Microcontroller Basics

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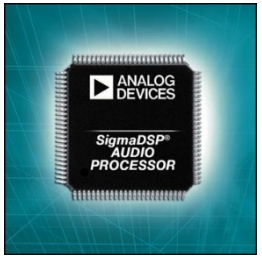
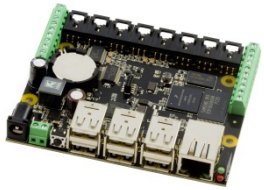
Microcontrollers

- What are microcontrollers?
  - Single-chip programmable “computers” used in embedded applications
  - Include a CPU, memory, input/output (I/O) and other peripherals
- How do they differ from microprocessors?
  - Microprocessors just contain a CPU and other basic hardware for executing instructions
  - Microprocessors need external memory, I/O, peripherals

Other Options

- Microprocessors
- Digital Signal Processors (DSPs)
  - Microprocessors with specialized hardware for fast signal processing calculations
  - Sometimes have some other I/O subsystems
- Field Programmable Gate Arrays (FPGAs)
  - Customizable chips with programmable gates
- Hybrids
  - Example: NI cRIO has an FPGA layer and a real-time (microprocessor) layer
- Single-board computers



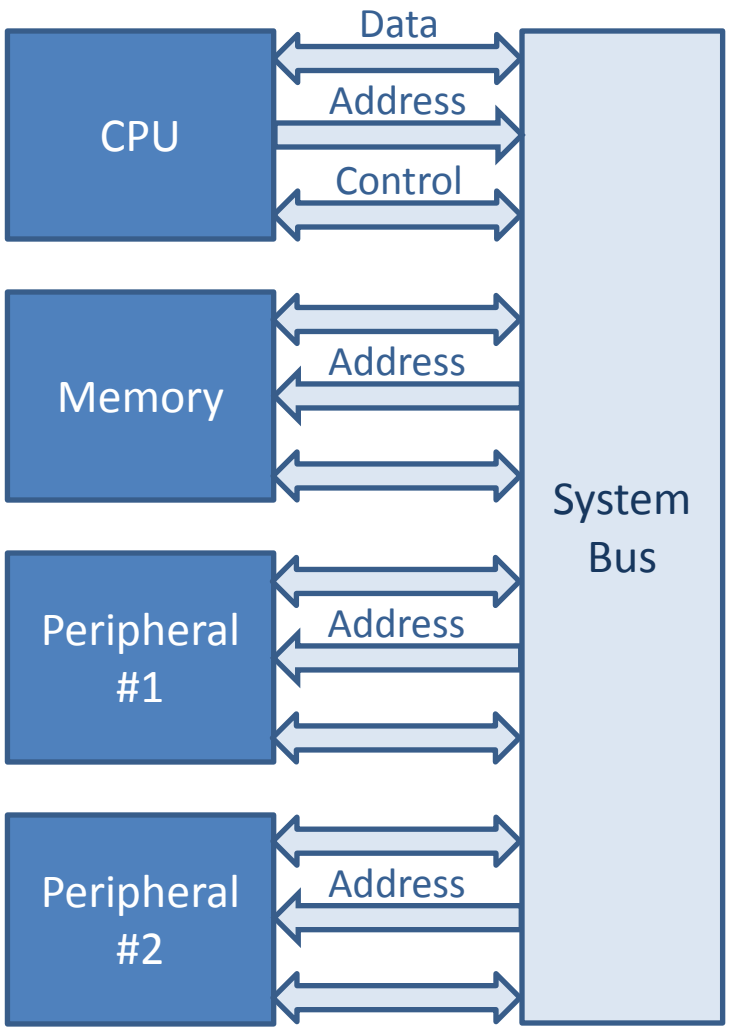


Microcontroller Components

- CPU
- Memory
  - Non-volatile (ROM – PROM, EPROM, EEPROM, Flash)
  - Volatile (RAM)
- I/O
  - Digital – serial and parallel
  - Analog-to-digital converters (A/D or ADC)
  - Pulse width modulation (PWM) outputs
- Timers
- Counters
- Comparators
- Internal buses that allow the CPU to communicate with peripherals
- Not present in most MCUs: D/A converters

