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11099 THC

Implementing an I²C™ Thermal Controller on a PIC® Microcontroller

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Learning Objectives

- At the end of this class you should be able to:
  - Explain 3-wire fan control
  - Explain how thermal controllers work
  - Implement an I²C™ Thermal Controller using a PIC16F886 Microcontroller
- Prerequisites
  - Analog-to-Digital Converter
  - Compare/Capture/PWM
  - Timer 1

Agenda

Today we will discuss…

- Thermal Management Basics
- 3-Wire Fans
- Thermal Controllers
- Implementing a Thermal Controller on a PIC16F886

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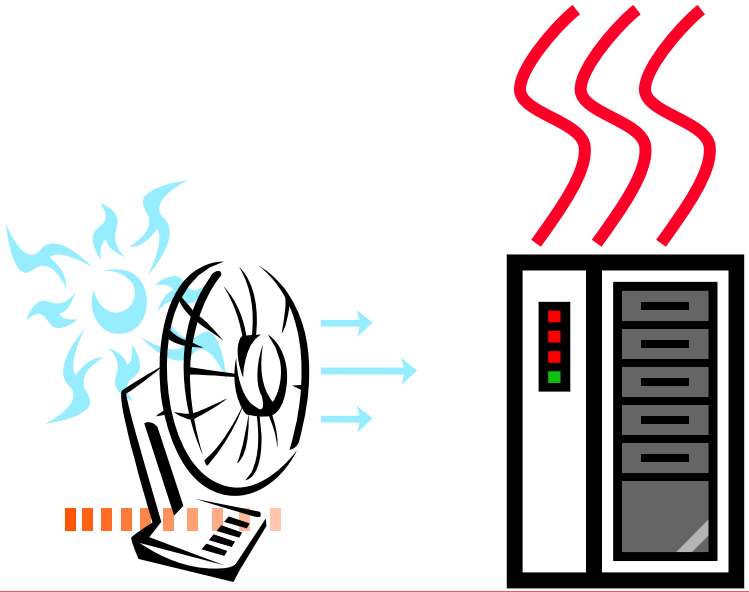
Course Background

Thermal Management

- What is thermal management?
  - Monitoring system temperature
  - Monitoring fan status
  - Optimizing the control of temperature through monitoring
  - Coordinated cooling
  - Proportional cooling

Thermal Management

- Why the need for thermal management?
  - More transistors running at higher speeds = Heat
  - Reduces system noise
  - Monitor failures
  - Lower power consumption

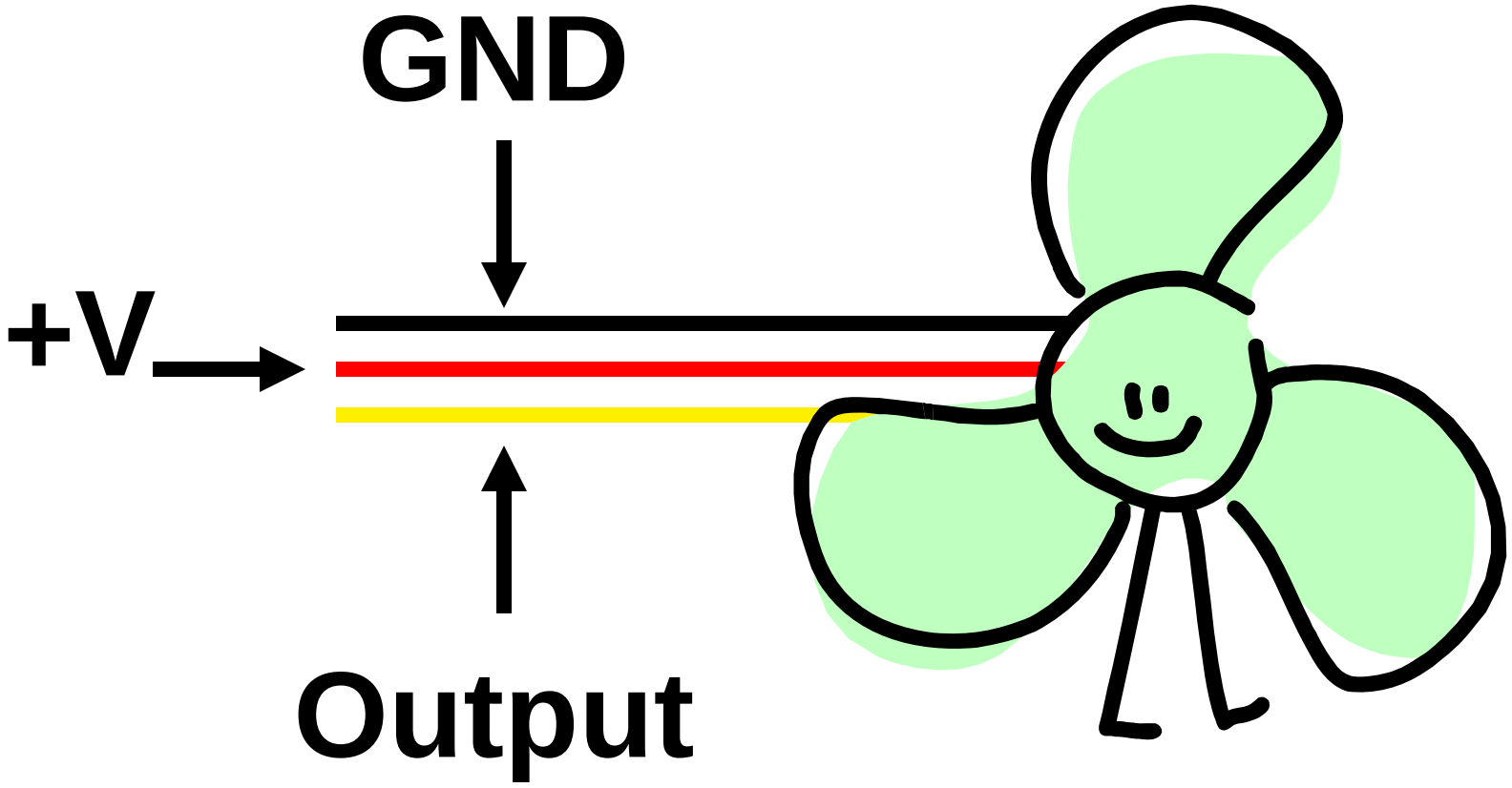


Thermal Management Controller

- Requirements:
  - Fan speed control
    - 2-, 3-, 4-wire fans
  - Temperature Sensing
  - Failure Detection
    - Fan speed detection
  - Communications
    - Serial Communications Protocols

3-Wire Fans

3-Wire Fans

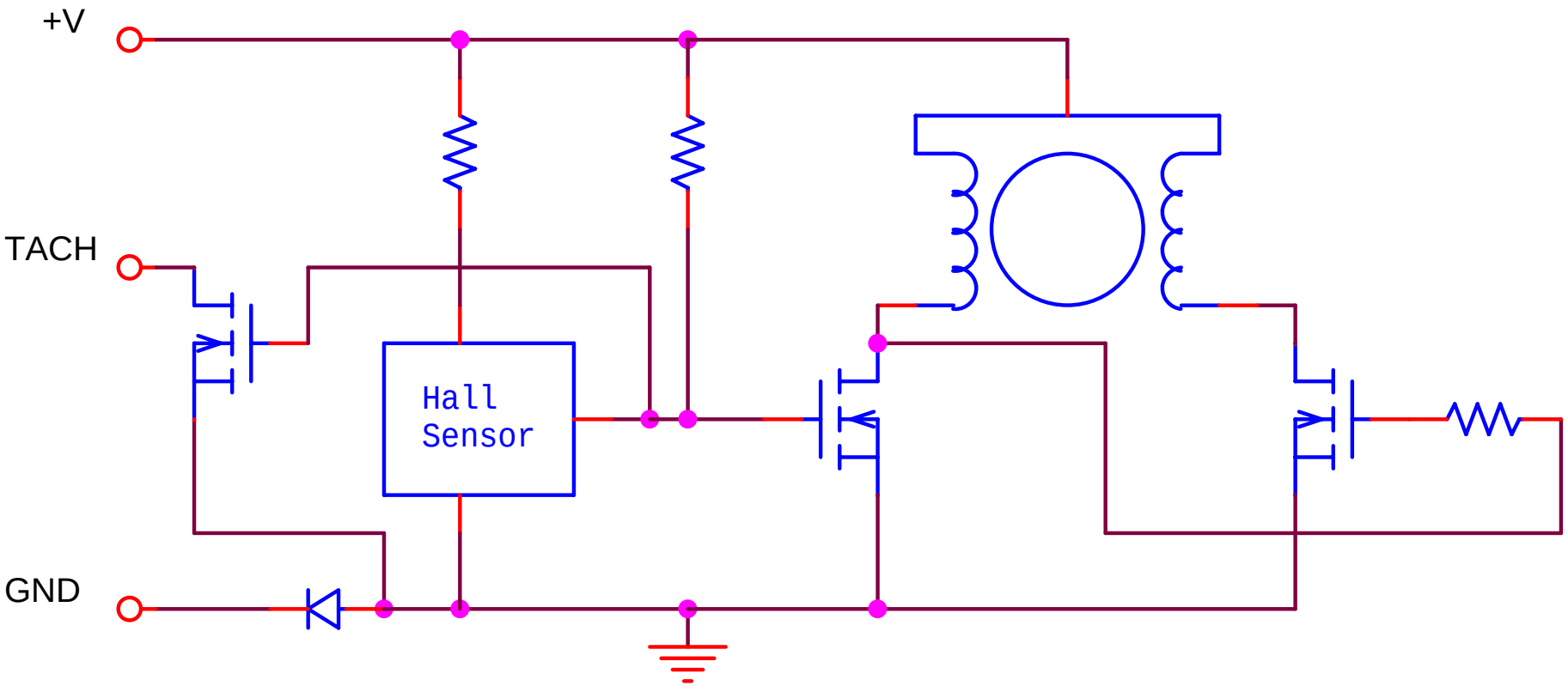


The Third Wire

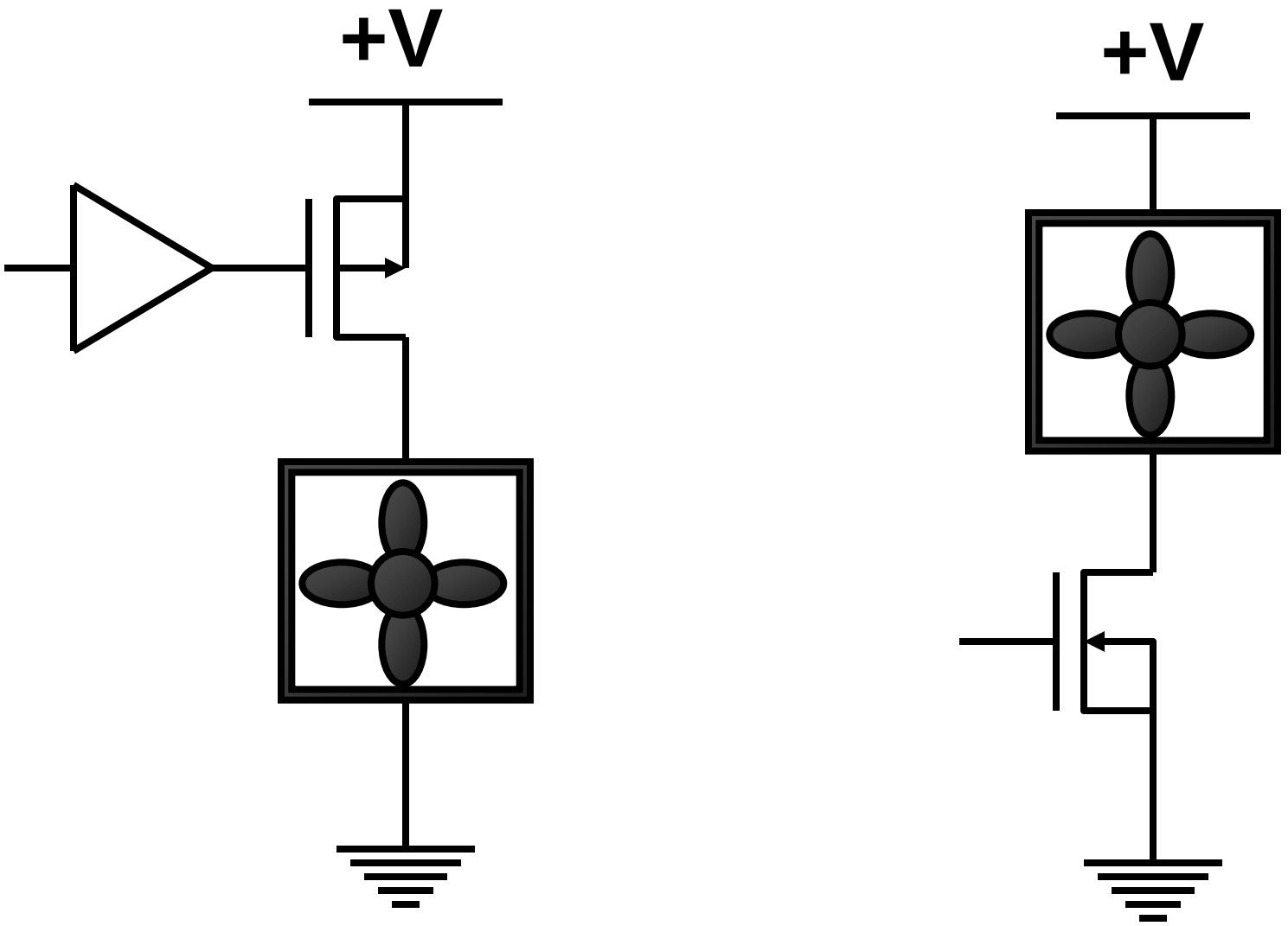
- Tachometer (most common)
  - 1, 2, or 4 pulses per revolution
  - Open collector output
- Alarm output
  - Signals when the fan has failed

