_o \\
\therefore V_0 &= -\frac{R_2}{R_1} V_i
\end{aligned}
$$

1.2 Effect of Finite Open-loop Gain

$$
\begin{aligned}
V_o &= A(V^+ - V^-) \\
V^+ = 0 \quad \text{and } V^- &= -\frac{V_o}{A} \\
\frac{V_i - (-\frac{V_o}{A})}{R_1} &= \frac{-\frac{V_o}{A} - V_o}{R_2} \\
R_2 V_i + R_2 \frac{V_o}{A} &= -R_1 \frac{V_o}{A} - R_1 V_o \\
R_2 V_i &= -V_o \left(\frac{R_2}{A} + \frac{R_1}{A} + R_1\right) \\
\frac{R_2}{R_1} V_i &= -V_o \left(\frac{R_2}{AR_1} + \frac{1}{A} + 1\right) \\
\therefore G = \frac{V_o}{V_i} &= \frac{-R_2/R_1}{1 + (1 + \frac{R_2}{R_1})/A}
\end{aligned}
$$

1.3 Non-Inverting





$$I_{\text{R1}} = I_{\text{R2}}$$

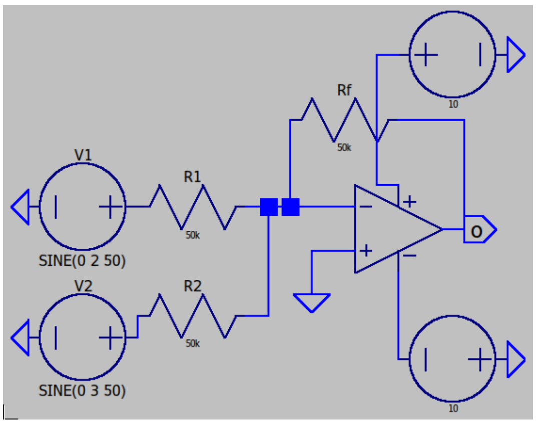
$$\frac{0 - V_i}{R_1} = \frac{V_i - V_o}{R_2}$$

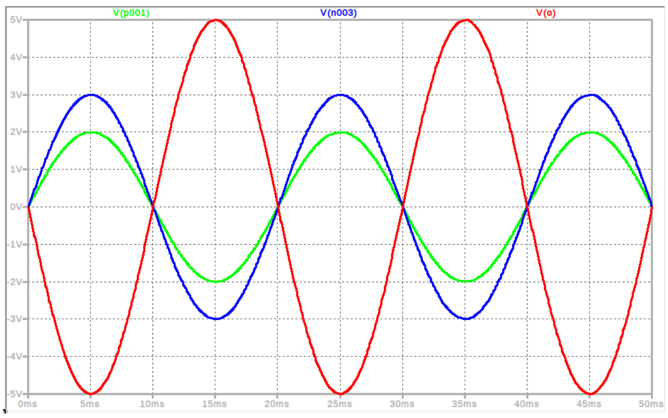
$$-R_2 V_i = R_1 V_i - R_1 V_o$$

$$-V_i(R_2 + R_1) = -R_1 V_o$$

$$\therefore V_o = V_i(1 + R_2/R_1)$$

1.4 Inverting Summer



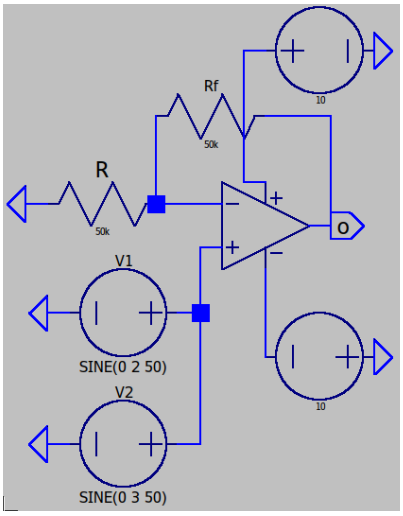


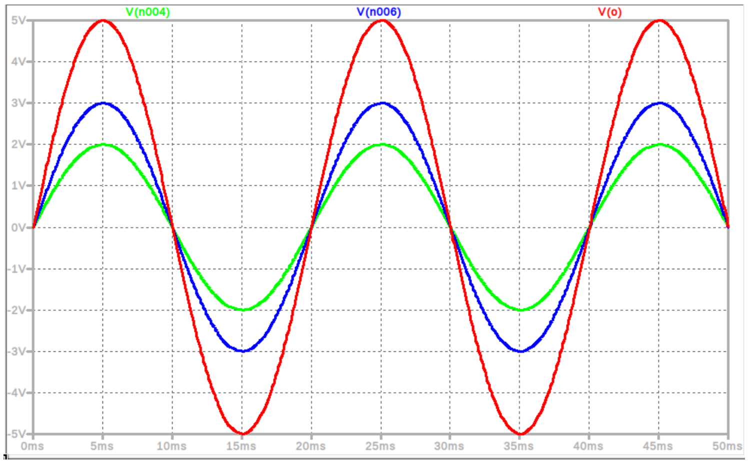
$$\because I_{\text{R1}} + I_{\text{R2}} = I_{R_f}$$

