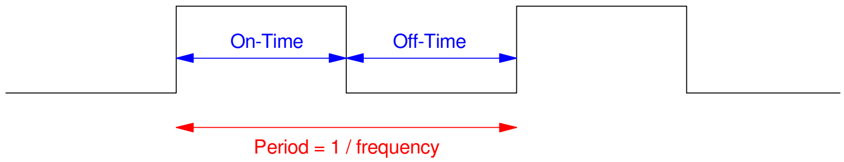
8. Timing

Time-Related Functions & the Time Library



Introduction:

In this lecture, we look things related to time. This includes measuring:

- The time between events
- The width of a pulse
- The period of a square wave (and hence its frequency)

We'll also look at

- How to generate a square wave of a given frequency,

With this, we'll be able to

- Measure your reflex time,
- Measure distance using an ultrasonic range sensor,
- Measure resistance, capacitance, and temperature using a 555 timer, and
- Play a tune with your Pi-Pico

Measuring Time

One of the more useful libraries is the *time* library. You can see the functions included by typing:

```
>>> import time
>>> dir(time)
['__class__', '__name__', '__dict__', 'gmtime', 'localtime',
'mktime', 'sleep', 'sleep_ms', 'sleep_us', 'ticks_add',
'ticks_cpu', 'ticks_diff', 'ticks_ms', 'ticks_us', 'time',
'time_ns']
```

To measure time, the funcitons we're going to use are:

```
ticks_ms          time since power up in ms
ticks_us          time since power up in us
ticks_cpu         time since power up in cpu clocks (varies with uP)
                  recommended you don't use ticks_cpu
```

For example, if you want to know how long the *time.sleep(1)* function takes, you could use the following code:

```
from time import ticks_cpu, ticks_ms, ticks_us, sleep

x0 = ticks_us()
sleep(1)
x1 = ticks_us()
print(x1 - x0)
```

shell

```
1000064
```

According to this test, the *sleep(1)* took 1,000,064 us to execute (it's a little high due to the time it takes to call the *ticks_us()* routine.) You could remove this time with

```
from time import ticks_cpu, ticks_ms, ticks_us, sleep

x0 = ticks_us()
sleep(1)
x1 = ticks_us()
x2 = ticks_us()
print(x1 - x0 - (x2-x1))
```

shell

```
1000004
```

Now, the one-second wait actually takes 1,000,004us or 1.000004 seconds.

If you chance this to ten seconds,

```
from time import ticks_cpu, ticks_ms, ticks_us, sleep

x0 = ticks_us()
sleep(10)
x1 = ticks_us()
x2 = ticks_us()
print(x1 - x0 - (x2-x1))
```

shell

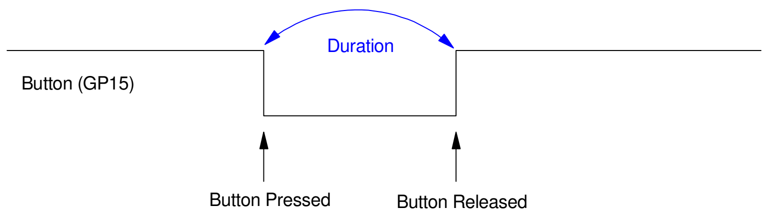
```
10000006
```

the ten-second sleep routine actually takes 10.000006 seconds. (the sleep() function is really accurate!).

OK - so now that we can measure time, let's have some fun with it.

Button Press Game: What's the shortest time I can press and release a button?

- Wait until you press the button (value goes to zero). Record that time.
- Then wait until you release the button (value goes to one). Record that time.
- The difference in time is how long you held the button down.



Button Press Game: Measure the time the button is held down.
Try to get the lowest score.