3-Wire Fan Schematic

- A look inside



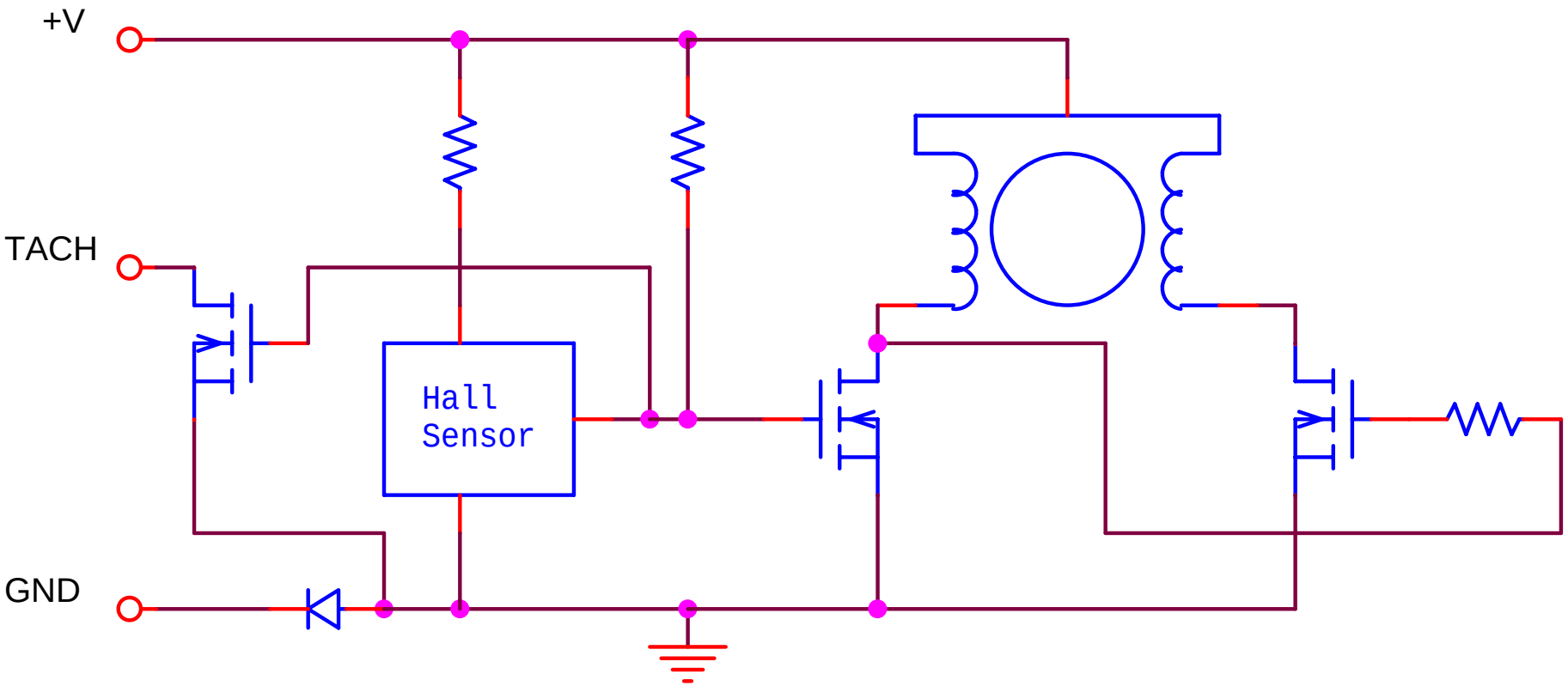
Low Frequency PWM 10-100 Hz



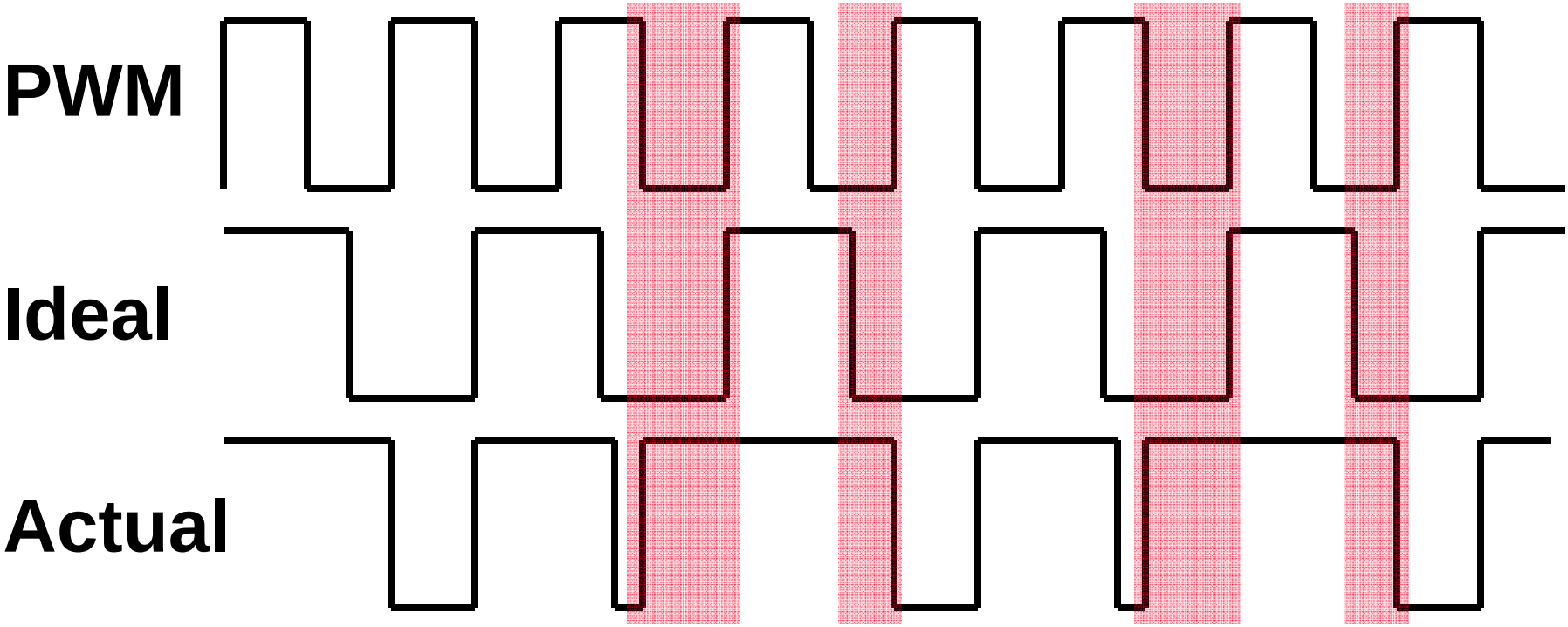
Low Frequency PWM

- Ability to extend operating range down to about 10% of max RPM
- Check with manufacturer if you can PWM the 3-Wire fan
- Tachometer output is no longer valid

3-Wire Schematic

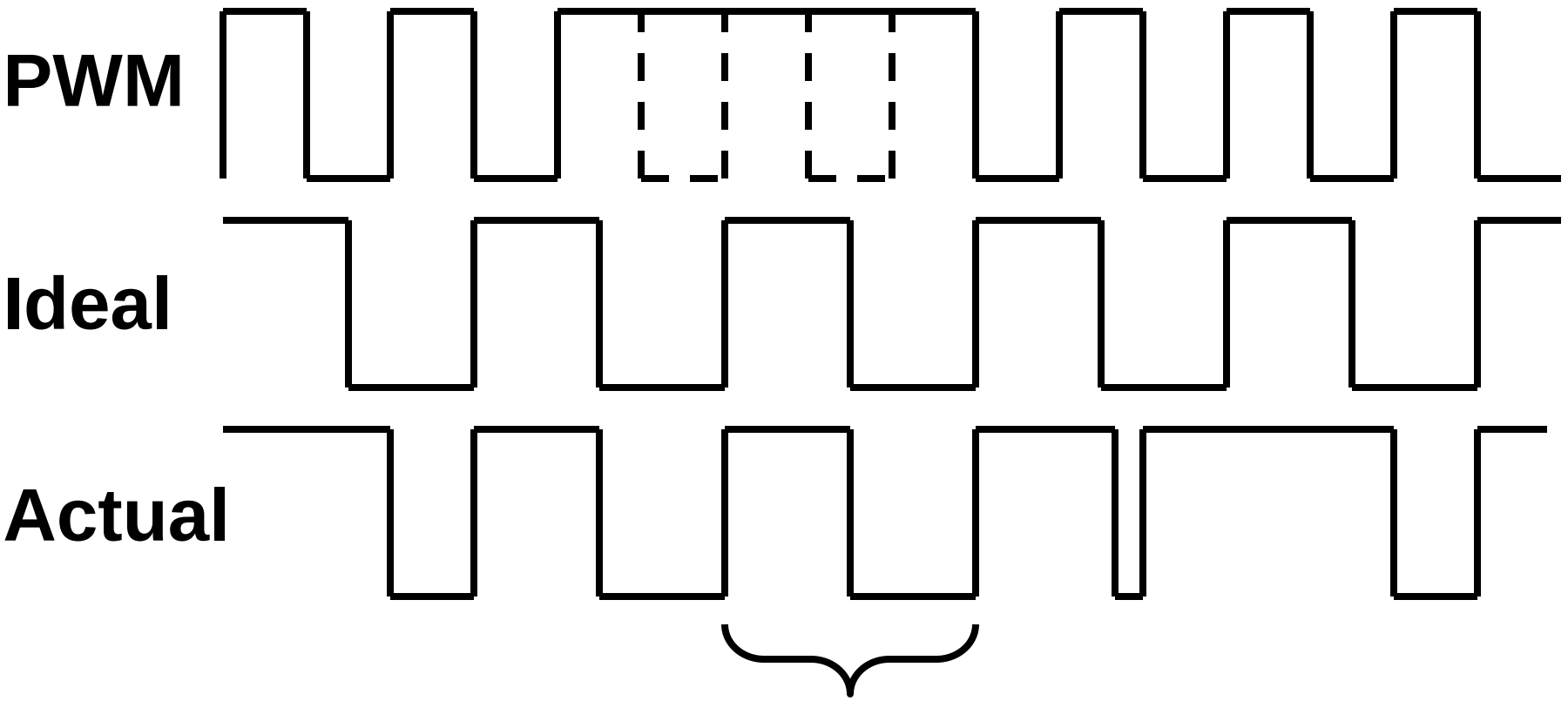


Tachometer Output



- Tachometer output is invalid

Creating a Valid Output



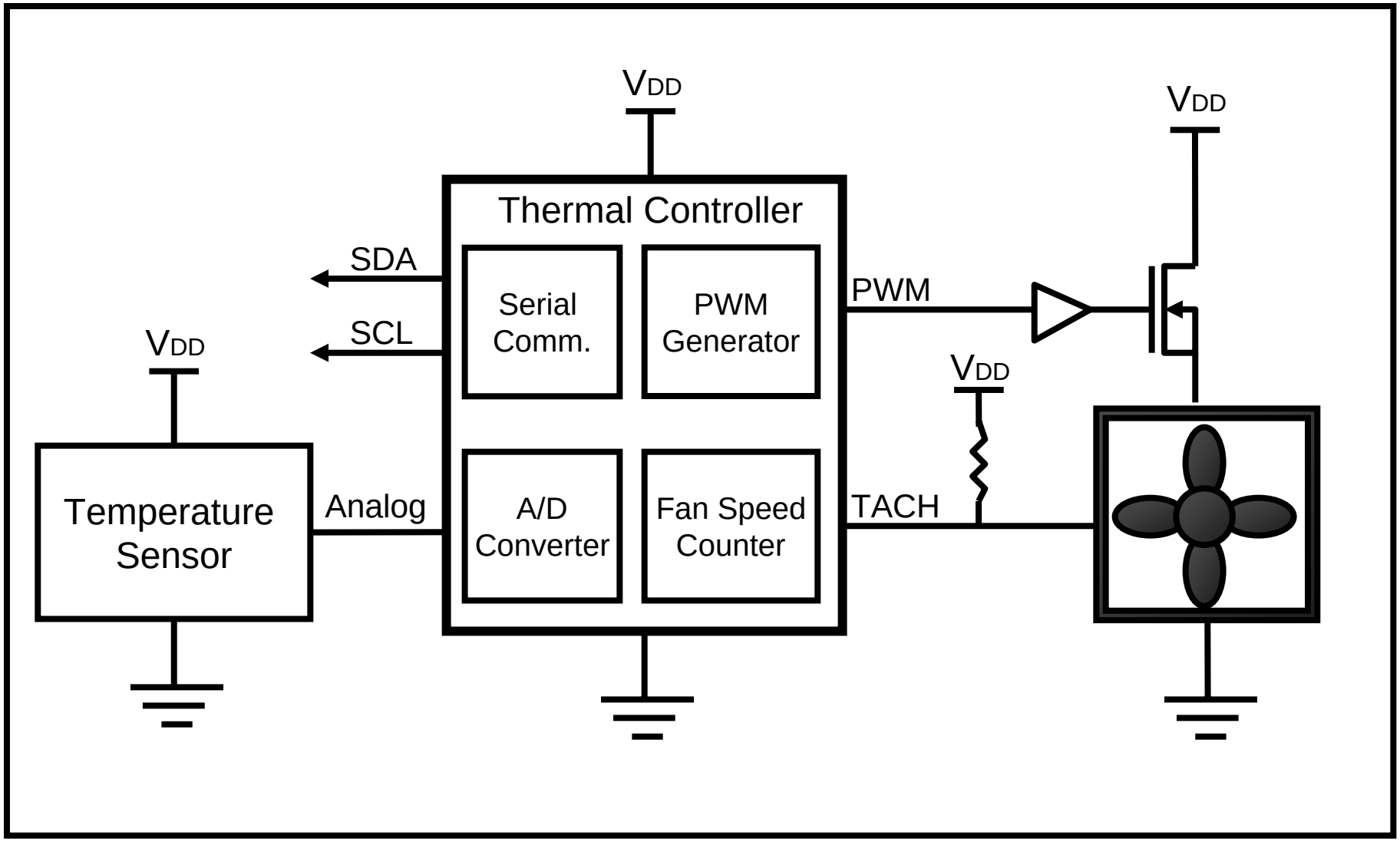
- Pulse stretching can be used to obtain a complete period

3-Wire Fans

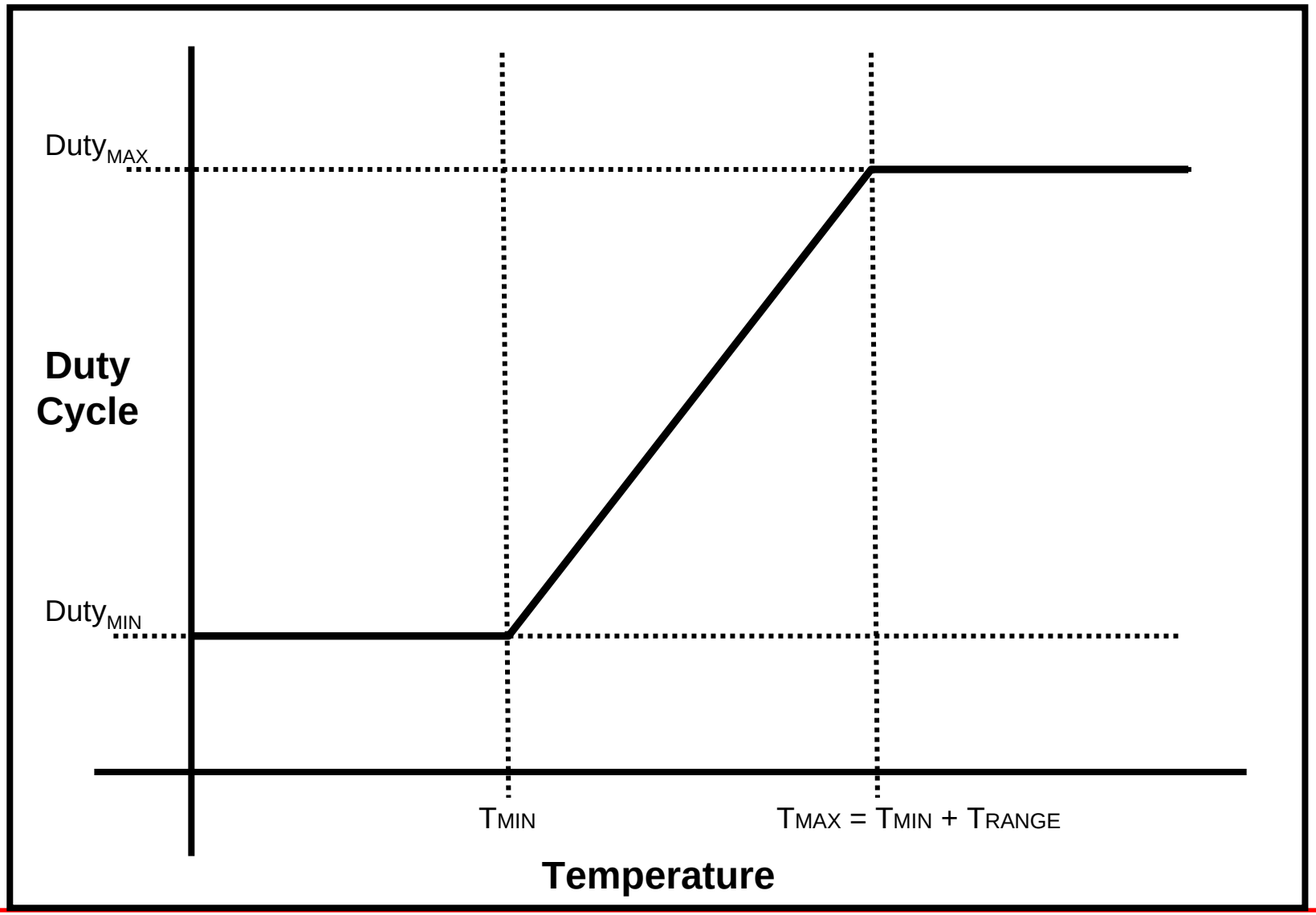
Questions?