$$\frac{V_1 - 0}{R_1} + \frac{V_2 - 0}{R_2} = \frac{0 - V_o}{R_f}$$

$$\therefore V_o = -(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2)$$

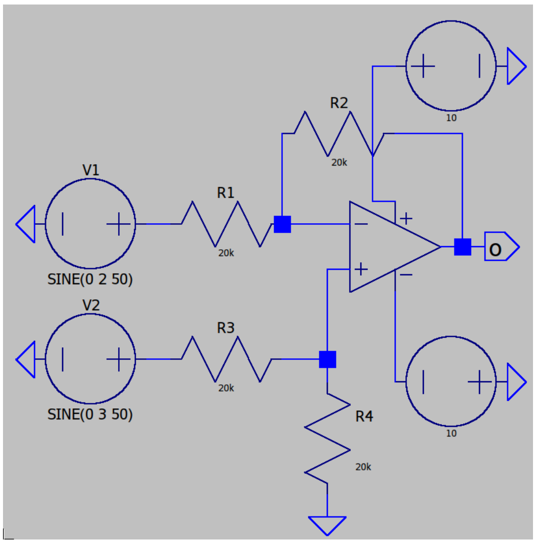
1.5 NonInverting Summer

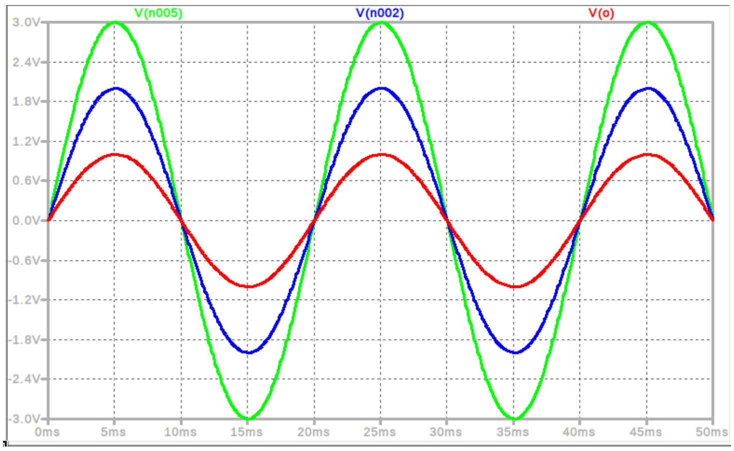




$$\because V^- = V^+$$
$$\frac{0-(V_1+V_2)}{R} = \frac{(V_1+V_2)-V_o}{R_f}$$
$$-R_f(V_1+V_2) = R(V_1+V_2) - RV_o$$
$$\therefore V_o = (1+R_f/R)(V_1+V_2)$$

1.6 Difference





Using Super position:

kill V2:

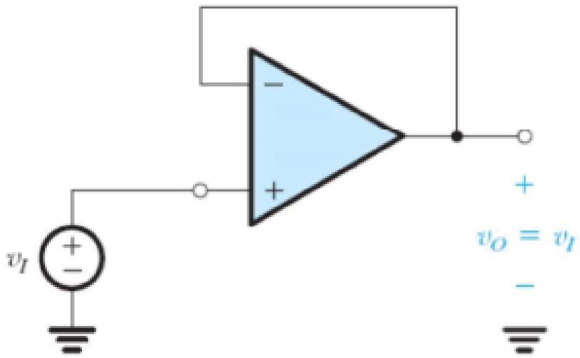
$$V_{o1} = -\frac{R_2}{R_1}V_1$$

kill V1:

$$\frac{0-\frac{R_4}{R_3+R_4}V_2}{R_1} = \frac{\frac{R_4}{R_3+R_4}V_2 - V_{o2}}{R_2}$$
$$\frac{-R_4R_2}{R_3+R_4}V_2 = \frac{R_4R_1}{R_3+R_4}V_2 - R_1V_{o2}$$
$$V_{o2} = \frac{R_2}{R_1}\frac{R_4}{R_3+R_4}V_2 + \frac{R_4}{R_3+R_4}V_2$$

$$V_o = V_{o1} + V_{o2}$$
$$V_o = -\frac{R_2}{R_1}V_1 + \frac{R_2}{R_1}\frac{R_4}{R_3+R_4}V_2 + \frac{R_4}{R_3+R_4}V_2$$
$$V_o = -\frac{R_2}{R_1}V_1 + \frac{R_4}{R_3+R_4}(\frac{R_2}{R_1}+1)V_2$$
$$\text{When } R_1 = R_3,\ R_2 = R_4$$
$$V_o = -\frac{R_2}{R_1}V_1 + \frac{R_2}{R_1+R_2}(\frac{R_2}{R_1}+1)V_2$$
$$V_o = -\frac{R_2}{R_1}V_1 + \frac{R_2}{R_1+R_2}(\frac{R_1+R_2}{R_1})V_2$$
$$\therefore V_o = -\frac{R_2}{R_1}(V_2 - V_1)$$

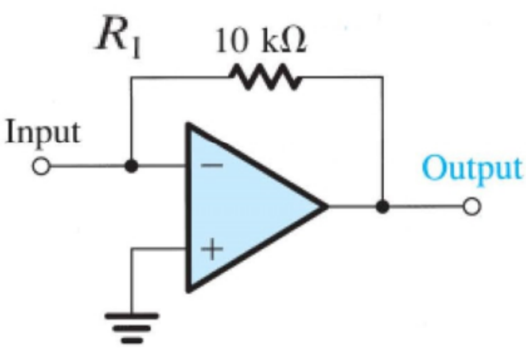
1.7 Buffer



$$V_o = V_i \tag{1.1}$$

The main function of an op-amp buffer is to provide a high input impedance and a low output impedance, which helps to reduce the loading effect on the circuit it is connected to.

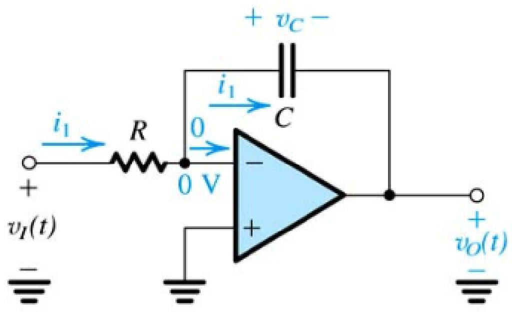
1.8 Trans-Impedance



$$I_i = I_R$$
$$I_i = \frac{0 - V_o}{R_f}$$
$$\therefore V_o = -R_f I_i$$

1.9 Integrator

1.9.1 Inverting Integrator

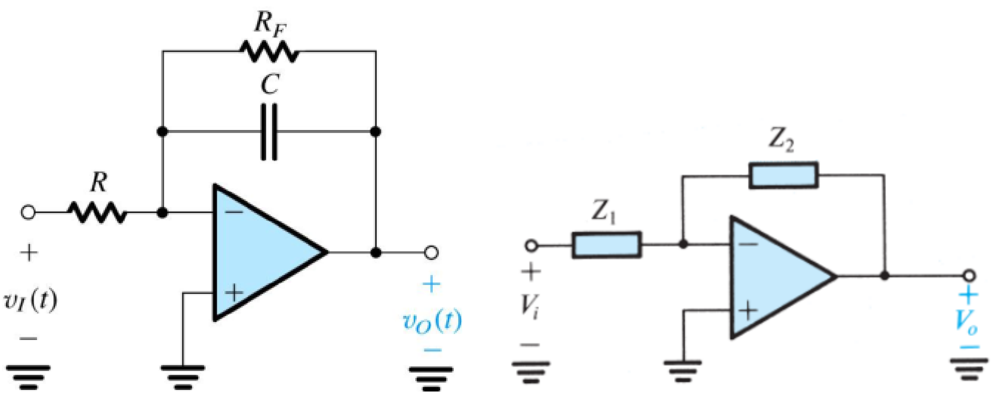


$$\frac{V_i - 0}{R} = I_c$$
$$\because V_o = -V_c$$
$$\frac{V_i - 0}{R} = -C\frac{dV_o}{dt}$$
$$\therefore V_o = \frac{-1}{RC}\int V_i dt$$

In s domain:

$$V_o = \frac{-1}{sRC}V_i$$
$$\frac{V_o(j\omega)}{V_i(j\omega)} = \frac{-1}{(j\omega)RC}$$
$$\frac{V_o(j\omega)}{V_i(j\omega)} = \frac{-(-j)}{(\omega)RC}$$
$$\text{As } j = cos(\frac{\pi}{2}) + jsin(\frac{\pi}{2}) = e^{j\frac{\pi}{2}}$$
$$\frac{V_o(\omega)}{V_i(\omega)} = \frac{e^{j\frac{\pi}{2}}}{\omega RC}$$
$$\therefore \left|\frac{V_o}{V_i}\right| = \left|\frac{1}{\omega RC}\right|$$
$$\phi = +90$$

1.9.2 Miller Integrator



The Miller integrator with alarge resistance RF connected in parallel with Cin order to provide negative feedback and hence finite gain at dc (A = $\frac{R_f}{R}$).

