LECTURES 1, 2 & 3 — LUMPED CIRCUIT ANALYSIS METHODS.

Method 1: Kirchhoff Laws

KVL $\sum_j v_j = 0$

KCL $\sum_j i_j = 0$

Method 2: Element combination rules

SERIES: $R = \sum_j R_j$ $\quad V = \sum_j V_j$

PARALLEL: $G = \sum_j G_j$ $\quad I = \sum_j I_j$

Method 3: Node Analysis

1: select ground
2: label other nodes
3: Write KCL for 2:
4: solve for node v
5: solve for branches i

Method 4: Superposition

1: Find responses for each source alone (other sources V = SHORT, I = OPEN)
2: Sum individual responses

Method 5: Thèvenin & Norton

$V_{TH} = v$ measured in OPEN circuit

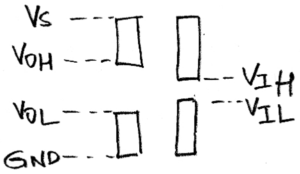
$I_{NO} = i$ measured in SHORT circuit

$R_{TH} = R_{NO} = r$ measured with all sources OUT

(1 to 5 applied to linear circuits, 1 to 3 applied to any circuit)

LECTURE 4 — THE DIGITAL ABSTRACTION

STATIC DISCIPLINE

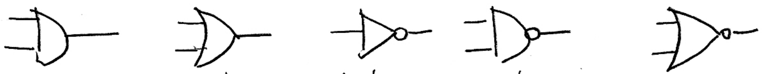


HIGH NOISE MARGIN $V_{OH} - V_{IH}$

LOW NOISE MARGIN $V_{IL} - V_{OL}$

FORBIDDEN REGION $V_{IH} - V_{IL}$

BOOLEAN LOGIC



A	B	AND
0	0	0
0	1	0
1	0	0
1	1	1

A	B	OR
0	0	0
0	1	1
1	0	1
1	1	1

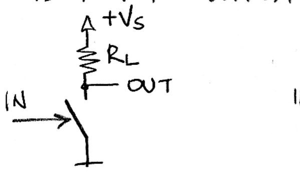
A	NOT
0	1
1	0

A	B	NAND
0	0	1
0	1	1
1	0	1
1	1	0

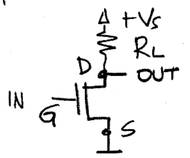
A	B	NOR
0	0	1
0	1	0
1	0	0
1	1	0

LECTURE 5 — INSIDE THE DIGITAL GATE

ABSTRACT SWITCH

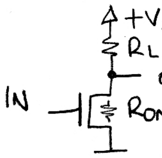


MOSFET S-MODEL



IN	OUT
$\geq V_T$	0
$< V_T$	V_S

MOSFET SR-MODEL (for digital applications)



IN	OUT
$\geq V_T$	$V_S \cdot R_{ON}/(R_L + R_{ON})$
$< V_T$	V_S

$V_T > V_{IL}$

$V_S \dfrac{R_{ON}}{R_L + R_{ON}} < V_{OL}$

LECTURE 6 & 7 — NON-LINEAR ANALYSIS & CIRCUITS

Method 1: Analytical — solve equations

Method 2: Graphical — Draw equations

Method 3: Piecewise linear — Aproximate with linear eq.

Incremental Analysis

$$i_D = f(V_D) + \left.\frac{df(v_D)}{dv_D}\right|_{v_D = V_D} \cdot \Delta v_D + \ldots \text{ neglect}$$

$$G = \left. df/dv_D \right|_{v_D = V_D}$$

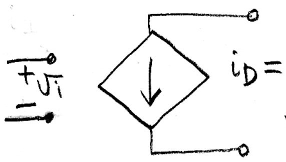
BIAS POINT

Small circuit method:

1. find BIAS point
2. Develop linearized circuit
3. Solve linear circuit

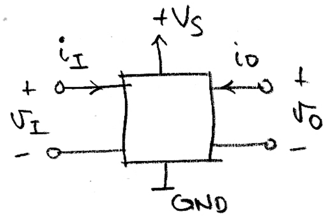
Topology remains. Small signal element equivalence

