Module 3

Pulse Width Modulation
(PWM)

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Reading

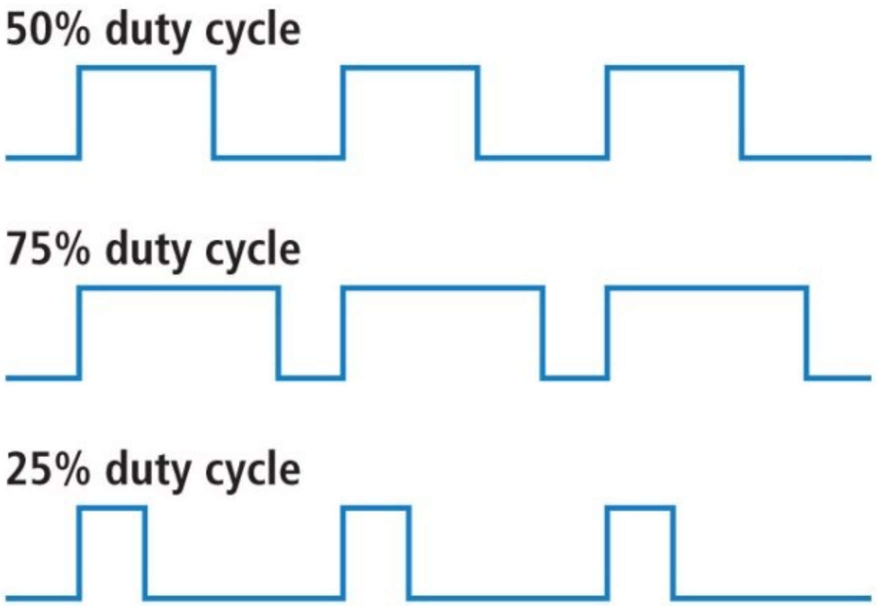
- Reading assignment:
  - PWM - Textbook, Chapter 15.3, Timers: PWM Output, pp. 384 – 395.

Future Reading

- Textbook, Chapter 22, Serial Communication Protocols, pp. 527 – 598
  - It’s a long chapter.
  - Let’s first look at Section 22.3, SPI, pp. 568–577.
  - Don’t worry so much about the USB section.
    - Read that only if you’re curious.
    - Your development board has no USB interface.
      - There are some USB provisions in the STM32F091, but would take much work.
    - Other books are better for understanding USB.

PWM Function

- Relatively simple
- Outputs a digital waveform (i.e. either 0 or 1), with a specific frequency and duty cycle.



All of these waves have the same frequency.

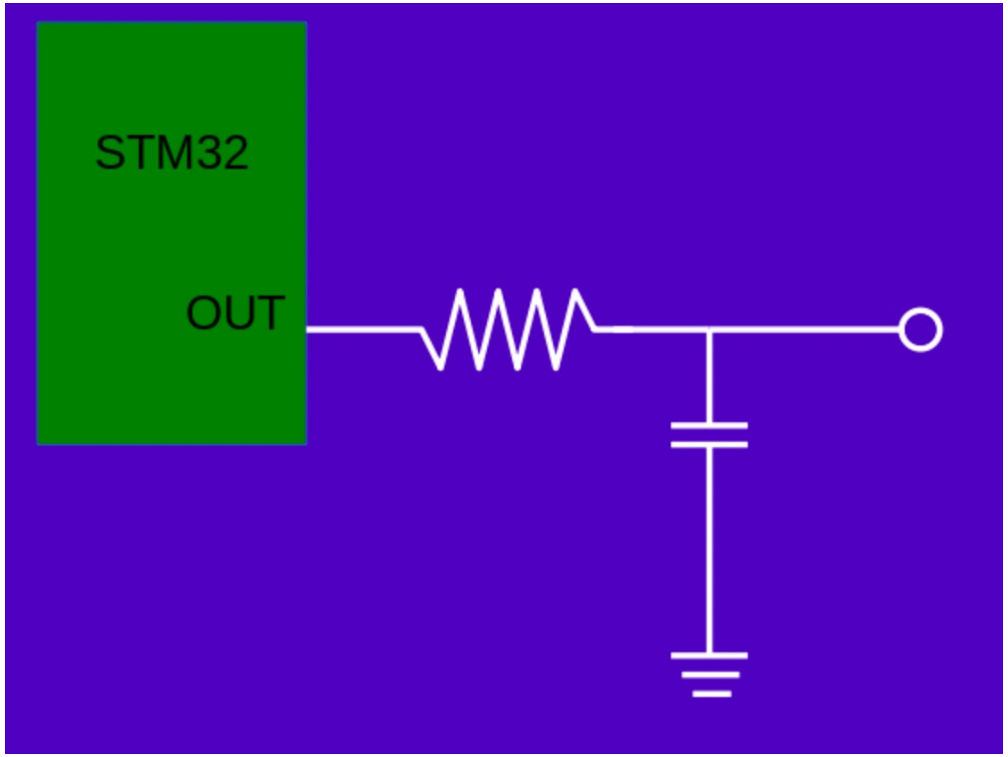
PWM allows you to program both duty cycle and frequency