Thermal Management Controllers

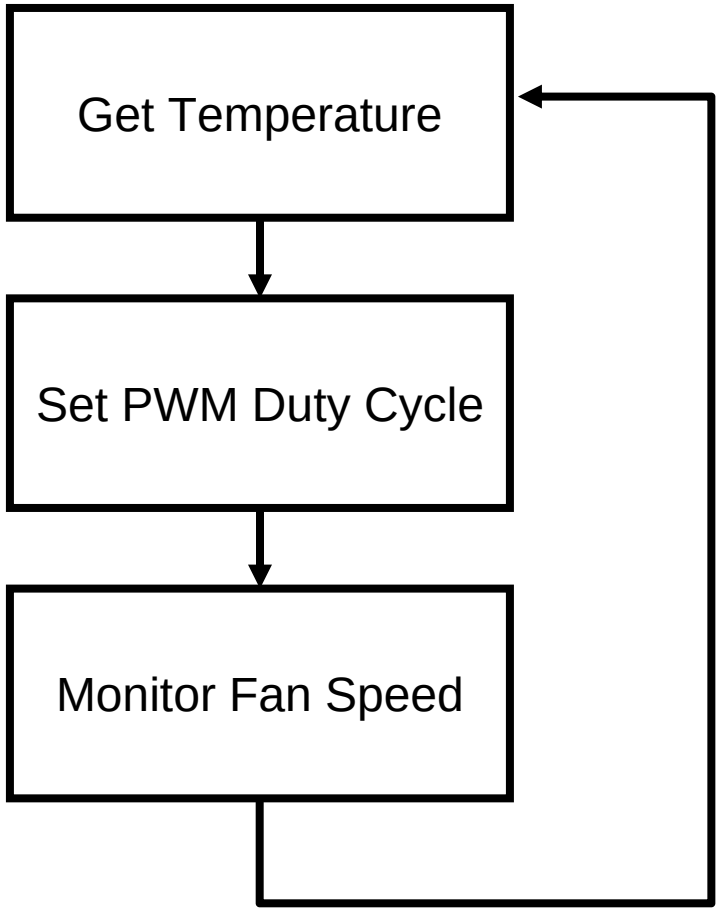
Example Thermal Controller Functions



Fan Temperature Control Algorithm



Thermal Controller Flowchart



Thermal Controller Configuration

- **Serial Communications**
- Control Registers:
  - Temperatures
  - Duty Cycle
  - PWM Frequency
- Status Registers:
  - Fan Speed
  - Temperature

Fan Controller Registers

Configuration
Status Register
PWM Frequency
Local Temperature High
Local Temperature Low
Duty Cycle Maximum
Duty Cycle Minimum
Fan Speed Reading

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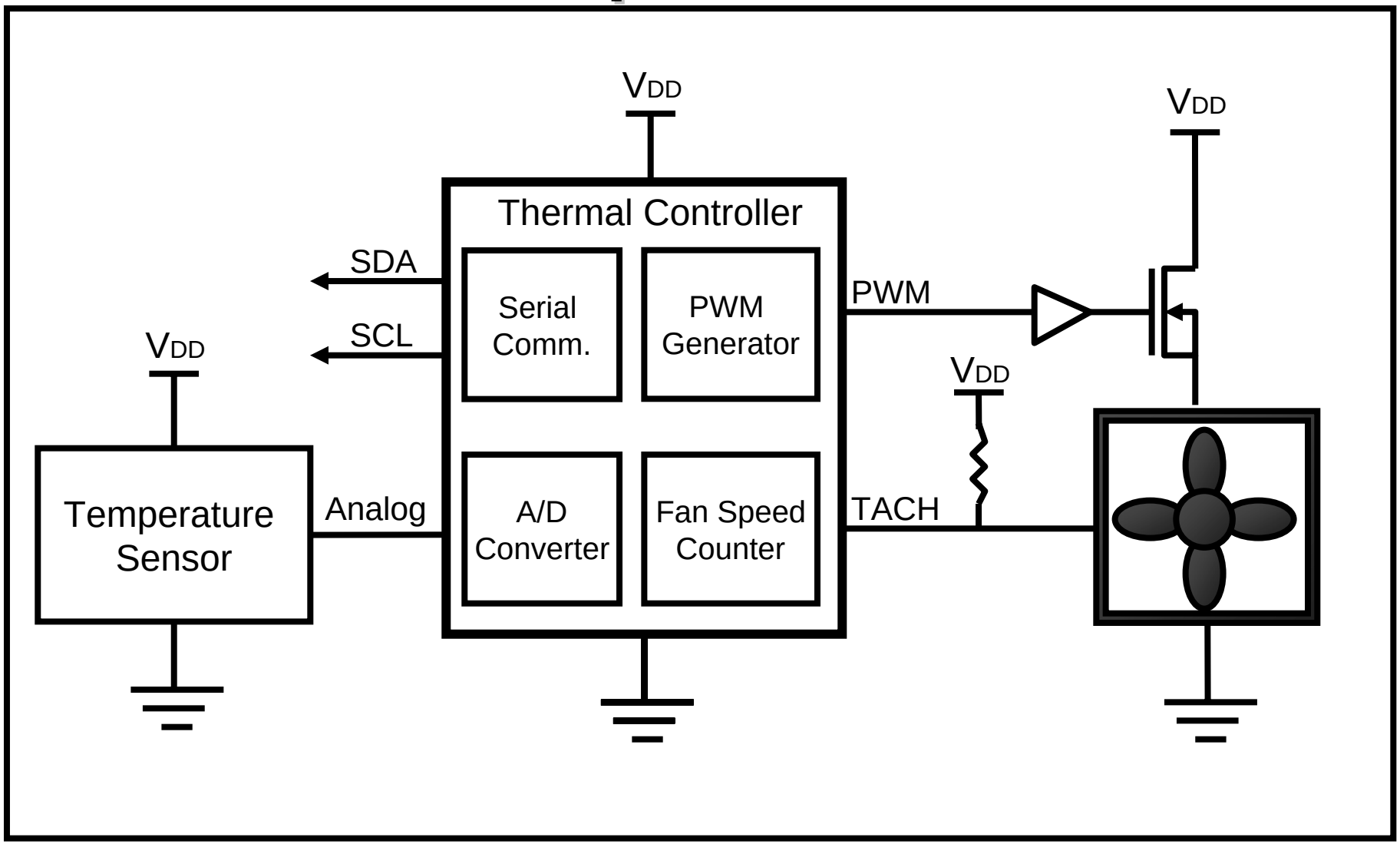
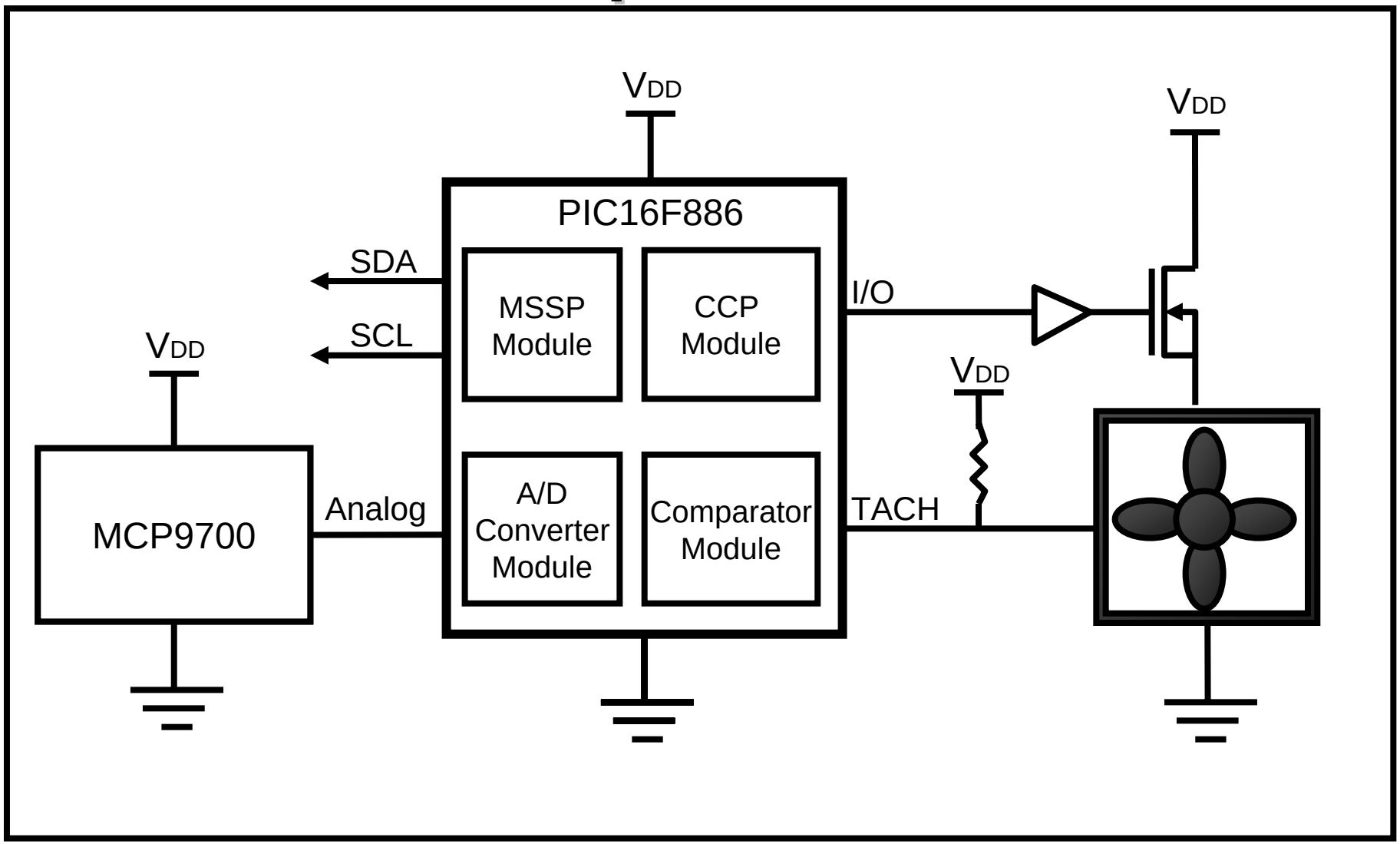
Implementing a Thermal Controller on a PIC16F886

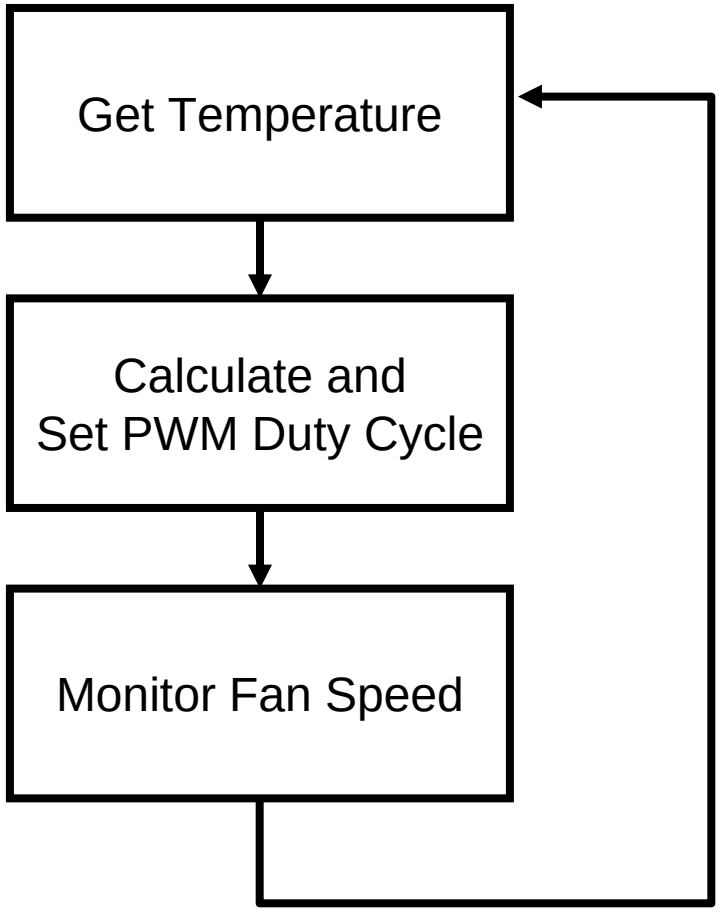
Thermal Controller Implementation



Thermal Controller Implementation

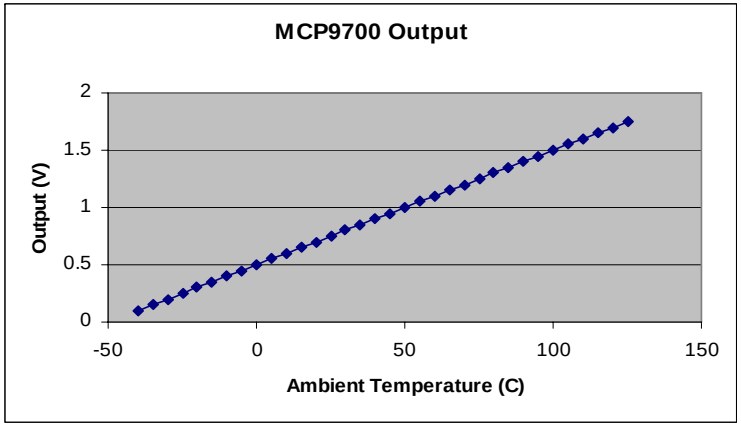


PIC® MCU Thermal Controller Flowchart



Temperature Measurement

- **MCP9700 Temperature Sensor**
- Analog Temperature Sensor



$$V_{OUT} = T_C * T_A + V_{0degC}$$

Where:

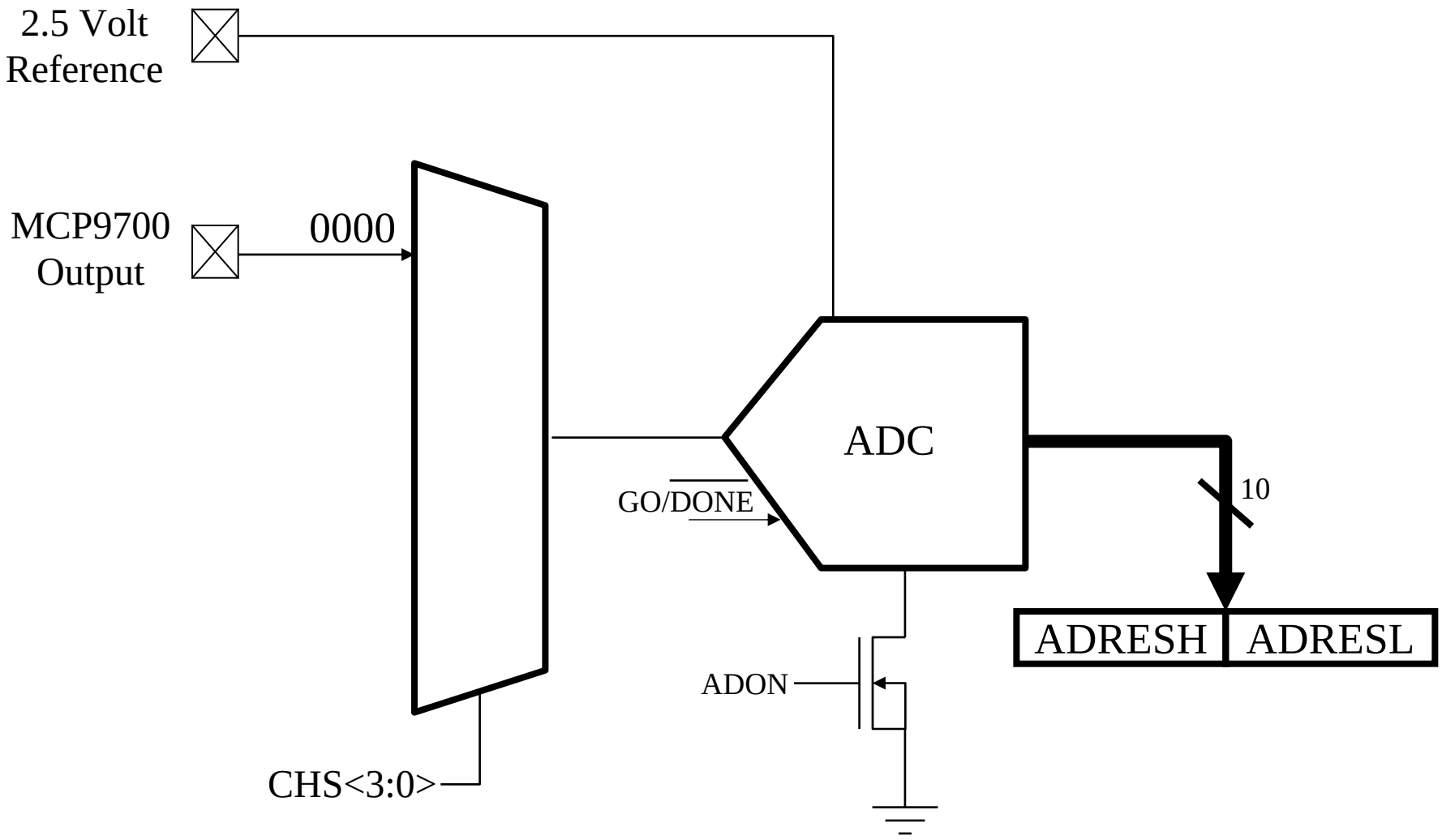
T_A = Ambient Temperature

V_{OUT} = Sensor Output Voltage

V_{0degC} = Sensor Output Voltage at 0 degC = 500 mV

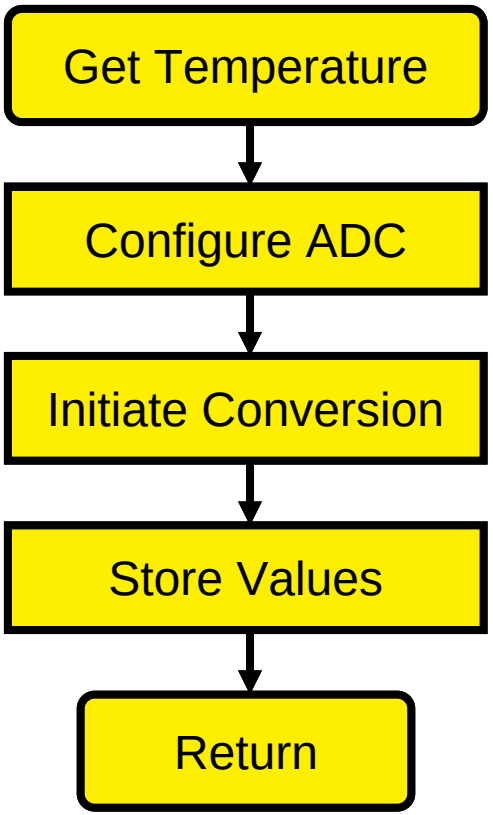
T_C = Temperature Coefficient = 10 mV/degC

