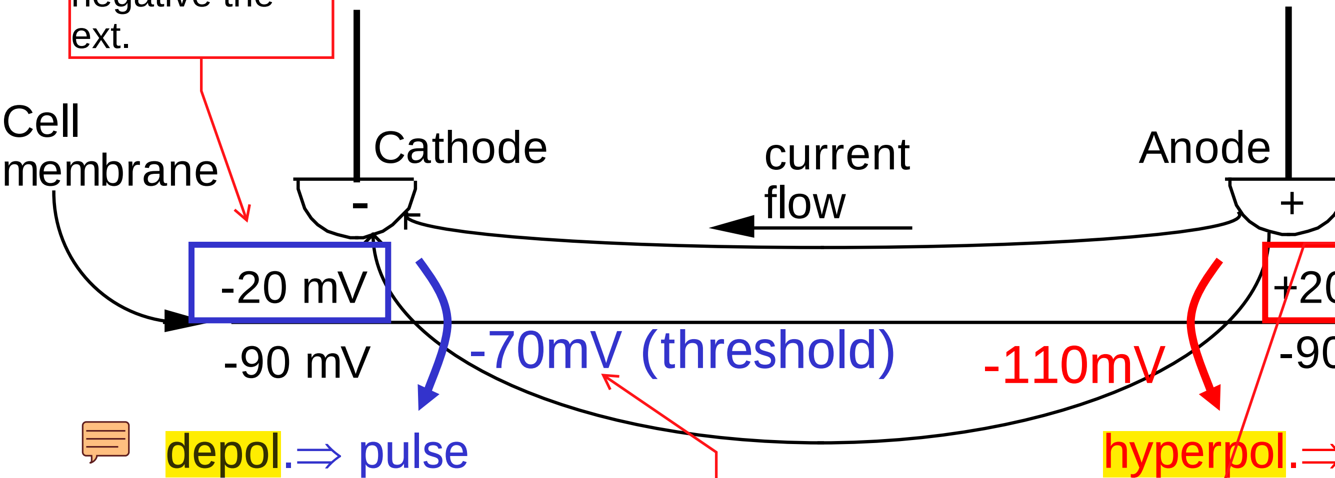
electrical **bipolar** stimulation

Pulses generation

-90mV resting potential

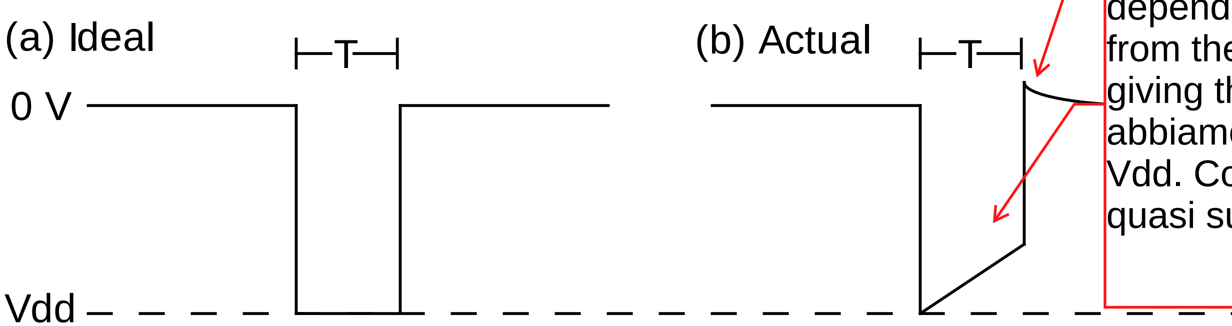
±20mV bipolar pulse

we put more negative the ext.



5)Il network torna alla situazione originaria. La ddp sul C non è come dovrebbe essere, si è scaricato, è < Vdd. So from kirkoff law the overall ddp is Vdd, but the intermediate block C is less, thus two remaining drops over the Resistors. Quindi parte positiva sul carico, circolazione di corrente che ricarica il condensatore.

the ddp decreases (in abs)



4)detail: the voltage on the load is not fixed at -Vdd but has a rise; depends on RC constant, because from the situation where we are giving the pulse (disegna il circuito) abbiamo la *scarica. A time 0 è Vdd. Comunque il pulse è rimosso quasi subito, quindi non arriva a 0.

