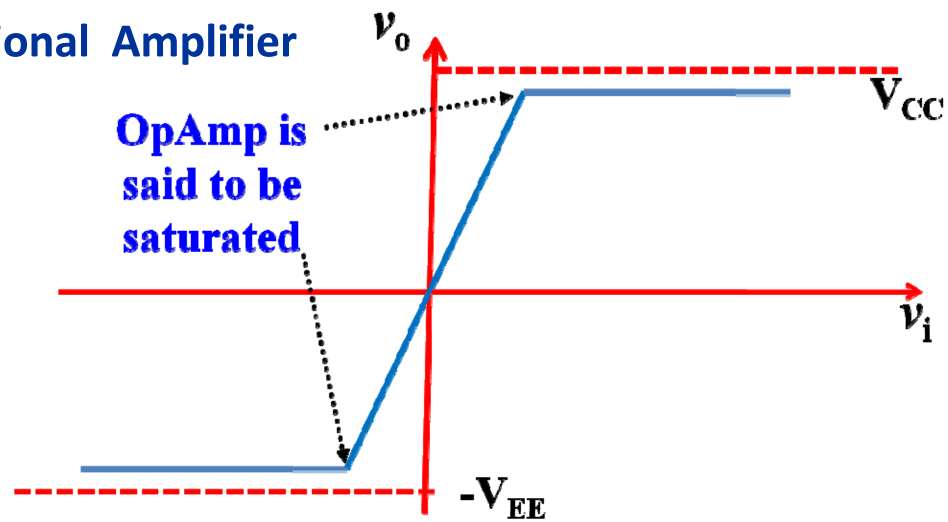
ESc201, Lecture 23: Operational Amplifier

OpAmp circuits

- Open Loop
- Closed-Loop
  - Negative Feedback
  - Positive Feedback



Closed-Loop Applications:

[With Negative (degenerative) Feedback]

Many applications i.e..

1. **Inverting and Non-Inverting Amplifiers**
2. **Summing Amplifier**
3. **Voltage Follower**
4. **Differential or Difference Amplifier (DA)**
5. **Instrumentation Amplifier**
6. **Level Shifter**
7. **Active Filter (*Low-Pass, High-Pass, Band-Pass)***
8. **Integrator and Differentiator**
9. **Logarithmic and Exponential Amplifier**

Closed-Loop Applications:

With Positive (Regenerative) Feedback

[*Concept of Virtual Ground and Summing Point Constraint can't be applied anymore*]

1. **Schmitt Trigger**
2. **Waveform Generation (Square- and Triangular-Wave)**
3. **Oscillators (Wein-Bridge and Phase-Shift)**

Open Loop Applications:

1. **Comparator**
2. **Zero Crossing Detector -Square Wave Generator.**

Check: NPTEL video course (IITK by R. N. Biswas and Baquer Mazhari) on Amplifiers, specially the part on OpAmp amplifiers

