Current & Heart Rate Sensors

ECE 476 Advanced Embedded Systems

Jake Glower - Lecture #22

Please visit Bison Academy for corresponding
lecture notes, homework sets, and solutions

Introduction:

The Raspberry Pi-Pico has four 12-bit analog inputs

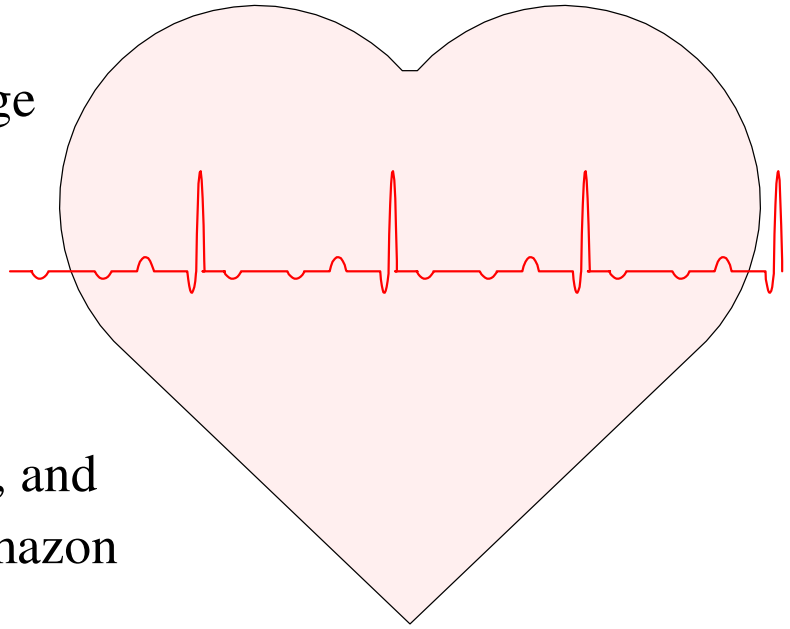
- Three are connected to the I/O pins on the Pi-Pico
- One of these three is unused on the Breakout Board Plus

With these A/D inputs, you can

- Directly read sensors whose output is voltage
- Read other sensors with some circuitry

This lecture looks at measuring

- Current using a current-sensing resistor
- Current using an N:1 transformer,
- The current of different types of light bulbs, and
- Heart rate using a heart rate sensor from Amazon



Current Sensing Resistors

Current tells you

- The energy left in a battery rated in mAh
- The torque of a DC motor
- The brightness of an LED

But, the A/D one Pi-Pico measures voltage

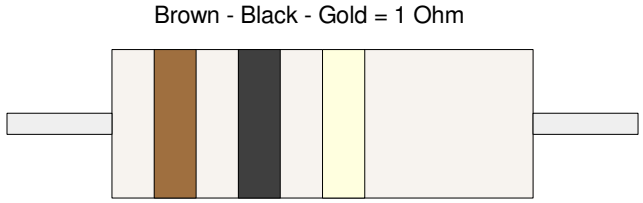
- not current

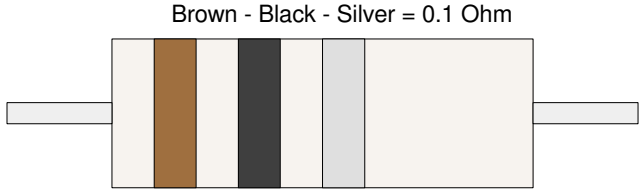
Solution: Convert current to votlage

- Add a resistor

Keep R small

- The sensor shouldn't change your circuit
- 1 Ohm or 0.1 Ohm are common





Example: Current to a Motor

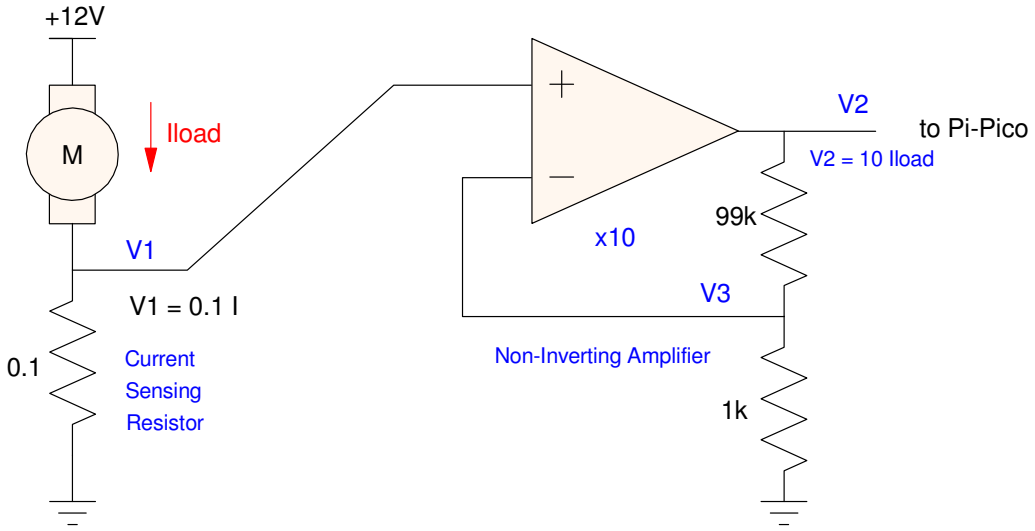
Add 0.1 Ohm to ground

$$V_1 = 0.1 \cdot I_{load}$$

Amplify 100x

$$V_2 = 10 \cdot I_{load}$$

Works as long as Iload > 0



Calculations:

$$V_3 = V_1$$

$$\left(\frac{V_3}{1k}\right) + \left(\frac{V_3 - V_2}{99k}\right) = 0$$

Example 2: Differential Amplifier

- a.k.a. Instrumentation Amplifier
- Needed when the current-sensing resistor isn't next to ground
- Amplify the voltage across the resistor (Va - Vb)

Equations:

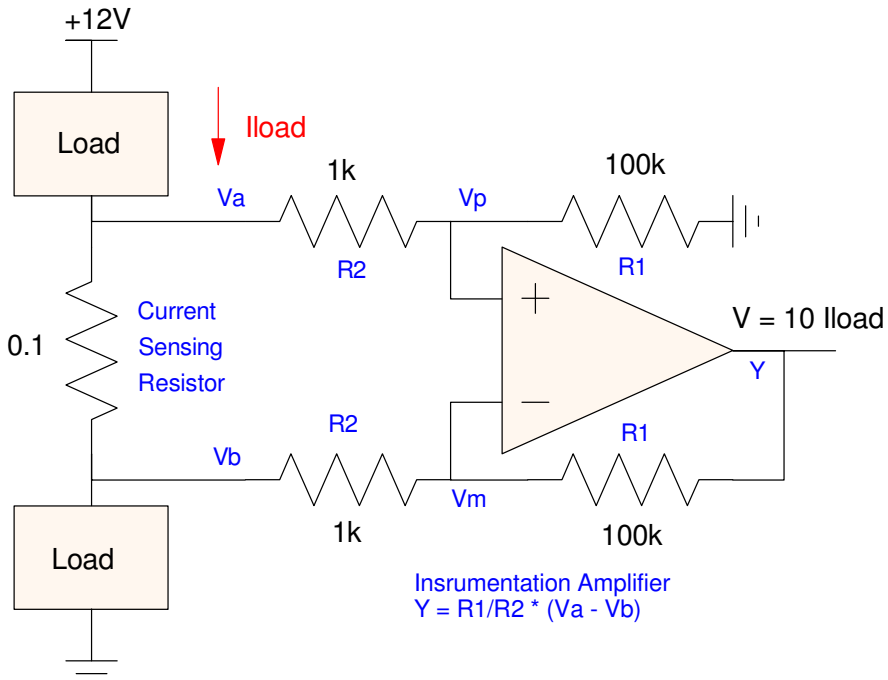
$$V_p = V_m$$

$$\left(\frac{V_p - V_a}{R_2}\right) + \left(\frac{V_p}{100k}\right) = 0$$

$$\left(\frac{V_m - V_b}{R_2}\right) + \left(\frac{V_m - Y}{R_1}\right) = 0$$

Doing some algebra

$$Y = \left(\frac{R_1}{R_2}\right)(V_a - V_b)$$



Example 3: +/- Current

If the current can be positive and negative,

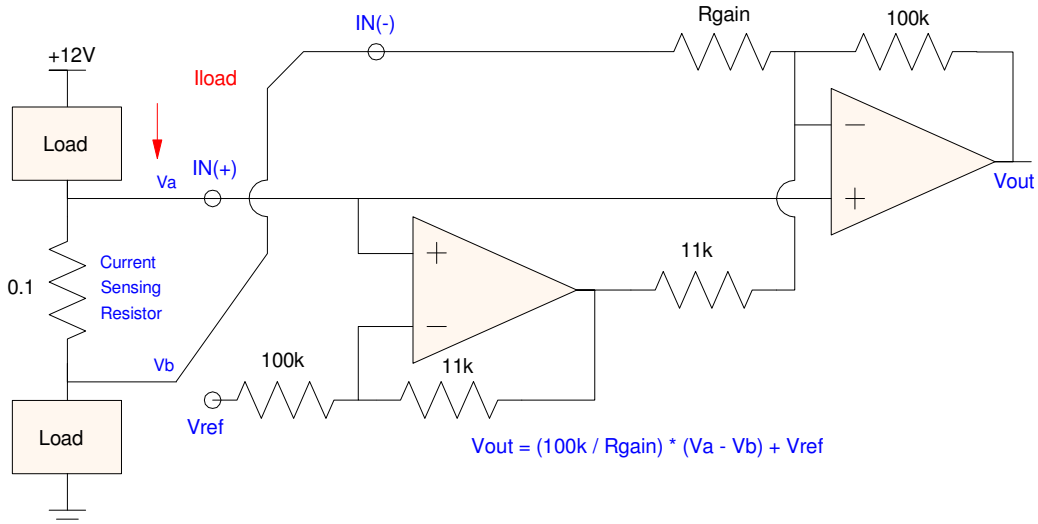
- Shift the DC level
- Allows +/- outputs without needind a +/- power supply

Example: AMP04

$$V_{out} = \left(\frac{100k}{R_{gain}}\right)(V_a - V_b) + V_{ref}$$

Setting Vref = 1.65V shifts the output

- Can get by with a single +3.3V power supply



Current Sensing Transformers

A second way to measure current

- Only works for AC signals
- Transformers don't work at DC

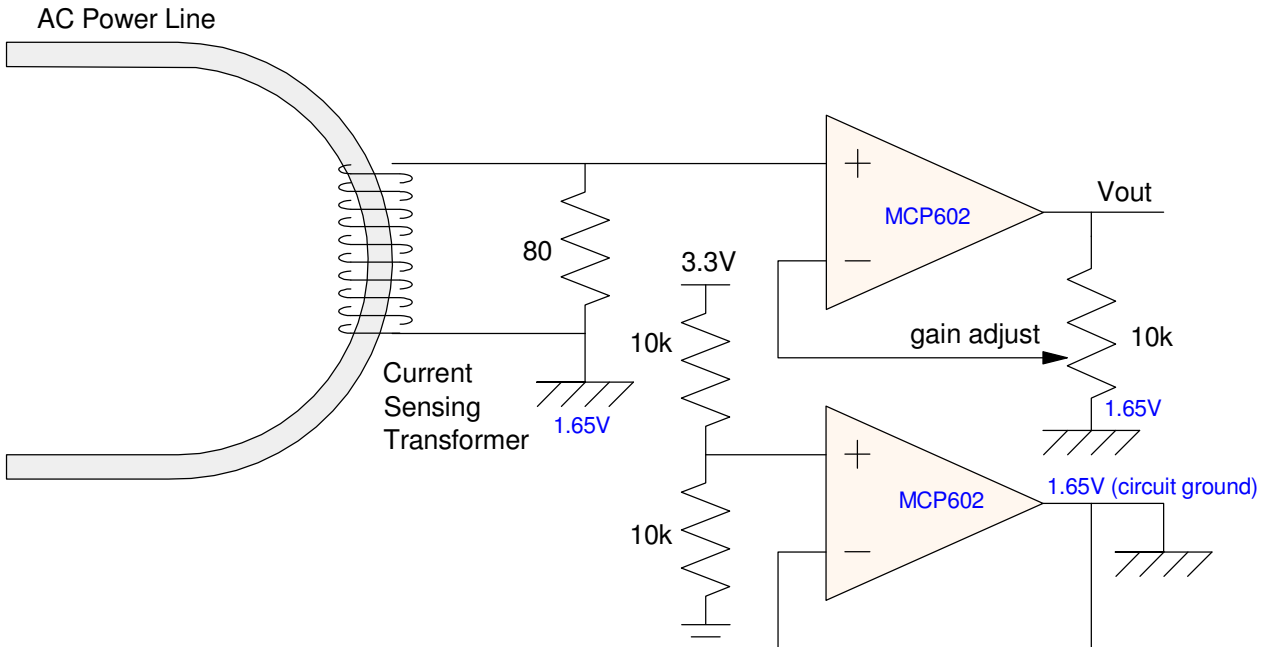
Current sensing transformers are useful when