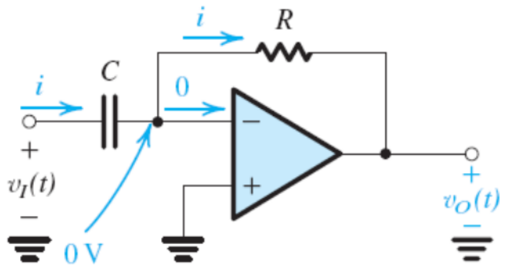
$$V_o = -\frac{Z_2}{Z_1}$$

$$Z_2 = \frac{R_f.\frac{1}{sC}}{R_f + \frac{1}{sC}}$$

$$Z_2 = \frac{R_f}{sR_fC + 1}$$

$$\therefore V_o = \frac{-R_f/R}{sR_fC + 1}.V_i$$

1.10 Differentiator

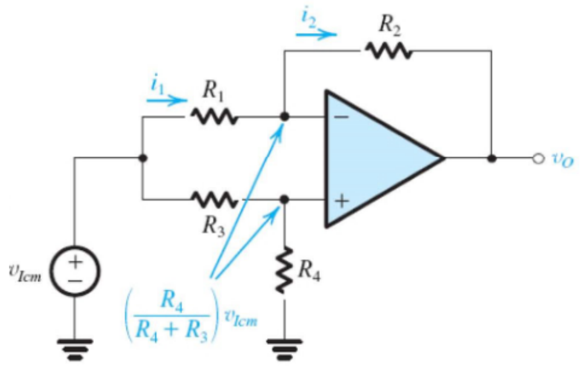


$$I_C = I_R$$

$$C\frac{dV_i}{dt} = \frac{0 - V_o}{R}$$

$$\therefore V_o = -RC\frac{dV_i}{dt}$$

1.11 Common Mode Gain



$$V^- = \frac{R_4}{R_4 + R_3} V_{\text{Icm}}$$

$$\frac{V_{\text{Icm}} - V^-}{R_1} = \frac{V_{\text{Icm}} - V_o}{R_2}$$

$$R_2 V_{\text{Icm}} - \frac{R_4 R_2}{R_4 + R_3} V_{\text{Icm}} = \frac{R_4 R_1}{R_4 + R_3} V_{\text{Icm}} - R_1 V_o$$

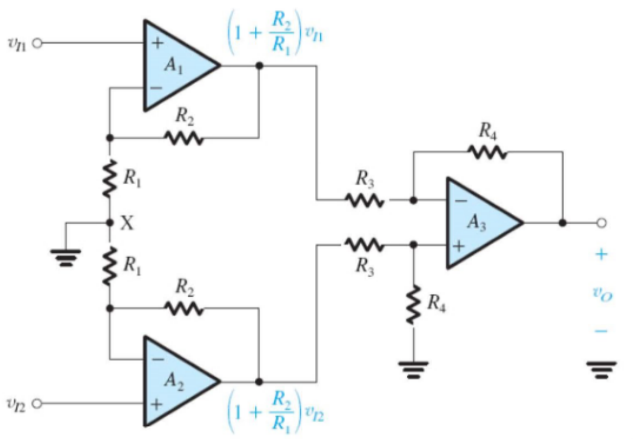
$$V_o = \frac{R_2}{R_1} \frac{R_4}{R_4 + R_3} V_{\text{Icm}} + \frac{R_4}{R_4 + R_3} V_{\text{Icm}} - \frac{R_2}{R_1} V_{\text{Icm}}$$

$$\frac{V_o}{V_{\text{Icm}}} = \frac{R_4}{R_4+R_3}\left(\frac{R_2}{R_1}+1-\frac{R_4+R_3}{R_4}.\frac{R_2}{R_1}\right)$$
$$\frac{V_o}{V_{\text{Icm}}} = \frac{R_4}{R_4+R_3}\left(\frac{R_2}{R_1}(1-\frac{R_4+R_3}{R_4})+1\right)$$
$$\frac{V_o}{V_{\text{Icm}}} = \frac{R_4}{R_4+R_3}\left(\frac{R_2}{R_1}(1-1-\frac{R_3}{R_4})+1\right)$$
$$\therefore A_{\text{cm}} = \frac{V_o}{V_{\text{Icm}}} = \frac{R_4}{R_4+R_3}\left(1-\frac{R_2}{R_1}\frac{R_3}{R_4}\right)$$

When $R_3 = R_1$ and $R_4 = R_2$
$A_{\text{cm}} = 0$

1.12 Instrumentation

To get high input impedance and zero common mode gain (less noise) we can use instrumentation Amplifier.

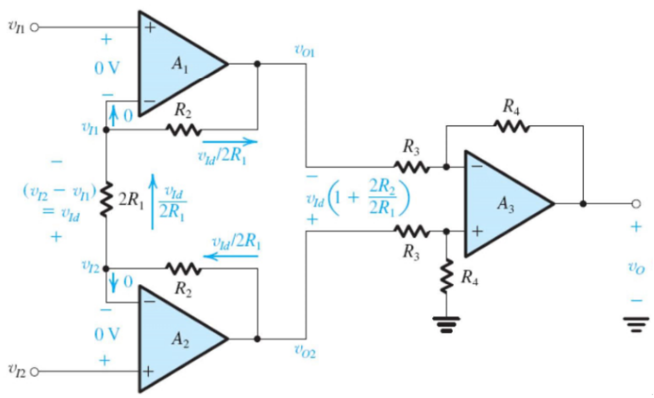


What're the major disadvantages of this configuration?

1- Saturation due to the common mode voltage.

2- Common mode voltage will be amplified unless we make perfect matching between the resistors which is very hard in practical.

