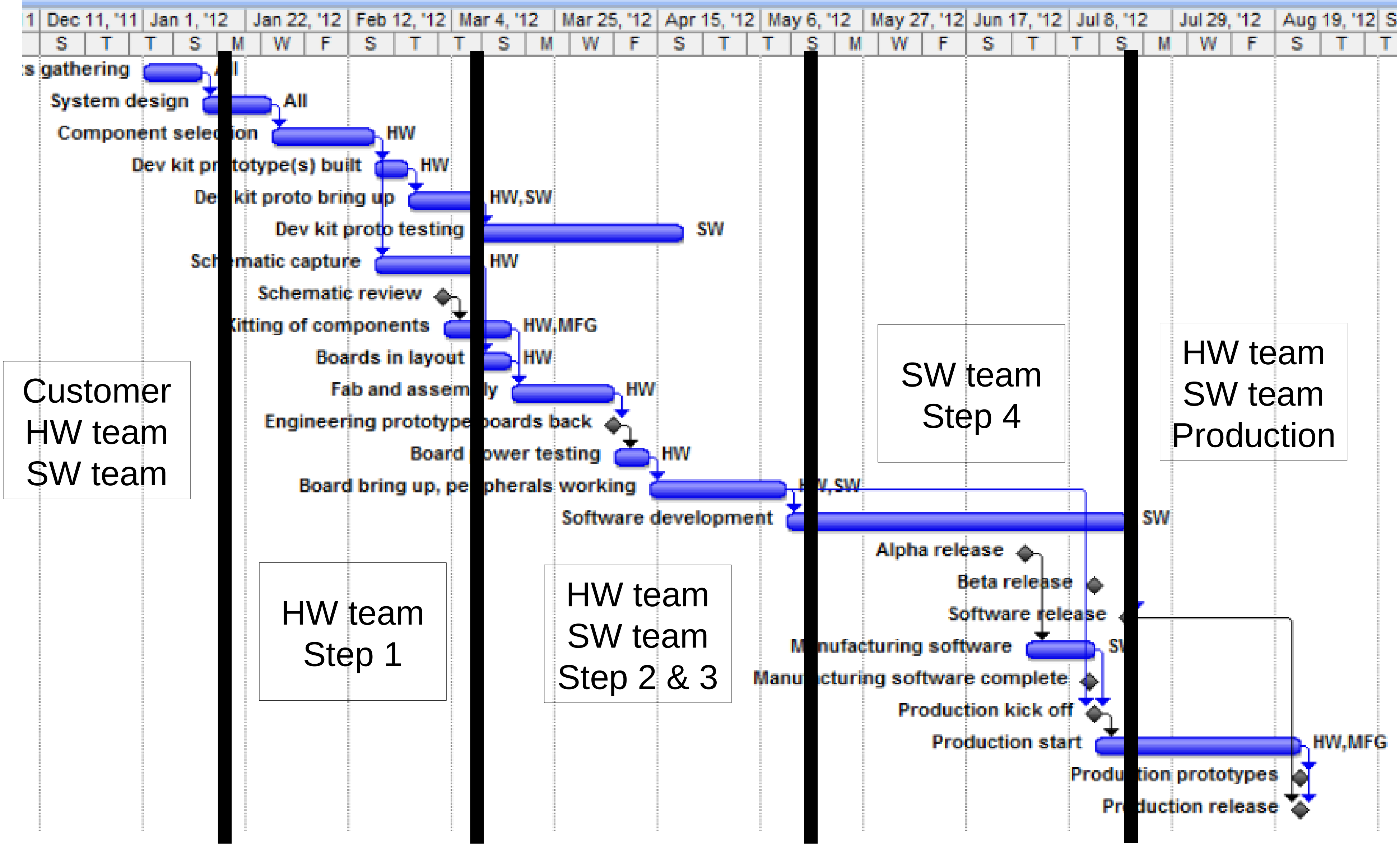
Begin with Hardware

Chapter 3

Project Flow



Customer
HW team
SW team

HW team
Step 1

HW team
SW team
Step 2 & 3

SW team
Step 4

HW team
SW team
Production

Hardware Team, Step 1

- Component Selection (one month or a few)
  - Requirements are given.
  - Selection criteria
    - Electrical and mechanical needs
      - Voltage, power, temperature, physical dimension
    - Functional needs
      - Parameters, speed, peripherals
    - Similar example applications
    - Performance
      - Response, precision, tolerance
    - Manufacture
      - Reputation, lead time, price
  - Results : 2-4 alternatives

Software Team, Step 1

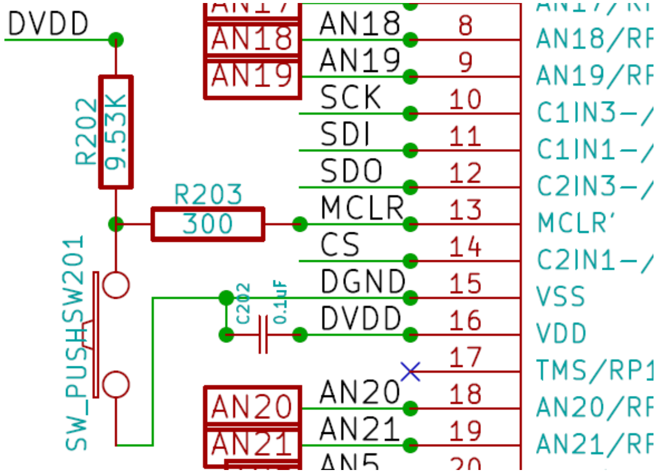
- After components are selected,
  - Processor is decided.
  - Tool chain: compiler, debugger, loader
    - Ideally in Integrated Development Environment (IDE)
    - Licensed: most chip makers provide dev kits
    - Free: gcc-based open source tool chains
- After schematic is completed,
  - Read schematic and datasheets
  - Read documentations
  - Develop software in dev kits and prototypes

Hardware Team, Step 2

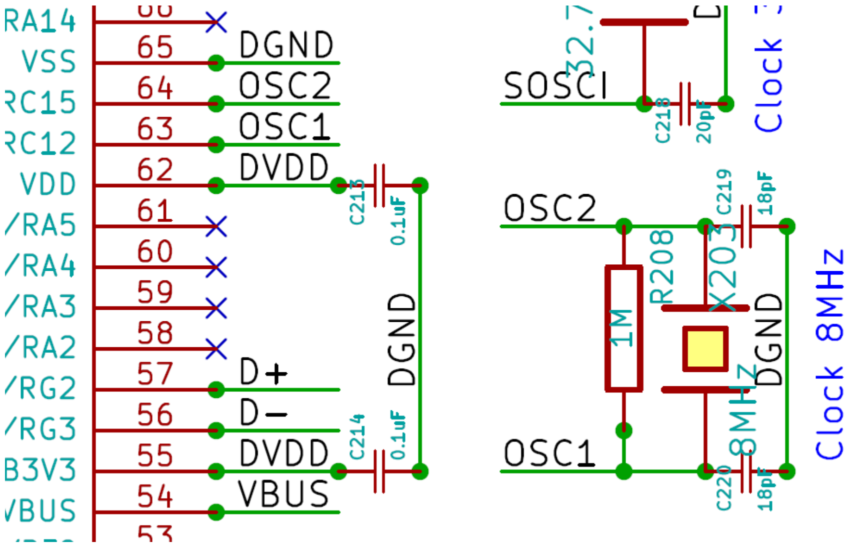
- Schematic Design (one month or a few)
  - Most time is spent on reading datasheets and selecting proper components.
  - Component size is proportional to the number of pins, and the largest component is usually the processor.
  - Key to SW is the IO map that describes the connection of each pin of the processor.
  - Every component has a label and a description.
  - Every wire and pin has a label.
    - Wires and pins of the same label are connected.

