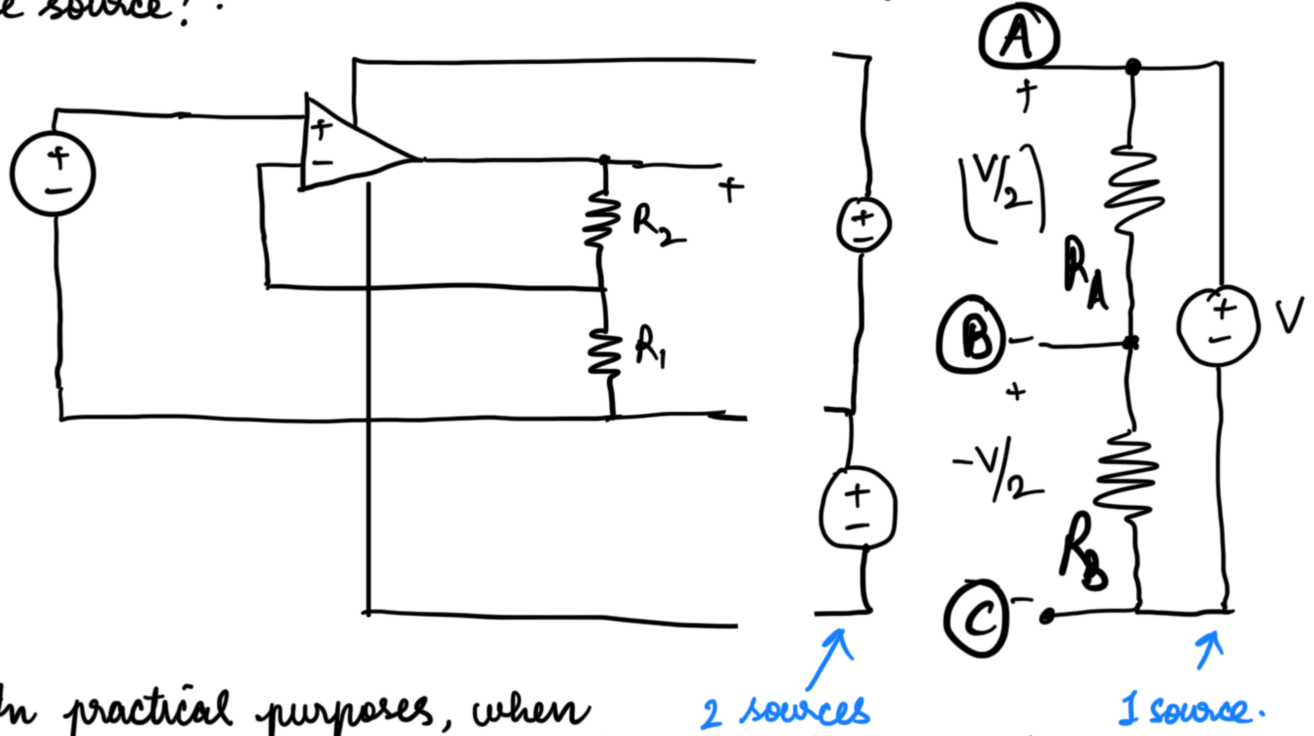
Nagendra Krishnapura Analog Notes - 2

Dual supply and single supply operation of Op-Amps.

How to simplify the Non inverting Amplifier ? [Instead of using two sources (V_{dd} & V_{ss}), trying to use just one source? :



[In practical purposes, when we are looking at bits and pieces of a circuit, we must make sure that the 2-Terminal components have one terminal grounded.]

Issue with the Voltage divider shown above (using 2 resistors) is that:

$V_{AB} + V_{BC}$ changes when current is being drawn from it.

$\hookrightarrow$ $V_{AB} = \frac{V}{2} - \Delta I \cdot \frac{R_0}{2}$ (Thevenin Equivalent)

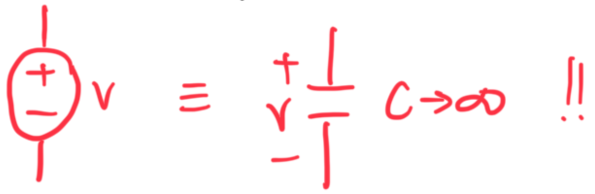
Even to tackle this problem, let's say, R_0 must be very small as compared to V.

$\Downarrow$

But this poses another problem! → If R_0 is very small, then the current through ABC will be much larger than the current drawn by the Op-Amp — Not useful.

Hence, this solution is not acceptable.

What shall we do? →



Now, another problem that we have is that, The grounds must be matched properly.