- You want to measure an AC current,
- Inserting a current-sensing resistor is not practical, or
- Inserting a current-sensor is not safe (due to the large voltages involved)

Current Transformer Circuit:

- Run one wire of your device through the transformer
- This steps down the current by 1000:1
- Add an 80 Ohm resistor to convert current to voltage
- Amplify (if needed)

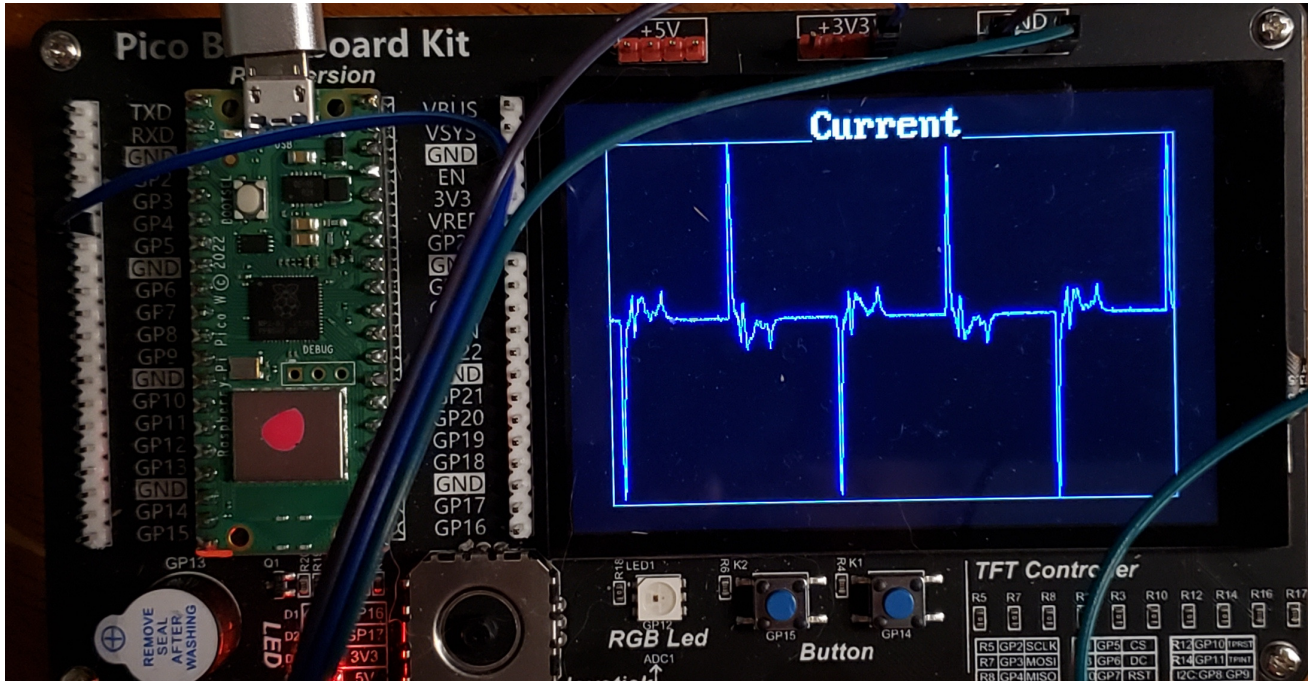
Optional: Offset the transformer by 1.65V



Current to a Light Bulb

Measure and display the current draw of different types of light bulbs

- Convert current to voltage (previous circuit)
- Read 1000 points over three cycles
  - Sampling rate = 20kHz
- Plot on the TFT display
  - Button 14: Discard data and try again
  - Button 15: Save the data to a file



Code

- Fairly lengthy
- Whole code is on Bison Academy (lecture #22)

1000 data points are sampled at 20kHz

- ballpark - set by sleep_us() command

```
raw = [0]*1000
Volts = [0]*1000
kV = 3.3 / 65535

while(1):
    for i in range(0:1000):
        raw[i] = a2d2.read_u16()
        sleep_us(10)

    for i in range(0:1000):
        Volts[i] = raw[i] * kV
```

58W Incandescent

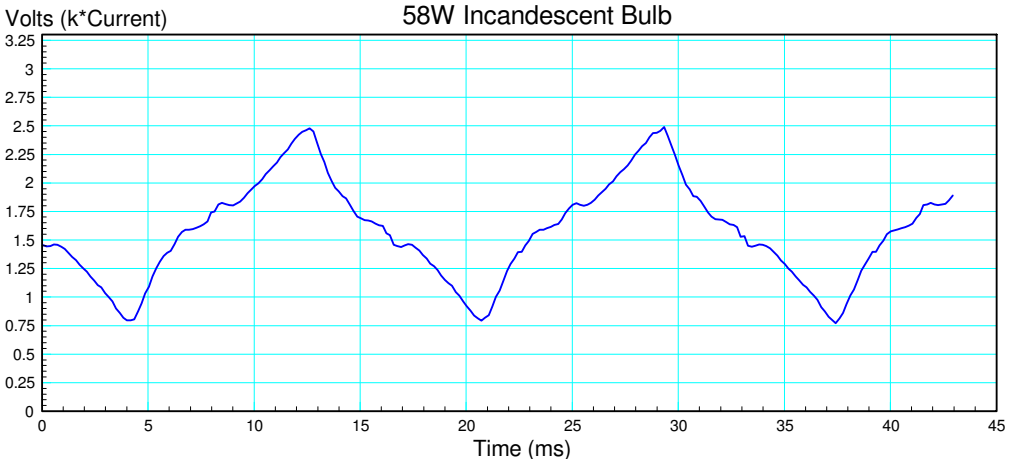
- 2.6% efficient light

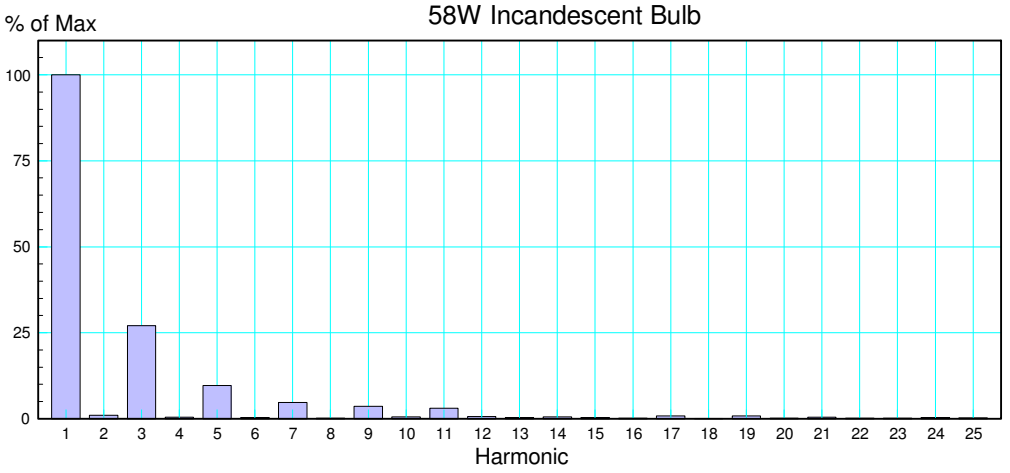
Current (top figure)

