EE101 Lecture 8, Jan 30, 2019.

Quiz #4 on Feb 5 (T) out of these

[1] prob. 3.58

[2] prob. 3.62

[3] prob. 3.64

[4] prob. 3.68

[5] prob. 3.72

[6] prob. 3.74

[7] prob. 3.77

[8] prob. 3.80

Quiz #3
Avg = 8.82
σ = 2.08

Mesh Analysis

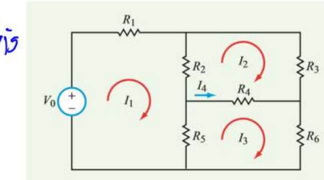


Figure 3-8: Circuit for Example 3-4.

Solution: (a) Applying the symmetry pattern inherent in the structure of the mesh-current equations, we have

$$(R_1 + R_2 + R_5)I_1 - R_2 I_2 - R_5 I_3 = V_0 \quad \text{(mesh 1)}, \quad (3.15a)$$

$$-R_2 I_1 + (R_2 + R_3 + R_4)I_2 - R_4 I_3 = 0 \quad \text{(mesh 2)}, \quad (3.15b)$$

and

$$-R_5 I_1 - R_4 I_2 + (R_4 + R_5 + R_6)I_3 = 0 \quad \text{(mesh 3)}. \quad (3.15c)$$

total resistance in Mesh1

" Mesh2

" Mesh3

negative because I_2, I_3 are in opposite direction w.r.t. I_1

$I_1, I_3 \Leftrightarrow I_2$

$I_1, I_2 \leftrightarrow I_3$

$$\begin{bmatrix} R_1+R_2+R_5 & -R_2 & -R_5 \\ -R_2 & R_2+R_3+R_4 & -R_4 \\ -R_5 & -R_4 & R_4+R_5+R_6 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} V_0 \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 1+2 & -2 & -1 \\ -2 & 2+1+3 & -1 \\ -8 & +8 & 1 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 10 \\ 0 \\ 0 \end{bmatrix}$$

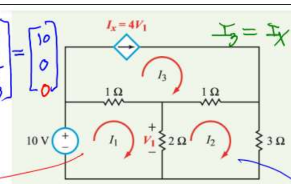


Figure 3-9: Mesh-current solution for a circuit containing a dependent source (Example 3-5).

$I_3 = I_x = 4V_1$

$= 8(I_1 - I_2)$

$V_1 = 2(I_1 - I_2)$

mesh1

$-10 + 1(I_1 - I_3) + 2(I_1 - I_2) = 0$

$-10 + I_1 - 8I_1 + 8I_2 + 2I_1 - 2I_2 = 0$

Mesh2

$2(I_2 - I_1) + 1(I_2 - I_3) + 3I_2 = 0$

$2I_2 - 2I_1 + I_2 - 8I_1 + 8I_2 + 3I_2 = 0$

Hence,

$$I_3 = 4V_1 = 8(I_1 - I_2). \quad (3.17)$$

After inserting Eq. (3.17) into Eqs. (3.16a and b) and collecting terms in I_1 and I_2, we end up with

$$\boxed{\begin{aligned} -5I_1 + 6I_2 &= 10, \\ -10I_1 + 14I_2 &= 0. \end{aligned}}$$

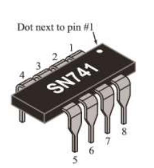
Solution of this pair of simultaneous equations gives

$$I_1 = -14\text{ A}, \qquad I_2 = -10\text{ A}.$$

CHAPTER 4

Operational Amplifiers

Contents



The introduction of the *operational amplifier* chip in the 1960s has led to the development of a wide array of *signal processing circuits*, enabling the creation of an ever-increasing number of *electronic applications*.

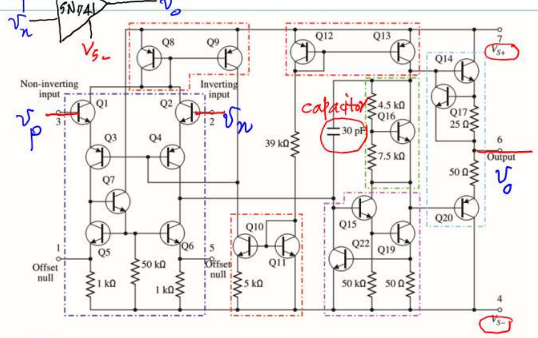


Figure 4-1: The circuit diagram of the Model 741 op amp consists of 20 transistors, several resistors, and one capacitor.