In Code:

```
from time import ticks_us, ticks_ms
from machine import Pin

Button = Pin(15, Pin.IN, Pin.PULL_UP)
while(1):
    while(Button.value() == 1):
        pass
    x0 = ticks_us()
    while(Button.value() == 0):
        pass
    x1 = ticks_us()
    print(x1-x0)
```

shell

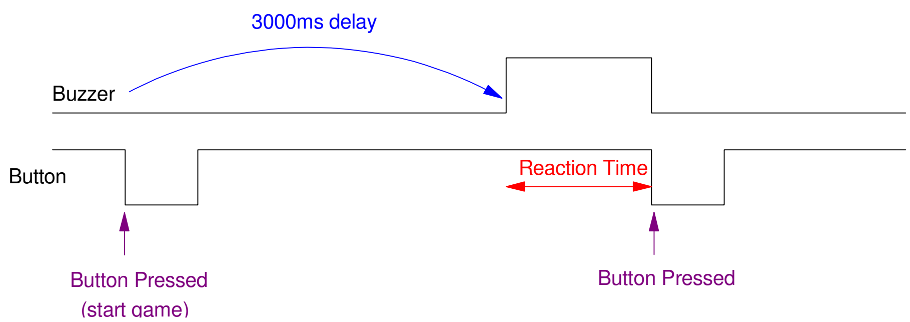
```
51494
48585
57623
55358
60112
39496
```

In six attempts, the shortest time I was able to record was 39,496us. With a little more code, you could keep track of the low score.

Example 2: Reaction Time Game: For some more fun, determine my reflex time.

- Start out by pressing a button.
- 3 seconds later, turn on the buzzer
- As soon as the buzzer turns on, press the button

The time delay from hearing the buzzer and pressing the button is your reflex time.



Reaction Time Game: Measure the time between when the buzzer turns on and you press a button

In code:

```
from time import ticks_us, sleep_ms
from machine import Pin

Buzzer = Pin(13, Pin.OUT)
Button = Pin(15, Pin.IN, Pin.PULL_UP)
while(1):
    while(Button.value() == 1):
        pass
    while(Button.value() == 0):
        pass
    sleep_ms(3000)
    Buzzer.value(1)
    x0 = ticks_us()
    while(Button.value() == 1):
        pass
    x1 = ticks_us()
    Buzzer.value(0)
    print(x1 - x0)
```

shell

```
134063
160489
125309
```

Result: My reaction times were {134063us, 160489us, 125309us)

Comments:

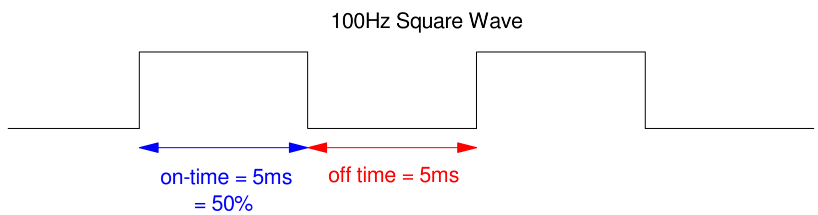
- It would be better if the time delay from hitting the button and the buzzer going off was random. It would prevent you from anticipating the buzzer.
- Once you can measure your reflex time, you can now start asking quesitons such as
  - What frequency works best?
  - Is a solid tone or a series of beeps better?

- Do you respond to light faster than sound?
- What color of light are people most responsive to?
- Do your reflexes improve after exercise? After a caffinated drink?
- etc.

Generate a Fixed Frequency

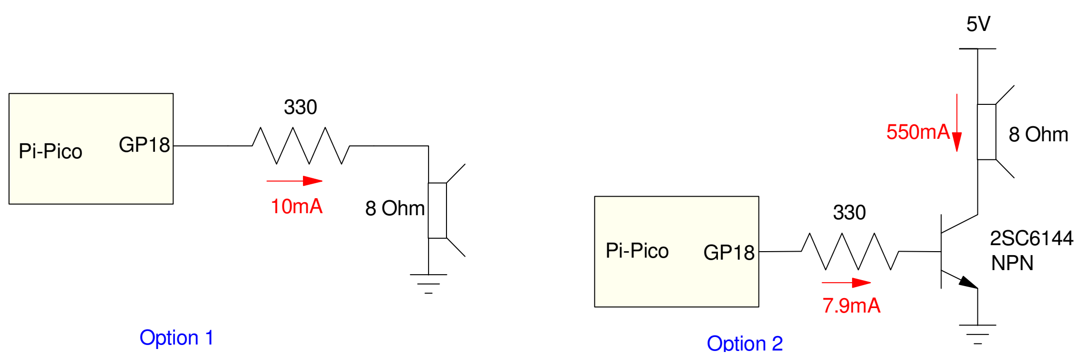
There are several ways to generate a square wave on an output pin. Using the time.sleep() function works, but it ties up the processor while waiting - and the frequency isn't very steady. A better way is to use the *PWM* function from library *machine.*

