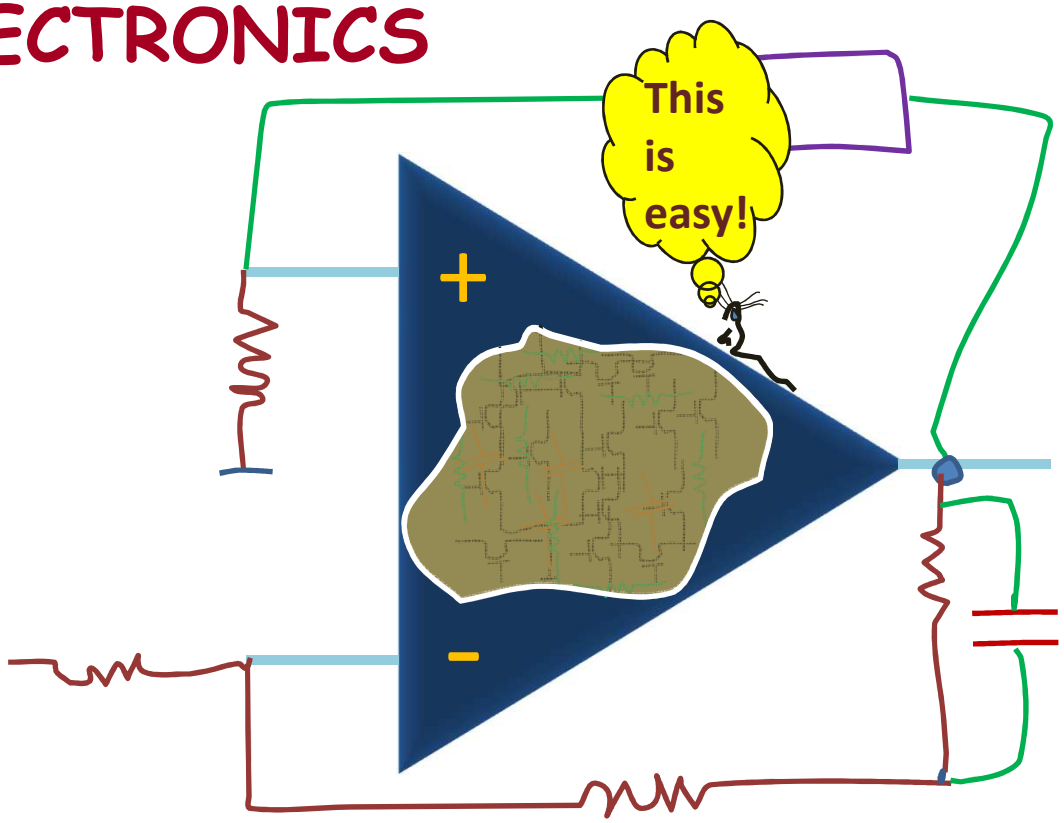
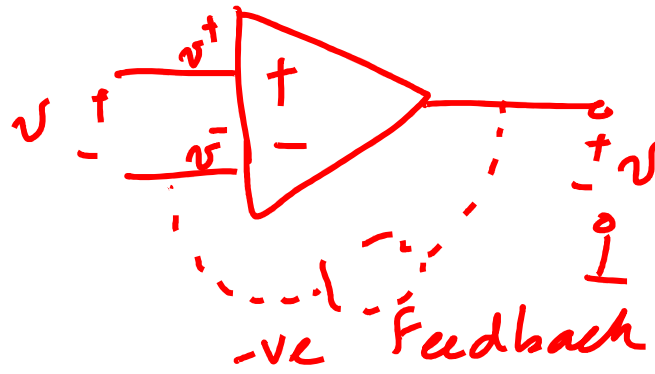
6.002x CIRCUITS AND ELECTRONICS

Operational Amplifier Circuits



Review Operational amplifier abstraction



- ∞ input resistance
- 0 output resistance
- Gain "A" very large

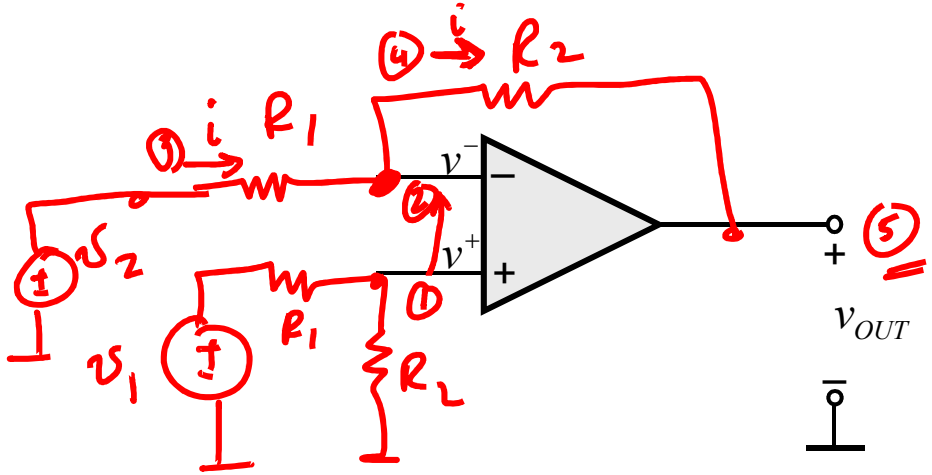
$v^+ \approx v^-$

virtual short method

- Basic building block for analog system
- Filters, clock generators, amplifiers, adders, integrators, differentiators, digital-to-analog converters

Reading: Chapter 15.5, 15.6 of A&L

Consider this circuit:



④ i thru R_2

⑤ $v_{OUT} = v^- - iR_2$

$= v^- - \frac{v_2 - v^-}{R_1} \cdot R_2$

$= v^- \left[1 + \frac{R_2}{R_1}\right] - v_2 \frac{R_2}{R_1}$

$= v_1 \left[\frac{R_2}{R_1+R_2}\right]\left[\frac{R_1+R_2}{R_1}\right] - v_2 \frac{R_2}{R_1}$

$= v_1 \frac{R_2}{R_1} - v_2 \frac{R_2}{R_1}$

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

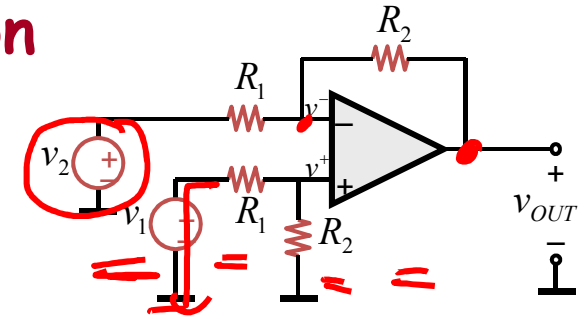
subtracts!

① $v^+ = v_1 \frac{R_2}{R_1+R_2}$

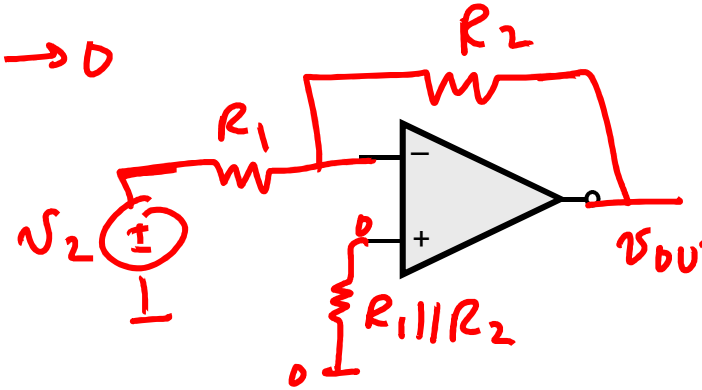
② $\approx v^-$

③ $i = \frac{v_2 - v^-}{R_1}$

Another way of solving — use superposition

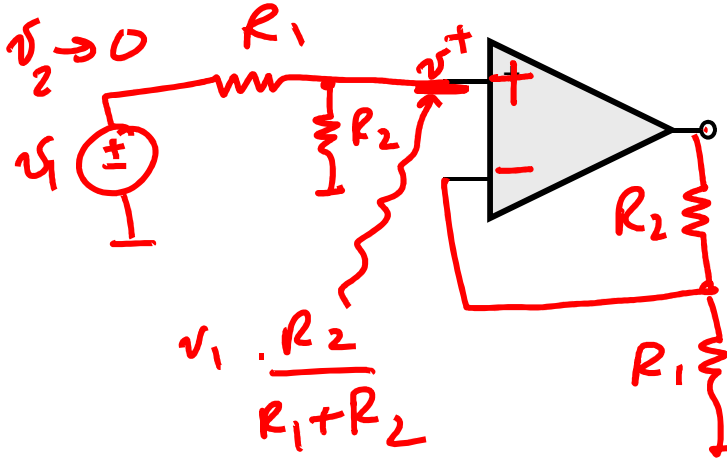


$v_1 \to 0$



$v_{OUT_2} = -\frac{R_2}{R_1} v_2$

$v_2 \to 0$



$v_{OUT_1} = v^+ \cdot \frac{R_1+R_2}{R_1}$

$= v_1 \cdot \frac{R_2}{R_1+R_2} \cdot \frac{R_1+R_2}{R_1}$

$= v_1 \frac{R_2}{R_1}$

$v_{OUT} = v_{OUT_1} + v_{OUT_2}$

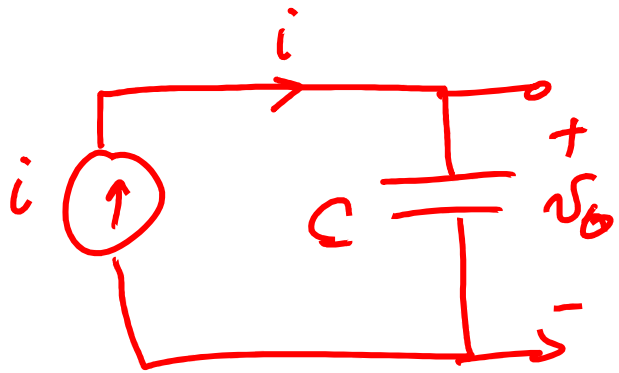
$= v_1 \frac{R_2}{R_1} + \left(-\frac{R_2}{R_1} v_2\right)$

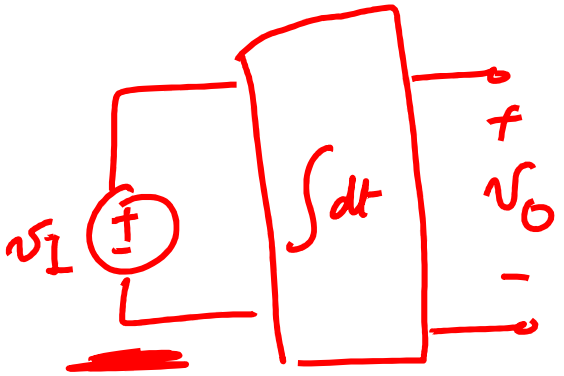
$= \frac{R_2}{R_1}(v_1 - v_2)$

... still a subtractor

Let's build an integrator...

