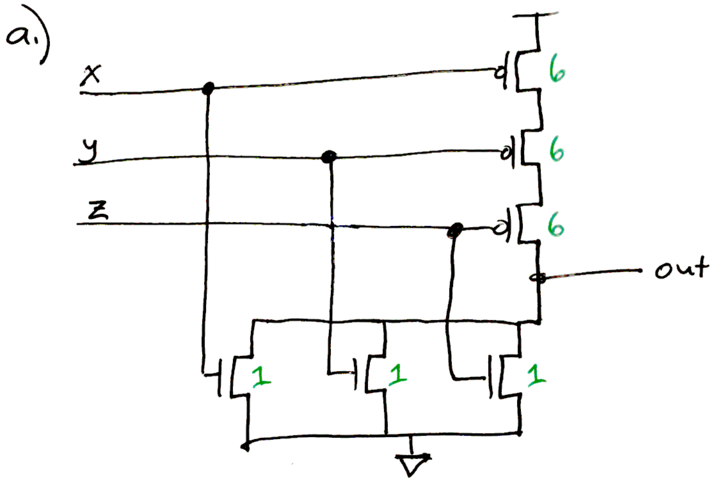
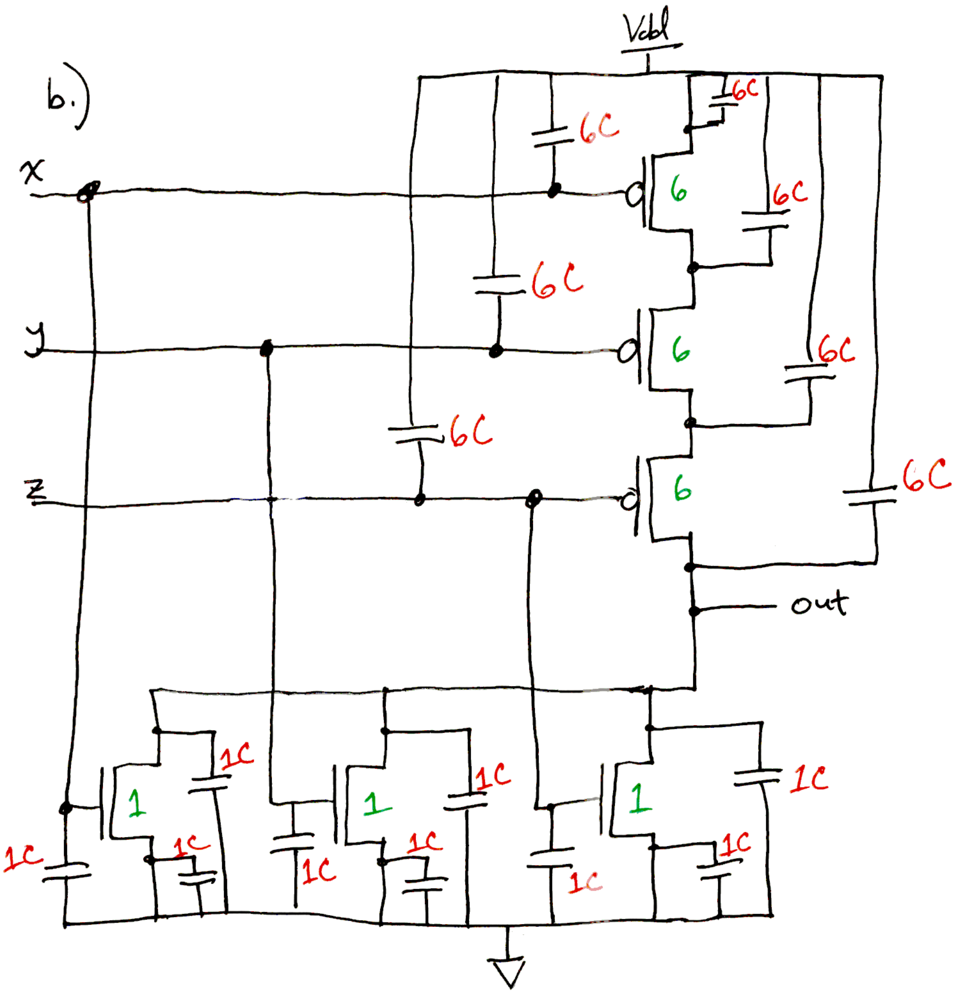
3-input CMOS NOR gate

