



Chapter 2: Introduction to Microcontrollers

Australia's Global University

Faculty of Engineering

School of Electrical Engineering and Telecommunications

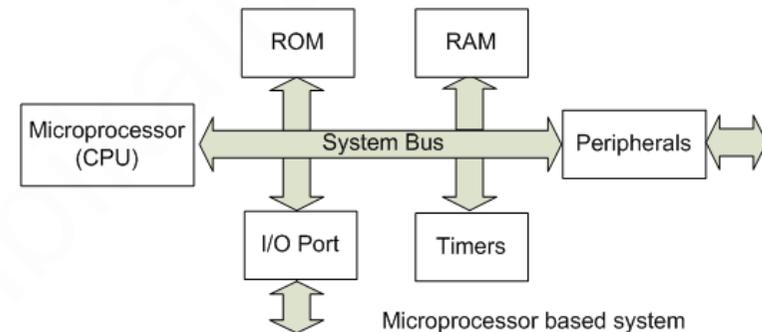
Professor Eliathamby Ambikairajah

Head of School of Electrical Engineering and
Telecommunications, UNSW, Sydney

Microcontroller

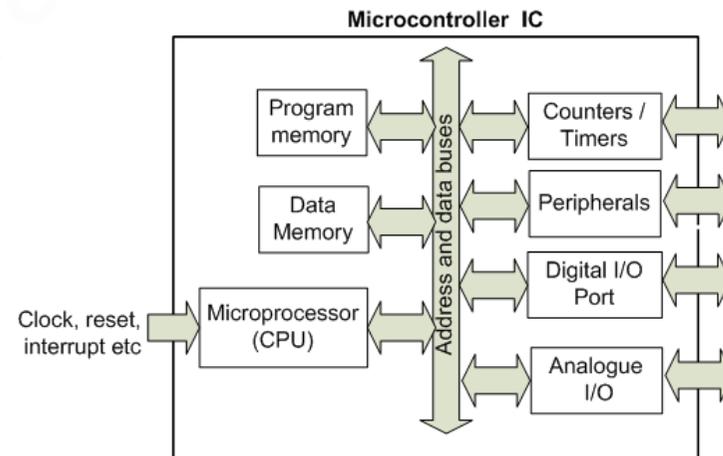
❖ **Microprocessor** is a CPU (8-bit, 16-bit, or 32-bit) onto a single chip, but don't have RAM, ROM and other peripherals on the chip.

- Microprocessor cannot work on its own unless RAM, ROM, peripherals, Input/Output ports etc. are connected to the microprocessor via its address, data and control buses.
- Applications of microprocessors include Desktop PC's, Laptops, tablets etc.



❖ **Microcontroller** is a small dedicated computer on a single chip containing a microprocessor (CPU), memory, and programmable input/output peripherals.

- Most modern electronic devices such as TVs, VCRs, microwaves etc contain microcontrollers.



- Most microcontrollers operate below 40 MHz
- Microprocessor based system operates above 1GHz

PIC Microcontrollers (**P**rogrammable **I**nterface **C**ontrollers)

- **PIC microcontrollers** are designed by Microchip Technology
 - ✓ **8-bit PIC MCU:** PIC10, PIC12, **PIC16**, PIC18
 - ✓ **16-bit PIC MCU:** PIC24F, PIC24H, PIC24E
 - ✓ **16-bit dsPIC DSC:** dsPIC30F, dsPIC33F, dsPIC33E
 - ✓ **32-bit PIC MCU:** PIC32