- Sort of a sine wave
- Offset by 1.65V
  - 1.65V = 0mA

Frequency Content

- Bottom Figure
- Strong 1st harmonic (60Hz)
- Weaker odd harmonics
- Not too much of a problem for utilities





Frequency Content

- a.k.a. Fourier Transform
- Can be computed in Matlab
- Can be computed in Python

Assume:

$$f(t) = \sum \left(a_n \cos\left(n\omega_0 t\right) + b_n \sin\left(n\omega_0 t\right)\right)$$

where

$$\omega_0 = \frac{2\pi}{T}$$

and T is the period of the sine wave.

$$a_n = \frac{2}{T}\int x(t) \cdot \cos\left(n\omega_0 t\right)$$

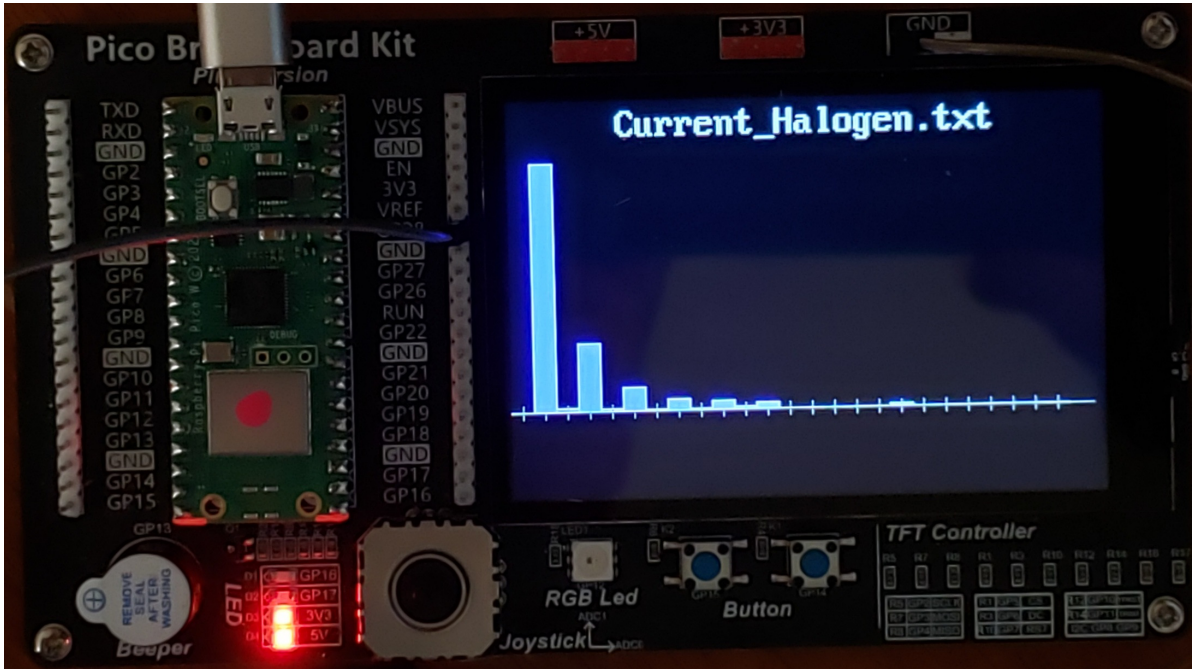
$$b_n = \frac{2}{T}\int x(t) \cdot \sin\left(n\omega_0 t\right)$$

The period doesn't affet the answer

- You can set the period to be 1 or 2 pi

In Python:

```
N = len(X)
dt = 1/N
w0 = 2*pi/N
c = [0] * 25
for n in range(1,25):
    a = b = 0
    for i in range(0,N):
        a += X[i] * cos(n*i*w0) * dt
        b += X[i] * sin(n*i*w0) * dt
    c[n] = (a**2 + b**2) ** 0.5
```



61W Halogen Light

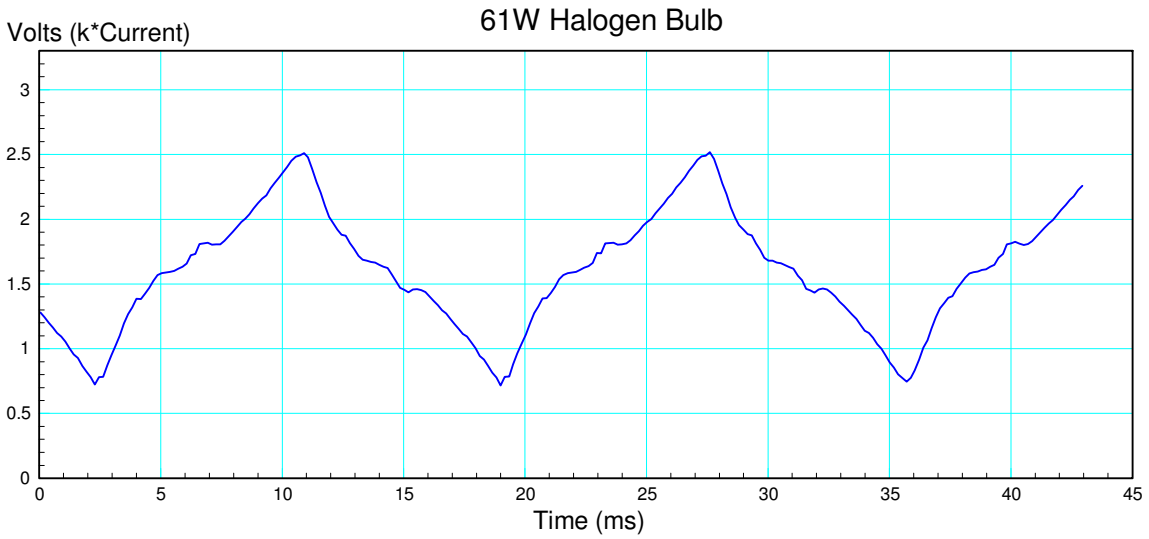
- 6% efficient
- Also resistive in nature

