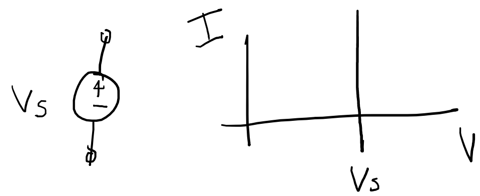
6-23, Lecture 2: 16 Review and Transistors

Tuesday, June 23, 2020 10:44 AM

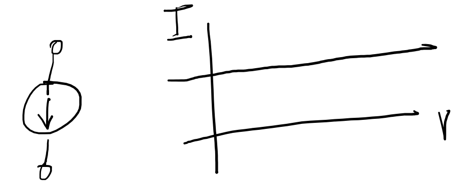
(useful eqns in green box)
(vocab underlined in blue)
(edits after class from OH & chat questions in purple)

16A Review

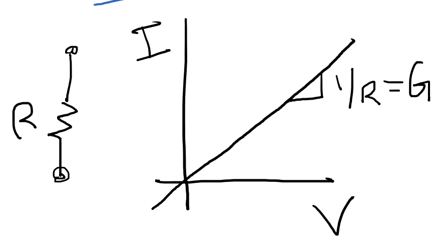
Voltage



Current



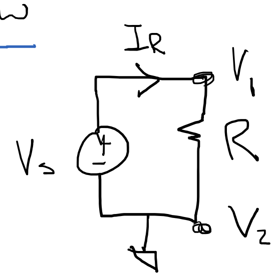
Resistor



Ohm's Law

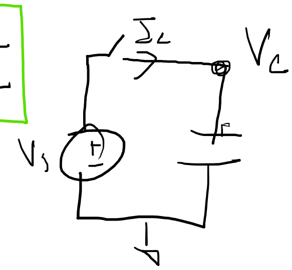
$$\boxed{V_R = I_R R}$$

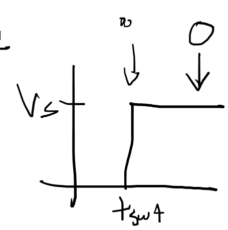
$V_R = V_1 - \cancel{V_2}^{\to 0}$



Capacitor

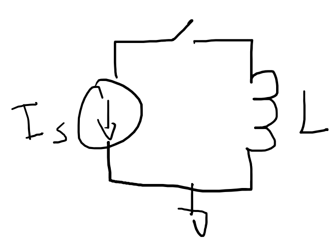
$$\boxed{\frac{dV}{dt} C = I}$$

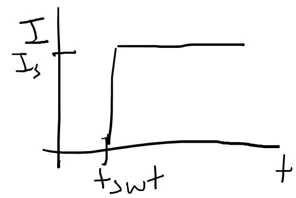




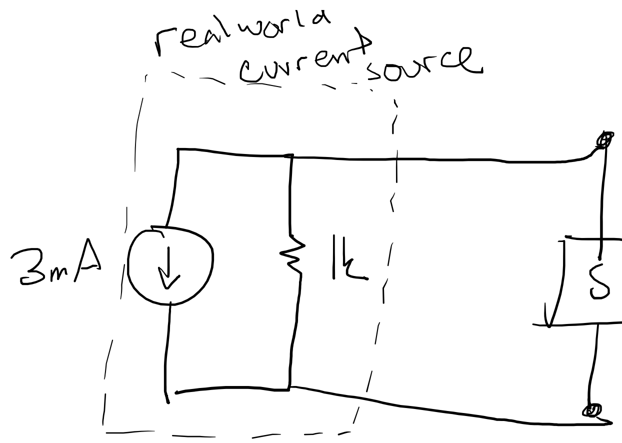
Inductor

$$\boxed{\frac{dI}{dt} L = V}$$

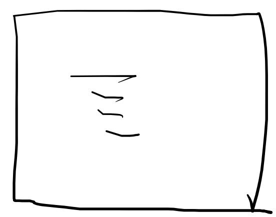




