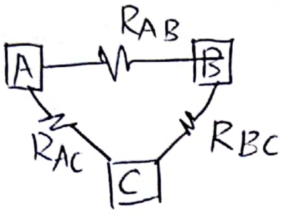
Spring 2018
Problem 5

a) Smart bandage

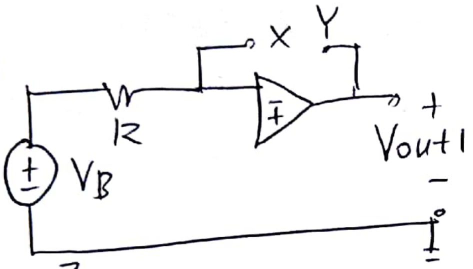


$R_{AB}, R_{BC}, R_{AC} \rightarrow$ Skin resistances

$50\Omega - 150\Omega$

$50\Omega \downarrow$ Wound healed; $150\Omega \downarrow$ Not healed

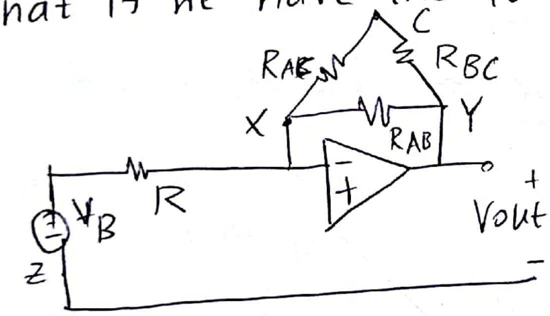
i)



Target: $V_{out1} = \text{function}(R_{AB}, R, V_B)$

$V_{out1} \neq \text{function}(R_{BC}, R_{CA})$

What if we have the following?



Inverting amplifier

$$V_{out1} = -\frac{R_{eq,XY}}{R} V_B$$

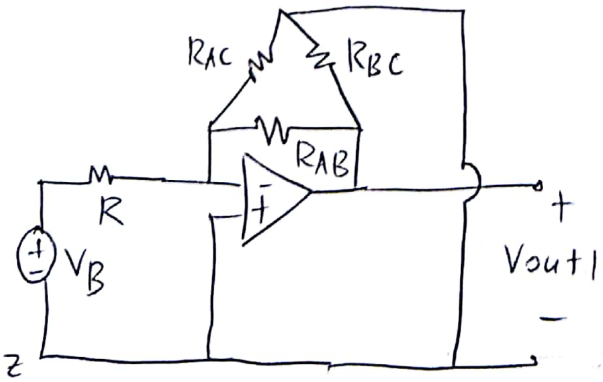
$$= -\frac{R_{AB} \parallel (R_{AC} + R_{BC})}{R} V_B$$

$\uparrow$ function of R_{AC}, R_{BC}

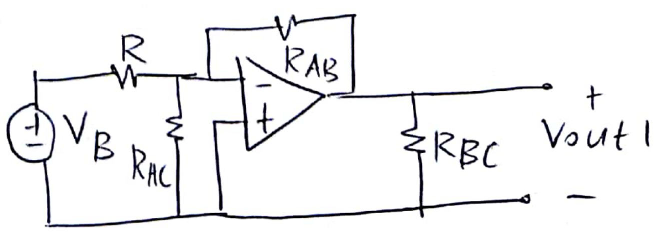
- Not a valid solution

* Also we need to connect C to any of the three nodes: X, Y, Z.

New approach



$\equiv$



Is V_{out1} a function of R_{AC} & R_{BC} now?

Clue: Redraw & simplify

* Is $V_{out1} = f(R_{BC})$?

Op-amp output V_{out1} is not a function of R_{BC}

$V_{out1} \neq f(R_{BC})$ (R_{BC} is virtually the load here, which does not change opamp V_{out})

* Is $V_{out1} = f(R_{AC})$?

Do we have feedback?

NFB (Clue: Dink the output & figure out)

Golden rule # 2 applies: $U^- = U^+$

Voltage across $R_{AC} = U^- = U^+ = 0$, No current through R_{AC}

$V_{out1} \neq f(R_{AC})$

ii) Find expression for Vout 1.