Configuring Analog-to-Digital Converter

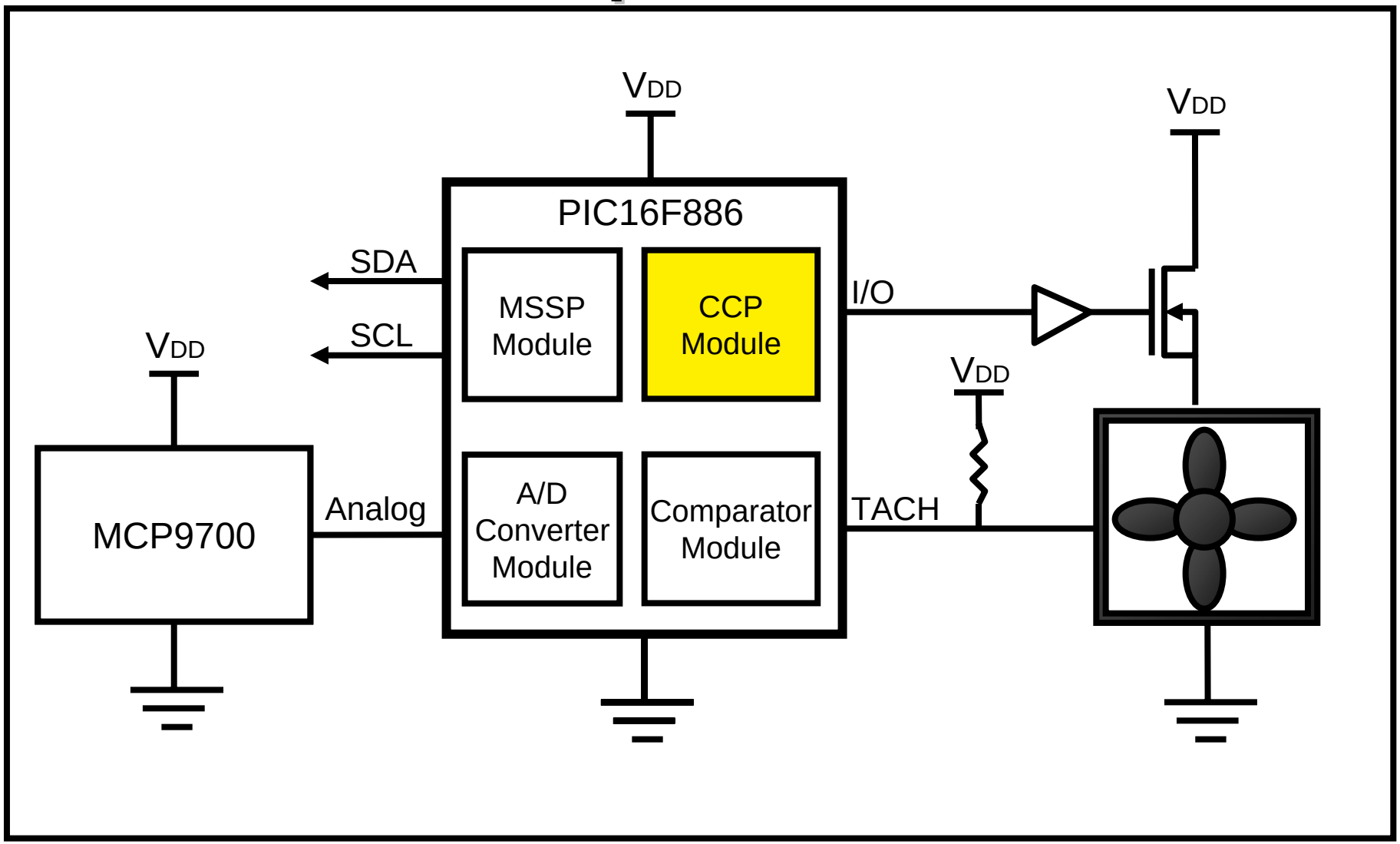


Temperature Measurement

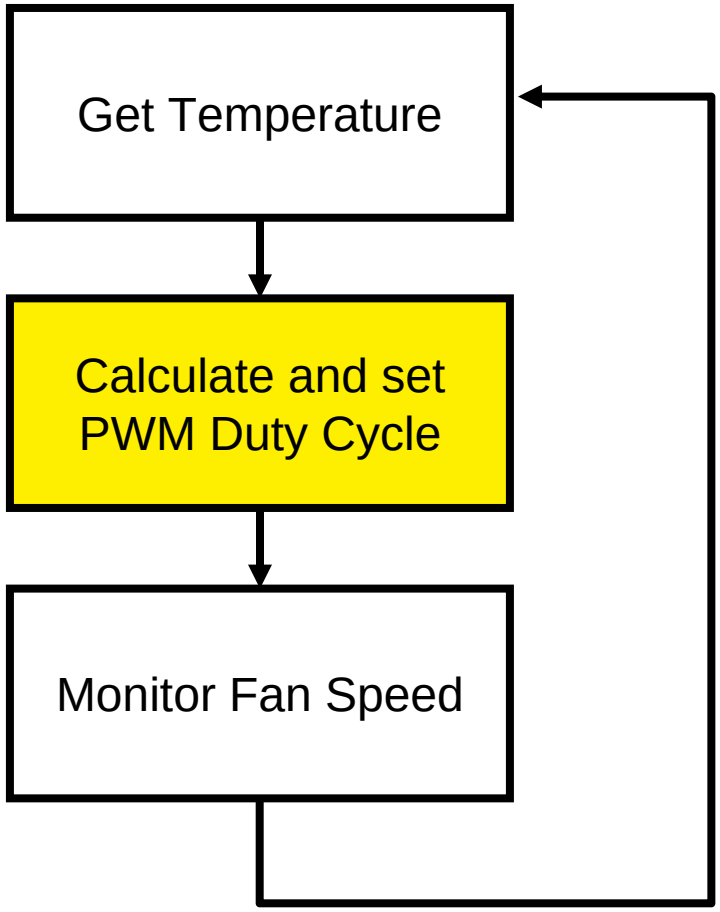
- 10-Bit Analog-to-Digital Conversion
- Store to 2 Byte Temperature Register



Thermal Controller Implementation



PIC® MCU Thermal Controller Flowchart

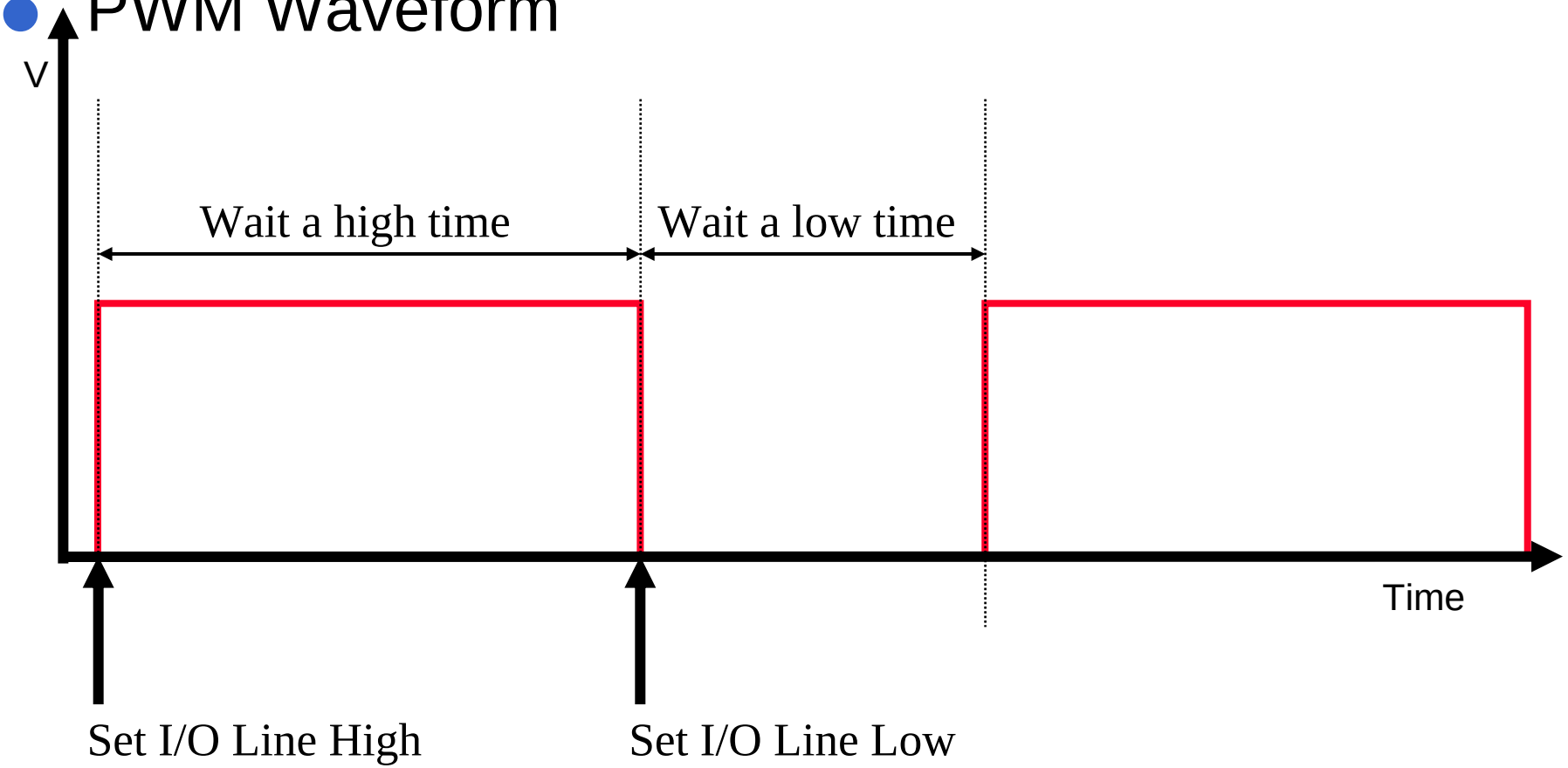


Generating a PWM Signal

- Requirement: Low-speed 10-100 Hz signal to control fan speed
- Problem: PWM module cannot generate a 10 Hz signal
- Solution: Software PWM

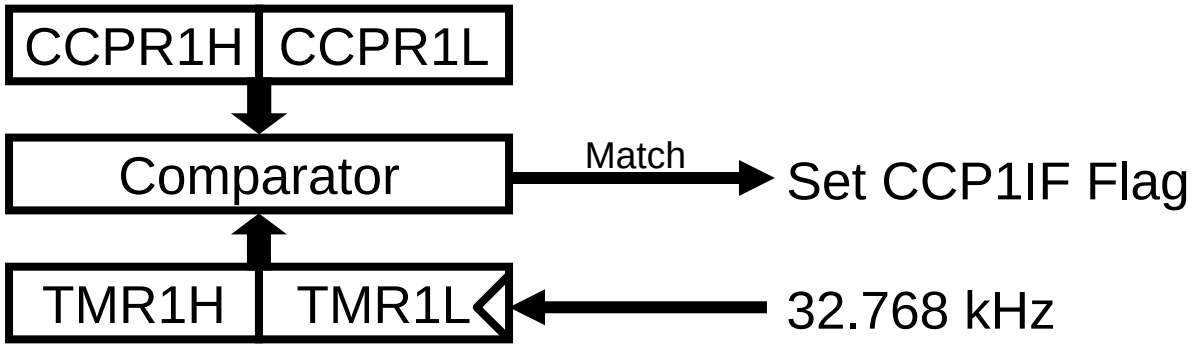
Generating a Software PWM

- PWM Waveform

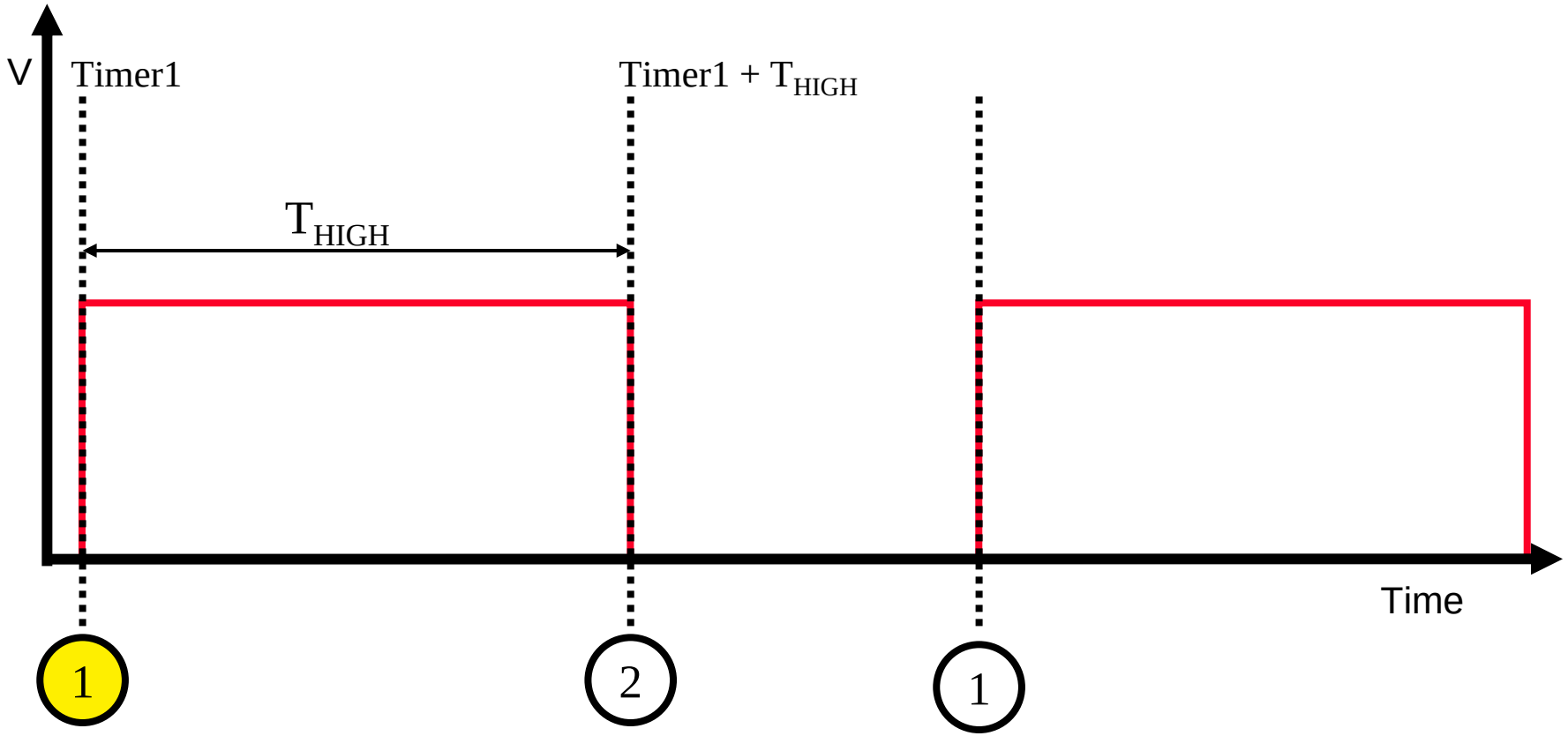


Generating a Software PWM with CCP Compare Mode

- **COMPARE** Mode to time when the I/O Line needs to be toggled
- Interrupt is generated when TMR1 equals CCPR1

