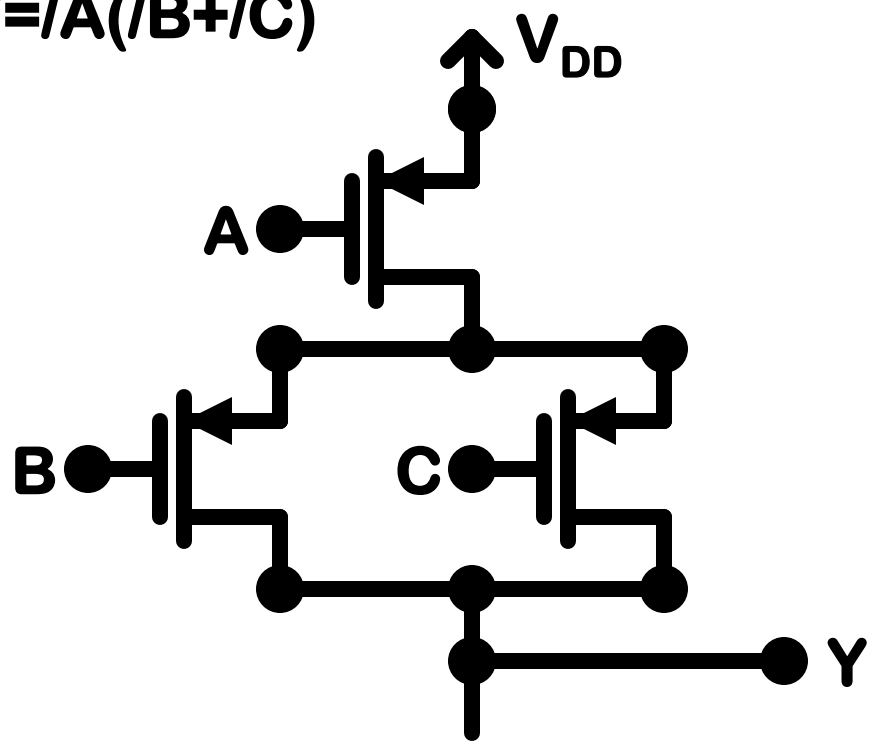
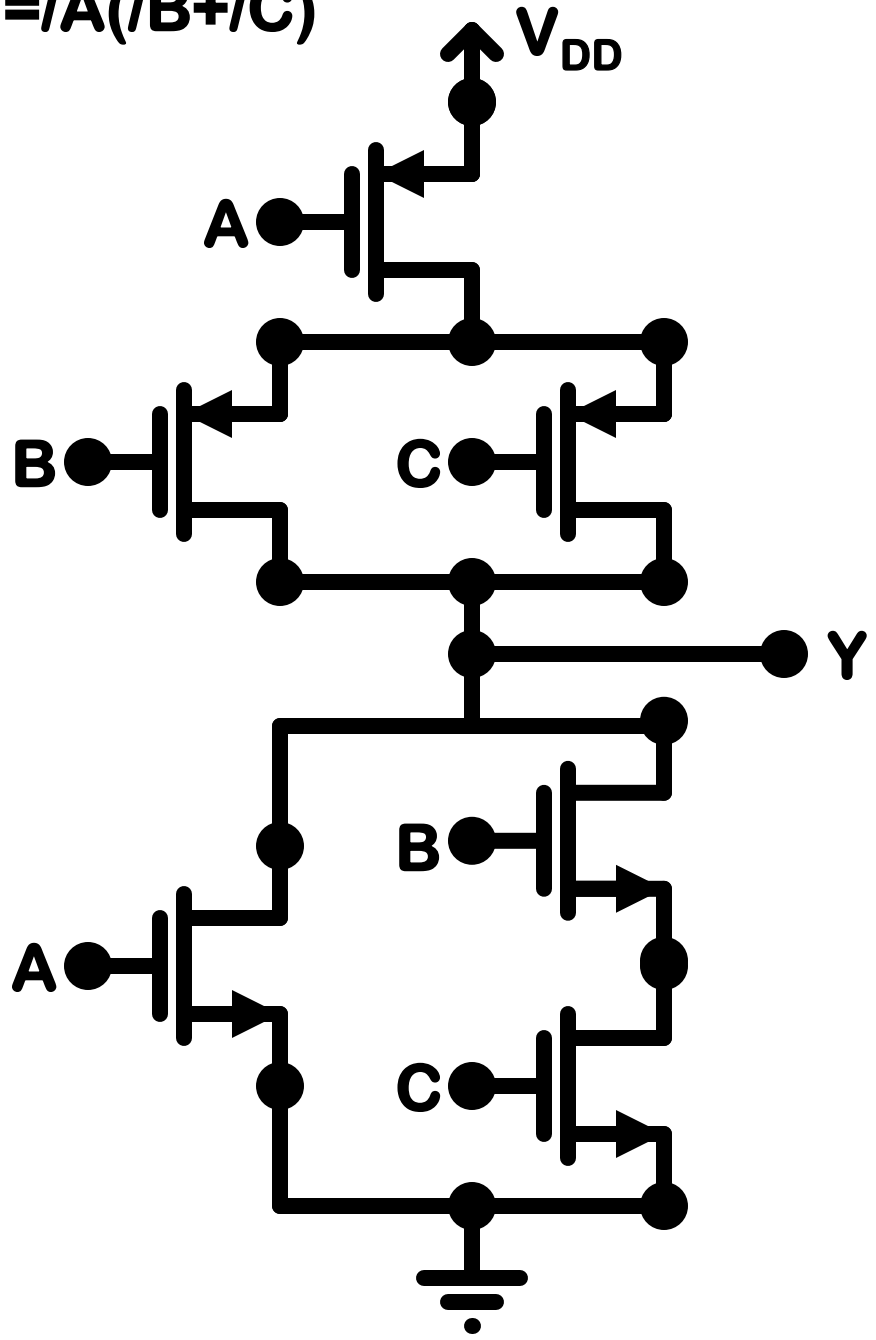