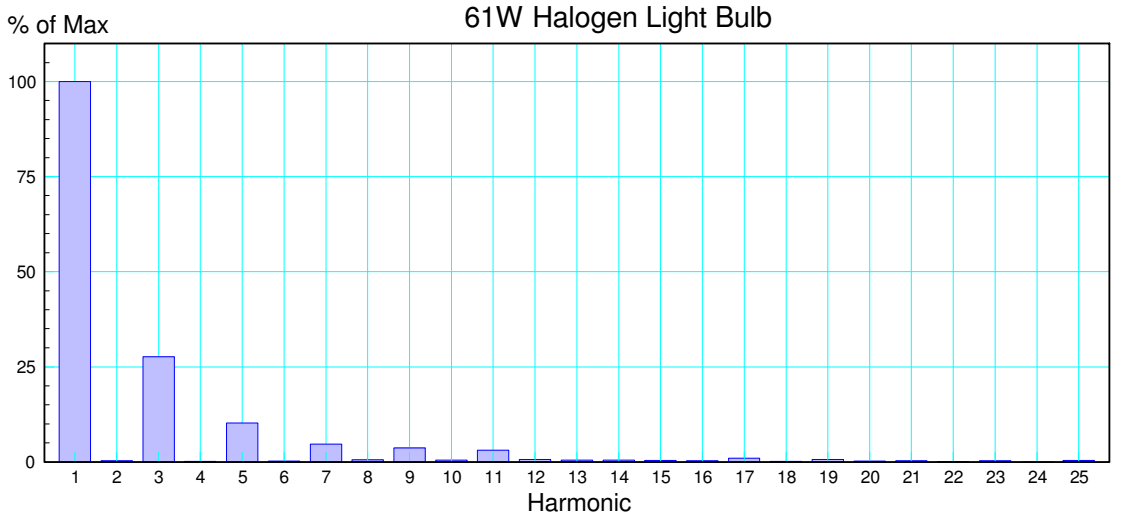
Current Waveform

- Top figure
- Sine-wave ish

Harmonics

- Bottom figure
- Strong 1st harmonic
  - 60Hz
- Odd harmonics decay quickly





21W CFL Light

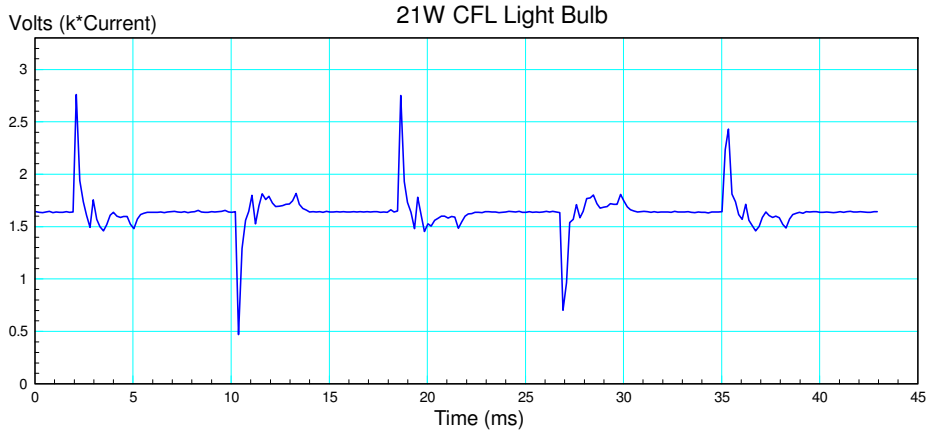
- 26% efficient
- Popular in the 1990's to 2000's

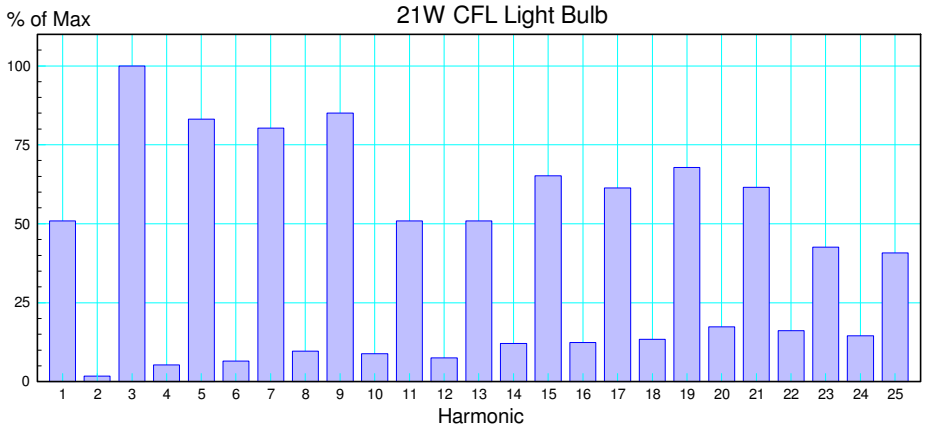
Current Waveform

- Top figure
- Strong spikes
- Indicates a full-wave AC to DC rectifier
  - ECE 320 lecture #8

Harmonics

- Bottom figure
- Lots of odd harmonics
- Can pose a problem for utilities if used en-mass





20W LED Light

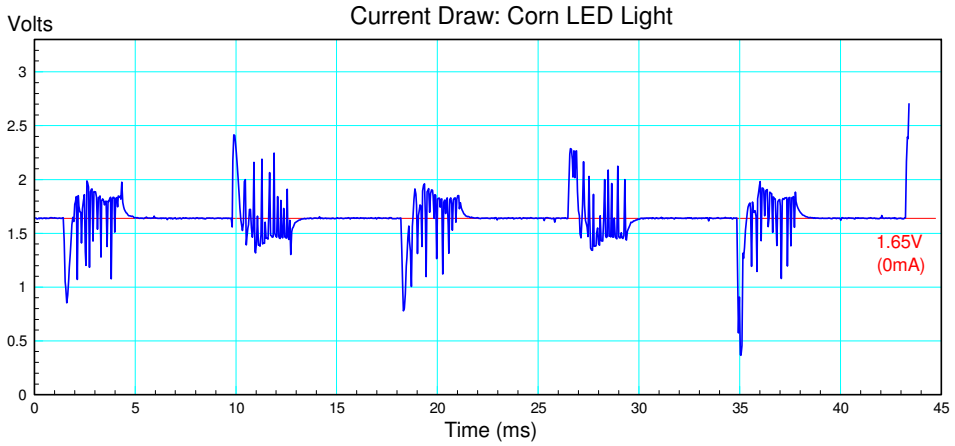
- 37% efficient
- Up to 80% efficient in theory