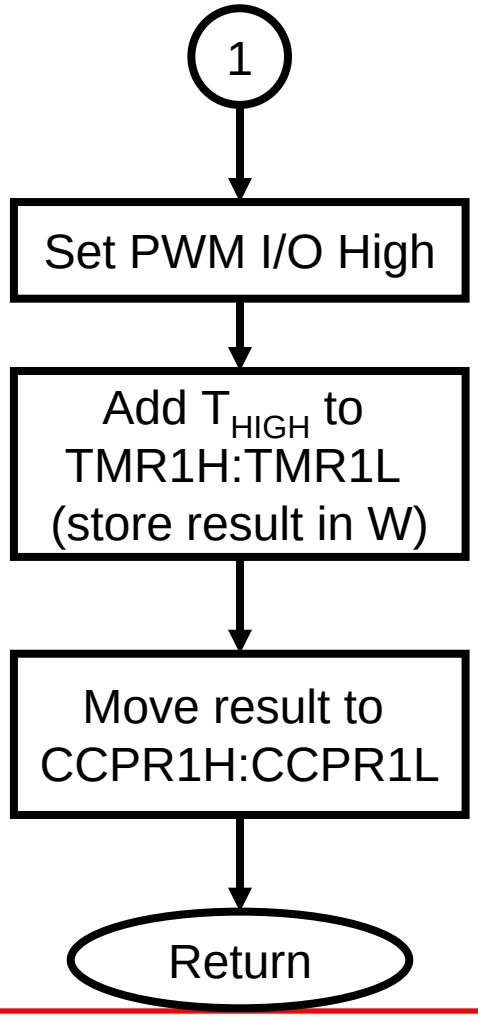


Generating a Software PWM using the CCP Compare Mode

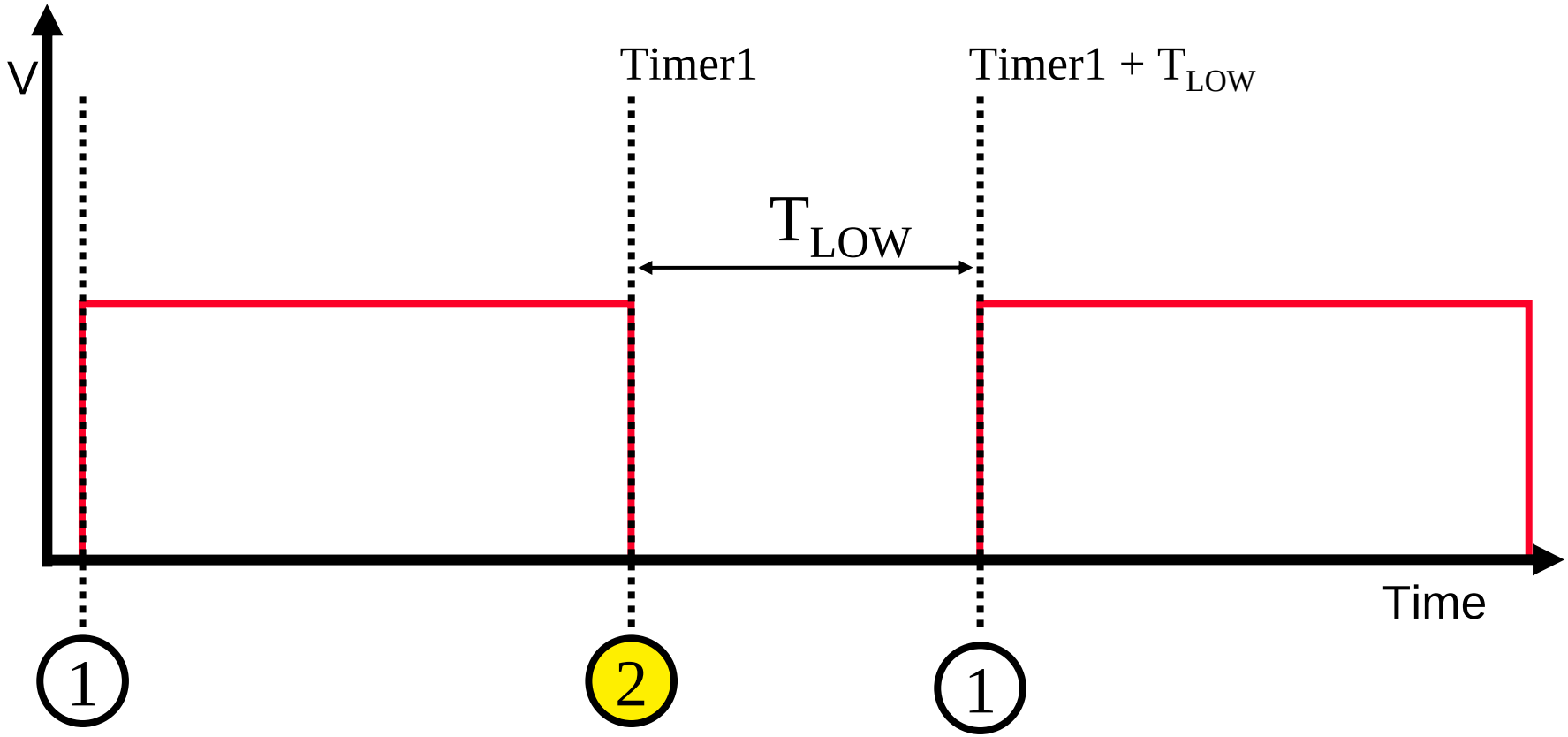


Software PWM Flowchart

- CCP (Compare) Interrupt

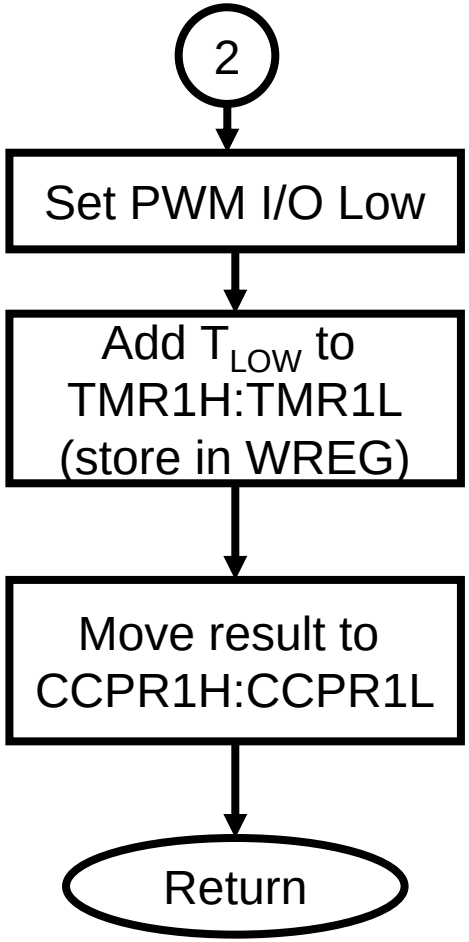


Setting PWM Duty Cycle

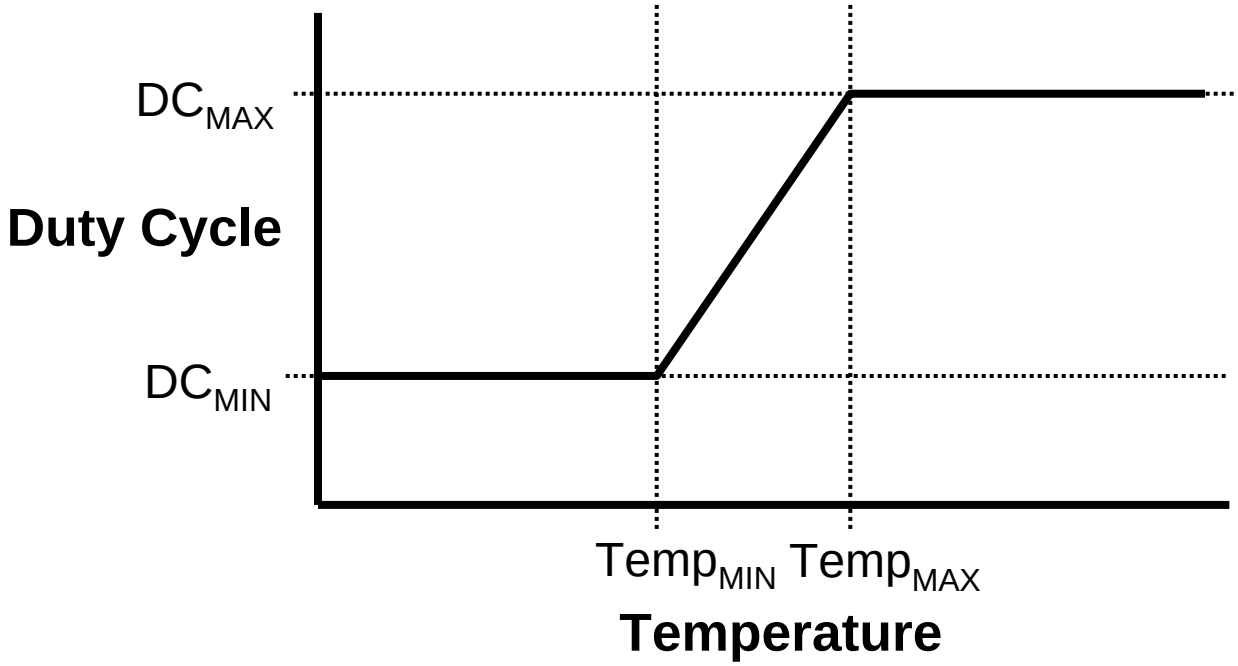


Software PWM Flowchart

- CCP (Compare) Interrupt

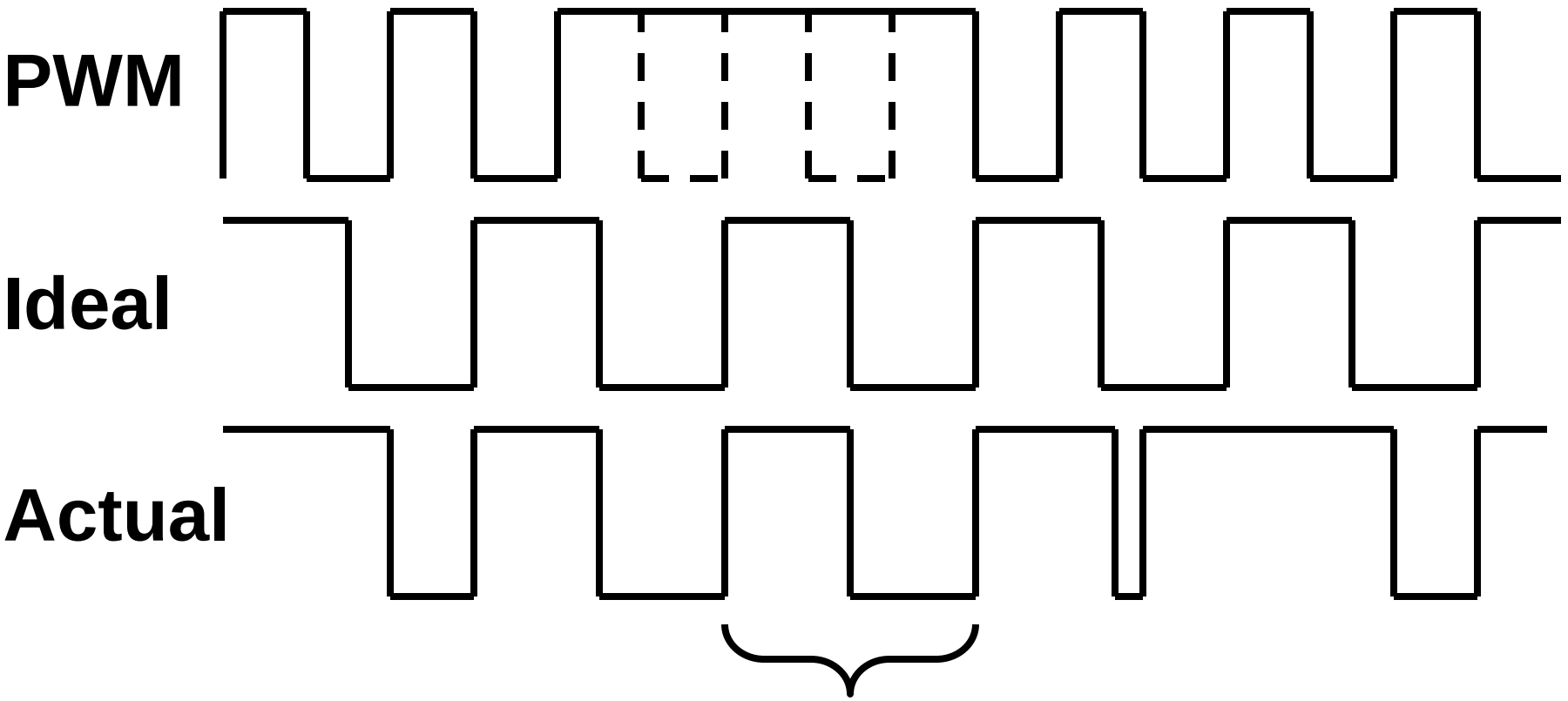


Calculating PWM Duty Cycle



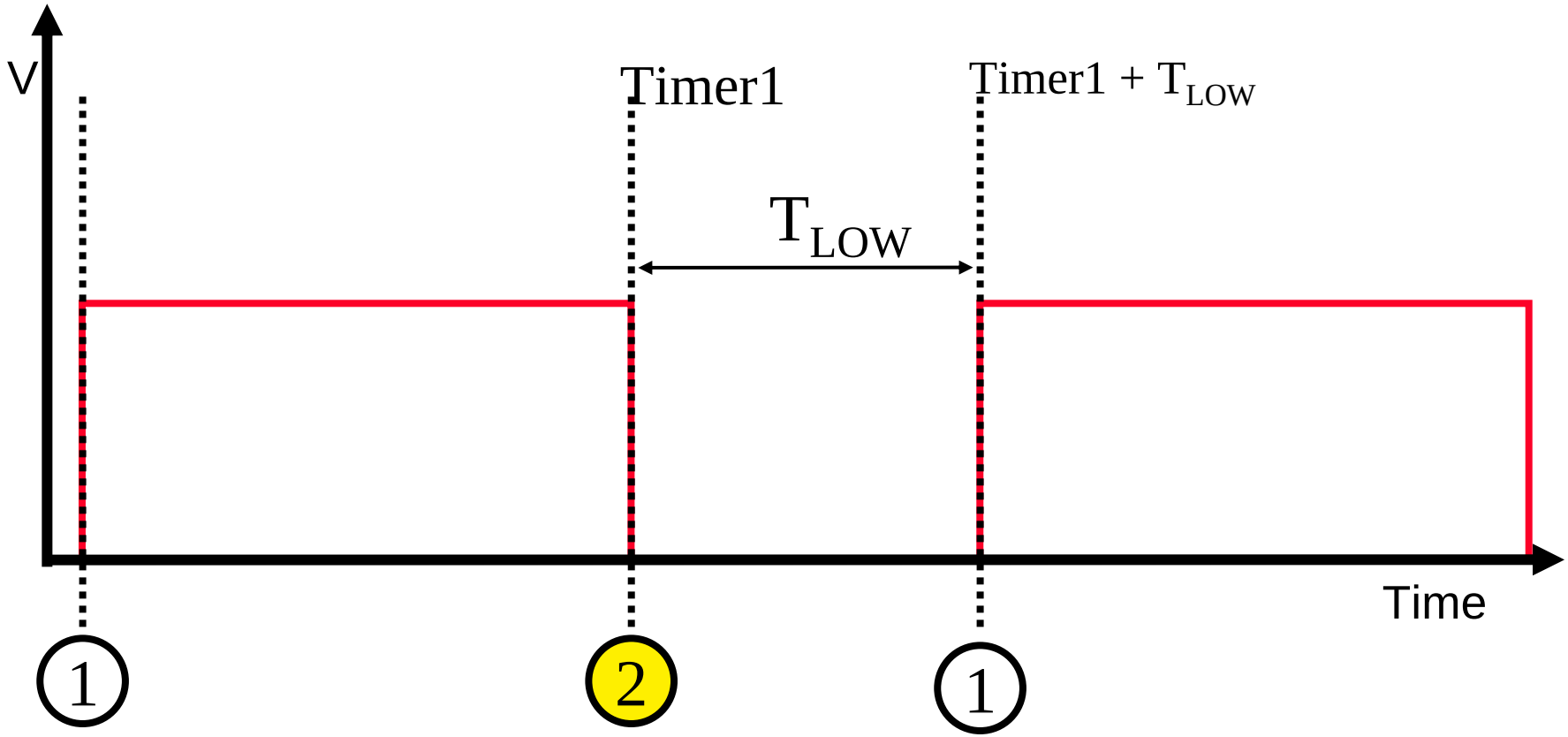
- $T_{HIGH} = \mathbf{T_A} * [(\mathbf{DC_{MAX}} - \mathbf{DC_{MIN}}) / (\mathbf{Temp_{MAX}}\text{-}\mathbf{Temp_{MIN}})]$
- $T_{LOW} = \mathbf{T_{PERIOD}} - T_{HIGH}$