3- We have to change at least 2 resistors to change the gain.



$$A_{\text{cm}} = 0$$

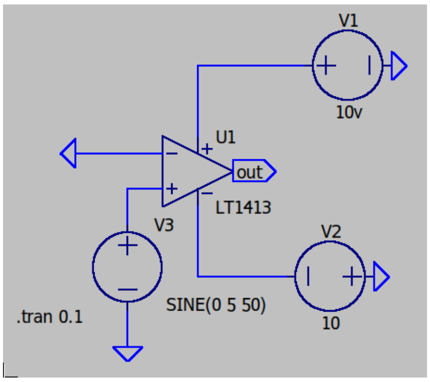
$$\text{A}_d = \tfrac{R_4}{R_3}(1+\tfrac{2R_2}{2R_1})$$

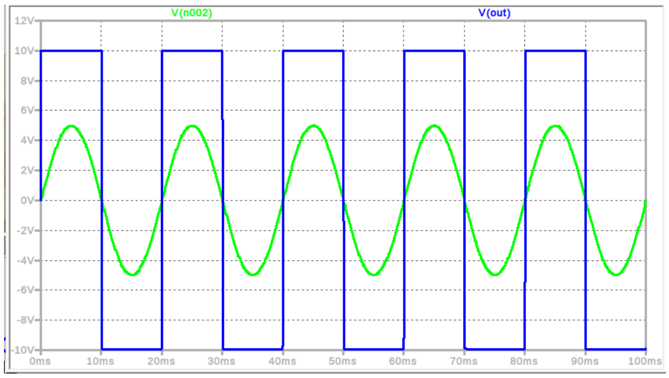
Chapter 2

Operational Amplifier (Non-Linear Applications)

2.1 Comparator

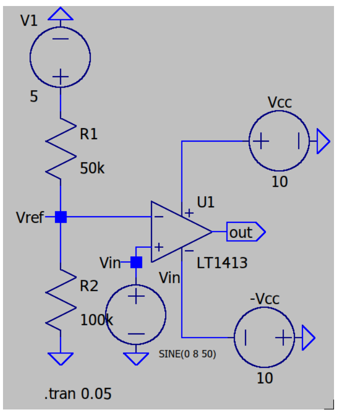
2.1.1 Zero-level detector

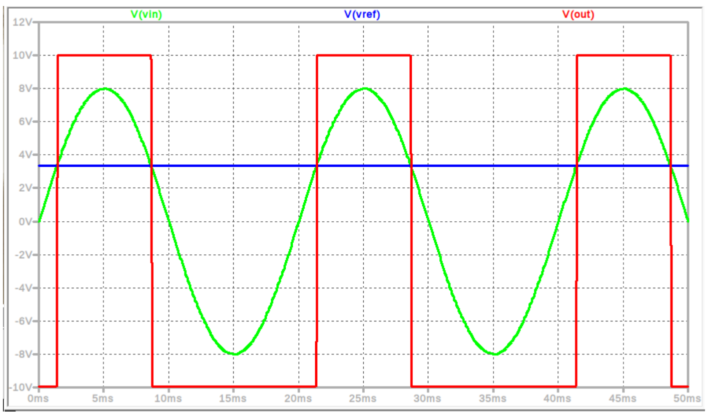




$$V_o = A(V^+ - V^-)$$
$$\because V^- = 0$$
$$V_o = V_{\text{cc}}$$

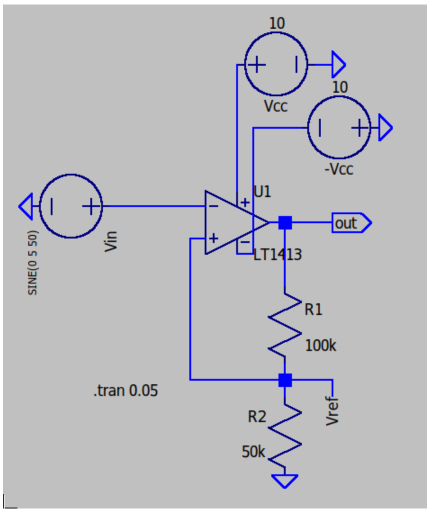
2.1.2 NonZero-level detector

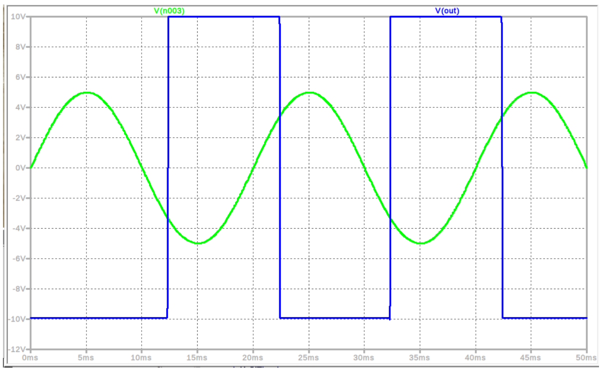


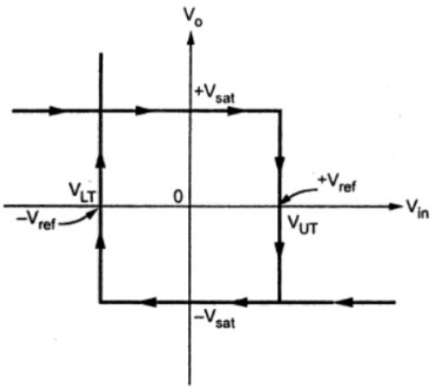


$$\because V_o = A(V^+ - V^-)$$
$$\because V^- = V_{\text{ref}} = V_1 . \frac{R_2}{R_2 + R_1}$$
$$\therefore V_o = +V_{\text{cc}} \quad \text{when} \quad V^+ > V_{\text{ref}}$$
$$\therefore V_o = -V_{\text{cc}} \quad \text{when} \quad V^+ \leq V_{\text{ref}}$$

2.1.3 Schmitt Trigger



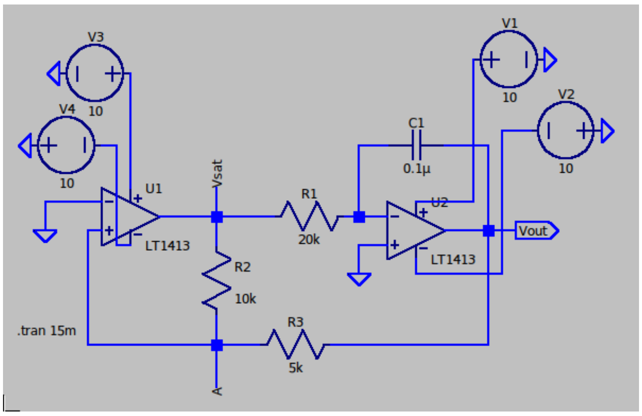


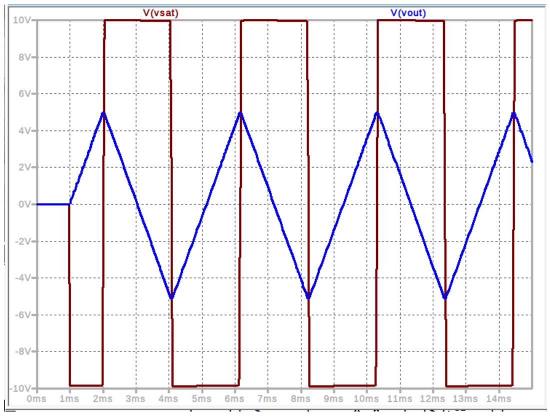


Using Schmitt Trigger reduces noise effects with hysteresis.