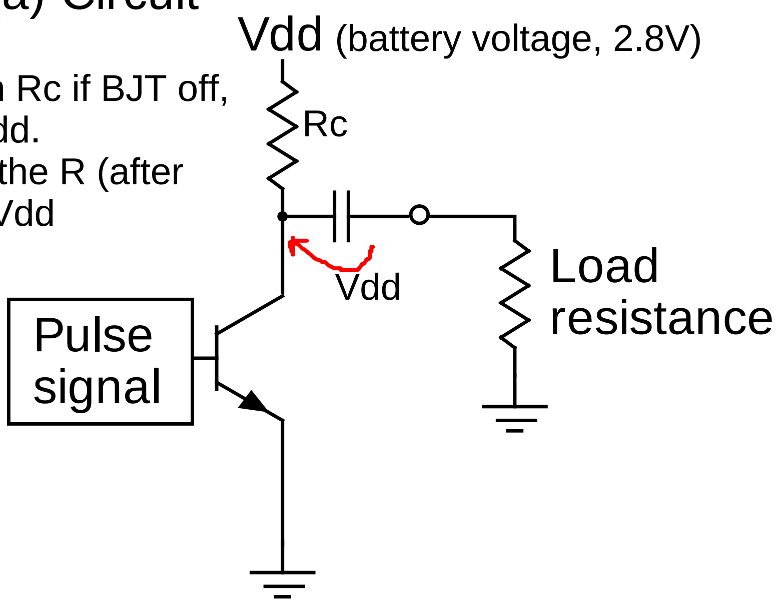
1)**Problematic:** the two points are connected :(. With unipolar one el. is simply far away. On the cathode we are supplying -20mv, on the anode +20mV. Stimulating from the external part of the membrane. Where does the AP takes place? On the CATHODE region, we have a resting pot. of -90mV between inside/outside. If we are lowering the voltage outside the membrane by -20mV, the NET effect is to REDUCE THE INTERMEMBRANE POTENTIAL TO -70mV. "less negative". This creates an AP. On the ANODE we hyperpolarize.

UNIPOLAR SYSTEM, we need provide a negative pulse

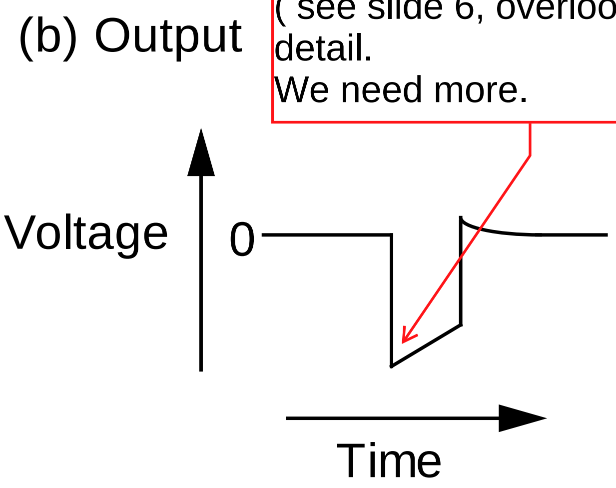
Pulses generator (basic)

common emitter

no current on Rc if BJT off, the C is at Vdd.
The drop on the R (after transient) is Vdd

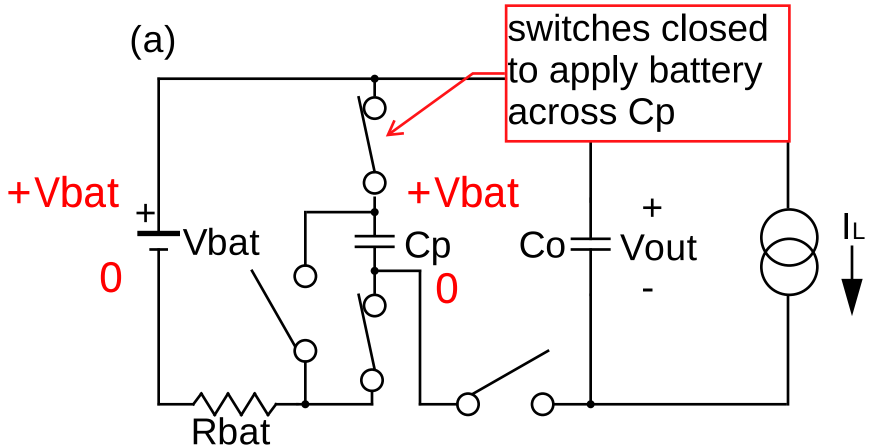


in realtà -Vdd is not sufficient :
(see slide 6, overlooked detail.
We need more.