Let's start with this insight:





$v_O = \frac{1}{C}\int_{-\infty}^{t} i\,dt$

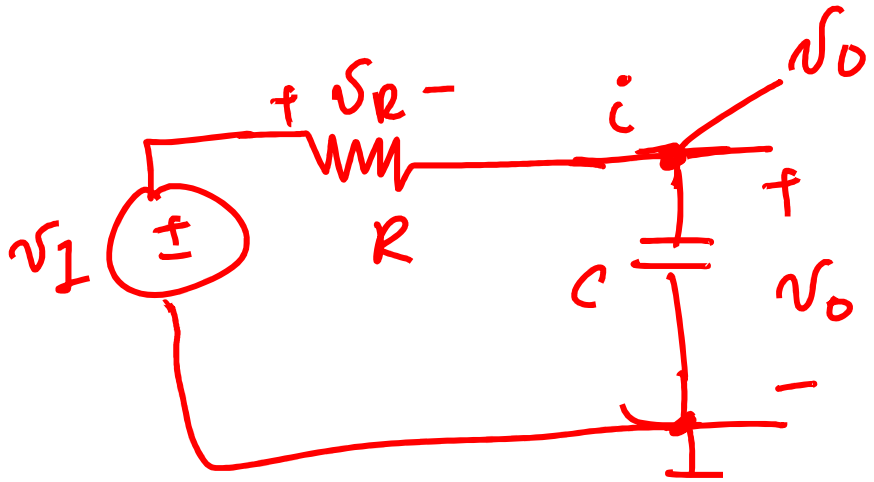
v_O is related to $\int i\,dt$

$v_O = A\int v_I\,dt$

But we need to somehow convert voltage v_I to a current

$v_I \xrightarrow{\text{magic}} i \longrightarrow v_O = \frac{1}{C}\int_{-\infty}^{t} i\,dt$

First try... use resistor

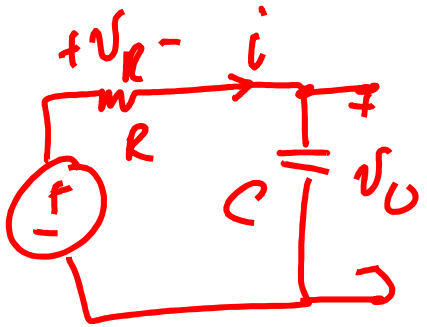


$\frac{v_I}{R} \xrightarrow{?} i$

Let's take a gamble & use a R

But, v_O must be very small compared to v_R, or else $i \neq \frac{v_I}{R}$

First try… use resistor



When is v_O small compared to v_R?

