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.

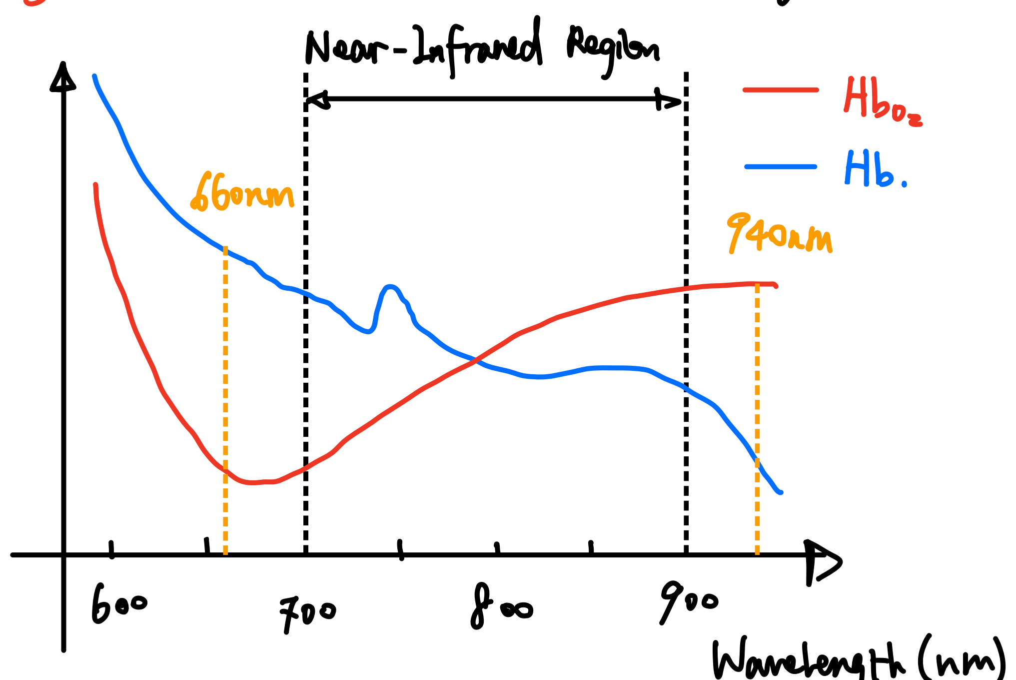
Absorbance:

$A = \varepsilon C L$.

* assume C and L constant.