LECTURE 8 — DEPENDENT SOURCES & AMPLIFIERS



Superposition method for dependent sources

- Leave all dependent sources
- Solve for one independent source at time

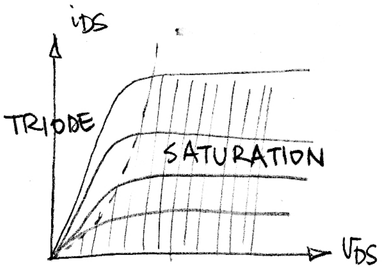


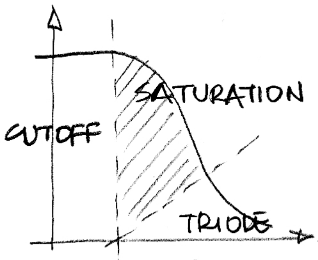
$$\frac{\Delta v_O}{\Delta v_I} > 1 \Rightarrow \text{Amplification}$$

LECTURES 9, 10 & 11

MOSFET SCS MODEL & SATURATION

Saturation discipline (analog designs)



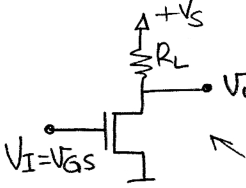


$v_{GS} > V_T$

$v_{DS} \geq v_{GS} - V_T$

$$i_{DS} = \frac{K}{2}(v_{GS} - V_T)^2$$

SMALL SIGNAL



$$\left.\begin{aligned} v_O &= V_S - i_D \cdot R_L \\ i_D &= \frac{K}{2}(v_I - V_T) \end{aligned}\right\}$$

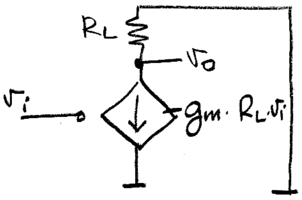
valid ONLY for this topology

capital O for BIAS

$$V_O = V_S - \frac{K}{2}(v_I - V_T)^2 \cdot R_L$$

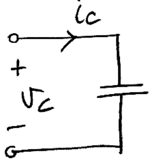
$$v_o = -K(V_I - V_T) \cdot R_L \cdot v_i$$

g_m transconductance



LECTURES 12 & 13

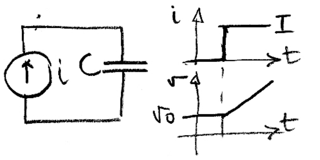
CAPACITORS, INDUCTORS & FIRST ORDER CIRCUIT



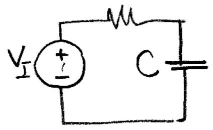
$$i = C \cdot \frac{dv}{dt}$$

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

CURRENT SOURCE

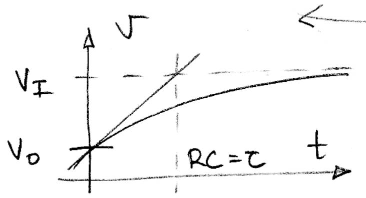


VOLTAGE SOURCE & RESISTOR



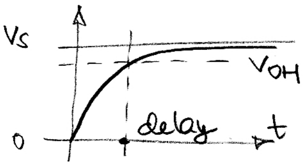
$$\frac{v_C - V_I}{R} + C\frac{dv_C}{dt} = 0$$

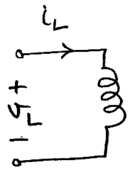
$$RC\frac{dv_C}{dt} + v_C = V_I$$



$$v(t) = V_0 e^{-t/RC} + V_I\left(1 - e^{-t/RC}\right)$$

V_S

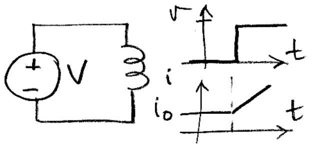




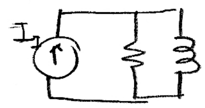
$$v_L = L\frac{di}{dt}$$

$$i = \frac{1}{L}\int_{-\infty}^{t} v\,dt$$

VOLTAGE SOURCE

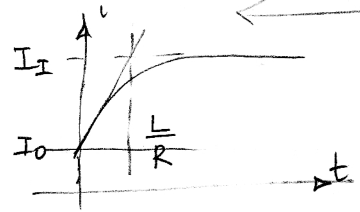


CURRENT SOURCE & RESISTOR



$$-I + \frac{v}{R} + i = 0$$

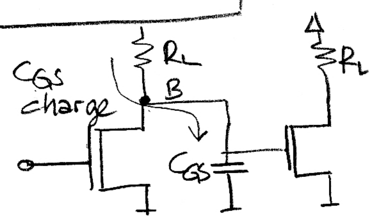
$$\frac{L}{R}\frac{di_L}{dt} + i_L = I_I$$