Using GPIO as a DAC

- We'd like to be able to have a DAC with a strong drive strength like we have with GPIO.
- We don't just want on/off states. We want multiple voltage levels.
- Consider a square wave with a varying duty cycle:
  - We average the area under the curve.
  - The duty cycle of the wave is then the analog level.
  - We can average using a low-pass filter.
  - As long as the wave frequency is much higher than the signal we want to model, no one will notice the averaging.

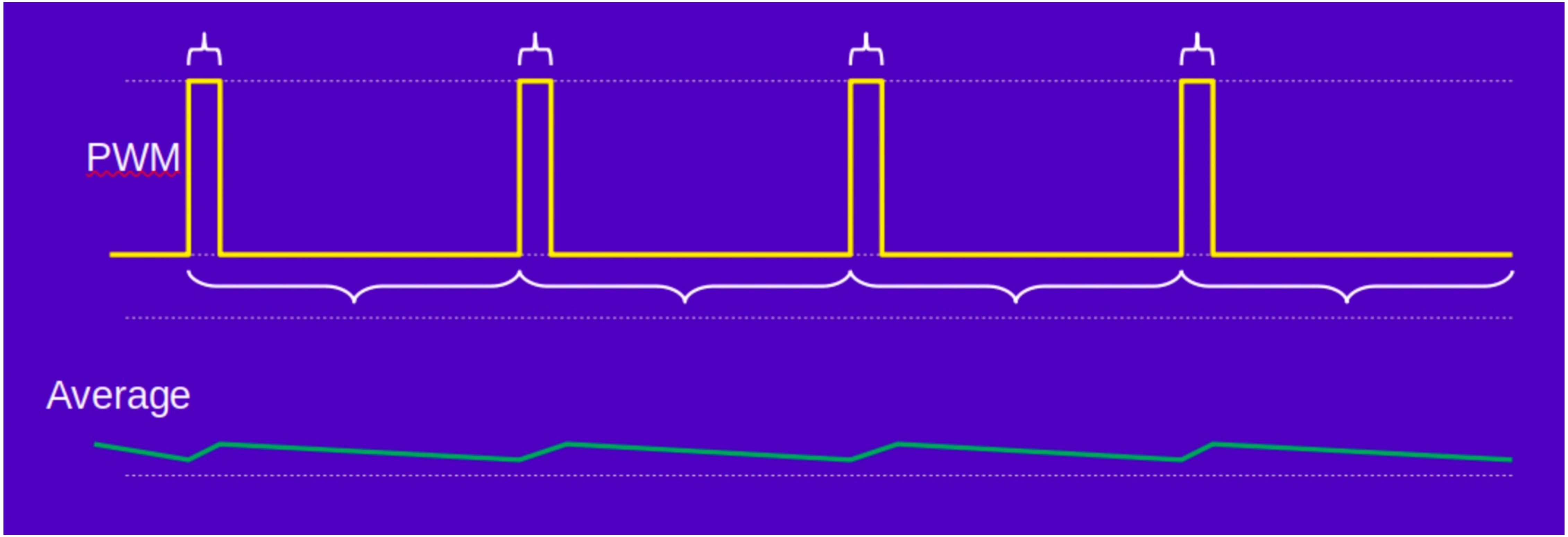
Averaging output

- Various ways to do this using low-pass filters.