C=1mmol

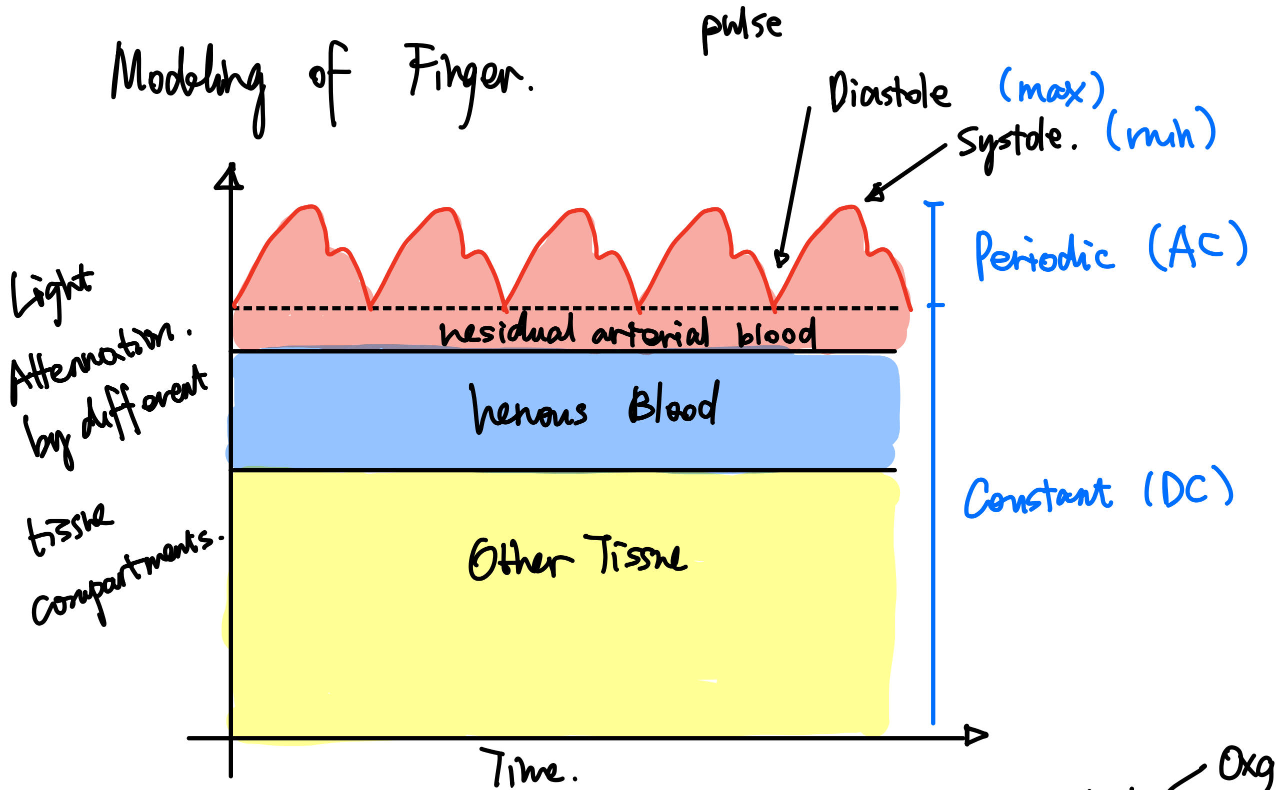
L: 1cm



wavelength	ε_{Hb}	ε_{Hbo_2}
λ_1 660	0.81	0.08
λ_2 940	0.18	0.29

(L/(mmol·cm))

Modeling of Finger.



Periodic arterial blood $\begin{cases} \text{Oxg} \\ \text{non-oxg.} \end{cases}$

at systole:

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

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)

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

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

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

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

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

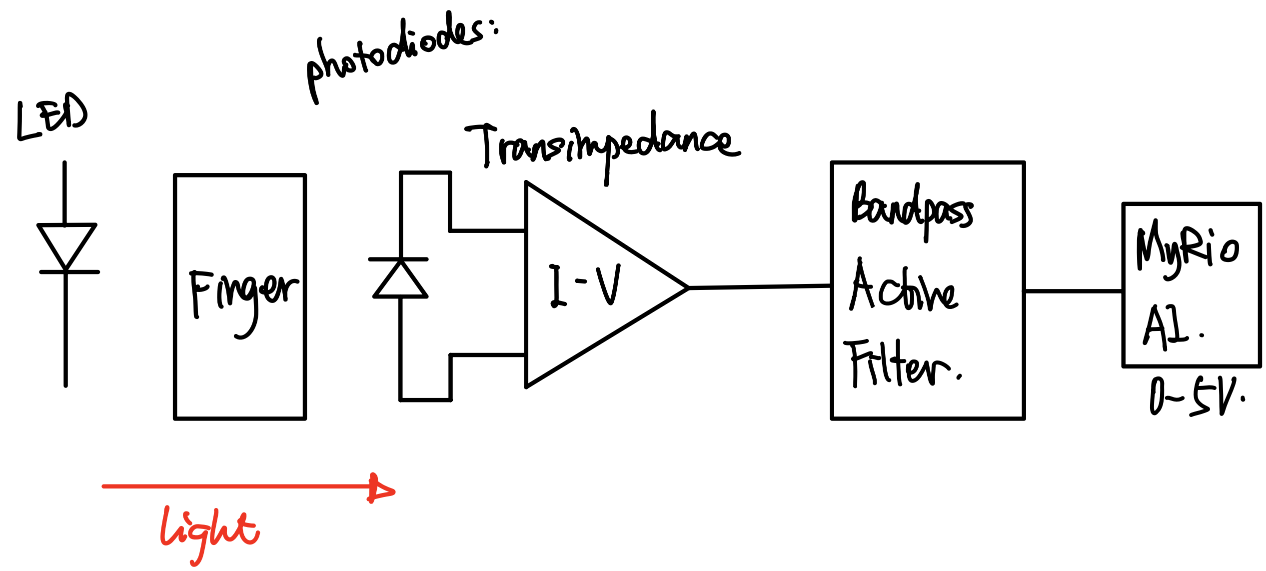
$$\Rightarrow \quad C_{Hb} = C_{HbO_2}\frac{(\varepsilon_{HbO_2,\lambda_1} A_{\lambda_2} - \varepsilon_{HbO_2,\lambda_2} A_{\lambda_1})}{(\varepsilon_{Hb,\lambda_2} A_{\lambda_1} - \varepsilon_{Hb,\lambda_1} A_{\lambda_2})}$$

