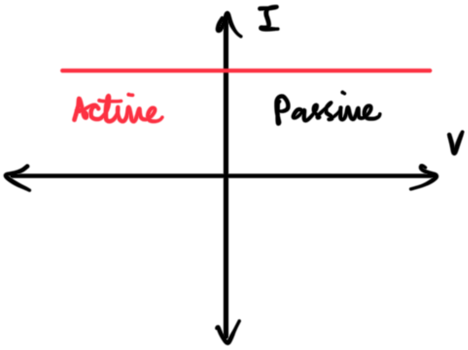
Nagendra Krishnapura's Analog Lectures

→ **Basic Elements : Passive and Active.**

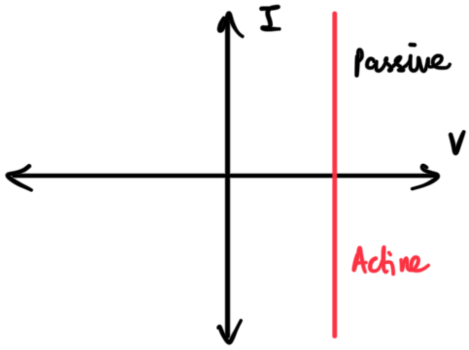
Passive : Only consumes power
Active : Can provide power.

→ How to characterise? If the I-V graph of an element is in 2^{nd} or 4^{th} quadrant, it is active. Else, it is passive.

Ideal current source:



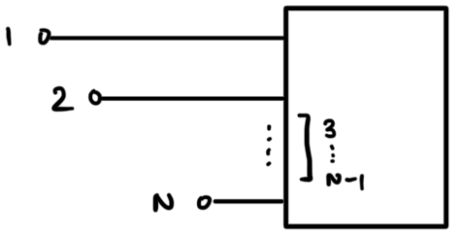
Ideal voltage source



For a 2 terminal element, drawing I-V graph and seeing in what quadrants the graph lies in — suffices.

What about, in general, n-terminal elements?

That is, elements that look like this:



Q) First of all, why do we need to classify if an element is active or passive??

↳ How many independent currents are there here? - N-1
↳ $I_N = -(I_1 + \cdots + I_{N-1})$

|||ly, N-1 independent voltage

If: $\sum_{k=1}^{N-1} V_k I_k \geq 0$ → Passive

$\sum^{N-1} V_k I_k < 0$ → Active

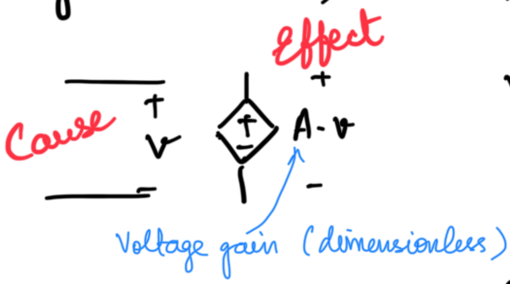
To make big big circuits, we need active elements [Atleast in some operating ranges] k=1

Now Coming to Dependent Sources:

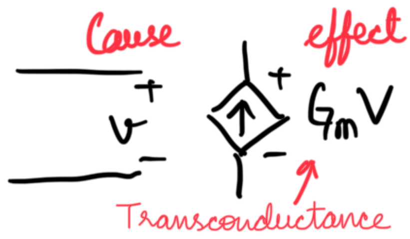
Aka controlled sources

What are they? → VCCS, VCVS, CCCS, CCVS

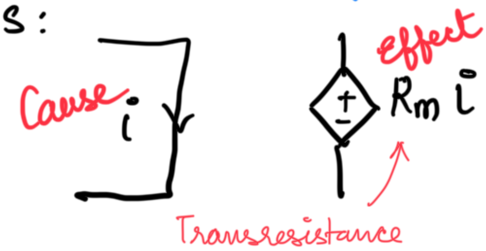
VCVS :



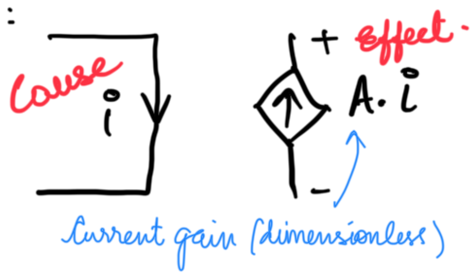
VCCS :



CCVS :



CCCS :



These controlled sources are the most important and interesting as well, in building "active" circuits

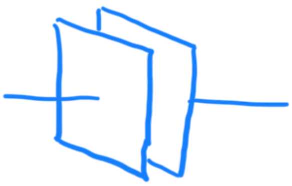
Q) Are controlled sources active / passive? Depends?

Depends on the value of A, G_m and R_m, we can make them "Active". With the use of Transistors, we can make this happen.

However, in this course, we won't look into How a transistor can make an "Active" dependent source.

