Passive sign convention: current enter at ⊕

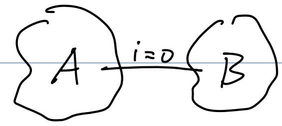
$\Delta q = i\Delta t \qquad p(t) = \frac{dw}{dt} = \frac{dw}{dq}\frac{dq}{dt} = v(t)\,i(t)$

Assumptions 1. Lumped action is instantaneous

2. No ext. fields (E/M)

3. Electrical neutrality

KCL Two parts connected via only 1 wire, $i=0$



E. antenna, not lumped (too long)

Node a region of circuit w/ connections

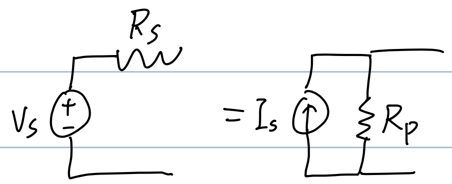
Circuit w/ n nodes → n−1 indep. KCL

1. $\sum_{enter}$ 2. $\sum_{leave}$ 3. $\sum = \sum$

KVL 1. $\sum = 0$ 2. $\sum_1 = \sum_2$

KCL + # KVL = # elements

Ext eq. cir.



with $R_s = R_p$

$i_s = \frac{V_s}{R_s}$

⊗ − 2 v.s. in parallel (eq. short) (if vs =, ∞ slns)

− 2 i.s. in series (~ open) (———————)

Wheatstone bridge: 2 v dividers

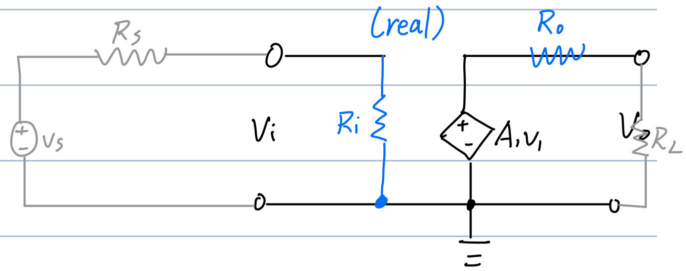
Active circuits – Linear dependent

VCVS	voltage controlled v. source	μV_c	v. gain
VCCS		$g_m V_c$	trans conductance
CCCS		$\beta\, i_c$	i. gain
CCVS		$r_m\, i_c$	trans resistance

if indep. $= 0 \rightarrow$ dep. $= 0$

Voltage amp., linear region & saturation

saturation $\rightarrow$ distortion



$V_I = \frac{R_i}{R_s + R_i} V_s \quad \rightarrow$ Need $R_i >> R_s$

$V_O = \frac{R_L}{R_o + R_L} A_v V_I \quad \rightarrow \sim \quad R_o << R_L$

OpAmp V_o come from $\pm V_{cc}$

$V_o = A\, v_D = A\,(v_P - v_N)$ At linear

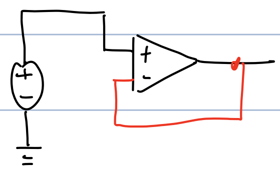
ideal: input $i \rightarrow 0$

$R_o \rightarrow 0$ Negative feedback ensures $V_N = V_I$

$A \rightarrow \infty$

V_o, i_o no limit

buffer

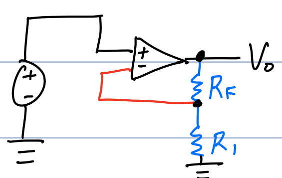


$V_D = V_i - V_o = V_i - A v_D$ neg. feedback

$V_D \approx 0$

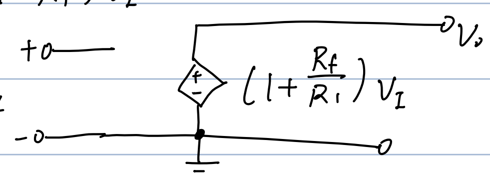
$v_o \approx V_i \quad \left(= \frac{A}{A+1} V_I \right)$

Ni. amp.

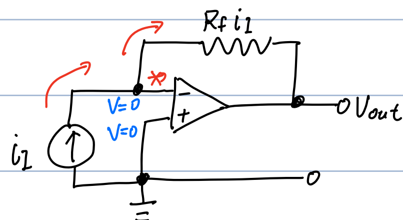


Voltage divider

$V_o = \left(1 + \frac{R_f}{R_1}\right) V_I \rightarrow$ ratio, makes it (E. temp.) indep.