Note: MCU – microcontrollers

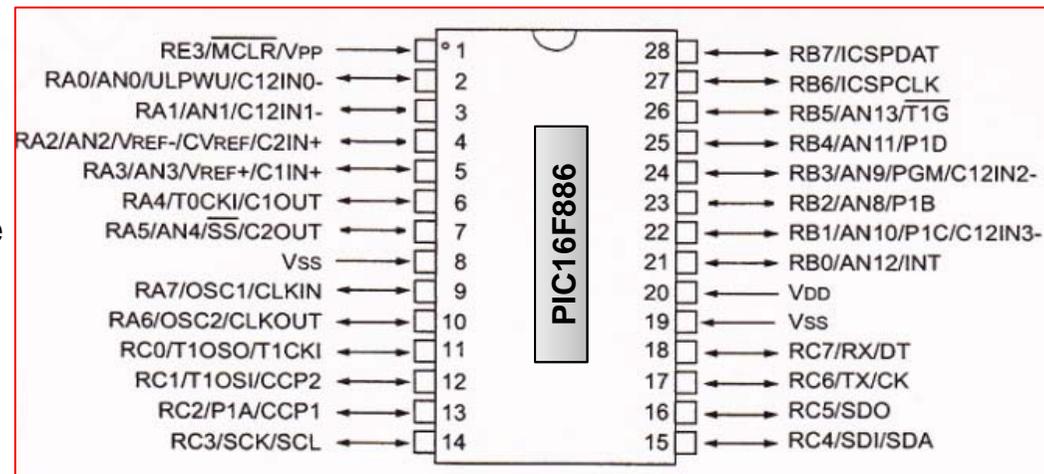
DSC – Digital Signal Controllers

In this course, we will look at the 8-bit **PIC16F886** microcontroller in detail

PIC16F886 Micro Controller Features

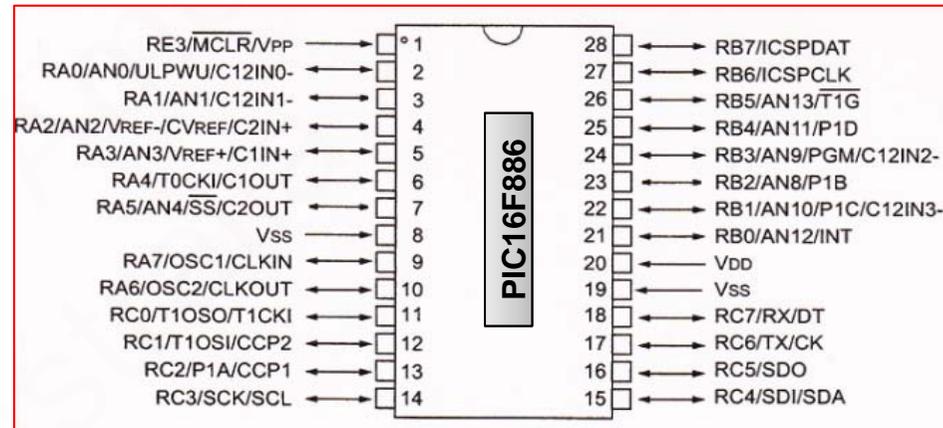
- ✓ 28-pin low power CMOS FLASH-based 8-bit microcontroller
- ✓ Power supply voltage 2.0-5.5V [Consumption: 220uA (2.0V, 4MHz), 50nA (stand-by mode)]
- ✓ 35 single word instructions (RISC core) (All single-cycle instructions except branches)
- ✓ 256 bytes of EEPROM data memory (FLASH) (Data can be written more than 1,000,000 times)
- ✓ 8192 word program memory (FLASH) (Chip can be reprogrammed up to 100,000 times)
- ✓ 368 bytes data memory (RAM)
- ✓ Eight level hardware stack
- ✓ 24 input/output pins.
- ✓ 11 channels of 10-bit Analogue-to-Digital (A/D) converter
- ✓ 1 Enhanced Capture/Compare/PWM: 10 bit with up to 4 output channels
- ✓ Enhanced USART: RS-485, RS-232 and Lin 2.0 support
- ✓ 2 analogue comparators
- ✓ Clock speed: DC to 20 MHz
- ✓ Precision Internal Oscillator
 - Software selectable frequency range
31 kHz to 8 MHz