Q) How to make a resistor? Almost anything you take has "R".

Q) Inductor?  Make a wire like this

Q) Capacitors?  Make 2 plates (metal) like this

Q) What about controlled sources? No idea as of now!

↓

Q) What is a transistor made of? Semiconductor.

Controlled sources are made of transistors, which in turn is made of semi conductors.

Most transistors are VCCS and the proportionality constants are varying with Temperature.

We need amplifiers EVERYWHERE. We also want it to be well-controlled → Factor of amplification or The gain should not vary all over the place.

Our problem: To make an accurate gain using elements whose gains are inherently not accurate.

Using the VCCS from transistors, we can make other controlled sources!

Semiconductors: Highly temp. sensitive and large parameter spread.

→ Realise accurate controlled sources using controlled sources that have a large parameter variation. Lesssgo!

Controlled sources are "Unilateral". That is, controlled source changes with source, but the source won't change according to the controlled source.

Now, how to achieve our goal? Our goal is to make an "ACCURATE Controlled source" out of the varying G_m of a VCCS [a transistor]

So, think of this as a scenario below:

→ We need to drive a vehicle at (some) "50 km/h" exactly. How much should we press the accelerator to achieve this?

The thing is, different vehicles have different dynamics.

So, you see the "speedometer" and push the accelerator. See if it is less than 50 or more. If it is less, push more or less press breaks and push the accelerator less.

This thing is what you call a "Feedback".

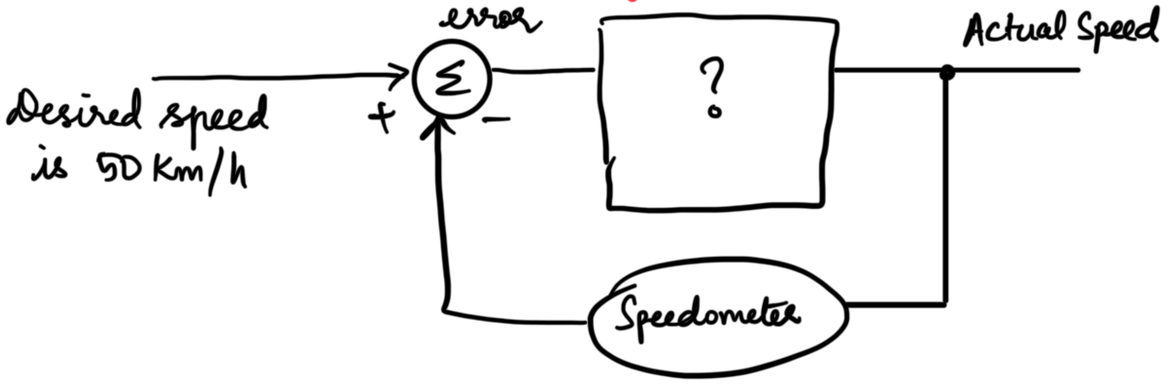
But this is "Negative Feedback". What is negative about it?

If something is less, we give more. If something is more, we give less. } → This is why.

The error magnitude should reach zero.

Negative Feedback:
→ Sense the output
→ Compare it to the desired value
→ Control the output in a direction that minimizes error.

Now, how to do the negative feedback??



Assuming Linearity, The question mark will be replaced by an Integrator.

Integrator acts as follows:

It is the function that is formed when the input signal is integrated.

Eg., if Input $= x(t)$, Output $= y(t) = \int x(t)\,dt$

When will the system reach steady state? [Or, the desired speed is reached?] When $x(t) = 0$, i.e., Error is zero and the current input = desired input.

Now, what is the physical analogue for integrator ?!

Capacitors and Inductors !! Wow!!

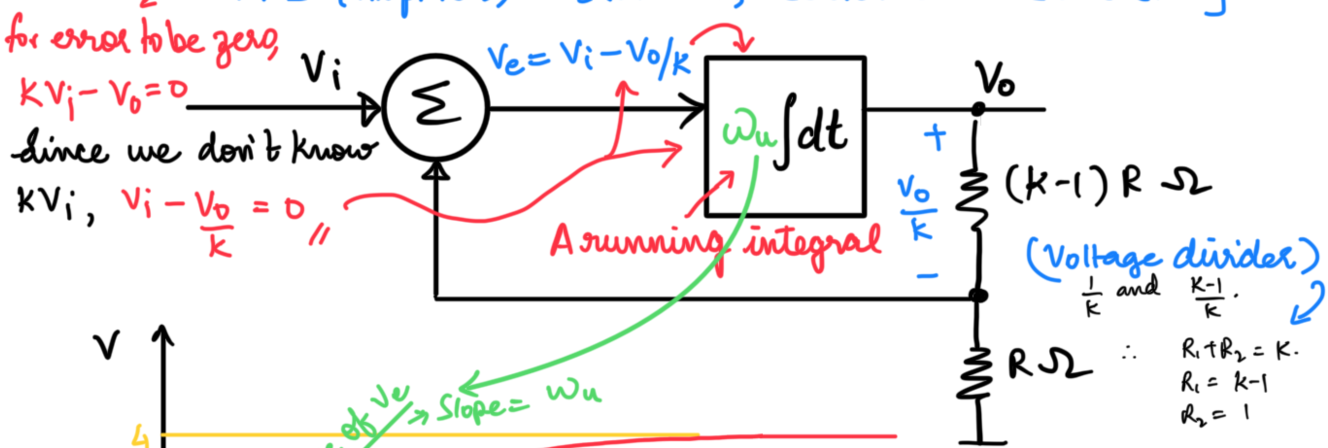
Negative feedback system:

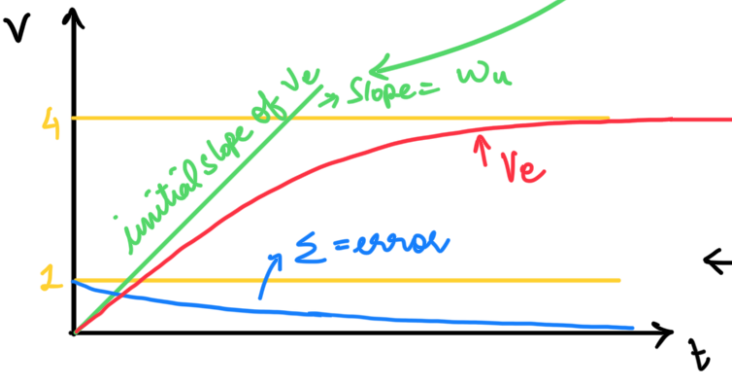
* Compute the error [Desired − actual]

* Integrate the error to drive the output.

Q) $V_o = K V_i$ → The one we need to get.

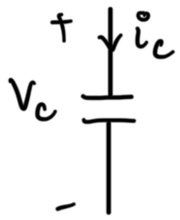
$K > 1$ (Amplifier) [for $K < 1$, we can use mere resistors]





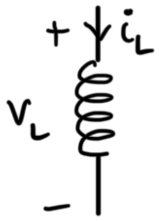
Taking $K = 4$ and $V_i = 1$,
← We get the following

Coming to the integrator:



$i_c = C \dfrac{dV_c}{dt}$

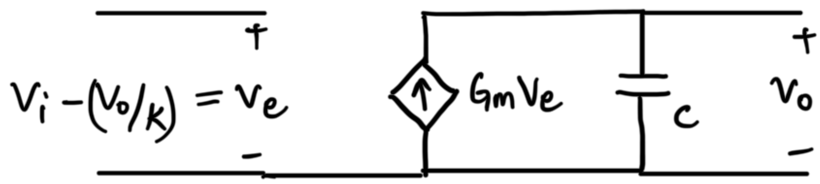
$V_c = \dfrac{1}{C} \int i_c \, dt$



$i_L = \dfrac{1}{L} \int V_L \, dt.$

Turns out, inductors are too bulky and we skip them as much as possible.

Now, a capacitor integrates a current. So, what should we do to make sure we integrate a voltage? : VCCS!



$V_o = \dfrac{G_m}{C} \int V_e \, dt$

W_u influences "How fast a steady state is reached" but not exactly "What the steady state is." That is the beauty of Negative feedback.

Here the proportionality const. is $\dfrac{G_m}{C}$, which might vary with Temperature!

But it will not affect what the value of steady state is to be achieved. Period.

And VCCS is a Transistor as we had discussed before.

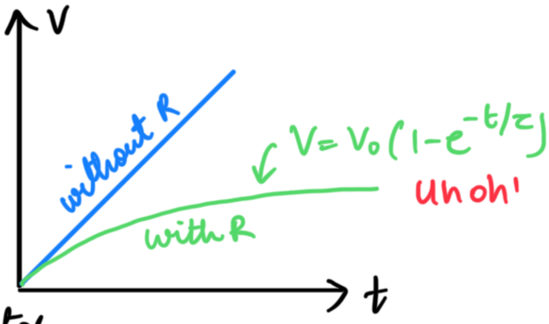
Kaboom! → Got the practical circuit of an Amplifier!

Final circuit:

Wait... We have a problem...

Initially, when $V_c = 0$, All of the current flows through the capacitor only.