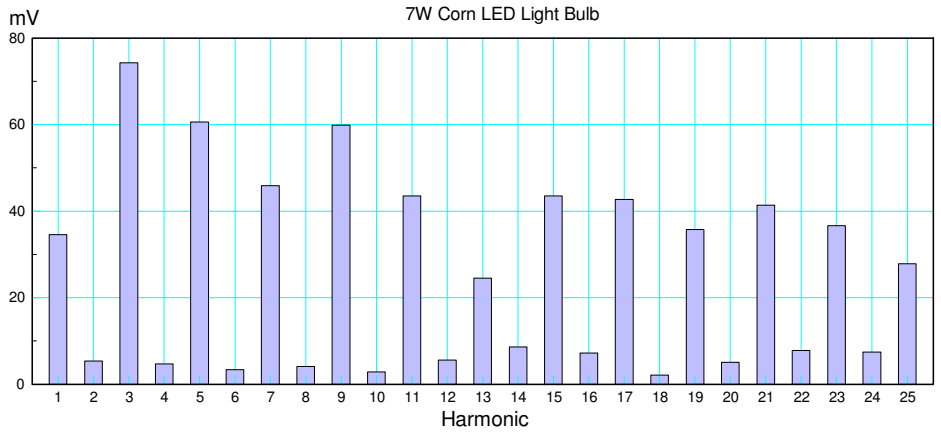
Current Waveform

- Top figure
- Spikes and noise
- Indicated a full-wave rectifier

Harmonics

- Bottom figure
- Lots of odd harmonics
- Can pose a problem for utilities if used en-mass





Billion Dollar Question:

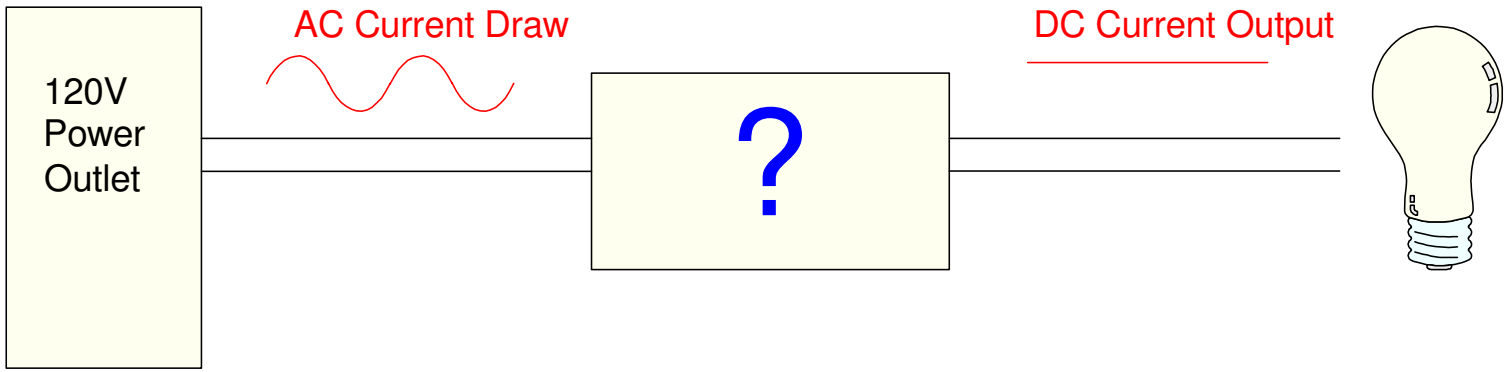
The harmonics can cause problems for a utility.

- The power grid is designed for 60Hz
- High-frequency terms create losses in transformers
- High-frequency terms can burn out neutral lines

How do you design a circuit which

- Draws current like a resistor (60Hz sine wave)
- Outputs a clean DC signal (to drive DC loads like LED lights)
- With 90% efficiency or more
- Using just electronics

Whoever figures this out will be worth billions.



Heart Rate Sensor

- Measure and display your pulse on the TFT display
- Sensor from Amazon

Theory:

- Oxygenated blood has a different absorption of green light than deoxygenated blood
- Each heartbeat, fresh oxygenated blood goes through your fingers
- By measuring the change in reflectance of green light, the heart rate can be measured

3PCS Pulse Sensor Heart Rate Sensor Monitor Pulse Sensor Compatible with Ar-duino Module Raspberry pi

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$16.99

Included Components	3 x Heart Rate Pulse Sensor Sensor Module Compatible with Ar-duino Raspberry pi
Compatible Devices	Ar-duino, Raspberry pi
Processor Count	1
UPC	768571606518

About this item

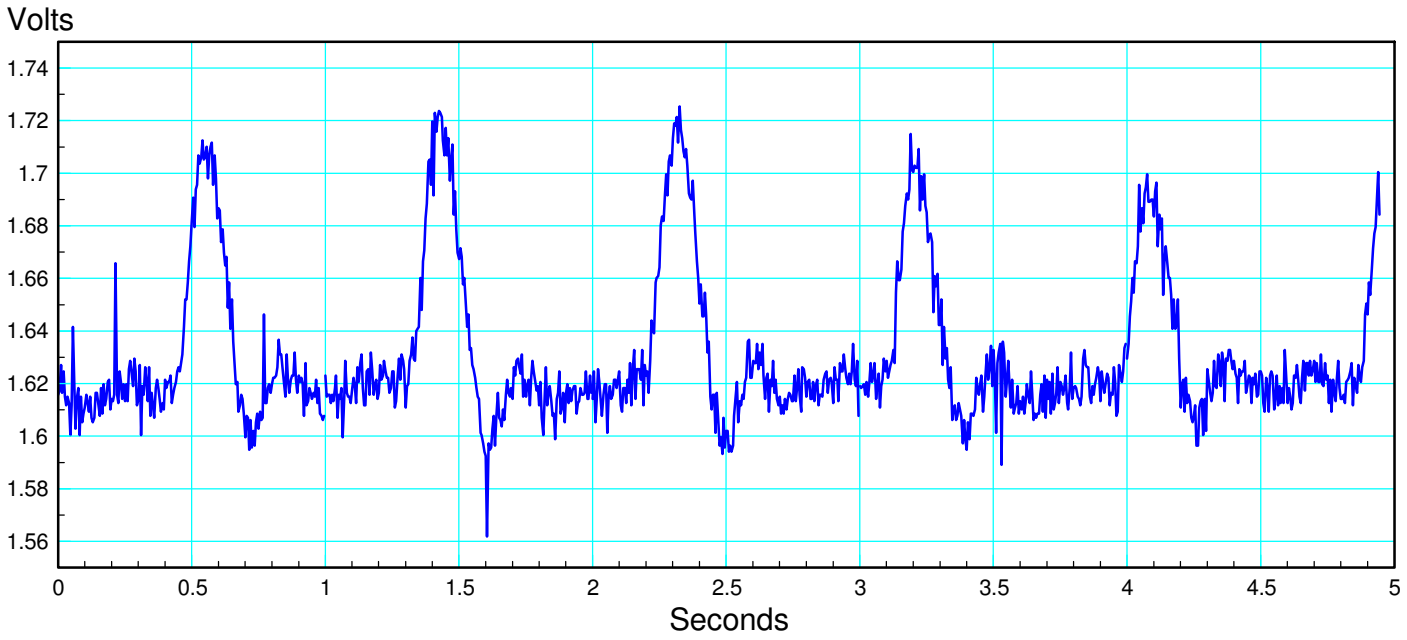
- Package Included: 3 x Heart Rate Pulse Sensor Sensor Module Compatible with Ar-duino Raspberry pi
- The power supply voltage: 3.3V ~ 5 v
- Diameter: 16mm,Magnification: 330,LED Wavelength: 609nm
- Pulse sensor Ar-duino is used to test the heart rate sensor, students, artists,athletes, creator, game developer, or mobile terminal can develop