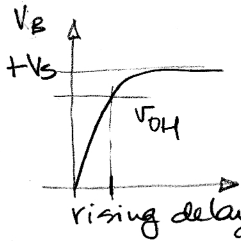


$$i(t) = I_0 e^{-Rt/L} + I_I\left(1 - e^{-Rt/L}\right)$$

LECTURE 14

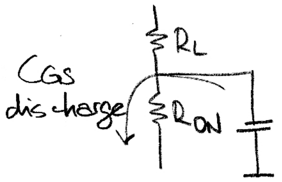
SPEED OF DIGITAL CIRCUITS

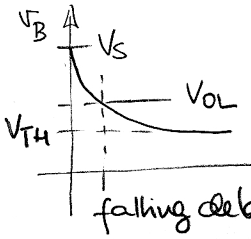




rising delay t_R

$$v_B = V_S\left(1 - e^{-t/R_L C_{GS}}\right)\Big|_{t=t_R} = V_{OH}$$





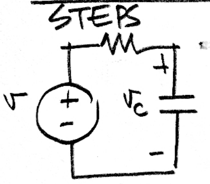
falling delay t_F

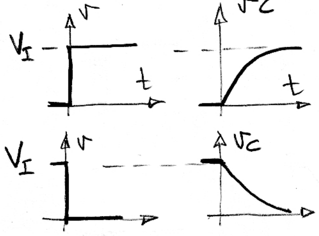
$$V_B = V_{TH} + (V_S - V_{TH}) \cdot e^{-t/R_{TH}C_{GS}}\Big|_{t=t_F}$$

$$V_{TH} = \frac{V_S R_{ON}}{R_L + R_{ON}} \qquad R_{TH} = \frac{R_L R_{ON}}{R_L + R_{ON}}$$