Pin diagram for PIC16F886



PINOUT DESCRIPTION

Pin Number	Function	Description	Input/output Type
1	RE3	General Purpose input Port E	TTL / -
	\overline{MCLR}	Low logic level resets microcontroller (Reset pin)	ST / -
	Vpp	Programming voltage	HV / -
2	RA0	General purpose I/O Port A	TTL / CMOS
	AN0	A/D channel 0 input	AN / -
	ULPWU	Ultra low-power wake-up-input	AN / -
	C12N0-	Comparator C1 or C2 negative input	AN / -
3	RA1	General Purpose I/O Port A	TTL / CMOS
	AN1	A/D channel 1 input	AN / -
	C12IN0-	Comparator C1 or C2 negative input	AN / -
4	RA2	General Purpose I/O Port A	TTL / CMOS
	AN2	A/D channel 2 input	AN / -
	Vref-	A/D Negative Voltage Reference input	AN / -
	CVref	Comparator Voltage Reference output	- / AN
	C2IN+	Comparator C2 positive input	AN / -
5	RA3	General Purpose I/O Port A	TTL / CMOS
	AN3	A/D channel 3 input	AN / -
	Vref+	A/D Positive Voltage Reference input	AN / -
	C1IN+	Comparator C1 positive input	AN / -
6	RA4	General Purpose I/O Port A	TTL / CMOS
	T0CKI	Timer 0 clock input	ST / -
	C1OUT	Comparator C1 output	- / CMOS
7	RA5	General Purpose I/O Port A	TTL / CMOS
	AN4	A/D channel 4 input	AN / -
	\overline{SS}	Slave Select input. i.e. Serial Peripheral interface (SPI) input	ST / -
8	C2OUT	Comparator C2 output	- / CMOS
	Vss	Ground reference	- / -

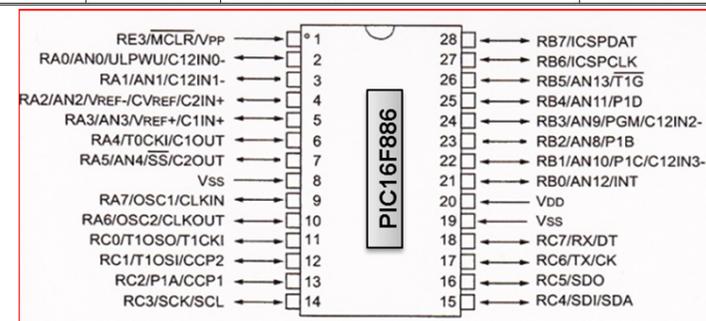


AN = Analogue input or output; TTL = TTL compatible input;
 CMOS = CMOS compatible input or output; HV = High Voltage ;
 XTAL = Crystal; ST = Schmitt Trigger input with CMOS levels