For example, to set up GP18 to output a 100Hz square wave



To hear this as a sound, connect GP18 to a speaker

- With a 330 Ohm resistor (to limit the current to 10mA), or
- With an NPN transistor (to make a loud annoying sound)



Two ways to connect a speaker to your Pico board. A resistor is simple, add a transistor and it's louder.

The code would be:

```
from machine import Pin, PWM

Spkr = Pin(18, Pin.OUT)
Spkr = PWM(Pin(18))
Spkr = freq(100)
Spkr.duty_u16(32768)

while(1):
    pass
```

The way this code works is as follows:

- Line 3: Set pin #18 to be an output pin. This presumable drives a speaker, strobe light, etc.
- Line 4: Set pin #18 to be a PWM signal (pulse-width modulation)
- Line 5: Set the frequency to 100Hz
- Line 6: Set the duty cycle to 50% (32768 / 65546)

note: The duty cycle is defined as the percent of time the square wave is high. The duty cycle is set by *duty_u16()* as

- 0 0% duty cycle square wave (off)
- 32768 50% duty cycle square wave
- 65535 100% duty cycle square wave (on)

You could also use the *duty_ns(5_000_000)* to set the on-time to 5,000,000ns (5ms or 50%). Your pick.

```
Spkr = Pin(18, Pin.OUT)
Spkr = PWM(Pin(18))
Spkr = freq(100)
Spkr.duty_ns(5_000_000)
```

If you want the output to cycle on and off every 500ms, flip between 50% duty cycle and 0% duty cycle:

```
from machine import Pin, PWM
from time import sleep_ms

Spkr = Pin(18, Pin.OUT)
Spkr = PWM(Pin(18))
Spkr = freq(100)
Spkr.duty_u16(32768)

while(1):
    Spkr.duty_16(32768)      # buzzer on
    sleep_ms(500)
    Spkr.duty_16(0)          # buzzer off
    sleep_ms(500)
```

3-Key Piano: Now that we can play a single note, play three different notes

- When GP20 is 0 (button pressed), play 220Hz
- When GP21 is 0, play 250Hz
- When GP22 is 0, play 280Hz
- Otherwise, remain silent

3-Key Piano

```
import time
from machine import Pin, PWM

# Construct PWM object, with LED on Pin(25)
Spkr = PWM(Pin(18))
B0 = Pin(20, Pin.IN, Pin.PULL_UP)
B1 = Pin(21, Pin.IN, Pin.PULL_UP)
B2 = Pin(22, Pin.IN, Pin.PULL_UP)

while(1):
    if(B0.value() == 0):
        Spkr.freq(220)
        Spkr.duty_u16(32768)
        while(B0.value() == 0):
            pass
    if(B1.value() == 0):
        Spkr.freq(250)
        Spkr.duty_u16(32768)
        while(B1.value() == 0):
            pass
    if(B2.value() == 0):
        Spkr.freq(280)
        Spkr.duty_u16(32768)
        while(B2.value() == 0):
            pass
    pwm.duty_u16(0)
```

Note that with this code, *while()* loops are used

- When a button is pressed (if-statement), the frequency and duty cycle are set.
- The code then waits (while loop) until the button is released

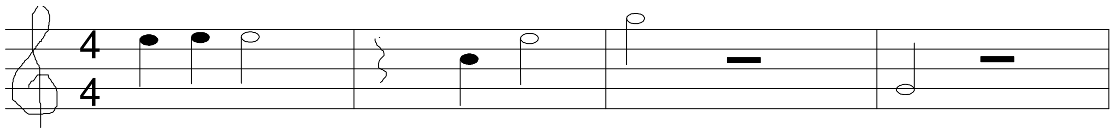
This holds the frequency as long as the button is pressed.

As a side light - what happens if you hold down two buttons at the same time?