$$Y = I_A(I_B + I_C)$$

$$Y = \overline{A}(\overline{B} + \overline{C})$$

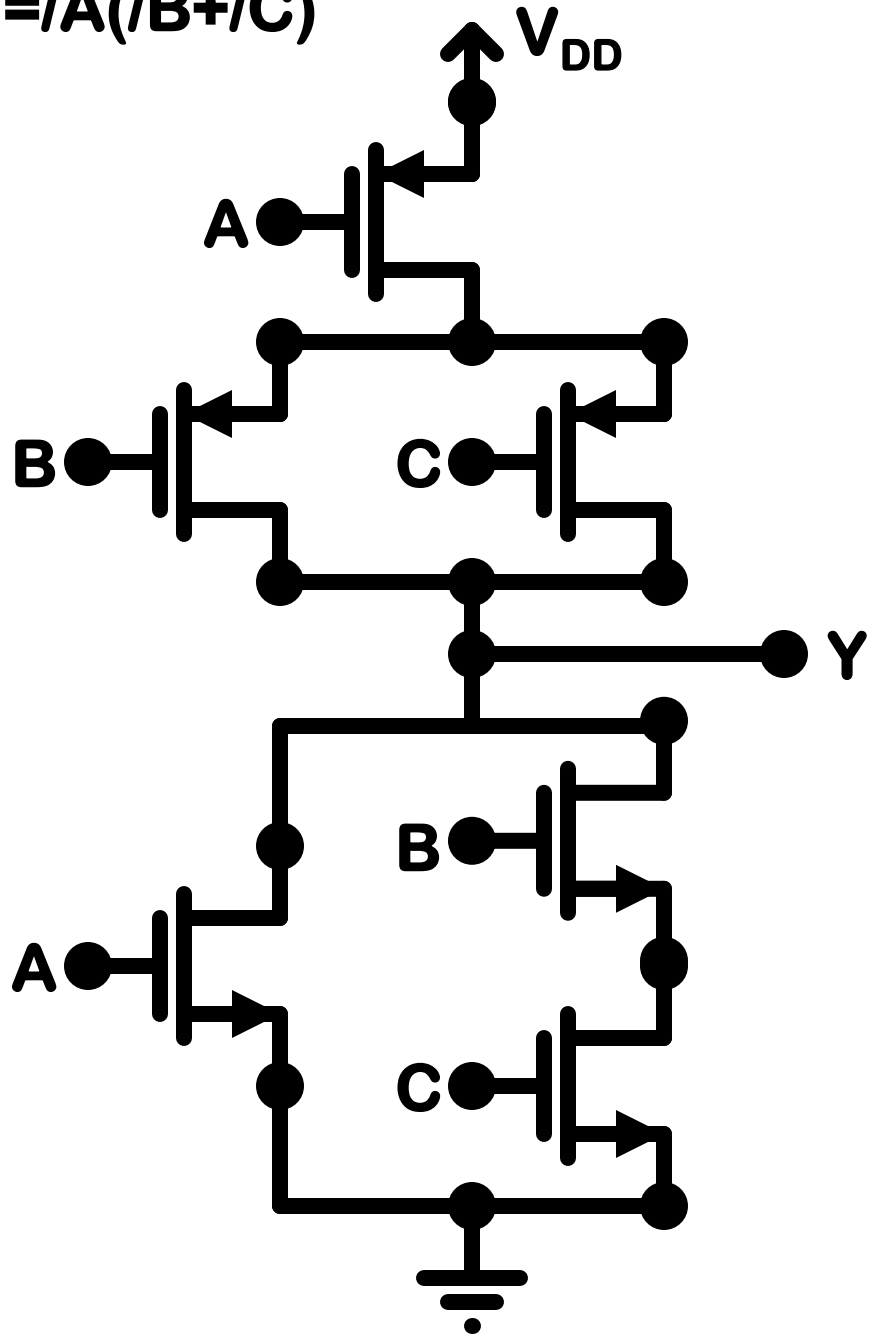


$$Y = \overline{A}(\overline{B} + C)$$

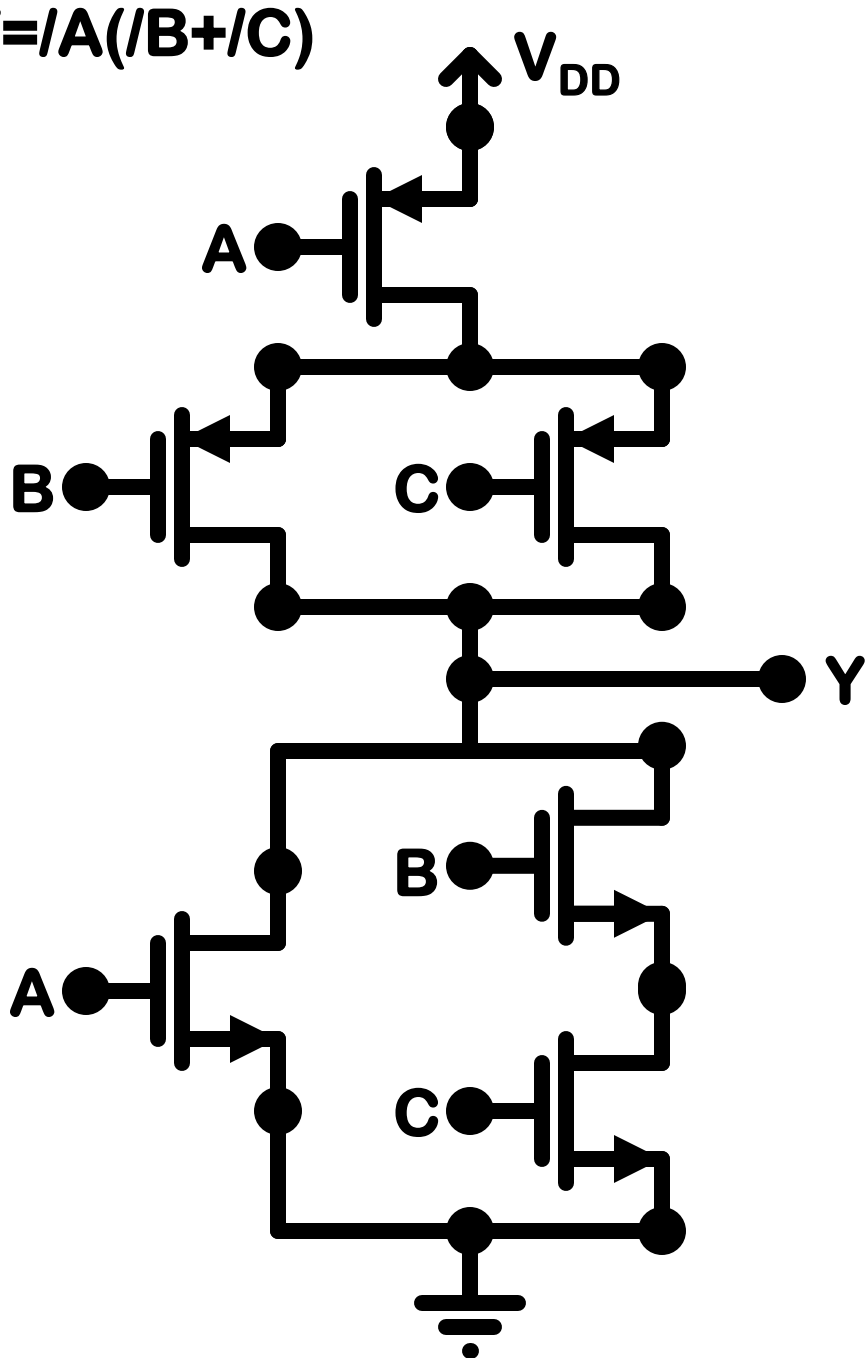


$$Y = \overline{A}(\overline{B} + C)$$

A B C r_{PUN} r_{PDN} Y

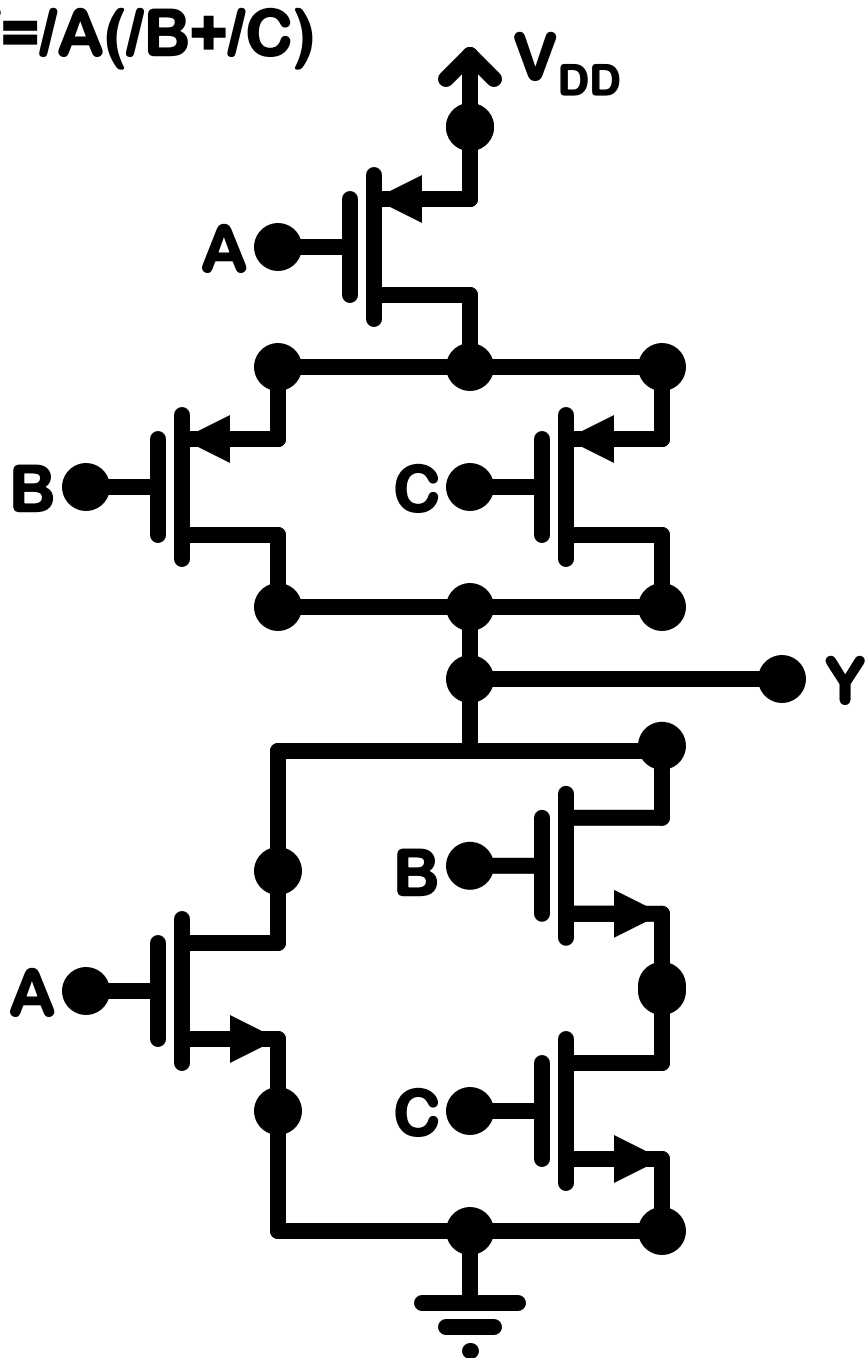


$$Y = \overline{A(B+C)}$$



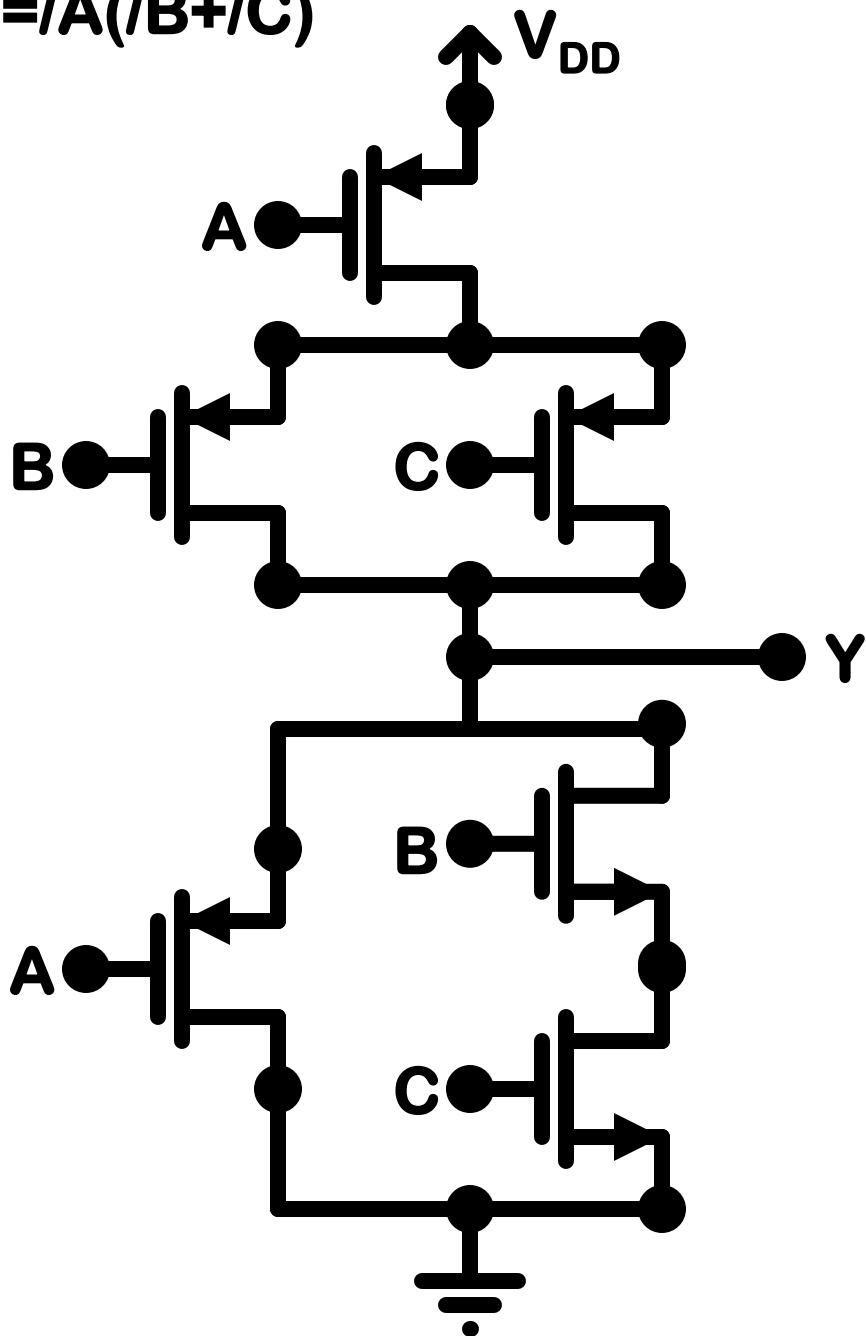
A	B	C	r_{PUN}	r_{PDN}	Y
0	0	0	$r+r/2$	open	1
0	0	1	$2r$	open	1
0	1	0	$2r$	open	1
0	1	1	open	$2r$	0
1	0	0	open	r	0
1	0	1	open	r	0
1	1	0	open	r	0
1	1	1	open	$r 2r$	0

$$Y = \overline{A(B+C)}$$



A	B	C	r_{PUN}	r_{PDN}	Y
0	0	0	$r+r/2$	open	1
0	0	1	$2r$	open	1