Similar progression as Weste + Harris Figure 4.7

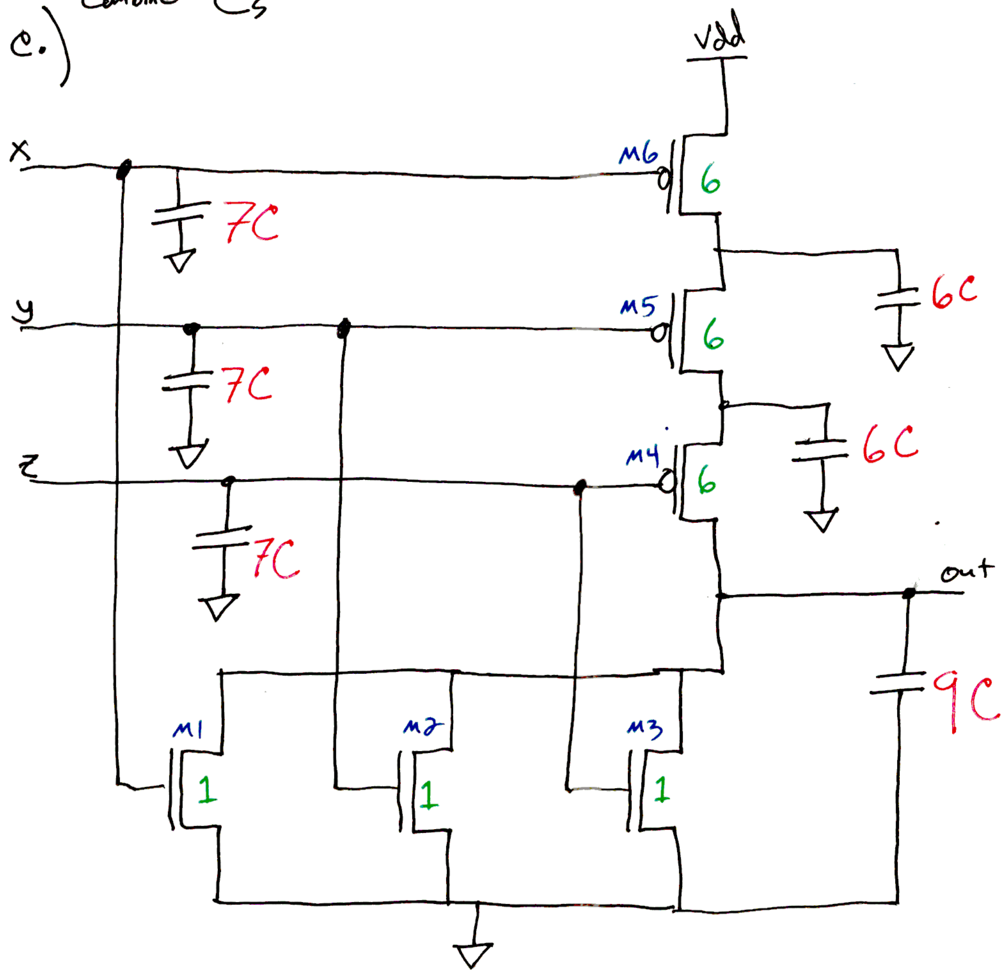
a.)



b.)