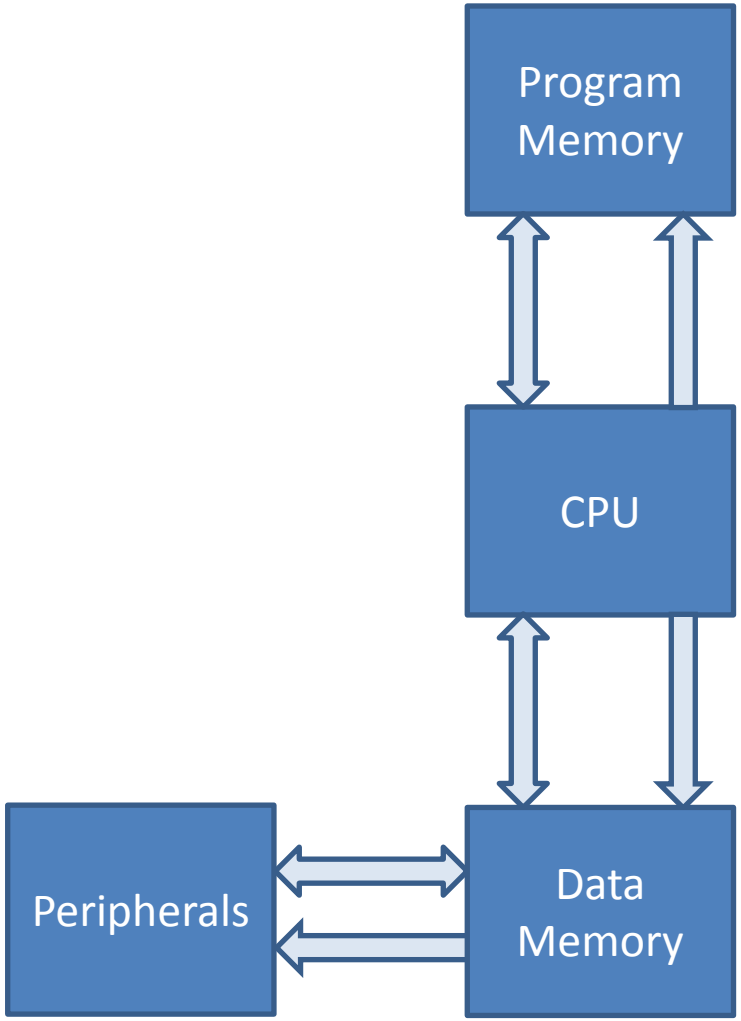
Von Neumann Architecture

- Program and data in the same memory
- Uses a single/shared “bus” (communication path) for the CPU to communicate with memory and peripherals
- Address and data have to move on the same pathway
- Simple, but can result in a bottleneck



Harvard Architecture

- Separate program and data memory and buses
- Faster execution
- More complex
- No bottleneck



Microcontroller Specs

- Architecture (Von Neumann vs. Harvard)
- Width of data path/bus
  - 8 bit, 16 bit, 32 bit
  - How much data can be transferred and operated on simultaneously
- Memory
  - Volatile (RAM)
  - Non-Volatile (EEPROM, Flash)
- Clock
  - Internal and external clock options
- Peripherals
- Number of pins
- Number of I/O pins
- Supply voltage
- Low-power options
- Cost
- Package

Programming Options

- High-level
  - Instructions look “English-ish”
  - High level of abstraction
  - C, C++, Java, Python

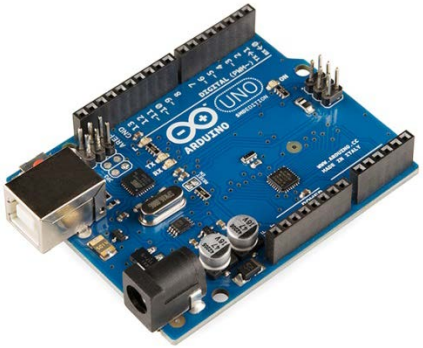
```
while(k < s)
   k++;
```

- Low-level
  - Instructions look more cryptic
  - Require explicit coding of all functions
  - Machine language
  - Assembly language

```
BRA 0x2C4
MOV [W14+2],W0
MOV [W14],W1
SUB W1,W0,[W15]
BRA LT,0x2C2
INC [W14],[W14]
```

Single-board Microcontrollers

- Microcontroller + peripherals + connectors + oscillator
  - Arduino – www.arduino.cc
  - Raspberry Pi – www.raspberrypi.org
  - Gumstix – www.gumstix.com
  - Many others