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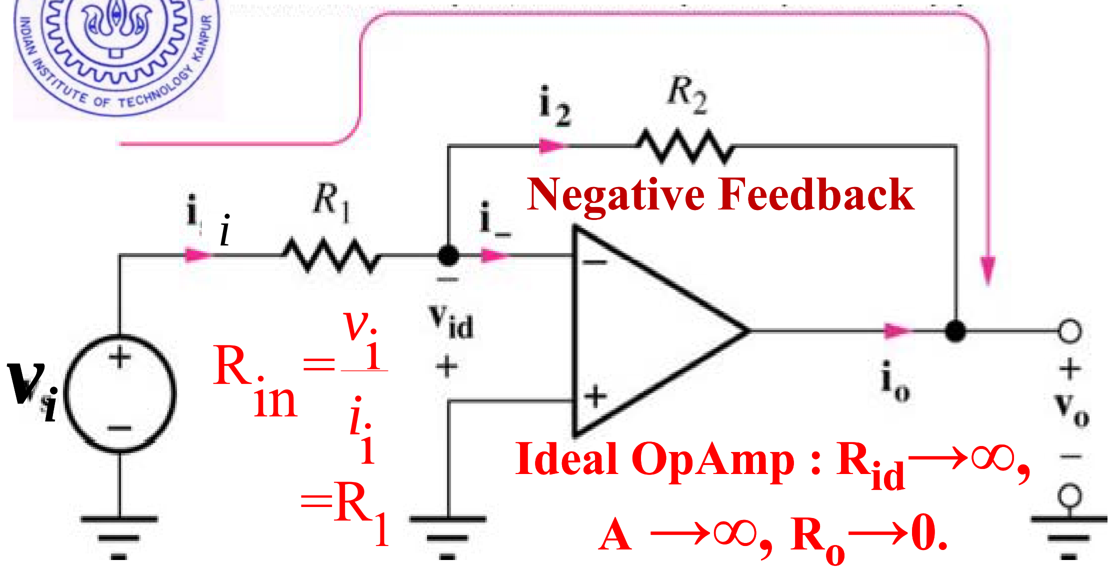


$R_{in} = \frac{v_1}{i_1} = R_1$

Ideal OpAmp : $R_{id} \rightarrow \infty$, $A \rightarrow \infty$, $R_o \rightarrow 0$.

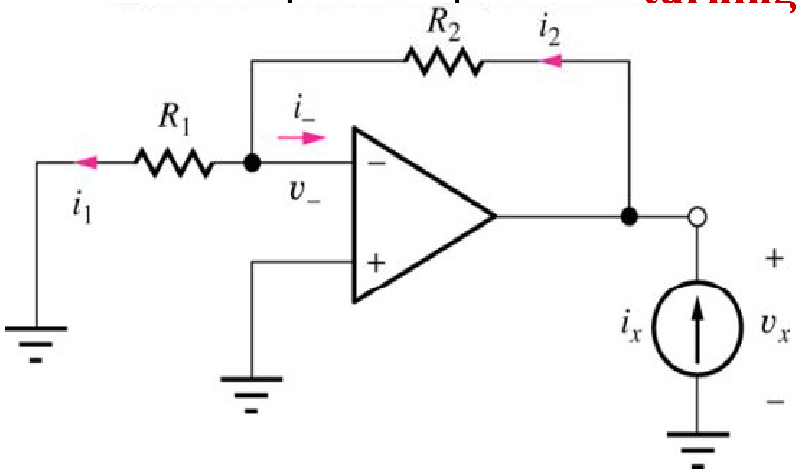
- Negative voltage gain implies 180^0 phase shift between dc/sinusoidal input and output signals.
- Gain greater than 1 if $R_2 > R_1$
- Gain less than 1 if $R_1 > R_2$
- Inverting input of op amp is at ground potential (not connected directly to ground) and is said to be at ***Virtual ground.*** $\therefore i_1 = \frac{v_1}{R_1}$

$v_1 - i_1 R_1 - i_2 R_2 - v_O = 0$ **But $i_i = i_2$ and $v_- = 0$ (since $v_{id} = v_+ - v_- = 0$)**

Famous OA paradox: **The input terminals are open and short at the same time ?????**

and $A_v = \frac{v_O}{v_i} = -\frac{R_2}{R_1}$

R_{out} is found by applying a test current (or voltage) source to amplifier output and determining the voltage(or current) and turning off all independent sources. Hence, $v_s = 0$



$v_X = i_2 R_2 + i_1 R_1$ **But $i_1 = i_2$** $\therefore v_X = i_1 (R_2 + R_1)$

Since $v_- = 0$, $i_1 = 0$ and $v_x = 0$ irrespective of the value of i_x. $\therefore R_{out} = 0$

Therefore, keeping R_2 fixed, reduce R_1 to increase gain (A_v), but that would reduce (R_{in}).