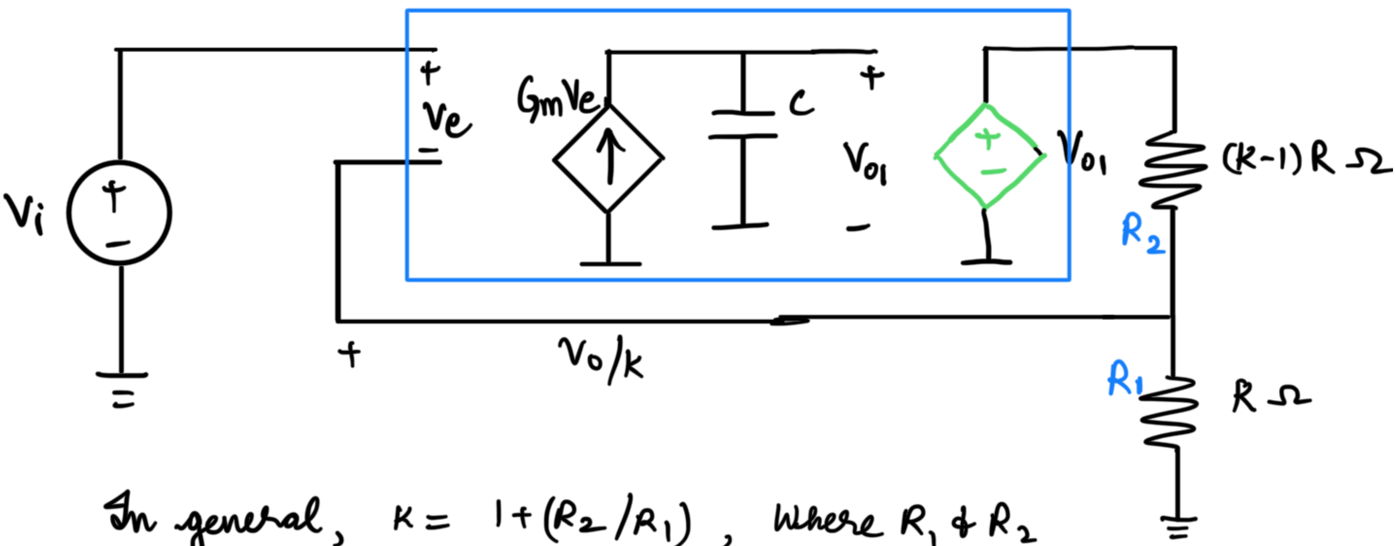
But as V_c builds up, some of the current leaks into the resistor.



This slows down the integrator!

Solution to this? If we find a way to supply voltage such that the resistor is not involved, then we're done.

This is solved by Buffer, which means, giving the output exactly the same as the input. Here, we'll use VCVS as the Buffer and the problem is solved.

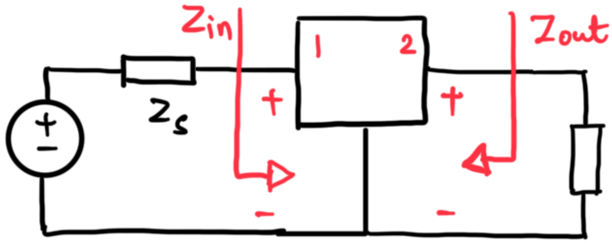


In general, $K = 1 + (R_2/R_1)$, where R_1 & R_2 are written in Blue in the above circuit.

(Here $w_u = G_m/C$)

Now moving further into Controlled sources:

Little Background of 2 port networks:

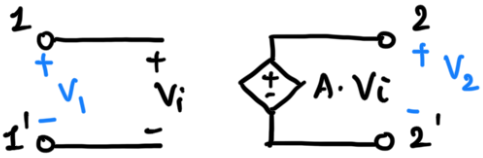


Zin depends on Z_L

Zout depends on Z_s

Now, coming back to controlled sources:

VCVS:



$R_i = \infty$

$R_o = 0$

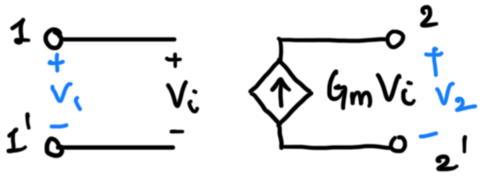
$Z_{11} = \left.\frac{V_1}{I_1}\right|_{I_2=0}$

$I_1 = 0$

$Z_{22} = \left.\frac{V_2}{I_2}\right|_{I_1=0}$

I did not understand How $R_o = 0$ above.

VCCS:



$R_i = \infty$

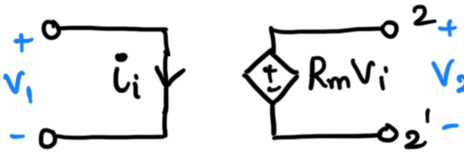
$R_o = \infty$

same as above

if $I_1 = 0, I_2 = 0$

$\therefore Z_{22} = \left.\frac{V_2}{I_2}\right|_{I_1=0}$

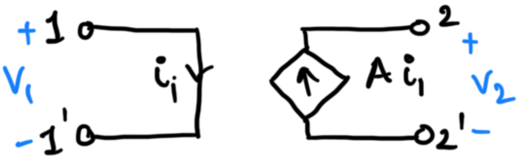
CCVS:



$R_i = 0$

$R_o = 0$

CCCS:



$R_i = 0$

$R_o = \infty$

Pattern observed: In a voltage controlled source, $R_{in} = \infty$.