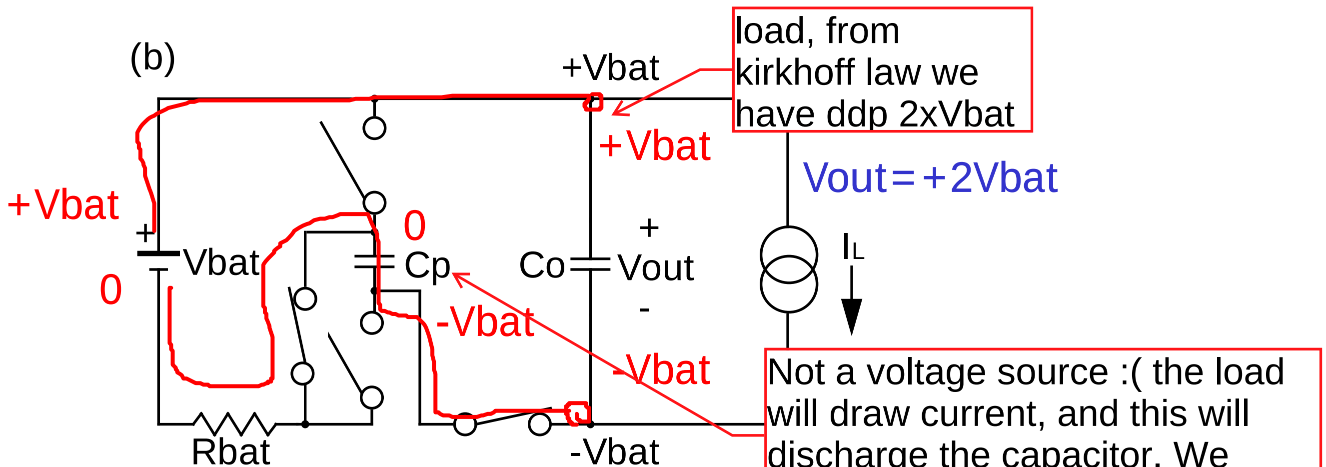


2)(descrizione fatta per il MOS) Then we supply a voltage, we switch on the transistor, and thus the drain drops down because there's a current across the R. Vds at limits goes to 0. Thus over the cap we go from vdd to 0 (node C). The cap is storing change, if that extremity goes to zero, the other goes to -Vdd. Thus we provide negative voltage to the load.TRICK: have a precharged capacitor of Vdd! After 1mS you stop the pulse.

