Project: Digital Pulse Oximeter.

Principle:

1). Beer's Law: $I = I_0 \cdot 10^{-\varepsilon C L}$

I_0: light intensity entering sample.
I: 〃 leaving sample.
ε: extinction coefficient
C: sample concentration
L: sample length (depth)

2) Absorbance of Hemoglobin (Hb) and Oxygenated Hemoglobin (Hb_{O_2}) at various wavelength.

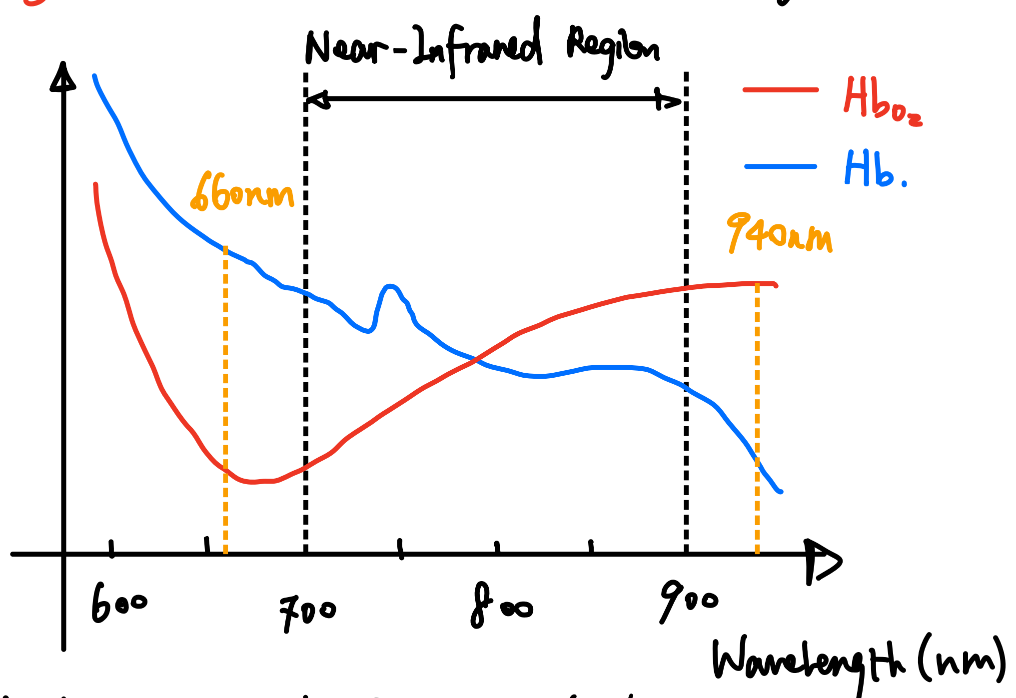
Absorbance:

$A = \varepsilon C L$.

* assume C and L constant.

