OPERATIONAL AMPLIFIER

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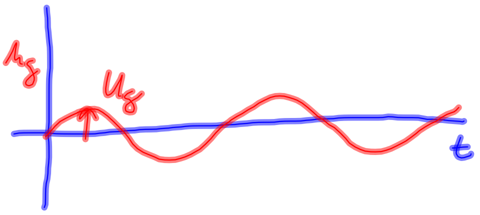
u_g ... INPUT VOLTAGE [V]

u_o ... OUTPUT VOLTAGE [V]

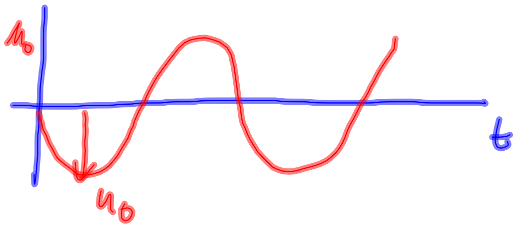
$u_o = -A \cdot u_g$

A ... GAIN

(-A) ... CHANGE POLARITY



$u_g = U_g \sin(\omega t)$



$u_o = -AU_g \sin(\omega t$

ABSOLUTE VALUE

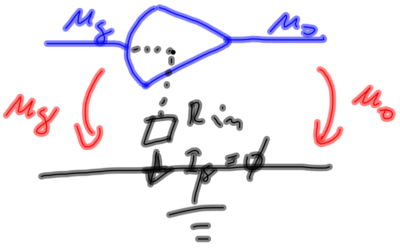
$$\text{GAIN} = \left|\frac{U_o}{U_g}\right| = A$$

IDEAL PROPERTIES

$A = \infty$

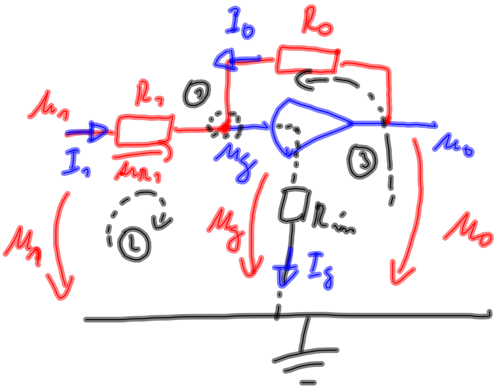
$R_{in} = \infty$ [Ω]

$R_{out} = 0$ [Ω]



$A \to -\infty$ ... ONLY THEORETICAL

PRACTICAL APPLICATION WITH RESISTORS



QUESTION: $\boxed{u_0 = f(u_1)}$??

I. KIR. LAW

① $I_1 + I_0 - I_g = 0$

II. KIRCH. LAW

② $R_1 I_1 + u_g - u_1 = 0$

$$\boxed{I_1 = \frac{u_1 - u_g}{R_1}}$$

③ $R_0 I_0 + u_g - u_0 = 0$

$$\boxed{I_0 = \frac{u_0 - u_g}{R_0}}$$

$$\boxed{I_g = \frac{u_g}{R_{in}}}$$

$u_g = ??$

PROPERTY OF OPER. AMPLIF.

$u_0 = -A \cdot u_g$

$$u_g = \frac{u_0}{-A} \approx \frac{u_0}{\infty} = 0$$

$A \leftarrow \infty$

$\boxed{u_g = 0}$!!

NOTE: $I_g = \frac{u_g}{R_{in}} = \frac{0}{\infty} = 0$

"VIRTUAL ZERO"

$$\frac{u_1 - \cancel{u_g}^{=0}}{R_1} + \frac{u_0 - \cancel{u_g}^{=0}}{R_0} - \frac{\cancel{u_g}^{=0}}{R_{in}} = 0$$

$$\frac{u_1}{R_1} + \frac{u_0}{R_0} = 0$$

$$\boxed{u_0 = -u_1 \cdot \frac{R_0}{R_1}}$$

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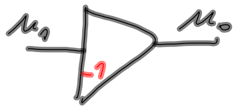
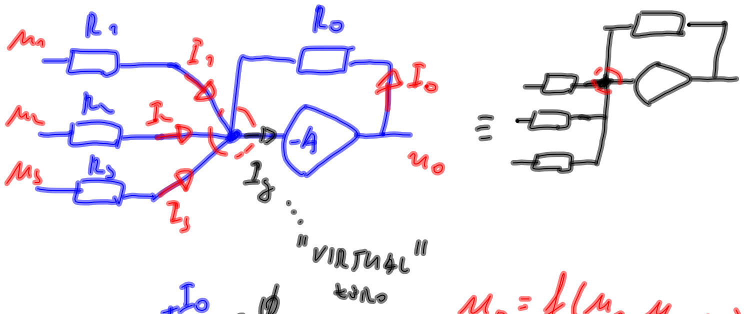
1) INVERTER $(R_0 = R_1)$



$$\boxed{u_0 = -u_1}$$

2) INVERTING SUMMER



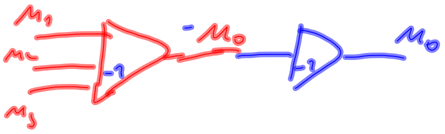
$u_0 = f(u_1, u_2, u_3)$?