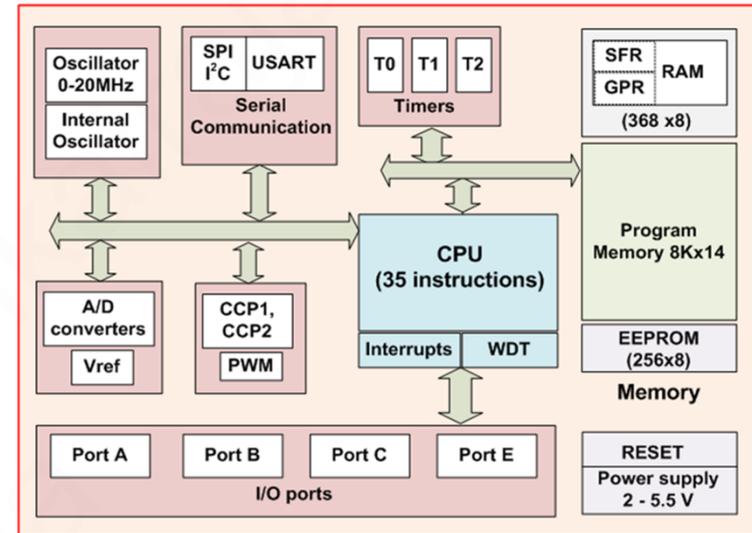
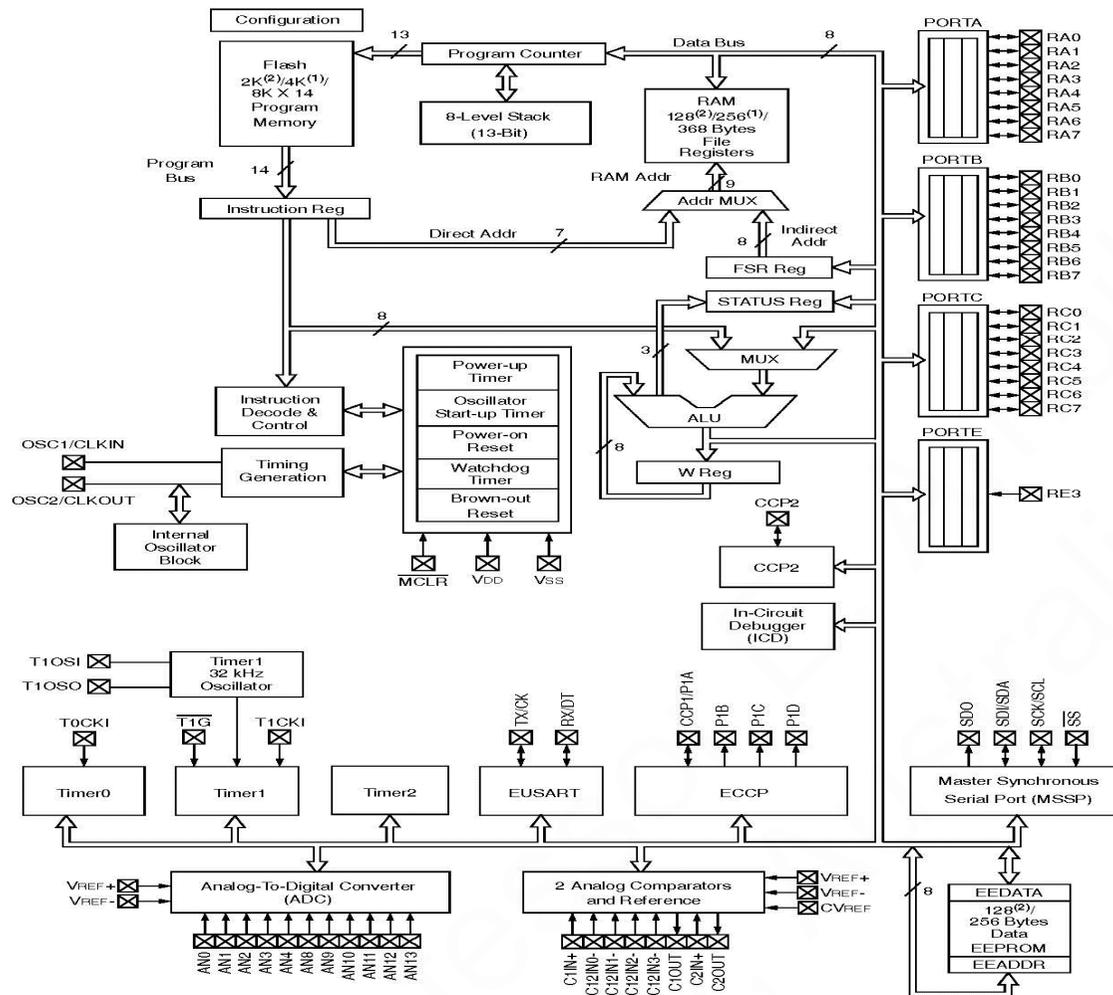
PINOUT DESCRIPTION

Pin Number	Function	Description	Input/output Type
9	RA7	General purpose I/O Port A	TTL / CMOS
	OSC1	Crystal / Resonator	XTAL / -
	CLKIN	External clock input/ RC oscillator connection	ST / -
10	RA6	General Purpose I/O Port A	TTL / CMOS
	OSC2	Master Clear with internal pull-up	- / XTAL
	CLKOUT	Fosc/4 output	- / CMOS
11	RC0	General Purpose I/O Port C	ST / CMOS
	T1OSO	Timer 1 oscillator output	- / CMOS
	CCP2	Timer 1 clock input	ST / -
12	RC1	General Purpose I/O Port C	ST / CMOS
	T1OSI	Timer 1 oscillator input	ST / -
	CCP2	Capture/Compare/PWM2	ST / CMOS
13	RC2	General Purpose I/O Port C	ST / CMOS
	P1A	PWM output	- / CMOS
	CCP1	Capture/Compare/PWM1	ST / CMOS
14	RC3	General Purpose I/O Port C	ST / CMOS
	SCK	SPI clock (MSSP module clock)	ST / CMOS
	SCL	I ² C clock (MSSP module clock)	ST / OD
15	RC4	General Purpose I/O Port C	ST / CMOS
	SDI	SPI data input (MSSP module)	ST / -
	SDA	I ² C data input/output (MSSP)	ST / OD
16	RC5	General Purpose I/O Port C	ST / CMOS
	SDO	SPI data output (MSSP module)	- / CMOS
17	RC6	General Purpose I/O Port C	ST / CMOS
	TX	USART asynchronous transmit	- / CMOS
18	CK	USART synchronous clock	ST / CMOS
	RC7	General Purpose I/O Port C	ST / CMOS
19	RX	USART asynchronous input	ST / -
	DT	USART synchronous data	ST / CMOS
20	Vss	Ground reference	- / -
20	VDD	Positive supply	Power / -