C = 1 mmol

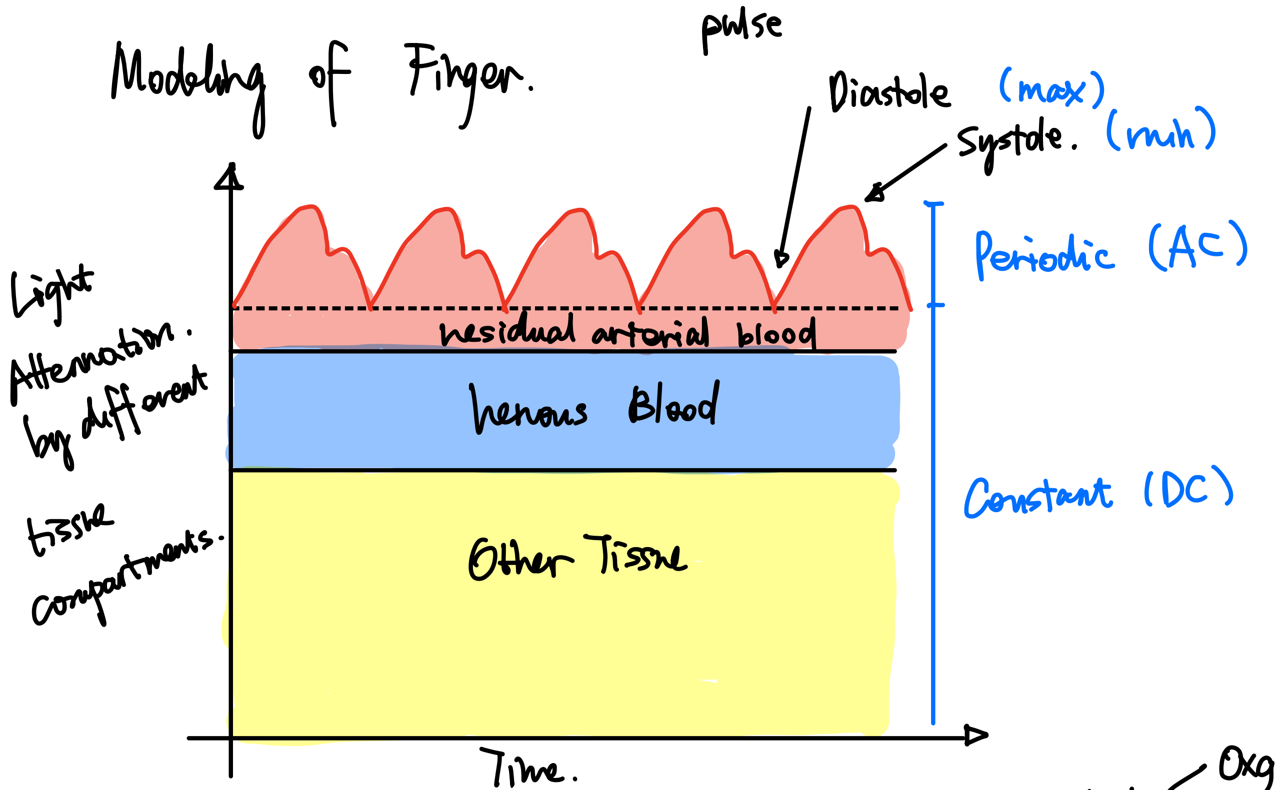
L: 1 cm



wavelength	ε_{Hb}	$\varepsilon_{Hb_{O_2}}$
660	0.81	0.08
940	0.18	0.29

(L/(mmol·cm))

Modeling of Finger.



Periodic arterial blood { Oxg / non-oxy.

at systole:

$$I_{min} = I_0 10^{-\varepsilon_{DC} C_{DC} \cdot L_{DC} - \underbrace{(\varepsilon_{Hb} C_{Hb} + \varepsilon_{HbO_2} C_{HbO_2})}_{} L_{max}}$$

at diastole:

$$I_{max} = I_0 10^{-\varepsilon_{DC} C_{DC} \cdot L_{DC} - (\varepsilon_{Hb} C_{Hb} + \varepsilon_{HbO_2} C_{HbO_2}) L_{min}}$$

ratio:

$$\frac{I_{min}}{I_{max}} = \frac{I_0 10^{-\varepsilon_{DC} C_{DC} \cdot L_{DC} - (\varepsilon_{Hb} C_{Hb} + \varepsilon_{HbO_2} C_{HbO_2}) L_{max}}}{I_0 10^{-\varepsilon_{DC} C_{DC} \cdot L_{DC} - (\varepsilon_{Hb} C_{Hb} + \varepsilon_{HbO_2} C_{HbO_2}) L_{min}}}$$

$$= 10^{\cancel{-\varepsilon_{DC} C_{DC} L_{DC}} - (\varepsilon_{Hb} C_{Hb} + \varepsilon_{HbO_2} C_{HbO_2})(L_{max} - L_{min}) + \cancel{\varepsilon_{DC} C_{DC} L_{DC}}}$$

$$= 10^{-(\varepsilon_{Hb} C_{Hb} + \varepsilon_{HbO_2} C_{HbO_2}) \Delta L}$$

$$\Rightarrow \log \frac{I_{min}}{I_{max}} = -(\varepsilon_{Hb} C_{Hb} + \varepsilon_{HbO_2} C_{HbO_2}) \Delta L$$

$$\boxed{A = (\varepsilon_{Hb} C_{Hb} + \varepsilon_{HbO_2} C_{HbO_2}) \Delta L = \log \frac{I_{max}}{I_{min}}}$$