Schematic (Case 7)

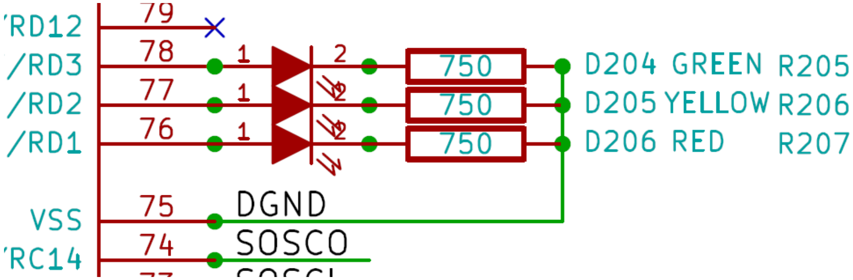
- Power and reset



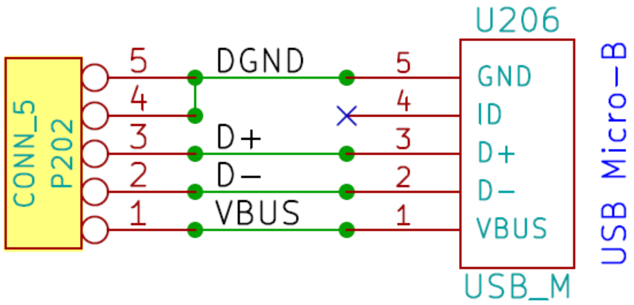
- Oscillator

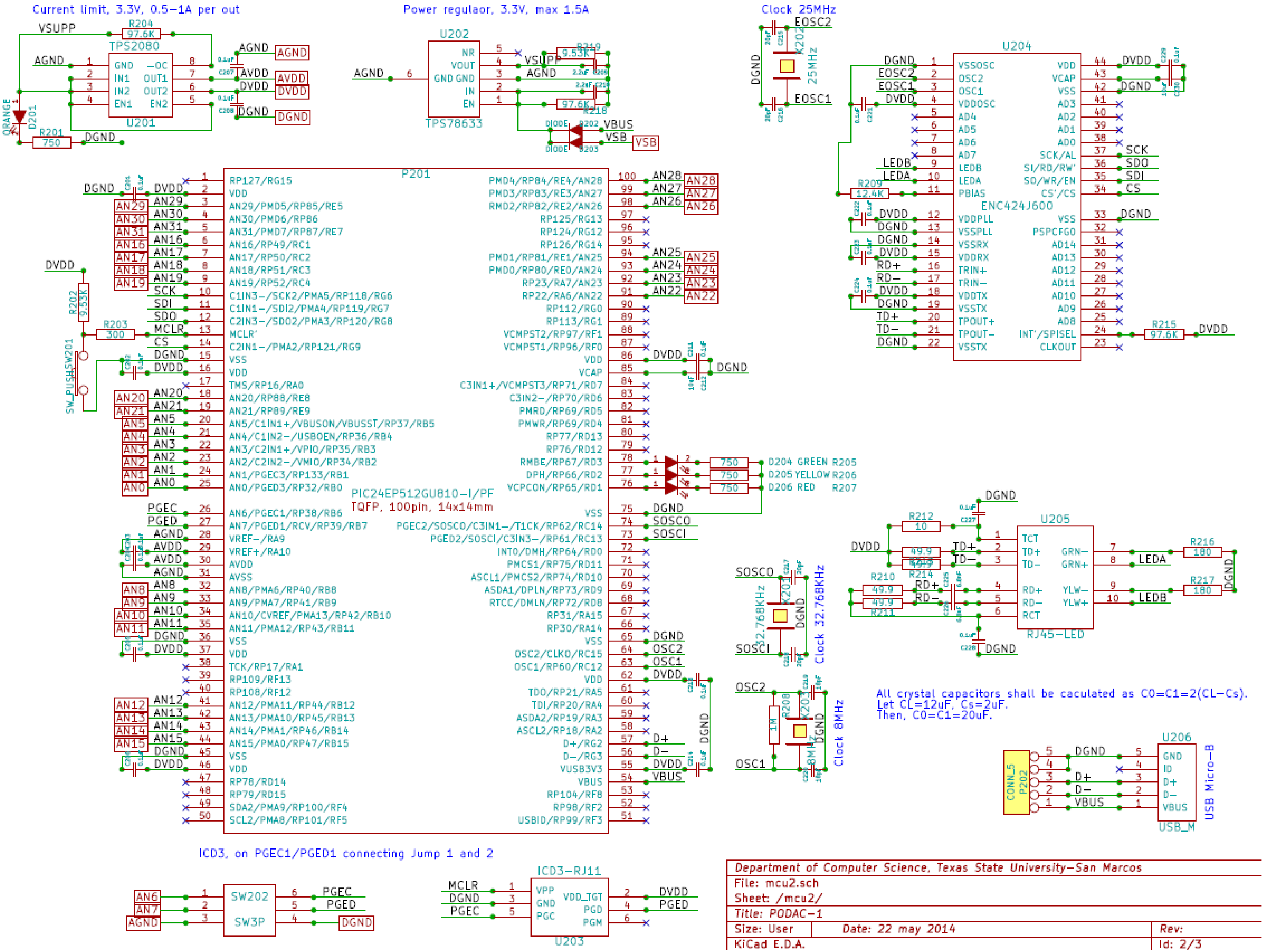


- LED



- USB





Department of Computer Science, Texas State University-San Marcos

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Sheet: /mcu2/

Title: *PODAC-1*

Size: User	Date: *22 may 2014*	Rev:
KiCad E.D.A.		Id: 2/3

Software Team, Step 2

- Read schematic and datasheets
  - While HW team is making PCB.
  - Every part on board has a datasheet.
  - Written for electrical engineering
    - No wonder very hard to read for software developer.
  - How to read the datasheet of processor.
    - In general, read TOC, then jump to the section of the component of concern
    - Description (overview and feature summary)
    - Theory of operation (functionality)
    - Pins and bus (data transfer)
    - Timing (operation and procedure)
    - Sample schematics and (application)
    - Performance (application requirements)