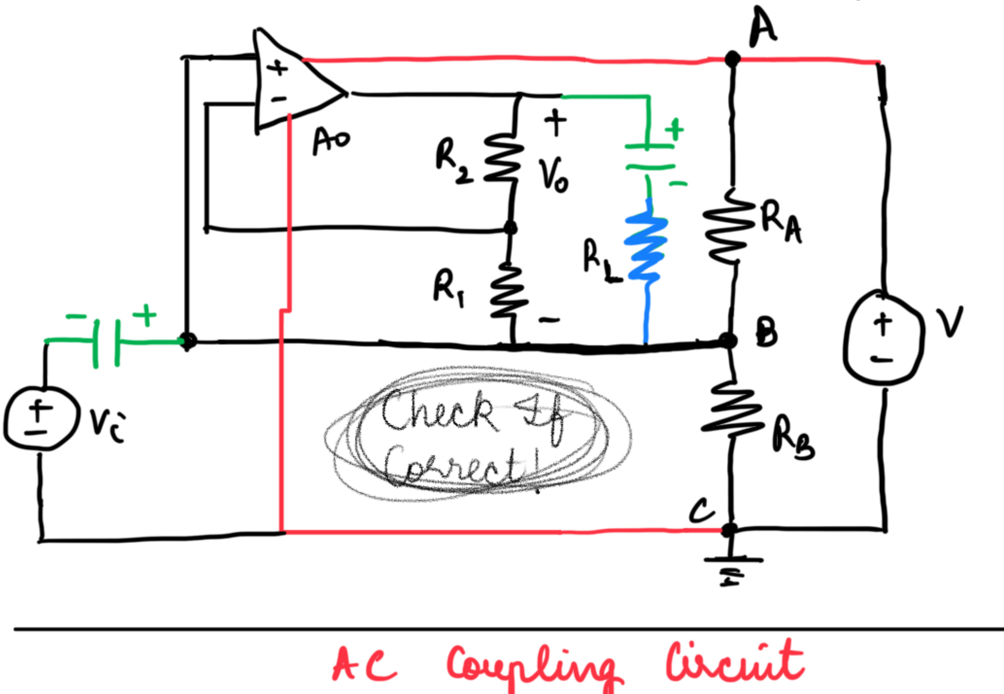
Since V_i ⊕ is now ⊕ V_i, if we are shifting our ground from B to C [Refer above diagram], We have to add V_{BC} to V_i.

↓

Umm, again adding a Voltage source? Bro - we started out "decreasing" the number of sources!

↓

Oh dear, this is where our Capacitor comes!



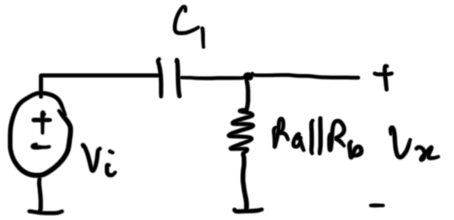
let $V = 24V$.

$\therefore V_{AB} = V_{BC} = 12V$.

This Circuit works for V_i = sinusoid.

$\omega \gg cR_a/2$

AC Coupling Circuit

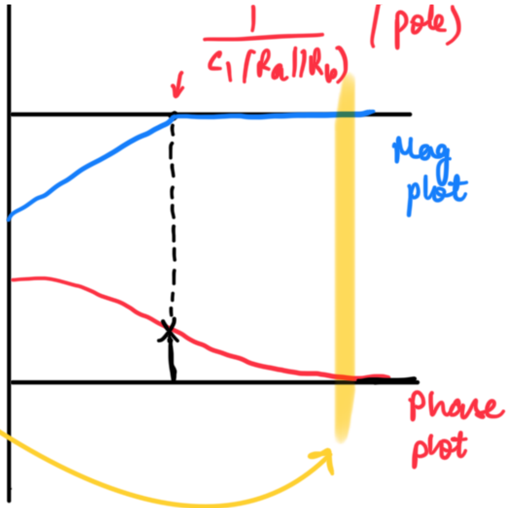


High Pass Filter.

$$\frac{V_x(s)}{V_i(s)} = \frac{sC_1(R_a \| R_b)}{1 + sC_1(R_a \| R_b)}$$

High pass how? → At high frequencies, Magnitude should be 1 and phase should be zero.

Here that's the case!!



So, if we have $V_i = \cos(\omega_1 t)$, we must choose such that $\omega_1 \gg\gg \frac{1}{C_1(R_a||R_b)}$ (pole)

↓ Choose corner frequency to be much smaller than the frequency of the sinusoid.

Now, if we want to operate over a range of frequencies
Make sure the lowest frequency is much larger than the pole.
↓
This involves many components and less constraints.

This means we need to have some intuition or experiment A LOT to arrive at a particular set of values for C_1, R_a & R_b.