Pattern matching? Inverting amplifier

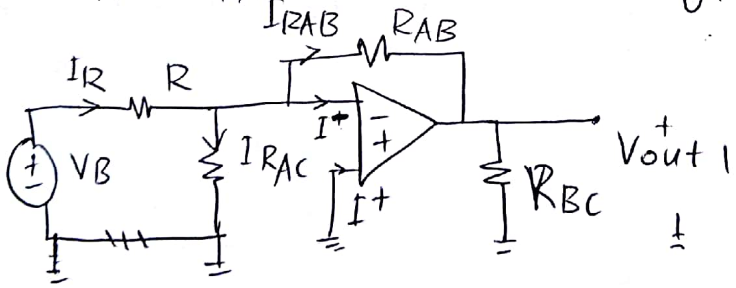
When in doubt → Nodal analysis

Golden rule #1

$I^+ = I^- = 0$

KCL: $I_R = I_{RAC} + I^- + I_{RAB}$

$\Rightarrow I_R = I_{RAB}$ (I)



Golden Rule #2

$U^- = U^+$

$\Rightarrow I_{RAC} = \frac{U^- - U^+}{R_{AC}} = 0$

$U^+ = 0 \Rightarrow U^- = 0$

$I_R = \frac{V_B - U^-}{R} = \frac{V_B}{R}$ (II)

$I_{RAB} = \frac{U^- - V_{out1}}{R_{AB}}$

$\Rightarrow V_{out1} = -I_{RAB} R_{AB}$ (III)

$$\begin{aligned}
\text{(III)} \rightarrow V_{out1} &= -I_{RAB} R_{AB} \\
&= -I_R R_{AB} \quad [\text{Using (I)}] \\
&= -\left(\frac{V_B}{R}\right) R_{AB} \quad [\text{Using (II)}] \\
&= -\left(\frac{R_{AB}}{R}\right) V_B
\end{aligned}$$

→ Inverting amplifier indeed.

iii) Target : $-1.5mV \leq V_{out1} \leq -0.5mV$, have to find R

$V_B = 5V$.

Also : $|I_{RAB}|, |I_{RAC}|, |I_{RBC}| < 100\mu A$

If $V_{out1} = -\frac{R_{AB}}{R} V_B$, we have,

For, $V_{out1} = -0.5\,mV \Rightarrow -\frac{R_{AB,min}}{R} V_B = -0.5mV$

$\Rightarrow -\frac{50}{R} \times 5 = -0.5mV \Rightarrow R = 500k\Omega$

For, $V_{out1} = -1.5mV \Rightarrow -\frac{R_{AB,max}}{R} V_B = -1.5\,mV$

$\Rightarrow -\frac{150}{R} \times 5 = -1.5\,mV \Rightarrow R = 500k\Omega$

Now, are the currents $< 100\mu A$ for worst case scenarios?

$\rightarrow I_{RAC} = 0 < 100\mu A$ ✓

$\rightarrow |I_{RAB,max}| = \left|\frac{V_{out1,\cancel{max}}}{R_{AB,\cancel{max}}}\right|_{max} = \frac{V_B}{R} = \frac{5V}{500k\Omega} = 10\mu A < 100\mu A$ ✓

↓

Not a function of R_{AB}

$\rightarrow |I_{RBC,max}| = \left|\frac{V_{out1,max}}{R_{BC,min}}\right|$

$= \frac{R_{AB,max}}{R} V_B \times \frac{1}{R_{BC,min}}$

$= \frac{150}{500k} \times 5 \times \frac{1}{50}$

$= 30\mu A < 100\mu A$

$\boxed{R = 500k\Omega \text{ works!}}$

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b) $-1.5mV \leq V_{out1} \leq -0.5mV$

Target: $500mV \leq V_{out2} \leq 1.5V$, with opamp(1) & resistors(2)

We can see that V_{out2} can be $-1000 V_{out1}$

$\rightarrow$ Inverting amplifier with a gain of 1000.