Negative Feedback→Stable System: All disturbances die down automatically.

ESc201, Lecture 22: OpAmp Non-Inverting Amplifier (IDEAL OPAMP)

Since i_-=0 $\quad v_1 = v_o\dfrac{R_1}{R_1+R_2}$

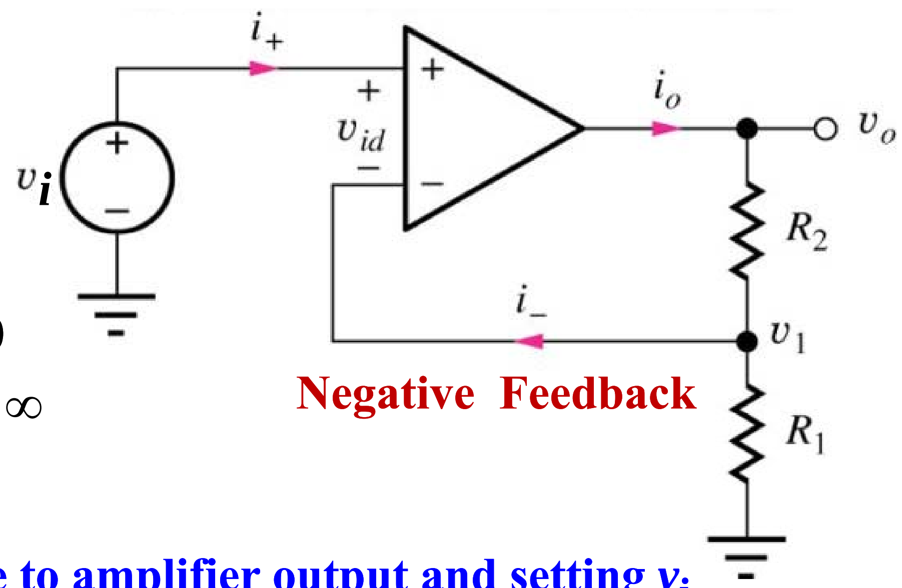
and $\quad v_i - v_{id} = v_1 \quad$ **But v_{id} =0** $\quad \therefore v_i = v_1$

$$v_o = v_i\frac{R_1+R_2}{R_1}$$

$$\therefore A_v = \frac{v_o}{v_i} = \frac{R_1+R_2}{R_1} = 1+\frac{R_2}{R_1}$$

Since i_+=0

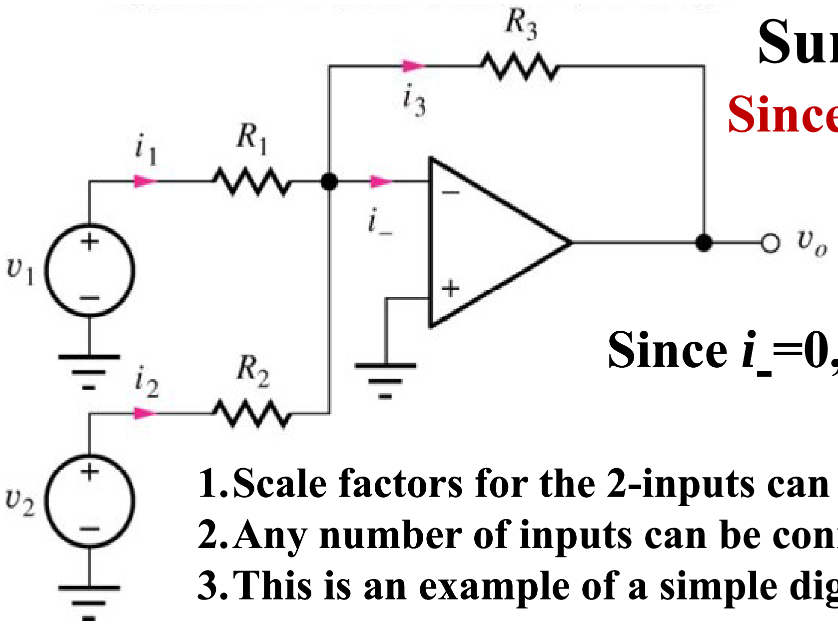
$$R_{in} = \frac{v_i}{i_+} = \infty$$



Negative Feedback

R_{out} is found by applying a test current source to amplifier output and setting v_i = 0 and is identical to the output resistance of inverting amplifier i.e. R_{out} =0