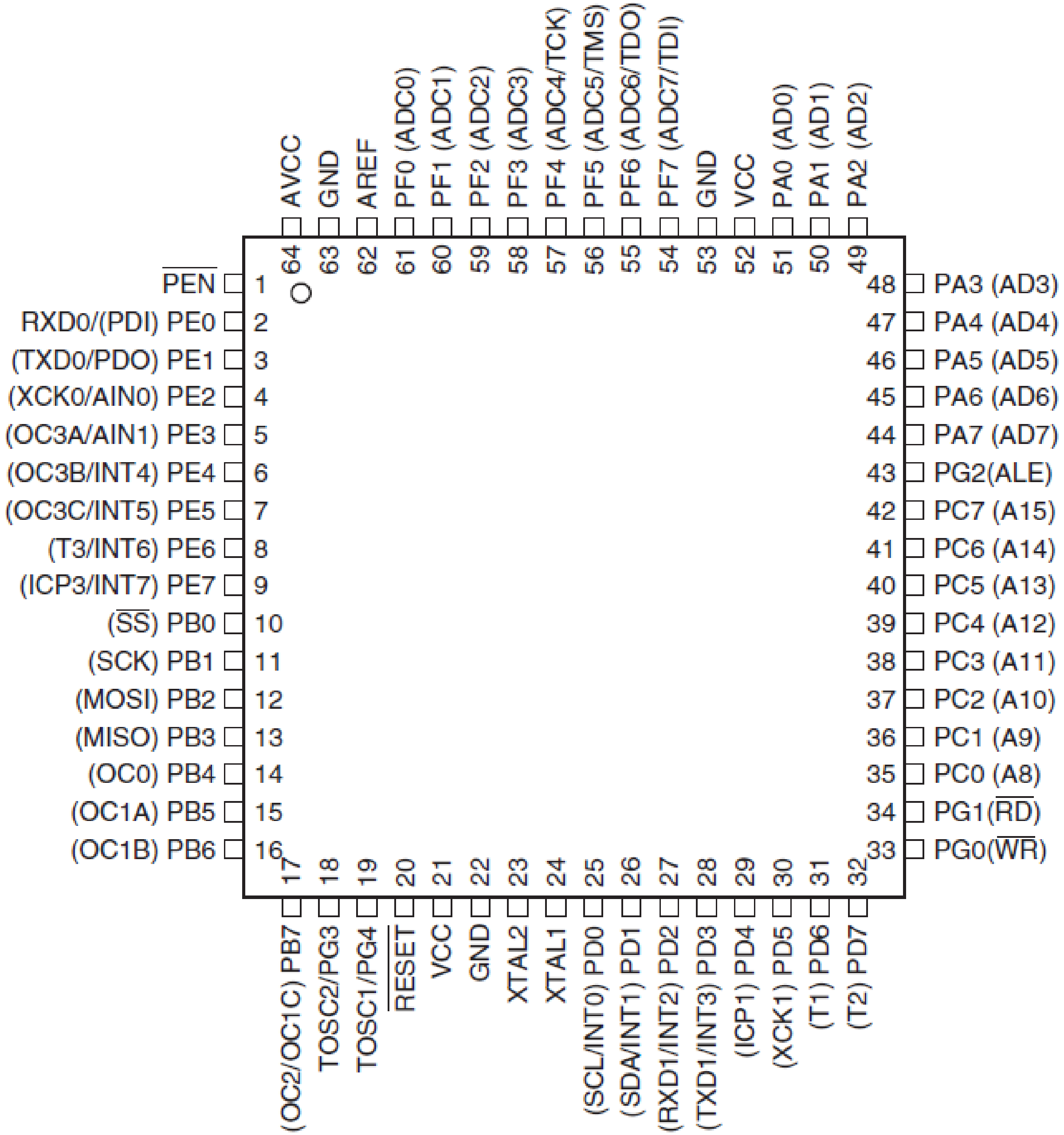
Software Team, Step 2

- Datasheet: Sections that must be read for software development.
  - Device overview: pin map
  - CPU: registers, addressing, instruct set
  - Memory organization: data and program
  - IO ports
  - Reset
  - Oscillator and clock
  - Interrupts
  - Timer/counter
  - Power saving

CPU Model (Case 9)

- Processor pins
    - Power supply (AVCC, DVCC)
    - Ground (DGND, AGND)
    - Clock
    - Reset
    - IO pins
    - Interrupt pins
    - Read pin (to external memory or peripherals)
    - Write pin (to external memory or peripherals)
    - Address pins (to external memory or peripherals)
    - Data pins (to external memory or peripherals)

Case9.atmega128

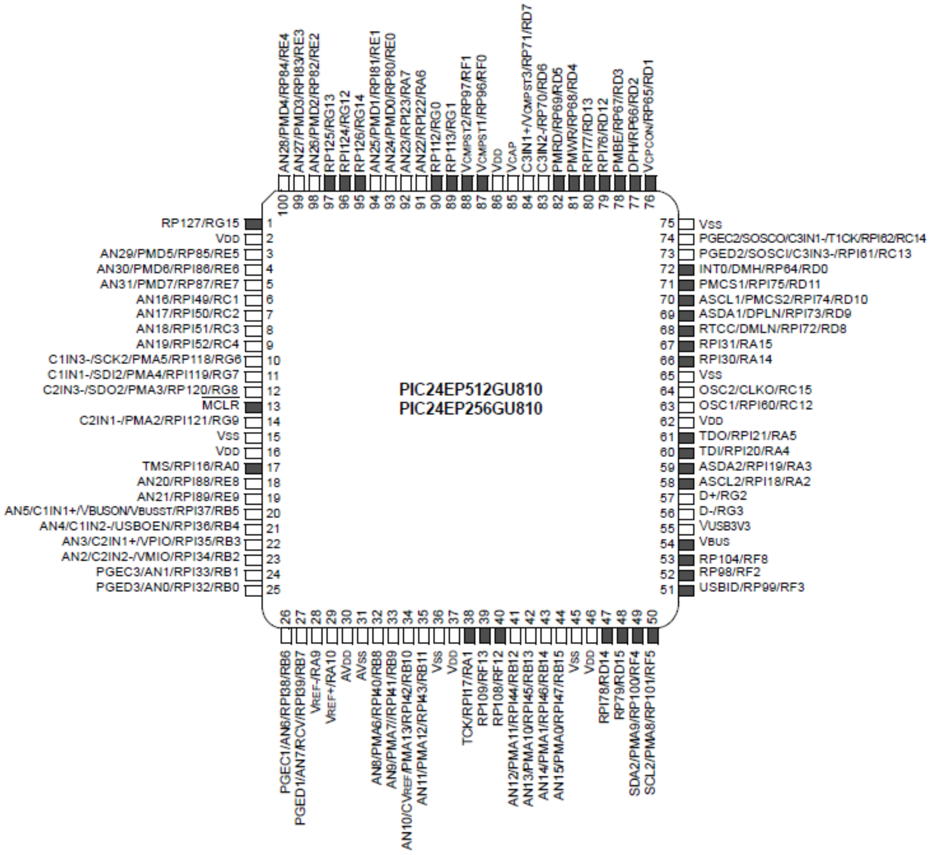


Case9.atmega128

- Processor pins
  - Power: 21, 52, 64
  - Ground: 22, 53, 63
  - Clock: 23, 24
  - Reset: 20
  - Interrupt pins: 25-28, 6-9
  - IO pins: PA-PG
  - Read pin: 34
  - Write pin: 33
  - Address pins: 51-44, 35-42
  - Data pins: 51-44