Generation of V > V_{supply}



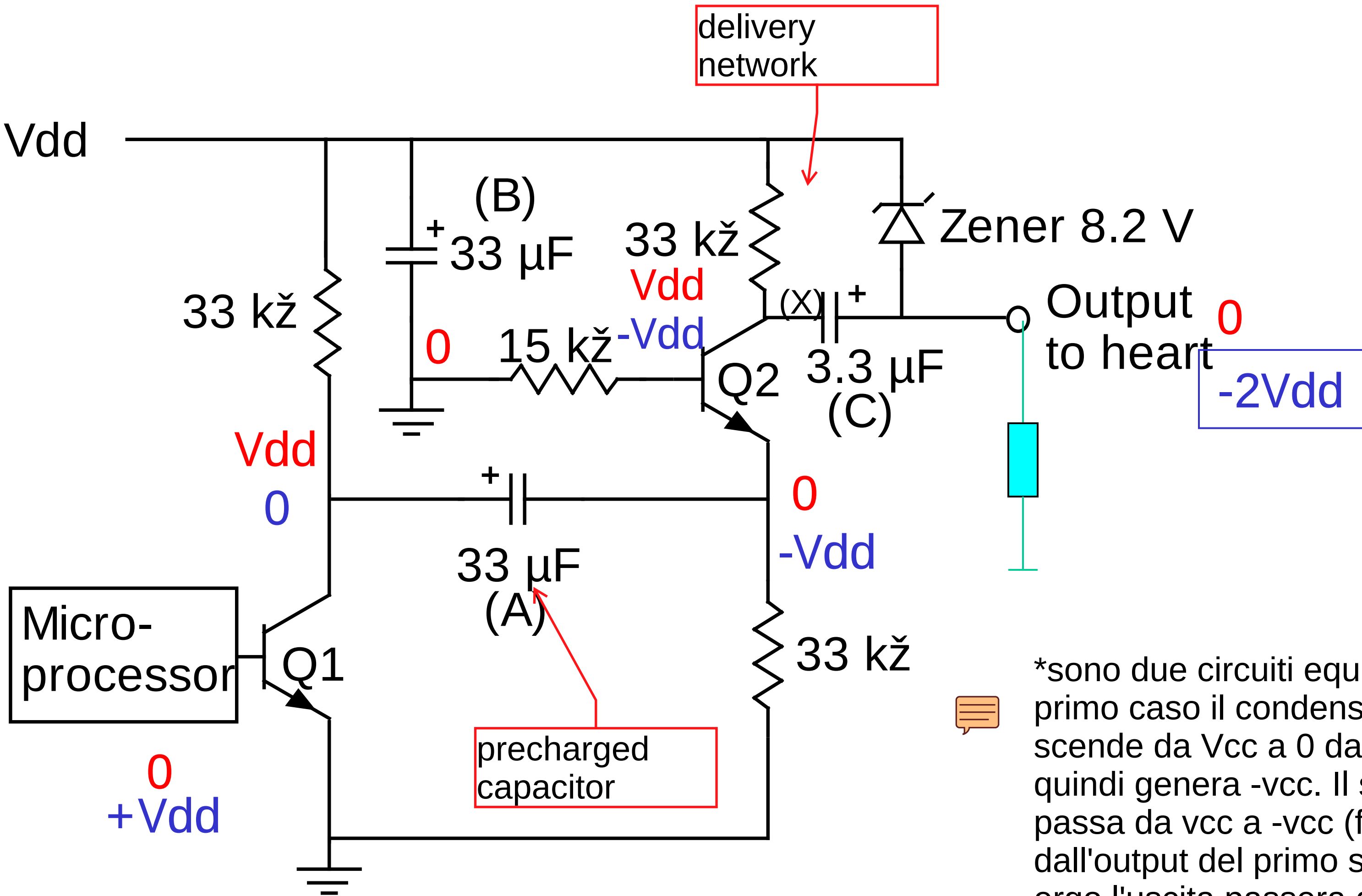
Phase I



Phase II

We need to provide more than Vdd, at least twice, due to the voltage partition. We precharge a cap with Vbattery, and then we use it in series with the battery.

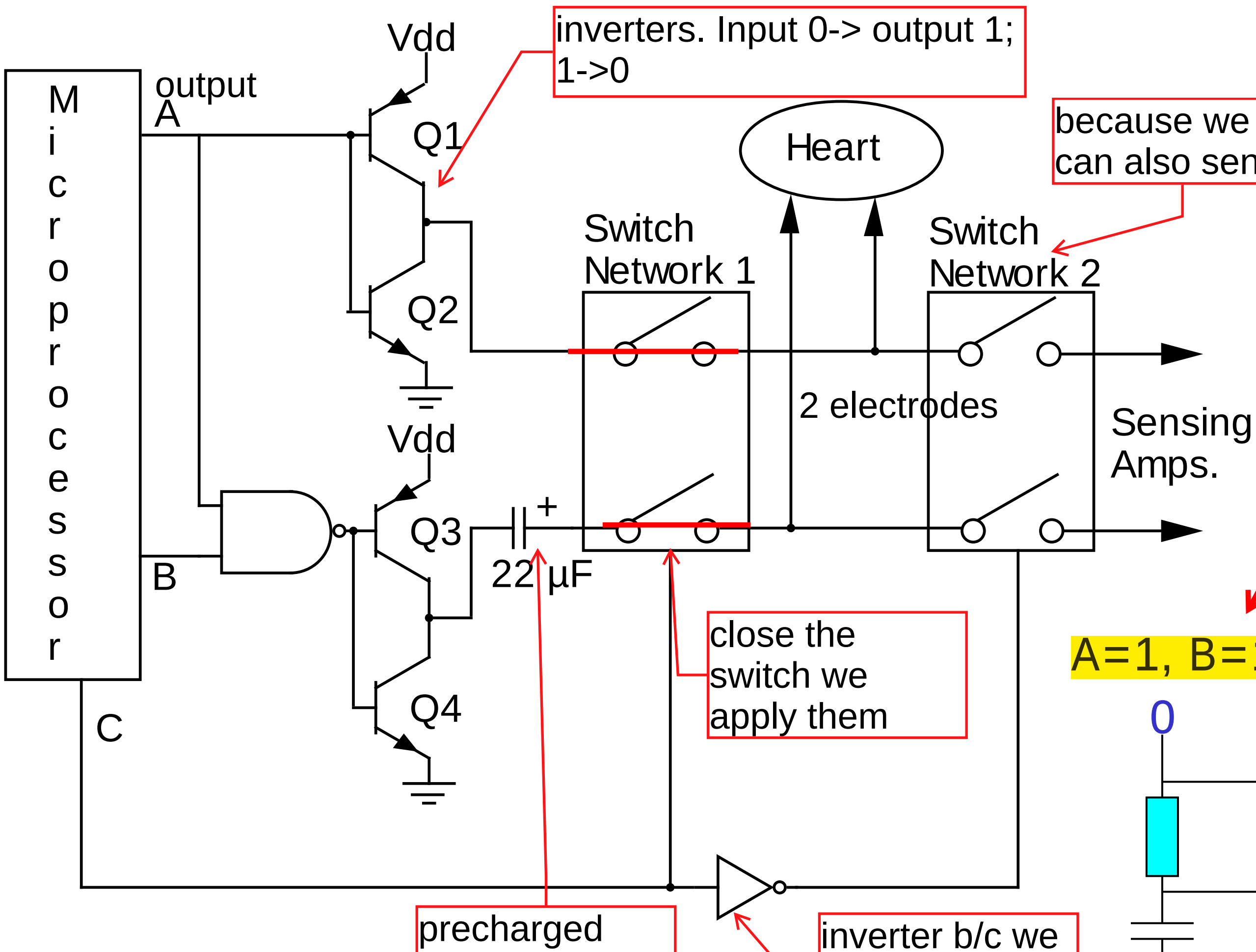
Pulses generator (unipolar)