- Pros: Convenient, fun, easy to learn
- Cons: Not small, cheap, or optimized
- Use for prototypes and projects, not products

Single-chip Microcontrollers

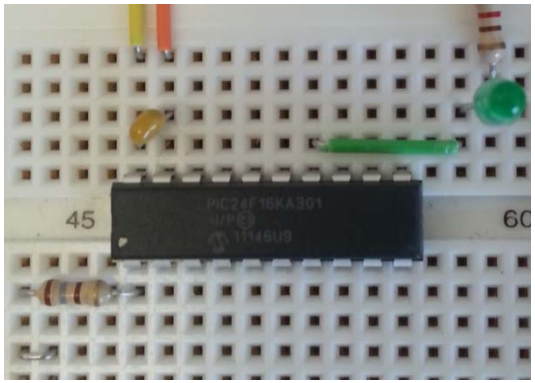
- Stand-alone chips – you provide the support circuitry
  - Microchip (PIC) – www.microchip.com
  - Atmel – www.atmel.com
  - Freescale (Motorola) – www.freescale.com
- Pros: Cost, performance
- Cons: Development time, skills, support circuitry
- Use in real products

The Challenges

- Limited resources
  - Speed
  - Memory
- Programming microcontrollers requires intimate knowledge of hardware
  - Circuitry
  - Internal memory and registers
- Registers
  - Special memory locations that allow us to configure how the microcontroller works, access peripheral functions, write to ports, read from ports, etc.
  - Register map in Table 4-3 through Table 4-26 that tell us what each register is and what it contains
  - Additional information in the individual sections
- Side note: when programming in assembly, also need to know how to use the working registers

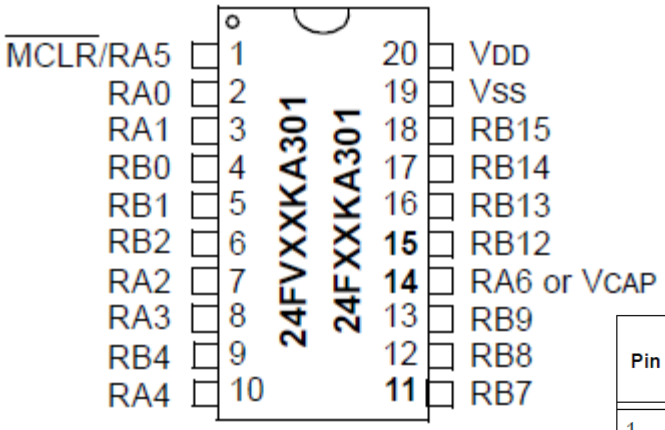
PIC24F16KA301

- Architecture: Modified Harvard
- Bus Width: 16-bit data, 24-bit address
- CPU Speed: 16 MIPS
- Flash Program Memory: 16 KB
- RAM: 2048 B
- Operating Voltage: 1.8-3.6 V
- Pin Count: 20
- I/O Pins: 18
- Serial Communication: 2 UART; 2 SPI; 2 I^2C
- Analog Inputs: 12-bit A/D at 100 ksps, 12 channels
- Comparators: 3
- PWM: 3 x 16-bit
- Timers: 11 x 16-bit; 5 x 32-bit