Case9.pic24ep512ug810

- 100-Pin TQFP



- 121-Pin TFBGA

	1	2	3	4	5	6	7	8	9	10	11
A	○ RE4	○ RE3	● RG13	○ RE0	● RG0	● RF1	○ VDD	● NC	● RD12	● RD2	● RD1
B	● NC	● RG15	○ RE2	○ RE1	○ RA7	● RF0	○ VCAP	● RD5	● RD3	○ VSS	○ RC14
C	○ RE6	○ VDD	● RG12	● RG14	○ RA6	● NC	○ RD7	● RD4	● NC	○ RC13	● RD11
D	○ RC1	○ RE7	○ RE5	● NC	● NC	● NC	○ RD6	● RD13	● RD0	● NC	● RD10
E	○ RC4	○ RC3	○ RG6	○ RC2	● NC	● RG1	● NC	● RA15	● RD8	● RD9	● RA14
F	● $\overline{\text{MCLR}}$	○ RG8	○ RG9	○ RG7	○ VSS	● NC	● NC	○ VDD	○ RC12	○ VSS	○ RC15
G	○ RE8	○ RE9	● RA0	● NC	○ VDD	○ VSS	○ VSS	● NC	● RA5	● RA3	● RA4
H	○ RB5	○ RB4	● NC	● NC	● NC	○ VDD	● NC	● VBUS	○ VUSB3V3	○ RG2	● RA2
J	○ RB3	○ RB2	○ RB7	○ AVDD	○ RB11	● RA1	○ RB12	● NC	● NC	● RF8	○ RG3
K	○ RB1	○ RB0	○ RA10	○ RB8	● NC	● RF12	○ RB14	○ VDD	● RD15	● RF3	● RF2
L	○ RB6	○ RA9	○ AVSS	○ RB9	○ RB10	● RF13	○ RB13	○ RB15	● RD14	● RF4	● RF5

Case9.pic24ep512ug810

- Processor pins
  - Power: Vdd, AVdd
  - Ground: Vss, AVss
  - Clock: 63,64, 73,74
  - Reset(MCLR): 13
  - Interrupt pins:
  - IO pins:
  - Read pin:
  - Write pin:
  - Address pins:
  - Data pins:

Reset

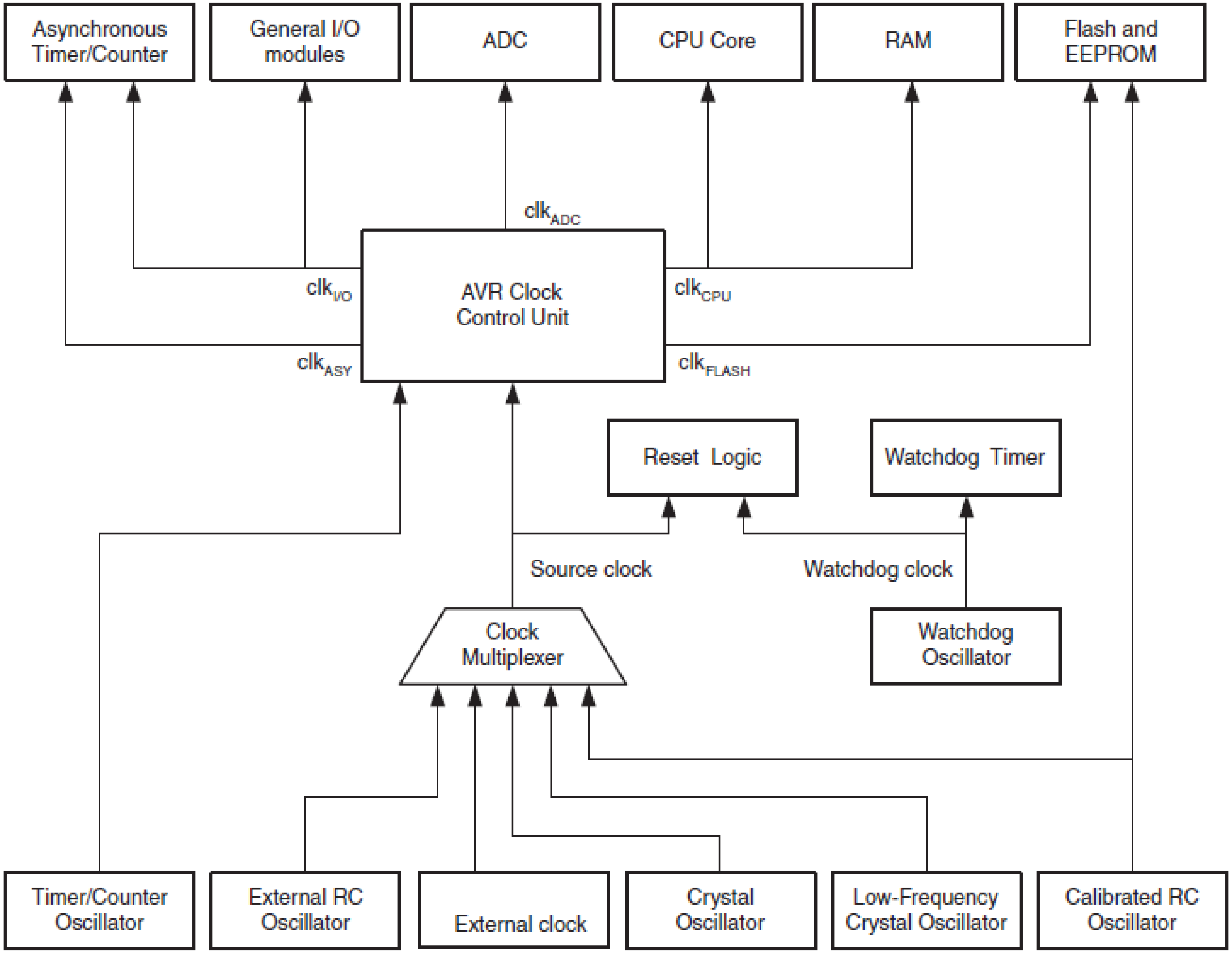
- RESET is an interrupt with the highest priority and at the lowest addresses in the program memory.
- The Reset vector can also be moved to the start of the boot Flash section for self-programming.
- Assembly
  - interrupt vector table (atmega128)
  - reset assembly instruction (pic24ep)
- C (case 11, both)

CPU Clock

- Clock sources
  - External clock
  - Internal clocks
- Clock generation
  - Multiplication
  - Divide
- Clock selection and configuration procedure
  - Step 1: set clock configuration registers
    - Done with loading/flashing (not running any code)
  - Step 2: run clock initialization routines
    - First routine to run after bootloading

Clock Selection (Atmega128)

- Page 36 in datasheet



Clock Selection (Atmega128)

- Atmega128:
  - Clock source fuses: CKOPT, CKSEL
  - Clock startup time fuses: SUT
  - Only programmed via a programmer.
  - Cannot be changed at run time.