For instance, $\omega_1 \gg \frac{1}{C_1(R_a||R_b)}$.

$$\Rightarrow C_1 \gg \frac{1}{\omega_1 (R_a||R_b)} . \rightarrow \text{If } 1\,nF,\ C_1 = 10 \text{ or } 100\,nF.$$

If we do this, then $\omega = \frac{10}{C_1(R_a||R_b)}$ ...

Substituting & Evaluating the Transfer Function:

$$\cancel{C_1(R_a||R_b)}\left(j \times \frac{10}{\cancel{C_1(R_a||R_b)}}\right) \Big/ \left(1 + j\, \frac{10}{\cancel{C_1(R_a||R_b)}} \times \cancel{C_1(R_a||R_b)}\right)$$

$$= \frac{10j}{1+10j} = 0.995 \angle 5.7^\circ$$

0.995 ↑ Close to 1 $\quad$ 5.7° ↑ Close to zero.

→ Choose ω to be 20 or 30 times, or even 100 times.

$$= \frac{100j}{1+100j} = \frac{100j\,(1-100j)}{1^2-(100j)^2} = \frac{100j + 10^4}{10001}$$

$$= \frac{100}{101}j + \frac{10000}{101} = 1 \angle 0.5729^\circ \;//$$

YaaaY!!

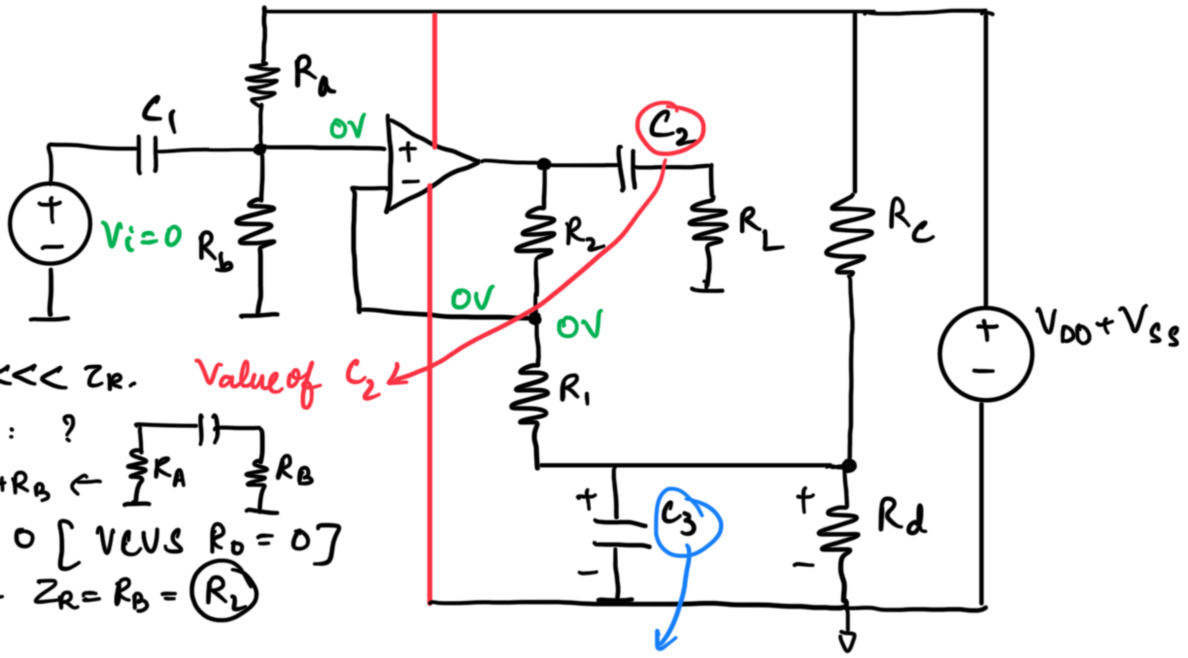
$\frac{V_c}{V_i}$ (instead of Resistor Voltage, capacitor Voltage)

= Mag will be very close → Behaves as a short when compared to resistor.

↓

This means, there is some change in the voltage, but it is so small that we neglect it.

Now the circuit Has emerged to this.



$Z_c <<< Z_R$.

Z_R : ?

↳ $R_A + R_B$ ← R_A R_B

$R_A = 0$ [VCVS $R_o = 0$]

$\therefore Z_R = R_B = R_2$

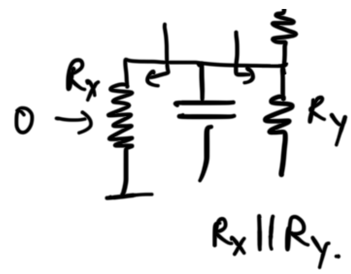
We can reduce it to a ← Value of C_3 ?

Capacitor in parallel with a Resistor as this is 1st order.