Summing Amplifier



Since negative amplifier input is at virtual ground,

$$i_1 = \frac{v_1}{R_1} \qquad i_2 = \frac{v_2}{R_2} \qquad i_3 = -\frac{v_o}{R_3}$$

Since i_-=0, i_3= i_1 + i_2, $\quad v_o = -\dfrac{R_3}{R_1}v_1 - \dfrac{R_3}{R_2}v_2$

1. **Scale factors for the 2-inputs can be independently adjusted by proper choice of R_2 and R_1.**
2. **Any number of inputs can be connected to summing junction through extra resistors.**
3. **This is an example of a simple digital-to-analog converter.**

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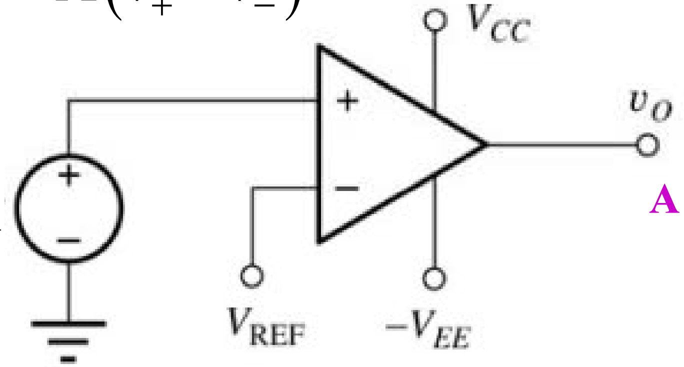
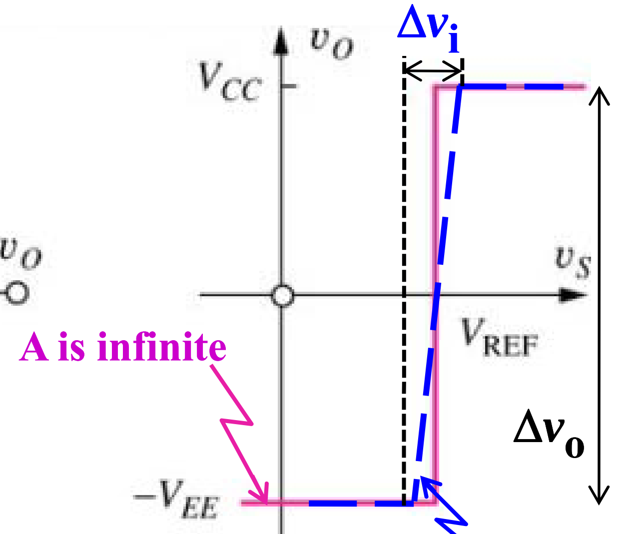
Comparator