LECTURE 15 — RAMPS, STEPS & IMPULSES

STEPS

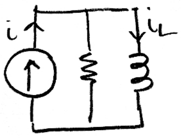


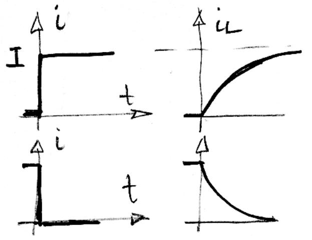


$V_I(1-e^{-t/RC})$

$V_I e^{-t/RC}$

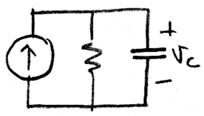
$\tau = RC$

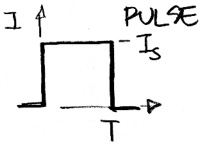




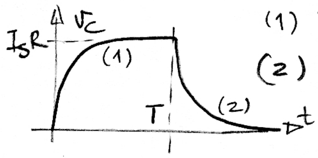
$I(1-e^{-tR/L})$

$I e^{-tR/L}$ $\quad \tau = \frac{L}{R}$





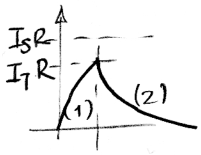
LONG $T \gg RC$



(1) $I_S R(1-e^{-t/RC})$

(2) $I_S R e^{-(t-T)/RC}$

SHORT

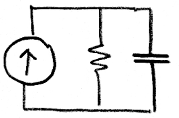


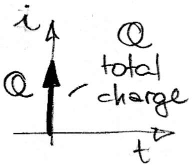
(1) $I_S R(1-e^{-t/R_C})$

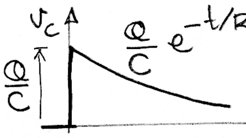
(2) $I_T R e^{-(t-T)/RC}$

$I_T = I_S R(1-e^{-T/RC})$

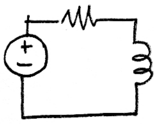
IMPULSES

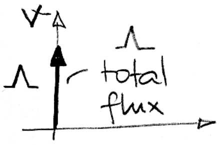


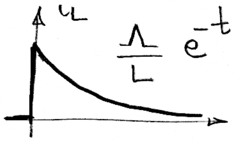




$\frac{Q}{C} e^{-t/RC}$

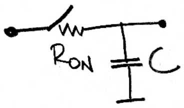


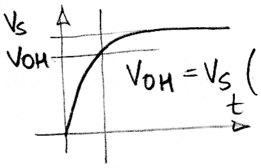




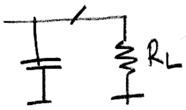
$\frac{\Lambda}{L} e^{-tR/L}$

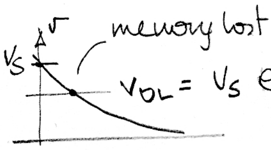
LECTURE 16 — STATE & MEMORY





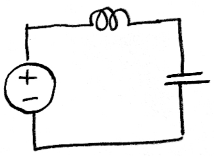
$V_{OH} = V_S(1-e^{-t/R_{ON}C})$





$V_{OL} = V_S e^{-t/R_L C}$

LECTURE 17 & 18 — SECOND ORDER SYSTEMS



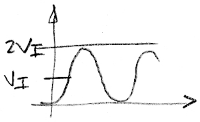
UNDAMPED

$v_C = v_H + v_P \quad \begin{cases} v_p = V_I \\ v_H = A_1 e^{j\omega_0 t} + A_2 e^{-j\omega_0 t} \end{cases}$

ZSR

$v(t) = V_I - V_I \cos\omega_0 t$

$i(t) = V_I C\omega_0 \operatorname{sen} \omega_0 t$



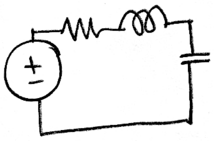
UNDAMPED ZIR $\quad v(0) = V \quad i(0) = 0$

$v(t) = V\cos\omega_0 t \qquad i(t) = -CV\omega_0 \operatorname{sen}\omega_0 t$

ENERGY

$E = \frac{1}{2}Cv^2 + \frac{1}{2}Li^2 = \text{CONSTANT}$

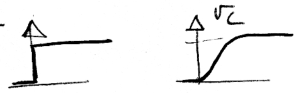
SERIES RLC

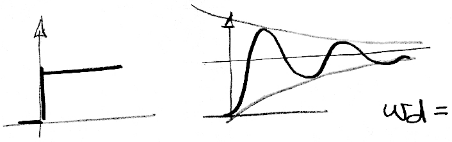


DAMPED

$s^2 + \frac{R}{L}s + \frac{1}{LC} = 0 \qquad s^2 + 2\alpha s + \omega_0^2 = 0 \qquad \omega_0 = \sqrt{\frac{1}{LC}} \qquad \alpha = \frac{R}{2L}$

- overdamped $\alpha > \omega_0$
- Underdamped $\alpha < \omega_0$



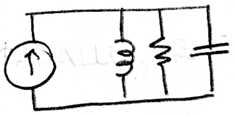


$V_I + A e^{-\alpha t}\cos(\omega_d t + \phi)$

$\omega_d = \sqrt{\omega_0^2 - \alpha^2} \qquad A = V_I \frac{\omega_0}{\omega_d}$

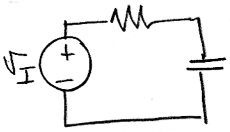
$\phi = -\arctan\frac{\alpha}{\omega_d}$

PARALLEL RLC



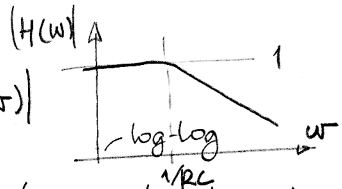
$\alpha = \frac{1}{2RC} \qquad \omega_0 = \sqrt{\frac{1}{LC}}$

LECTURE 19 — SINUSOIDAL STEADY STATE



$v_I = \begin{cases} V_I\cos\omega t & t \geq 0 \\ 0 & t < 0 \end{cases}$

$|V_p| = |V_i| \cdot |H(\omega)|$

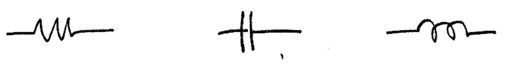


$v_C = v_p + \cancel{v_H} = v_p = \frac{V_i}{\sqrt{1+\omega^2R^2C^2}}\cos(\omega t + \phi) \qquad \phi = -\arctan(\omega RC) = \angle H(\omega)$