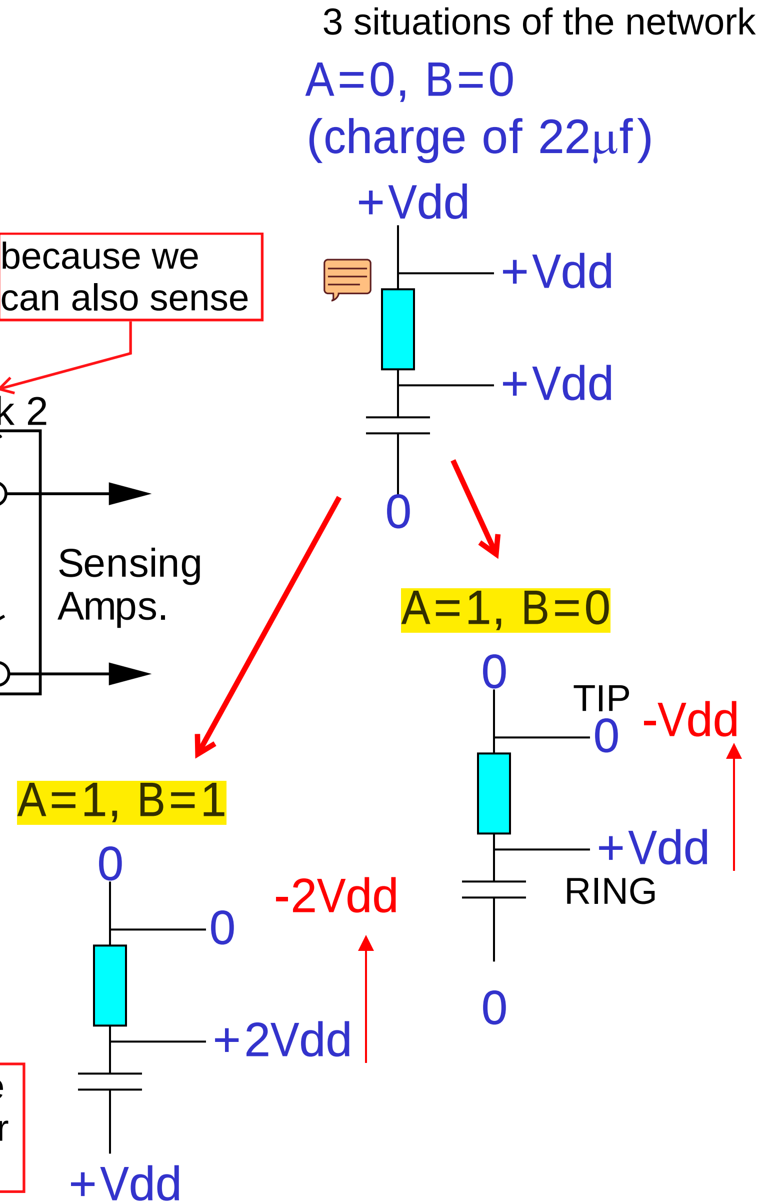


*sono due circuiti equivalenti, nel primo caso il condensatore scende da Vcc a 0 da un lato, quindi genera -vcc. Il secondo passa da vcc a -vcc (fornito dall'output del primo stadio). ergo l'uscita passera da 0 a -2vcc.

"the charges are not changed immediately and thus the right part goes to -Vdd"

Pulses generator (bipolar)