PWM: Pulse-Width Modulation

- Each timer has a PWM mode where the output starts high, and goes low when CNT == CCRx

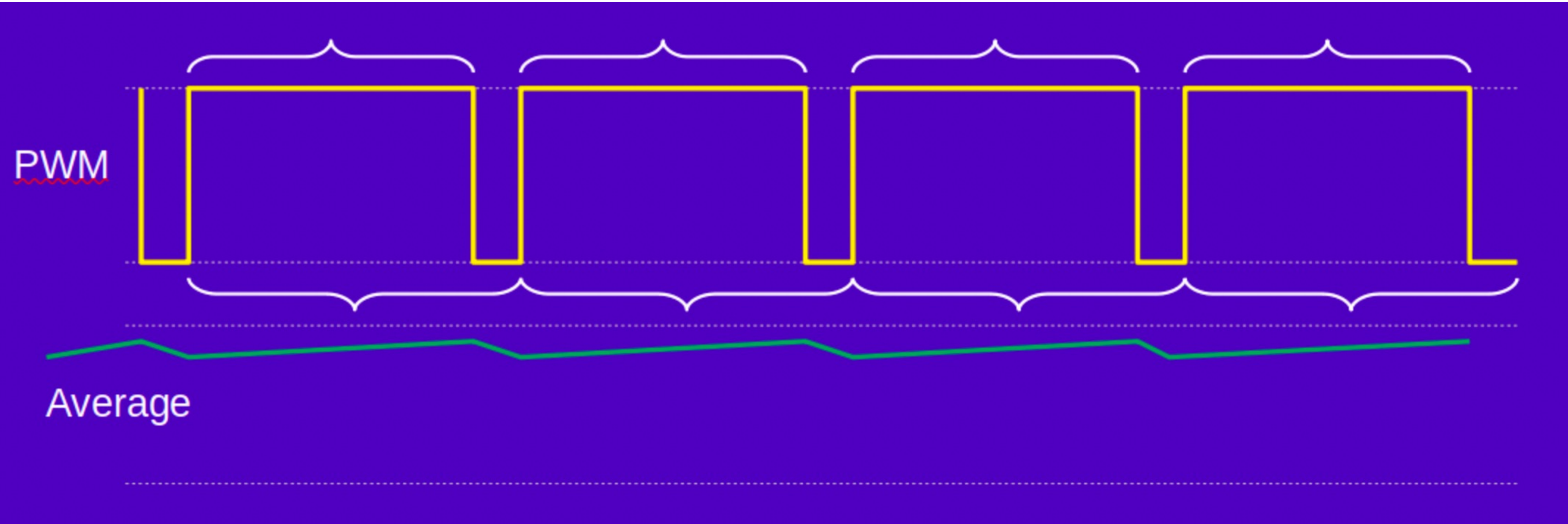


Determining PWM characteristics

- Textbook, 15.3:
  - PWM freq = CK_INT / (PSC + 1) / (ARR + 1)
    - e.g., CK_INT == 48MHz
  - PWM duty cycle = CCRx / (ARR + 1)
- Note: CCRx == 0: Never on.
- Note: CCRx >= ARR + 1: Always on.

