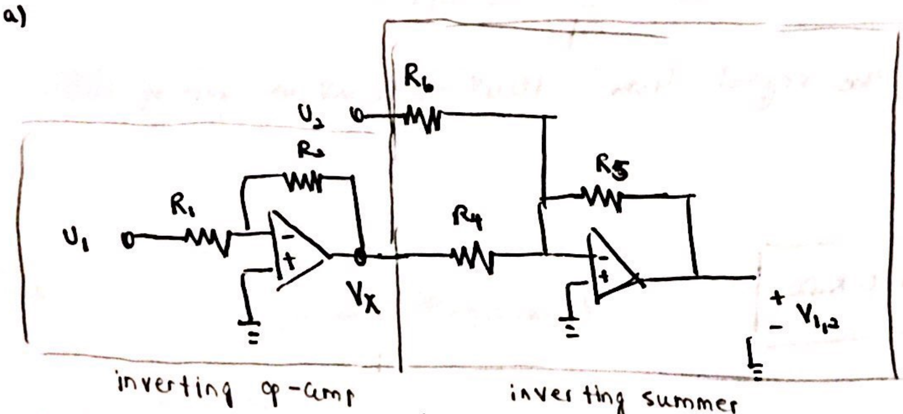
Spring 2017 Final

3. a)

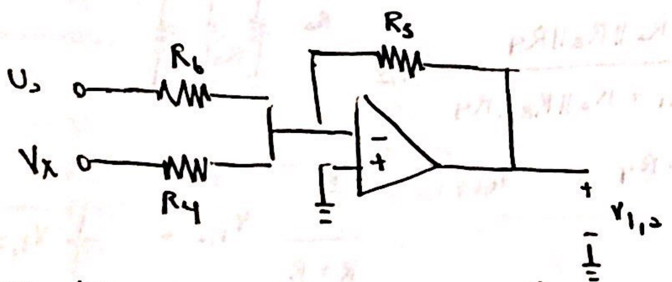



This is a cascade of ~~op-amp~~ two op-amp circuit blocks: an inverting op amp and an inverting summer.

We can simplify by looking at the first block and solving for $v_x$.

$v_x = \frac{-R_2}{R_1} v_1$ (basic inverting op-amp)

We can then redraw the circuit as




Doing KCL at node $v^-$: $\frac{\cancel{v^-}^{0} - v_2}{R_6} + \frac{\cancel{v^-}^{0} - v_x}{R_4} + \frac{\cancel{v^-}^{0} - v_{1,2}}{R_5} = 0$

$v^- = 0$ by Golden Rules

$$\Rightarrow v_{1,2} = -\left[\frac{R_5}{R_4} v_x + \frac{R_5}{R_3} v_2\right]$$

$$= -\left[\frac{R_5}{R_4}\left(\frac{-R_2}{R_1} v_1\right) + \frac{R_5}{R_3} v_2\right]$$

We are given $R_1 = R_2$, $R_3 = R_4$

$$\boxed{\Rightarrow v_{1,2} = \cancel{-} \frac{R_5}{R_4}(v_2 - v_1)}$$ 负号反了

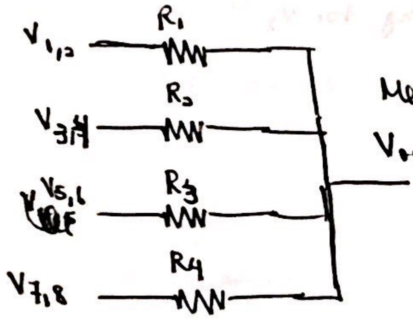
b) From part (a), we have $V_{1,2} = \frac{R_5}{R_4}(U_2 - U_1)$.

We want to amplify the signal from $10\,\mu V$ to $10\,mV \Rightarrow$ gain of 1000.

Therefore $\frac{R_5}{R_4} = 1000$.

$$\boxed{R_4 = 100\,\Omega \rightarrow R_5 = 100\,k\Omega}$$

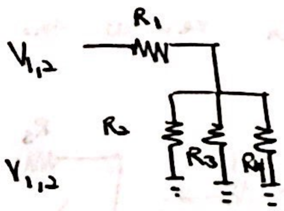
c) We want to build a circuit that takes the average of all 4 signals, and then amplifies by 25. We can average by using the summing circuit from the "cookbook".




We can solve for $V_{out}$ in two ways:

Method 1. Use superposition and voltage dividers.