0	1	0	$2r$	open	1
0	1	1	open	$2r$	0
1	0	0	open	r	0
1	0	1	open	r	0
1	1	0	open	r	0
1	1	1	open	$r 2r$	0

$$Y = \overline{A(B+C)}$$



A	B	C	r_{PUN}	r_{PDN}	Y
0	0	0	$r+r/2$	open	1
0	0	1	$2r$	open	1
0	1	0	$2r$	open	1
0	1	1	open	$2r$	0
1	0	0	open	r	0
1	0	1	open	r	0
1	1	0	open	r	0
1	1	1	open	$r 2r$	0

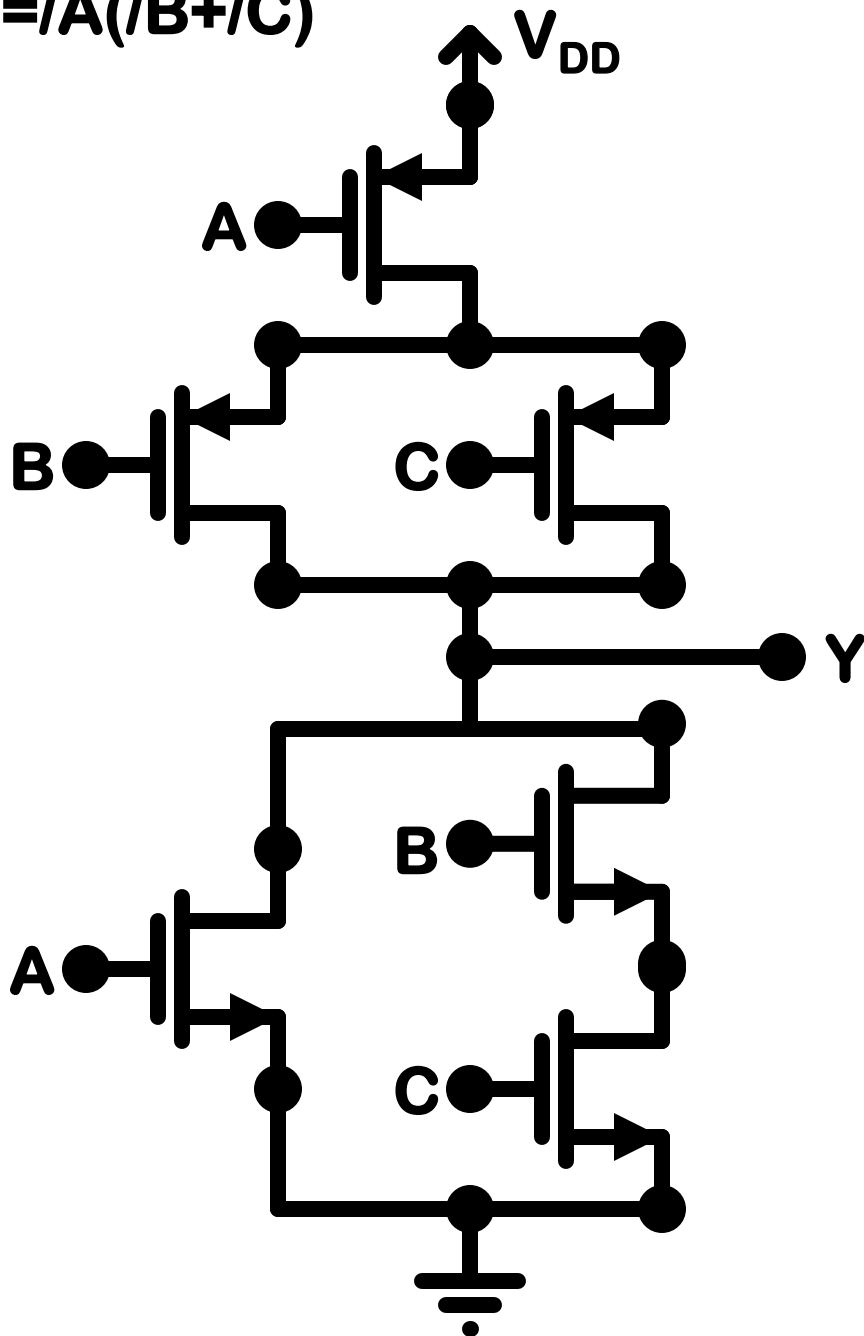
$$V_{DD} = 3V$$

$$k_n = k_p = k = 10\text{mA/V}^2$$

$$V_{tn} = |V_{tp}| = V_t = 1V$$

$$C = 80\text{pF}$$

$$Y = \overline{A(B+C)}$$



A	B	C	r_{PUN}	r_{PDN}	Y
0	0	0	$r+r/2$	open	1
0	0	1	$2r$	open	1
0	1	0	$2r$	open	1
0	1	1	open	$2r$	0
1	0	0	open	r	0
1	0	1	open	r	0
1	1	0	open	r	0
1	1	1	open	$r 2r$	0