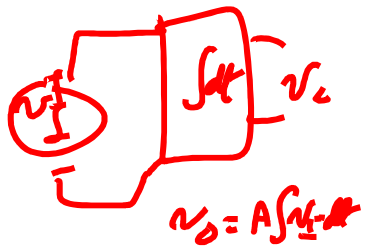
$$RC\frac{dv_O}{dt} + v_O = v_I$$

v_R ??? Make believe this is true

$$i = C\frac{dv_O}{dt}$$

If $RC\frac{dv_O}{dt} \gg v_O$

Time const. is large

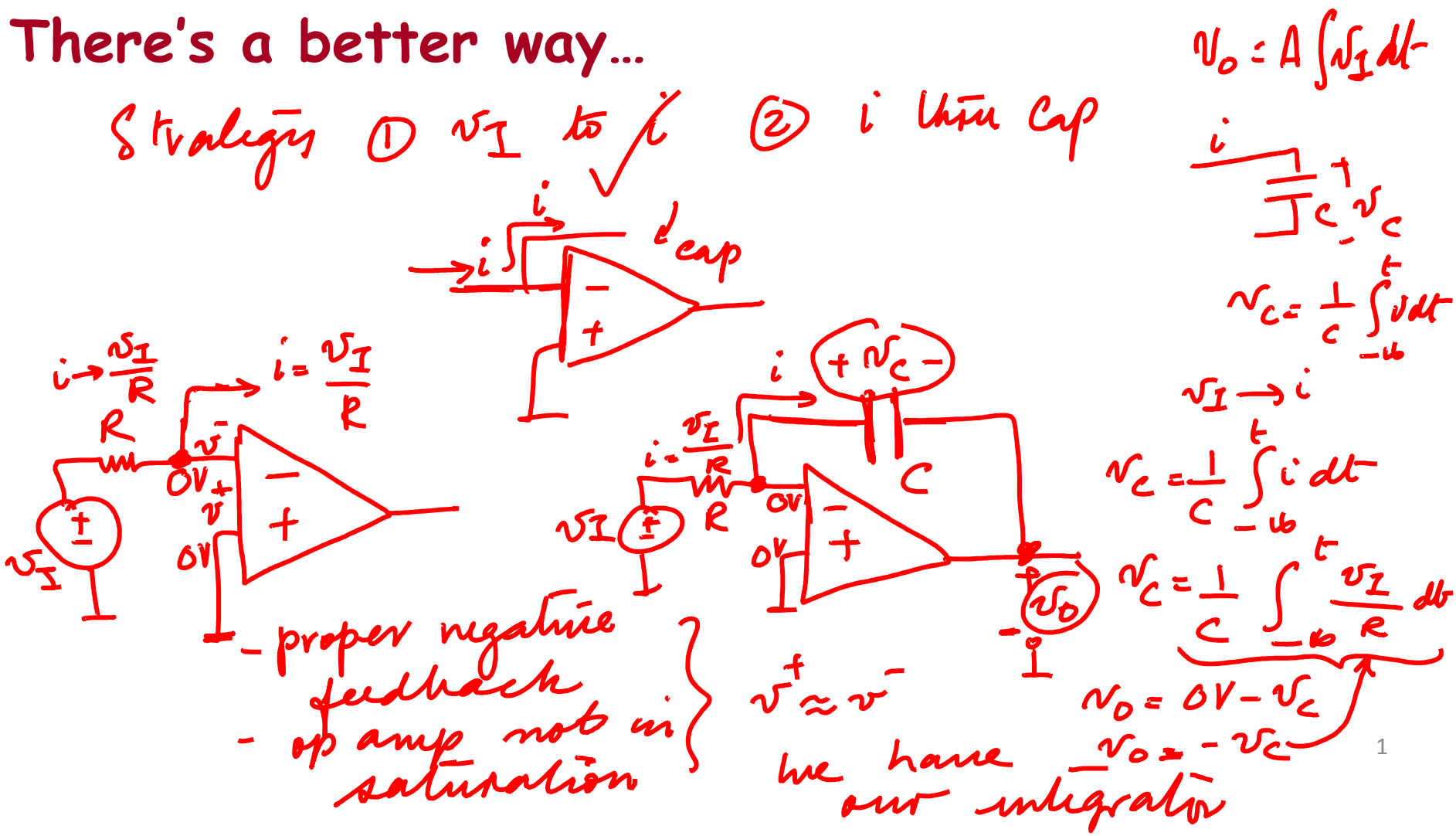


$$RC\frac{dv_O}{dt} \approx v_I$$

$$\text{then } v_O \approx \frac{1}{RC}\int_{-\infty}^{t} v_I\,dt$$

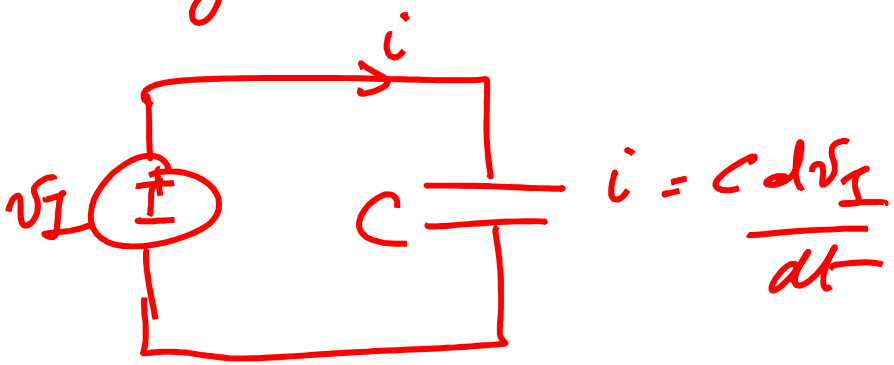
I get what I want!

There's a better way...

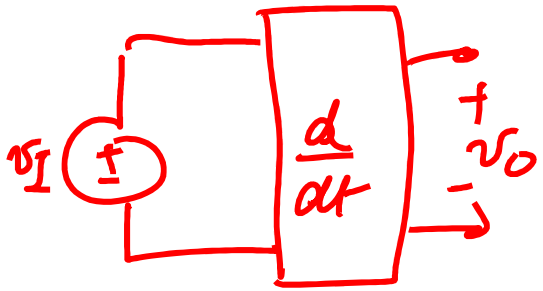


Now, let's build a differentiator...

Let's start with the following insight:



$$i = C\frac{dv_I}{dt}$$

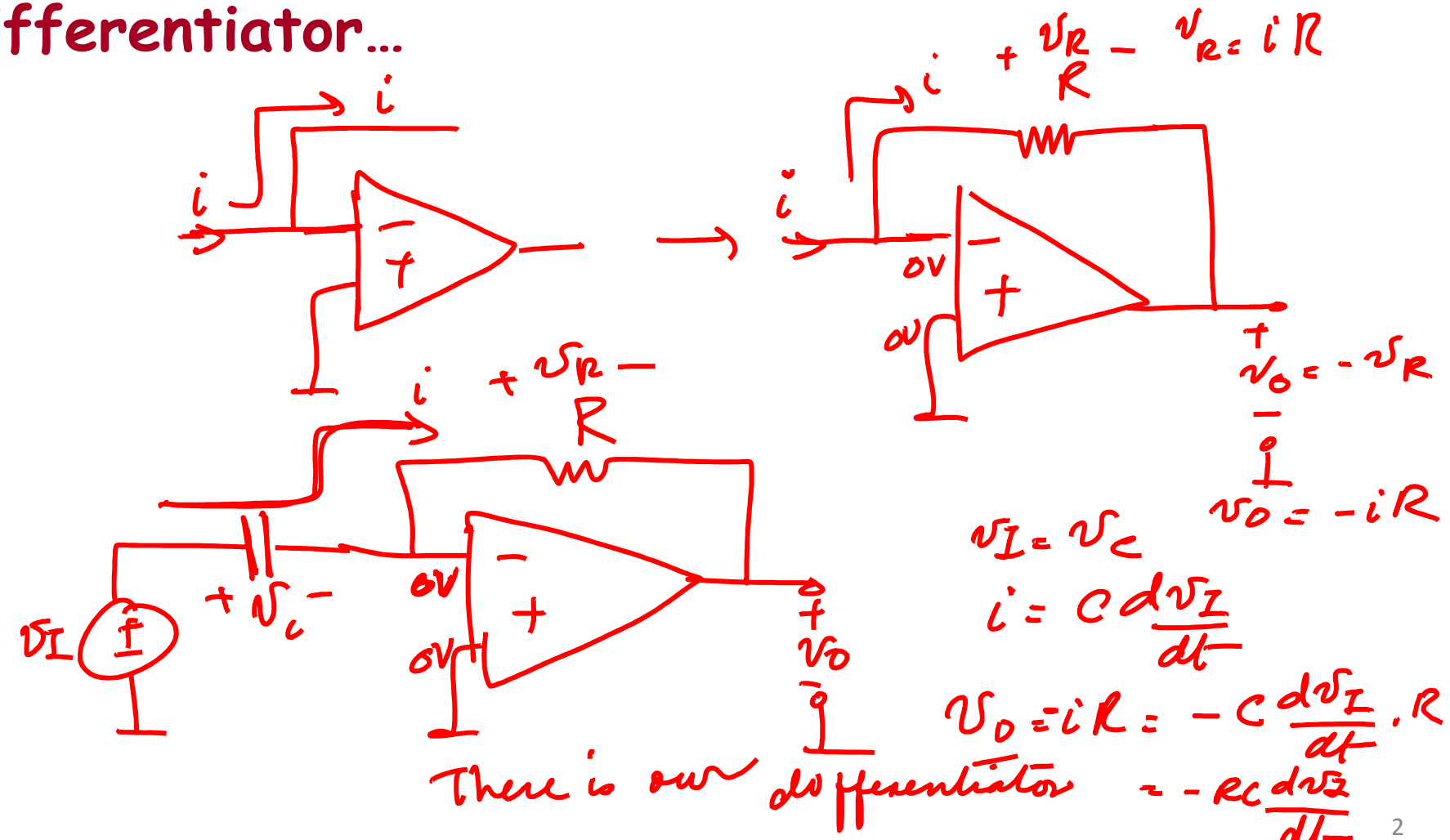


$$v_O = A\frac{dv_I}{dt}$$

i is related to $\frac{dv_I}{dt}$ ... but, we need to somehow convert current to a voltage

① v_I across cap, i will be related to dv_I/dt ② $i \rightarrow v_O$

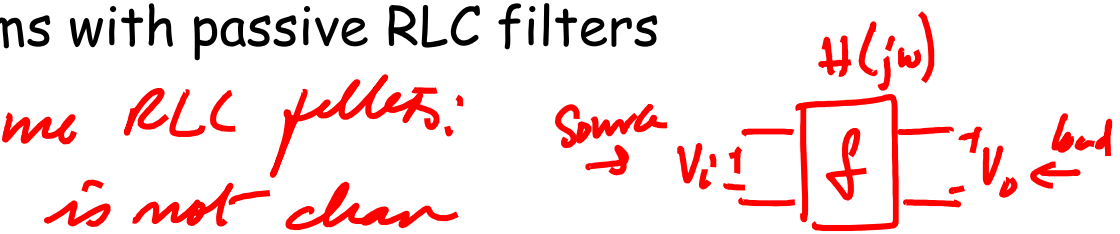
Differentiator...