Pin Number	Function	Description	Input/output Type
21	RB0	General purpose I/O Port B	TTL / CMOS
	AN12	A/D channel 12	AN / -
	INT	External interrupt	ST / -
22	RB1	General Purpose I/O Port B	TTL / CMOS
	AN10	A/D channel 10	AN / -
	P1C	PWM output	- / CMOS
23	RB2	General Purpose I/O Port B	TTL / CMOS
	AN8	A/D channel 8	AN / -
	P1B	PWN output	- / CMOS
24	RB3	General Purpose I/O Port B	TTL / CMOS
	AN9	A/D channel 19	AN / -
	PGM	Low-voltage ICSP programming enable pin	ST / -
25	RB4	General Purpose I/O Port B	TTL / CMOS
	AN11	A/D channel 11	AN / -
	P1D	PWN output	- / CMOS
26	RB5	General Purpose I/O Port B	TTL / CMOS
	AN13	A/D channel 13	AN / -
	T1G	Timer 1 gate input	ST / -
27	RB6	General Purpose I/O Port B	TTL / CMOS
	ICSPCLK	Serial programming clock	ST / -
28	RB7	General Purpose I/O Port B	TTL / CMOS
	ICSPDAT	ICSP Data I/O	ST / CMOS



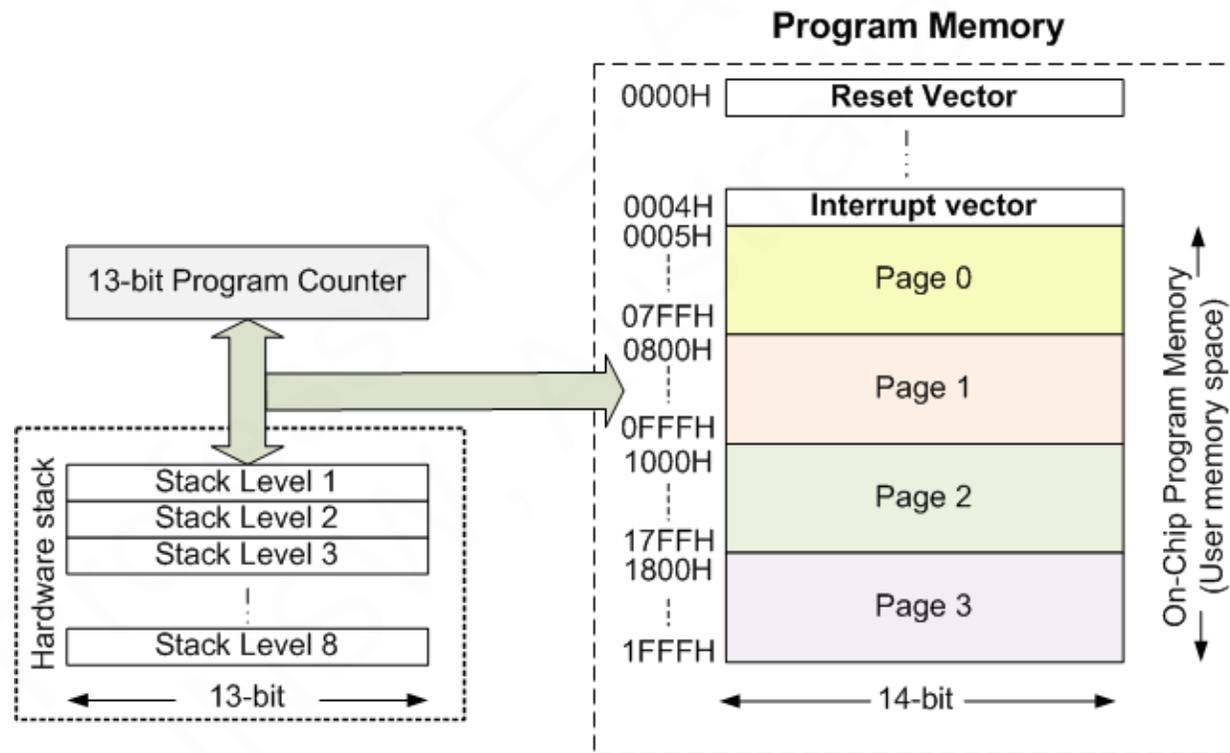
PIC16F886 Block Diagram



- SFR: Special Function Registers (Data Memory)