What is the significance of this? [It's quite interesting!]

- From the input side, we see the VCCS or VCVS as open circuit.
- If we connect another circuit with 2 nodes to the VCS, and try to measure the voltage across it, we will succeed as $R_{in} = \infty$.

This means that it shouldn't draw any current when measuring it, ideally. (Remember Voltmeter?)

Similarly, Current Controlled sources, $R_{in} = 0$

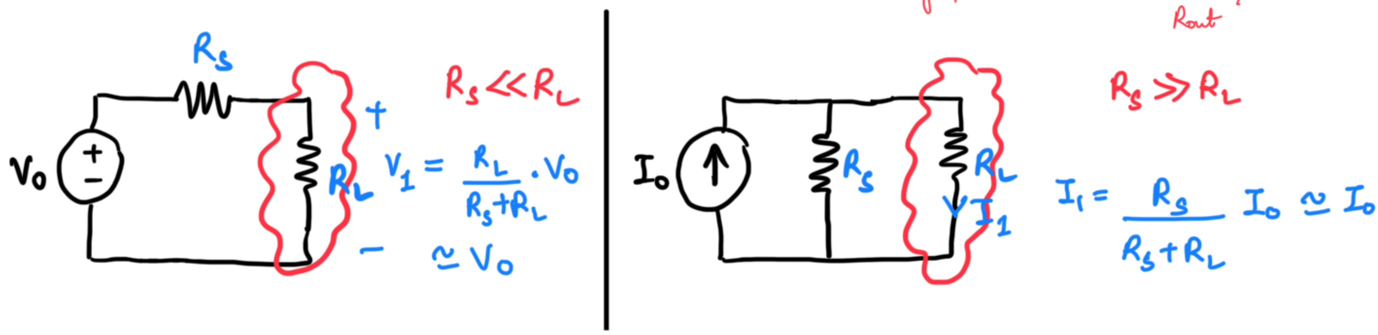
We can use them to measure the current flowing through a particular branch. (Remember Ammeter ?)

Voltage sources have zero Rout – R_{TH} of Voltage source = 0

↳ So that V doesn't change, or it'd be $V - R_{out} i \neq V$

Current sources have infinite Rout – R_{TH} of current source = ∞

↳ So that I doesnt change, or it'd be $I - \frac{V}{R_{out}} \neq I$.



In steady state, $V_e = 0$ ⇒ Negative feedback gives rise to a virtual short [i.e, the wires aren't shorted – They are separated, yet V=0]

AT STEADY STATE:

Now, we can further simplify the blue box in the above circuit [scroll back a lot!] into a single VCVS:

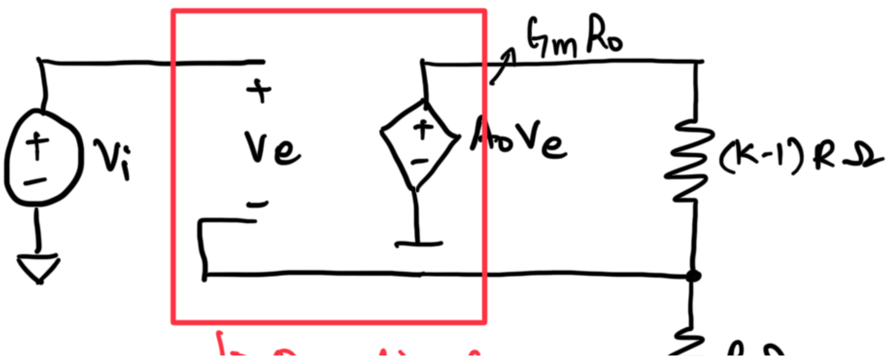
with Gain = $G_m R_0$ – A_0 where $A_0 \to \infty$ as $R_0 \to \infty$.

↑ Rout of the VCCS in the previous circuit

↳ This is what you call Steady State model using a high gain amplifier.

In steady state, Capacitor → Open circuit. Assuming Rout of VCCS as some very large R_0, we have one VCCS and VCVS.

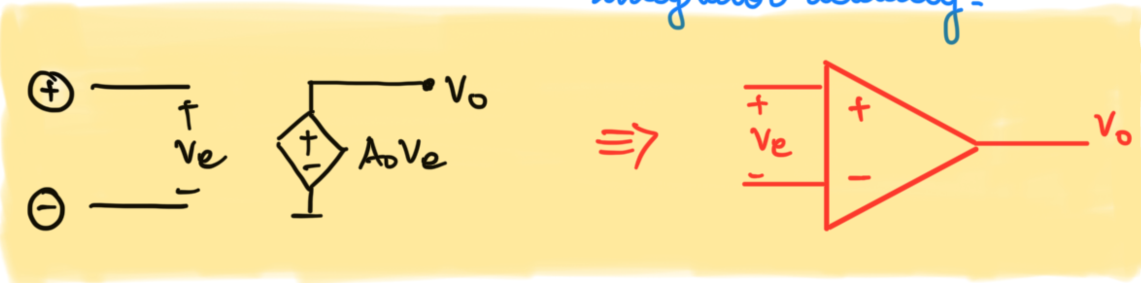
This, we can simplify as a single VCVS, with gain as the G_m of VCCS times R_0, which is high gain.