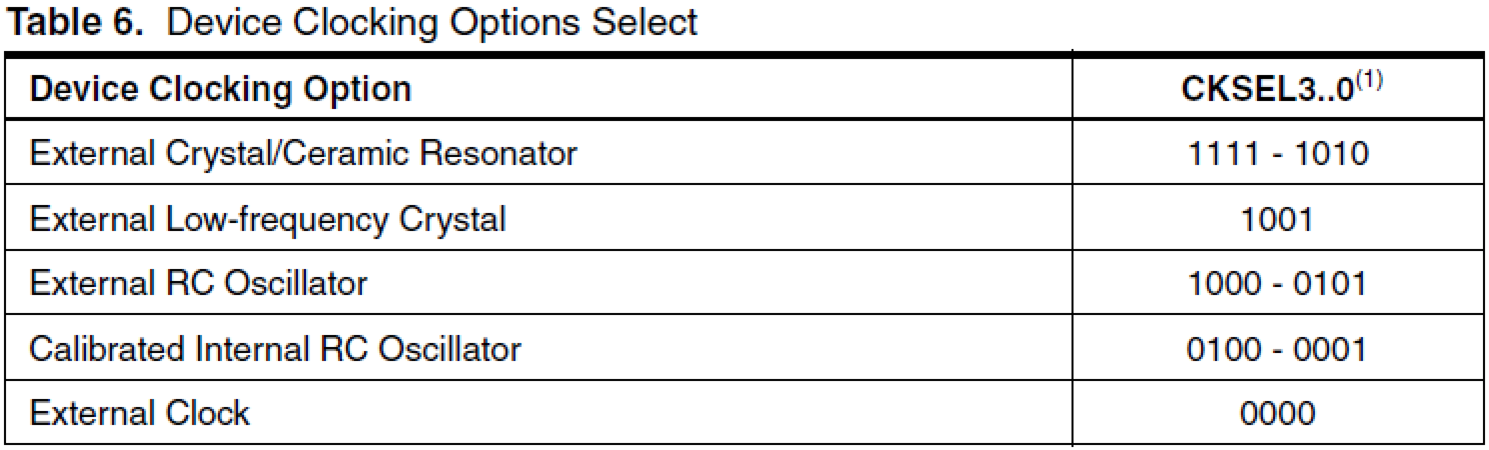


Table 6. Device Clocking Options Select

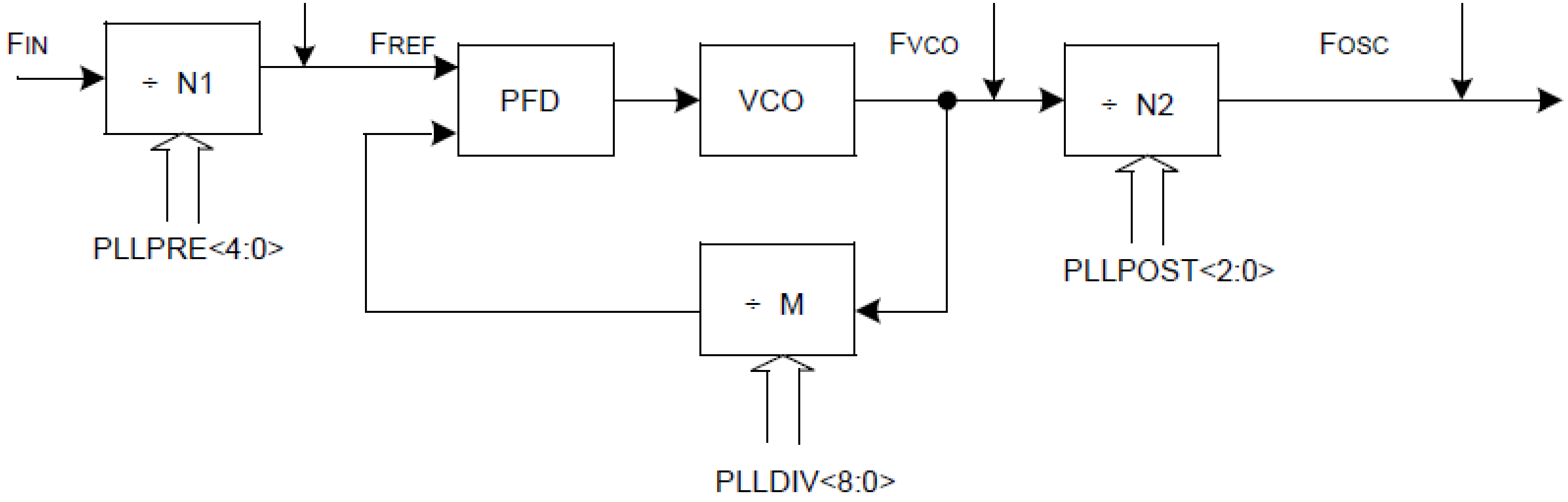
Device Clocking Option	**CKSEL3..0**[1]
External Crystal/Ceramic Resonator	1111 - 1010
External Low-frequency Crystal	1001
External RC Oscillator	1000 - 0101
Calibrated Internal RC Oscillator	0100 - 0001
External Clock	0000

Clock Selection Examples

- External Crystal Oscillator (page 38, datasheet)
  - Operating modes: CKOPT, CKSEL3..1
  - Startup times: CKSEL0, SUT1..0
  - ToDo: 8MHz, crystal oscillator, fast rising power
  - Table 8: CKOPT=1, CKSEL3..1=111
  - Table 9: CKSEL0=1, SUT1..0=10
- Internal RC Oscillator (page 41, datesheet)
  - CKOPT unprogrammed
  - Operating modes: CKSEL3..0
  - Startup times: SUT1..0
  - ToDO: 8MHz, fast rising power
  - Table 13: CKSEL3..0=0100
  - Table 14: SUT1..0=01
- We set clock in simulator

Clock Selection (Case10.pic24ep)

- Section 9 in datasheet: feature summary
  - Comprehensive reference is at Section 7 “Oscillator” (DS70580)
  - Figure 9-1 on page 177 of datasheet
    - Fcy = Fosc / 2
  - Figure 9-2 on page 178 of datasheet
    - Explain Equation 9-2



Clock Selection (Case10.pic24ep)

- Configuration bits in ConfigurationBits.h
  - Determine clock sources
  - Table 9-1 on page 179 of datasheet