$\to 0$ steady state

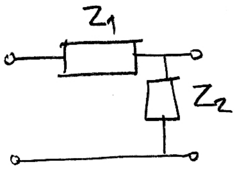
LECTURE 20 — THE IMPEDANCE MODEL

1. Replace sources by complex amplitudes
2. Replace elements by impedances
3. Solve circuit
4. Obtain time domain variables



$Z_R = R \qquad Z_C = \frac{-j}{\omega C} \qquad Z_L = j\omega L$

LECTURE 21 & 22 — FILTERS, TIME DOMAIN & FREQUENCY DOMAIN

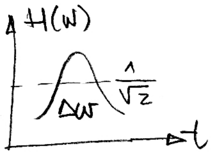


$H(\omega) = \frac{Z_2}{Z_1 + Z_2}$

Second order filters

$$\frac{\text{Numerator}}{s^2 + 2\alpha s + \omega_0^2}$$

$Q = \frac{\omega_0}{2\alpha}$ quality factor



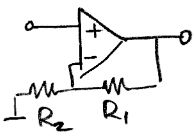
selectivity

$Q = \frac{\omega_0}{\Delta\omega}$ bandwidth

(number of rings for a step input

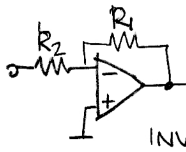
LECTURES 23, 24 & 25 — OPERATIONAL AMPLIFIER

Negative feedback: virtual short / virtual ground



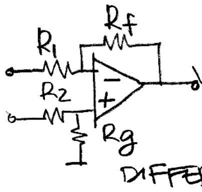
$\frac{v_0}{v_i} = \frac{R_1 + R_2}{R_1}$

NON-INVERTING AMPLIFIER



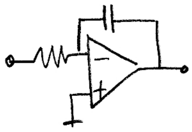
$\frac{v_0}{v_i} = -\frac{R_1}{R_2}$

INVERTING AMPLIFIER



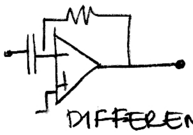
$v_0 = \frac{R_f + R_1}{R_g + R_2} \frac{R_g}{R_1} v_2 - \frac{R_f}{R_1} v_1$

DIFFERENTIAL AMPLIFIER



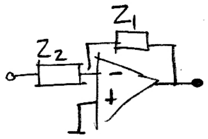
$v_0 = -\frac{1}{RC} \int v_{in}\,dt$

INTEGRATOR



$v_0 = -RC \frac{dv_{in}}{dt}$

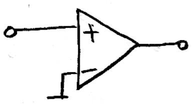
DIFFERENCIATOR

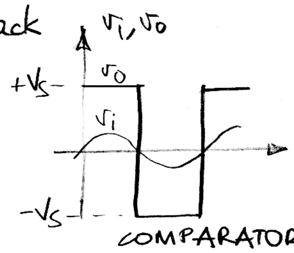


IMPEDANCE $\frac{v_0}{v_i} = -\frac{Z_1}{Z_2}$

diode $i = ae^{bv}$

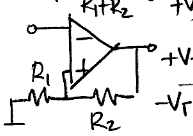
Positive feedback

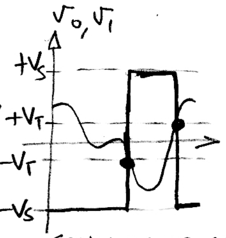




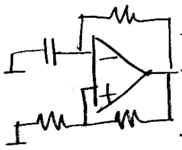
COMPARATOR

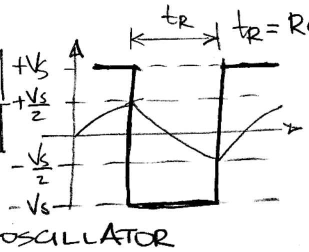
$V_T = \frac{R_1}{R_1 + R_2} V_s$





SCHMIDT-TRIGGER





$t_R = RC\ln 3$

OSCILLATOR

LECTURES 26 — ENERGY & POWER

$$\bar{P} = \frac{V_s^2}{2R_L} + CV_s^2 \cdot f$$

$\frac{V_s^2}{2R_L}$ → STATIC POWER

$CV_s^2 \cdot f$ → DYNAMIC POWER