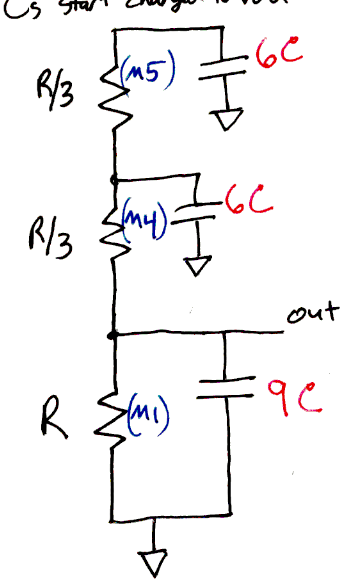


c.) Combine C's



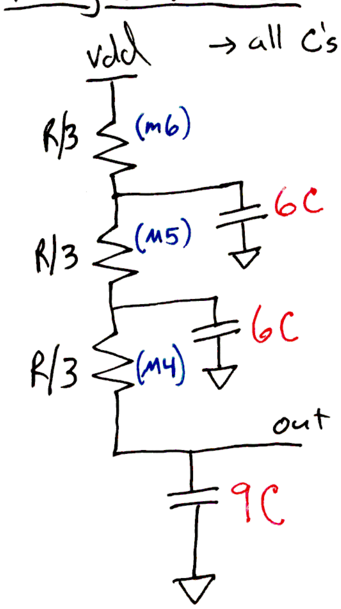
d) Falling worst-case

→ all C's start charged to Vdd



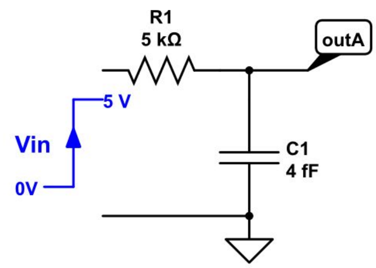
e.) Rising worst-case

→ all C's start discharged

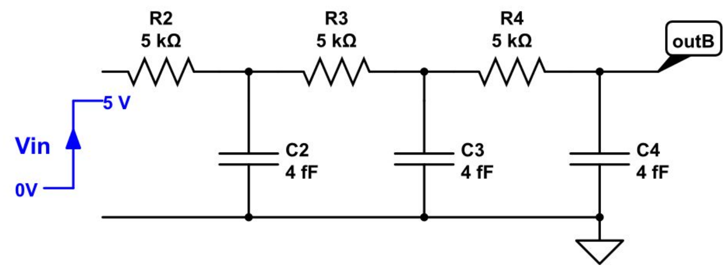


RC network responses

(a)



(b)



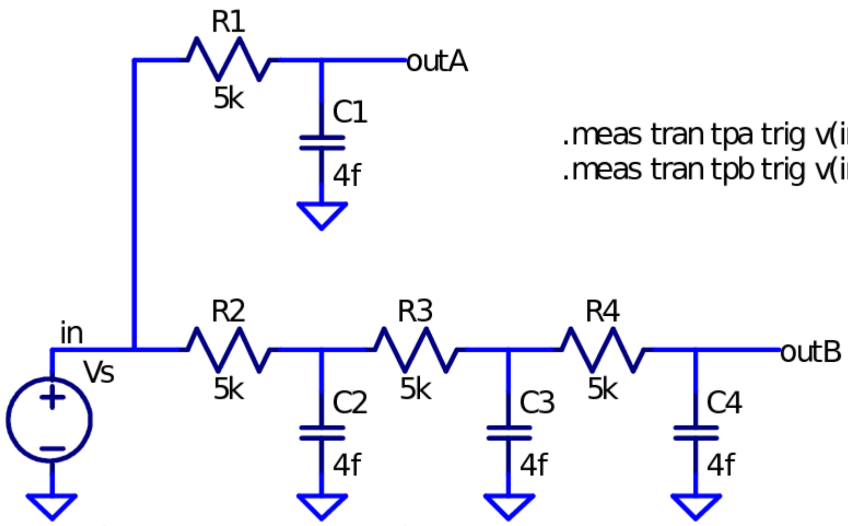
Calculations

- Find the propagation delay **`tpdr`** (in ECE 340 this was named **`tpLH`**) of Figure (a) using the circuit equations.
- Find the propagation delay **`tpdr`** of Figure (b) by using a similar technique as book section 4.3.4 and equation (4.13) to approximate as a single time constant system. This is the Elmore delay. There will still be a (ln2) factor in your math, we are not dropping it yet like the book's equation (4.9).

Simulations

Simulate the transient response of the two networks using LTspice. Be sure the input waveform's rise time is less than 1/10th of the output's rise time.

- Find the propagation delay **`tpLH`** of Figure (a). This should be exactly the same as your calculated value.
- Find the propagation delay **`tpLH`** of Figure (b).
  - Compare this to your Elmore-estimated value.
  - Do you think it will always be an over/under estimate?



.meas tran tpa trig v(in) val=2.5 targ v(outA) val=2.5
.meas tran tpb trig v(in) val=2.5 targ v(outB) val=2.5