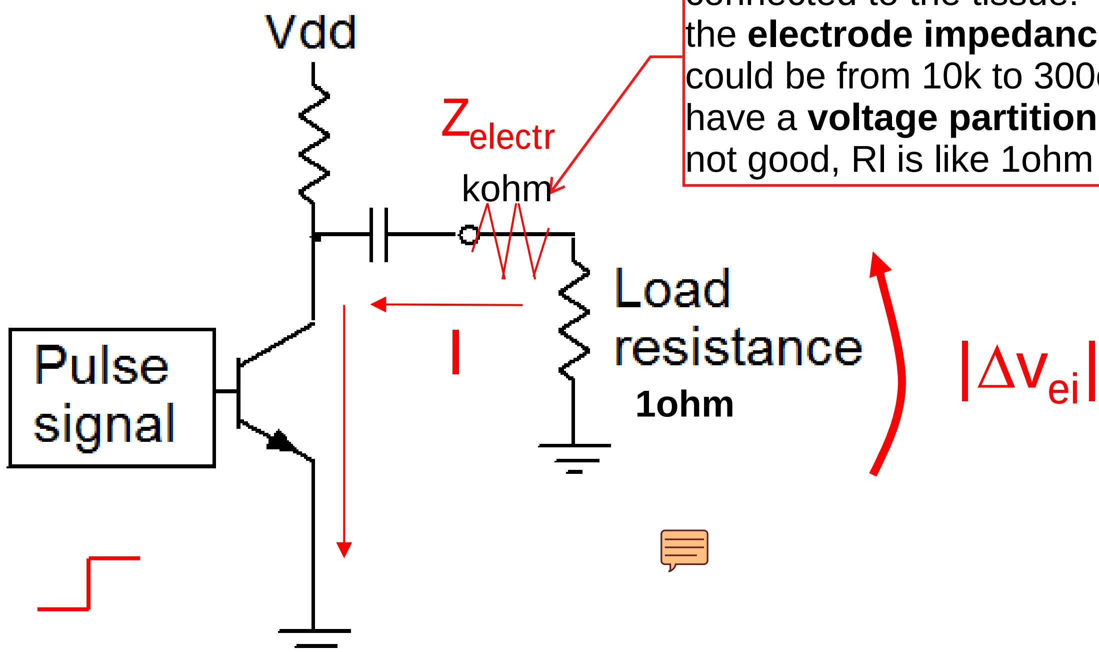


C: 1 (pulse), 0 (sense)

Current vs. pulse duration

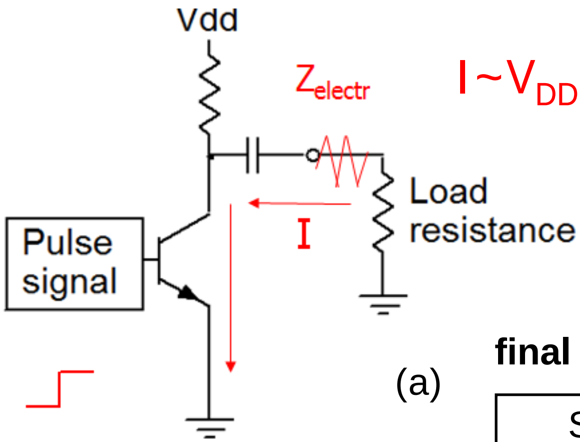
We first observe that:

output pin IS NOT directly connected to the tissue! There's the **electrode impedance**!! It could be from 10k to 300ohm. We have a **voltage partition**. Also not good, Rl is like 1ohm :((.



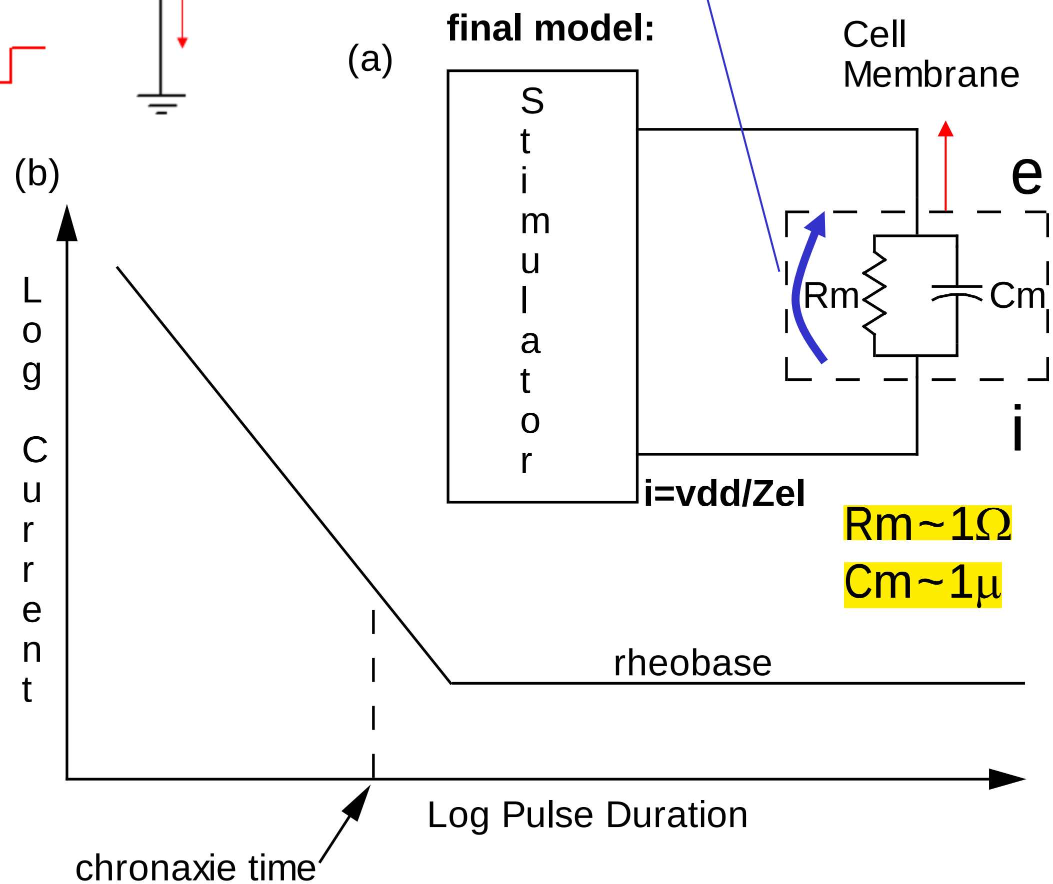
1) Due to $Z_{electr} >> R_{load}$, $\Rightarrow |\Delta V_{ei}| << Vdd$ (that's why we tried to increase Vdd)
2) $I \sim Vdd/Z_{electr}$ (it does not depend on the load and it is increased by means of Vdd)

