Introduction to Design (2)

Microcontroller Systems and Interfacing

Week 04

LEDs, duty cycle, and PWM

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this week

passive components

- diodes
- light-emitting diodes

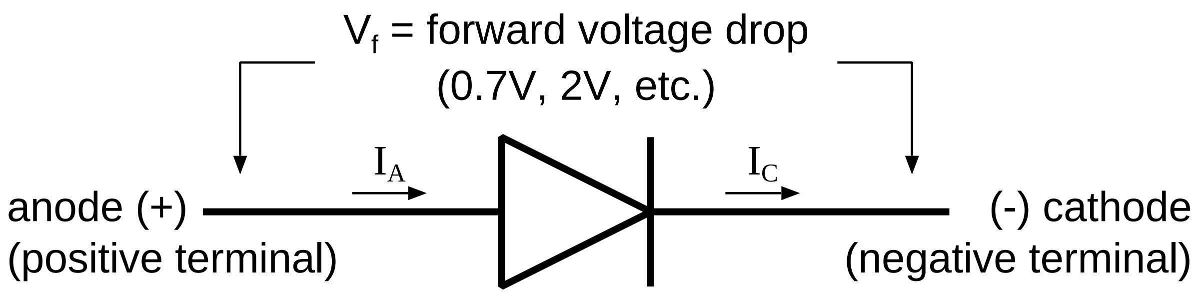
digital signals

- pulses, duty cycle, modulation

a diode conducts in only one direction

a *diode*

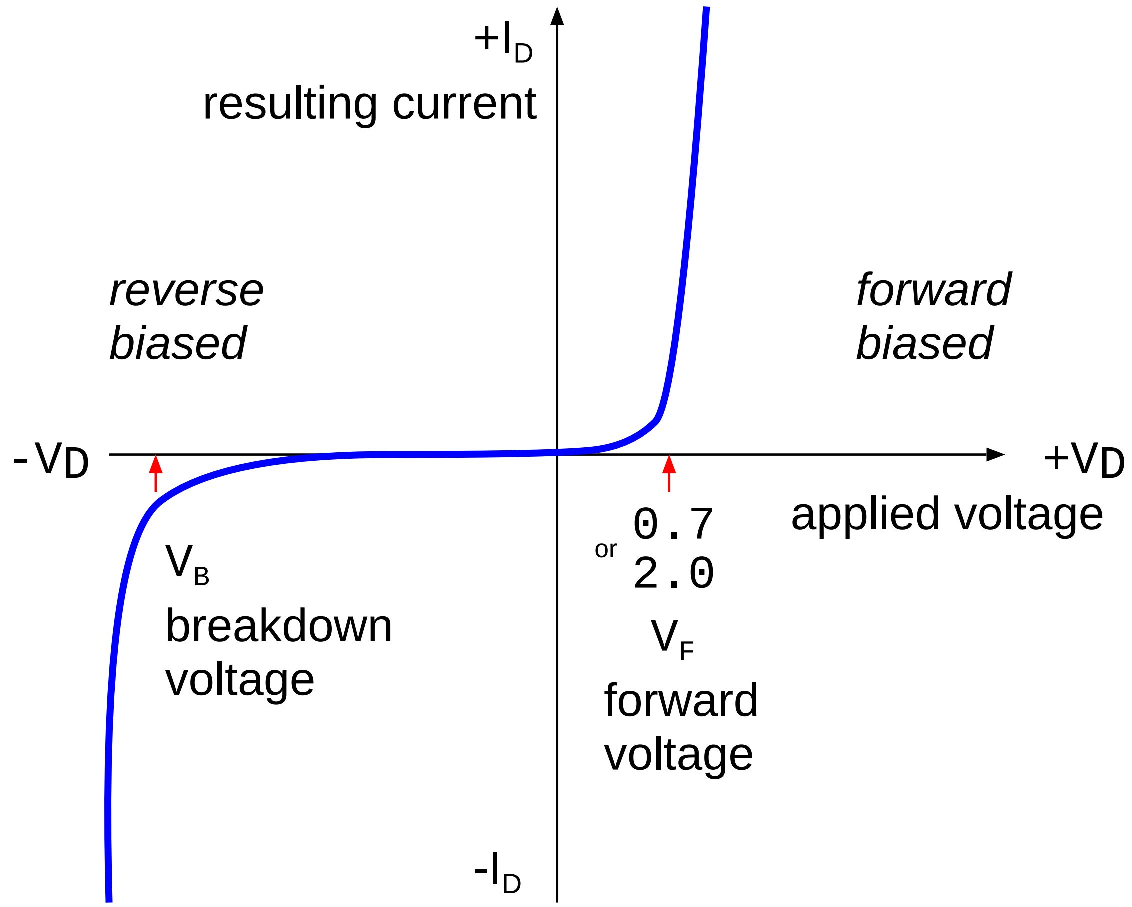
- has two terminals, the *anode* and the *cathode*
- conducts electricity in only one direction
  - when the **anode is more positive than the cathode** (*forward biased*)
- has very little (effectively zero) resistance when conducting