$$\Rightarrow C_{Hb} = \frac{A}{\Delta L} - \frac{\varepsilon_{HbO_2} C_{HbO_2}}{\varepsilon_{Hb}}, \quad C_{HbO_2} = \frac{A}{\Delta L} - \frac{\varepsilon_{Hb} C_{Hb}}{\varepsilon_{HbO_2}}$$

at λ_1 and λ_2 (660 nm and 940 nm to maximize diffs)

$$A_{\lambda_1} = (\varepsilon_{Hb,\lambda_1} C_{Hb} + \varepsilon_{HbO_2,\lambda_1} C_{HbO_2})\Delta L$$

$$A_{\lambda_2} = (\varepsilon_{Hb,\lambda_2} C_{Hb} + \varepsilon_{HbO_2,\lambda_2} C_{HbO_2})\Delta L$$

$$\frac{A_{\lambda_1}}{A_{\lambda_2}} = \frac{\varepsilon_{Hb,\lambda_1} C_{Hb} + \varepsilon_{HbO_2,\lambda_1} C_{HbO_2}}{\varepsilon_{Hb,\lambda_2} C_{Hb} + \varepsilon_{HbO_2,\lambda_2} C_{HbO_2}}$$

$$(\varepsilon_{Hb,\lambda_2} C_{Hb} + \varepsilon_{HbO_2,\lambda_2} C_{HbO_2}) A_{\lambda_1} = (\varepsilon_{Hb,\lambda_1} C_{Hb} + \varepsilon_{HbO_2,\lambda_1} C_{HbO_2}) A_{\lambda_2}$$

$$C_{Hb}(\varepsilon_{Hb,\lambda_2} A_{\lambda_1} - \varepsilon_{Hb,\lambda_1} A_{\lambda_2}) = C_{HbO_2}(\varepsilon_{HbO_2,\lambda_1} A_{\lambda_2} - \varepsilon_{HbO_2,\lambda_2} A_{\lambda_1})$$

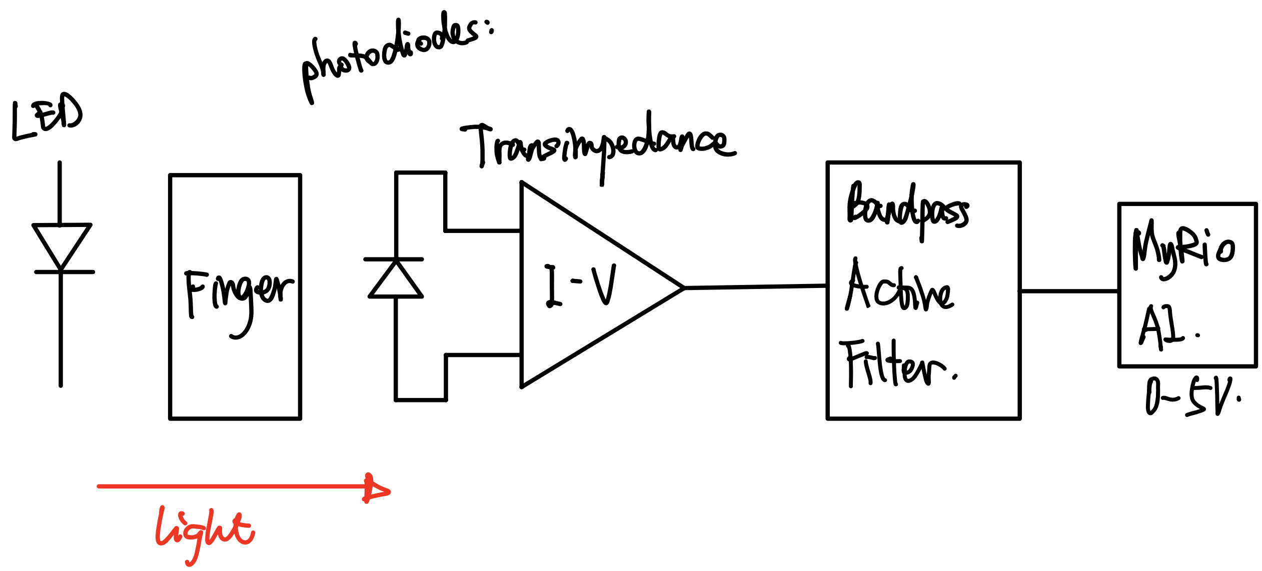
$$\Rightarrow \quad C_{Hb} = C_{HbO_2} \frac{(\varepsilon_{HbO_2,\lambda_1} A_{\lambda_2} - \varepsilon_{HbO_2,\lambda_2} A_{\lambda_1})}{(\varepsilon_{Hb,\lambda_2} A_{\lambda_1} - \varepsilon_{Hb,\lambda_1} A_{\lambda_2})}$$