As written, the first button pressed wins. As long as that button is held down (value() == 0), you're stuck in a while-loop and the other buttons are ignored.

There are other ways to write this program - but as is, only one note will be played at a time.

Super Mario Brothers Theme: As a third example, play the first four bars of SuperMario Brothers:



To do this, create a subroutine which plays a given note for a fix duration:

- Hz is the frequency of the note in Hz
- Eighths sets the duration of the note in 1/8th notes
- The last 50ms of each note is silent, allowing you to hear the same note played twice:

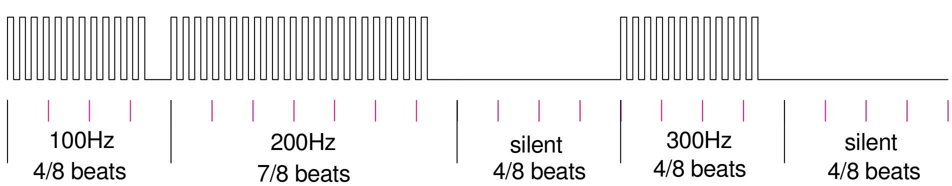
```
def Play(Hz, Eighths):
    if(Hz > 0):
        Spkr.freq(int(Hz))
        Spkr.duty_u16(32768)
    else:
        Spkr.duty_u16(0)
    time.sleep_ms(75 * Eights - 50)
    Spkr.duty_u16(0)
    time.sleep(0.05)
```

With this routine, you could play

- 100Hz for 4/8th beat, then
- 200Hz for 7/8th beat
- Go silent for 4/8th beat
- 300Hz for 4/8 beat

with the following program:

```
Play(100, 4)
Play(200, 7)
Play(0, 4)
Play(300,4)
Play(0,4)
```



Output of the Play() subroutine

Placing the frequencies and durations into an array, you can go through the array to play a tune, such as Super Mario Brothers:

Super Mario Brothers (take 2)

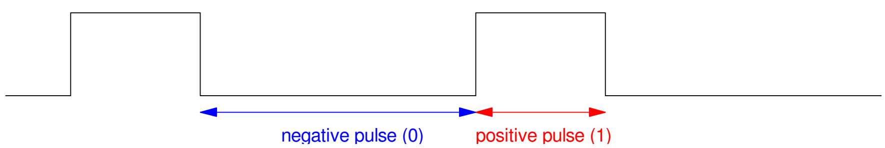
```
# Play the opening notes for Super Mario Brothers

from time import sleep_ms
from machine import Pin, PWM

Spkr = PWM(Pin(18))

def Init():
   Spkr.freq(100)
   Spkr.duty_u16(0)

def Play(Hz, Eighths):
    if(Hz > 0):
        Spkr.freq(int(Hz))
        Spkr.duty_u16(32768)
    else:
        Spkr.duty_u16(0)
    sleep_ms(75 * Eights - 50)
    Spkr.duty_u16(0)
    sleep_ms(50)

G3 = 195
A3 = 220
B3 = 233
C4 = 262
D4 = 277
E4 = 330
F4 = 349
G4 = 392
A4 = 440
B4 = 494

Notes   =  [E4, E4, E4, 0, C4, E4, G4, 0, G3, 0]
Dur     =  [2,  2,  4,  2,  2,  4,  4, 4,  4, 4]

def Play_Tune():
    for i in range(0, len(Notes)):
        Play(Notes[i], Dur[i])

Init()
while(1):
    Play_Tune()
    time.sleep(1)
```

Measuring Pulse Width

A little more stylish way to measure a pulse width is to use the *time_pulse_us()* function in library *machine*. The format for using this funciton is:

```
Tp = time_pulse_us(17, 1, 100_000)   # time of a positive pulse
Tm = time_pulse_us(17, 0, 100_000)   # time of a negative pulse
```

- The first number (17) is the pin you're trying to measure.
- The second number (1, 0) indicated whether you're measuring a positive pulse (1) or negative pulse(0)
- The third number is the max time in microseconds. If a pulse isn't detected withing this time it kicks out rather than being stuck in an infinite loop.



