EE101 Lecture 13 Feb 7, 2018

(Op Amps continued)

✓ Midterm Exam on Monday, Feb 12.
(There will be 5 Problems, covering up to chap. 4)
• Ohm's Law, • KCL, • KVL; • nodal & • mesh (loop) analyses, • Thevenin's & Norton's equivalent ckts, • superposition principle, • Requivalent calculation (including Δ–Y, Y–Δ transformation), • Maximum Power Transfer.

✓ Office hour on Monday, Feb 12 cannot be held.

✓ Please come to see me at 4 pm. Feb 7 (today) if you have any question.

✓ On Friday, Feb 9 we will review course materials.

$v_d = v_a - v_b$,

R_i = input resistance, very large

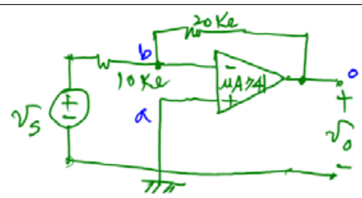
R_o = output resistance, very small

Input resistance $R_{ab} = R_i$

output resistance $R_{eq} = R_o$ with all indep. sources set to zero.

Thus $v_a = v_b = v_d = 0$ (shorted)

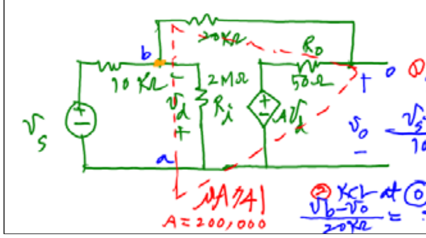
$Av_d = 0$ also



$R_i = 2\,M\Omega$

$R_o = 50\,\Omega$

$A = 200{,}000$



① KCL at node (b)

$$\frac{v_s - v_b}{10\,K\Omega} = \frac{v_b - v_o}{20\,K\Omega} + \frac{v_b}{2\,M\Omega} \quad (1)$$

② KCL at (o)

$$\frac{v_b - v_o}{20\,K\Omega} = \frac{v_o - A(0 - v_b)}{50\,\Omega} \quad (2)$$

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(1) × 2 MΩ → $200(v_s - v_b) = 100(v_b - v_o) + v_b$ (1)′

(2) × 20 KΩ → $v_b - v_o = (v_o + A v_b)\cdot 400$ (2)′

$$\begin{bmatrix} 301 & -100 \\ (400A-1) & 401 \end{bmatrix} \begin{bmatrix} v_b \\ v_o \end{bmatrix} = \begin{bmatrix} 200 v_s \\ 0 \end{bmatrix} \quad \text{where } A = 200{,}000$$

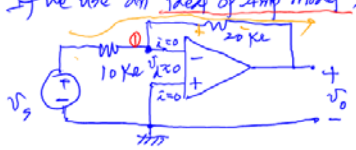
$$v_o = \frac{\begin{vmatrix} 301 & 200 v_s \\ 400A-1 & 0 \end{vmatrix}}{\begin{vmatrix} 301 & -100 \\ 400A-1 & 401 \end{vmatrix}} = \frac{-200 v_s (400A-1)}{301(401) - (-100)(400A-1)}$$