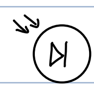


$i \rightarrow v$ converter

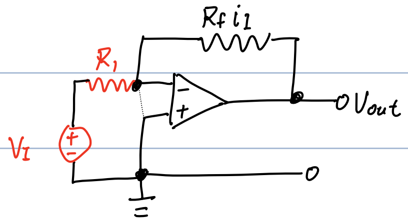


$V_o = -R_f\, i_I$

E. transducer, photodiode

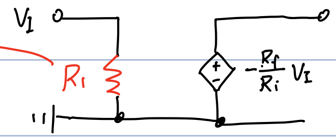


I. amp.



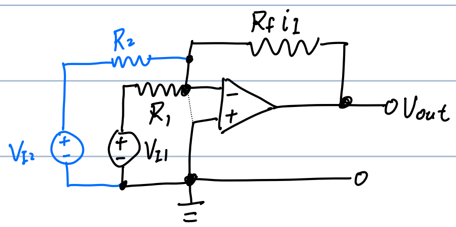
$i_I \to V_I,\ R_1$ $V_o = -\frac{R_f}{R_1} V_I$

problem!



Typically start with ni (buffer)

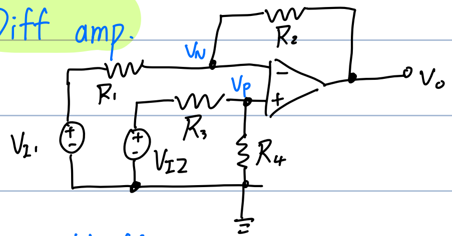
Sum amp.



Combine currents $V_o = -\left(\frac{R_f}{R_1} V_{I1} + \frac{R_f}{R_2} V_{I2}\right)$

Casade   gain X

Diff amp.



KCL $\frac{V_{I1} - V_N}{R_1} = \frac{V_N - V_o}{R_2}$

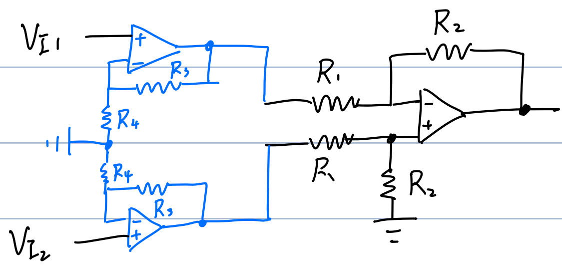
$V_P = V_{I2} \frac{R_4}{R_3 + R_4}$

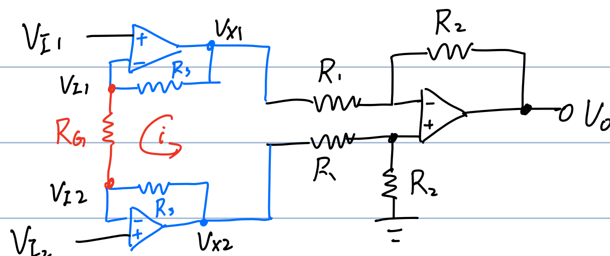
$V_N = V_P$

$R_2\left(V_{I1} - V_{I2}\frac{R_4}{R_3+R_4}\right) = R_1 V_{I2}\frac{R_4}{R_3+R_4} - V_o$

If $\frac{R_3}{R_4} = \frac{R_1}{R_2}$, $V_o = \frac{R_2}{R_1}(V_{I2} - V_{I1})$

w/ buffer:





instrumentation amp.

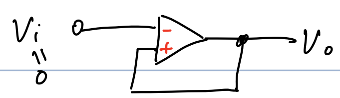
$i = \frac{V_{N1} - V_{N2}}{R_G} = \frac{V_{I1} - V_{I2}}{R_G}$

$V_{x1} - V_{x2} = (R_G + 2R_3)\, i$

$= \left(1 + \frac{2R_3}{R_G}\right)(V_{I1} - V_{I2})$

$V_o = -\frac{R_2}{R_1}\left(1 + \frac{2R_3}{R_G}\right)(V_{I1} - V_{I2})$

Positive feedback



blow up! (until sat.)