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

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

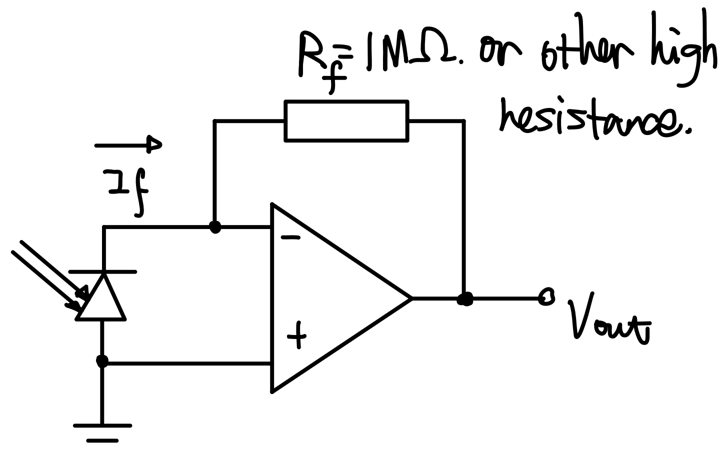
or = ______

Theoretical Schematic



- Power.

- Transimpedance Amplifier.

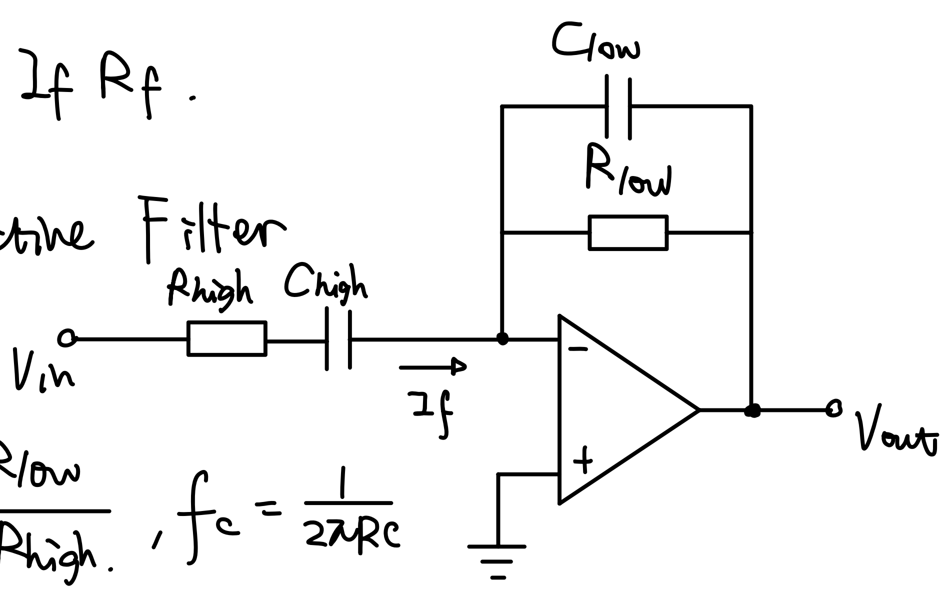


– Measure idle. voltage / finger-inserted voltage.