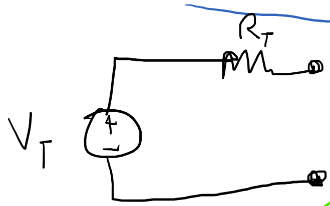
real world current source



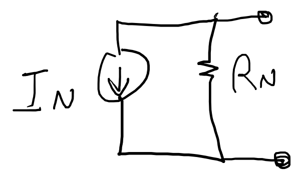
Data sheet



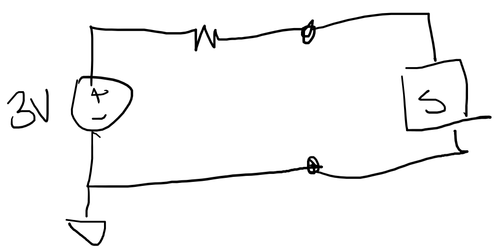
Thevenin

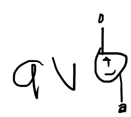


Norton

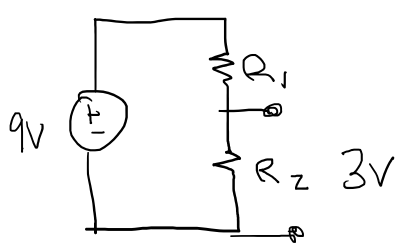


$$\boxed{\begin{gathered} R_T = R_N \\ V_T = R_{T/N} I_N \end{gathered}}$$





Voltage Divider



$$\boxed{V_o = V_{in} \frac{R_2}{R_1 + R_2}}$$

$$3V = 9V \frac{R_2}{R_1 + R_2}$$

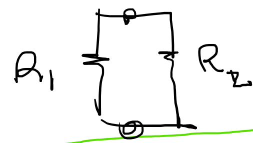
$$\frac{R_1}{R_2} = \frac{2}{1} \qquad \frac{2k}{1k}$$

Resistor Equivalence

Series

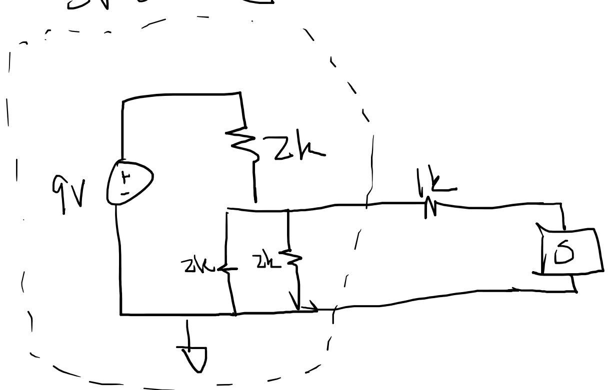
$$\boxed{R_s = R_1 + R_2}$$

parallel

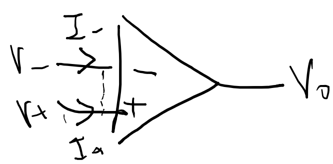


$$\boxed{R_p = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{R_1 R_2}{R_1 + R_2}}$$

Non-Ideal
3V source



Opamps (!)