↳ $Z_c <<< Z_R$.

$R_y = R_c + R_d$

$R_x = R_1 \rightarrow$ How?



$\frac{1}{\omega C_3} \ll R_1 || (R_c + R_d)$ ← Large.

This is known as Level shifting [Adding voltage to input signal]

(1/2/17)

Now let's see Where is the Biasing (operating) point.

In the above diagram,

Not very Clear...

C_1 & C_2 : ac coupling capacitors (or dc blocking)

C_3 : Bypass capacitor.

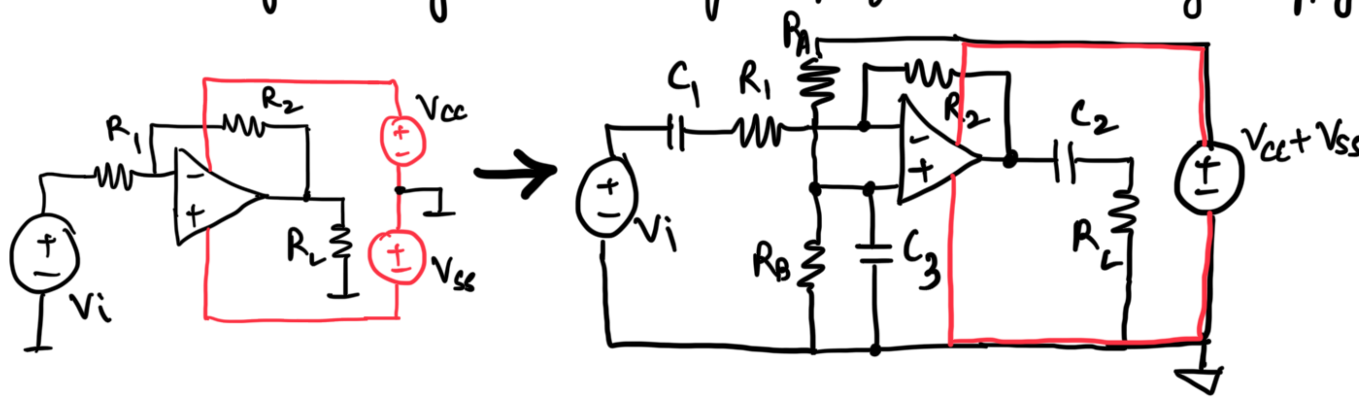
Bias/operating point of Op Amp

aka DC point.

Basically, the voltage of input (and output) of the Op Amp when no V_i is connected, and only the Op Amp supplies are connected.

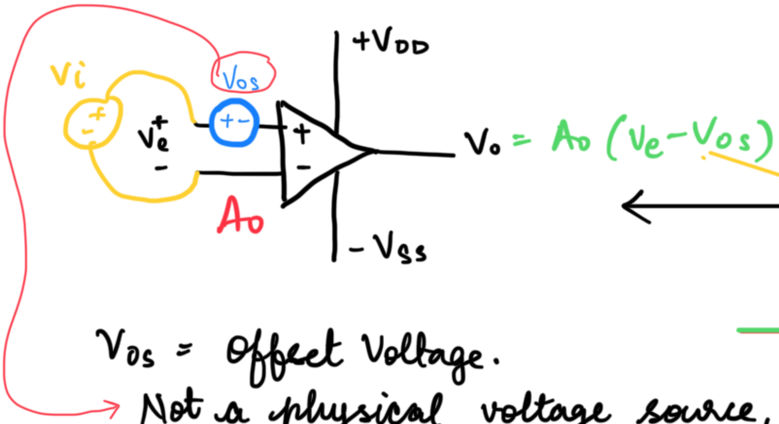
We were keen on making a non-inverting amplifier from a dual supply to a single supply.

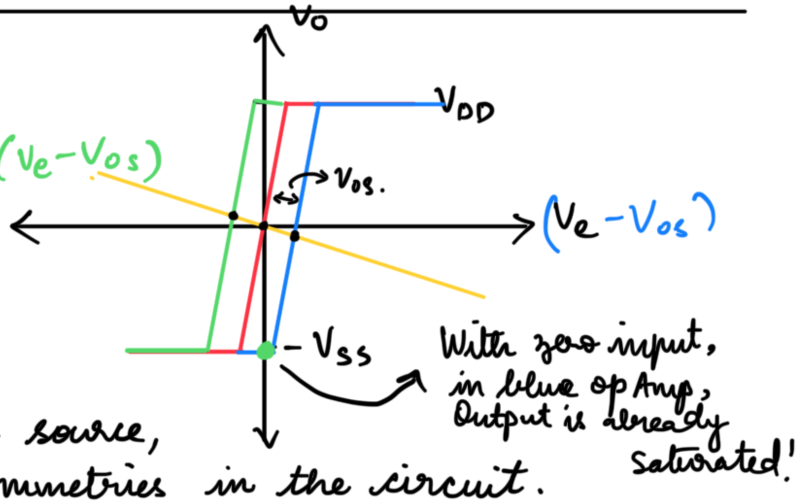
Now let's try making an inverting amplifier work on single supply



C_1 : $\frac{1}{\omega_1 C_1} \ll R_1$; C_2 : $\frac{1}{\omega_1 C_2} \ll R_L$; C_3 :

Active feedback : Only for DC, not for AC.