$$SpO_2 = \frac{C_{HbO_2}}{C_{HbO_2} + C_{Hb}} = \frac{\cancel{C_{HbO_2}}}{\cancel{C_{HbO_2}}\left(1 + \frac{(\varepsilon_{HbO_2,\lambda_1} A_{\lambda_2} - \varepsilon_{HbO_2,\lambda_2} A_{\lambda_1})}{(\varepsilon_{Hb,\lambda_2} A_{\lambda_1} - \varepsilon_{Hb,\lambda_1} A_{\lambda_2})}\right)}$$

$$\boxed{= \frac{(\varepsilon_{Hb,\lambda_2} A_{\lambda_1} - \varepsilon_{Hb,\lambda_1} A_{\lambda_2})}{(\varepsilon_{Hb,\lambda_2} A_{\lambda_1} - \varepsilon_{Hb,\lambda_1} A_{\lambda_2}) + (\varepsilon_{HbO_2,\lambda_1} A_{\lambda_2} - \varepsilon_{HbO_2,\lambda_2} A_{\lambda_1})}}$$

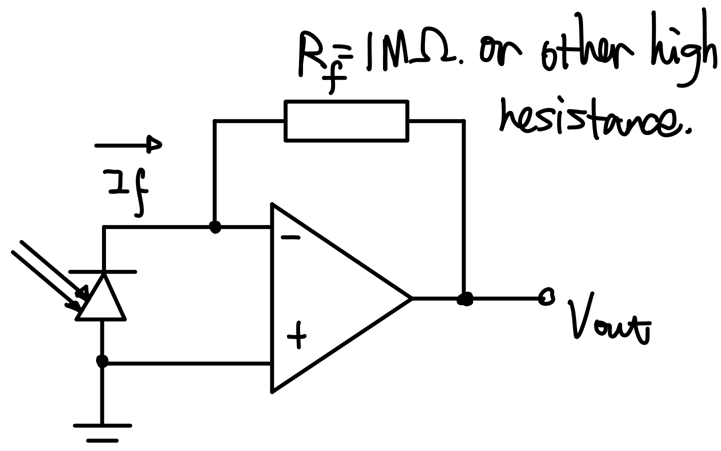
or $=$ ____________________

Theoretical Schematic



- Power.

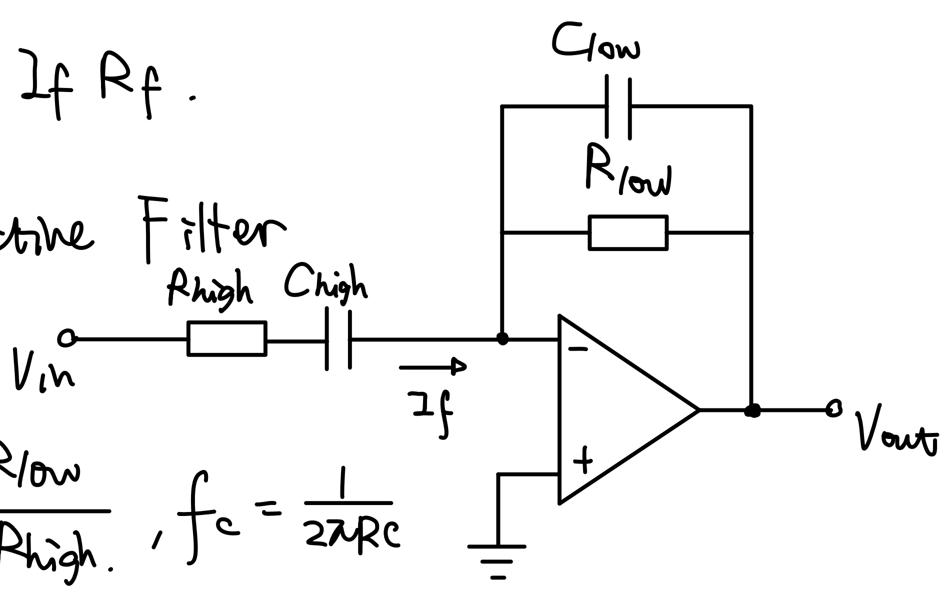
- Transimpedance Amplifier.