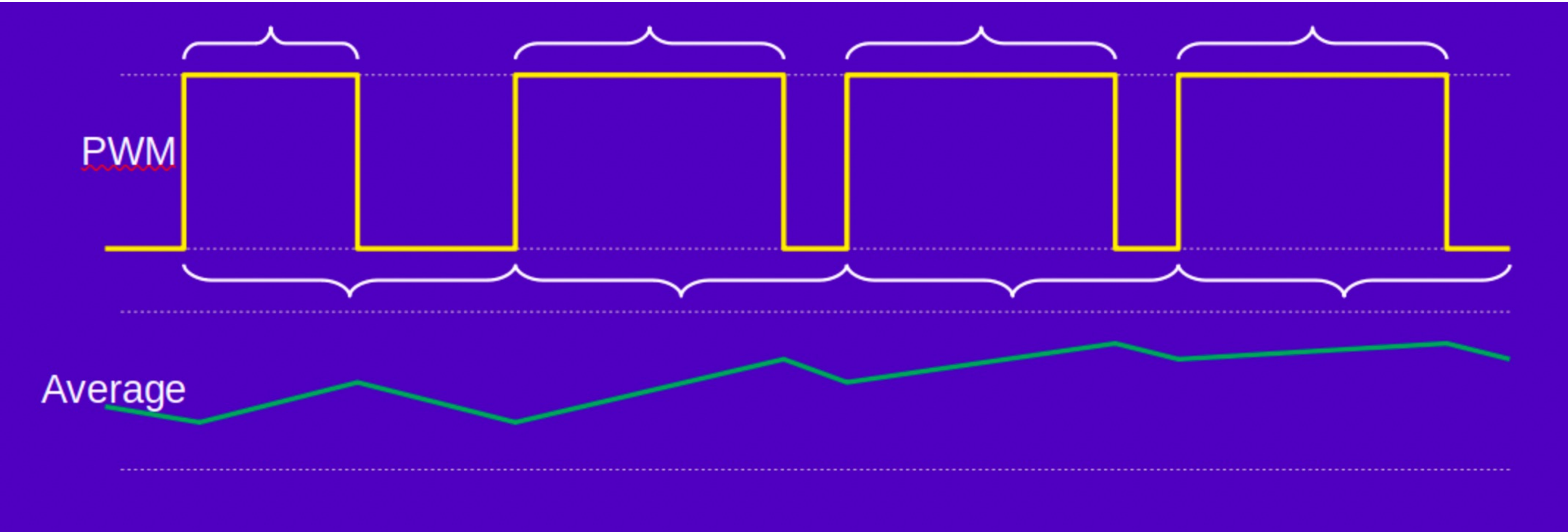
Higher duty-cycle, higher average

- Over the long term, the average output will be proportional to the duty cycle.



Dynamically changing duty-cycle

- The timer system has a convenient way of changing the duty cycle of an output wave.

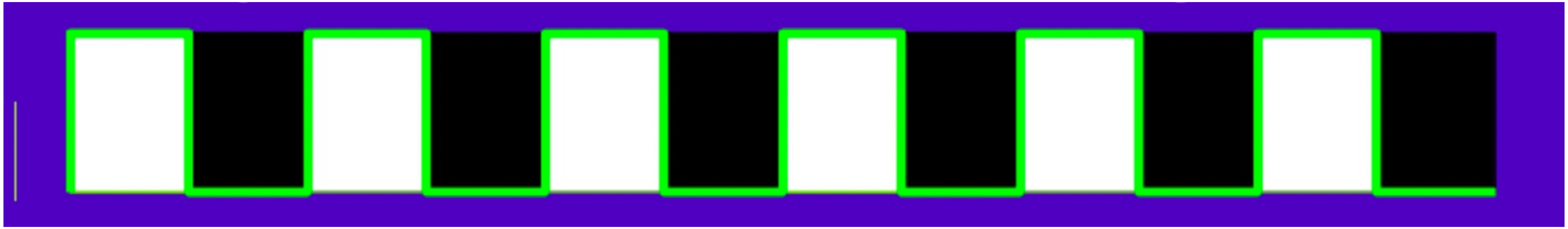


Must use high pulse frequency

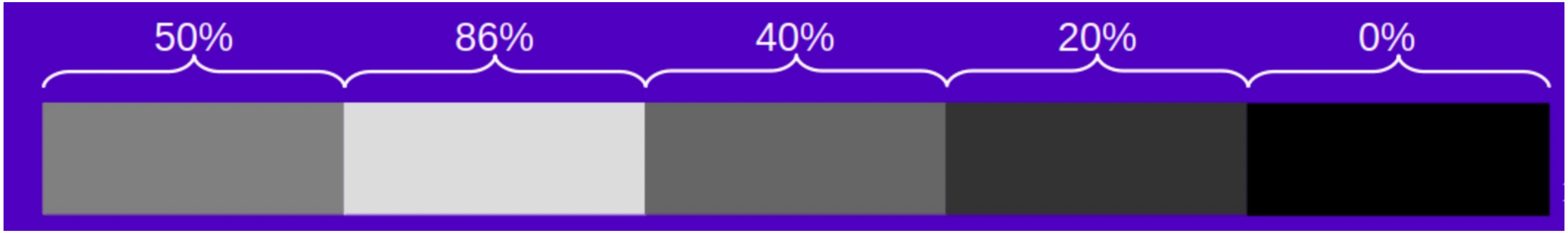
- If the pulse frequency is much higher than that of the desired signal, the "noise" will be imperceptible.

PWM noise is similar

- Color the "high" part of the wave white and the "low" part black. What would you see?