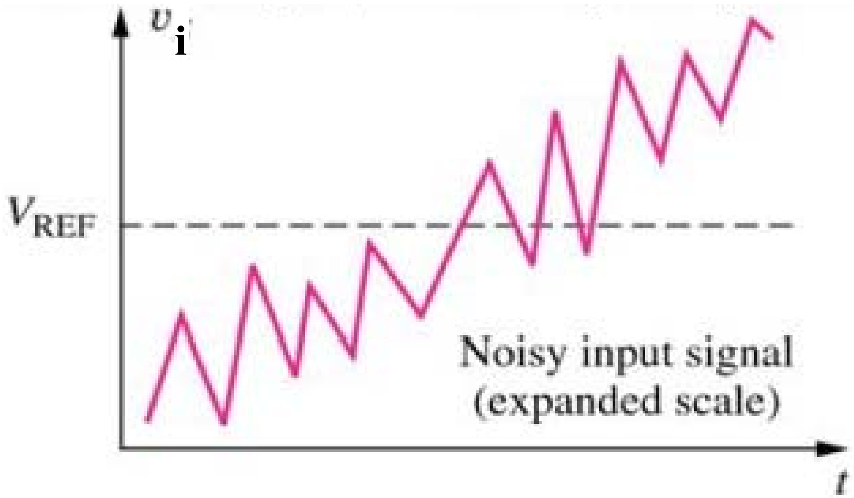
$$v_o = A(v_+ - v_-)$$

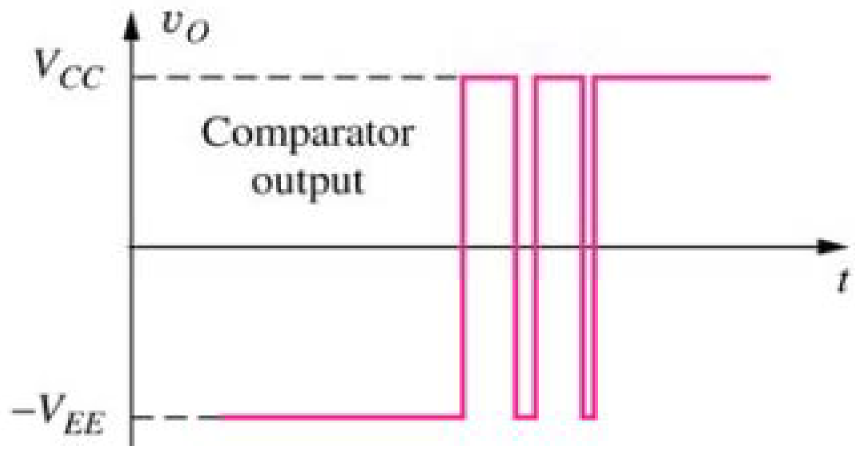
For inputs > V_{REF}, output saturates at $V_{+Sat} \approx V_{CC}$.
For inputs < V_{REF}, output saturates at $V_{-Sat} \approx V_{EE}$.





- Amplifiers built for use as comparators can handle saturation at the voltage extremes without incurring excessive internal time delays.
- For finite open loop gain 'A', $\Delta v_i = (V_{+Sat} - V_{-Sat})/A_{finite}$.
- Can also be used for digital comparision (i.e. comparrison between 1's and 0's).
- For noisy inputs, multiple transitions may occur as input signal crosses. (Not good, but high precision or speed means unnecessary transitions—have to take care with capacitors





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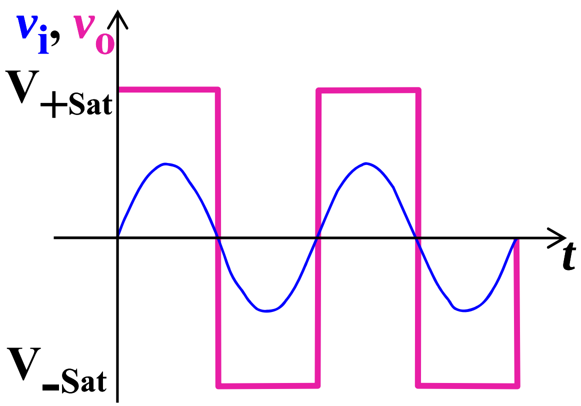
Zero-Crossing Detector (Square-Wave Generator):