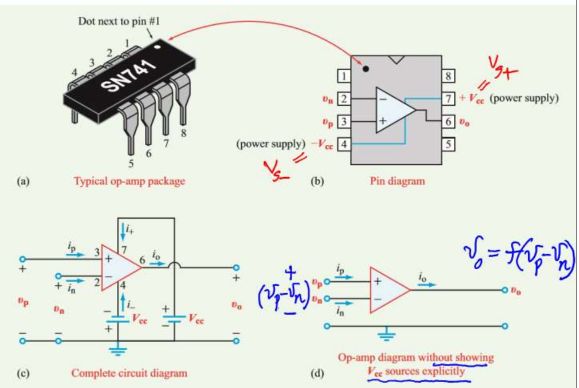


Figure 4-2: Operational amplifier.

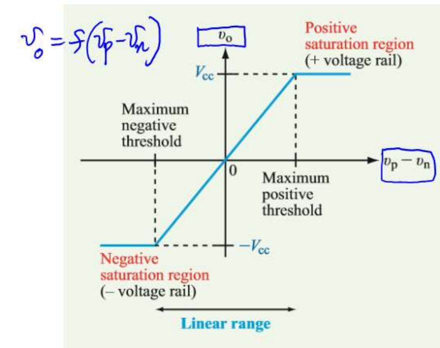


Figure 4-3: Op-amp transfer characteristics. The linear range extends between $v_o = -V_{cc}$ and $+V_{cc}$. The slope of the line is the op-amp gain A

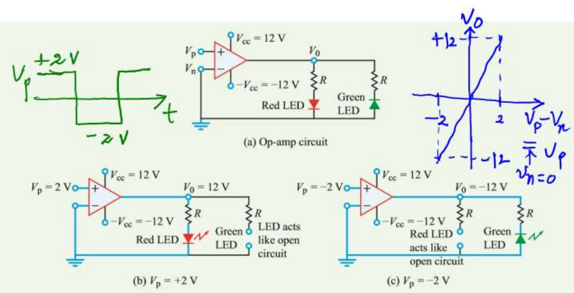


Figure 4-5: Op amp operated as a switch. The $\pm V_{cc}$ flags indicate the dc supply voltages connected to pins 7 and 4.

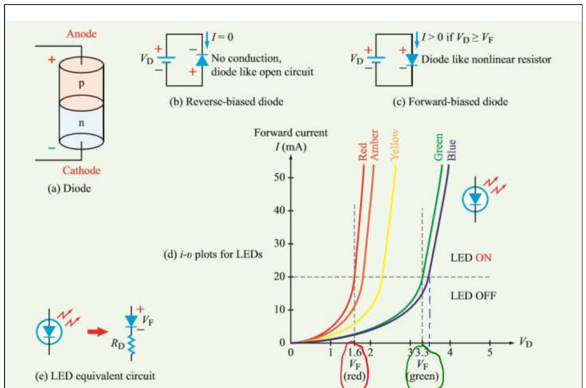
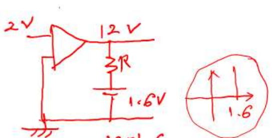


Figure 2-8: p-n junction diode (a) configuration, (b) reverse biased, (c) forward biased, (d) typical i-v plots for LEDs, and (e) LED equivalent circuit.

For Red LED



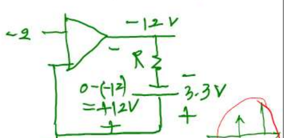
$I_R = \frac{12-1.6}{R}$

$P_{Red LED} = 1.6 \times \left(\frac{12-1.6}{R}\right)$

If $R = 1\,k\Omega$

$P_{Red LED} = 16.64$ mW

For Green LED



$I_R = \frac{12-3.3}{R}$

$P_{Green LED} = 3.3\left(\frac{12-3.3}{R}\right)$

$P_{Green LED} = 28.7$ mW

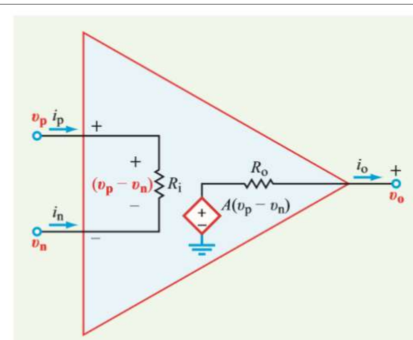


Figure 4-6: Equivalent circuit model for an op amp operating in the linear range ($v_o \le |V_{cc}|$). Voltages v_p, v_n, and v_o are referenced to ground.

Table 4-1: Characteristics and typical ranges of op-amp parameters. The rightmost column represents the values assumed by the ideal op-amp model.