time_pulse_us() lets you measure the width of a negative or positive pulse

For example,

- measure the pulse width of pin #17 (positive pulse default)
- measuring positive pulse (pulse_level = 1) or negative pulse (pulse_level = 0)
- time-out if longer than 5,000,000us

```
from machine import Pin, time_pulse_us

Button = Pin(17, Pin.IN, Pin.PULL_UP)
while(1):
    x = time_pulse_us(17, 0, 5_000_000)
    print(x)
```

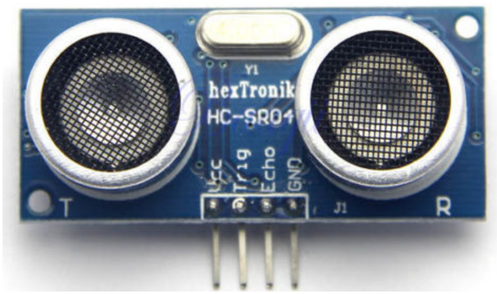
shell

```
51494
48585
57623
55358
60112
39496
```

The results in the shell window give the negative pulse width (equal to the time the button was held down) in micro-seconds. From the data, my shortest time was 39,496us.

Ultrasonic Range Sensor:

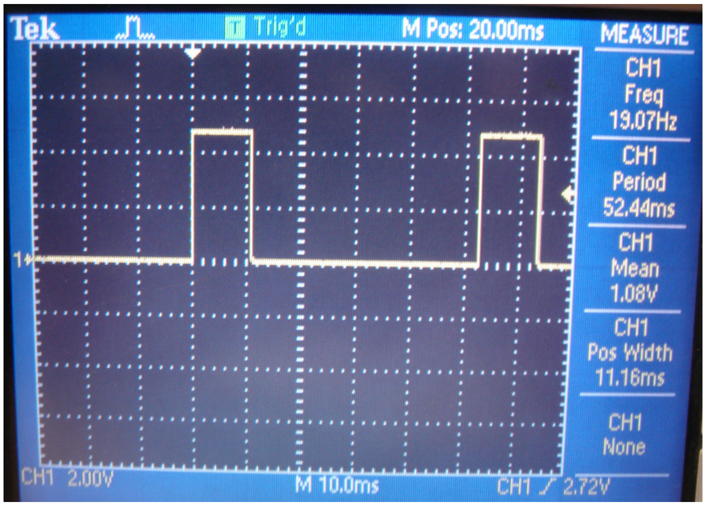
With this funciton you can measure distance using an ultrasonic range sensor.



This device has four pins:

- Vcc: input: +5V
- Trig: input: Square wave from the RPi-Pico
- Echo: output: Pulse to the RPi-Pico (note: you need to drop this down to 3.3V)
- Gnd: input: 0V

Each time you sent from the range sensor. The time it takes for the sound to return is the duration of the pulse on Echo. For example, if Trig is a 20Hz square wave, the signal on Echo might look like this:

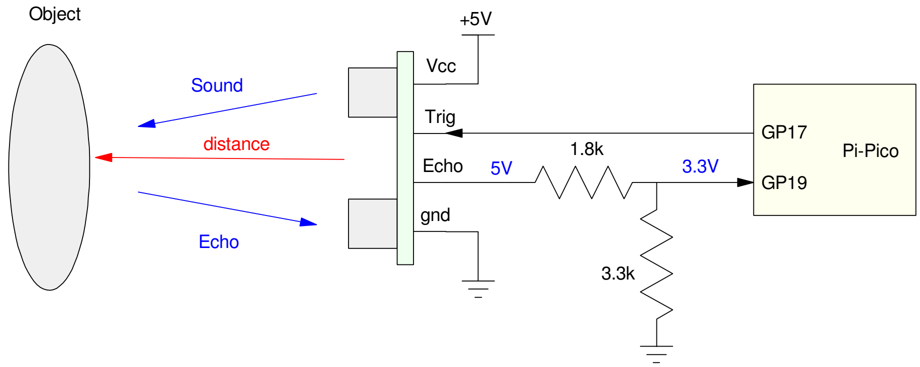


The pulse width is a measure of distance to an object. Assuming the speed of sound is 343 m/s, each microsecond of pulse width corresponds to a distance of

$$2d = (343\tfrac{m}{s}) \cdot (1\mu s)$$

$$d = 171.5\mu m$$

(the 2 is due to the sound having to travel to and back from the object - so the effective distance the sound travels is 2d)