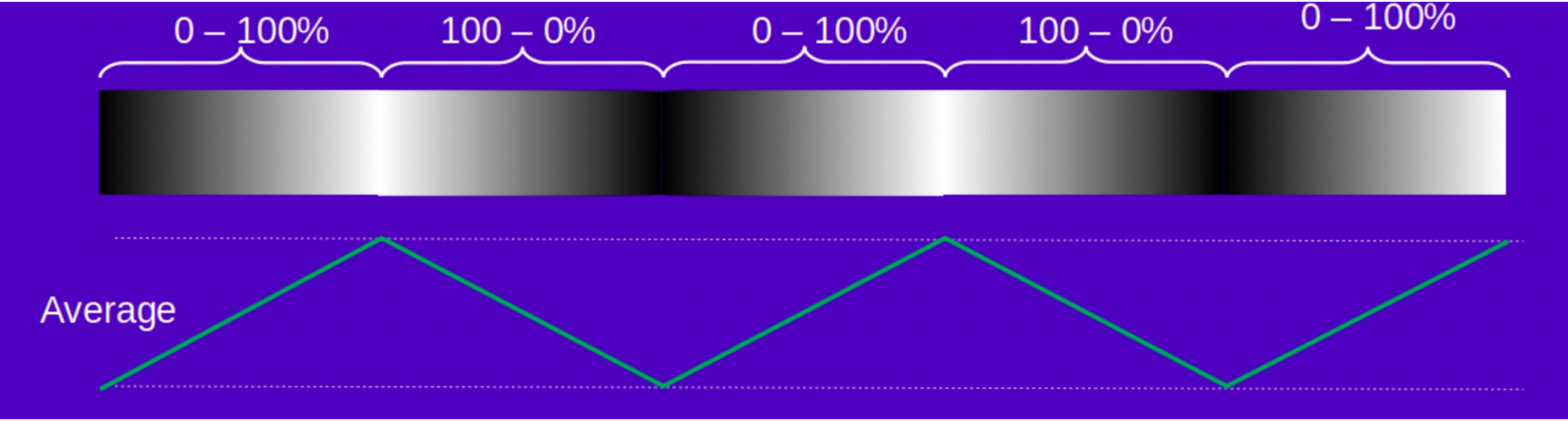


- If we turn off the green waveform, and if the alternation (frequency) is dense enough, you see only a shade of gray.



Continuous variation

- If you can vary the duty cycle after every period, you can have continuous variation.



Not hard to imagine a sine wave

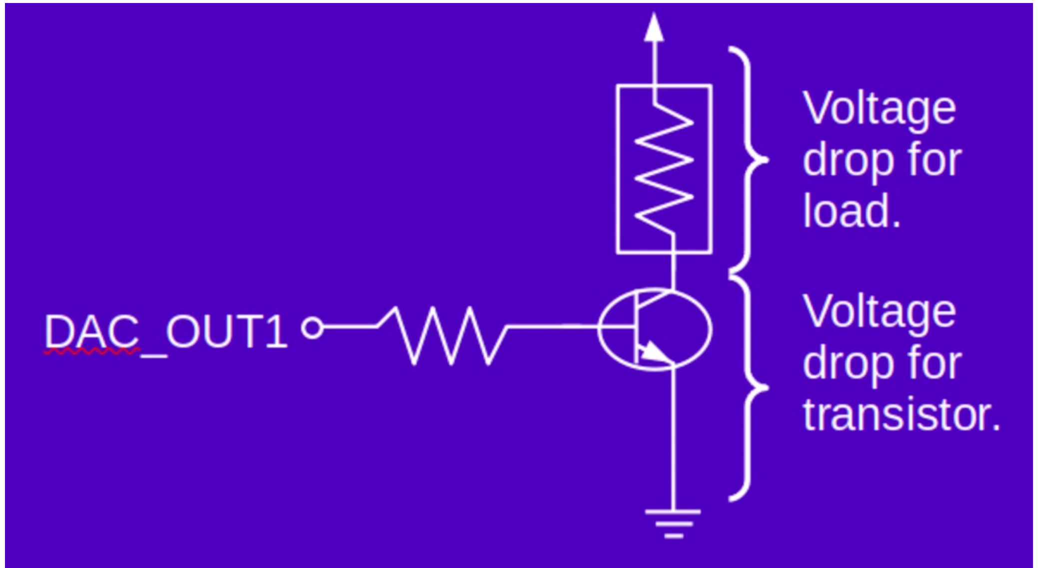
- If we had a way to update the duty cycle at the end of every clock period
- Could use the update interrupt, which happens whenever the counter reaches the maximum (when up-counting).
  - ISR can read a value from a wave table, and store it into the CCRx register.
- But the interrupt will occur when the next clock period is already in progress

Set the OCxPE bit

- If OCxPE is set in the CCMRx register, it will turn on "preload enable".
  - An update to the CCRx value will actually not be loaded until the next counter "update".
  - The new comparison value will be deferred until after the current comparison value is definitely used.
- Similar flag in TIMx_CR1 called ARPE: "Auto-reload preload enable"
  - If you want to change the PWM period, but not until the next cycle begins, set ARPE.