$$\boxed{A_v = \frac{V_o}{V_{in}}}$$

Idea: $A_v = \frac{3V}{9V}$

Golden Rules

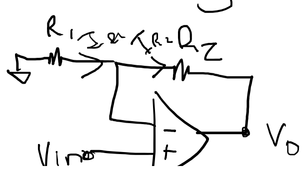
(1) virtual short

$V_+ = V_-$

(2) infinite input impedance $\left(\frac{V}{I}\right)$

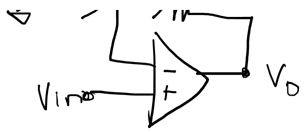
$I_- = I_+ = 0$

Non-Inverting Opamp



(1) $V_+ = V_- = V_{in}$

(2) $I_{R1} = I_{R2}$

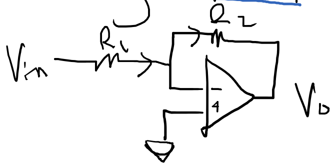


(2) $I_{R1} = I_{R2}$

$$\frac{0 - V_{in}}{R_1} = \frac{V_{in} - V_o}{R_2}$$

$$\boxed{A_v = \frac{V_o}{V_{in}} = \frac{R_2}{R_1} + 1}$$

Inverting Opamp



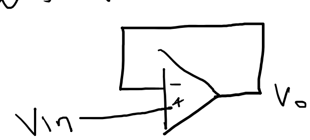
(1) $V_+ = V_- = 0$

(2) $I_{R1} = I_{R2}$

$$\frac{V_{in} - 0}{R_1} = \frac{0 - V_o}{R_2}$$

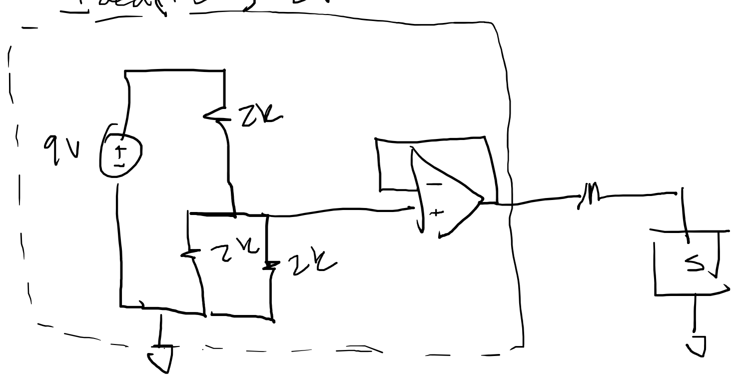
$$\boxed{A_v = \frac{V_o}{V_{in}} = \frac{-R_2}{R_1}}$$

Buffer (Non-Inverting)

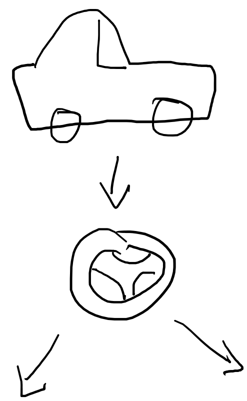


$$A_v = \frac{R_2}{R_1} + 1 = 1$$

Ideal(ish) 3V



Choosing the right model...



Drives down roads

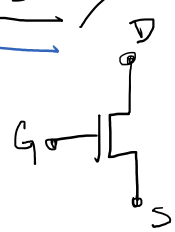
Driver

Human
- identify pedestrians

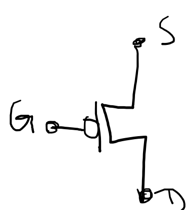
Computer
- fast reaction

Transistors

MOSFET



NMOS

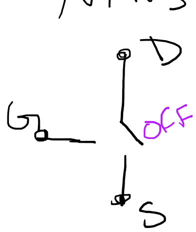


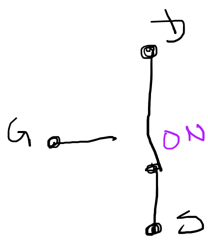
PMOS

switch model

~~16A~~

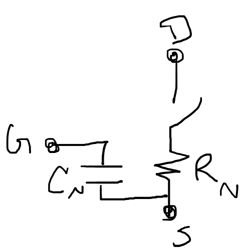
NMOS



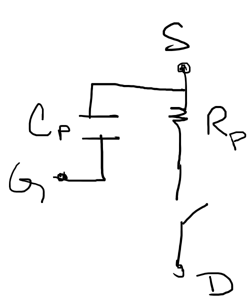


	OFF	ON
N	G = 0	G = 1
P	G = 1	G = 0

16B model



NMOS



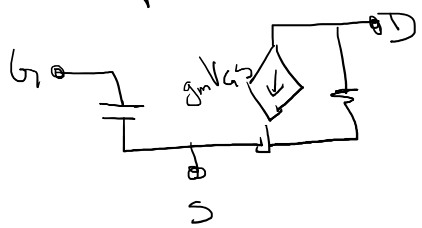
PMOS

	OFF	ON
N	$G < V_{TH}$	$G > V_{TH}$
P	$G > V_{TH}$	$G < V_{TH}$

NMOS

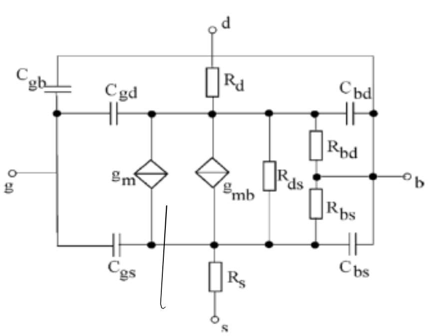
- switch resistance
- gate capacitance
- theshold voltage