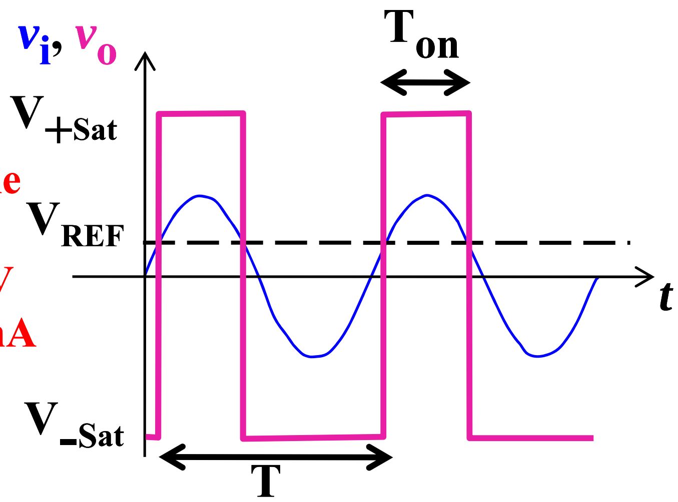
V_{REF} is finite (positive in the case shown here)
Duty cycle can be changed by adjusting V_{REF}.



Comparator with Sinusoidal input (v_i)
(other input $V_{REF} = 0$)

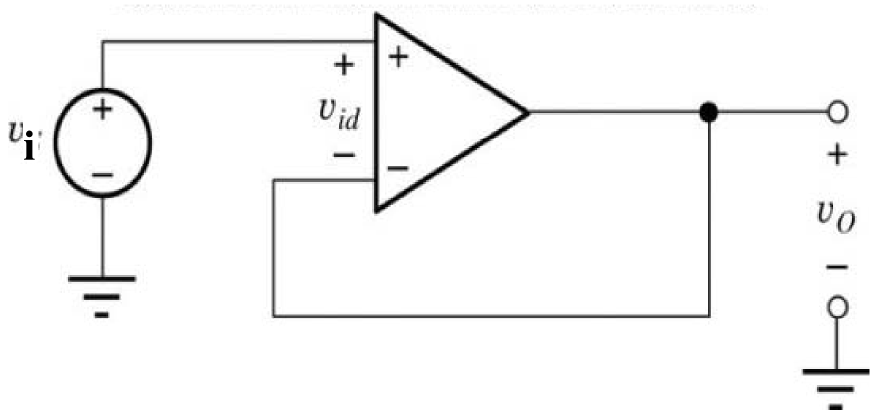
Duty cycle $= T_{on}/T$

Life is not that simple
Real deivces have
Offset Voltage ~ 5mV
Offset Current ~ 10nA



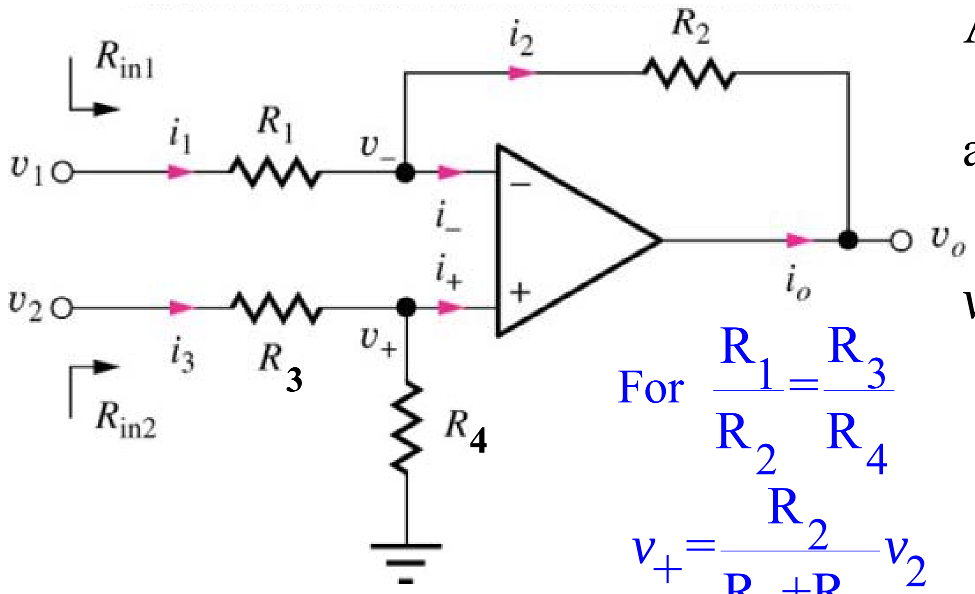
Comparator with Sinusoidal input (v_i)