Recall: Pulse Stretching



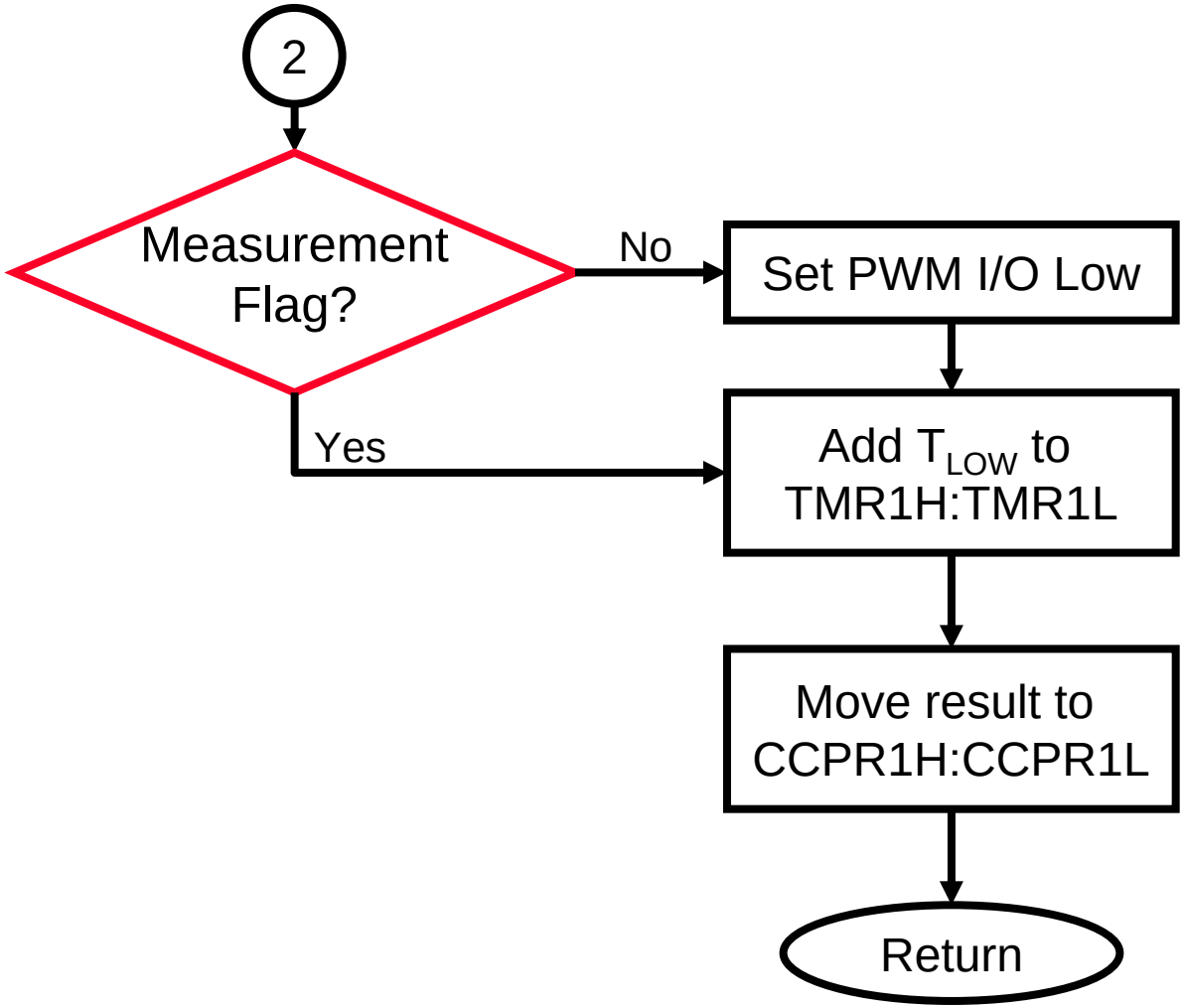
- Must leave the PWM line high if a measurement in progress
- Solution: Create a flag called **Measurement Flag** to indicate when a measurement is in progress

Setting PWM Duty Cycle



Software PWM Flowchart

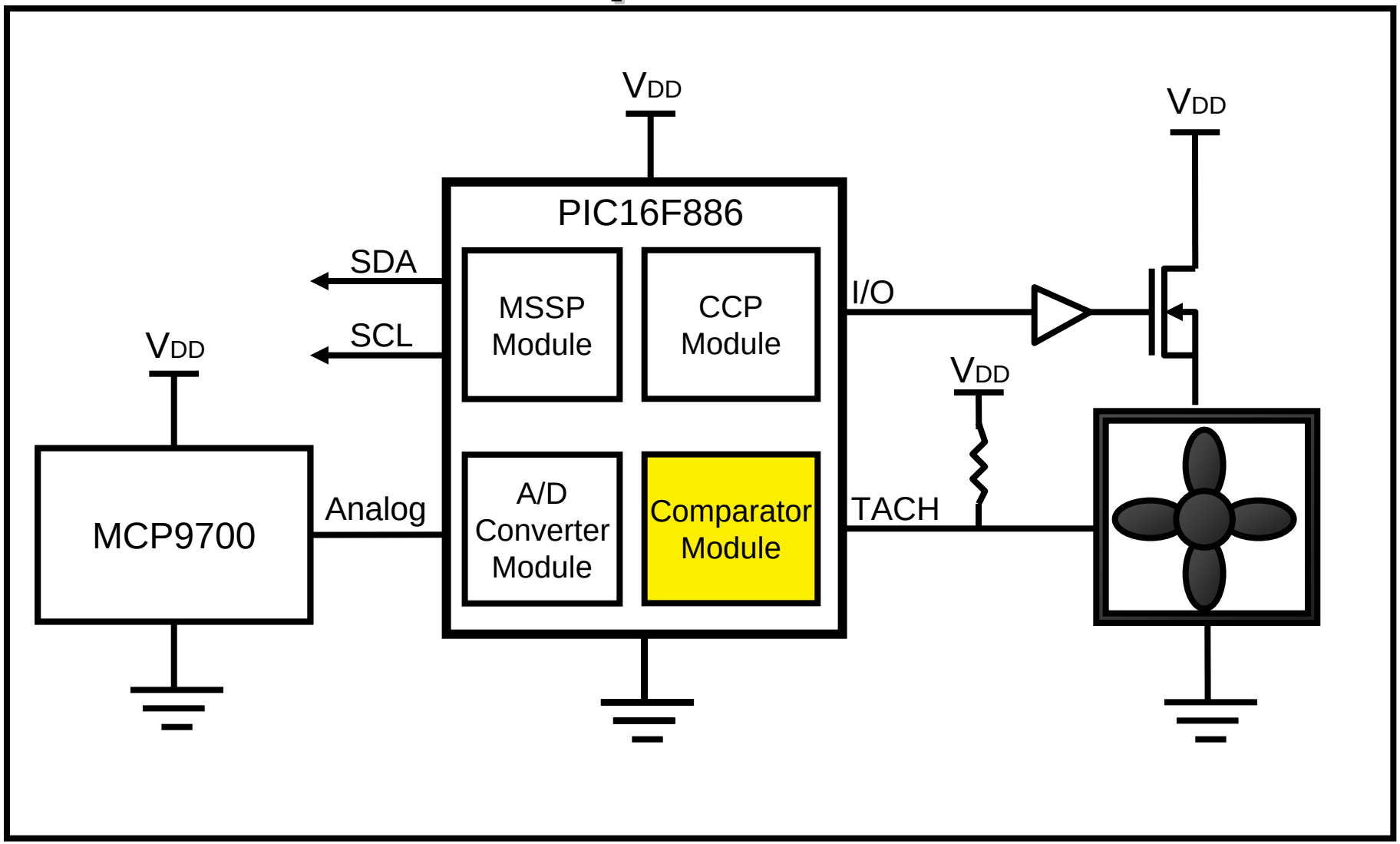
- CCP (Compare) Interrupt



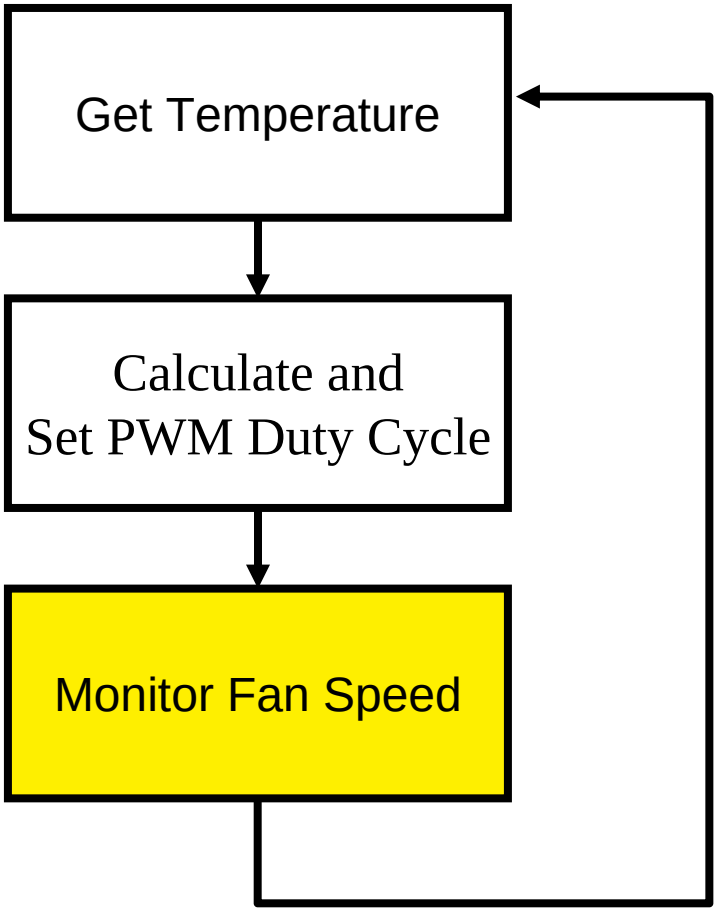
PWM Generation

Questions?

Thermal Controller Implementation



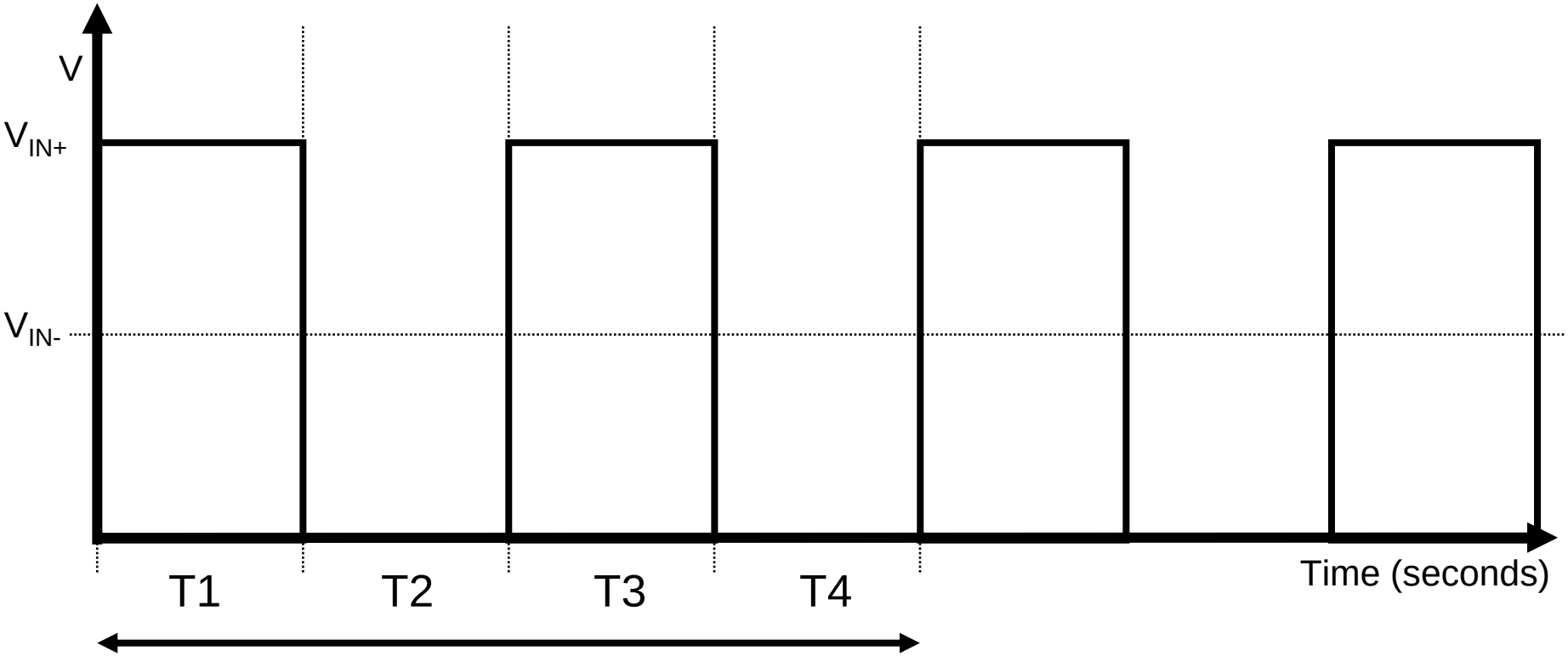
PIC® MCU Thermal Controller Flowchart



Measuring Fan Speed

- Comparator and timer 1 peripheral
- 4 transitions per revolution on TACH line
  - Fan datasheet specifies TACH line output