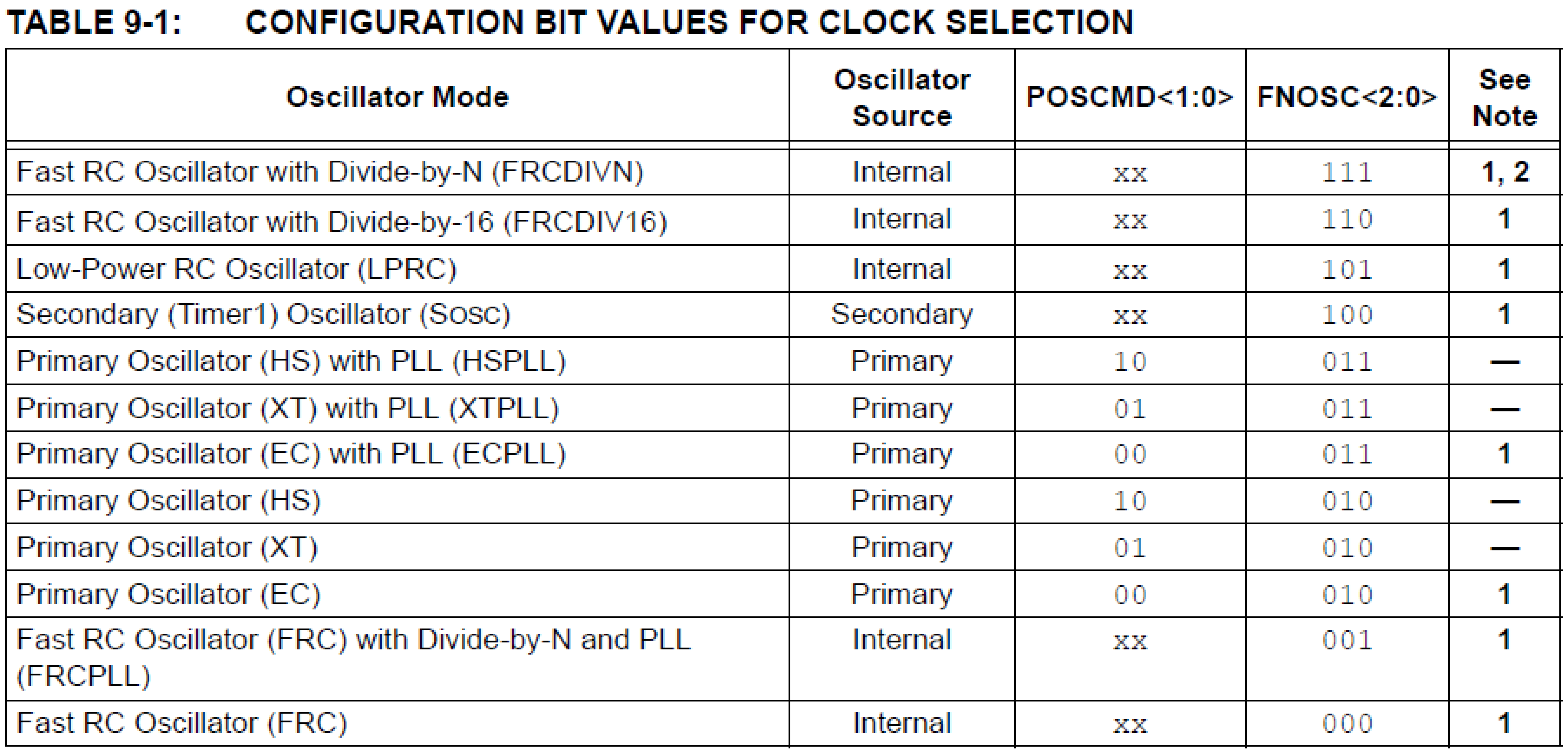


TABLE 9-1: CONFIGURATION BIT VALUES FOR CLOCK SELECTION

Oscillator Mode	Oscillator Source	POSCMD<1:0>	FNOSC<2:0>	See Note
Fast RC Oscillator with Divide-by-N (FRCDIVN)	Internal	xx	111	**1, 2**
Fast RC Oscillator with Divide-by-16 (FRCDIV16)	Internal	xx	110	**1**
Low-Power RC Oscillator (LPRC)	Internal	xx	101	**1**
Secondary (Timer1) Oscillator (SOSC)	Secondary	xx	100	**1**
Primary Oscillator (HS) with PLL (HSPLL)	Primary	10	011	—
Primary Oscillator (XT) with PLL (XTPLL)	Primary	01	011	—
Primary Oscillator (EC) with PLL (ECPLL)	Primary	00	011	**1**
Primary Oscillator (HS)	Primary	10	010	—
Primary Oscillator (XT)	Primary	01	010	—
Primary Oscillator (EC)	Primary	00	010	**1**
Fast RC Oscillator (FRC) with Divide-by-N and PLL (FRCPLL)	Internal	xx	001	**1**
Fast RC Oscillator (FRC)	Internal	xx	000	**1**

Clock Selection (Case10.pic24ep)

- Clock frequency calculation
  - Equation 9-2 to calculate Fosc

$$F_{OSC} = F_{IN} \times \left(\frac{M}{N1 \times N2}\right) = F_{IN} \times \left(\frac{(PLLDIV+2)}{(PLLPRE+2) \times 2(PLLPOST+1)}\right)$$

  - Initsystem

```
void initializeSystem() {
    // Configure the device PLL to obtain 60 MIPS operation. The crystal
    // frequency is 8MHz. Divide 8MHz by 2, multiply by 60 and divide by
    // 2. This results in Fosc of 120MHz. The CPU clock frequency is
    // Fcy = Fosc/2 = 60MHz. Wait for the Primary PLL to lock
    PLLFBD = 58;            /* M = 60 */
    CLKDIVbits.PLLPRE = 0;  /* N1 = 2 */
    CLKDIVbits.PLLPOST = 0; /* N2 = 2 */
    /*  Initiate Clock Switch to Primary
     *  Oscillator with PLL (NOSC= 0x3)*/
    __builtin_write_OSCCONH(0x03);
    __builtin_write_OSCCONL(0x01);
    while (OSCCONbits.COSC != 0x3);
    // Wait for PLL to lock
    while (OSCCONbits.LOCK != 1);
}
```

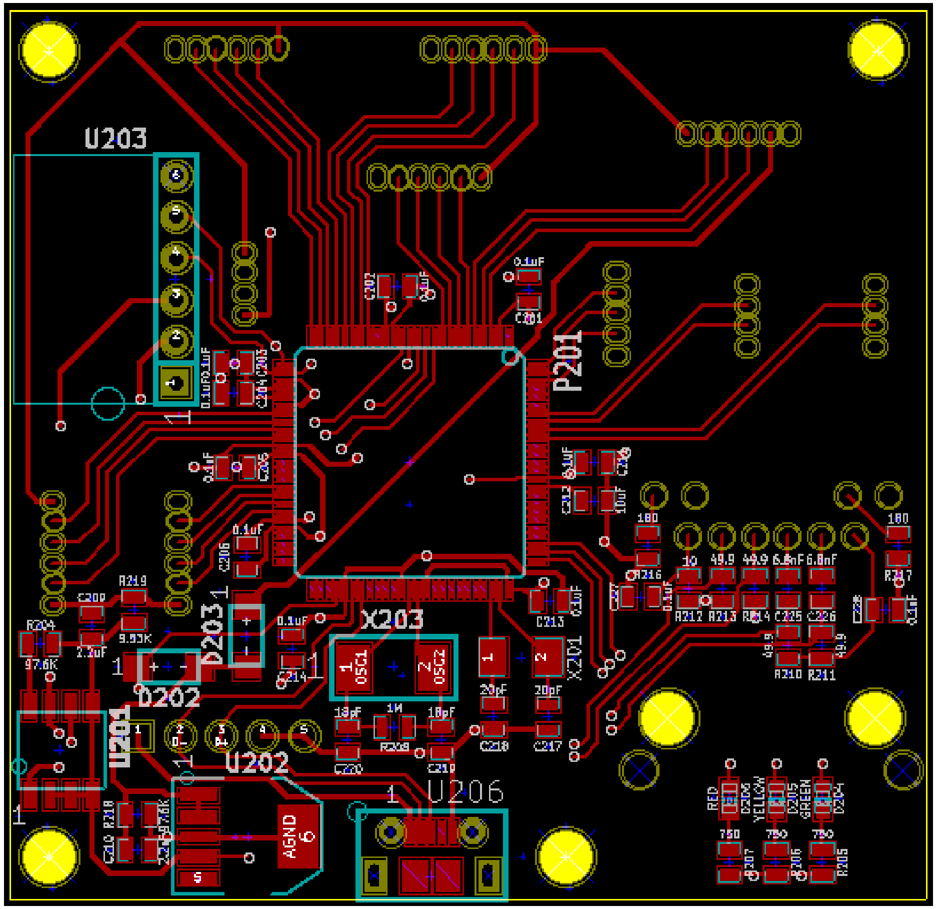
Clock Setting in Simulator

- We need a clock with right frequency in simulator too to observe timing.
- Atmel Studio
  - Debug/Processor View/Frequency
- MPlab X
  - Properties/Simulator