compare to myRio AI. port.

$$V_{out} = -I_f R_f.$$

- Bandpass Active Filter

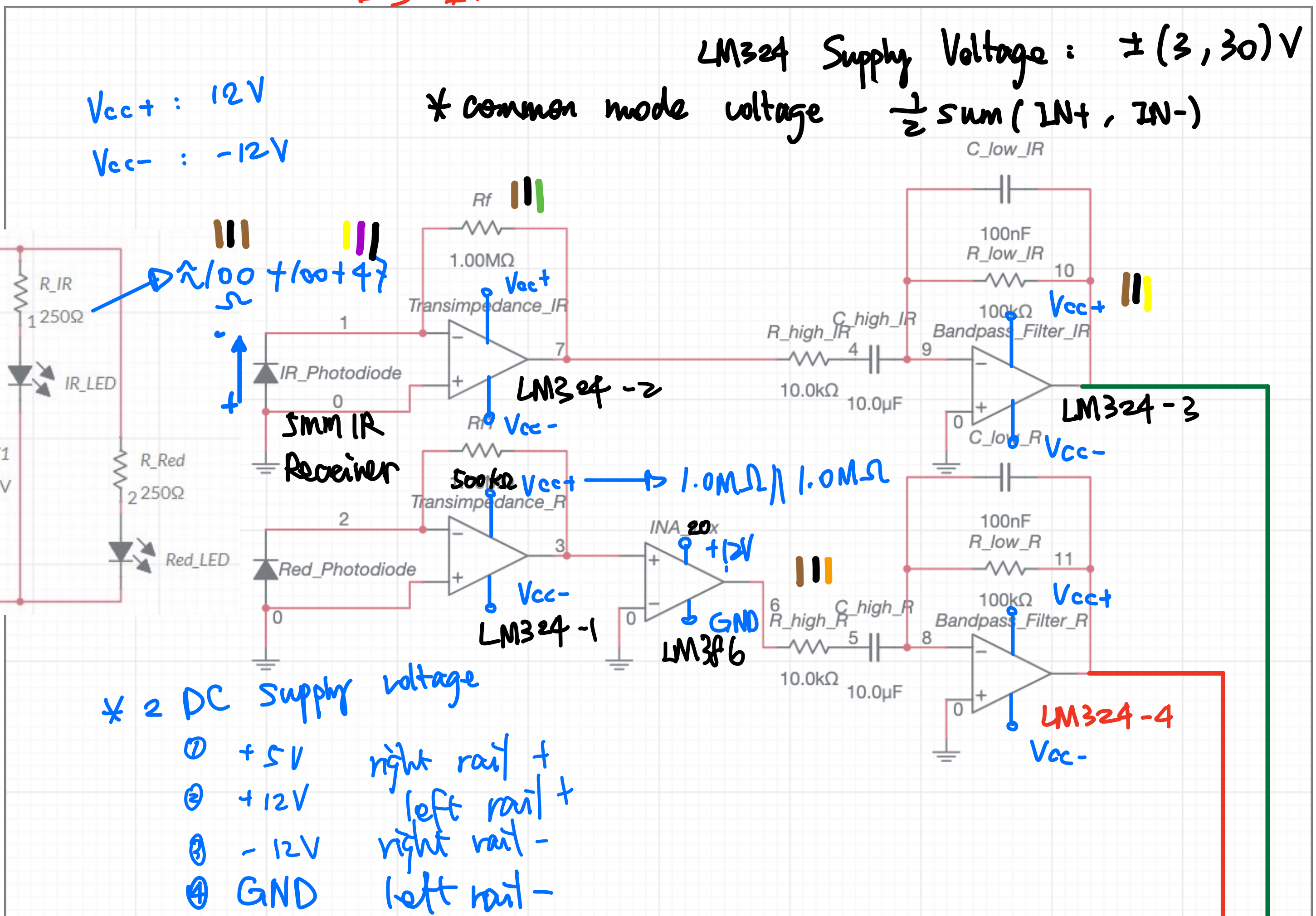


$$\frac{V_{out}}{V_{in}} = \frac{R_{low}}{R_{high}}, \quad f_c = \frac{1}{2\pi RC}$$

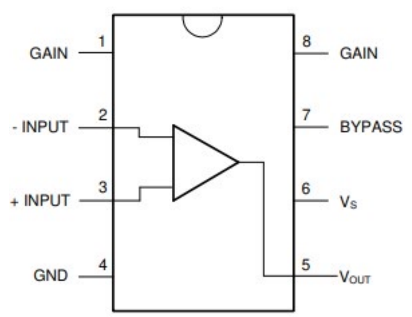
Wiring:

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

±5 ±12



LM386



LM324