from anode to cathode there is a (fixed) voltage drop

- called the *forward voltage*, V_f, of the diode
- the cathode voltage V_C is V_f volts below the anode voltage V_A; $V_C = V_A - V_f$
- V_f depends on the type of diode
  - simple diodes, $V_f \approx 0.7\,V$

characteristic voltage/current curve for diodes

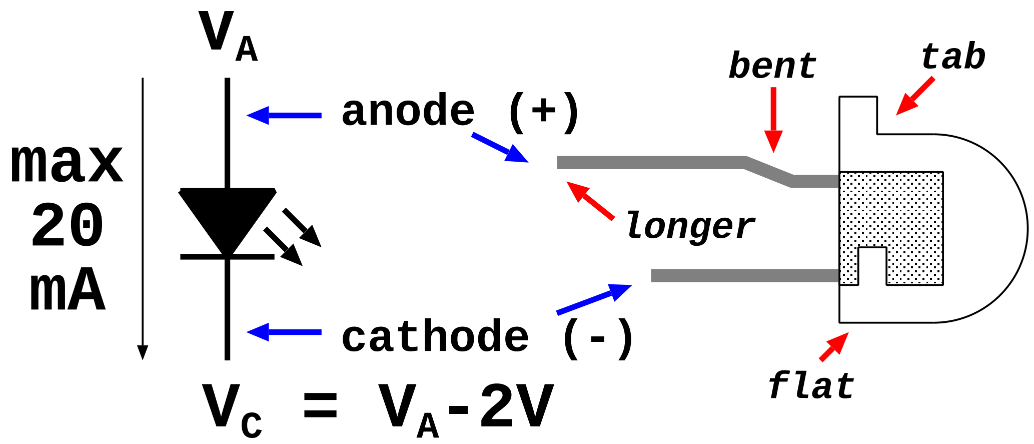


from this we see that

- the sudden conduction above V_f causes the constant forward voltage drop
- too much reverse bias causes ‘breakdown’ conduction (usually avoided)

light-emitting diodes

LEDs are diodes that emit light when forward biased

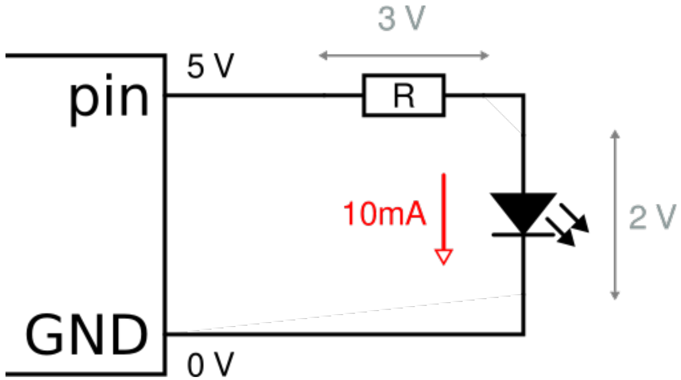


LED emits light when *forward biased* (anode positive, cathode negative)