divide both sides by $(400A-1)$

$$= \frac{-2 v_s}{1 + \frac{(301)(401)}{100(400A-1)}} \approx -2 v_s$$

$(-1.9999699\, v_s)$ to be precise

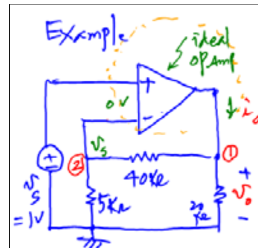
If we use an ideal op Amp model, then



KCL at node ①: $\frac{v_s - 0}{10\,K\Omega} = \frac{0 - v_o}{20\,K\Omega}$

× 20 KΩ → $2 v_s = -v_o$, $v_o = -2 v_s$

Example



Find i_o & v_o

KCL at node ①

$$i_o - \frac{v_o - v_s}{40\,K\Omega} = \frac{v_o}{20\,K\Omega} \quad (1)$$

KCL at node ②

$$\frac{v_s}{5\,K\Omega} + \frac{v_s - v_o}{40\,K\Omega} = 0 \quad (2)$$

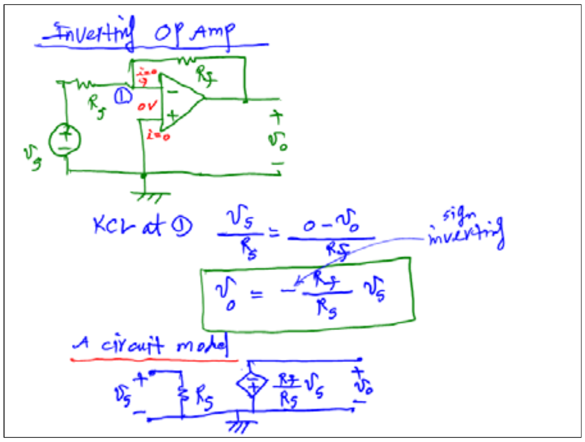
Multiplying 40 KΩ to (2) yields

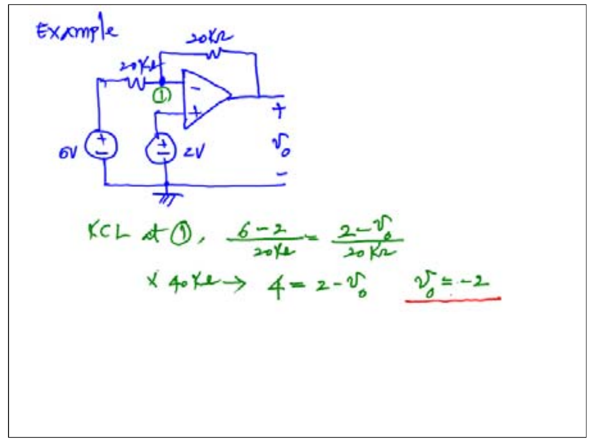
$$8 v_s + v_s - v_o = 0 \quad (2)'$$

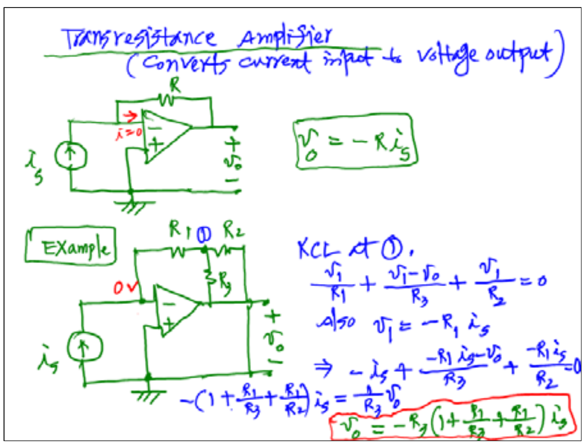
$$\boxed{v_o = 9 v_s} = 9\,V$$

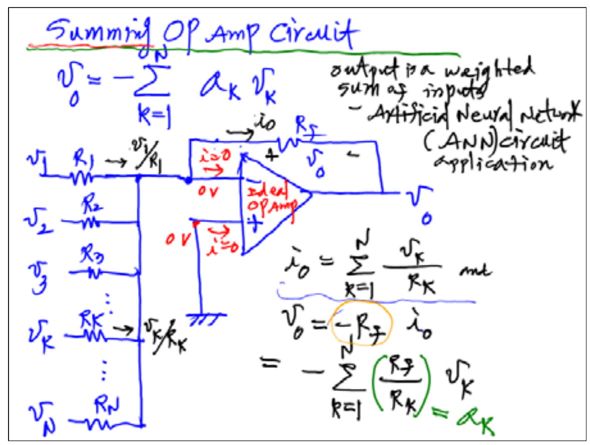
From (1) $i_o = \frac{9 v_s - v_s}{40\,K\Omega} + \frac{9 v_s}{20\,K\Omega}$

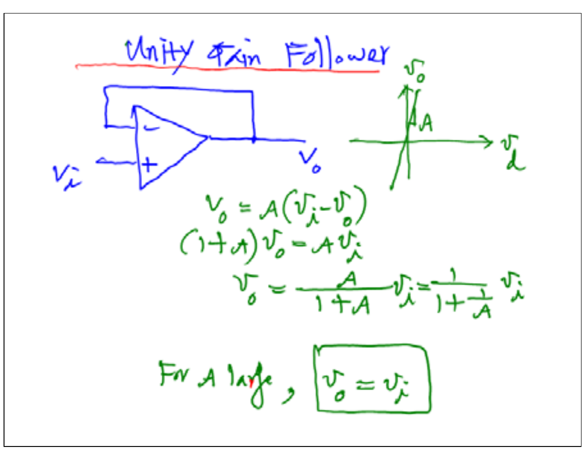
$i_1 = 0.2\,mA + 0.45\,mA = 0.65\,mA$

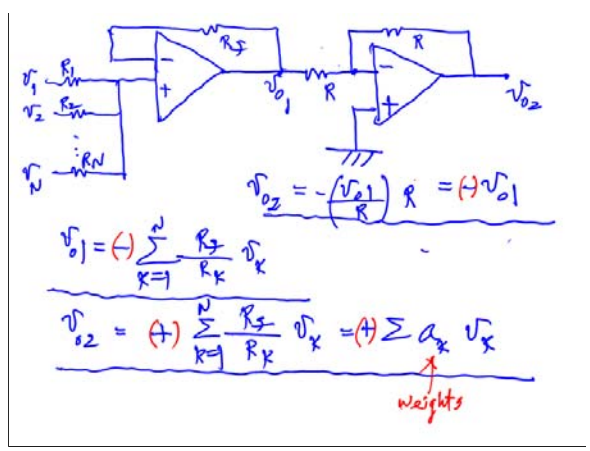

Inverting Op Amp
Rf
Rs
i=0
0V
vs
vo
KCL at ① vs/Rs = (0 − vo)/Rf
sign inverting
vo = −(Rf/Rs) vs
A circuit model
Rs
(Rf/Rs) vs