Op Amp Filters

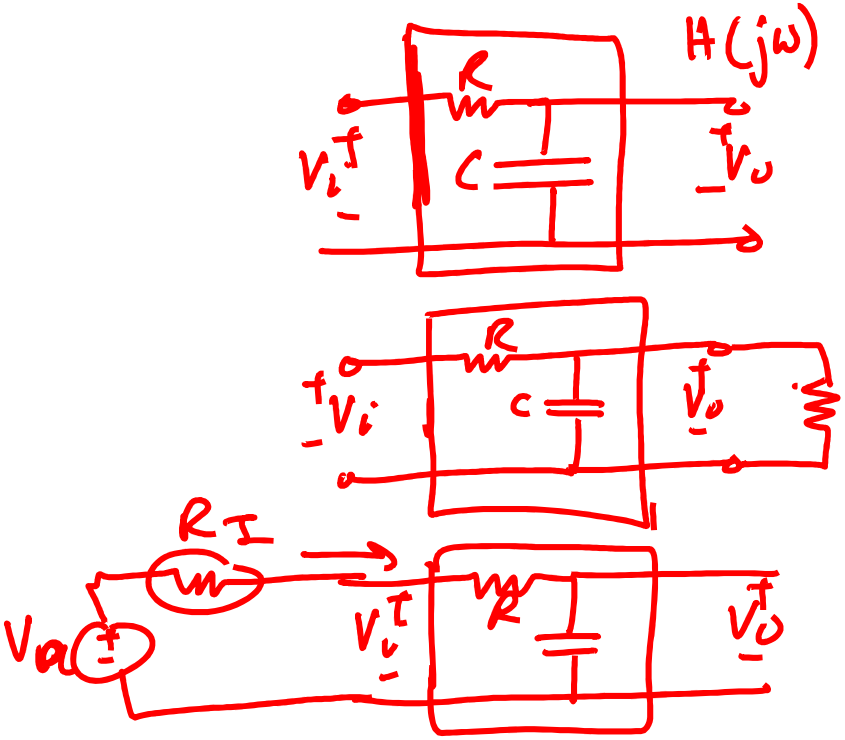
Problems with passive RLC filters

Problems with passive RLC filters:
Filter characteristics is not clear



ideally $V_o = H(j\omega)V_i$

$s = j\omega$



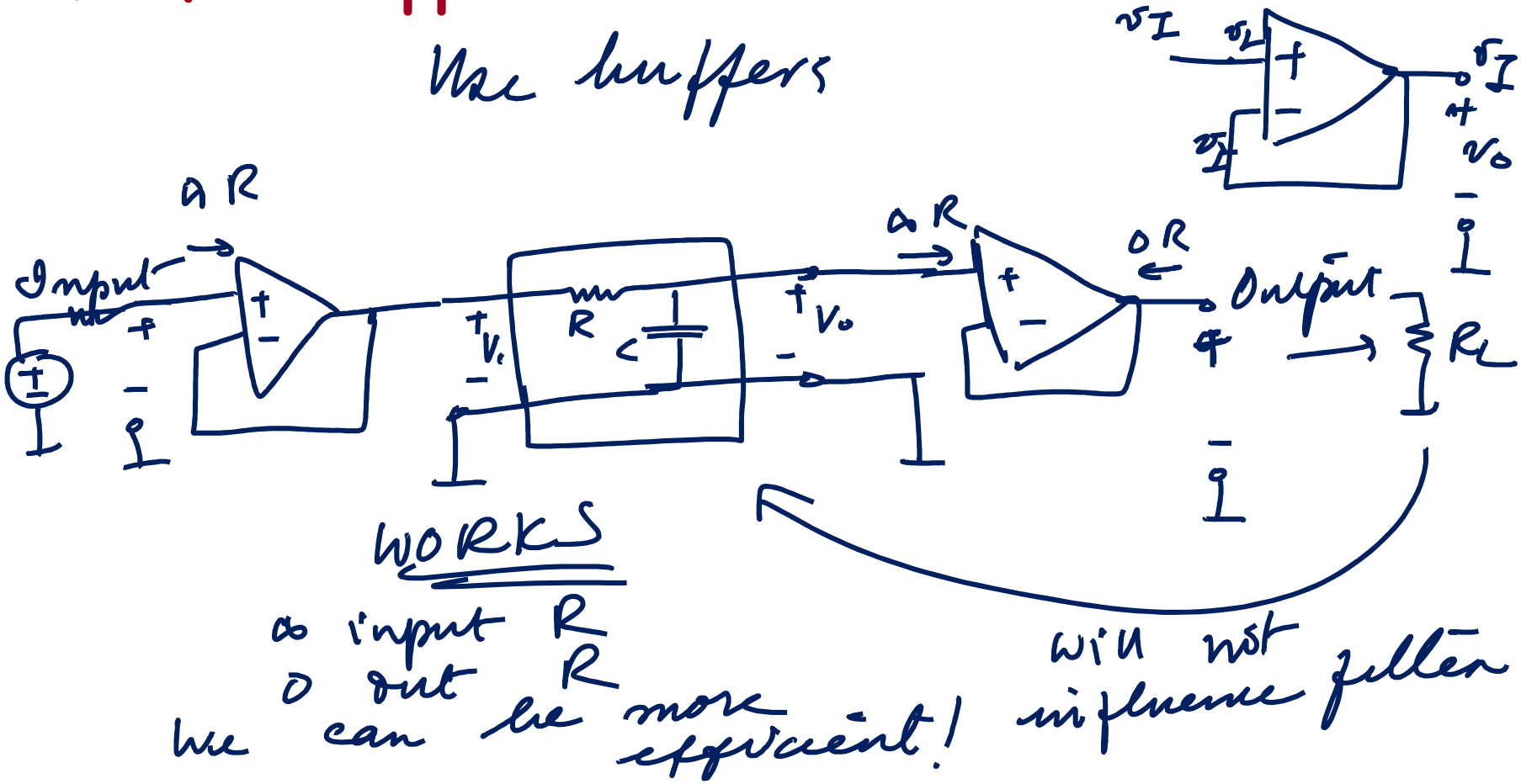
- Load changes $H(j\omega)$!

$$H(j\omega)' = \frac{\frac{1}{sC} \| R_L}{\frac{1}{sC} \| R_L + R}$$

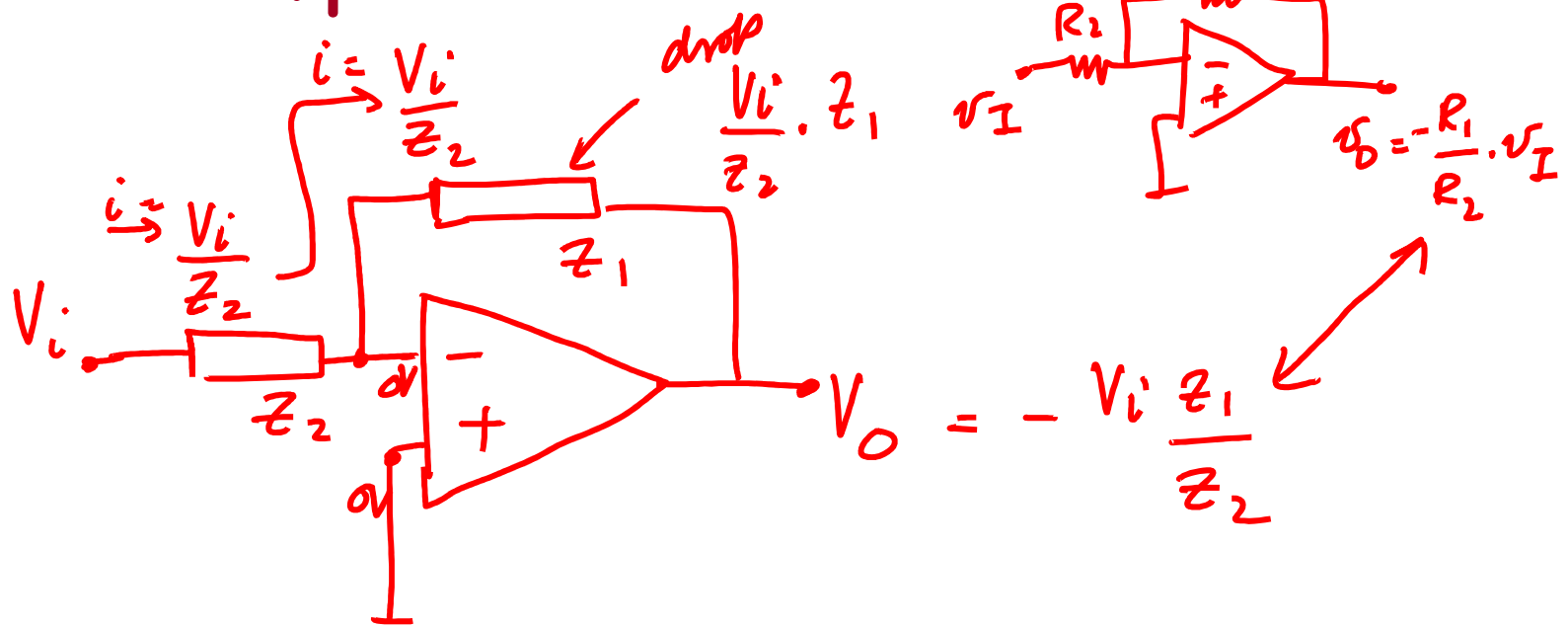
NOT good!