- they have a higher forward voltage than other diodes: $V_f \approx 2\,\text{V}$
- they have a specified maximum safe current
  - too much current ($> 20\,\text{mA}$) will damage the LED
  - giving them about $10\,\text{mA}$ is perfectly safe

how can we prevent more than $10\,\text{mA}$ flowing through an LED?

adding LEDs to digital outputs



as with a loudspeaker, use a *current-limiting resistor*

when the LED is on

- the digital pin is at 5 V, GND is at 0 V
- 2 V is dropped across the diode (necessary for the diode to conduct)
- 3 V therefore remains to be dropped across the resistor R
- the diode has effectively zero resistance
- the total resistance of the circuit is therefore equal to R

the resistor value R can be chosen so that exactly 10 mA flows around the circuit

$$\begin{aligned} R &= V/I \\ &= 3/0.01 \\ &= 300\,\Omega \end{aligned}$$

the next higher standard value is 330 Ω

adding LEDs to digital outputs

Arduino has one programmable LED on the board

- digital output 13

adding more LEDs is often useful

- to display more than one information (or debugging) signal
- many interesting *emission* displays are based on LEDs

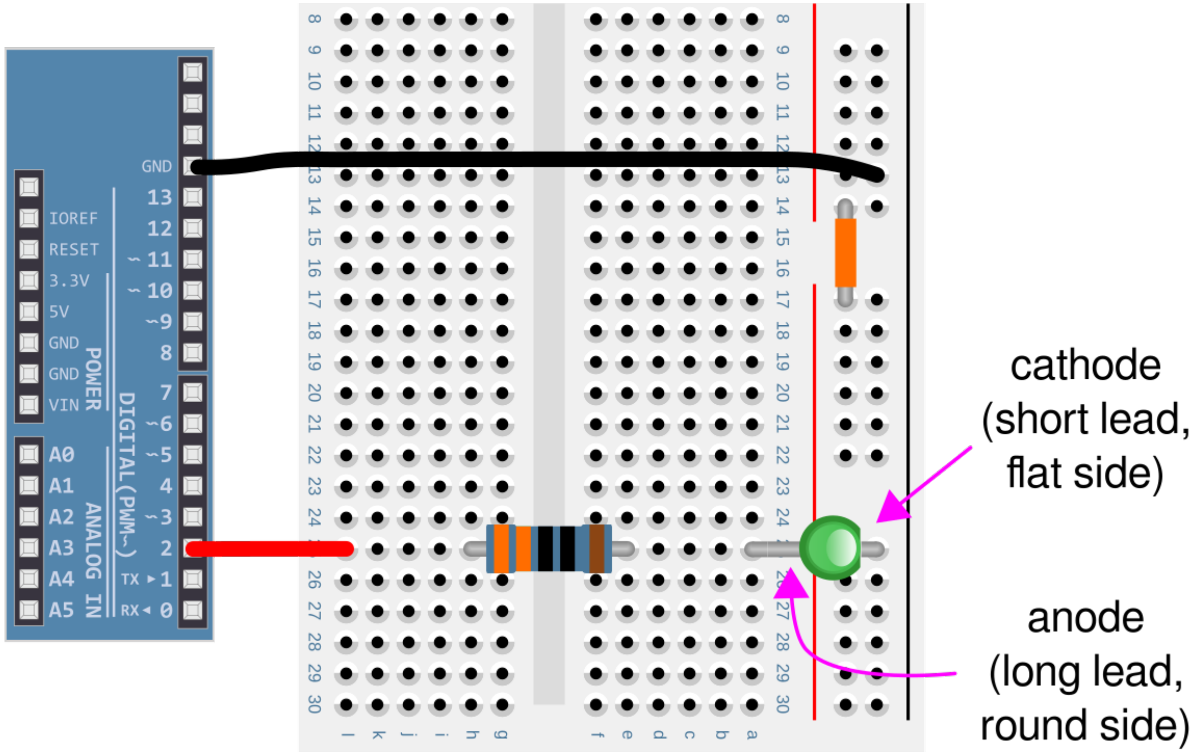
most LED applications require each LED to be connected independently