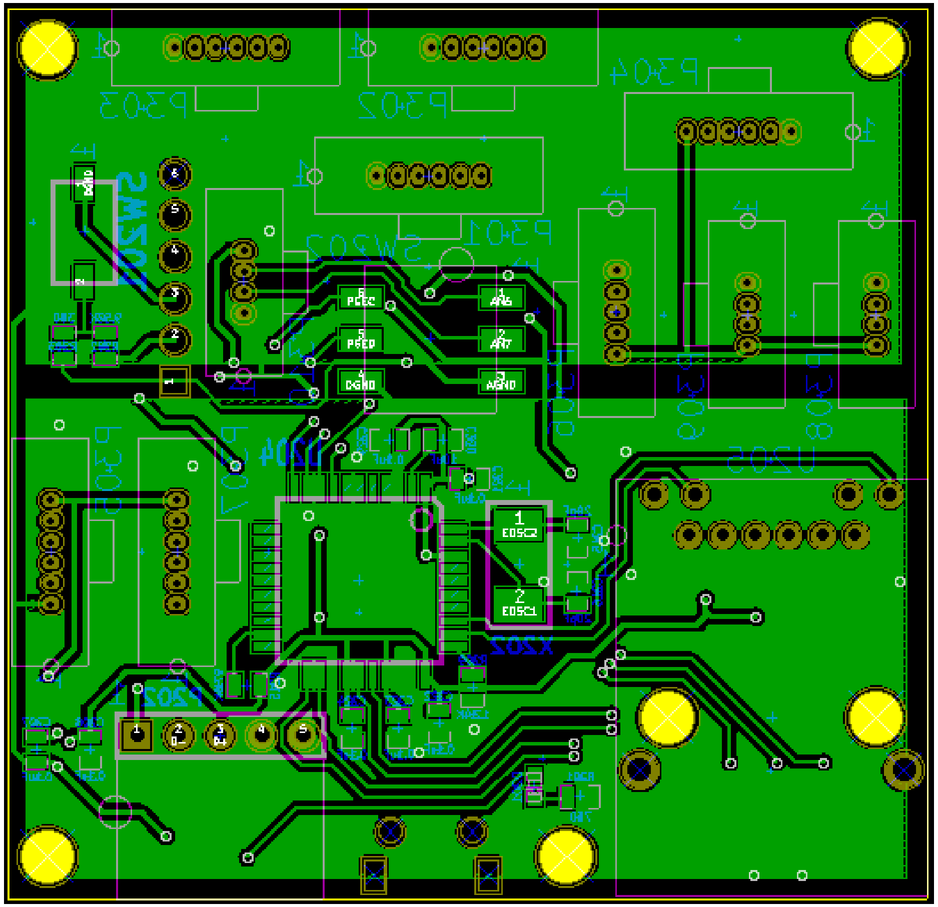
Hardware Team, Step 3

- Printed Circuit Board (PCB) Manufacturing
  - Layout (half month)
  - Fabrication (one week)
    - Lead time: 1 week
  - Assemble (One week or a few months)
    - Bill of Material (BOM)
    - Lead time
      - Parts: 1 week to a few months
      - Assemble: 1 week
  - Shipping (one week)

PCB Layout (Case 8)