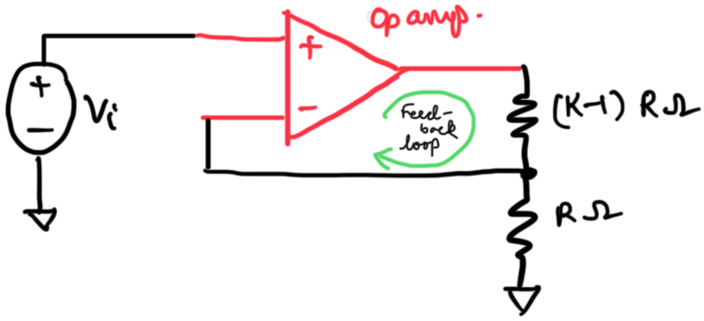
→ Operational Amplifier

This is so commonly used! ←

→ Quite close to an integrator actually.

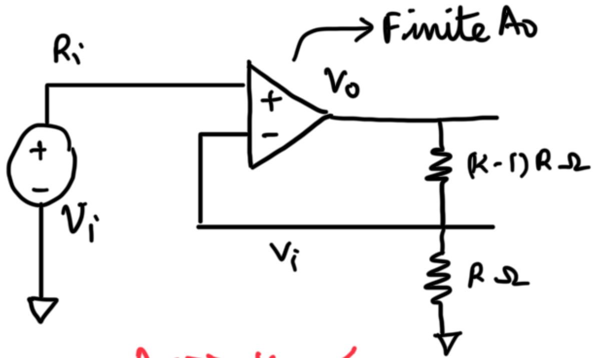


Now, our circuit becomes :



Op-Amp circuits have zero voltage difference if it is in Negative feedback [and in Steady state] - Virtual short.

If $A_o = \infty$: $R_i = \infty$ and $R_o = 0$ for the amplifier, regardless of the i/p & o/p resistances of the op-amp – If in Negative feedback loop.



$$\frac{V_o}{V_i} = \frac{A_o K}{A_o + K}$$

$$= K \cdot \frac{A_o}{A_o + K}$$

$$= \boxed{K \left[\frac{1}{1 + \frac{K}{A_o}} \right]} \simeq K.$$

$A_o \ggg K.$

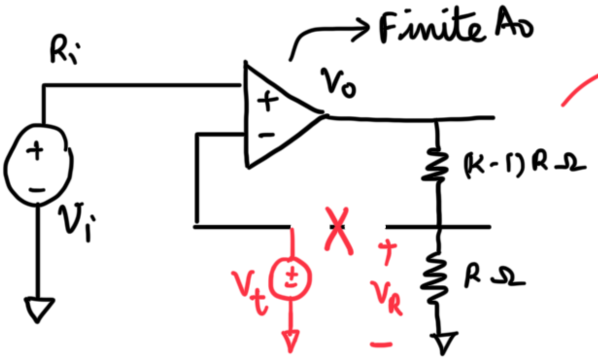
Relative error : K/A_o. We must minimize this error

Loop Gain : Quantifies Negative Feedback.

Find the loop, break it – Connect a V_{test} in one of the terminals and measure Voltage in the other terminal (Say V_{return}).

Loop Gain $= -V_{return} = L$

$$\frac{\quad}{V_{test}}$$



Here, $V_R = -\left(\frac{A_0}{k}\right) V_t$

$$\therefore \frac{V_R}{V_t} = -\frac{A_0}{k}$$

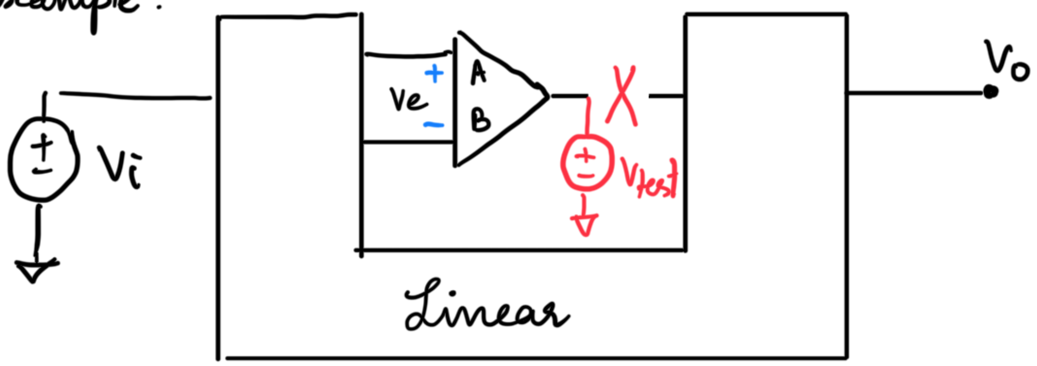
$$\text{Loop Gain} = -\frac{V_R}{V_t} = \frac{A_0}{k}$$

$$\text{Loop Gain} = \frac{1}{\text{Relative Error}}$$

Higher the loop Gain, lower the Relative error is.