Tachometer Output



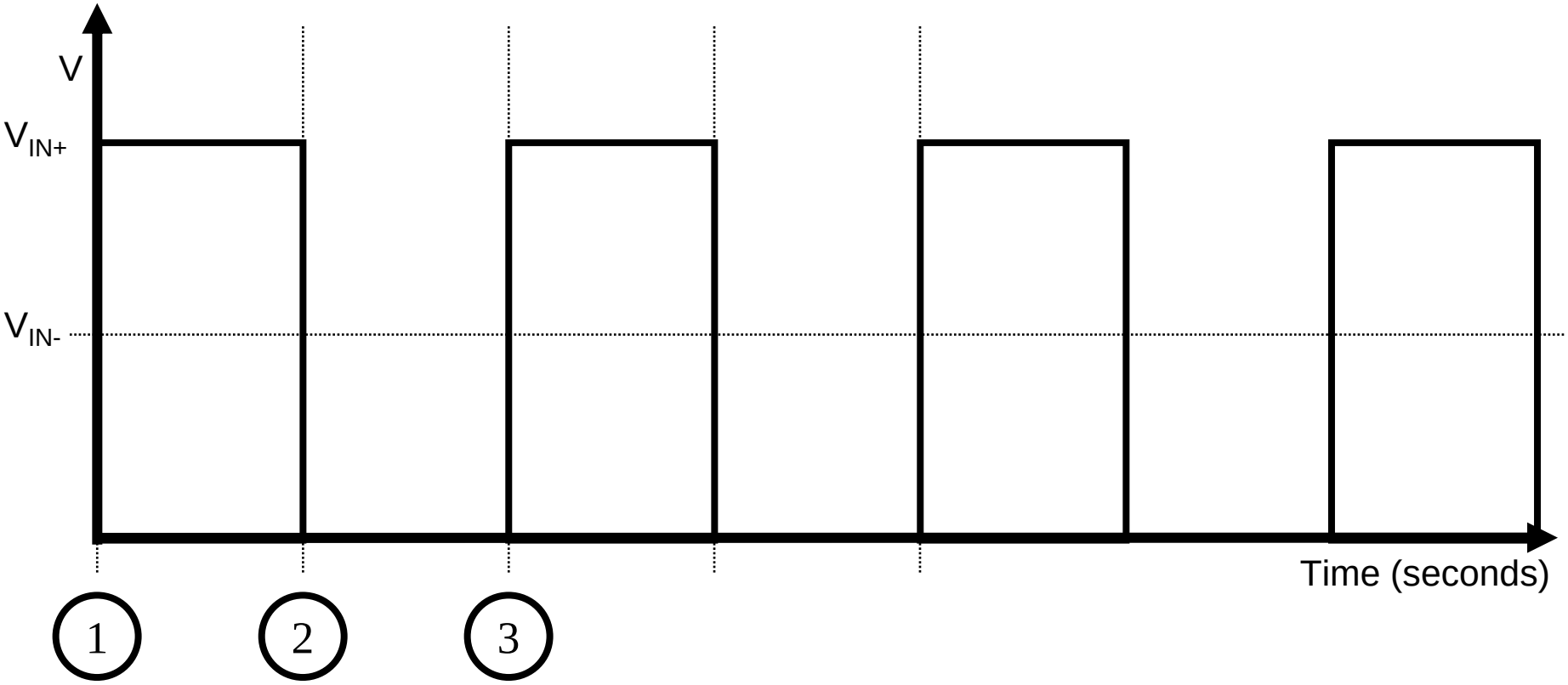
T = 1 Rotation

T = T1 + T2 + T3 + T4

T1 = T2 = T3 = T4 = 60 / (4 x RPM)

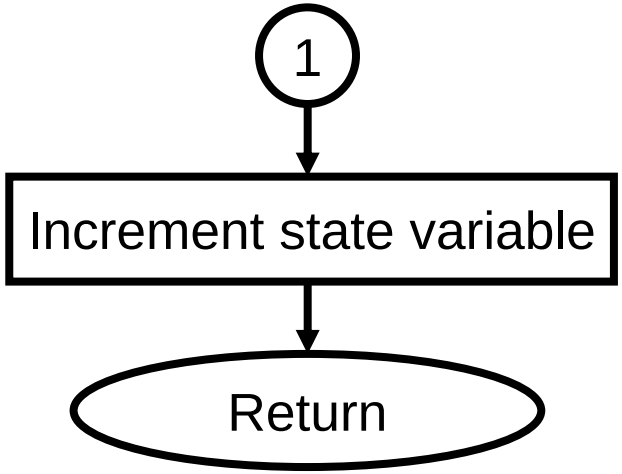
RPM = 60 / (4 x T1)

Comparator Interrupts

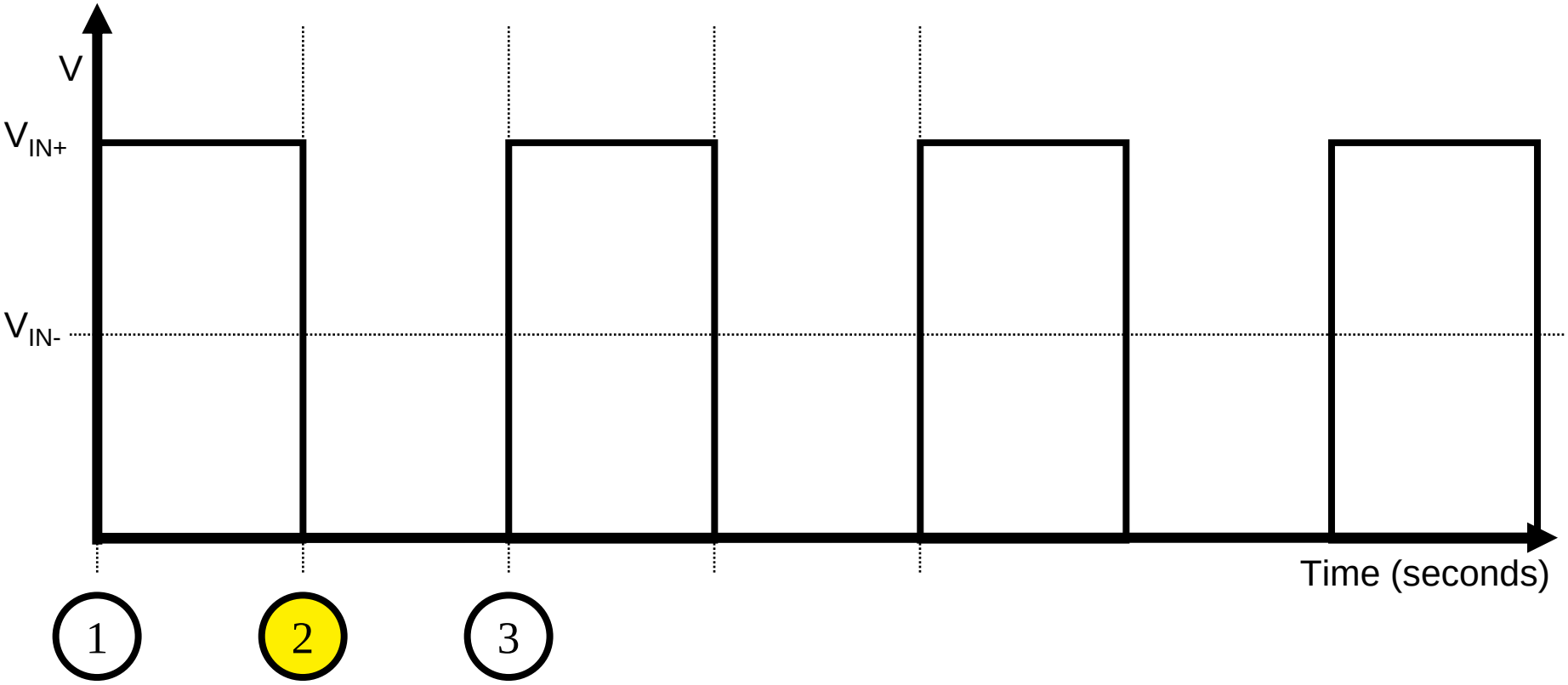


Measuring Fan Speed

- Comparator Interrupt
- Increment the state variable
- Ignore first edge (allows Hall sensor to stabilize)

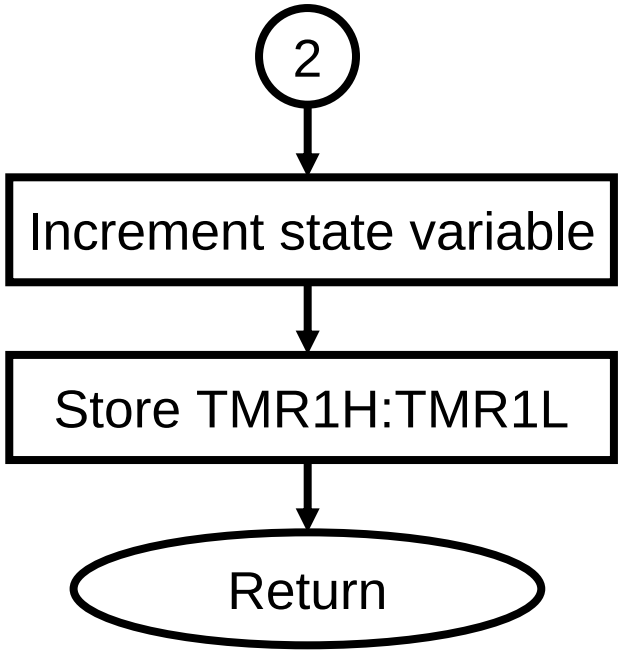


Comparator Interrupt 2

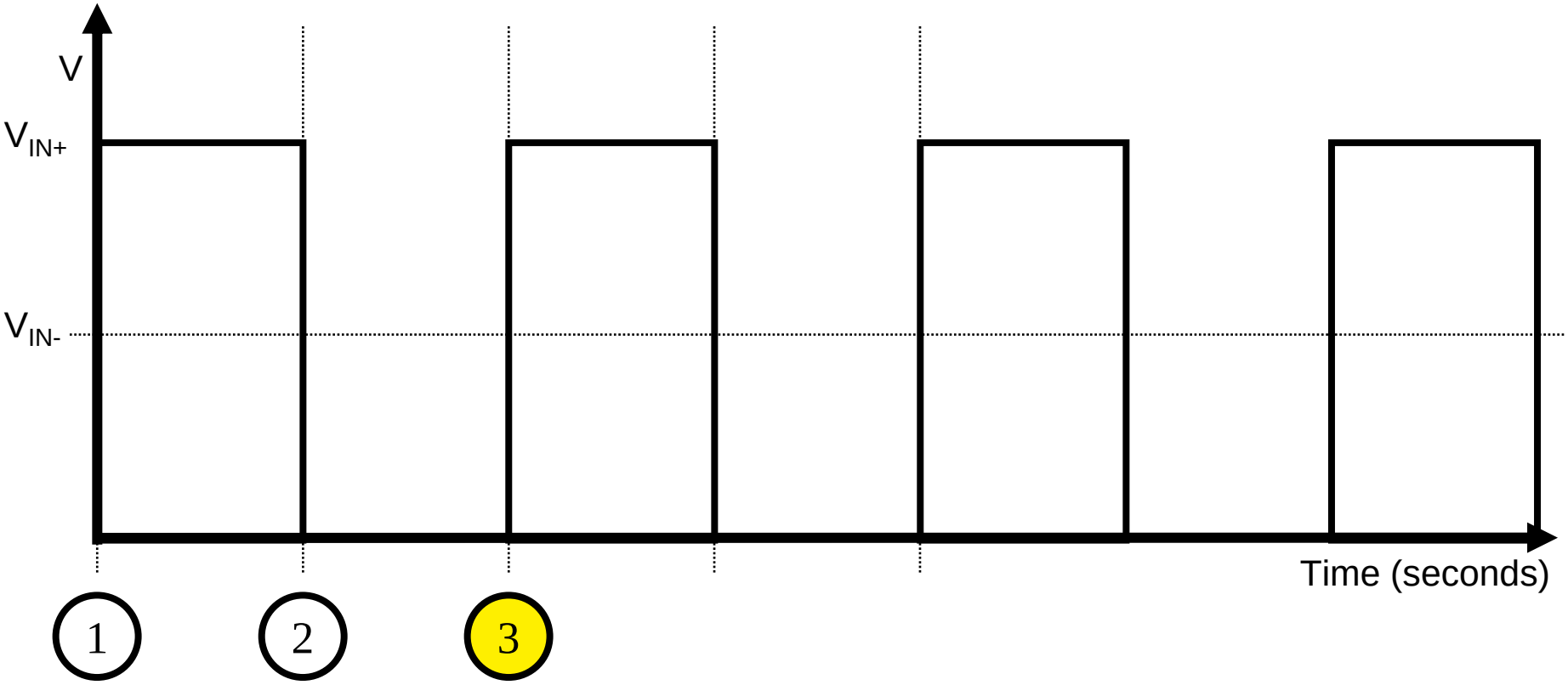


Measuring Fan Speed

- Comparator Interrupt
- Second interrupt stores Timer 1 value
- Begin Measurement