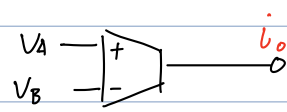
unstable eq.

Comparator

no feedback, saturated, faster

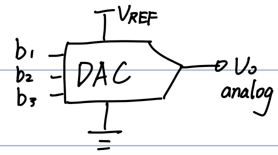
Transconductor

VCCS, $i_o = G_m (V_A - V_B)$



E. transistor, but idealized linear relation

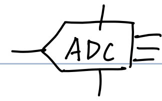
D→A converter (sum amp.), V_o is inverted !



A→D converter compare V_I with diff. refs. (E. 3-bit : 0.5V ~ 6.5V)

0.5 Ω –1Ω– 1.5 Ω

⟹ logic converter → output



Systematic tech.

Node voltage analysis E. circuit w/ ①, ⏦ . Use KCL on every node

E. book p 228,
$$\begin{bmatrix} \frac{1}{R_1}+\frac{1}{R_2} & -\frac{1}{R_2} \\ -\frac{1}{R_2} & \frac{1}{R_2}+\frac{1}{R_3} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} i_{s1} \\ i_{s1}+i_{s2} \end{bmatrix}$$

std. form
$$\underbrace{\begin{bmatrix} G_1+G_2 & -G_2 \\ -G_2 & G_2+G_3 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}}_{\text{unknown node } v} = \underbrace{\begin{bmatrix} i_{s1} \\ i_{s1}+i_{s2} \end{bmatrix}}_{\text{indep. } i. \text{ sources}}$$

$$\underline{G}\,\underline{v} = \underline{i_s}$$

$$\underline{v} \overset{\text{Matlab}}{=} \underline{G}^{-1}\,\underline{i_s}$$

det

Cramer's rule $\Delta \mathrel{\dot{=}} G_1G_2 + G_2G_3 + G_3G_1$

To find v_2, find Δ_2 by replacing 2^{nd} col. of $\underline{G}$ by $\underline{i_s}$ and find det

$$\Delta_2 = \begin{vmatrix} G_1+G_2 & i_{s1} \\ -G_2 & -i_{s1}+i_{s2} \end{vmatrix} \mathrel{\dot{=}} -G_1 i_{s1} + (G_1+G_2)\, i_{s2}$$

$$V_2 = \frac{\Delta_2}{\Delta} = \frac{-G_1}{G_1G_2+G_2G_3+G_3G_1}\, i_{s1} + \frac{G_1+G_2}{G_1G_2+G_2G_3+G_3G_1}\, i_{s2}$$

+ dep. source ◇ 1. VCCS (similar)

2. CCCS write i of interest in terms of node voltages

+ voltage source (don't know i thru ⊕)

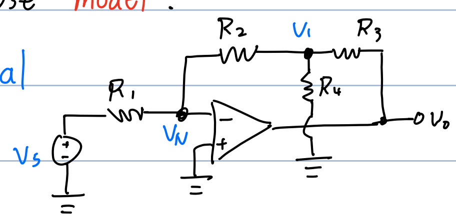
Already gives an eq. relating 2 node V.

Create supernode by finding all i crossing the ⊕ and any ∥ R.

+ dep. voltage source ◇ (same thing)

+ Op Amp Use model !

E. ideal

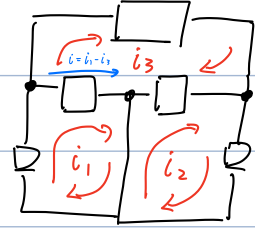


KCL
$$G_1(V_N - V_s) + G_2(V_N - V_1) = 0$$
$$G_2(V_1 - V_N) + G_4 V_1 + G_3(V_1 - V_o) = 0$$

$V_N = 0$ due to negative feedback

$$V_o = -V_s\left(\frac{R_2}{R_1} + \frac{R_3}{R_1} + \frac{R_2}{R_1}\frac{R_3}{R_4}\right)$$

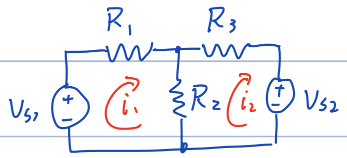
Mesh-current analysis – only valid for planar circuits (no crossing wires)



Mesh: loop w/o any inner loops

Unknown: mesh currents (usually same dir.)