$$I_1 + I_2 + I_3 - I_g = 0 \quad (+I_0,\; I_g = 0)$$

$$\frac{u_1}{R_1} + \frac{u_2}{R_2} + \frac{u_3}{R_3}^{\,-0} + \frac{u_0}{R_0} = 0$$

$$u_0 = \underbrace{(-)}_{\text{INVERTING}}\underbrace{\left(\frac{R_0}{R_1}u_1 + \frac{R_0}{R_2}u_2 + \frac{R_0}{R_3}u_3\right)}_{\text{SUMMER}}$$

SPECIAL CASE $(R_0 = R_1 = R_2 = R_3)$ SUMMER



$$u_0 = u_1 + u_2 + u_3$$

→ WHAT HAPPENS IF:

$R_1 = 2R_0$ AND $u_1 = u_2 = u_3 = \dots = u_i$

$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \parallel$

$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad U_{REF}$

$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ E.G. $-1V$

$R_2 = 4R_0$

$R_3 = 8R_0$

$\vdots$

$R_i = 2^i R_0$

... THEN

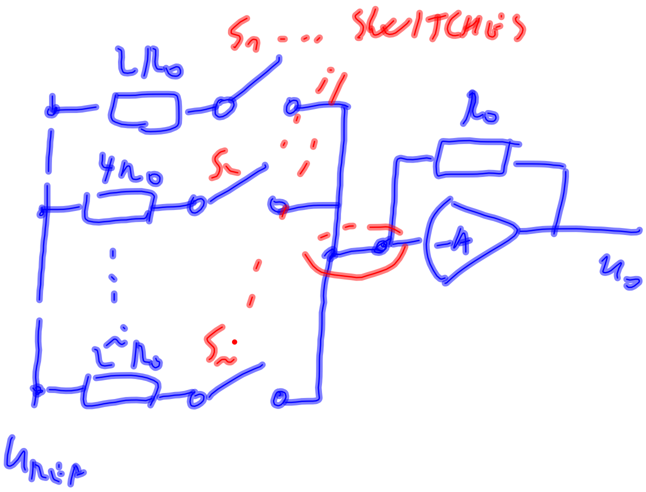
$$u_0 = -\left(\frac{R_0}{2R_0}\underset{\substack{\downarrow \\ -1V}}{U_{REF}} + \frac{R_0}{4R_0} U_{REF} + \dots\right)$$

$$u_0 = +\left(\underset{\substack{\parallel \\ 2^{-1}}}{\frac{1}{2}} + \underset{\substack{\parallel \\ 2^{-2}}}{\frac{1}{4}} + \underset{\substack{\parallel \\ 2^{-3}}}{\frac{1}{8}} + \dots + \underset{\substack{\parallel \\ 2^{-i}}}{\frac{1}{2^i}}\right)$$

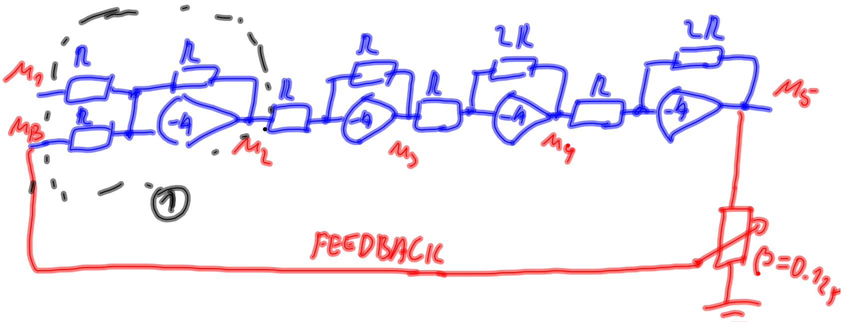
BINARY REPRESENTATION OF "NORMALIZED" NUMBER (< 1)

$$\begin{matrix} & & & 2^{-3} & 2^{-4} & \\ & & & \nearrow & \nearrow & \\ 0. & 1 & 0 & 1 & 1 & 0 \\ & \swarrow & \searrow & & & \\ & 2^{-1} & 2^{-2} & & & \end{matrix}$$

⇒ USAGE IN D/A, A/D CONVERTERS



EX ANALYZE CIRCUIT WITH O.A.