Null $V_{3,4}$, $V_{5,6}$, $V_{7,8}$:




$$V_{out\,1,2} = \frac{R_2 \| R_3 \| R_4}{R_1 + R_2 \| R_3 \| R_4} V_{1,2}$$

If $R_1 = R_2 = R_3 = R_4$: $V_{out\,1,2} = \frac{\frac{R}{3}}{R + \frac{R}{3}} V_{1,2} = \frac{1}{4} V_{1,2}$

Repeating this process for $V_{out\,3,4}$, $V_{out\,5,6}$, $V_{out\,7,8}$

we get $V_{out} = \frac{1}{4}\left[V_{1,2} + V_{3,4} + V_{5,6} + V_{7,8}\right]$

This performs the averaging operation we wanted!

Method 2: $I_{out} = \frac{V_{1,2}}{R_1} + \frac{V_{3,4}}{R_2} + \frac{V_{5,6}}{R_3} + \frac{V_{7,8}}{R_4}$

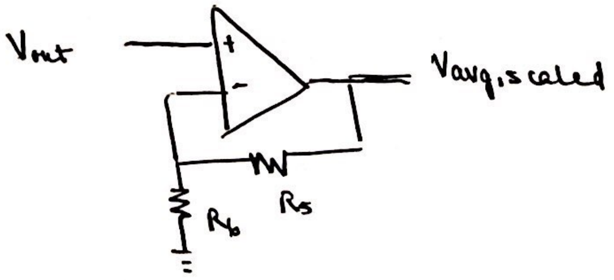
$R_{out} = R_1 \| R_2 \| R_3 \| R_4$

$$V_{out} = I_{out} R_{out} = \left(\frac{V_{1,2}}{R_1} + \frac{V_{3,4}}{R_2} + \frac{V_{5,6}}{R_3} + \frac{V_{7,8}}{R_4}\right)\left(\frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}}\right)$$

If $R_1 = R_2 = R_3 = R_4$

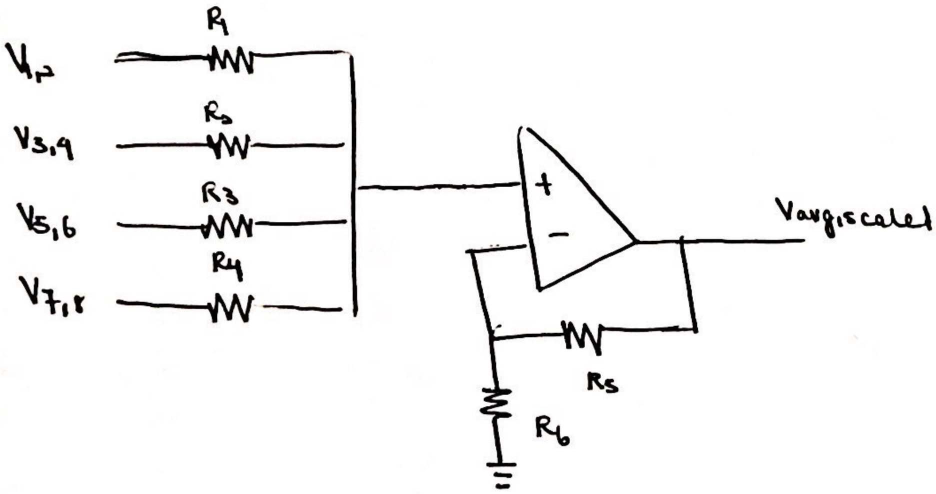
$$V_{out} = \frac{1}{\cancel{R}}\left[V_{1,2} + V_{3,4} + V_{5,6} + V_{7,8}\right]\left(\frac{\cancel{R}}{4}\right) = \frac{1}{4}\left(V_{1,2} + V_{3,4} + V_{5,6} + V_{7,8}\right)$$

Now we need a gain of 25. We can simply feed Vout into a non-inverting op amp configuration.




$$\frac{V_{avg,scaled}}{V_{out}} = 1 + \frac{R_5}{R_6} = 25 \Rightarrow \frac{R_5}{R_6} = 24$$

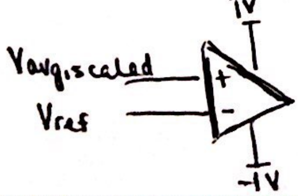
So, the overall circuit looks like this:




$R_1 : R_2 : R_3 : R_4 : R_5 : R_6 = 1:1:1:1:24:1$

( $R_1 - R_4$ need to be the same, $R_5 : R_6 = 24:1$ )

d) The max value Vavg,scaled will reach when AWAKE is 125 mV.
The max value Vavg,scaled will reach when SLEEPY is 375 mV.
We can ~~implement~~ use a comparator.




$125\text{ mV} < V_{ref} < 375\text{ mV}$