Unity-gain Buffer or Voltage follower: Special case of non-inverting amplifier with infinite R_1 and zero R_2. Hence $A_v = 1$.



1. Provides excellent impedance-level transformation while maintaining signal voltage level.
2. Ideal voltage buffer does not require any input current and can drive any desired load resistance without loss of signal voltage (limited by finite sink capacity of the OpAmp).
3. Unity-gain buffer is used in may sensor and data acquisition systems.

Difference Amplifier (done in previous class with open loop). But this would make the output saturate if the gain A is high. Then it will not serve any useful purpose if an offset voltage is present as the input has to be less than this value if the out should not saturate.



As $i_1 = i_2$ for $i_- = 0$, $\dfrac{(v_1 - v_-)}{R_1} = \dfrac{(v_- - v_o)}{R_2}$

and $v_+ = \dfrac{R_4}{R_3 + R_4} v_2$

$$v_o = -\frac{R_2}{R_1}(v_1 - v_-) + \left(\frac{R_1 + R_2}{R_1}\right)\left(\frac{R_4/R_3}{1 + R_4/R_3}\right)$$

For $\dfrac{R_1}{R_2} = \dfrac{R_3}{R_4}$

$$v_+ = \frac{R_2}{R_1 + R_2} v_2$$

$$v_o = v_- - i_2 R_2 = v_- - i_1 R_2$$

$$= v_- - \frac{R_2}{R_1}(v_1 - v_-) = \left(\frac{R_1 + R_2}{R_1}\right) v_- - \frac{R_2}{R_1} v_1$$

R_{in2} is series combination of R_1 and R_2 as $i_+ \approx 0$.
For $v_2 = 0$, $R_{in1} = R_1$, as the circuit reduces to an inverting amplifier.
For general case, i_1 is a function of both v_1 and v_2.

Since $v_- = v_+$

$$v_o = -\frac{R_2}{R_1}(v_1 - v_2)$$

v_{ic}= $(v_1 + v_2)/2$ will not affect the output if the CMRR is large. However, in practice it is large but finite, so some change is observed if v_1, v_2 changes keeping v_{id} same.