- GPR : General Purpose Register (Data Memory)
- USART: Universal Synchronous Asynchronous Receiver Transmitter
- SPI: Serial Peripheral Interface (serial communication)
- I²C : Inter-Integrated circuit
- A/D: Analogue to digital converter (10 bit); Also contain 14 separate analogue inputs
- Analogue comparators: two analogue comparators available
- CCP: Capture/Compare/PWM (allows the user to time and control different events)
- PWM: Pulse Width Modulation (PWM) can generate signals of varying frequency and duty cycle
- I/O ports: Input/Output ports (used for connecting with peripherals)
- Timers (T0,T1,T2) : completely independent timers/counters

Program Memory Organisation

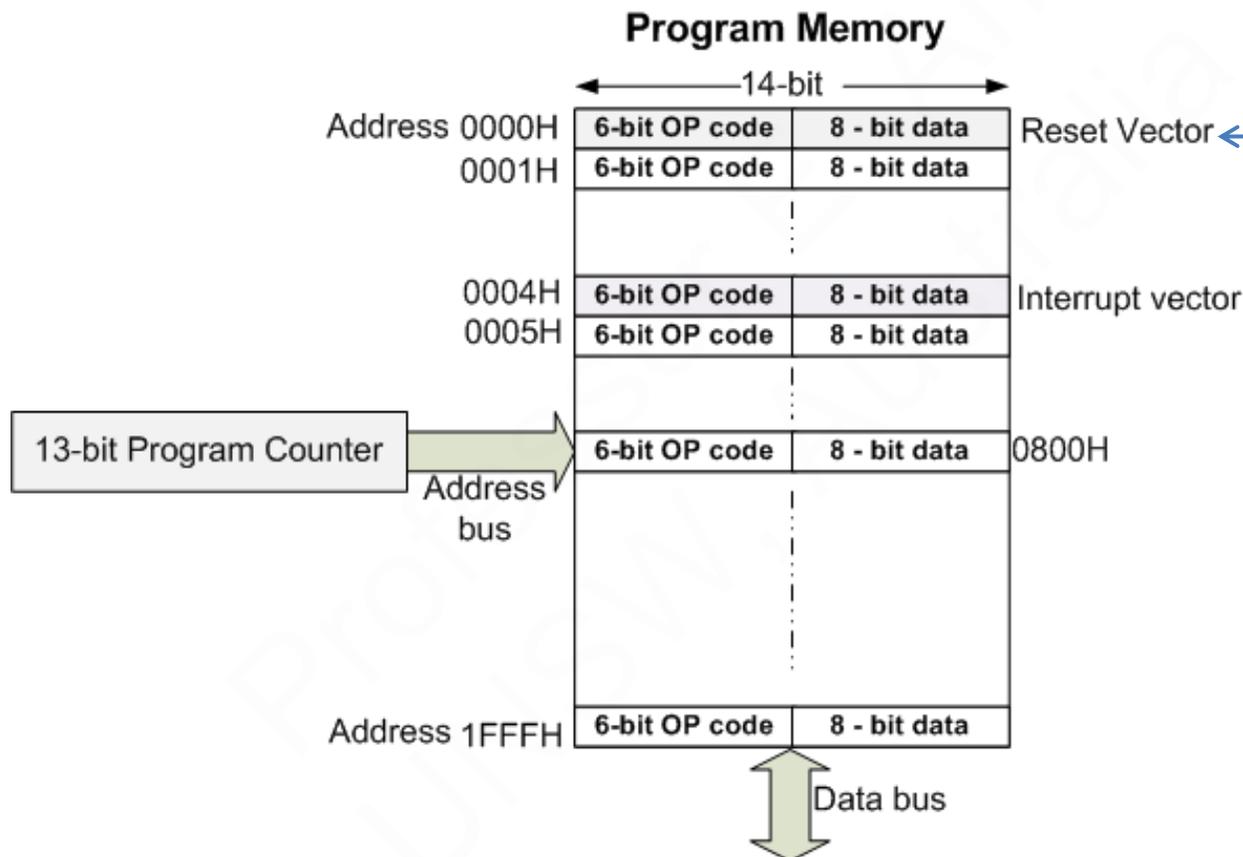
- PIC16F886 microcontroller program memory map is shown below and it shows the following:
 - The 13 - bit Program Counter (PC)
 - The 8 - level Stack (8 x 13 bits)
 - The Program memory (8K x 14 bits) [It is loaded with the program code that the microcontroller executes]