[Side note:

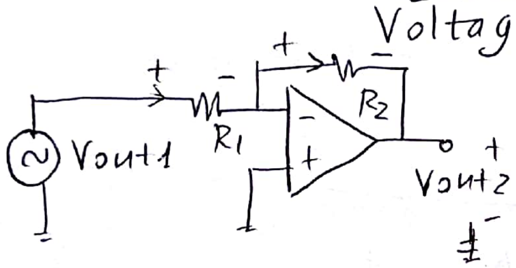
What if we needed $V_{out2}: -0.5V \leq V_{out2} \leq 0.5V$

and V_{out1} was: $0 \leq V_{out1} \leq 1mV$

$V_{out2} = 1000 V_{out} \underbrace{-0.5V}$

Voltage shifter required: See Dis 10A]

i)



$R_2 = 1000 R_1$

$V_{out2} = -\frac{R_2}{R_1} V_{out1}$

ii) To prevent skin damage

Power(R_1) < ~~10~~ $1\mu W$

Power(R_2) < $1\mu W$

[Problem description has $1\mu W$. I did it with $10\mu W$ in review by mistake! My bad!]

$$\text{Power dissipated in } R_1 = \frac{(V_{diff,R1})^2}{R_1} = \frac{(V_{out,1}-0)^2}{R_1} = \frac{|V_{out,1}|^2}{R_1}$$

$$\text{Power dissipated in } R_2 = \left(\frac{V_{diff,R2}}{R_2}\right)^2 = \frac{(0-V_{out2})^2}{R_2} = \frac{|V_{out,2}|^2}{R_2}$$

Now, ~~Vout~~ $P_{R1,max} < 1\mu W$

$\Rightarrow \frac{|V_{out1}|^2_{max}}{R_1} < 1\mu W$

$\Rightarrow \frac{|-1.5mV|^2}{R_1} < 1\mu W$

$\Rightarrow R_1 > 2.25\Omega$

$P_{R2,max} < 1\mu W$

$\Rightarrow \frac{|V_{out2}|^2_{max}}{R_2} < 1\mu W$

$\Rightarrow \frac{1.5^2 V}{R_2} < 1\mu W$

$\Rightarrow R_2 > 2.25M\Omega$

What if we choose: $\boxed{\begin{matrix} R_1 = 3k\Omega > 2.25\Omega \\ R_2 = 3M\Omega > 2.25M\Omega \end{matrix}}$ } Works!

c)

$V_W \rightarrow$ voltage signal from wound

$V_h \rightarrow$ voltage signal from healthy skin

Target: LED shines brighter ($V_{LED} \uparrow$) when ~~W~~ ($V_W - V_h$) increases.

★ Can we use a comparator to compare V_W & V_h?

No. Comparators has two levels of voltage.

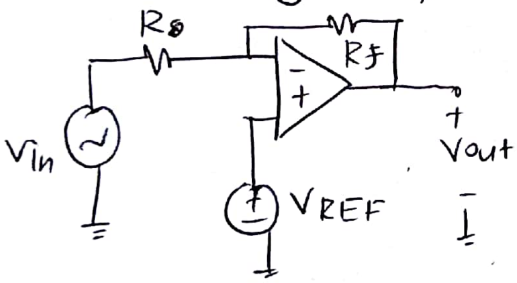
We need continuous change in V_{LED}

We need $V_{LED} = V_W - V_h \rightarrow$ Negative Feedback will work.

How do we approach this problem?

<u>Cookbook shortcut approach:</u>

Inverting amplifier: Example



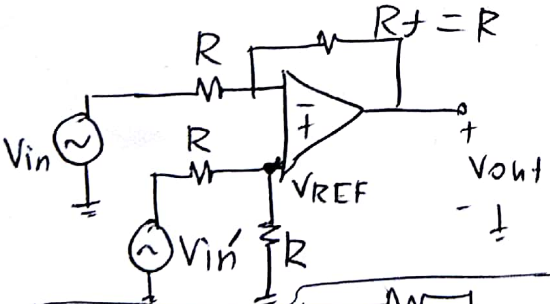
$$V_{out} = \underbrace{V_{in}\left(-\frac{R_f}{R}\right)}_{-ve} + \underbrace{V_{REF}\left(\frac{R_f}{R}+1\right)}_{+ve}$$

can make this work.