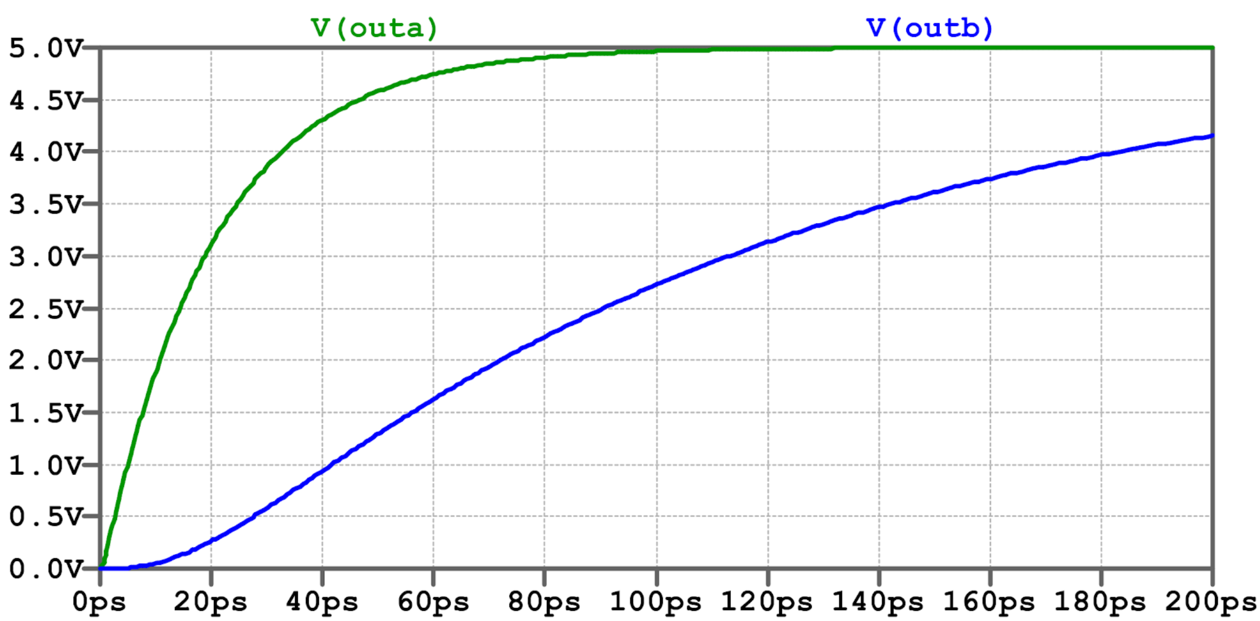
Sim results:
tpLH A = 13.9 ps
tpLH B = 90.1 ps

PULSE(0 5 0 1p 1p 300p 600p)

.tran 300p

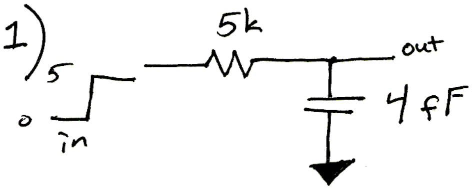
```
tpa=1.38724e-011 FROM 5e-013 TO 1.43724e-011

tpb=9.00547e-011 FROM 5e-013 TO 9.05547e-011
```



RC network delays

• 1)



Find $t_{P_{LH}}$ of this circuit.

$$V_{out}(t) = (5V)\left[1 - \exp\left(\frac{-t}{R \cdot C}\right)\right]$$

delay is 50% of input to 50% of output transition.

$$\frac{5}{2} = (5V)\left[1 - \exp\left(\frac{-t}{RC}\right)\right]$$

$$\frac{1}{2} - 1 = -\exp\left(\frac{-t}{RC}\right)$$

$$\exp\left(\frac{-t}{RC}\right) = \frac{1}{2}$$

$$\frac{-t}{RC} = \ln\left(\frac{1}{2}\right)$$

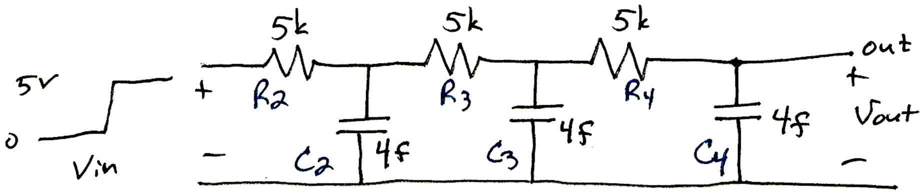
$$-t = RC \cdot \ln\frac{1}{2}$$

$$\cdot\left(\ln(1) - \ln(2)\right)$$

$$-t = RC \cdot (\phi - \ln 2)$$

$$t = RC \cdot \ln 2$$

$$\boxed{t = 13.9 \text{ ps}}$$



Estimate t_{PLH} by approximating as a single time constant "Elmore style"

$$\tau \approx R_2C_2 + (R_2+R_3)C_3 + (R_2+R_3+R_4)C_4$$

$$= 20ps + 40ps + 60ps$$

$$\tau = 120\ ps$$

not the same!

$$t_{PLH} = \tau \cdot \ln 2$$

$$\boxed{t_{PLH} \approx 83.2\ ps}$$

Simulations

Figure (a) $t_{PLH} = 13.9\ ps$ – exactly the same

Figure (b) $t_{PLH} = 90.1\ ps$

↳ estimate was 7.7% low

whether this estimate is high/low depends on the distribution of the R and C values along the "line"/path.