$$V_{DD} = 3V$$

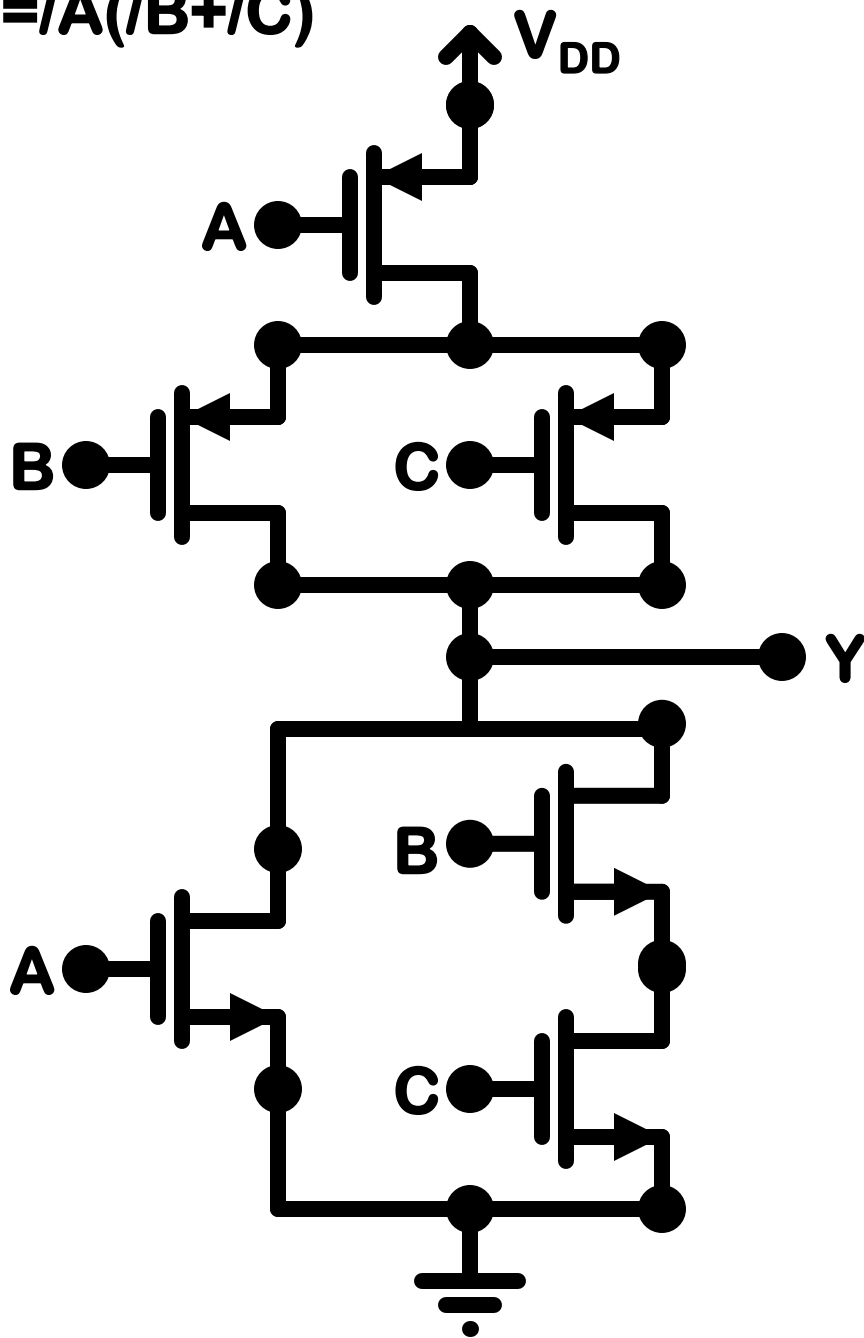
$$k_n = k_p = k = 10\text{mA/V}^2$$

$$V_{tn} = |V_{tp}| = V_t = 1V$$

$$C = 80\text{pF}$$

$$r = 1/(k(V_{DD} - V_t)) = 50\Omega$$

$$Y = \overline{A(B+C)}$$



A	B	C	r_{PUN}	r_{PDN}	Y
0	0	0	$r+r/2$	open	1
0	0	1	$2r$	open	1
0	1	0	$2r$	open	1
0	1	1	open	$2r$	0
1	0	0	open	r	0
1	0	1	open	r	0
1	1	0	open	r	0
1	1	1	open	$r 2r$	0