$$
\begin{aligned}
\because V_o &= A(V^+ - V^-) \\
= V_o &= A(V_{\text{ref}} - V_{\text{in}}) \\
\text{As } V_{\text{ref}} &= V_{\text{cc}} \cdot \frac{R_2}{R_2 + R_1}
\end{aligned}
$$

2.2 Practical Triangular-Wave Oscillator





Let V_{UTP} be the Upper Trigger Point (UTP) (V_{out})
And V_{LTP} be the Lower Trigger Point (LTP)
KCL at pint A:

$$
\begin{aligned}
\frac{V_{\text{out}} - V_A}{R_3} &= \frac{V_A - V_{\text{sat}}}{R_2} \\
\text{As } V_{\text{out}} &= V_{\text{UTP}} = |V_{\text{LTP}}| \\
R_2 V_\text{o} - R_2 V_A &= R_3 V_A - R_3 V_{\text{sat}} \\
V_\text{o} &= \frac{R_3}{R_2} V_A - \frac{R_3}{R_2} V_{\text{sat}} + V_A \\
&= \frac{R_3}{R_2}(V_A - V_{\text{sat}}) + V_A \\
\text{At } V_A &= 0 \\
V_\text{o} &= -V_{\text{sat}} \frac{R_3}{R_2}
\end{aligned}
$$

So we can find out that:

$$V_{\text{UTP}} = \frac{R_3}{R_2} V_{\text{sat}}$$

$$V_{\text{LTP}} = -\frac{R_3}{R_2} V_{\text{sat}}$$

4 of the capacitor charging time is the Periodic time.

$$V_{\text{UTP}} = \frac{1}{R_1 C} \int dV_{\text{sat}} dt$$

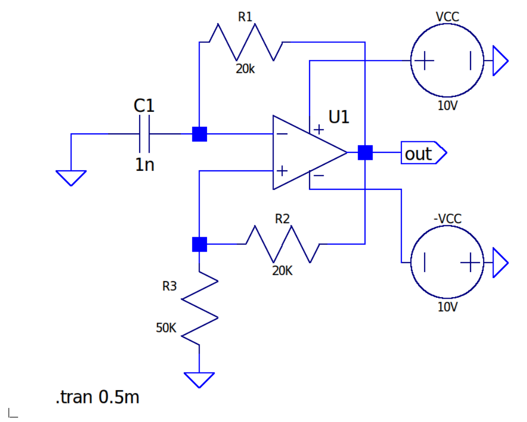
$$\frac{R_3}{R_2} V_{\text{sat}} = \frac{1}{R_1 C} V_{\text{sat}} t$$

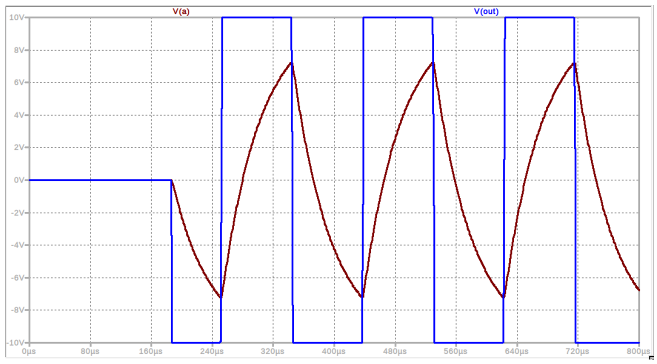
$$t = R_1 C \frac{R_3}{R_2}$$

$$T = 4t = 4 \frac{R_3}{R_2} R_1 C$$

$$\therefore F = \frac{1}{T} = \frac{1}{4 R_1 C} \cdot \frac{R_2}{R_3}$$

2.3 Square-Wave Oscillator (Astable Multivibrator)





When $V_c = 0$ and Capacitor begins charging
$\because V_o = A \cdot (V_f - V_c)$
$\because V_f > V_c$
$\therefore V_o = V_{\text{sat}}$
When $V_c \geq V_f$
$V_o = -V_{\text{sat}}$
$\because V_f = \beta V_{\text{sat}}$ As $\beta = \frac{R_3}{R_3 + R_2}$
Using KCL

$$\frac{V_{\text{sat}} - V_c}{R_1} = C \frac{dV_c}{dt}$$

$$\frac{V_{\text{sat}} - V_c}{R_1 C} = \frac{dV_c}{dt}$$

$$\int_0^t \frac{dt}{R_1 C} = \int_{-v_f}^{v_f} \frac{dV_c}{V_{\text{sat}} - V_c}$$

$$\frac{t}{R_1 C} = \ln(V_{\text{sat}} + V_f) - \ln(V_{\text{sat}} - V_f)$$

$$\frac{t}{R_1C} = \ln(\frac{V_{\text{sat}} + V_f}{V_{\text{sat}} - V_f})$$

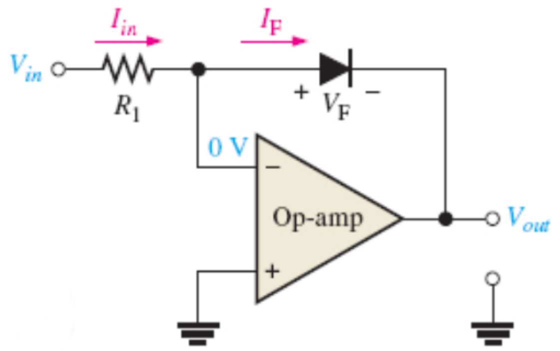
$$t = R_1C.\ln(\frac{1+\beta}{1-\beta})$$

$$T = 2t = 2R_1C.\ln(\frac{1+\beta}{1-\beta})$$

$$\therefore F = \frac{1}{2R_1C.\ln(\frac{1+\beta}{1-\beta})}$$

2.4 Log and Antilog Amplifier

2.4.1 Basic log Amplifier



$$I_D = I_F = I_R e^{\frac{V_F}{V_T}}$$

$$I_R \quad \text{is const}$$

$$V_T = \frac{q}{kt} \approx 26mV$$

$$V_o = -V_F$$

Using KCL:

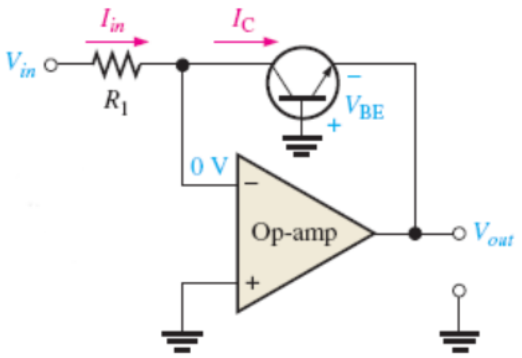
$$I_{\text{in}} = I_F$$

$$\frac{V\text{in}}{R_1} = I_R e^{\frac{-V_o}{V_T}}$$

$$\frac{-V_o}{V_T} = \ln(\frac{V_{\text{in}}}{R_1 I_R})$$

$$\therefore V_o = -V_T \ln(\frac{V_{\text{in}}}{R_1 I_R})$$

2.4.2 Log Amplifier with BJT



$$I_E = I_C + I_B$$

$$I_C >> I_B$$

$$I_E \approx I_C$$

$$I_c = I_{\text{EBO}} e^{\frac{V_{\text{BE}}}{V_T}}$$

$$I_{\text{in}} = I_C$$

$$\frac{V_i}{R_1} = I_{\text{EBO}} e^{\frac{-V_o}{V_T}}$$

$$\therefore V_o = -V_T \ln(\frac{V_{\text{in}}}{R_1 I_{\text{EBO}}})$$

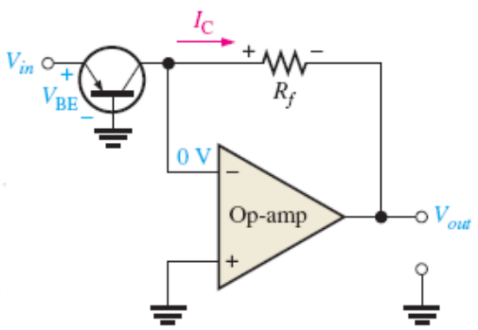
2.4.3 Basic Antilog

$$V_o = -R_f I_C$$

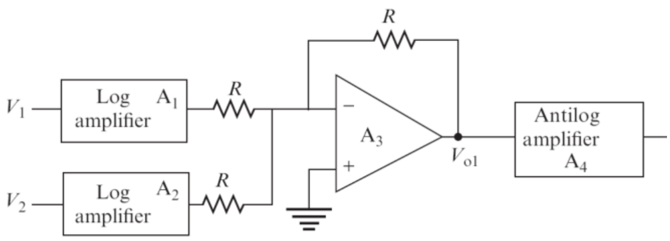
$$I_C = I_{\text{EBO}} e^{\frac{V_i}{V_T}}$$

$$\therefore V_o = -R_f I_{\text{EBO}} e^{\frac{V_i}{V_T}}$$

$$V_o = -R_f I_{\text{EBO}} \text{antilog}(\frac{V_i}{26mV})$$



2.5 Multiplier



$$V_{o1} = V_T\left(ln(\frac{V_1}{RI_{\text{EBO}}}) + ln(\frac{V_2}{RI_{\text{EBO}}})\right)$$

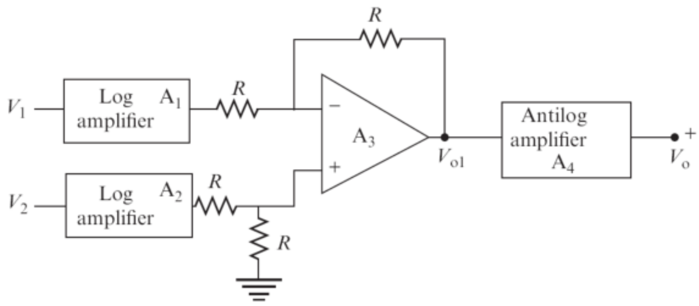
$$= V_T\left(ln(\frac{V_1V_2}{R^2I_{\text{EBO}}^2})\right)$$

$$V_o = -RI_{\text{EBO}}e^{ln(\frac{V_1V_2}{R^2I_{\text{EBO}}^2})}$$

$$= -RI_{\text{EBO}}\frac{V_1V_2}{R^2I_{\text{EBO}}^2}$$

$$\therefore V_o = -\frac{V_1V_2}{RI_{\text{EBO}}}$$

2.6 Divider



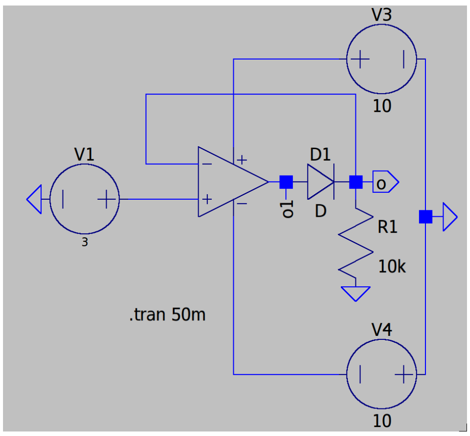
$$V_{o1} = -V_Tln(\frac{V_2}{RI_{\text{EBO}}}) + V_Tln(\frac{V_1}{RI_{\text{EBO}}})$$

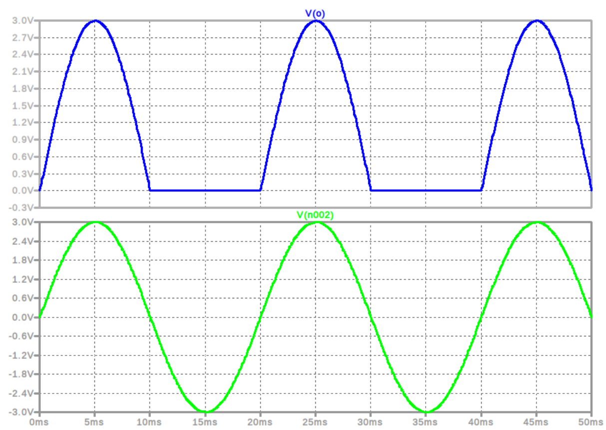
$$= V_T\left(ln(\frac{V_1}{V_2})\right)$$