For $R_2 = R_1$, $v_o = -(v_1 - v_2)$

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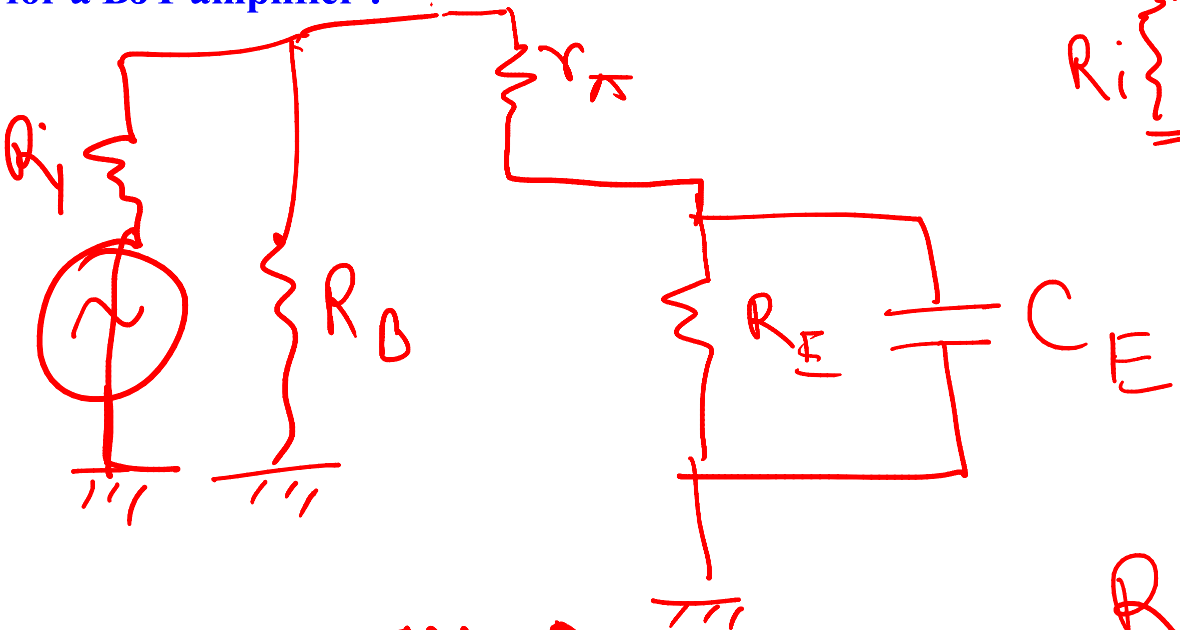
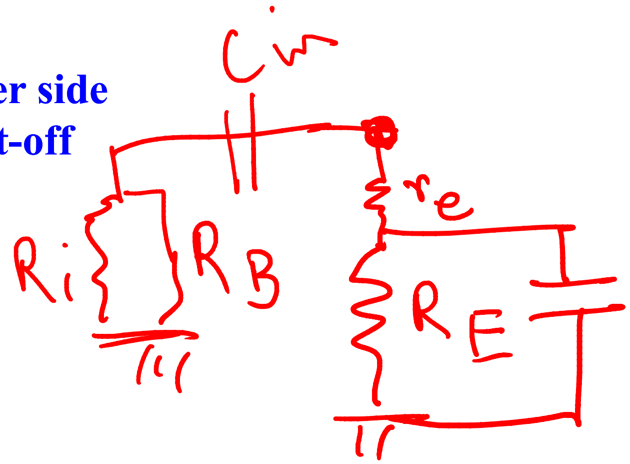
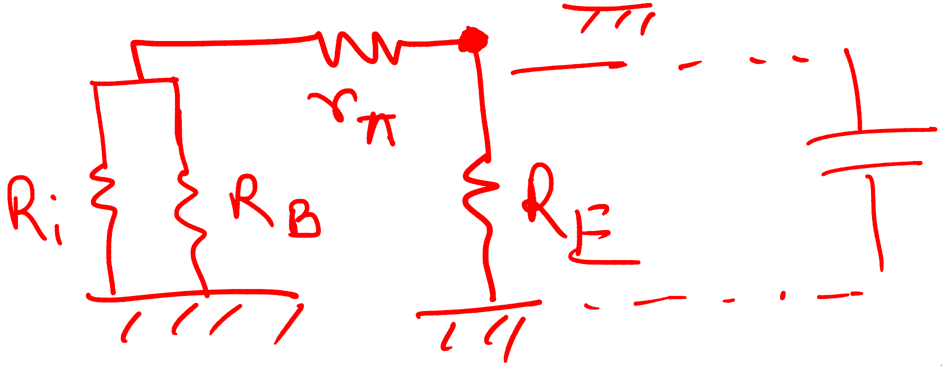
Transferring Impedances from the Base side to the Emitter side for calculation of the Dominant pole for low frequency cut-off for a BJT amplifier :







R_{eq}

$$R_E \,\|\, \left(\frac{r_\pi + R_i \| R_B}{\beta + 1} \right)$$

$$R_E \,\|\, \left(r_e + \frac{R_i \| R_B}{\beta + 1} \right)$$