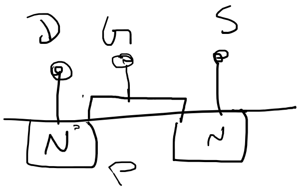
105 model



- analog VGS
- current source

140 model





- details of analog

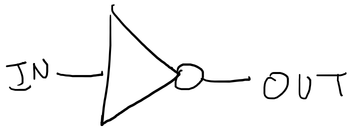
Simulation Model

```
* PTM 130nm NMOS

.model  nmos-BSIM130  nmos  level = 54

+version = 4.0        binunit = 1          paramchk= 1          mobmod  = 0
+capmod  = 2          igcmod  = 1          igbmod  = 1          geomod  = 1
+diomod  = 1          rdsmod  = 0          rbodymod= 1          rgatemod= 1
+permod  = 1          acnqsmod= 0          trnqsmod= 0

+tnom    = 27         toxe    = 2.25e-9    toxp    = 1.6e-9     toxm    = 2.25e-9
+dtox    = 0.65e-9    epsrox  = 3.9        wint    = 5e-009     lint    = 10.5e-009
+ll      = 0          wl      = 0          lln     = 1          wln     = 1
+lw      = 0          ww      = 0          lwn     = 1          wwn     = 1
+lwl     = 0          wwl     = 0          xpart   = 0          toxref  = 2.25e-9
+xl      = -60e-9
+vth0    = 0.3782     k1      = 0.4        k2      = 0.01       k3      = 0
+k3b     = 0          w0      = 2.5e-006   dvt0    = 1          dvt1    = 2
+dvt2    = -0.032     dvt0w   = 0          dvt1w   = 0          dvt2w   = 0
+dsub    = 0.1        minv    = 0.05       voffl   = 0          dvtp0   = 1.2e-010
+dvtp1   = 0.1        lpe0    = 0          lpeb    = 0          xj      = 3.92e-008
+ngate   = 2e+020     ndep    = 1.54e+018  nsd     = 2e+020     phin    = 0
+cdsc    = 0.0002     cdscb   = 0          cdscd   = 0          cit     = 0
+voff    = -0.13      nfactor = 1.5        eta0    = 0.0092     etab    = 0
+vfb     = -0.55      u0      = 0.05928    ua      = 6e-010     ub      = 1.2e-018
+uc      = 0          vsat    = 100370     a0      = 1          ags     = 1e-020
+a1      = 0          a2      = 1          b0      = 0          b1      = 0
+keta    = 0.04       dwg     = 0          dwb     = 0          pclm    = 0.06
+pdiblc1 = 0.001      pdiblc2 = 0.001      pdiblcb = -0.005     drout   = 0.5
+pvag    = 1e-020     delta   = 0.01       pscbe1  = 8.14e+008  pscbe2  = 1e-007
+fprout  = 0.2        pdits   = 0.08       pditsd  = 0.23       pditsl  = 2.3e+006
+rsh     = 5          rdsw    = 200        rsw     = 100        rdw     = 100
+rdswmin = 0          rdwmin  = 0          rswmin  = 0          prwg    = 0
+prwb    = 6.8e-011   wr      = 1          alpha0  = 0.074      alpha1  = 0.005
+beta0   = 30         agidl   = 0.0002     bgidl   = 2.1e+009   cgidl   = 0.0002
```

Integrated Circuit (IC)

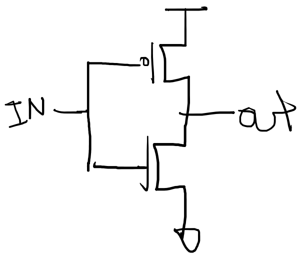
-

Models in Practice: Inverter



IN	OUT
0	1
1	0

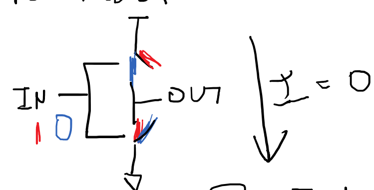
1 is any voltage $> V_{TH}$ (usually V_{DD})
0 is any voltage $< V_{TH}$ (usually GND)