Connections for an Ultrasonic Range Sensor.
Notes: The range senosr needs 5V to operate. The 5V echo needs to be reduced to 3.3V at the Pi-Pico

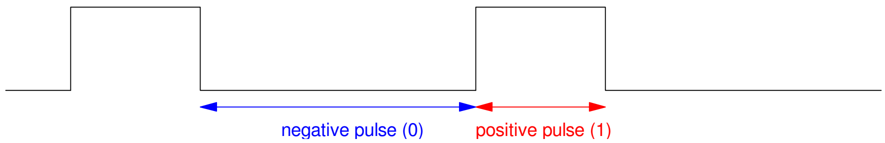
With the range sensor connected to pins 17 (trigger) and 19 (echo), the program would look like:

 # Range Sensor

```
from machine import Pin, PWM, time_pulse_us
from time import sleep_ms

TRIG = 17
ECHO = 19

def setup():
    global p_Trig, p_Echo
    p_Trig = Pin(TRIG, Pin.OUT)
    p_ECHO = Pin(ECHO, Pin.IN)
    p_Trig = PWM(Pin(TRIG))
    p_Trig.freq(50)
    p_Trig.duty_ns(1000)
    p_Echo = Pin(ECHO, Pin.IN, Pin.PULL_UP)

def distance():
    mm = time_pulse_us(ECHO, 11) * 0.1715
    return mm

def loop():
    dis = distance()
    print (dis, 'mm')
    sleep_ms(300)

# Main Routine
setup()
while(1):
    loop()
```

Measure Period (or frequency)

With *time_pulse_us()* you can measure the positive or negative pulse of a square wave. Add the two together and you get the period.



For example

- Set up GP18 to be a 100Hz square wave with a positive pulse of 10ms (10,000 us)
- Set up GP17 to be an input pin
- Short pin 17 to pin 17
- Measure the period of the signal on GP17

```
from machine import Pin, PWM, time_pulse_us
from time import ticks_cpu, ticks_ms, ticks_us

buzzer = Pin(18, Pin.OUT)
buzzer = PWM(Pin(18))
buzzer = freq(100)
buzzer.duty_ns(10000)

Button = Pin(17, Pin.IN, Pin.PULL_UP)
while(1):
    x = time_pulse_us(17, 1, 100_000)
    y = time_pulse_us(17, 0, 100_000)
    print('Period = ,x+y,' us')
    sleep_ms(100)
```

Result: Period = 9808 us

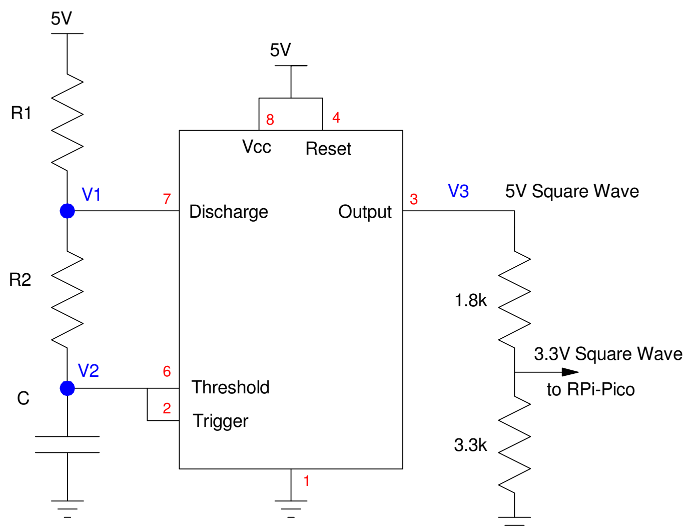
Measure Resistance (LM555 Timer)

If you can measure frequency, you can measure resistance. The following 555 timer outputs a square wave where

$$T_{on} = (R_1 + R_2) \cdot C \cdot \ln(2)$$

$$T_{off} = R_2 \cdot C \cdot \ln(2)$$

If R1 and C are known, you can determine R2 by measuring the period (or the off-time)