http://ww1.microchip.com/downloads/en/DeviceDoc/39995d.pdf

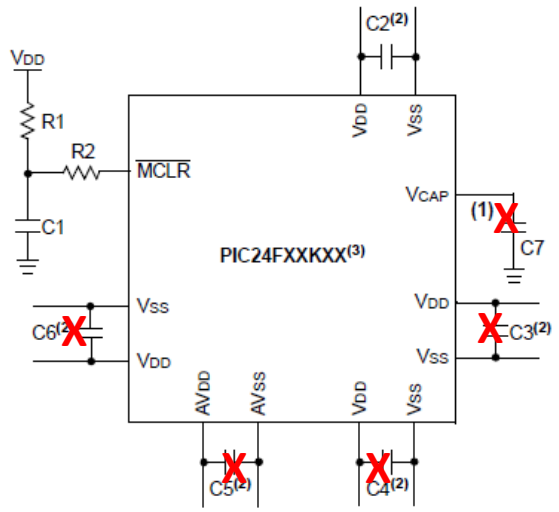
PIC24F16KA301 Pinout



Pin	Pin Features	
	PIC24FVXXKA301	PIC24FXXKA301
1	MCLR/VPP/RA5	MCLR/VPP/RA5
2	PGEC2/VREF+/CVREF+/AN0/C3INC/SCK2/CN2/RA0	PGEC2/VREF+/CVREF+/AN0/C3INC/SCK2/CN2/RA0
3	PGED2/CVREF-/VREF-/AN1/SDO2/CN3/RA1	PGED2/CVREF-/VREF-/AN1/SDO2/CN3/RA1
4	PGED1/AN2/ULPWU/CTCMP/C1IND/C2INB/C3IND/U2TX/SDI2/OC2/CN4/RB0	PGED1/AN2/ULPWU/CTCMP/C1IND/C2INB/C3IND/U2TX/SDI2/OC2/CN4/RB0
5	PGEC1/AN3/C1INC/C2INA/U2RX/OC3/CTED12/CN5/RB1	PGEC1/AN3/C1INC/C2INA/U2RX/OC3/CTED12/CN5/RB1
6	AN4/SDA2/T5CK/T4CK/U1RX/CTED13/CN6/RB2	AN4/SDA2/T5CK/T4CK/U1RX/CTED13/CN6/RB2
7	OSCI/AN13/C1INB/C2IND/CLKI/CN30/RA2	OSCI/AN13/C1INB/C2IND/CLKI/CN30/RA2
8	OSCO/AN14/C1INA/C2INC/CLKO/CN29/RA3	OSCO/AN14/C1INA/C2INC/CLKO/CN29/RA3
9	PGED3/SOSCI/AN15/U2RTS/CN1/RB4	PGED3/SOSCI/AN15/U2RTS/CN1/RB4
10	PGEC3/SOSCO/SCLKI/U2CTS/CN0/RA4	PGEC3/SOSCO/SCLKI/U2CTS/CN0/RA4
11	**U1TX/C2OUT/OC1/IC1/CTED1/INT0/CN23/RB7**	**U1TX/INT0/CN23/RB7**
12	SCL1/U1CTS/C3OUT/CTED10/CN22/RB8	SCL1/U1CTS/C3OUT/CTED10/CN22/RB8
13	SDA1/T1CK/U1RTS/IC2/CTED4/CN21/RB9	SDA1/T1CK/U1RTS/IC2/CTED4/CN21/RB9
14	VCAP	**C2OUT/OC1/IC1/CTED1/INT2/CN8/RA6**
15	**AN12/HLVDIN/SCK1/SS2/IC3/CTED2/INT2/CN14/RB12**	**AN12/HLVDIN/SCK1/SS2/IC3/CTED2/CN14/RB12**
16	AN11/SDO1/OCFB/CTPLS/CN13/RB13	AN11/SDO1/OCFB/CTPLS/CN13/RB13
17	CVREF/AN10/C3INB/RTCC/SDI1/C1OUT/OCFA/CTED5/**INT1**/CN12/RB14	CVREF/AN10/C3INB/RTCC/SDI1/C1OUT/OCFA/CTED5/**INT1**/CN12/RB14
18	AN9/C3INA/SCL2/T3CK/T2CK/REFO/SS1/CTED6/CN11/RB15	AN9/C3INA/SCL2/T3CK/T2CK/REFO/SS1/CTED6/CN11/RB15
19	VSS/AVSS	VSS/AVSS
20	VDD/AVDD	VDD/AVDD

PIC24F16KA301 Minimum Connections

FIGURE 2-1: RECOMMENDED MINIMUM CONNECTIONS



Key (all values are recommendations):

C1 through C6: 0.1 µF, 20V ceramic

C7: 10 µF, 16V tantalum or ceramic

R1: 10 kΩ

R2: 100Ω to 470Ω

Note 1: See Section 2.4 "Voltage Regulator Pin (VCAP)" for explanation of VCAP pin connections.