– Measure idle voltage / finger-inserted voltage.
compare to myRio AI. port.

$V_{out} = -I_f R_f$.

- Bandpass Active Filter

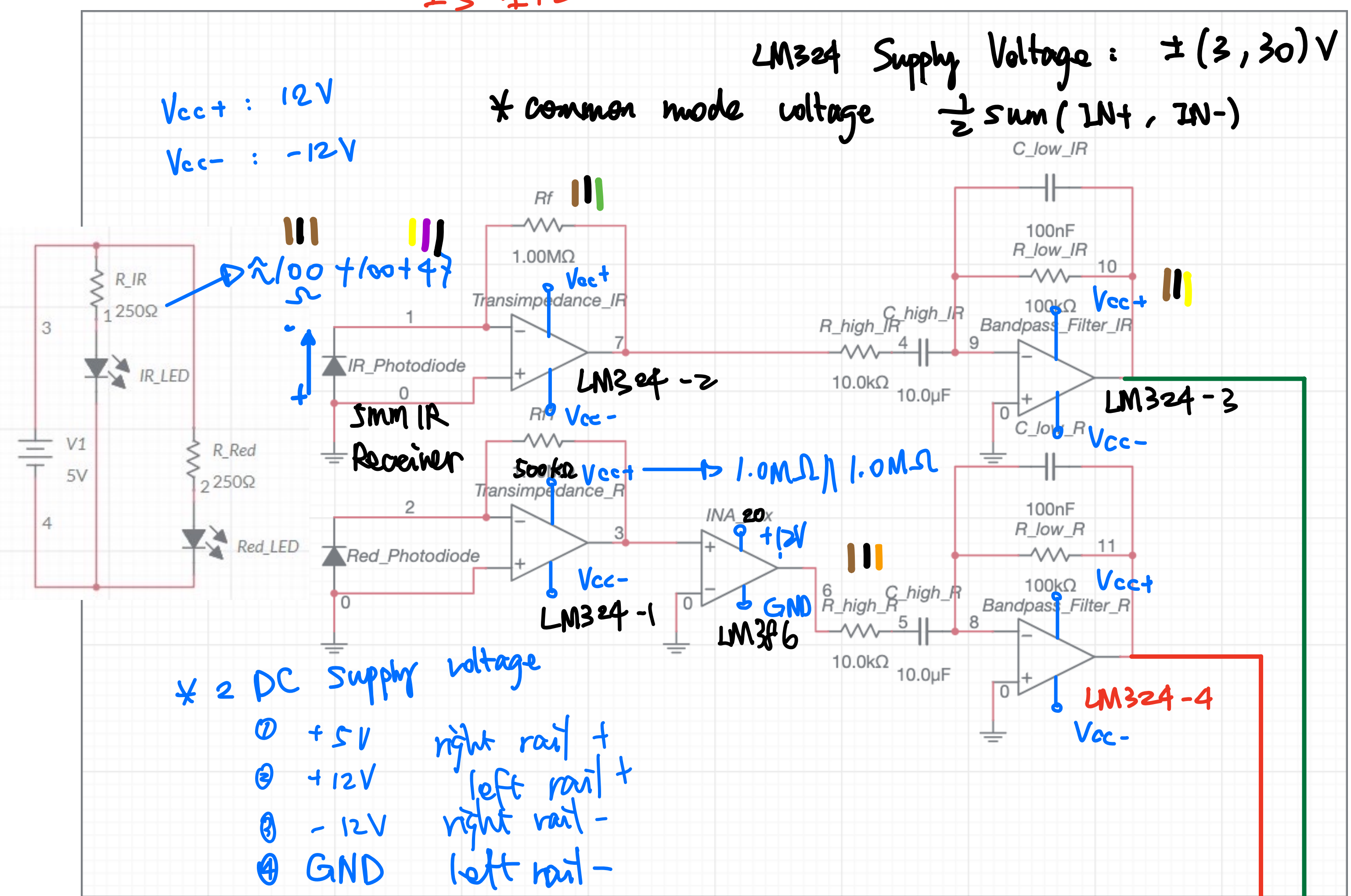


$\frac{V_{out}}{V_{in}} = \frac{R_{low}}{R_{high}}$, $f_c = \frac{1}{2\pi RC}$

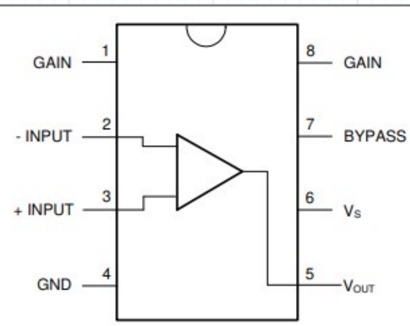
Wiring:

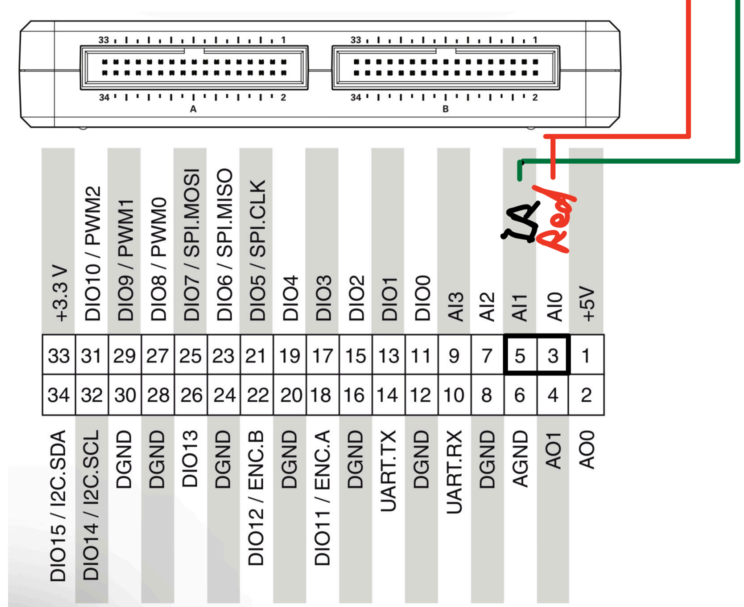