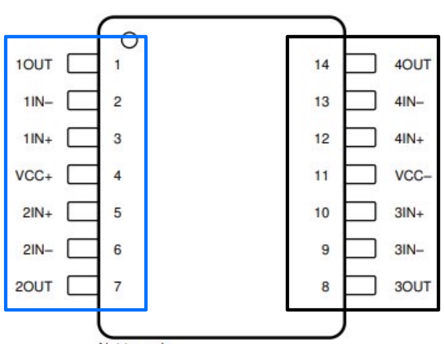
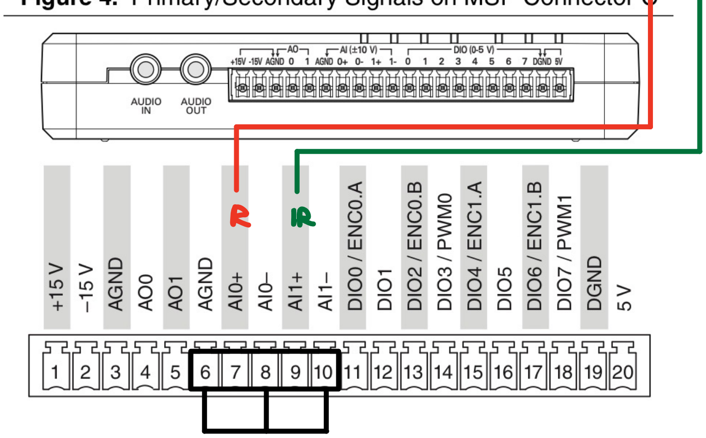


Figure 4. Primary/Secondary Signals on MSP Connector C



$V_R = V_{AI0+} - V_{AI0-}$

$V_{IR} = V_{AI1+} - V_{AI1-}$

Trans-impedance Active filter.

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

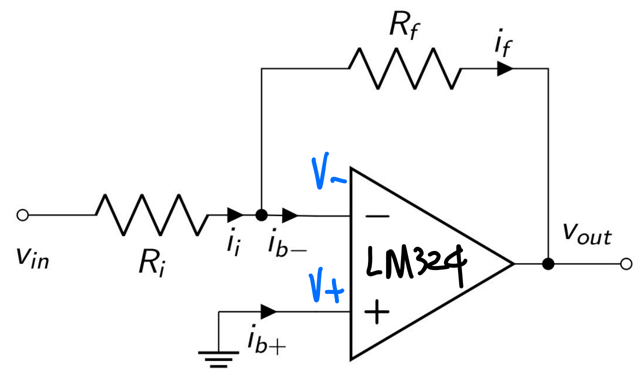
LM324:

- 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.

$$V_- = V_+ = 0\,V$$

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

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

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

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

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

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

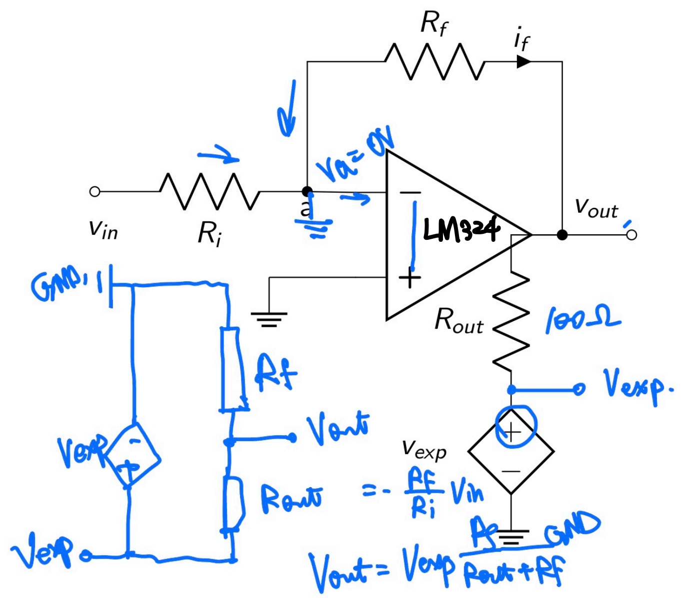
* the desired upper bound of R_f is around $130\ k\Omega$

- output impedance (R_{out})

  $= 300\Omega$

- output current (I_{out})

  $\leq -60mA$



* 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 $\frac{V_{out}}{V_{exp}}$

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

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

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

Circuit Characterization.

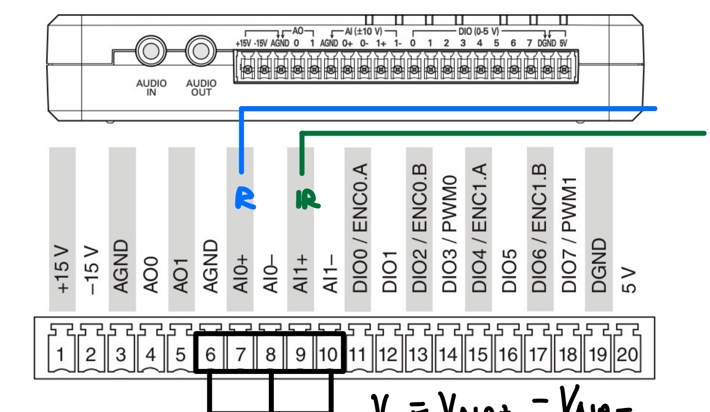
pin layout:

Fgen : offset sine signal.
- R : A/AO1, 4 → +INPUT, 3
- IR : A/AO0, 2 → 3IN⁻, 9

Circuit Output :

amplified & filtered signal
- R : 4OUT, 14 → C/AI0+, 3
- IR : 3OUT, 8 → C/AI1+, 5

Figure 4. Primary/Secondary Signals on MSP Connector C



$V_R = V_{AI0+} - V_{AI0-}$

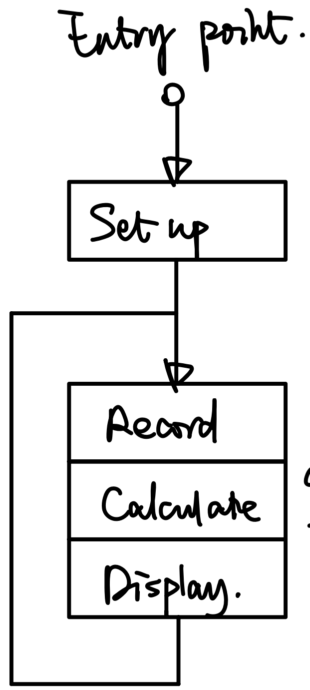
- Characterize : Gain vs. Input Frequency

$V_{IR} = V_{AI1+} - V_{AI1-}$

Labview Program Design:

① Super Loop vs. Producer consumer loop.