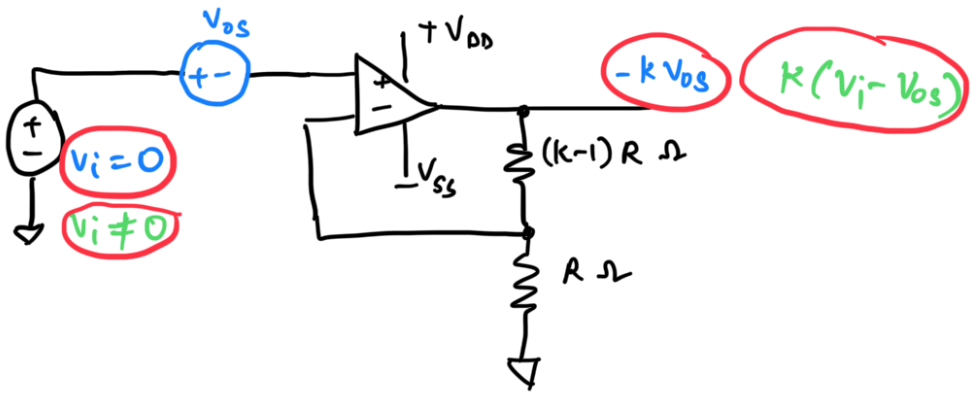
V_{os} = Offset Voltage.

Not a physical voltage source, but a result of some asymmetries in the circuit.

↳ similar to zero error.

V_{os} : random : Gaussian distribution, centered at zero.

Let's take our good old Non-inverting amplifier



Now, By doing KVL and KCL, we get the Vo in terms of Ve.

V_o vs V_e having A_o as the slope is the Op Amp's characteristics.

$V_o = -kV_e$ is the output of the whole circuit. [I.e., the negative amplifier.

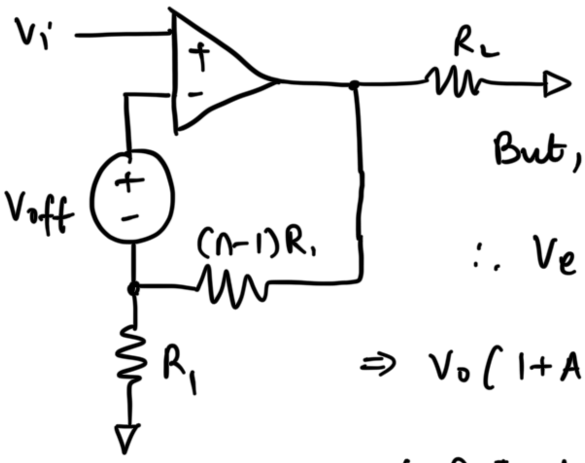
* Op Amp has a built-in offset (modelled by a voltage source in series with the input)

↳ random, Gaussian.

$$\left(\frac{1}{\sqrt{2\pi}} e^{-x^2/2\sigma^2} \right)$$

$3\sigma \rightarrow 99.9\,\%$

$\sigma \rightarrow 65\%$



→ $V_e = V_+ - V_- - V_{off}$.

But, we know, $V_o = A(V_e - V_{off})$.
and ↓

$\therefore V_e = V_i - \frac{V_o}{n} \Rightarrow V_o = A\left(V_i - \frac{V_o}{n} - V_{off}\right)$

$\Rightarrow V_o(1 + A/n) = AV_i - AV_{off}$.

$\therefore$ Output DC offset $= -\frac{AV_{off}}{(1 + A/n^2)}$

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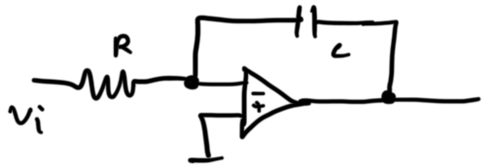
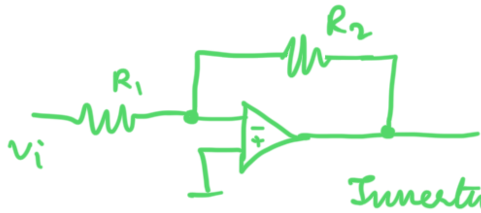
* Negative feedback (DC) [as the offset is DC] around the op amp is absolutely essential to set the opamp's operating point in the high gain region.
↓
Since the offset is DC, The operating point is also called the DC point.