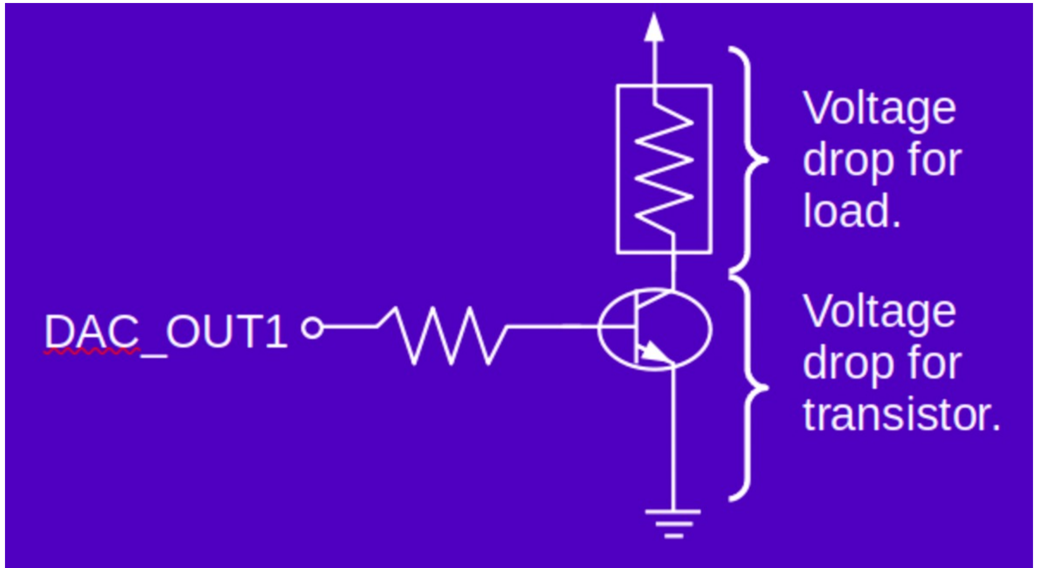
Power-inefficiency of analog control

- A DAC can change voltage incrementally, but you wouldn't use it to dim a light bulb or heavy load.
  - Voltage of DAC determines IBE current, which controls ICE current, which controls the load current.
  - Transistor driving the bulb would be in the "active mode" with current flowing through a voltage drop.
  - Watts of power dissipated as heat by transistor.



On-off switching is efficient

- When switching on or off (as with PWM), a transistor is either:
  - conducting fully with no voltage drop, or
  - not conducting at all with no current.
- Either way, no power loss
- by the transistor.



Sometimes, you don't need a physical low-pass filter.

- If signal is going to be perceived by a human:
  - Your eyes cannot register changes faster than 50 Hz.
  - Your ears cannot register changes faster than 16 kHz.
- If signal is damped by something else:
  - A motor (inertia of rotor is a low-pass filter).

Other perception problems

- What happens if you use PWM with a frequency in the range of 100 – 1000 Hz to drive a DC motor?
  - You’ll hear it whine.
  - Sometimes motors resonate at certain PWM frequencies.
  - Sometimes you can use PWM above audible frequencies (>16 kHz)
  - Sometimes the speed of the motor limits the usable PWM frequencies.
  - Usually need to do some experimentation.

Warning

Warning: If you have epilepsy, or are prone to vision-induced seizures, you will need to close your eyes for this demonstration.

- The rest of you should be okay

Demonstration

- Remember the timer subsystem?
  - It can create square waves with varying duty cycles.
  - Prescaler divides down the system clock.
  - A free-running counter counts up to a max value.
  - A comparator triggers an event when the counter matches a CCR register.
  - The TIM_CCMR OCxPE bit enables "preload".
    - An update to the CCR doesn’t take effect until the next update event.

Turn on/off LED with PWM

- Full on.
- Vary the frequency with 50% duty cycle.
  - 10, 20, 30, 40, 50Hz
    - At what frequencies can you detect flicker?
  - Another interesting effect.
- Vary the duty cycle at 100Hz.