$$V_{DD} = 3V$$

$$k_n = k_p = k = 10\text{mA/V}^2$$

$$V_{tn} = |V_{tp}| = V_t = 1V$$

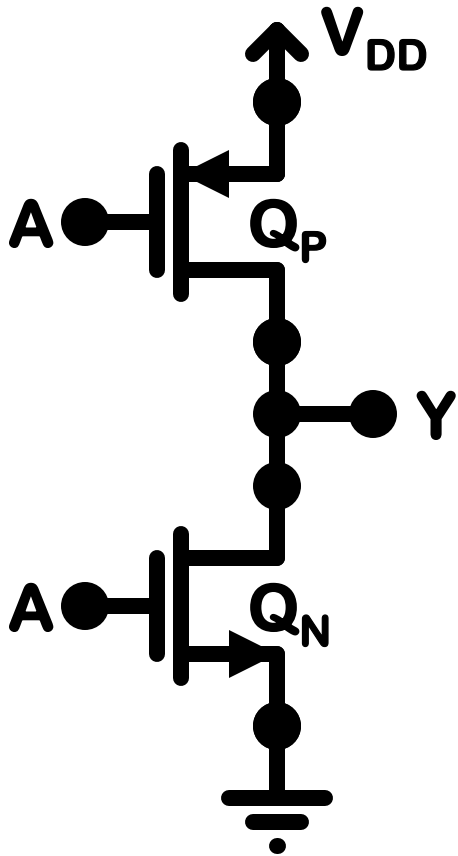
$$C = 80\text{pF}$$

$$r = 1/(k(V_{DD} - V_t)) = 50\Omega$$

$$\tau_{P_MAX} = 2r \cdot C \cdot \ln(2) = 5.5\text{ns}$$

$$\tau_{T_MAX} = 2r \cdot C \cdot \ln(9) = 17.6\text{ns}$$

Inverter

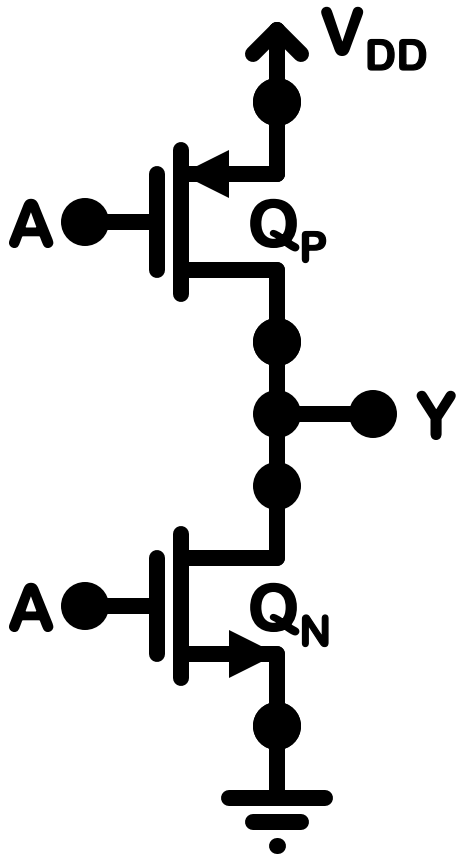


Meets timing requirements with

Q_P : k_p' , $|V_{tp}|$, V_{DD} , $(W/L)_p = p$

Q_N : k_n' , V_{tn} , V_{DD} , $(W/L)_n = n$

Inverter



Meets timing requirements with

$$Q_P: k_p', |V_{tp}|, V_{DD}, (W/L)_p=p$$

$$Q_N: k_n', V_{tn}, V_{DD}, (W/L)_n=n$$

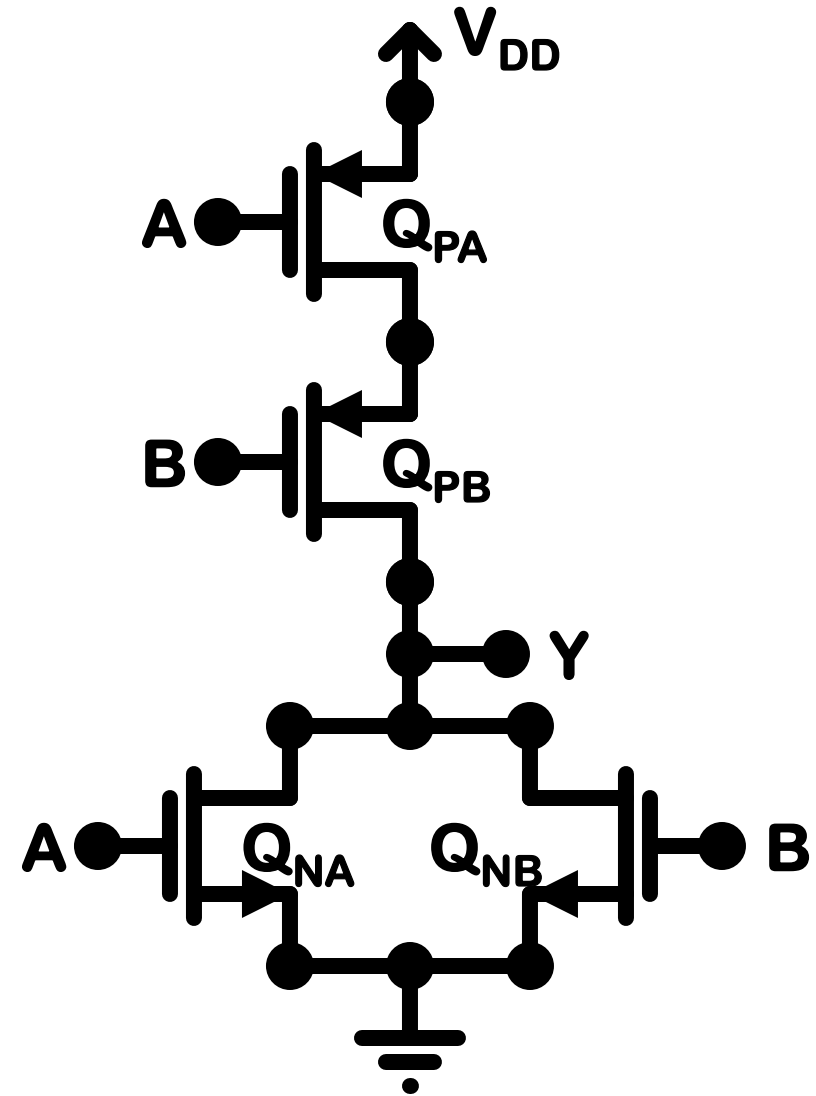
$$r_{PUN} = 1/(k_p'(W/L)_p(V_{DD}-|V_{tp}|))$$

$$r_{PUN} = 1/(k_p'p(V_{DD}-|V_{tp}|))$$

$$r_{PDN} = 1/(k_n'(W/L)_n(V_{DD}-V_{tn}))$$

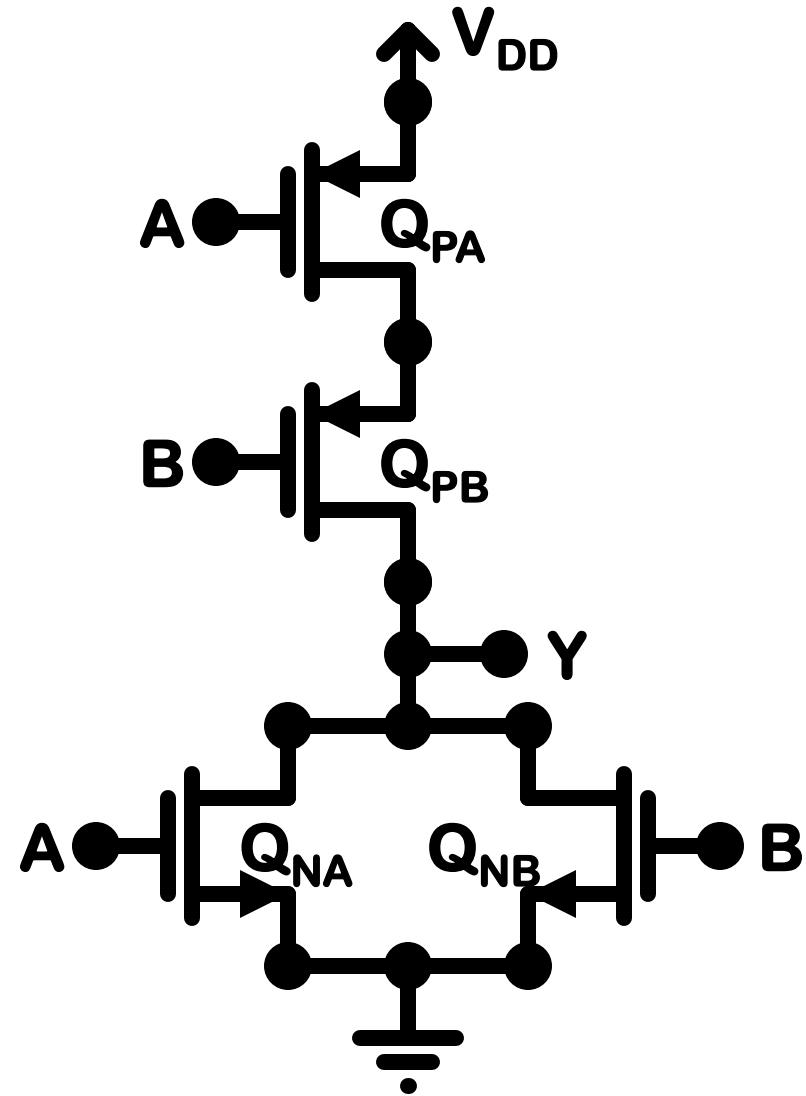
$$r_{PDN} = 1/(k_n'n(V_{DD}-V_{tn}))$$

NOR



What sizes of the transistors will meet timing for all possible input values?

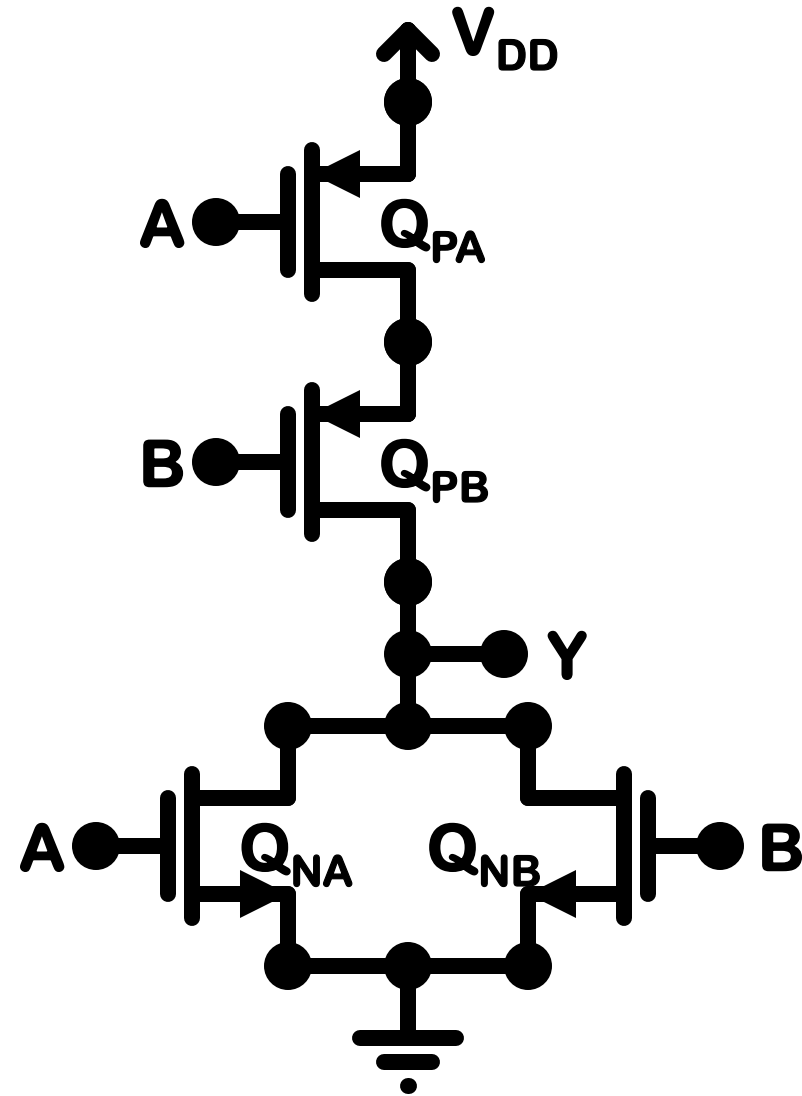
NOR



What sizes of the transistors will meet timing for all possible input values?