Integrator using an op amp.

^ Usually a Capacitor or an inductor, but see:



$V_o = \frac{-1}{sCR} \cdot V_i$

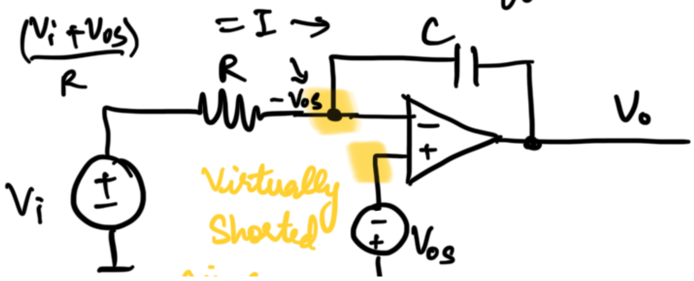


Inverting Amplifier

$V_o = \left(-\frac{R_2}{R_1}\right) V_i$

$V_o(t) = \frac{-1}{CR} \int v_i \, dt$

Another thing : Integrator has no DC feedback !! and the OpAmp's offset also.



$V_c = \frac{1}{C} \int \left(\frac{V_i + V_{os}}{R}\right) dt$.

since Op Amp is in −ve feedback

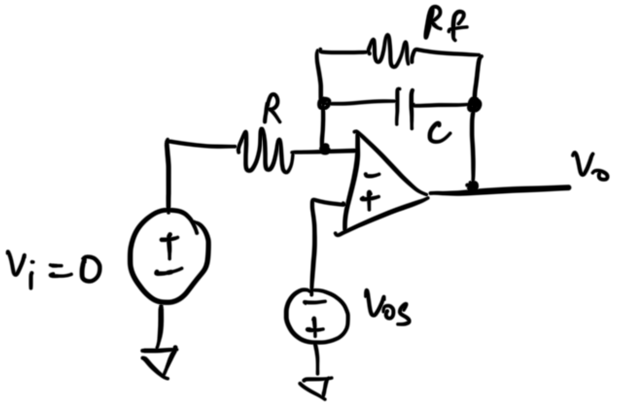
Problem: Even with $V_i = 0$, $V_C = \frac{1}{C}\int \frac{V_{OS}}{R}$, And $V_o = -V_{OS} - \frac{1}{C}\int \frac{V_{OS}}{R}$

So the circuit will not work. [If this is the only circuit that's there]. How how how???

In one of the labs, we will use this circuit, along with another "non-linear" circuit, that won't let it go to saturation. So, without something else giving feedback, this circuit will not work.

The integrator alone doesn't work. But however, it can work for some time, when it is in the region in between the saturation levels (V_{DD} & V_{SS})

Now, let's think of a way to give negative feedback to our Integrator's Op Amp [DC negative feedback]-



Maybe, add a resistor?
Hmm, let's try.

But now, is this an integrator?? Ouch.
let's see if that's true.

$$\frac{V_o}{V_i} = -\frac{1}{R(sC + 1/R_f)} = \frac{-R_f/R}{1 + sCR_f} \sim [\text{Low pass filter}]$$