Assume R1 = 10k, R2 = 100k, and C = 0.1uF. Then

$$T_{off} = 6931.47\mu s$$

$$R_2 = 100k\Omega \cdot \left(\frac{T_{off}}{6931.47\mu s}\right) = 14.427 \cdot T_{off}(\mu s)$$

Code:

```
from machine import Pin, PWM, time_pulse_us
from time import ticks_cpu, ticks_ms, ticks_us

T555 = Pin(17, Pin.IN, Pin.PULL_UP)
while(1):
    Toff = time_pulse_us(17, 0, 100_000)
    R2 = 14.427 * Toff
    print(R2)
    sleep_ms(100)
```

Measure Temperature (555 Timer)

If you can measure resitance, you can measure tempeature. Replace R2 with a thermistor, such as

$$R = 1000 \cdot \exp\left(\frac{3905}{T+273} - \frac{3905}{298}\right)\Omega$$

and you can compute temperature in degees C (T) as a funciton of pulse width.

$$T = \left(\frac{3905}{\ln\left(\frac{R}{1000}\right) + \left(\frac{3905}{298}\right)}\right) - 273$$

or

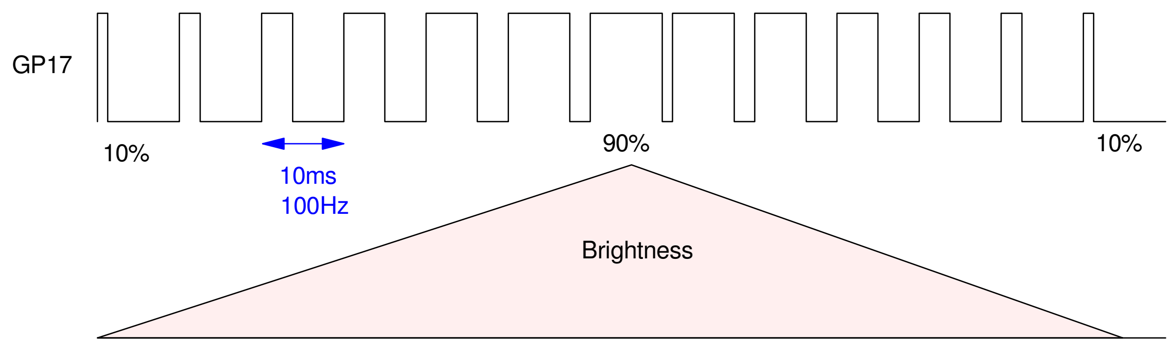
$$T = \left(\frac{3905}{\ln\left(\frac{14.427 \cdot T_{off}}{1000}\right) + \left(\frac{3905}{298}\right)}\right) - 273$$

```
from machine import Pin, PWM, time_pulse_us
from time import ticks_cpu, ticks_ms, ticks_us
from math include log

T555 = Pin(17, Pin.IN, Pin.PULL_UP)
while(1):
    Toff = time_pulse_us(17, 0, 100_000)
    R2 = 14.427 * Toff
    T = 3905 / ( log(R/1000) + (3905/298) ) - 273
    print(T)
    sleep_ms(100)
```

This is termed *theoretical calibration*: given the reading, go backwards through the calculations to get the temeprature.

Vary Brightness of LED

Finally, by varying the duty cycle, you can vary the brightness of an LED. The following code makes the LED on GP17 vary from 0% on to 100% on then back over and over again




```
# Fade LEDs on and off
 from time import sleep_ms
 from machine import Pin, PWM

 LED = Pin(17, Pin.OUT)
 LED = PWM(Pin(17))
 LED.freq(100)

 x = 0
 dx = 100

 while(1):
     x += dx
     LED.duty_u16(x)
     if(x > 65000):
         dx = -abs(dx)
     if(x <= 0)
         dx = abs(dx)
     sleep_ms(1)
```

Summary:

The Pi-Pico is really quite versitile. With it, you can

- Output square waves at a given frequency and duty cycle
- Measure time to one micro-second
- Mesure the width of a pulse (positive or negative),

amoung other things. Add in a sensor, and you can measure distance, temperature, light, etc.