- Filter loads the source and is sensitive to load
- Inductors hard to build in ICs.

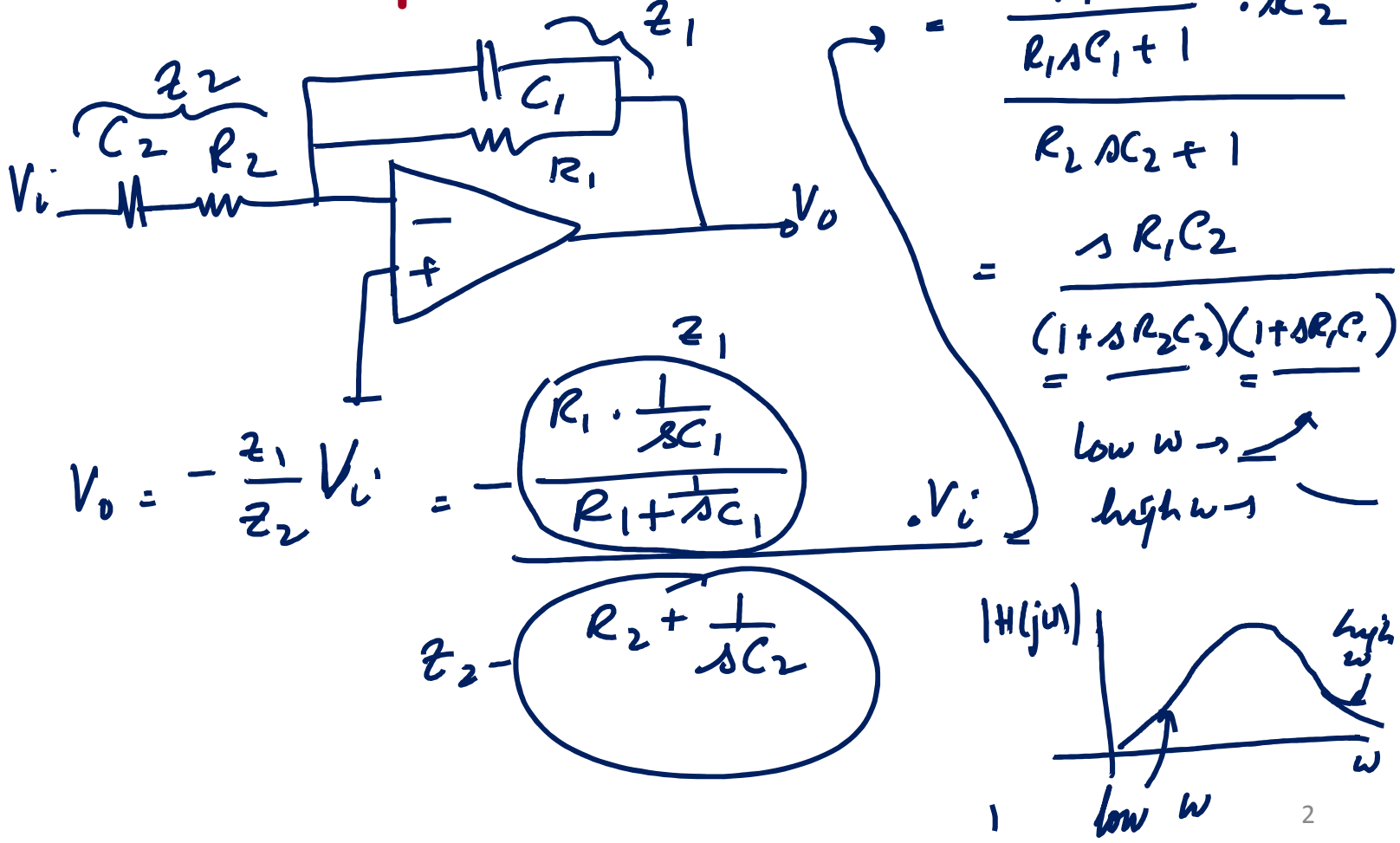
Brute force approach



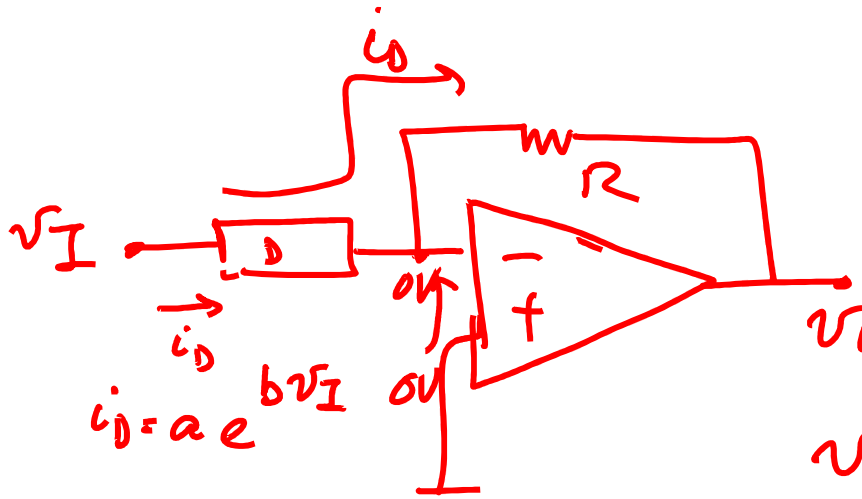
Op Amps and impedances



Op Amp filter example



Nonlinear Op Amp circuits

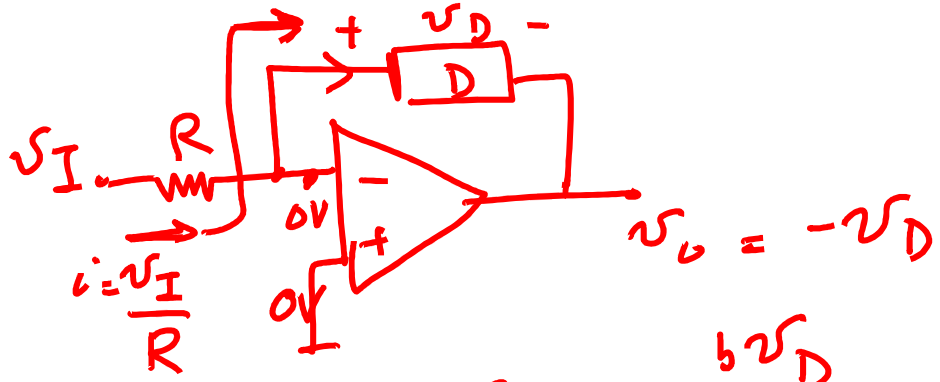


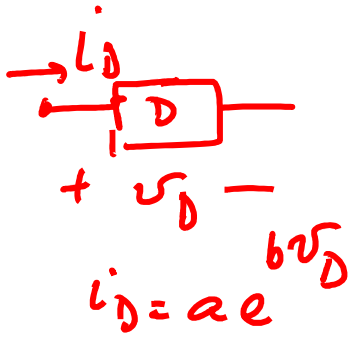
$v_O = - i_D R$

$v_O = - a e^{b v_I} \cdot R$

Exponentiator!