CPU Designer
- Power
- Heat
- Speed

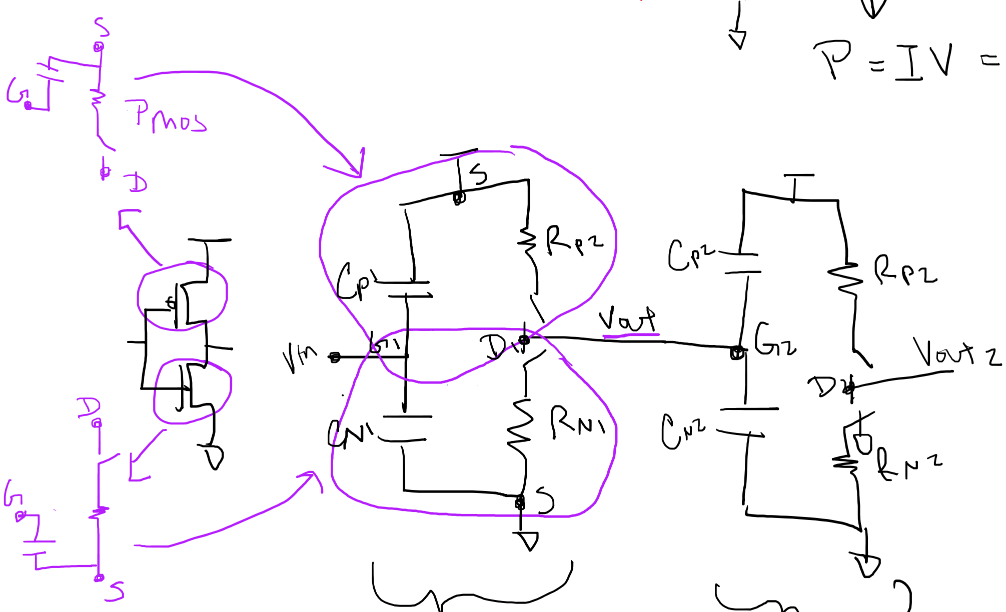
What's the Power?