Choose $R_f = R$,

$$V_{out} = -V_{in} + 2V_{REF}$$

Can we make $V_{REF} = \frac{1}{2}V_{in}'$? $\rightarrow$ Voltage divider

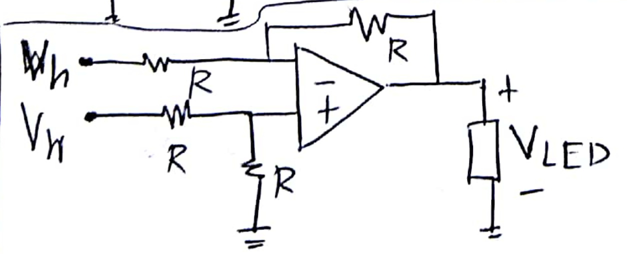


For this circuit:

$$\underline{V_{out} = V_{in}' - V_{in}}$$

Subtraction operation can use this!

Ans:



$$V_{LED} = V_W - V_h$$

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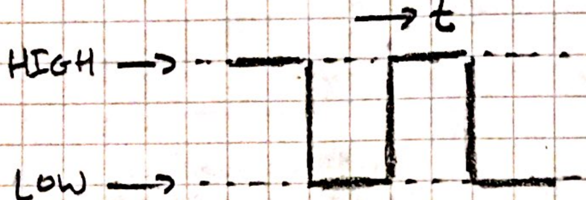
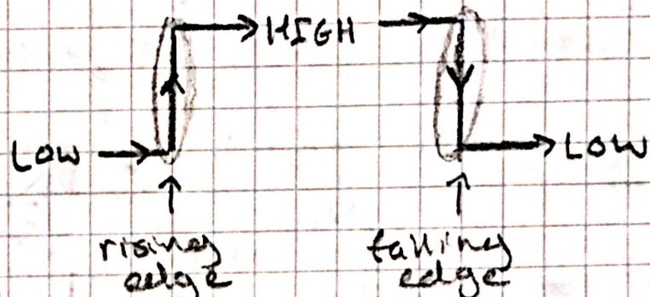
Spring 2018 #6

Some quick terminology I will be using:

for a square wave, which looks like this:





rising edge: LOW → HIGH
falling edge: HIGH → LOW

a) want a sensor circuit with specifications:

Jewanna steps off creates a rising edge

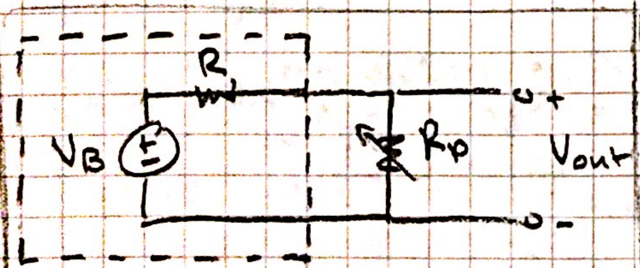
output: $V_{out} = 0.5V$ ($R_p = 1k\Omega$) output: $V_{out} = 2V$ ($R_p = 10k\Omega$)

we're given a force sensitive resistor such that when Jewanna is on the sensor, $R_p = 1k\Omega$ and when she is off the sensor, $R_p = 10k\Omega$

we notice that small R_p corresponds to small V_{out} and bigger R_p corresponds to bigger V_{out}.
What kind of circuit does that sound like?

Voltage divider, where $V_{out} = \frac{R_p}{R+R_p} V_B$

We're given this R_p, and a voltage source and other resistors to design the circuit, so let's draw it and solve for R and V_B, our design variables



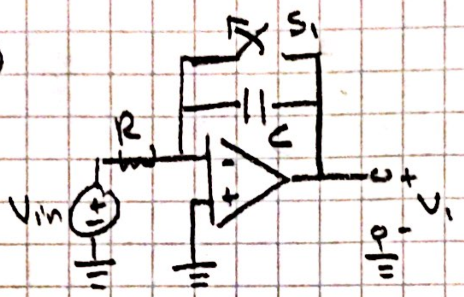
rearranging our voltage divider eq.

$$V_{out} R - R_p V_B = -V_{out} R_p$$

$$(0.5)R - (1k)V_B = -0.5k$$
$$(2)R - (10k)V_B = -20k$$

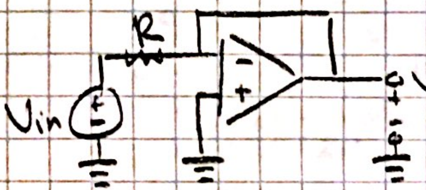
$$\Rightarrow \boxed{\begin{array}{l} R = 5k\Omega \\ V_B = 3V \end{array}}$$

We have two sets of R_p, V_{out}, so this is a system of linear equations b)



We want V_1 in terms of V_{in}.
We're given that C is discharged at $t=0$, and $V_{in}=0$ at $t=0$.
after $t=0$, V_{in} is a constant.
Let's look at the cases for S_1 open and S_1 closed.