Heart Rate Sensor: Operation

- Power with 3.3V and ground
- Place your fingertip over the green light
- Feed the signal (yellow) wire to the A/D input

The raw signal is

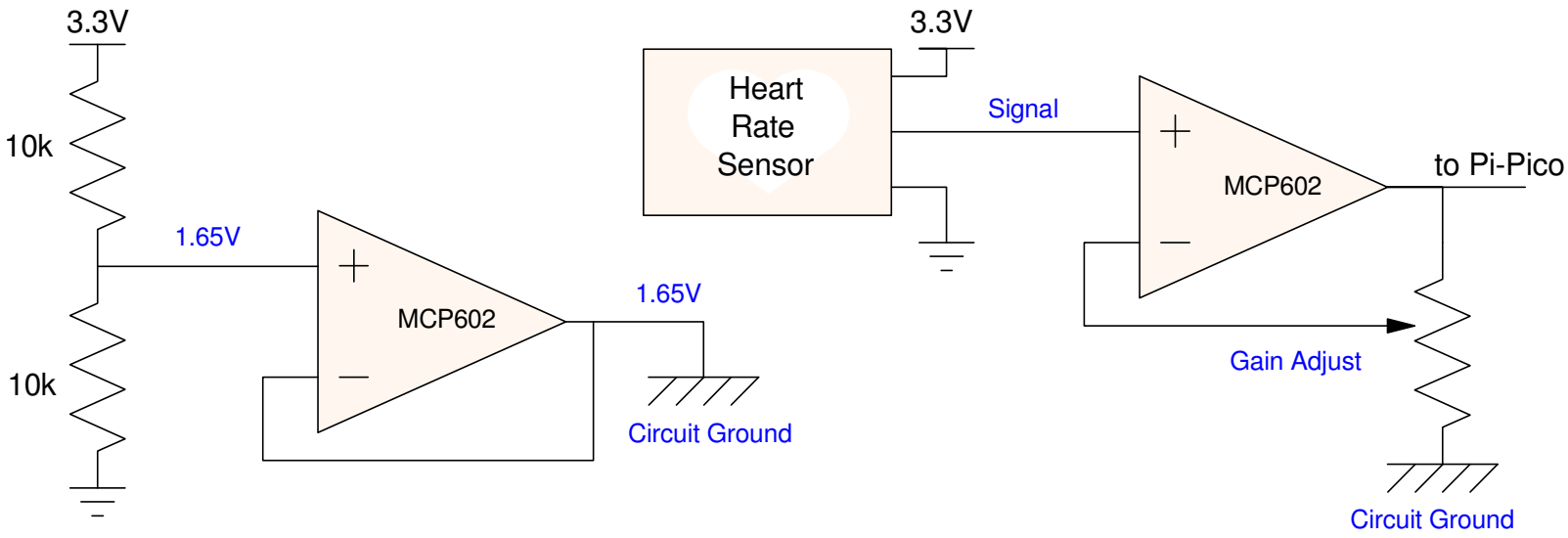
- Centered at 1.65V
- 100mVpp (varies)