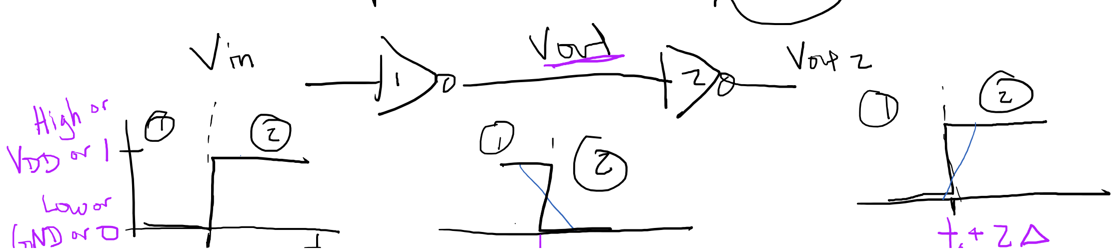
1/6A model

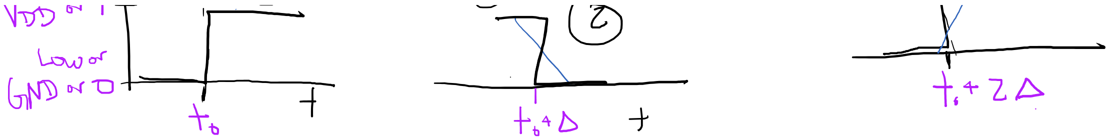


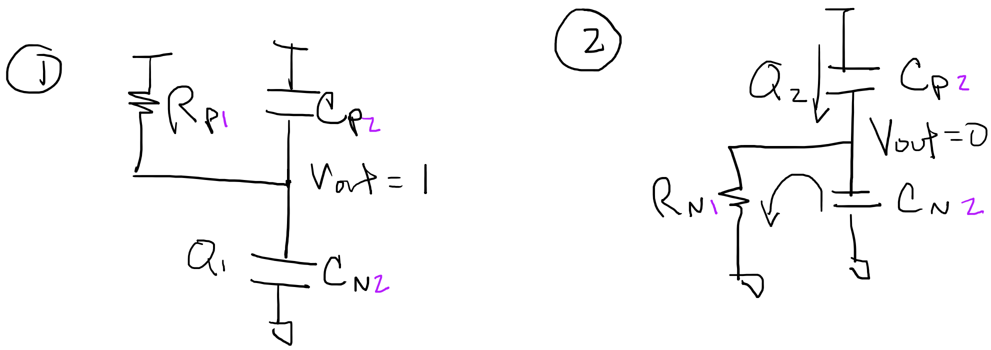
$P = IV = 0$

Intuitively wrong, so switches only are a bad model









Useful eqns

$$\boxed{\begin{aligned} E &= Pt = \tfrac{1}{2} Q V_c \\ Q &= C V_c = \int I_c\, dt \end{aligned}}$$

1

$$Q_1 = C_N V_{out} = C_N V_{DD}$$

2

$$Q_2 = C_P V_{out} = C_P V_{DD}$$

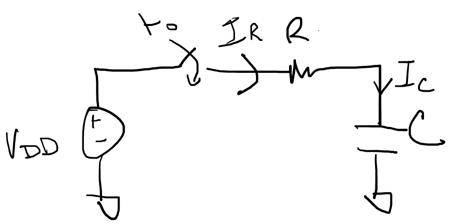
$$\boxed{\begin{aligned} E &= \tfrac{1}{2} Q V_{DD} \\ &= \tfrac{1}{2} (C_{N/P} V_{DD}) V_{DD} \end{aligned}}$$

Power

$$P = \frac{E}{t} \leftarrow \text{speed?}$$

Charging a cap in time

We want to know how fast we can run our logic, so we need to know where the delay comes from.



Useful eqns

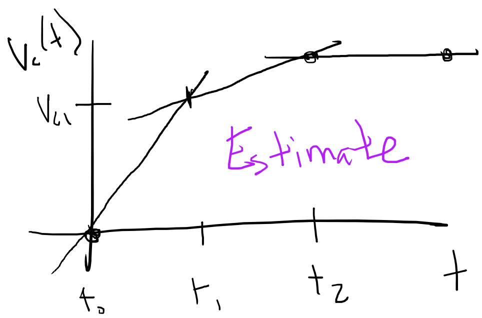
$$\boxed{\begin{aligned} I_c(t) &= C \frac{d}{dt} V_c(t) \\ Q &= C V_c(t) = \int I_c(t)\, dt \end{aligned}}$$

$$I_R(t) = \frac{V(t)}{R}$$

$$I_R(t) = I_c(t)$$

$$V_{DD} = V_R(t) + V_c(t)$$

$V(t)$



$$V_C(t) = \frac{1}{C}\int I_C(t)\,dt$$

$$I(t) = \frac{V_{DD} - V_C(t)}{R}$$

t_0: $V_C(t_0) = 0$

$$I_R(t_0) = \frac{V_{DD}}{R}$$

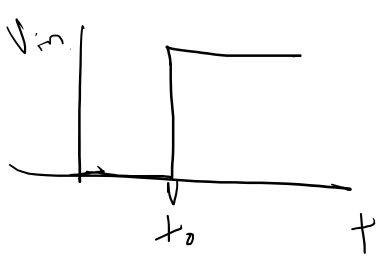
$>$

t_1: $V_C(t_1) = V_{C1}$

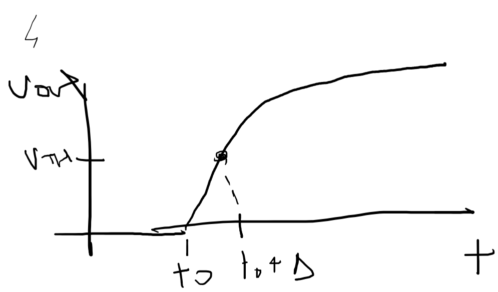
$$I_R(t_1) = \frac{V_{DD} - V_{C1}}{R}$$

Intuition: capacitors charge slower the more charge on them

$I_C(t)\downarrow$ as $V_C(t)\uparrow$ for const V_S



$\Rightarrow$



What do w/ Δt ?

How math Δt ?

Scroll Box