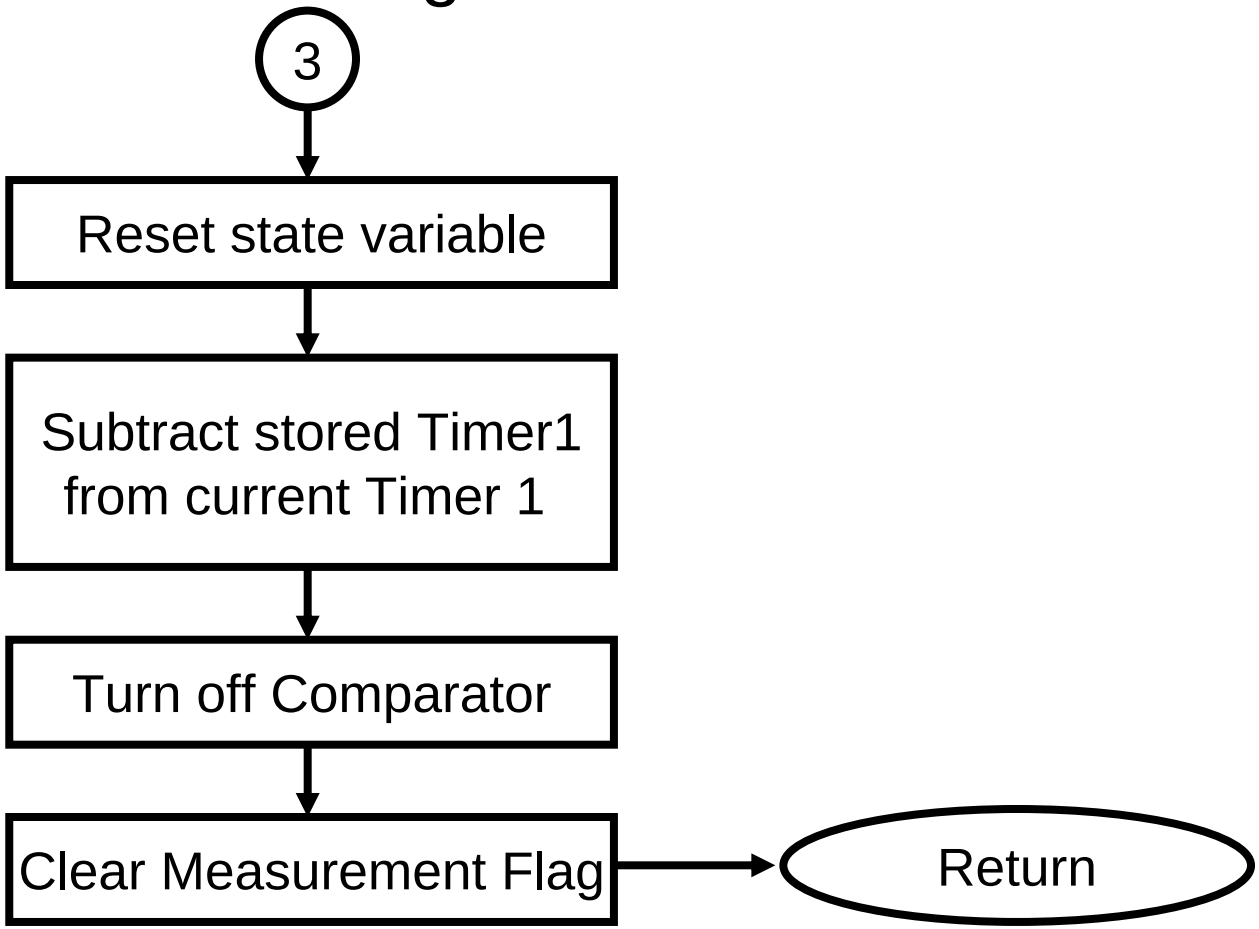


Comparator Interrupt 3

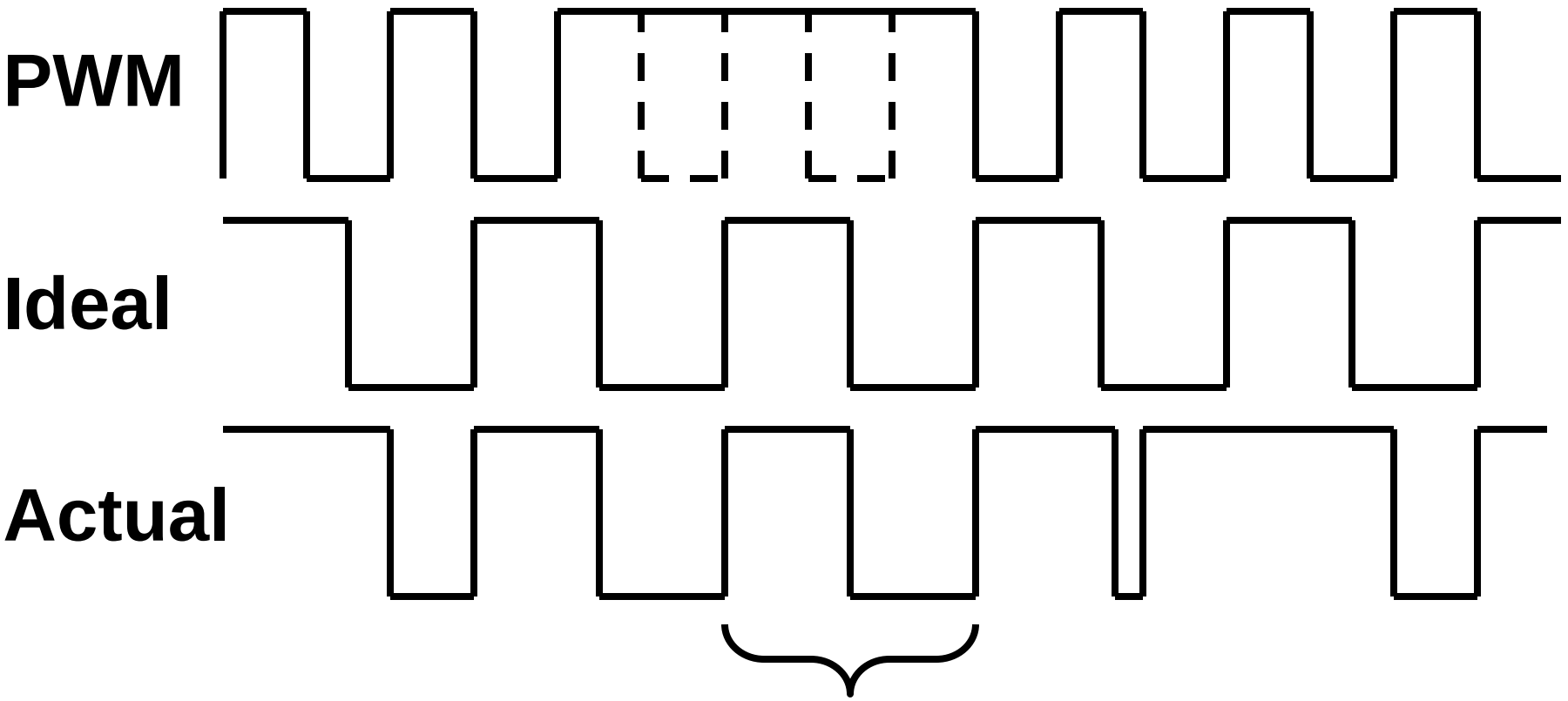


Measuring Fan Speed

- Comparator Interrupt
- Third determines the change in time

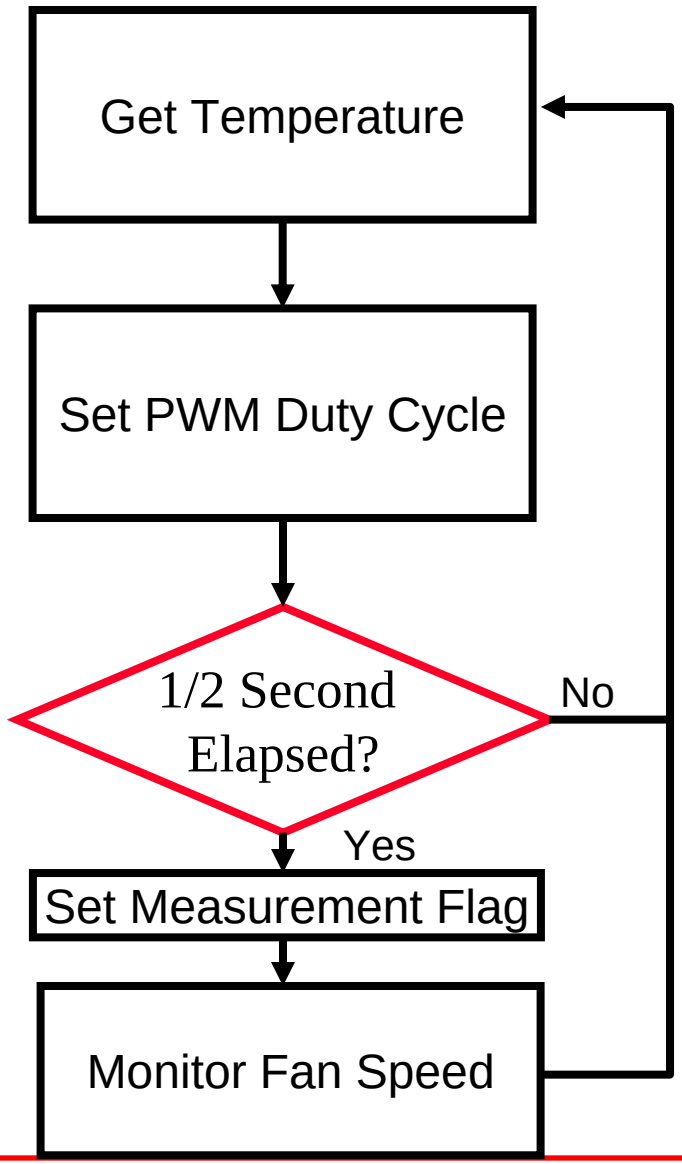


Problem: Measuring Too Often



- Fan will be full on during measurements
- Measuring too often can change the speed of a fan
- Not measuring enough may yield inaccurate speed measurements
- Solution: Measure every half second

Solution



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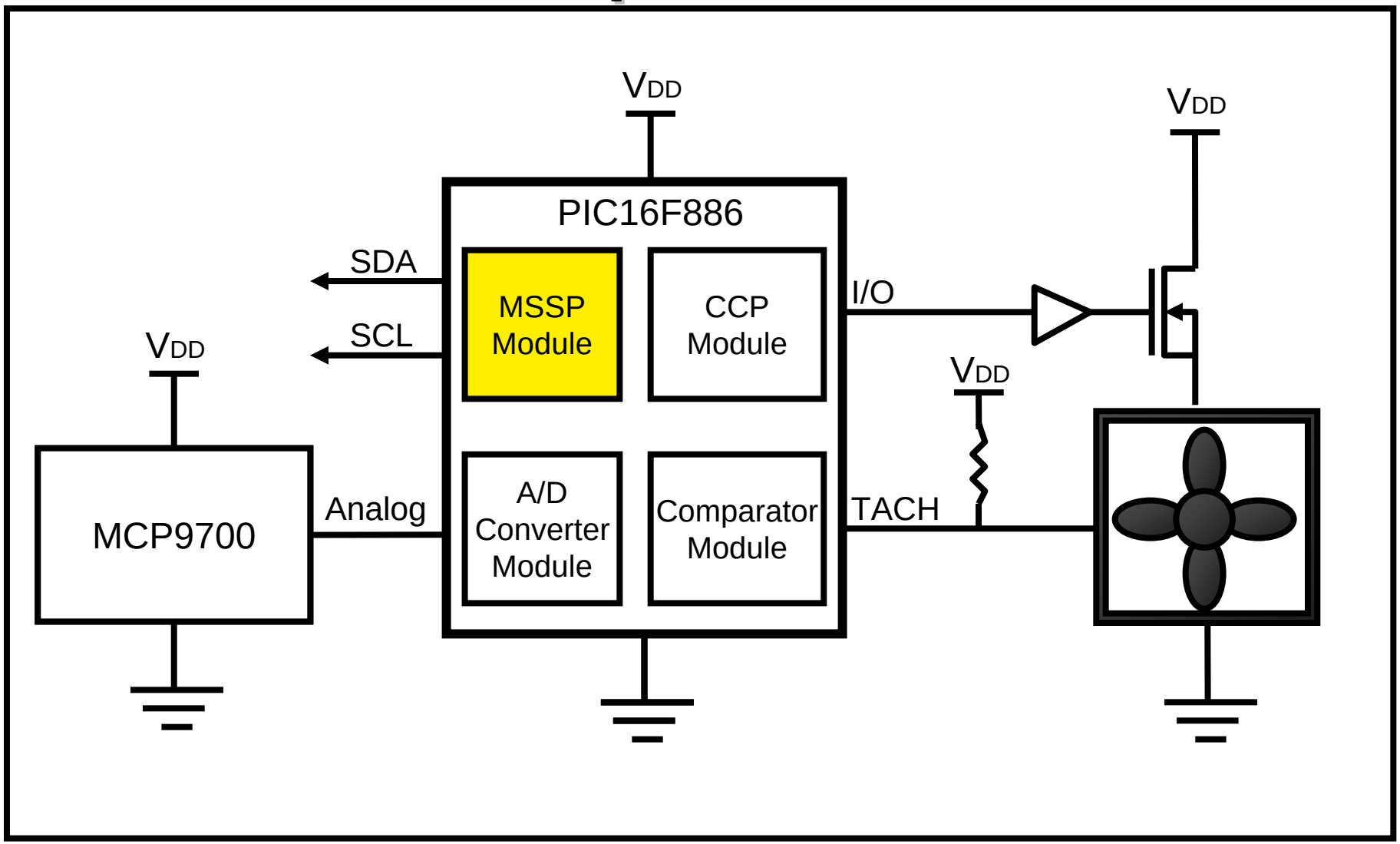
Measuring Fan Speed

Questions?

Thermal Controller Implementation

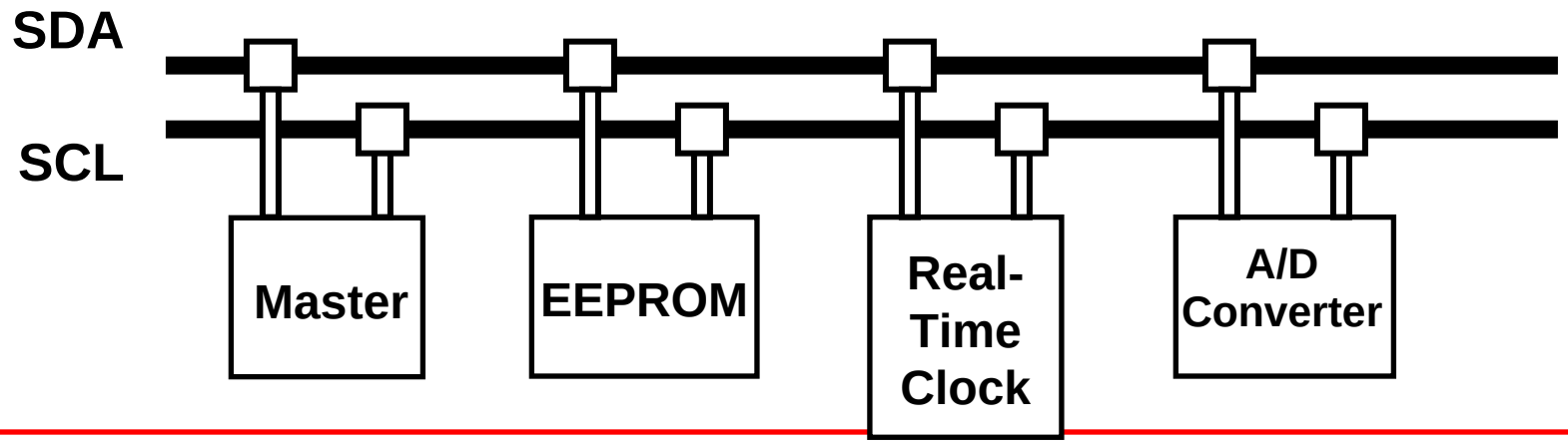


MSSP Basics

- MSSP I²C™ Mode Supports:
  - Master/Multi-Master Mode
  - Slave Mode
  - 7 or 10-bit Addressing
- Configurations:
  - I²C Master Mode
  - I²C Slave Mode
  - I²C Slave Mode with Start and Stop bit interrupts enabled
  - I²C firmware controlled master, slave is idle

I²C™ Basics

- NXP(Philips) Inter-Integrated Circuit (I²C)
  - Specification:
    www.standardics.nxp.com/literature/books/i2c/pdf/i2c.bus.specification.pdf
- Synchronous (not like RS232)
- Master-Slave Protocol
- Bidirectional
- Half Duplex Serial Interface



I²C™ Message Formatting

- Master **Write** to Slave

From master to slave

From slave to master

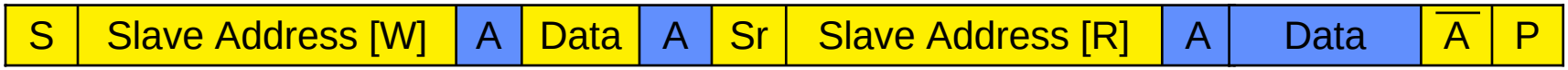
A = **Acknowledge**

S = **Start** Condition

P = **Stop** Condition

I²C™ Message Formatting

- Master **Combination Read** from Slave



From master to slave

From slave to master

A = **Acknowledge**

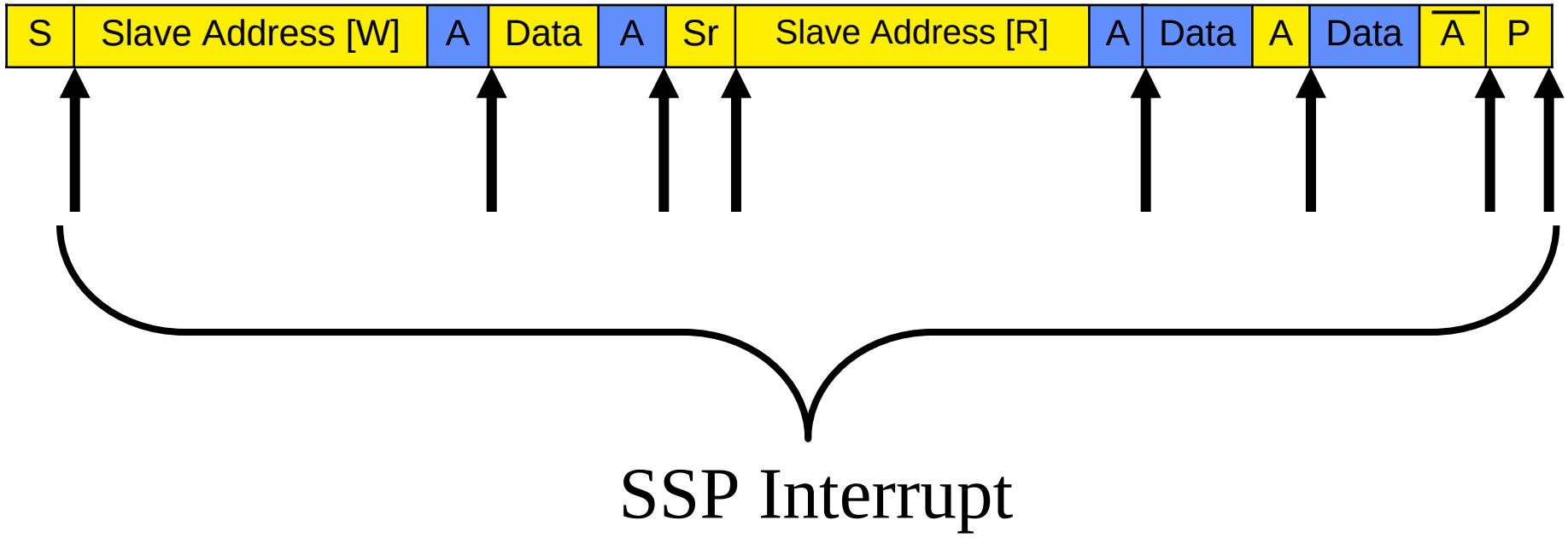
$\overline{A}$ = **No Acknowledge**

S = **Start**

Sr= **Repeated Start**

P = **Stop**

I²C™ Slave Mode Firmware Overview



Thermal Management Controller Registers

- Fan Controller writes data to GPR
- Fan Controller data is made read/writable through the I²C™ Slave Mode Firmware

General Purpose Registers

Offset Register	0x00
Temperature_H	0x01
Temperature_L	0x02
PWM High Time_H	0x03
PWM High Time_L	0x04
PWM High Time Max_H	0x05
PWM High Time Max_L	0x06
PWM High Time Min_H	0x07
PWM High Time Min_L	0x08
PWM Period_H	0x09
PWM Period_L	0x0A

Temperature Max_H	0x0B
Temperature Max_L	0x0C
Temperature Min_H	0x0D
Temperature Min_L	0x0E
Fan Speed_H	0x0F
Fan Speed_L	0x10
Fan Status	0x11

Summary

- Thermal Management Basics
- 3-Wire Fans
- Thermal Controllers
- Implementing a Thermal Controller on a PIC16F886

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