$$V_o = -RI_{\text{EBO}}e^{ln(\frac{V_1}{V_2})}$$

$$\therefore V_o = -RI_{\text{EBO}}\frac{V_1}{V_2}$$

2.7 Positive half-wave rectifier

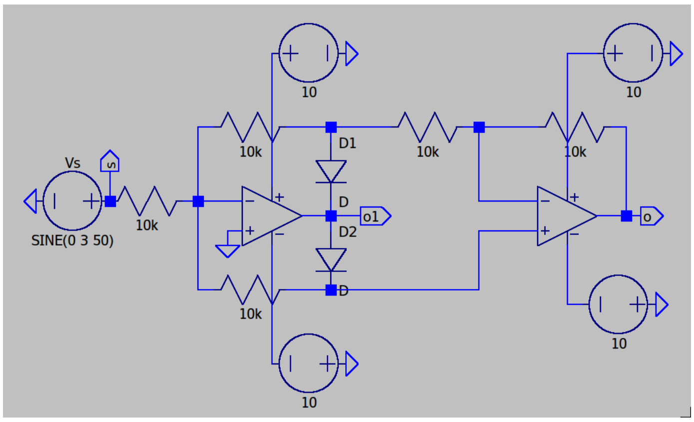


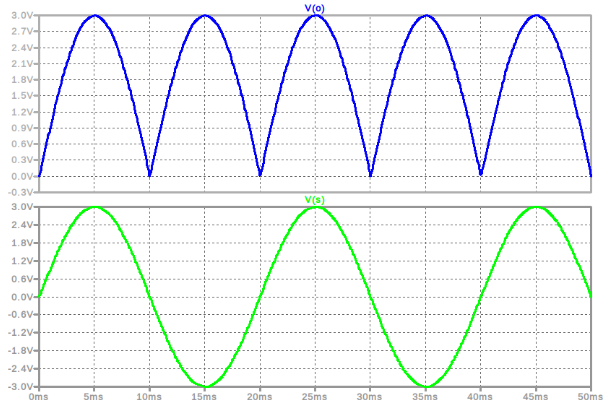


$$V_{o1} \approx V_1 + 0.623$$

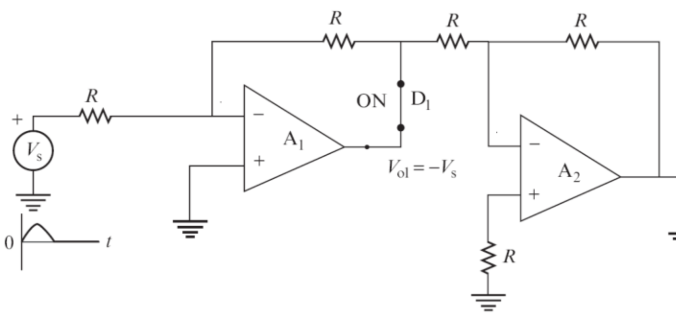
$$V_o = V_1 \text{ Rectified}$$

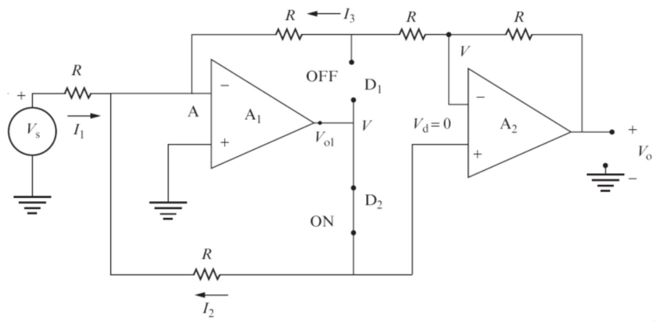
2.8 Full-wave Rectifier





During positive half cycle **During negative half cycle**





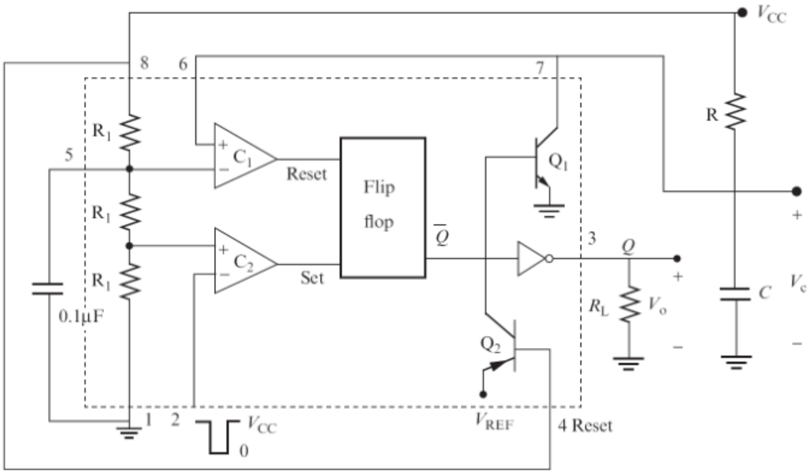
$$\frac{V_s - o}{R} = \frac{0 - V_{o1}}{R}$$
$$V_{o1} = -V_s$$
$$\frac{V_{o1} - o}{R} = \frac{0 - V_o}{R}$$
$$V_o = -V_{o1}$$
$$\therefore V_o = V_s$$

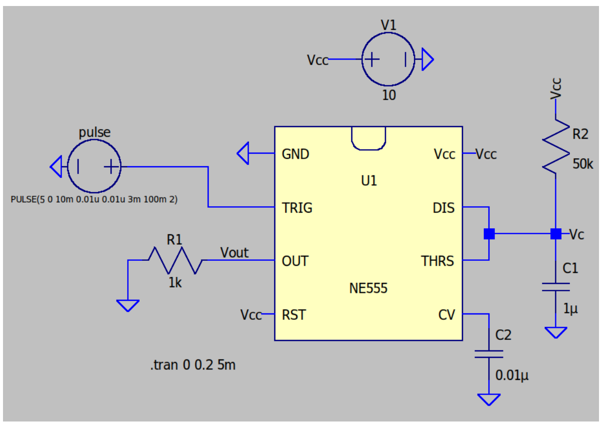
$$I_1 + I_2 + I_3 = 0$$
$$\frac{V_s}{R} + \frac{V}{R} + \frac{V}{2R} = 0$$
$$V = -\frac{2}{3}V_s$$
$$\frac{0 - V}{2R} = \frac{V - V_o}{R}$$
$$V_o = \frac{3}{2}V$$
$$V_o = \frac{3}{2}\left(-\frac{2}{3}V_s\right)$$
$$\therefore V_o = -V_s$$