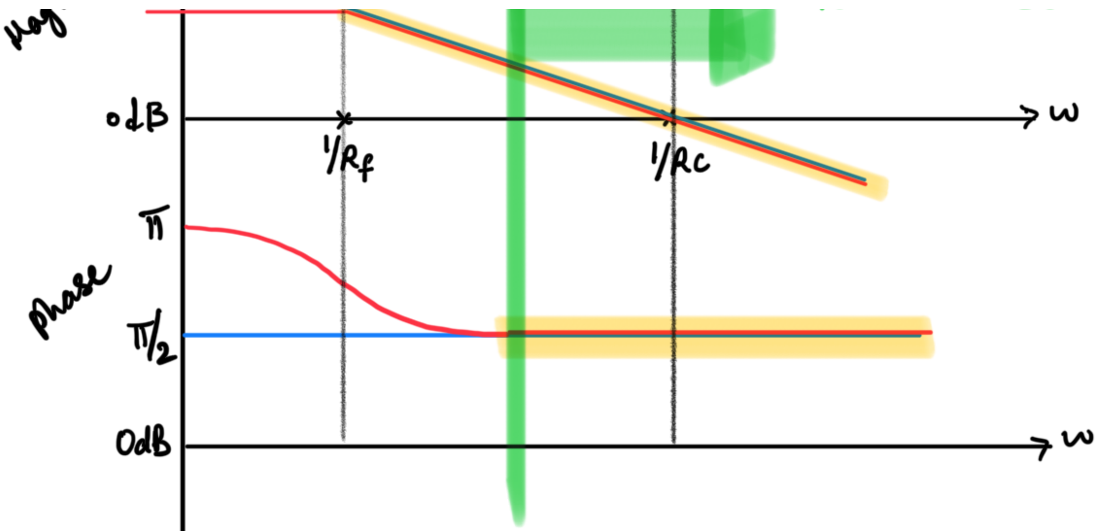
Transfer function of

a) Ideal Integrator $\frac{V_o}{V_i} = \frac{-1}{sCR}$

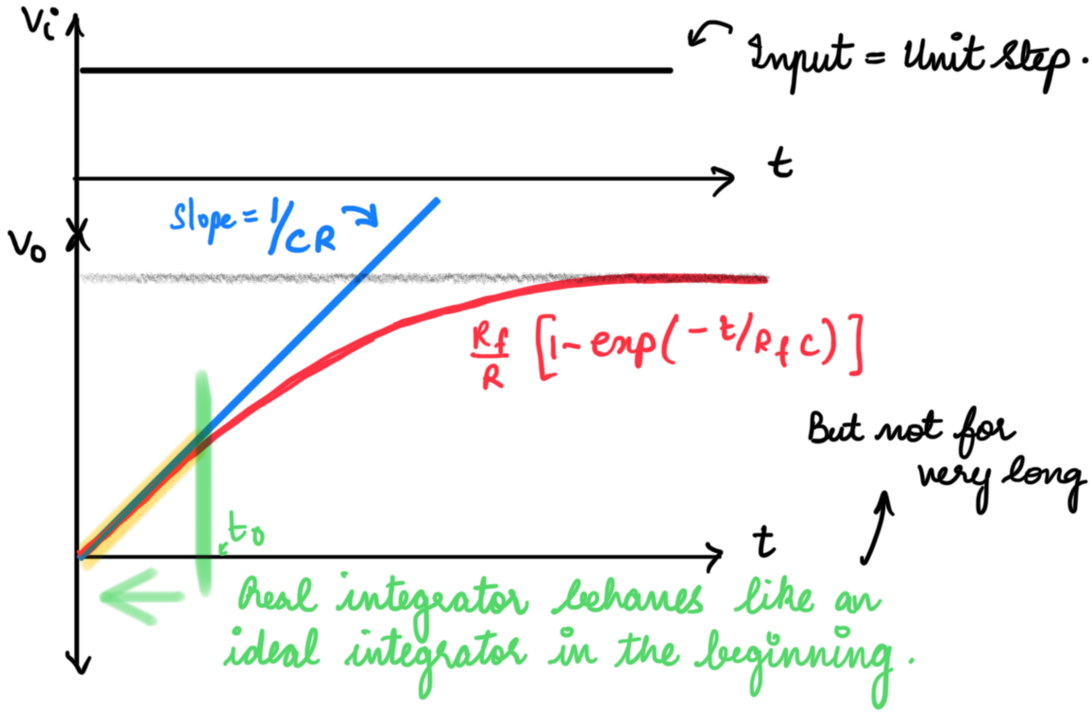
b) Real integrator $\frac{V_o}{V_i} = \frac{R_f/R}{1 + sCR_f}$

Let's Bode Plot!

Real ≈ Ideal



Now, time domain plot



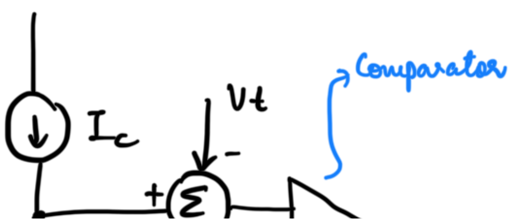
DC gain of an integrator $= \infty$

[Recap Pole zero graph and related stuff].

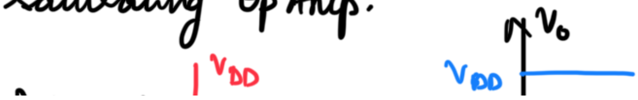
For stability, the poles must lie on the left half of s- plane.

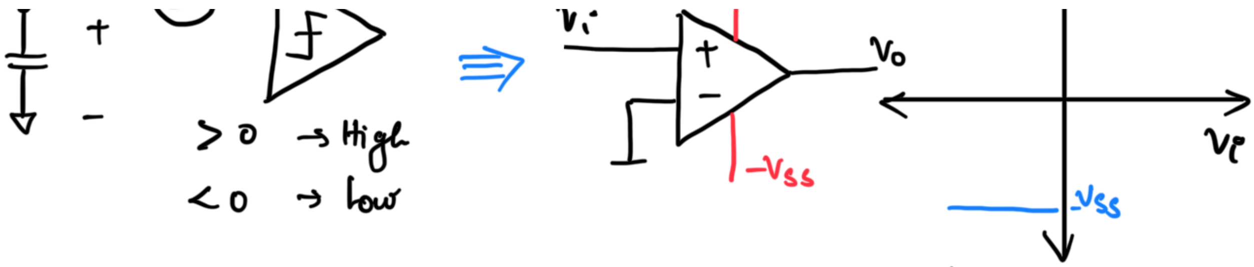
Please take a look at this from EE1101.