To find out the signs of the Op-Amp, we have to find Loop Gain and investigate the sign.

For example:



Assuming $A = \oplus$ and B is $\ominus$, We get $V_e = aV_i + bV_o$, as the circuit box is linear.

But since we need "How much of the Op-Amp's output comes to itself" [Loop Gain], We just need V_o & V_e.

Hence, we can even set $V_i = 0$, doesn't matter to us.

$\therefore V_e = bV_o$. If b is -ve, then $A = \oplus$ & $B = \ominus$ is correct.

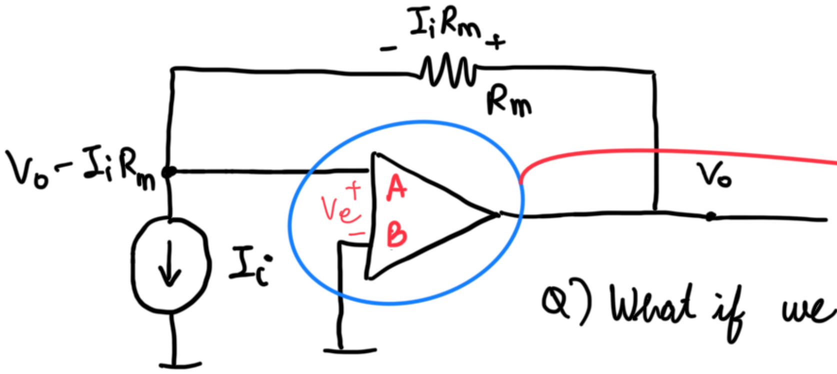
Else, just switch the polarities.

Now, let's go to Current Controlled Voltage source.

$V_o = R_m I_i$ ← trans-resistance / transfer resistance

Implement this using Negative Feedback?

$V_e = V_o - I_i R_m = \frac{V_o}{R_m} - I_i$



$\frac{V_e}{V_o} = +ve. \quad \therefore A = (-), \; B = (+)$

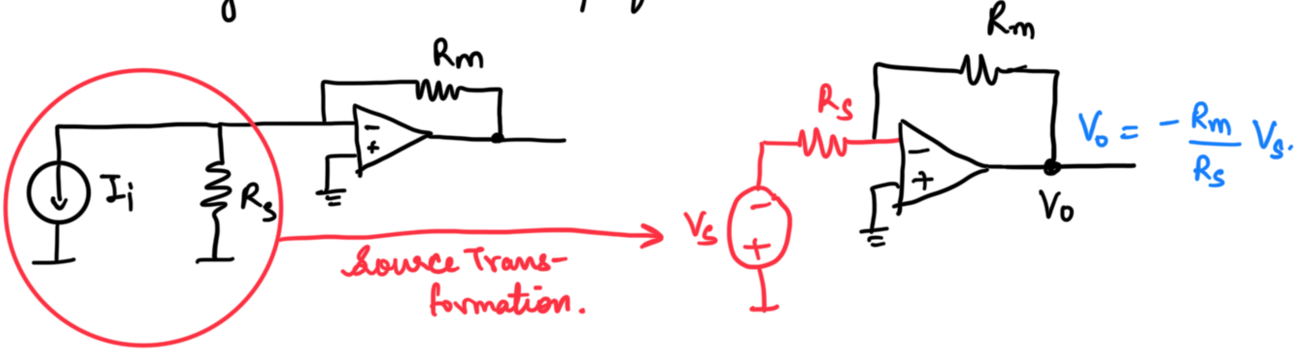
Q) What if we define $I_i R_m - V_o = V_e$?

This is a transimpedance amplifier

- $R_{in} = 0 \rightarrow$ due to the virtual short of Negative Feedback.
- $R_{out} = 0 \rightarrow V_{out}$ is virtually short due to Negative Feedback.

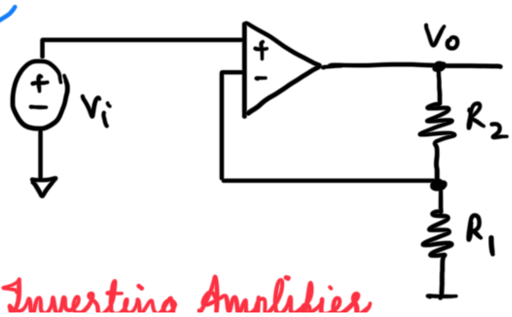
These 2 hold until the OpAmp's Gain is ∞.