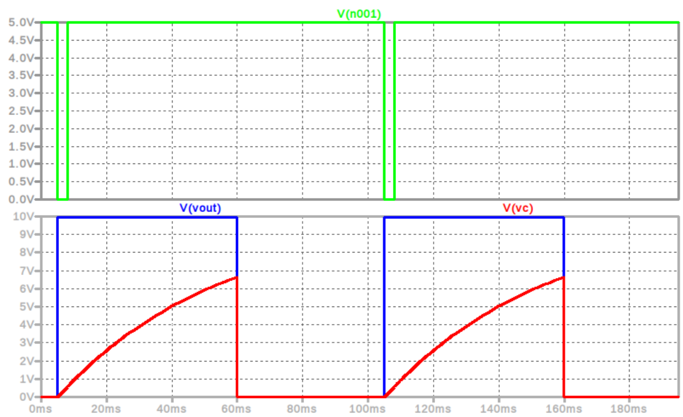
Chapter 3

Timer 555

3.1 Monostable Multivibrator

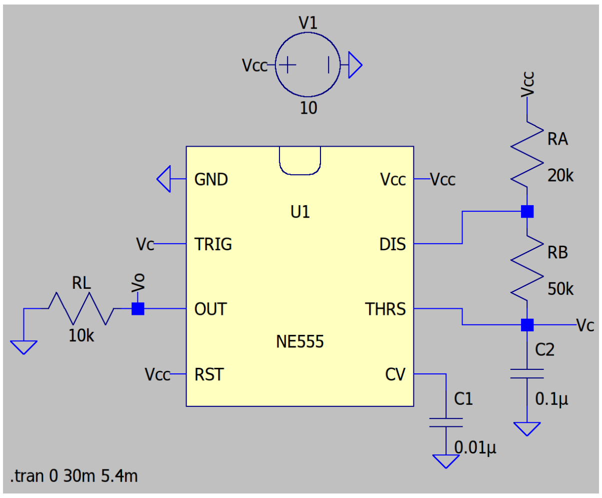


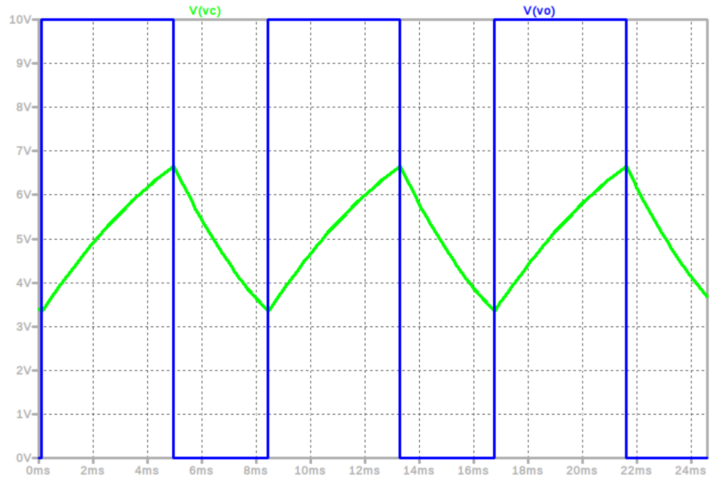




$$V_c(t) = V_F - (V_F - V_I)e^{\frac{-t}{\tau}}$$
$$V_c(t) = V_{cc} - (V_{cc} - o)e^{\frac{-t}{RC}}$$
$$\text{At } t = T,\ V_c(t) = \frac{2}{3}V_{cc}$$
$$\frac{2}{3}V_{cc} = V_{cc}\left(1 - e^{\frac{-T}{RC}}\right)$$
$$e^{\frac{-T}{RC}} = \frac{1}{3}$$
$$\frac{-T}{RC} \approx -1.1$$
$$\therefore T = 1.1RC$$

3.2 Astable Multivibrator





$$V_c(t) = V_F - (V_F - V_I)e^{\frac{-t}{\tau}}$$

As V_c is applied to Trigger and Threshold:

$$V_F = V_{cc} \text{ and } V_i = \frac{1}{3}V_{cc}$$

$$V_c(t) = V_{cc} - (V_{cc} - \frac{1}{3}V_{cc})e^{\frac{-t}{\tau_c}}$$

$$V_c(t) = \frac{2}{3}V_{cc}$$

$$t = T_1 \rightarrow \text{Time of charging}$$

$$\frac{2}{3}V_{cc} = V_{cc} - \left(V_{cc} - \frac{1}{3}V_{cc}\right)e^{\frac{-T_1}{\tau_c}}$$

$$\frac{2}{3} = 1 - \frac{2}{3}e^{\frac{-T_1}{\tau_c}}$$

$$\frac{1}{2} = e^{\frac{-T_1}{\tau_c}}$$

$$-0.693 = -\frac{T_1}{\tau_c}$$

$$\tau_c = (R_A + R_B)C$$

$$\therefore T_1 = 0.693\tau_c = 0.693(R_a + R_b)C$$

Calculation of T_2 :

$$V_c(t) = V_F - (V_F - V_I)e^{\frac{-t}{\tau_d}}$$

$$V_F = 0 \text{ and } V_i = \frac{2}{3}V_{cc}$$

$$V_c(t) = \frac{1}{3}V_{cc}$$

$$t = T_2 \rightarrow \text{Time of discharging}$$

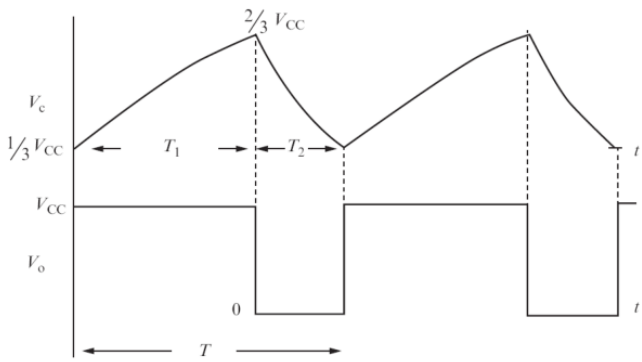
$$\frac{1}{3}V_{cc} = \frac{2}{3}V_{cc}e^{\frac{-t}{\tau_d}}$$

$$\frac{1}{2} = e^{\frac{-t}{\tau_d}}$$

$$0.693 = \frac{t}{\tau_d}$$

$$\tau_d = R_B$$

$$\therefore T_2 = 0.693R_BC$$



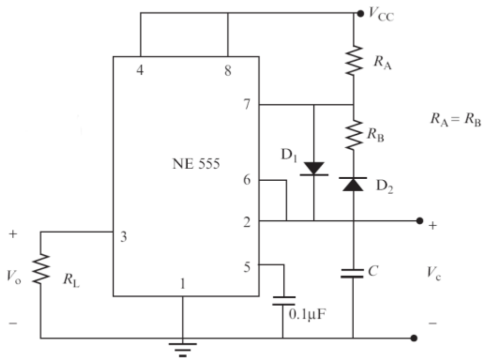
$$T = T_1 + T_2$$

$$= 0.693(R_A + R_B)C + 0.693R_bC$$

$$\therefore T = 0.693(R_A + 2R_B)C$$

$$f = \frac{1}{T}$$

$$\text{Duty cycle } = D = \frac{T_1}{T}$$



To get 50% Duty cycle

$$T_1 = 0.693R_AC$$

$$T_2 = 0.693R_BC$$

$$\text{If } R_A = R_B$$

$$D = \frac{T_1}{T_1 + T_2}.100 = 50\%$$