We want the maximum r_{PUN} to be the same as that of the inverter.

NOR



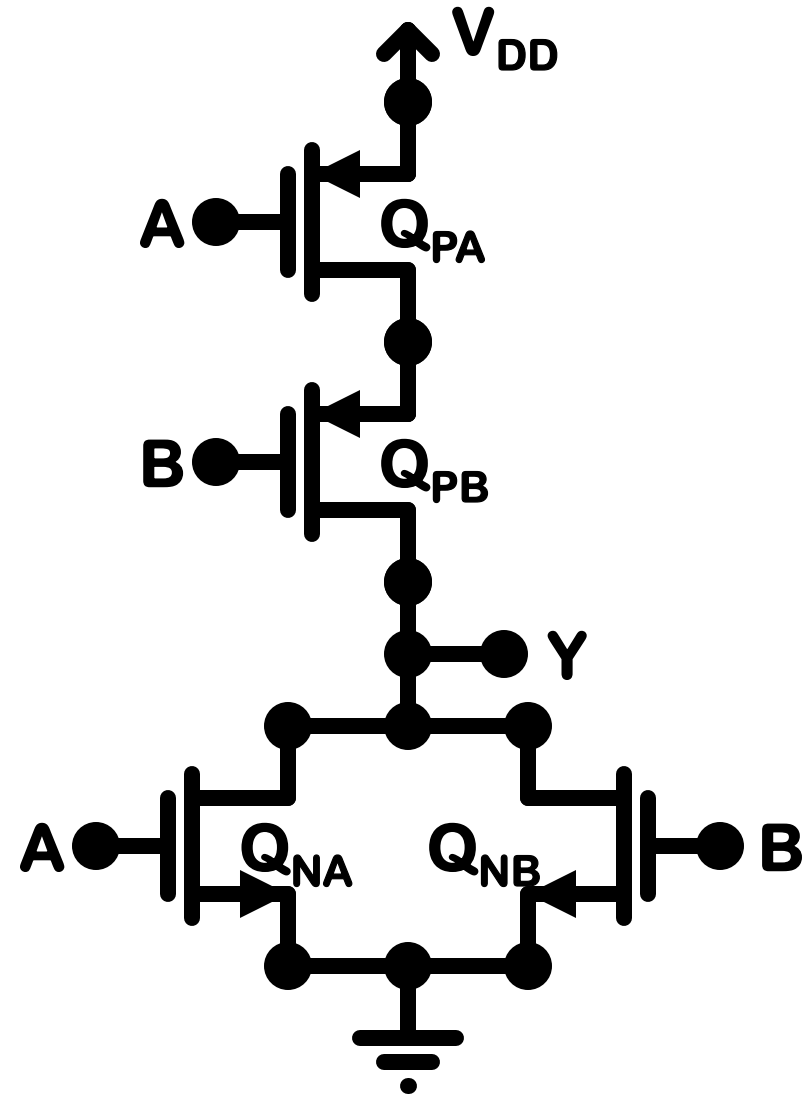
What sizes of the transistors will meet timing for all possible input values?

We want the maximum r_{PUN} to be the same as that of the inverter.

$$r_{PUN_MAX} = r_{PA} + r_{PB}$$

$$r_{PUN_MAX} = 2 / (k_p' (W/L)_{PA,PB} (V_{DD} - |V_{tp}|))$$

NOR



What sizes of the transistors will meet timing for all possible input values?

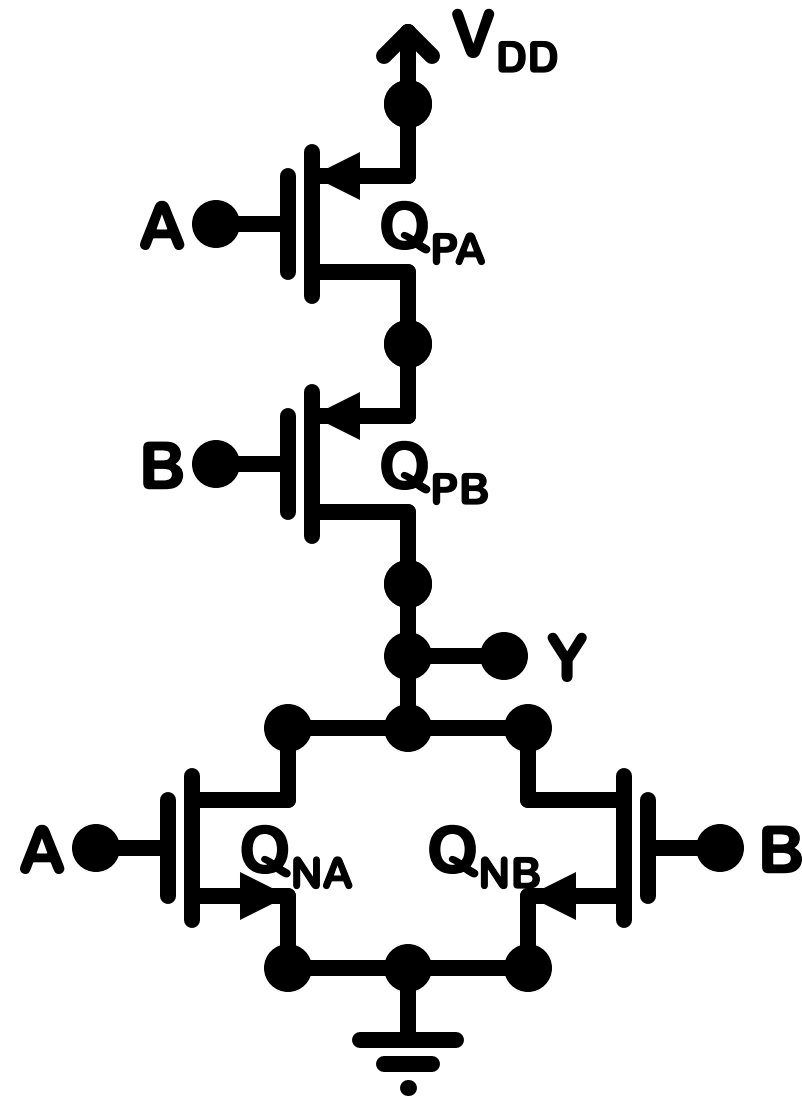
We want the maximum r_{PUN} to be the same as that of the inverter.

$$r_{PUN_MAX} = r_{PA} + r_{PB}$$

$$r_{PUN_MAX} = 2 / (k_p' (W/L)_{PA,PB} (V_{DD} - |V_{tp}|))$$

$$1 / (k_p' p (V_{DD} - |V_{tp}|)) = 2 / (k_p' (W/L)_{PA,PB} (V_{DD} - |V_{tp}|))$$

NOR



What sizes of the transistors will meet timing for all possible input values?