E.



KVL $-V_{s1} + R_1 i_1 + R_2(i_1 - i_2) = 0$

$V_{s2} + R_2(i_2 - i_1) + R_3 i_2 = 0$

$\Rightarrow$

$(R_1 + R_2) i_1 - R_2 i_2 = V_{s1}$

$-R_2 i_1 + (R_2 + R_3) i_2 = V_{s2}$

$\underline{R}\, \underline{i} = \underline{V_s}$

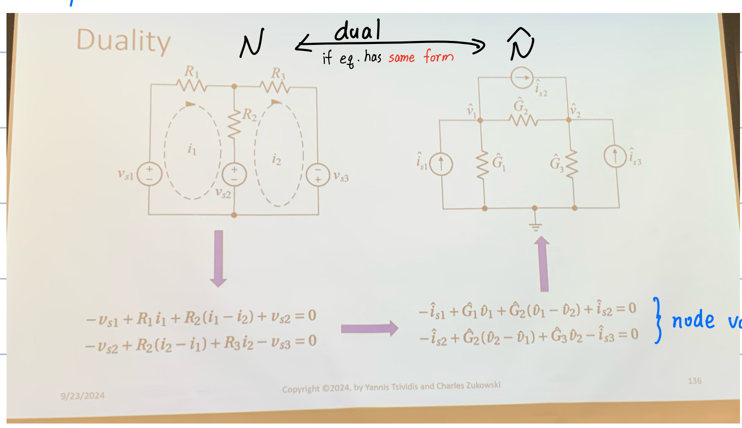
* if see a − in ⊖, put a −, when thru R, use +

+ ⊕, predefine an i branch, create supermesh skipping ⊕

	Node v	Mesh i
		planar only!
good for	parallel	series
solving for	v	i

Always simplify!

Duality node ↔ mesh



} node voltage eqns.

$v \to i$, $R \to G$ (Ω, S), series → parallel

exact dual if same numerical value

Pathological $\Delta = 0$, or overconstrained

put small R is series w/ ⊖, large R ∥ w/ ⊕

Linear circuit prop. & thm.

output, indep. sources (inputs)

$$y = \underbrace{c_1 x_{s_1}}_{\equiv\, y_1} + \cdots + \underbrace{c_k x_{s_k}}_{\equiv\, y_k}$$

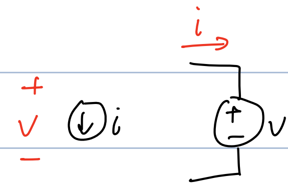
Proportionality & superposition $\quad y_1 + \cdots + y_k$

$$y = \sum^{k} (\text{output w/ only } \overset{\text{indep}}{\text{one source}} \text{ on})$$

Kill: Short (±), open (↑)

Eq. R only R and ◇ $\quad v = R_{eq}\, i$

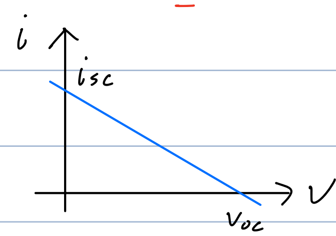
+ indep. sources ○ $\quad$ By conv., i is leaving the + term.



V_{oc} voltage when terminal of interest is open

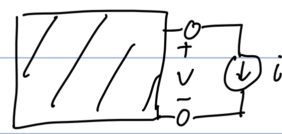
i_{sc} current when terminal is shorted

Two-term $i-v$ char



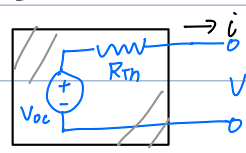
Thévenin $\quad V_{oc}$ series w/ R_{Th} → R_{eq}, killing all indep. sources w/i

Pf. Superpos $\quad$ Drive circuit by i

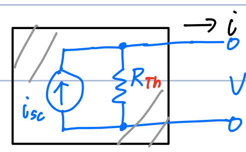


1. ext. source $= 0$, $\quad V = V_{oc}$
2. int. indep.! source $= 0$, $\quad v = R_{Th}(-i)$

1+2 $\quad v = V_{oc} - R_{Th}\, i$



Norton $\quad i_{sc}$ parallel w/ R_{Th}



T vs N $\quad R_{Th} = \dfrac{V_{oc}}{i_{sc}}$