- each LED has its own digital output
- each LED has its own current-limiting resistor

we will connect LEDs starting from digital output 2

- outputs 0 and 1 are used for serial communication

one LED per digital output




```
void setup() {
  pinMode(2, OUTPUT); // not pin 13!
}

void loop() {
  digitalWrite(2, HIGH);  delay(500);
  digitalWrite(2,  LOW);  delay(500);
}
```

experiments

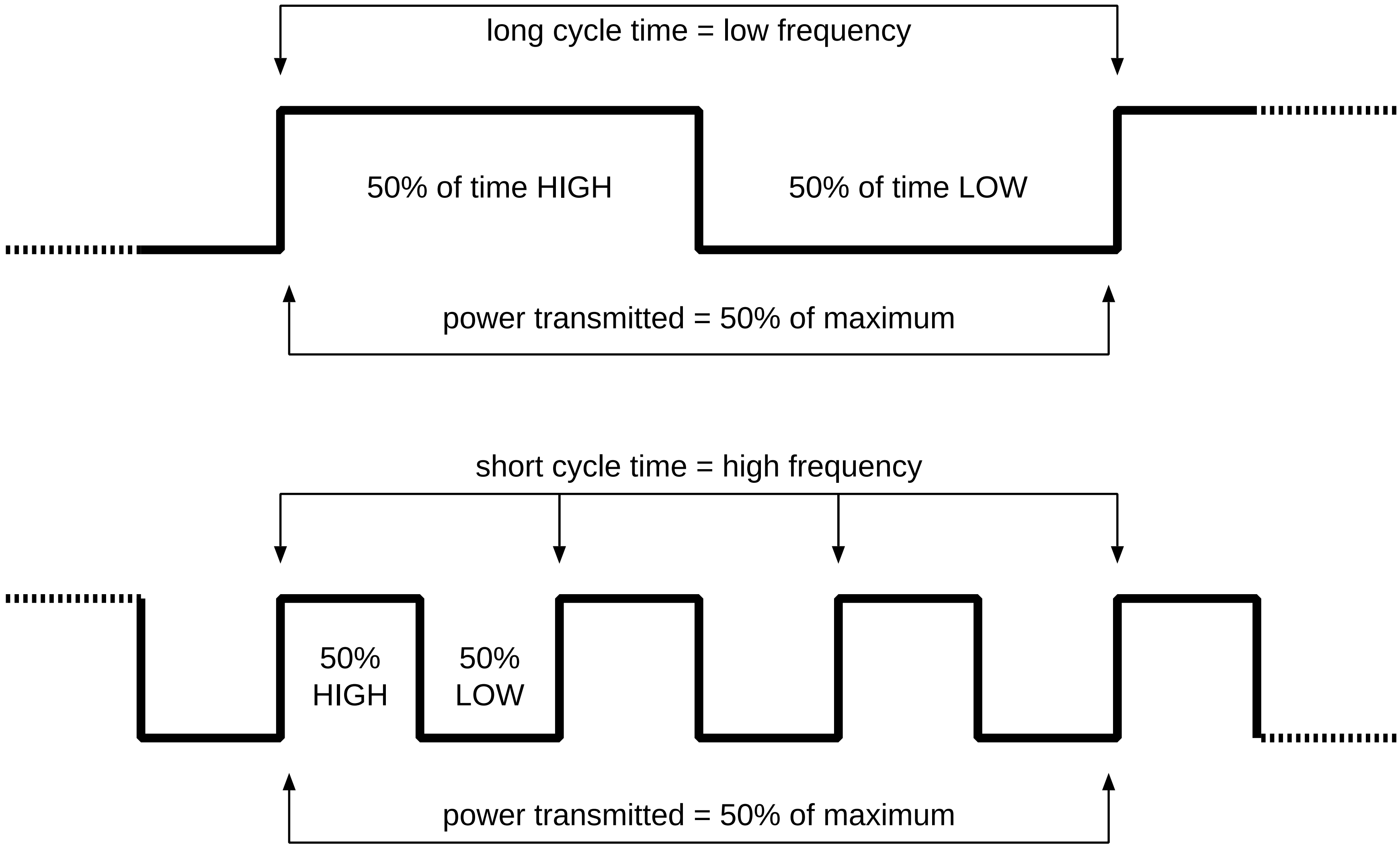
recommendation

to maximise your discovery and fun:

please complete as many of the lab experiments as possible

before reading the remainder of the slides

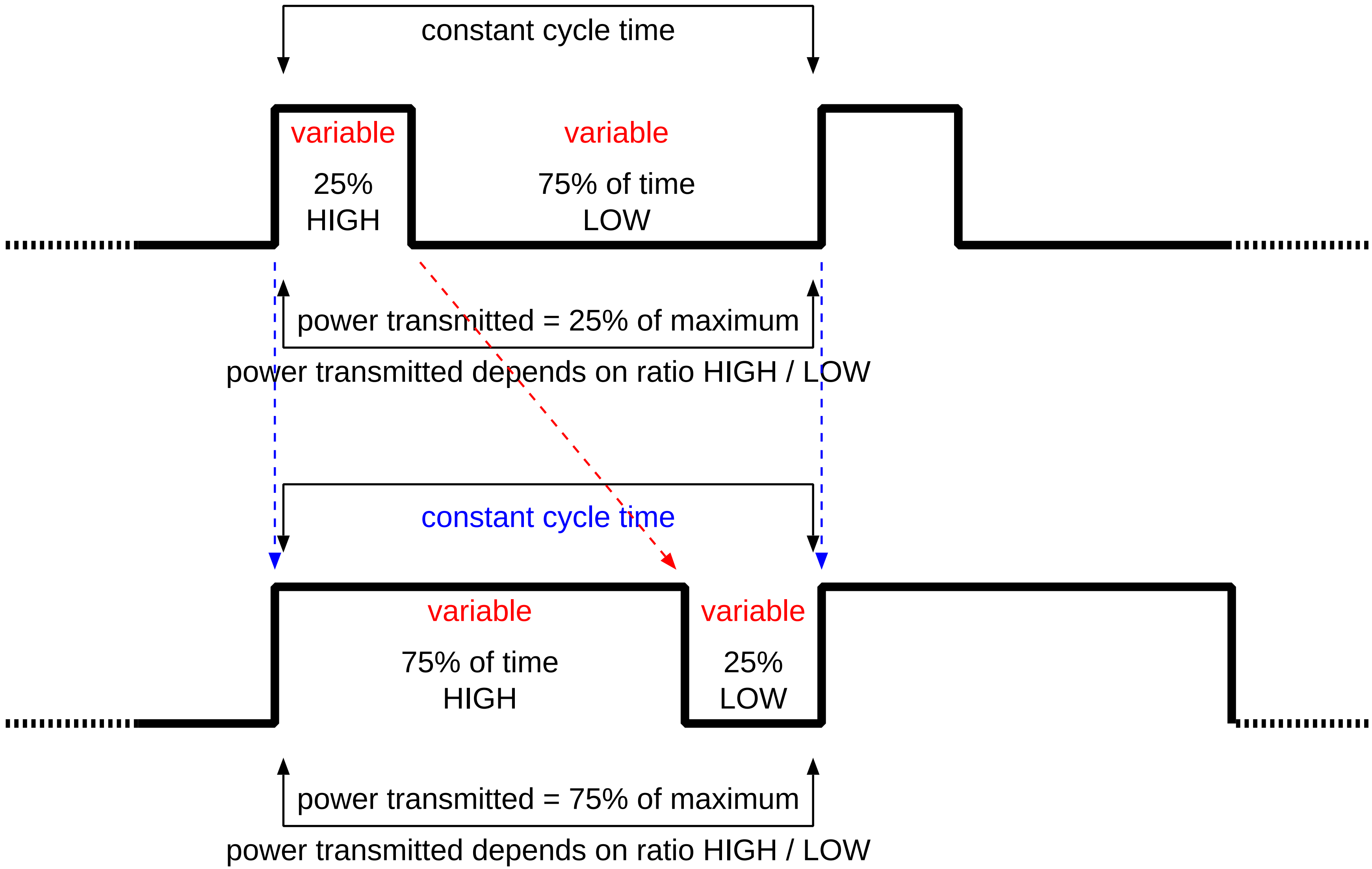
frequency depends on cycle time



power transmitted is independent of cycle (HIGH or LOW) time

power transmitted is consant, always 50% of maximum

high and low half cycles can vary from 0% to 100%



$$t_{LOW} = t_{cycle} - t_{HIGH}$$

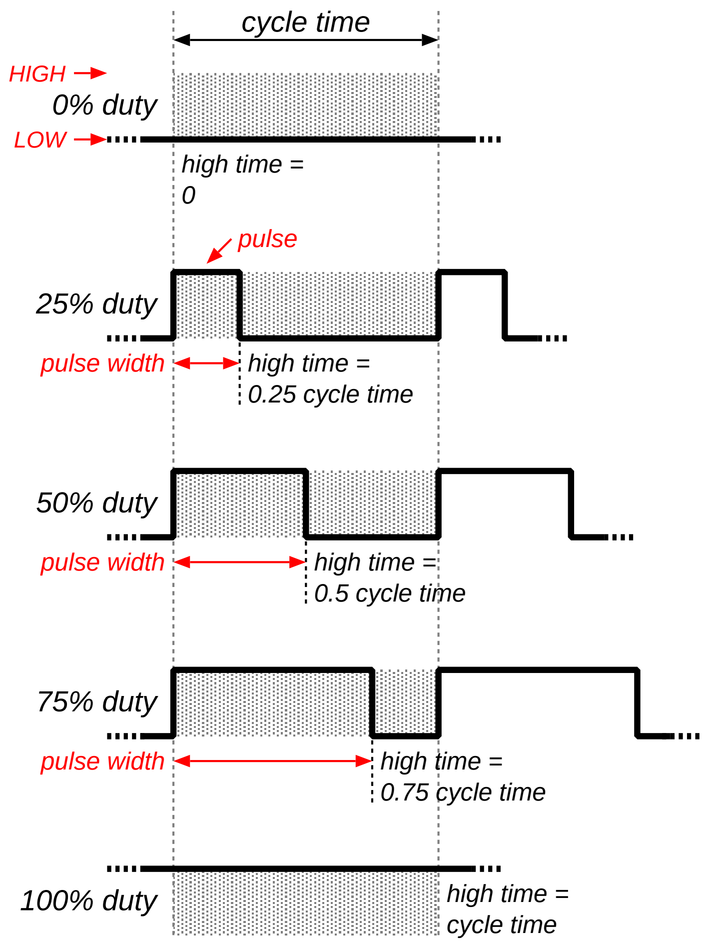
power transmitted: 0% ($t_{HIGH} = 0, t_{LOW} = t_{cyc}$) to 100% ($t_{HIGH} = t_{cyc}, t_{LOW} = 0$)

pulse width modulation (PWM)

unequal `HIGH` and `LOW` times produce an asymmetrical signal

- the ratio $t_{\mathtt{HIGH}}/t_{\text{cycle}}$ determines the amount of power in the signal
  - low power ⇒ low volume, low brightness, etc.
- expressed as a percentage, this ratio is called the *duty* of the signal

```
void loop() {
  digitalWrite(pin, HIGH);
  delayMicroseconds(highTime);
  digitalWrite(pin, LOW);
  delayMicroseconds(cycleTime - highTime);
}
```



when one signal A controls another signal B

- A modulates B

if A is desired change in power delivered by B

- A must change the duty cycle of B
- A modulates the width of the pulses in signal B
- hence *pulse width modulation*