* color code: Vcc GND Signal (Red) Signal (IR)

±5 ±12

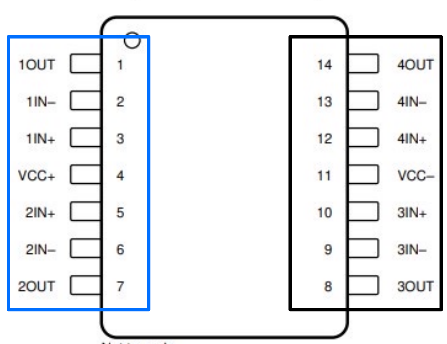


LM386





LM324



Trans-impedance Active filter.

Resistor choice: (based on LM324; LM386 has preset gains)

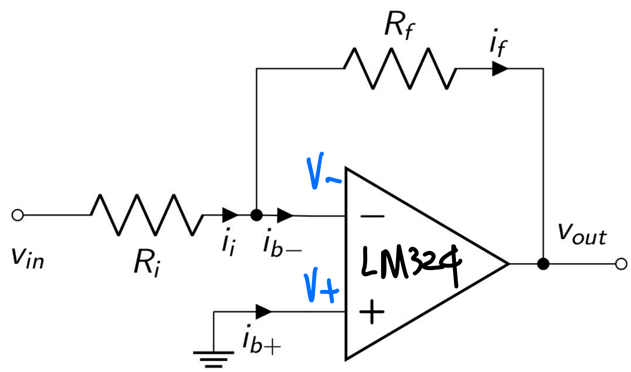
LM324:

- bias current (i_b)

  $\leq \pm 35\,nA$

- input impedance (R_{in})