Made an Oscillator in the lab:

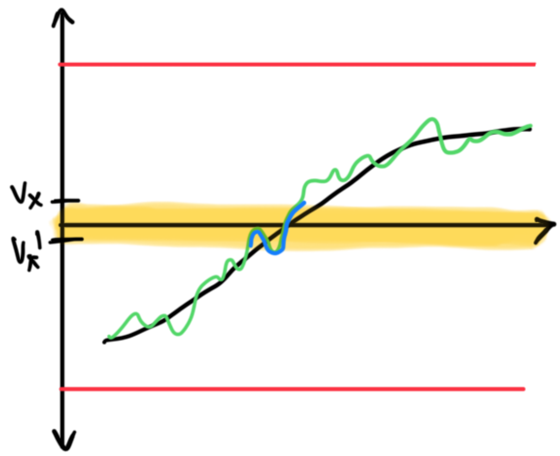


To realise a comparator, we use a saturating Op Amp.





Now, for the Opamp to become a Comparator:



— Ideal smooth signal
— Real, jittery signal
— The boundary of Comparison.

Q) How to figure out "firmly" what value should we give for the blue part of the green signal?

Basically what we'll do is that, we keep the threshold [for o/p high] as something higher than the actual threshold.

|||ly for lower o/p, look at a threshold, which is a bit lesser than the actual threshold.

This is what we call – Hysteresis.

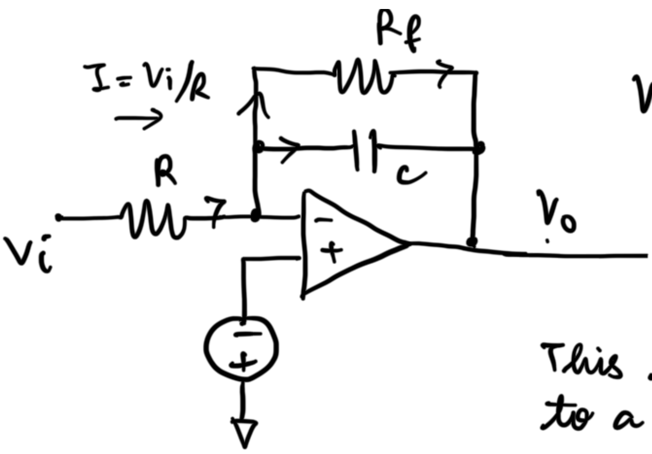
Refer the above graph, see y axis.

When V_i is rising, look for: [if ($V_i > V_x > 0$)]
When V_i is falling, look for: [if ($V_i < V_x' < 0$)]

We will realise this Hysteresis Comparator in the next Class.

In the previous lecture ~~note, [Analog notes 2]~~, I understood how we get $\frac{V_o}{V_i} = -\frac{1}{sCR}$ for an ideal integrator.

But I didn't understand for real integrator. Now I understood, and I'll explain below:



$$V_o = -\frac{V_i}{R(sC + 1/R_f)}$$

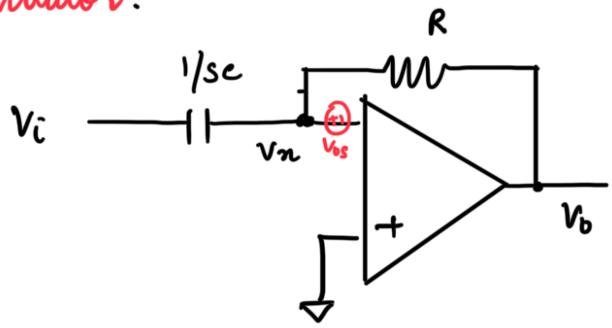
$$\Rightarrow \frac{V_o}{V_i} = \frac{-R_f/R}{1 + sCR_f}$$

This transfer function corresponds to a low pass filter.

When $R_f = R$, $\frac{V_o}{V_i} = -\frac{1}{1+sCR}$ → similar to the ideal case if $sCR \gg 1$.

is this correct?

Differentiator:



Suppressing the offset voltage – Possible.

But measuring the offset accurately and connecting it to the negative feedback terminal of the OpAmp is way more difficult – Not within the scope of this course.

Now: What is this ??

See Saurabh's Notes and write over here properly.