Current vs. pulse duration



$I \sim V_{DD}/Z_{electr}$

$|\Delta V_{ei}|$ for depol. $= +20mV$



Rm~1Ω

Cm~1μ

- We need a large Vdd to create the minimum ΔV of 20mV on the load
- The load can be represented by a Cm in parallel to a Rm
- If we think in terms of current I (instead of Vdd), we can determine a minimum current I necessary to provide 20mV of stimulation:

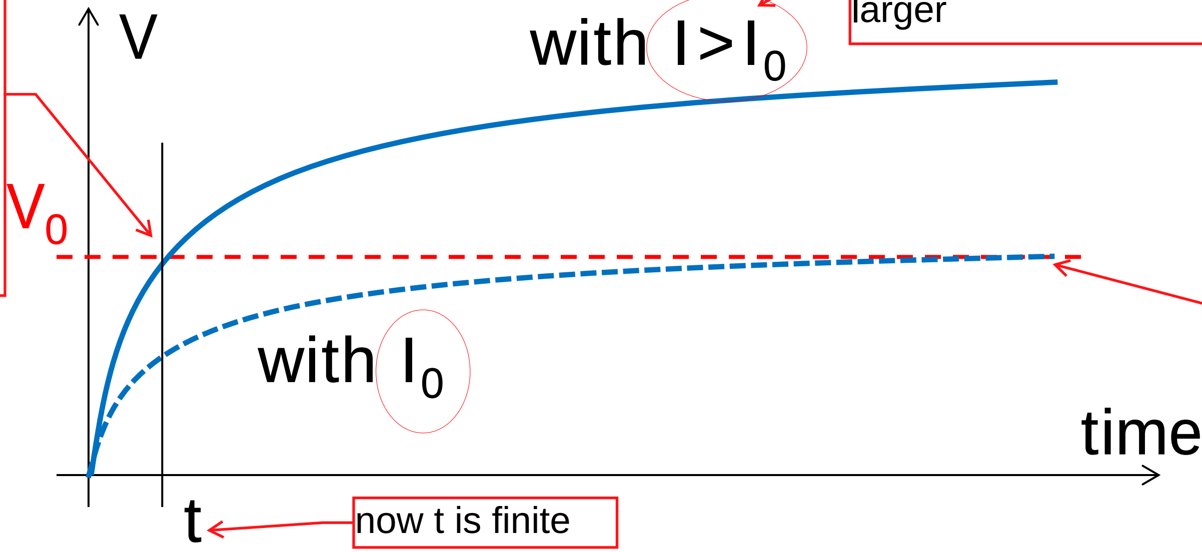
$$V = IR(1 - e^{-t/RC})$$

$$I = 20\text{ mV} / 1\,\Omega = 20\text{ mA}$$

*cioè, Vdel/Zel => 20mA

we still stop when we reach 20mV. Potrei anche fare supply di current ancora maggiore, ma per tempo minore (impulso maggiore, più stretto). Ho bisogno di più Vdd

we can supply more, the asyntothic value is larger



$I = \alpha I_0$

minimum current (I0, 20mA): after inf. time we get there

now t is finite

t: pulse duration

$$V_0 = \alpha I_0 R(1 - e^{-t/RC})$$

alpha: multiplying factor >1, how much larger than I0 should I supply

V_0 can be reached
with $I = I_0$ ($\alpha = 1$), but with a pulse duration $t \to \infty$
or
with $I > I_0$ and a finite pulse duration t

$\Rightarrow$ which is the best compromise for I and t?

*per realizzare AP devo depolarizzare di 20mV. Considerando l'impedenza Rm=1ohm, il minimo è 20mA di stimolo per tempo finito. Se fornisco una corrente maggiore allora il tempo per dep. a 20mV si riduce. In questo caso viene considerata anche Cm!