Op-Amp Characteristics	Parameter	Typical Range	Ideal Op Amp
• Linear input-output response	Open-loop gain A	10^4 to 10^8 (V/V)	∞
• High input resistance	Input resistance R_i	10^6 to 10^{13} Ω	∞ Ω
• Low output resistance	Output resistance R_o	1 to 100 Ω	0 Ω
• Very high gain	Supply voltage V_{cc}	5 to 24 V	As specified by manufacturer

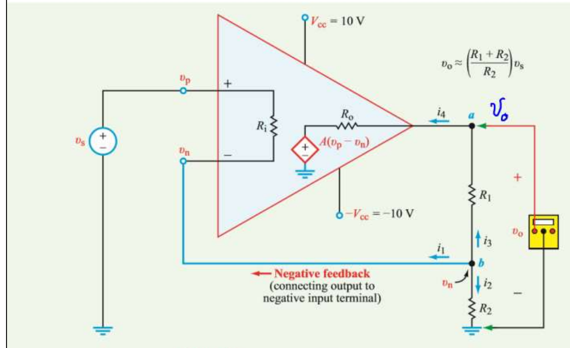
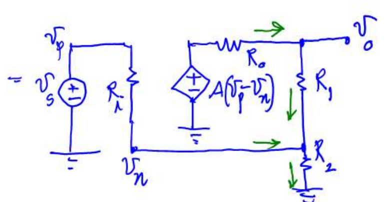


Figure 4-7: Noninverting amplifier circuit of Example 4-1.



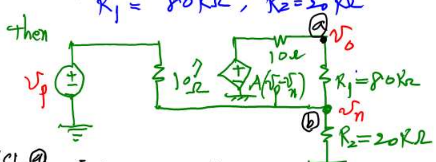
KCL at v_o node : $\dfrac{A(v_s - v_n) - v_o}{R_o} = \dfrac{v_o - v_n}{R_1}$ (1)

" v_n node : $\dfrac{v_o - v_n}{R_1} + \dfrac{v_s - v_n}{R_i} = \dfrac{v_n}{R_2}$ (2)

Solve for v_o . (v_s is the Known voltage source)

For $\begin{cases} R_i = 10^6 \sim 10^{13}\,\Omega, \text{ let's assume } R_i = 10\text{M}\Omega = 10^7\Omega \\ R_o = 1 \sim 100\,\Omega, \quad " \quad R_o = 10\,\Omega \\ A = 10^4 \sim 10^8\,[\text{V/V}], \quad " \quad A = 10^6 \\ R_1 = 80\text{K}\Omega,\ R_2 = 20\text{K}\Omega \end{cases}$

then



KCL ⓐ

$$\frac{10^6(v_s - v_n) - v_o}{10} = \frac{v_o - v_n}{80 \times 10^3} \quad (2)$$

$$\frac{v_o - v_n}{80 \times 10^3} + \frac{v_s - v_n}{10^7} = \frac{v_n}{20 \times 10^3} \quad (3)$$

$(2) \times (8 \times 10^3) \rightarrow 8 \times 10^9 (v_p - v_n) - 8 \times 10^3 v_o = v_o - v_n$

$$8 \times 10^9 v_p = [8 \times 10^9 - 1] v_n + (8 \times 10^3 + 1) v_o \quad (2)'$$

$(3) \times (8 \times 10^7) \rightarrow 10^3 (v_o - v_n) + 8(v_p - v_n) = 4 \times 10^4 v_n$

$$8 v_p = (10^3 + 8 + 4 \times 10^4) v_n - 10^3 v_o \quad (3)'$$

$(2)'$ can be approximated as

$$8 \times 10^9 v_s = 8 \times 10^9 v_n + 8 \times 10^3 v_o \quad (4)$$

$(3)'$ " " $\quad 8 v_s = 41 \times 10^3 v_n - 10^3 v_o \quad (5)$

$(4) + 8 \times (5) \Rightarrow (8 \times 10^9 + 64) v_s = (8 \times 10^9 + 328 \times 10^3) v_n$

$v_n = v_s \left(\dfrac{8 \times 10^9 + 64}{8 \times 10^9 + 328 \times 10^3} \right)$, $v_o = \left(\dfrac{41 \times 10^3 v_n - 8 v_s}{10^3} \right)$

$= 41 v_n - 8 \times 10^{-3} v_s$

$$v_s - v_n = v_s \left(1 - \frac{8 \times 10^9 + 64}{8 \times 10^9 + 328 \times 10^3}\right)$$

$$= v_s \frac{8 \times 10^9 + 328 \times 10^3 - 8 \times 10^9 - 64}{8 \times 10^9 + 328 \times 10^3}$$

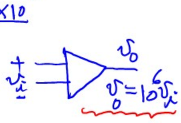
$$= v_s \frac{328 \times 10^3 - 64}{8 \times 10^9 + 328 \times 10^3}$$