Amplification

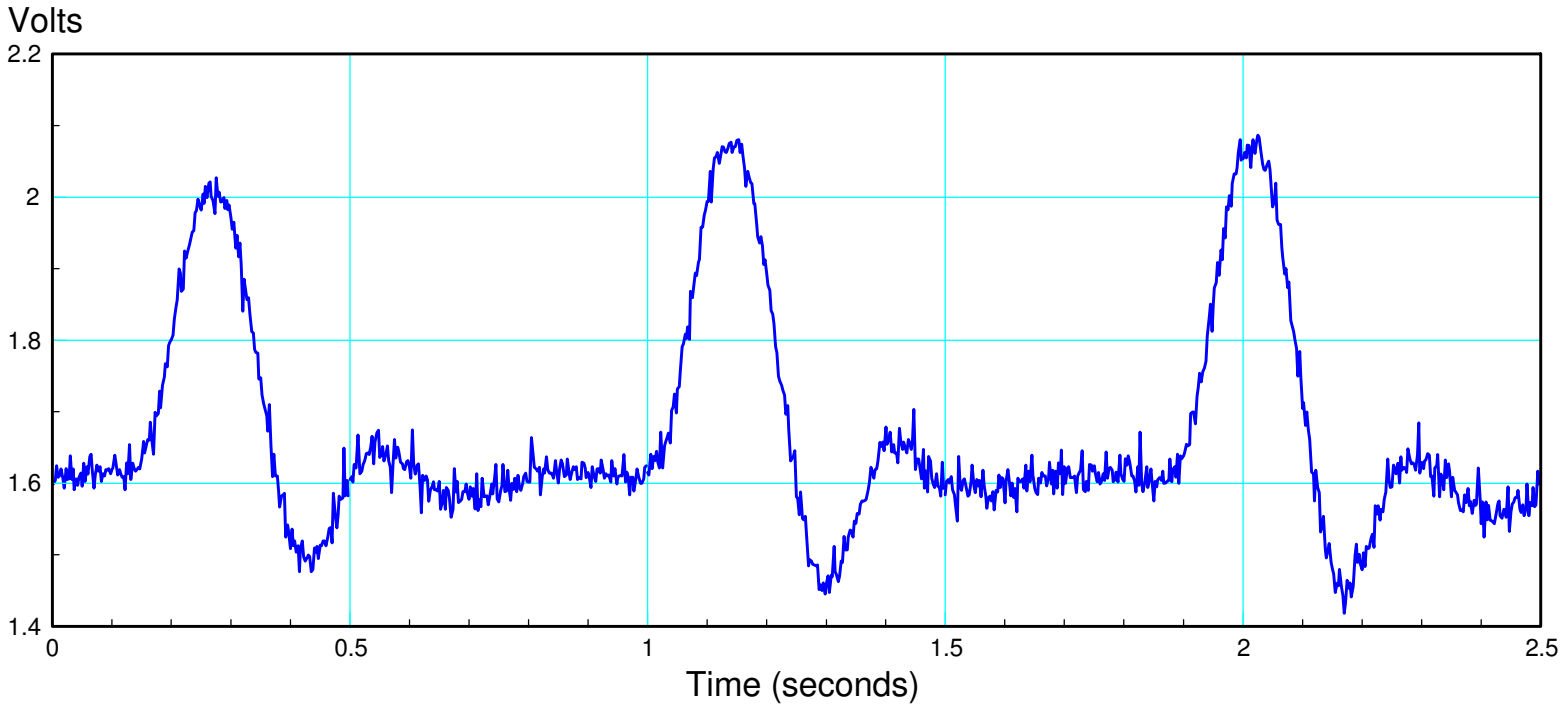
Add a non-inverting amplfier

- Set circuit ground to 1.65V
- Amplifies the heart signal, relative to 1.65V
- Adjust the gain until it's close to 3.3Vpp



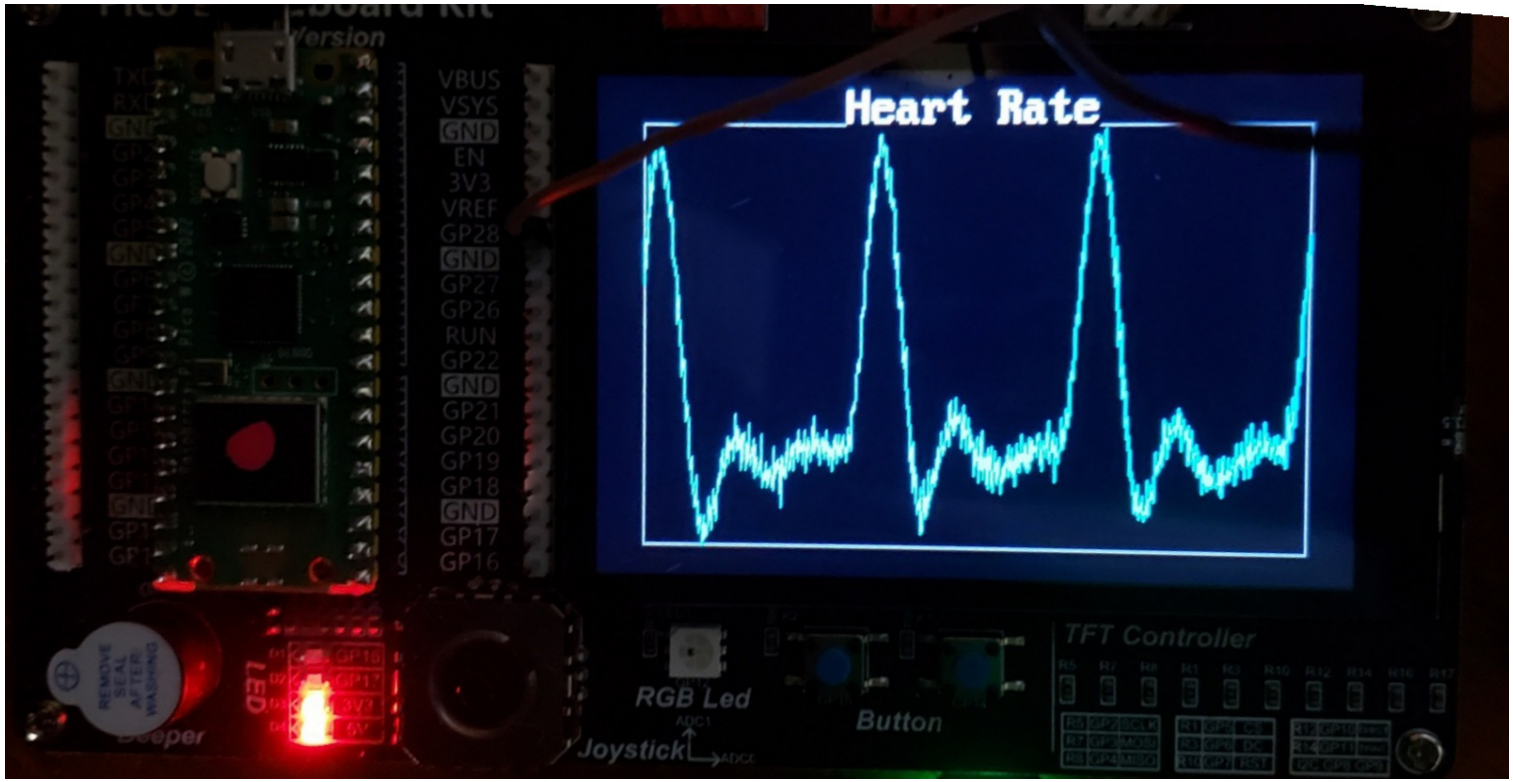
Once amplified, the analog signal can be collected with a Pi-Pico.

- Button GP14: Discard data and collect a new set of 1000 points
- Button GP15: Save the data to a file



On Bison Academy, the program *22 Heart Rate*

- Uses timer interrupts to set the sampling rate to 2.5ms
- Collects 1000 data points over a span of 2.5 seconds
- Once collected, the signal is displayed on the TFT graphics display.
- Save (GP15) or discard (GP14) the data and go again



Summary:

The Pi-Pico's 12-bit A/D allows you to measure analog signals. Couple this with a circuit to measure current or your pulse and you can record

- The current draw of different types of light bulbs
- Your pulse with a heart rate sensor,

or just about anything else.

References

Pi-Pico and MicroPython

- https://github.com/geeekpi/pico_breakboard_kit
- https://micropython.org/download/RPI_PICO/
- https://learn.pimoroni.com/article/getting-started-with-pico
- https://www.w3schools.com/python/default.asp
- https://docs.micropython.org/en/latest/pyboard/tutorial/index.html
- https://docs.micropython.org/en/latest/library/index.html
- https://www.fredscave.com/02-about.html

Pi-Pico Breadboard Kit

- https://wiki.52pi.com/index.php?title=EP-0172

Other

- https://docs.sunfounder.com/projects/sensorkit-v2-pi/en/latest/
- https://electrocredible.com/raspberry-pi-pico-external-interrupts-button-micropython/
- https://peppe8o.com/adding-external-modules-to-micropython-with-raspberry-pi-pico/
- https://randomnerdtutorials.com/projects-raspberry-pi-pico/
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