We want the maximum r_{PUN} to be the same as that of the inverter.

$$r_{PUN_MAX} = r_{PA} + r_{PB}$$

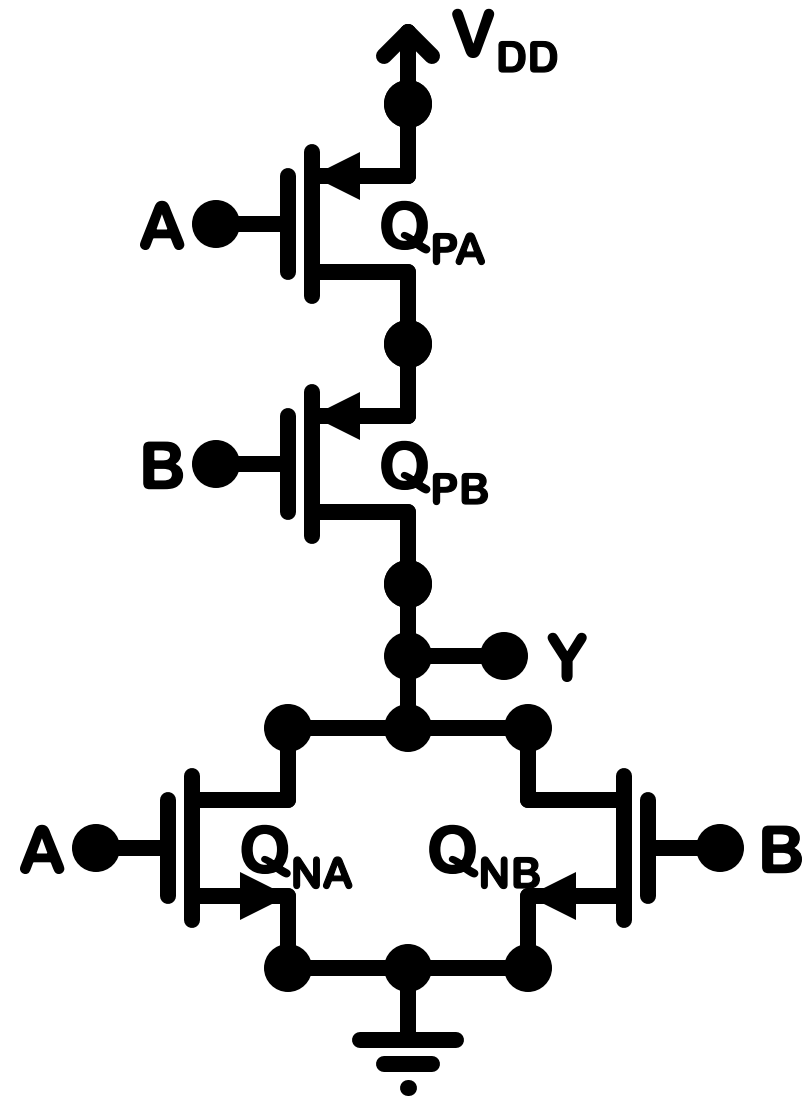
$$r_{PUN_MAX} = 2 / (k_p' (W/L)_{PA,PB} (V_{DD} - |V_{tp}|))$$

$$1 / (k_p' p (V_{DD} - |V_{tp}|)) = 2 / (k_p' (W/L)_{PA,PB} (V_{DD} - |V_{tp}|))$$

$$1/p = 2 / (W/L)_{PA,PB}$$

$$(W/L)_{PA,PB} = 2p$$

NOR



What sizes of the transistors will meet timing for all possible input values?

We want the maximum r_{PUN} to be the same as that of the inverter.

$$r_{PUN_MAX} = r_{PA} + r_{PB}$$

$$r_{PUN_MAX} = 2 / (k_p' (W/L)_{PA,PB} (V_{DD} - |V_{tp}|))$$

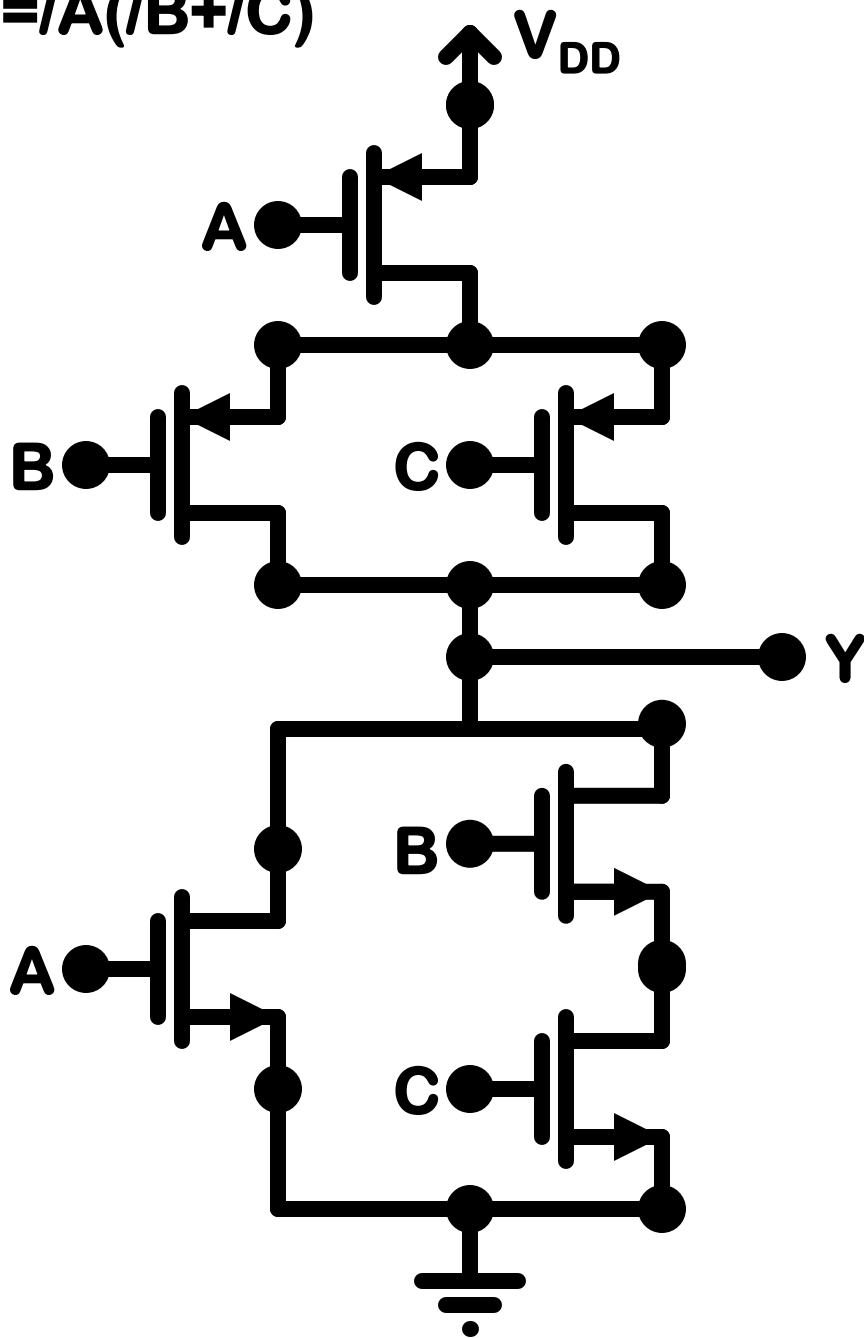
$$1 / (k_p' p (V_{DD} - |V_{tp}|)) = 2 / (k_p' (W/L)_{PA,PB} (V_{DD} - |V_{tp}|))$$

$$1/p = 2 / (W/L)_{PA,PB}$$

$$(W/L)_{PA,PB} = 2p$$

What about the NMOS sizes?