S_1 closed

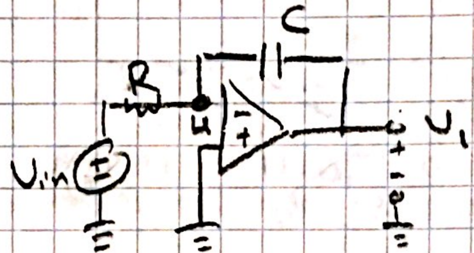


by golden rules, we can see

$V_1 = 0$

$t < 0$

S_2 open



using nodal analysis at u

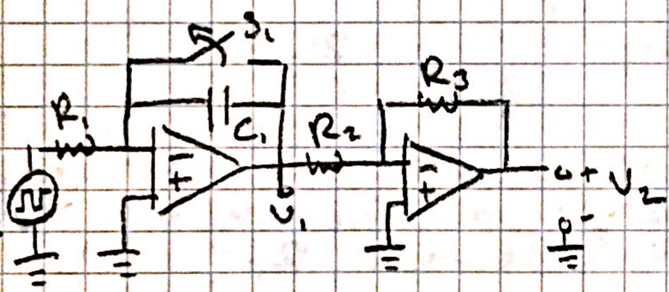
$$\frac{V_{in}}{R} = -C\frac{dV_1}{dt}$$

with a negative to account for current direction. Integrating,

$$V_1 = \frac{-1}{RC}\int V_{in}\,dt = \frac{-1}{RC}\left(V_{in}t + V_{in}(0)\right)$$

$$\Rightarrow \boxed{V_1 = \frac{-1}{RC}V_{in}t} \quad t \geq 0$$

c)

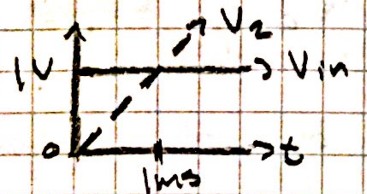


given $R_1 = R_2 = R_3 = 1k\Omega$
$C_1 = 1\mu F$
and op amp rails are both $\pm 1V$
C starts discharged at $t=0$

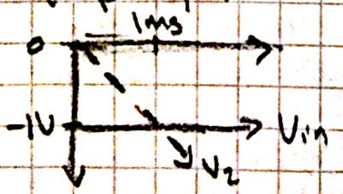
since $R_2 = R_3$, the next op amp circuit is an inverter, so that $V_2 = -V_1$

$$\Rightarrow V_2 = \frac{1}{RC}\int V_{sq}\,dt \quad \text{and } RC = (1k\Omega)(1\mu F) = 1ms$$

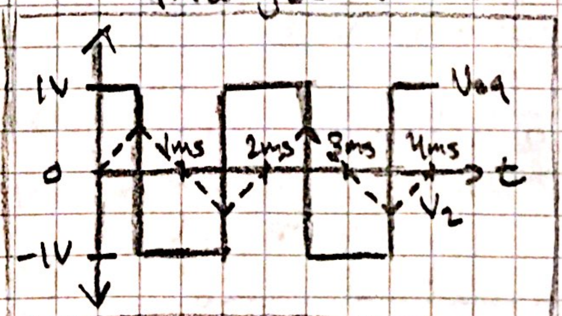
for a constant positive input, $RC = 1ms$



for a constant negative input, $RC = 1ms$



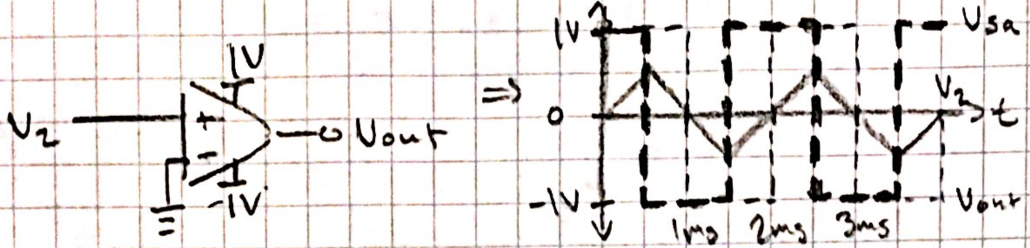
so then our square wave input should give us a triangle wave.