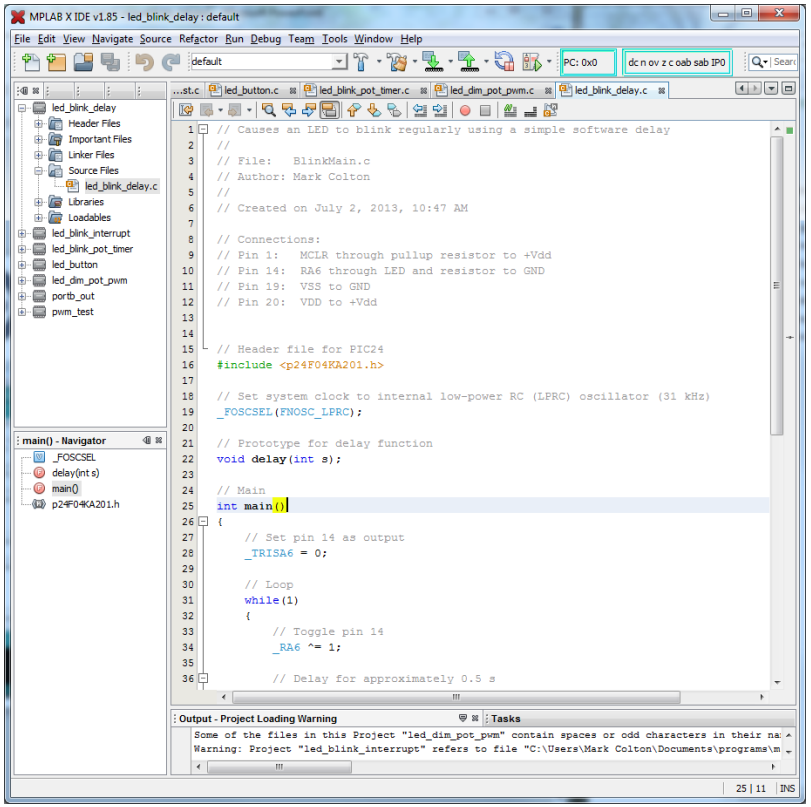
2: The example shown is for a PIC24F device with five VDD/VSS and AVDD/AVSS pairs. Other devices may have more or less pairs; adjust the number of decoupling capacitors appropriately.

3: Some PIC24F K parts do not have a regulator.

- V_{DD} (positive power)
  - 1.8-3.6 V
- V_{SS} (ground)
- 0.1 µF bypass caps across all V_{DD} and V_{SS} pins
  - Only one V_{DD} and V_{SS}
- V_{CAP}, AV_{DD} and AV_{SS} only on the PIC24FV models
- Very simple connections!

MPLAB X

- Integrated Development Environment (IDE)
  - Write code
  - Build code
  - Debug code
- Need a compiler
  - XC16 (C compiler for MPLAB X for use with 16-bit PIC micros)

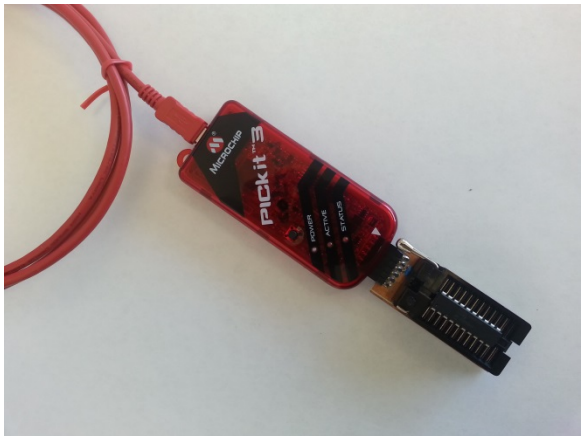


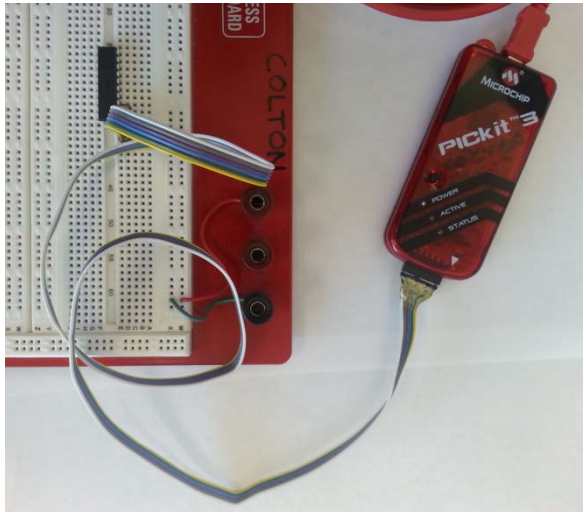
PICkit 3

- Affordable programmer/debugger for PIC micros
- USB connection
- Pinout for connections in documentation