$A = -\infty$, $\beta = 0.125$, $u_1 = 0.3V$, $R = \cancel{1000\Omega}$ NOT NEEDED

$u_\beta = \beta \cdot u_5$

→ COMPUTE $\boxed{u_5 = f(u_1)}$!!

$$u_2 = -\left(u_1 \frac{\cancel{R}}{\cancel{R}} + \overset{\beta \cdot u_5}{\overset{\parallel}{u_\beta}} \frac{\cancel{R}}{\cancel{R}}\right)$$ ... ① INVERTING SUMMER

$$u_3 = -u_2 \frac{\cancel{R}}{\cancel{R}}$$ ... INVERTER

$$u_4 = -u_3 \frac{2\cancel{R}}{\cancel{R}}$$ ... AMPLIFIERS

$$u_5 = -u_4 \frac{2\cancel{R}}{\cancel{R}}$$

SUBSTITUTE : $u_3 = -u_2 = u_1 + \beta u_5$

$$u_4 = -2u_3 = -2(u_1 + \beta u_5)$$

$$\underline{u_5} = -2u_4 = -2(-2(u_1 + \beta u_5)) =$$

$$= 4u_1 + 4\beta \underline{u_5}$$

$$u_5 = \frac{4}{1 - 4\underbrace{\beta}_{=0.125}} \cdot u_1 = \underline{\underline{8u_1}}$$

NOTE: $\beta \neq \frac{1}{4}$

SUMMARIZE LECLE

→ SOLUTION OF "LINEAR" CIRCUITS

R, L, C ← (AC / DC)

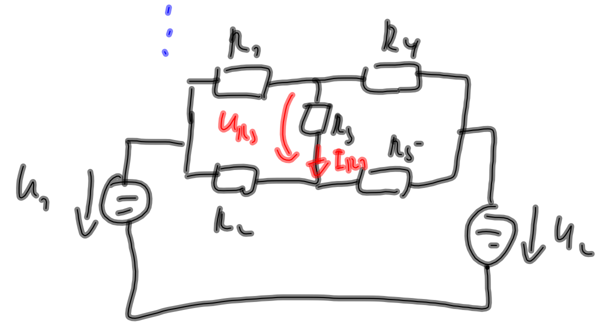
↓

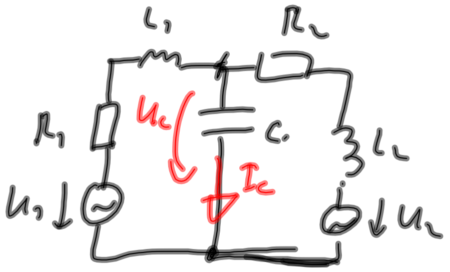
STEADY STATE

COMPLEX NUMBERS

- METHOD OF SIMPLIFIC.
- LOOP CURRENT METHOD
- NODE VOLTAGE METHOD
- THEVENIN'S THEOREM

⋮





THEVENIN'S THEOREM

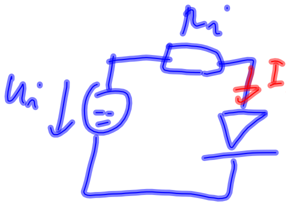
→ SOLUTION OF "NON-LINEAR" EL. CIRC.

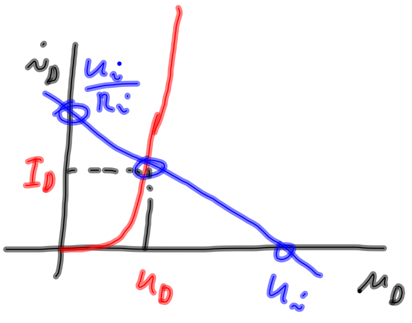
(GRAPHICAL SOLUTION)

DIODES, TRANSISTORS → GAIN

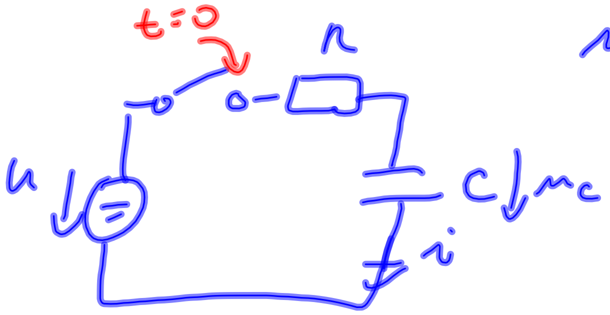
PN JUNCTIONS

THEVENIN'S THEOREM





→ TRANSIENT STATES IN RLC CIRCUITS (DIFFERENTIAL EQUATIONS)



$$u_c' = \frac{i}{C} \quad , u_c(0) = u_{c0}$$

$$i = \frac{u_R}{R}$$

$$u_R + u_c - u = 0$$

$$\underline{\underline{f(u_c', u_c)}} = ?$$

u_c is well known

u_c'

$\underline{\underline{C}} = ?$

→ + OPERATIONAL AMPLIFIERS