Relationship between current and duration.

$$V_0 = \alpha I_0 R(1-e^{-t/RC})$$

V0 is 20mV. **t** is the time to reach 20mV

$$\frac{V_0}{\alpha I_0 R} = (1-e^{-t/RC}) \qquad -\frac{t}{RC} = \ln(1-\frac{V_0}{\alpha I_0 R})$$

approx if time is low

$$\ln(1+x) \approx x \qquad \frac{t}{RC} \approx \frac{V_0}{\alpha I_0 R} \qquad t \approx \cancel{R}C\frac{V_0}{\underbrace{\alpha I_0}_{=I} \cancel{R}}$$

inverse proportionality between I and t (for large I)

multiply and divide for I0:

$$t = C\frac{V_0}{\underbrace{I}_{I=aI0}} \qquad I = C\frac{V_0}{t}\frac{I_0}{I_0} \qquad I = I_0\frac{t_c}{t} \qquad (t_c = CV_0/I_0)$$

$$I = I_0\frac{t_c}{t}$$

OK for t small

se il tempo che ci vogliamo mettere è inf allora deve venire fuori I0!

no OK for $t \to \infty$
(does not go to I_0) I goes to 0 :(

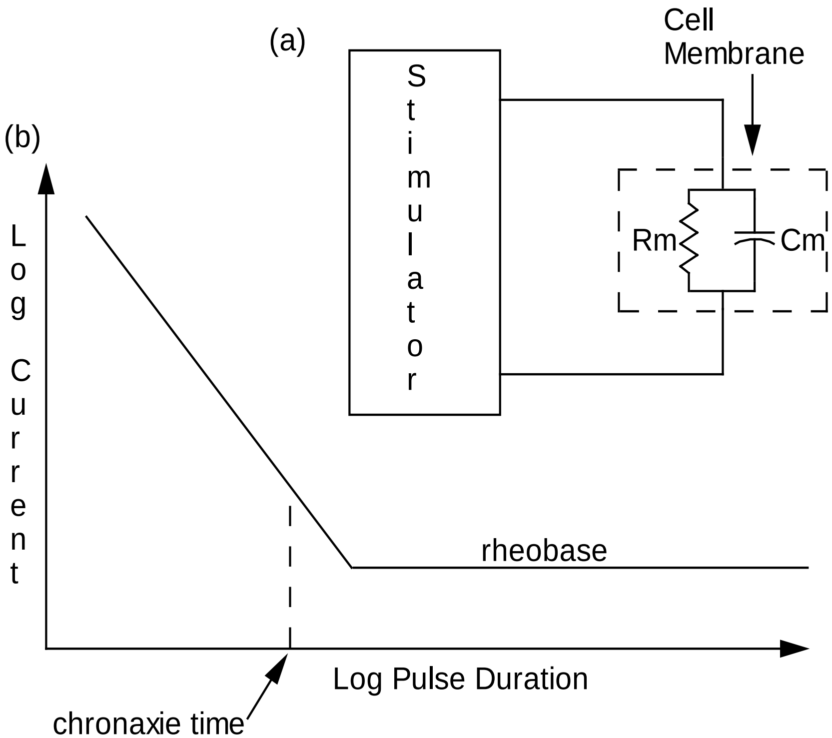
$\Rightarrow$

we can add +1 to fix this..:

$$\boxed{I = I_0(1+t_c/t)}$$

($I \to I_0$ for $t \to \infty$) Now it works

key point: charge consumption for the battery. How much charge is delivered in the two pulses? they are not the same (*il tempo si stringe non linearmente con l'intensità).
t=> tempo che vogliamo



$$\boxed{I = I_0(1 + t_c / t)}$$

which is the best compromise for I and t?

(not power)!

$\Rightarrow$ minimize the energy consumption

$$E = I^2 Zt$$

En=Power*time

we put the I calculated:

$$\frac{dE}{dt} = I_0^2 Z\left(1 - \frac{t_c^2}{t^2}\right)$$

minimization=>
we put d/dt = 0

$$\frac{dE}{dt} = 0 \quad \text{for } t = t_c \Rightarrow \boxed{I = 2I_0}$$

$$E = (2I_0)^2 Zt_c = \underline{4}I_0^2 Zt_c$$ best case

$$E = \underline{7.2}I_0^2 Zt_c \quad (t = 0.2t_c)$$ small t

$$E = \underline{4.5}I_0^2 Zt_c \quad (t = 2t_c)$$

We consider constant impedance. We put the current calculated, we obtain that the CURRENT IS TWICE THE I0. Optimum current for minimum energy consumption: is in between, not too hight, not the minimum. **We set 40mA.**