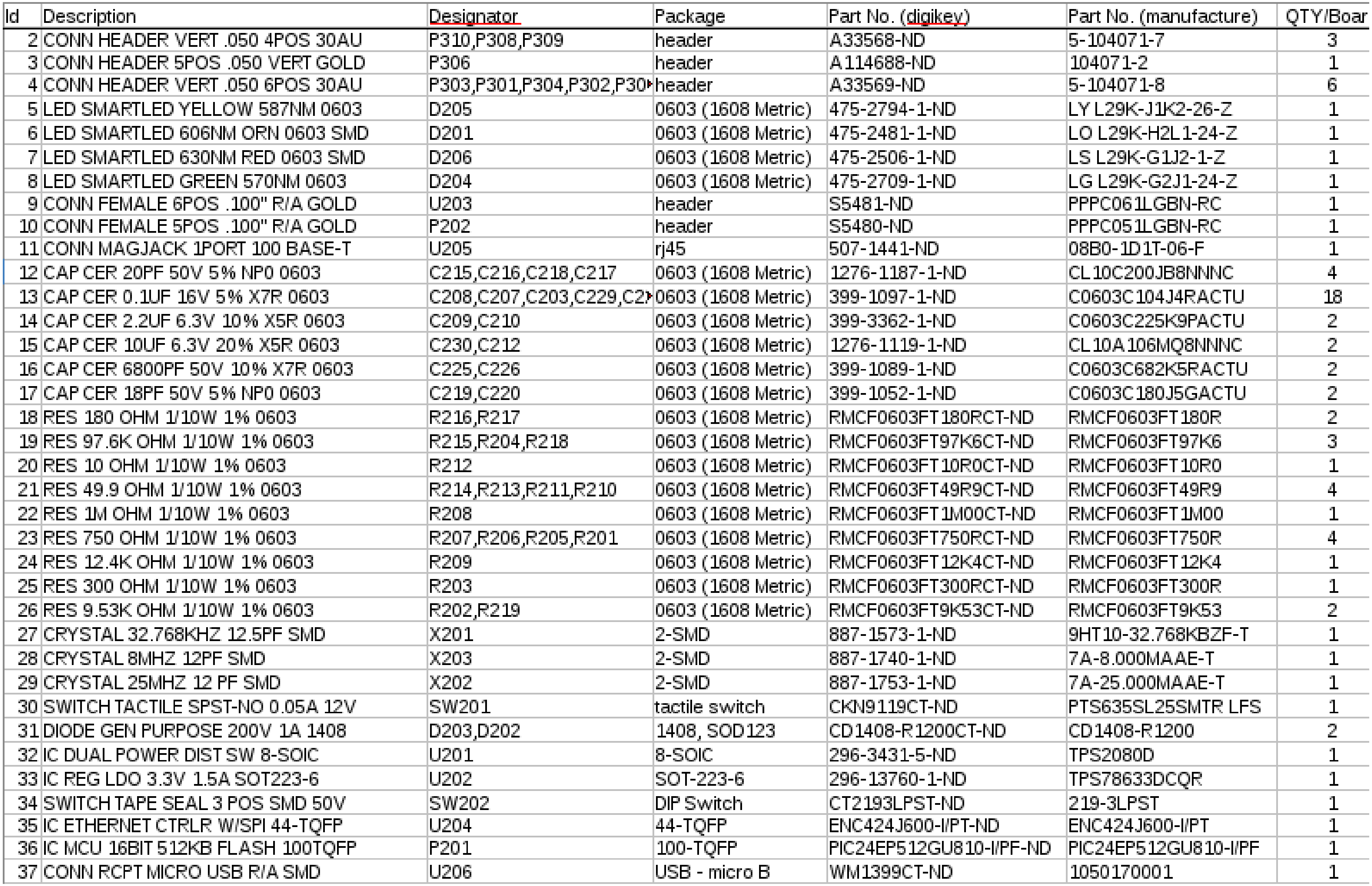


Front



Back

BOM



Id	Description	Designator	Package	Part No. (digikey)	Part No. (manufacture)	QTY/Boar
2	CONN HEADER VERT .050 4POS 30AU	P310,P308,P309	header	A33568-ND	5-104071-7	3
3	CONN HEADER 5POS .050 VERT GOLD	P306	header	A114688-ND	104071-2	1
4	CONN HEADER VERT .050 6POS 30AU	P303,P301,P304,P302,P30	header	A33569-ND	5-104071-8	6
5	LED SMARTLED YELLOW 587NM 0603	D205	0603 (1608 Metric)	475-2794-1-ND	LY L29K-J1K2-26-Z	1
6	LED SMARTLED 606NM ORN 0603 SMD	D201	0603 (1608 Metric)	475-2481-1-ND	LO L29K-H2L1-24-Z	1
7	LED SMARTLED 630NM RED 0603 SMD	D206	0603 (1608 Metric)	475-2506-1-ND	LS L29K-G1J2-1-Z	1
8	LED SMARTLED GREEN 570NM 0603	D204	0603 (1608 Metric)	475-2709-1-ND	LG L29K-G2J1-24-Z	1
9	CONN FEMALE 6POS .100" R/A GOLD	U203	header	S5481-ND	PPPC061LGBN-RC	1
10	CONN FEMALE 5POS .100" R/A GOLD	P202	header	S5480-ND	PPPC051LGBN-RC	1
11	CONN MAGJACK 1PORT 100 BASE-T	U205	rj45	507-1441-ND	08B0-1D1T-06-F	1
12	CAP CER 20PF 50V 5% NP0 0603	C215,C216,C218,C217	0603 (1608 Metric)	1276-1187-1-ND	CL10C200JB8NNNC	4
13	CAP CER 0.1UF 16V 5% X7R 0603	C208,C207,C203,C229,C2	0603 (1608 Metric)	399-1097-1-ND	C0603C104J4RACTU	18
14	CAP CER 2.2UF 6.3V 10% X5R 0603	C209,C210	0603 (1608 Metric)	399-3362-1-ND	C0603C225K9PACTU	2
15	CAP CER 10UF 6.3V 20% X5R 0603	C230,C212	0603 (1608 Metric)	1276-1119-1-ND	CL10A106MQ8NNNC	2
16	CAP CER 6800PF 50V 10% X7R 0603	C225,C226	0603 (1608 Metric)	399-1089-1-ND	C0603C682K5RACTU	2
17	CAP CER 18PF 50V 5% NP0 0603	C219,C220	0603 (1608 Metric)	399-1052-1-ND	C0603C180J5GACTU	2
18	RES 180 OHM 1/10W 1% 0603	R216,R217	0603 (1608 Metric)	RMCF0603FT180RCT-ND	RMCF0603FT180R	2
19	RES 97.6K OHM 1/10W 1% 0603	R215,R204,R218	0603 (1608 Metric)	RMCF0603FT97K6CT-ND	RMCF0603FT97K6	3
20	RES 10 OHM 1/10W 1% 0603	R212	0603 (1608 Metric)	RMCF0603FT10R0CT-ND	RMCF0603FT10R0	1
21	RES 49.9 OHM 1/10W 1% 0603	R214,R213,R211,R210	0603 (1608 Metric)	RMCF0603FT49R9CT-ND	RMCF0603FT49R9	4
22	RES 1M OHM 1/10W 1% 0603	R208	0603 (1608 Metric)	RMCF0603FT1M00CT-ND	RMCF0603FT1M00	1
23	RES 750 OHM 1/10W 1% 0603	R207,R206,R205,R201	0603 (1608 Metric)	RMCF0603FT750RCT-ND	RMCF0603FT750R	4
24	RES 12.4K OHM 1/10W 1% 0603	R209	0603 (1608 Metric)	RMCF0603FT12K4CT-ND	RMCF0603FT12K4	1
25	RES 300 OHM 1/10W 1% 0603	R203	0603 (1608 Metric)	RMCF0603FT300RCT-ND	RMCF0603FT300R	1
26	RES 9.53K OHM 1/10W 1% 0603	R202,R219	0603 (1608 Metric)	RMCF0603FT9K53CT-ND	RMCF0603FT9K53	2
27	CRYSTAL 32.768KHZ 12.5PF SMD	X201	2-SMD	887-1573-1-ND	9HT10-32.768KBZF-T	1
28	CRYSTAL 8MHZ 12PF SMD	X203	2-SMD	887-1740-1-ND	7A-8.000MAAE-T	1
29	CRYSTAL 25MHZ 12 PF SMD	X202	2-SMD	887-1753-1-ND	7A-25.000MAAE-T	1
30	SWITCH TACTILE SPST-NO 0.05A 12V	SW201	tactile switch	CKN9119CT-ND	PTS635SL25SMTR LFS	1
31	DIODE GEN PURPOSE 200V 1A 1408	D203,D202	1408, SOD123	CD1408-R1200CT-ND	CD1408-R1200	2
32	IC DUAL POWER DIST SW 8-SOIC	U201	8-SOIC	296-3431-5-ND	TPS2080D	1
33	IC REG LDO 3.3V 1.5A SOT223-6	U202	SOT-223-6	296-13760-1-ND	TPS78633DCQR	1
34	SWITCH TAPE SEAL 3 POS SMD 50V	SW202	DIP Switch	CT2193LPST-ND	219-3LPST	1
35	IC ETHERNET CTRLR W/SPI 44-TQFP	U204	44-TQFP	ENC424J600-I/PT-ND	ENC424J600-I/PT	1
36	IC MCU 16BIT 512KB FLASH 100TQFP	P201	100-TQFP	PIC24EP512GU810-I/PF-ND	PIC24EP512GU810-I/PF	1
37	CONN RCPT MICRO USB R/A SMD	U206	USB - micro B	WM1399CT-ND	1050170001	1

Software Team, Step 3

- Read document of development kits
  - Most likely, the programming language is C
  - Compiler
    - Avr-gcc: Extension to gcc
      - Libraries
    - XC16: Extension to standard C
      - Keywords
        - Variable attributes
        - Function specifiers and attributes
      - Expression
        - Constants
      - Implementation-defined behavior
        - Standard C does not specify the implementation.

Software Team, Step 3

- Read document of development kits
  - Library
    - Standard C library
    - Processor library
  - Development kits
    - Schematic
    - Layout
    - Features
      - Power
      - USB
      - LED
      - Oscillator

Libraries

- Example: Avr-gcc
  - C libs: stdxxx.h, string.h, math.h
  - Avr libs:
    - eeprom.h
    - interrupt.h
    - io.h
    - pgmspace.h
    - power.h
    - sleep.h
    - delay.h
    - crc16.h
    - atomic.h
    - sfr_defs.h

Libraries

- Example: xc16-gcc
- Standard C functions
  - Functions: stdio.h, stdlib.h, math.h, assert.h, string.h, time.h
  - Types: stdbool.h, stdint.h
- Peripheral Libraries
  - Timer, I/O, UART, SPI, I2C, ADC, DMA, Reset, CRC, RTCC,
  - http://www.microchip.com/SWLibraryWeb/product.aspx?product=PIC24%20MCU%20dsPIC%20Peripheral%20Lib
- Application libraries
  - USB, Graphics, Memory Disk Drive, TCP/IP Stack, mTouchCap, Smart Card, MiWi
  - http://www.microchip.com/mplab/microchip-libraries-for-applications

Software Team, Step 4

- Board Bring-up and Testing
  - Work with HW team
    - Making a board is not a process with a lot of iterations.
  - Make each component individually testable
  - Start testing on the lowest level parts.
    - Programming interface
    - Power and reset
    - Clock (Oscillator)
    - IOs (LED)
  - Move on to test complex parts.
    - On-chip components
      - DMA, ADC, DAC, SPI, UART, FLASH
    - Peripheral components or chips
      - USB, Network controller,

Software Team, Step 4

- Be safe and do not damage board
- Tools for software diagnosis with HW team:
  - Digital Multimeter (DMM)
  - Oscilloscopes
  - Logic Analyzers
- Testing Hardware
  - Write and read hardware components.
  - Verify that hardware components can work.
  - Two types of tests
    - Unit test
    - Power-on self-test