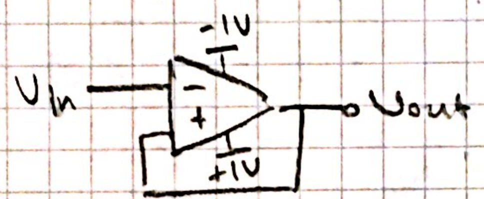
note: at $t = \frac{1}{2}ms$, $V_2 = \frac{1}{2}V$
from $V_2 = \frac{1}{RC}V_{in}t$

so our peaks are at $\pm\frac{1}{2}V$

d) since we only have resistors and an op amp, our first guess should be a comparator, since the comparator will spit out constant voltages as long as the input voltage doesn't cross V_{ref} in time.

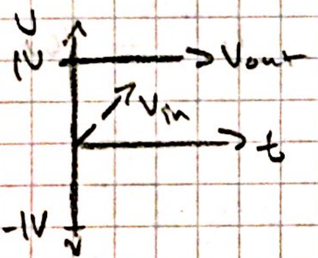


almost, but it's shifted in time, so we want a reference voltage that changes depending on the input. we accomplish this with some feedback

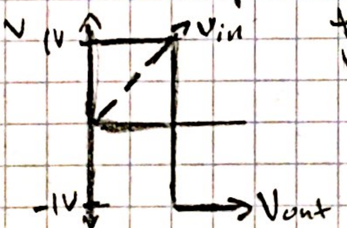


note: has to be positive feedback because we still want the opamp to rail to give us the square wave effect: only constant voltages.

so assume Vout starts higher than V_{in}.



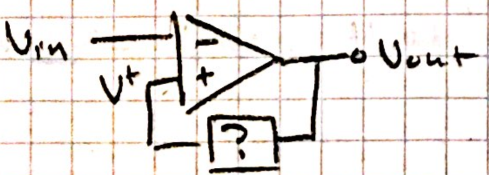
when V_2 passes Vout



then Vout rails to the bottom because of the comparator effect, since now $V^- > V^+$.

we can see how to get the edges at the peaks of a triangle wave.

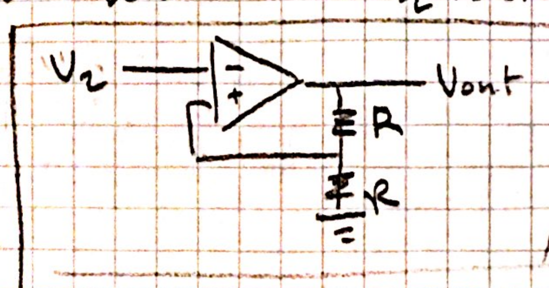
but our V_2 only reaches up to $\frac{1}{2}$V and $-\frac{1}{2}$V, so we need to lower the feedback input (V^+), since we can't raise the V_2 peak (we only have one op amp)

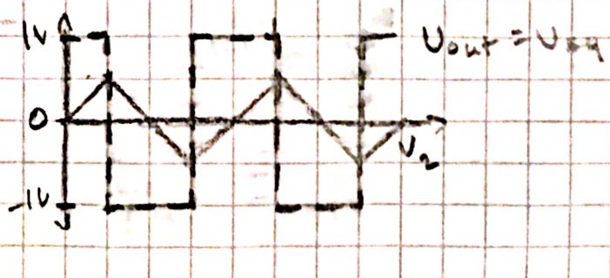


so how do we scale down Vout so that V^+ will switch at the Vin peaks?

Voltage Divider! we know max/min are ± 1V, and the input peaks are $\pm\frac{1}{2}$V,

so we want $V^+ = \frac{1}{2}V_{out}$.

=> 



e) pulses have a period of 2ms, so when Dewanna starts running, the pulses start going, and when she finishes, the switch switches back and the V_2 goes back to zero, stopping the pulses.

total time is then # pulses x pulse period