  $= 1\,G\Omega$



To avoid signal clipping at A10, let ideal output

$$V_{out,i} = 5V \cdot 90\% = -4.5V$$

and the error tolerance 1%

in worse case $V_{out} = (1 - 1\%) \times V_{out,i} = -4.4550V$

assume ideal non-inverting input & virtual short.

$$V_- = V_+ = 0V$$

$$i_f = \frac{V_- - V_{out}}{R_f} = \frac{4.4550V}{R_f}$$

$$V_{in} = -V_{out,i} \cdot \frac{R_i}{R_f} = 4.5V \cdot \frac{R_i}{R_f}$$

$$i_i = \frac{V_{in} - V_-}{R_i} = \frac{V_{in}}{R_i} = \frac{4.5V}{R_f}$$

According to KCL (at - input node): $i_i = i_{b-} + i_f$

$i_{b-} = i_i - i_f$ and $i_{b-} = 35\,nA = \dfrac{4.5V - 4.4550V}{R_f}$

so $R_{f,upper} = \dfrac{(4.5-4.4550)V}{35\times10^{-9}A} = 1.3\times10^{6}\Omega = 1.3M\Omega$

· however, the input impedance $R_{in} = 1G\Omega$

we want $R_f <<< R_{in}$

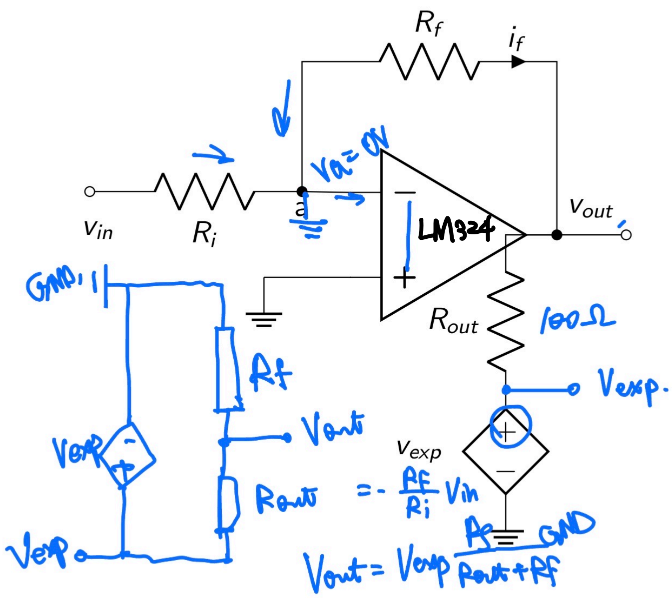
* the desired upper bound of R_f is around $130\ k\Omega$

· output impedance (R_{out})

$= 300\Omega$

· output current (I_{out})

$\leq -60\ mA$



* assume input side fully ideal, $V_a = 0V$

the output impedance R_{out} forms a voltage divider with R_f

if we would like 99% preserved $\dfrac{V_{out}}{V_{exp}}$

$$V_{out} = V_{exp}\cdot\frac{R_f}{R_f+R_{out}} \Rightarrow \frac{R_{f,lower}}{R_{f,lower}+300\Omega} = 0.99$$

$$\Rightarrow R_{f,lower} = 29.7\ k\Omega$$

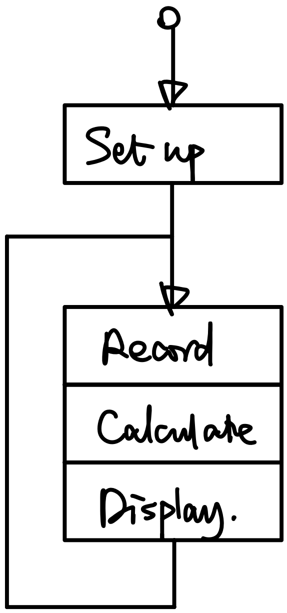
Thus for LM324: $30\ k\Omega \leq R_f \leq 130\ k\Omega$

Labview Program Design:

① Super Loop vs. Producer consumer loop.

Super Loop:

Entry point.



AIOs, calibration data.

2 Voltage readings

$\xrightarrow{\text{convert}}$ Intensity, I_{max}/I_{min}, A, O_2 saturation

$\xrightarrow{\text{FFT}}$ heart rate

② Sub VIs :