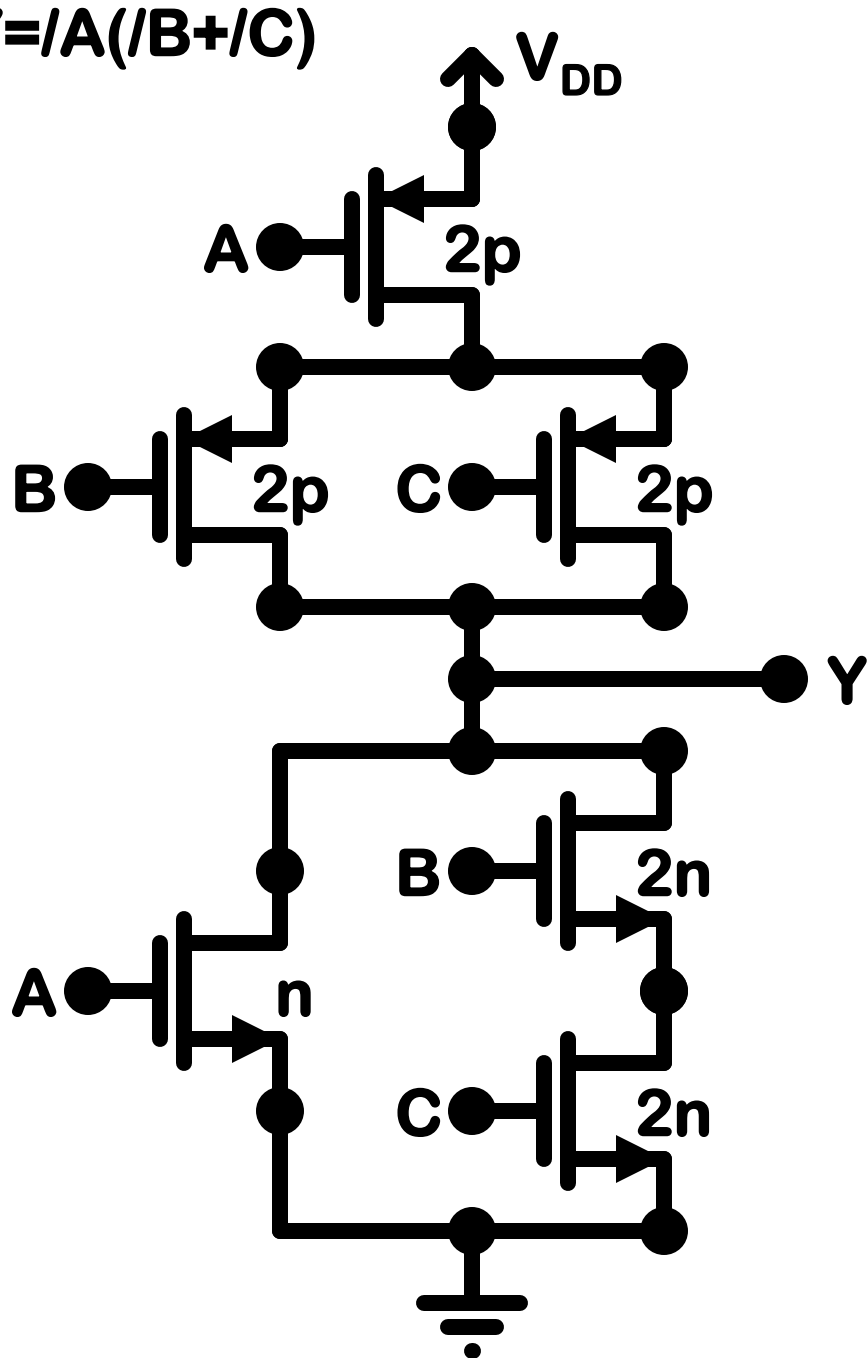
$$Y = \overline{A(B+C)}$$



A	B	C	r_{PUN}	r_{PDN}	Y
0	0	0	$r+r/2$	open	1
0	0	1	$2r$	open	1
0	1	0	$2r$	open	1
0	1	1	open	$2r$	0
1	0	0	open	r	0
1	0	1	open	r	0
1	1	0	open	r	0
1	1	1	open	$r 2r$	0

If we have an inverter that meets timing with the PMOS (W/L)= p and NMOS (W/L)= n , how should $Y = \overline{A(B+C)}$ transistors be sized?

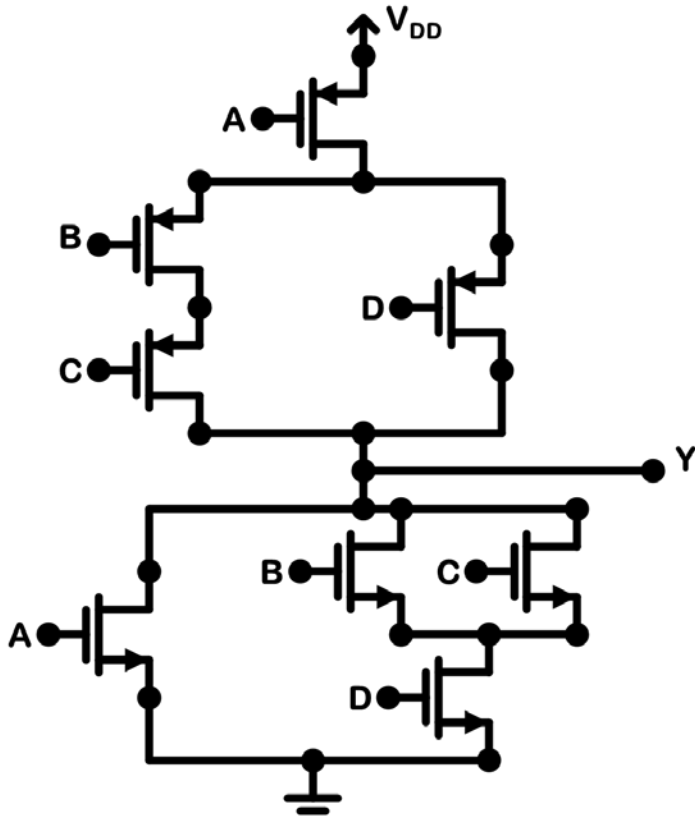
$$Y = \overline{A(B+C)}$$



A	B	C	r_{PUN}	r_{PDN}	Y
0	0	0	$r+r/2$	open	1
0	0	1	$2r$	open	1
0	1	0	$2r$	open	1
0	1	1	open	$2r$	0
1	0	0	open	r	0
1	0	1	open	r	0
1	1	0	open	r	0
1	1	1	open	$r 2r$	0

$$Y = \frac{1}{A} \cdot \left(\frac{1}{B} \cdot \frac{1}{C} + \frac{1}{D} \right)$$

$$Y = /A \cdot (/B \cdot /C + /D)$$



Procedure:

1. Identify worst case path.

$$\text{PUN } A \Rightarrow B \Rightarrow C$$

2. Express resistance of the worst-case path to the that of an inverter.

$$r_{SDA} + r_{SDB} + r_{SDC} = r_{INV}$$

3. Relate resistances to (W/L)

$$1/(W/L)_A + 1/(W/L)_B + 1/(W/L)_C = 1/p$$

4. Assume all unknowns are equal

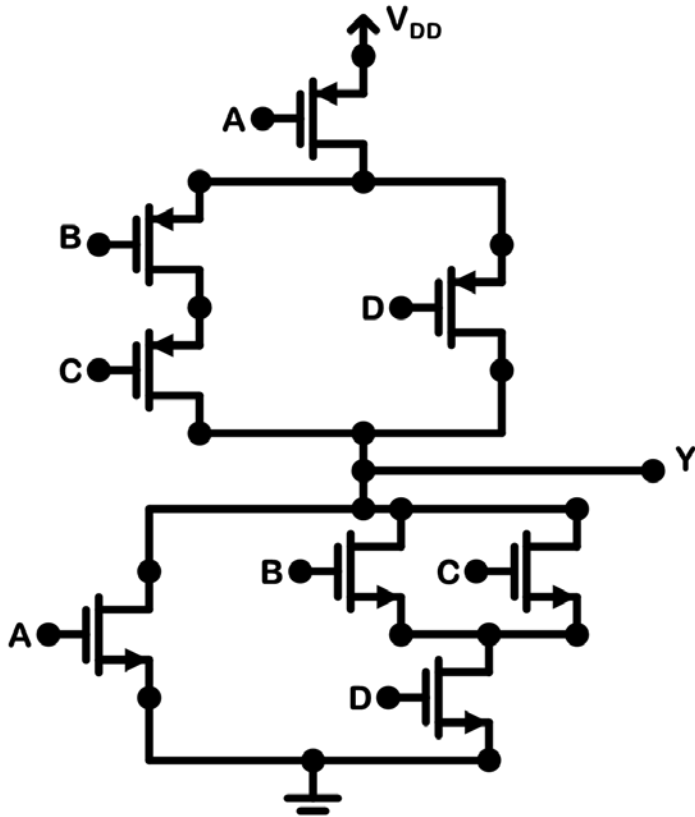
$$3/(W/L)_{A,B,C} = 1/p$$

5. Solve

$$(W/L)_{A,B,C} = 3p$$

6. Do the same process for the next worst-case path.

$$Y = /A \cdot (/B \cdot /C + /D)$$



Procedure:

1. Identify next worst case path.

PUN A => D

2. Express resistance of the worst-case path to the that of an inverter.

$$r_{SDA} + r_{SDD} = r_{INV}$$

3. Relate resistances to (W/L)

$$1/3p + 1/(W/L)_D = 1/p$$

4. Assume all unknowns are equal

$$1/(W/L)_D = 3/3p - 3/p$$

5. Solve

$$(W/L)_D = 3p/2$$

6. Do the same process for the next worst-case path.