http://ww1.microchip.com/downloads/en/DeviceDoc/52010A.pdf

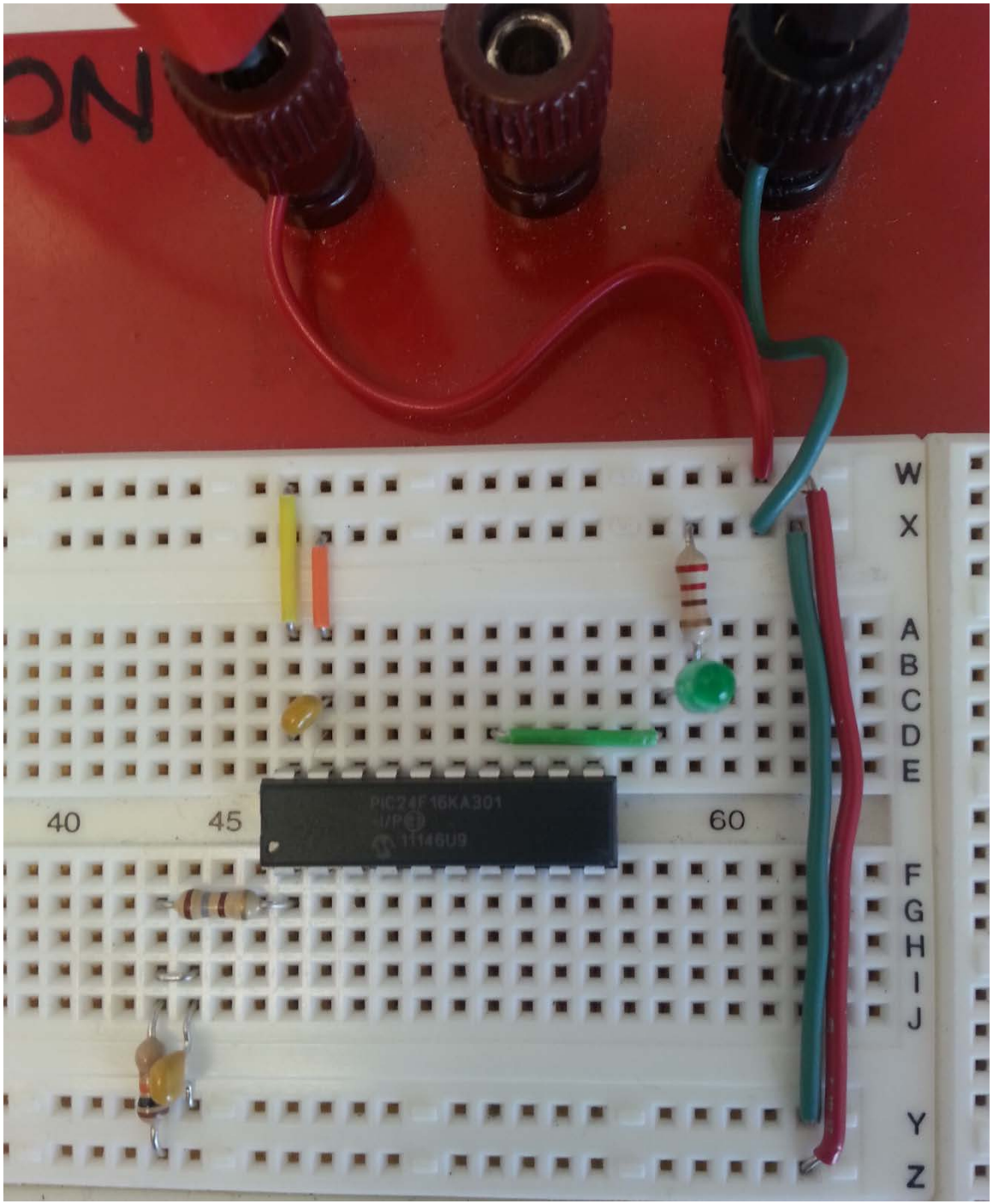
http://ww1.microchip.com/downloads/en/DeviceDoc/52116A.pdf





Example

- Open MPLAB X
- Create new project
  - Microchip Embedded
  - Standalone Project
- Select device
  - 16-bit MCUs (PIC24) family
  - PIC24F16KA301 device
- Select programmer (PICkit3)
- Select compiler (XC16)
- Name project
- Add .c source file
- Project Properties | PICkit 3 | Power | Power target from PICkit 3


ON
W
X
A
B
C
D
E
40
45
60
PIC24F16KA301
F
G
H
I
J
Y
Z