Super Loop:



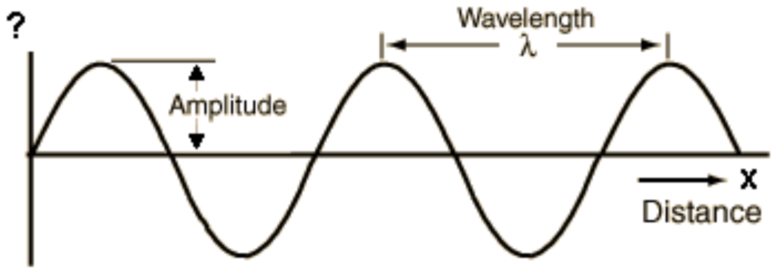
AIOs, calibrationdata.

2 Voltage readings

convert → Intensity, Imax/Imin, A, O_2 saturation

FFT → heart rate

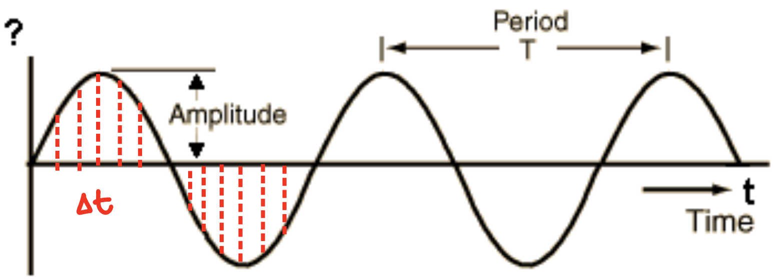
② Test Program:



Sine Pattern

Inputs
- # sample
- amplitude
- cycles

output
- sine wave Y array



Period T, Freq $f = \frac{1}{T}$

Equations:

$$\text{Waveformduration} = \text{Period} \cdot \#\text{ of period}.$$

$$\Delta t \cdot \#\text{sample} = T \cdot \#\text{ cycle}.$$

$$\Delta t \cdot \#\text{sample/cycle} \cdot \cancel{\#\text{cycle}} = \frac{1}{f} \cdot \cancel{\#\text{ cycle}}.$$

$$\Delta t = \frac{1}{f \cdot \#\text{sample/cycle}}$$

if $f = 10\,Hz = 10\,s^{-1}$, $\#\text{sample/cycle} = 128/\text{cycle}$.

$$\Delta t = \frac{1}{10\,s^{-1} \cdot 128} = \frac{1}{1280\,s^{-1}} = \frac{1}{1280}\,s.$$

Use Scope & Fgen for NI myRio.

③ Sub VIs :

1. SpO_2 calculator.

Inputs: (I_{max}, I_{min}) at $\lambda_{1,2}$

$$A_{\lambda_i} = \log \frac{I_{max,\lambda i}}{I_{min,\lambda i}} \quad , \quad \lambda_i \ , \ i \in 1,2$$

	wavelength	ε_{Hb}	ε_{HbO_2} $(L/(mmol \cdot cm))$
λ_1	660	0.81	0.08
λ_2	940	0.18	0.29

$$SpO_2 = \frac{(\varepsilon_{Hb,\lambda_2} A_{\lambda_1} - \varepsilon_{Hb,\lambda_1} A_{\lambda_2})}{(\varepsilon_{Hb,\lambda_2} A_{\lambda_1} - \varepsilon_{Hb,\lambda_1} A_{\lambda_2}) + (\varepsilon_{HbO_2,\lambda_1} A_{\lambda_2} - \varepsilon_{HbO_2,\lambda_2} A_{\lambda_1})}$$

Output: SpO_2

2. FFT- Frequency Analysis.