Let's say we have an imperfect CCVS :



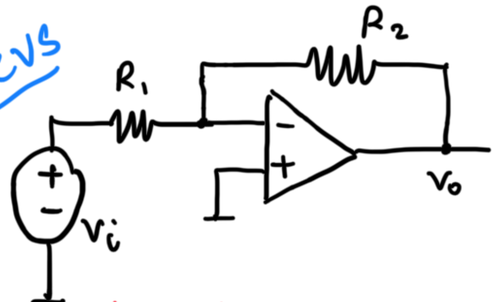
The 2 popular OpAmp Circuits :

VCVS



Non-Inverting Amplifier

CCVS



Inverting Amplifier

$$\frac{V_0}{V_i} = \left(1 + \frac{R_2}{R_1}\right) \text{ (+ve gain)}$$

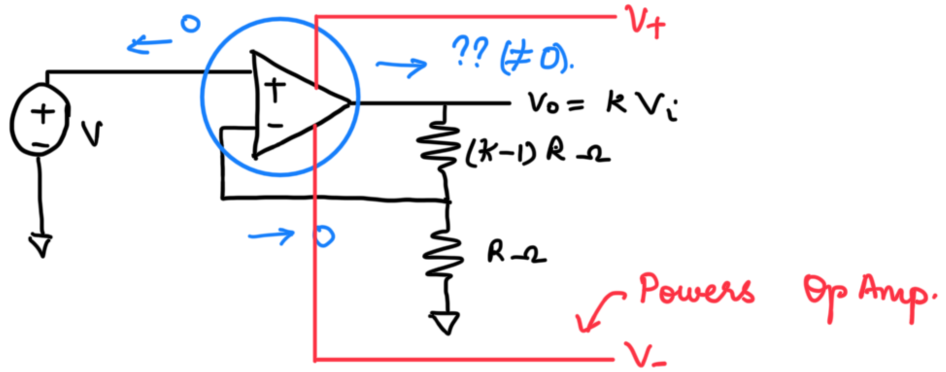
ratio is independent of internal voltage of the source, no matter what it is. It is also insensitive to any load that is connected to V_0.

$$\frac{V_0}{V_i} = -\frac{R_2}{R_1} \quad \text{(-ve gain)}$$

ratio is independent of internal resistance of the source, unless $R_s \lll R_1$. It is the ratio of output voltage to input current that is insensitive to various parameters.

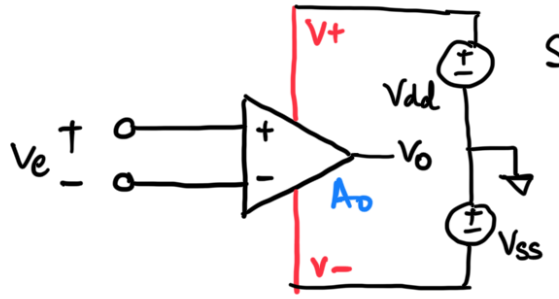
Usually Voltage input is useful as distrubuting a voltage is much easier than distrubuting a current.

Now consider KCL :

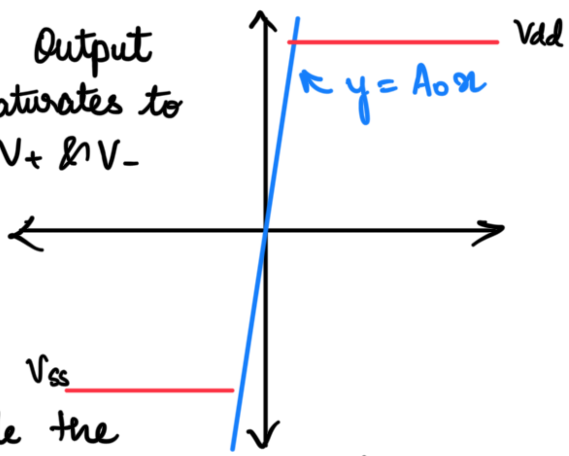


Role of these 'Supplies' ?

- Supply the current to the Op Amp.



Output Saturates to V+ & V−



If only VCVS is there inside the Op Amp, that blue line in the graph goes on and on. To restrict this, the supplies come into action. - Saturation

Why do we choose $V_{dd} = V_{ss}$?? Usually the source for our "OpAmp, we have a sinusoid. The upper limit (if A) and the lower limit (will be -A) will be equal in magnitude.

This set up of the OpAmp is known as the Dual Supply operation of the OpAmp.

Let's Redraw the Circuit, (Non inverting Amplifier) that shows all the Ground connections:

[Continued in Analog 2]

hello
how are

Hello

Hello how are you

I am fine where is Divya

Hello how are you