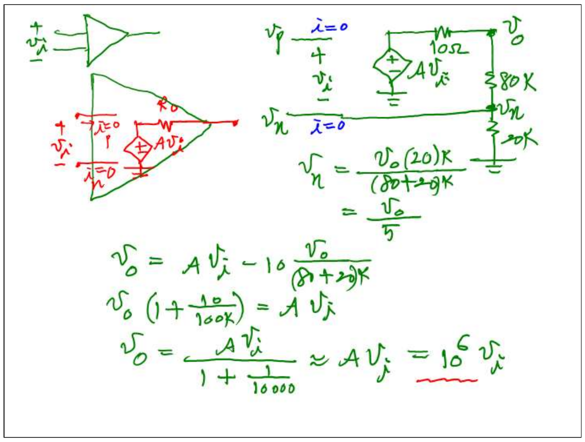
$$v_o = 41 v_n - 8 \times 10^{-3} v_s$$

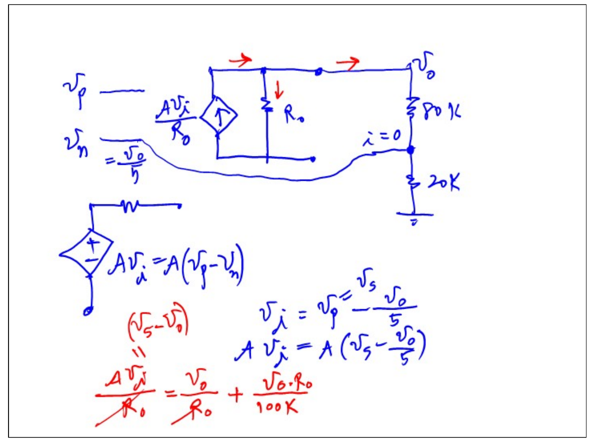
$$= \left(41 \times \frac{8 \times 10^9 + 64}{8 \times 10^9 + 328 \times 10^3} - 8 \times 10^{-3}\right) v_s$$

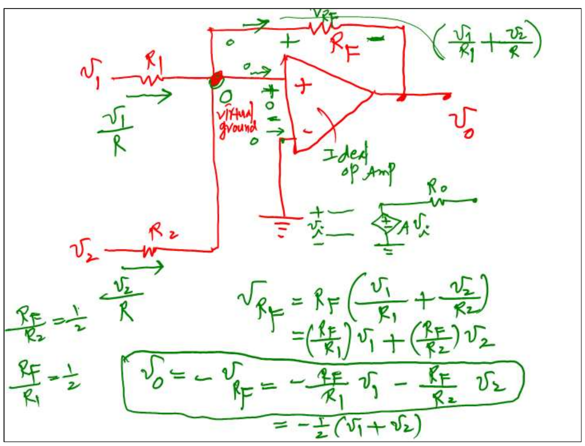
$$\frac{v_o}{v_s - v_n} = \frac{41(8 \times 10^9 + 64) - 8 \times 10^{-3}}{328 \times 10^3 - 64}$$

$$\approx \frac{41 \times 8 \times 10^9}{328 \times 10^3} = 10^6$$




$i=0$
10Ω
$80K$
$20K$
R_o
AV_i
$v_n = \frac{v_o(20)K}{(80+20)K} = \frac{v_o}{5}$
$v_o = Av_i - 10\frac{v_o}{(80+20)K}$
$v_o\left(1+\frac{10}{100K}\right) = Av_i$
$v_o = \frac{Av_i}{1+\frac{1}{10000}} \approx Av_i = 10^6 v_i$


R_o
$80K$
$20K$
$i=0$
$\frac{AV_i}{R_o}$
$= \frac{v_o}{5}$
$AV_i = A(v_p - v_n)$
$v_i = v_p = v_s - \frac{v_o}{5}$
$AV_i = A\left(v_s - \frac{v_o}{5}\right)$
$(v_s - v_o)$
$\frac{AV_i}{R_o} = \frac{v_o}{R_o} + \frac{v_o \cdot R_o}{100K}$


v_1
R_1
v_2
R_2
R_F
v_{R_F}
$\left(\frac{v_1}{R_1} + \frac{v_2}{R}\right)$
virtual ground
Ideal op Amp
v_o
R_o
AV_i
$\frac{v_1}{R}$
$\frac{v_2}{R}$
$\frac{R_F}{R_2} = \frac{1}{2}$
$\frac{R_F}{R_1} = \frac{1}{2}$
$v_{R_F} = R_F\left(\frac{v_1}{R_1} + \frac{v_2}{R_2}\right) = \left(\frac{R_F}{R_1}\right)v_1 + \left(\frac{R_F}{R_2}\right)v_2$
$v_o = -v_{R_F} = -\frac{R_F}{R_1}v_1 - \frac{R_F}{R_2}v_2$
$= -\frac{1}{2}(v_1 + v_2)$