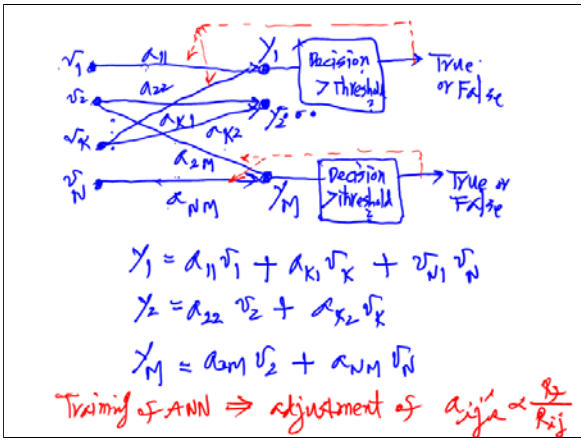

Example
20kΩ
20kΩ
6V
2V
vo
KCL at ①, (6−2)/20kΩ = (2−vo)/20kΩ
× 40kΩ → 4 = 2 − vo   vo = −2

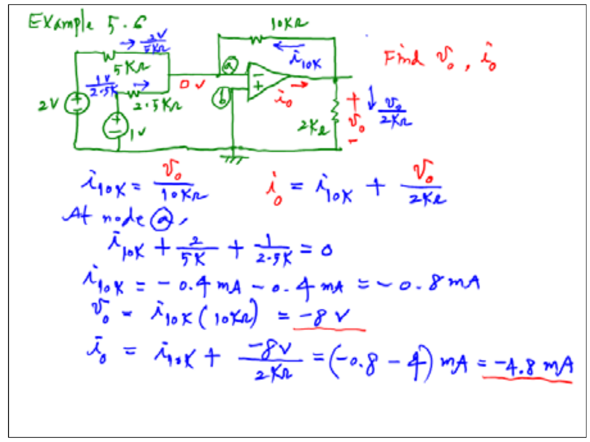

Transresistance Amplifier
(Converts current input to voltage output)
R
i=0
is
vo
vo = −R is
Example
R1 ① R2
R3
0V
KCL at ①,
v1/R1 + (v1−vo)/R3 + v1/R2 = 0
also v1 = −R1 is
⇒ −is + (−R1 is − vo)/R3 + (−R1 is)/R2 = 0
−(1 + R1/R3 + R1/R2) is = (1/R3) vo
vo = −R3(1 + R1/R3 + R1/R2) is


Summing Op Amp Circuit
vo = −Σ_{k=1}^{N} ak vk
output is a weighted sum of inputs
− Artificial Neural Network (ANN) circuit application
v1 R1 → v1/R1
i=0
io Rf
0V
Ideal Op Amp
v2 R2
v3 R3
vk Rk → vk/Rk
vN RN
io = Σ_{k=1}^{N} vk/Rk and
vo = −Rf io
= −Σ_{k=1}^{N} (Rf/Rk) vk
= ak


Unity Gain Follower
vi
vo
vd
A
vo = A(vi − vo)
(1 + A) vo = A vi
vo = A/(1+A) vi = 1/(1 + 1/A) vi
For A large, vo = vi


Rf
R
R
v1 R1
v2 R2
vN RN
vo1
vo2
vo2 = −(vo1/R) R = (−) vo1
vo1 = (−) Σ_{k=1}^{N} (Rf/Rk) vk
vo2 = (+) Σ_{k=1}^{N} (Rf/Rk) vk = (+) Σ ak vk
weights


Decision
> Threshold
True or False
Decision
> threshold
True or False
Y1 = a11 v1 + aK1 vK + vN1 vN
Y2 = a22 v2 + aK2 vK
YM = a2M v2 + aNM vN
Training of ANN ⇒ adjustment of aij's ∝ Rf/Rij


Example 5.6
10KΩ
5KΩ
2.5KΩ
2KΩ
2V
1V
0V
Find vo, io
i10K = vo/10KΩ
io = i10K + vo/2KΩ
At node a,
i10K + 2/5K + 1/2.5K = 0
i10K = −0.4 mA − 0.4 mA = −0.8 mA
vo = i10K (10KΩ) = −8 V
io = i10K + −8V/2KΩ = (−0.8 − 4) mA = −4.8 mA