Another nonlinear Op Amp circuit





$$i = \frac{v_I}{R} = a e^{b v_D}$$

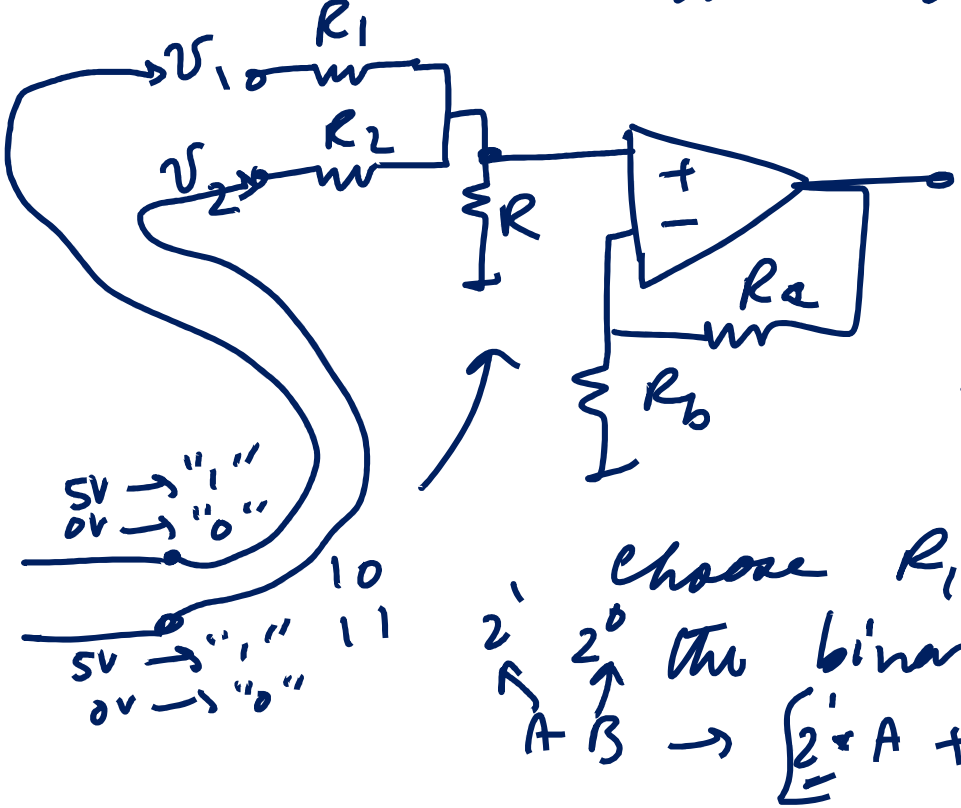
log amp!

$$\frac{v_I}{aR} = e^{b v_D}$$

$$\frac{1}{b} \ln \frac{v_I}{aR} = v_D$$

$$v_o = -\frac{1}{b} \ln \frac{v_I}{aR}$$

Prob 15.6 @ end of chap 15 in textbook



v_o → related to sum of v_1 and v_2

Digital-to-analog converter: DtoA

choose R_1 and R_2 to weight the binary digits appropriately.