Program memory size: 8K x 14 bits

The Program Counter

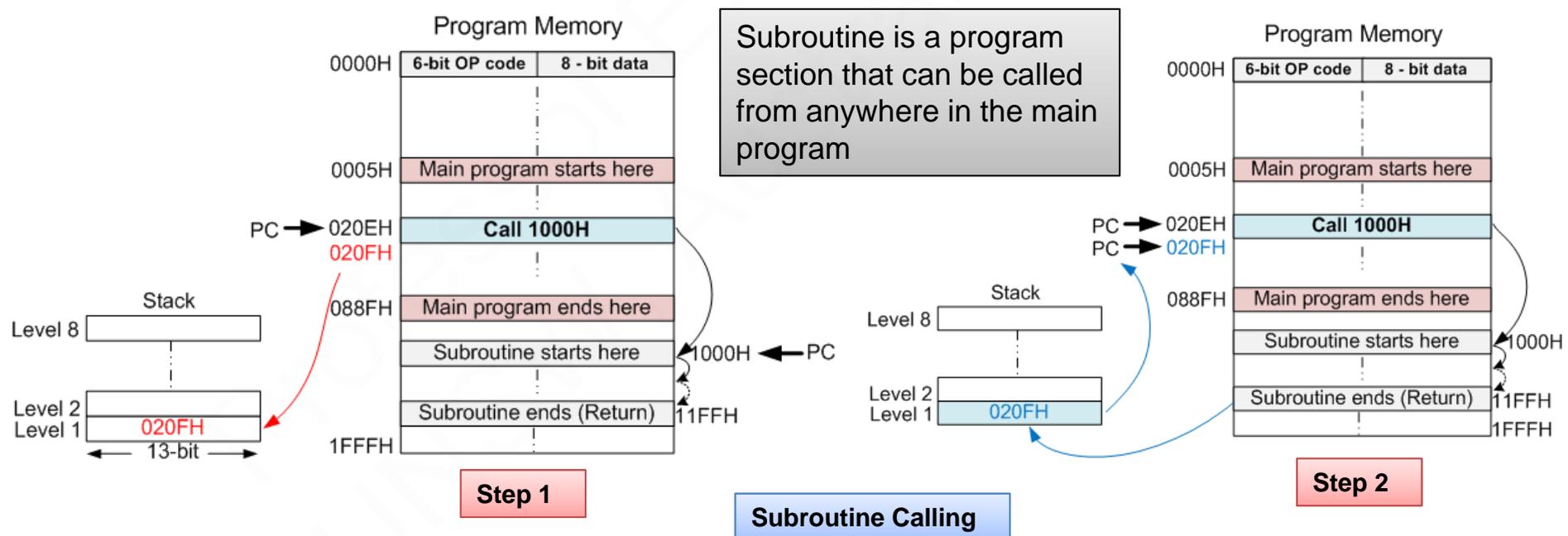
- The Program counter is a 13-bit counter capable of addressing a 8K x 14 bits (0000H – 1FFFH) of program memory space. (i.e. it acts as a pointer to the program memory)
- The control unit of the microcontroller automatically increments the program counter in order to get the next instruction (6-bit operation code) to be executed.



During power-up, the program counter is reset to zero by the control unit, which allows microcontroller to execute the instruction from the program memory address zero.

The stack (8 x 13 bits)

- The PIC16F886 microcontroller stack is a dedicated bank of 13-bit registers that can only be used to store return addresses during a call instruction (subroutine) or interrupt.
- Before the microcontroller starts to execute a subroutine, the program counter (PC) content is pushed onto the stack, so that the microcontroller knows from where to continue the regular program execution on return from the subroutine.
- The stack is structured as FILO (first in last out) memory.

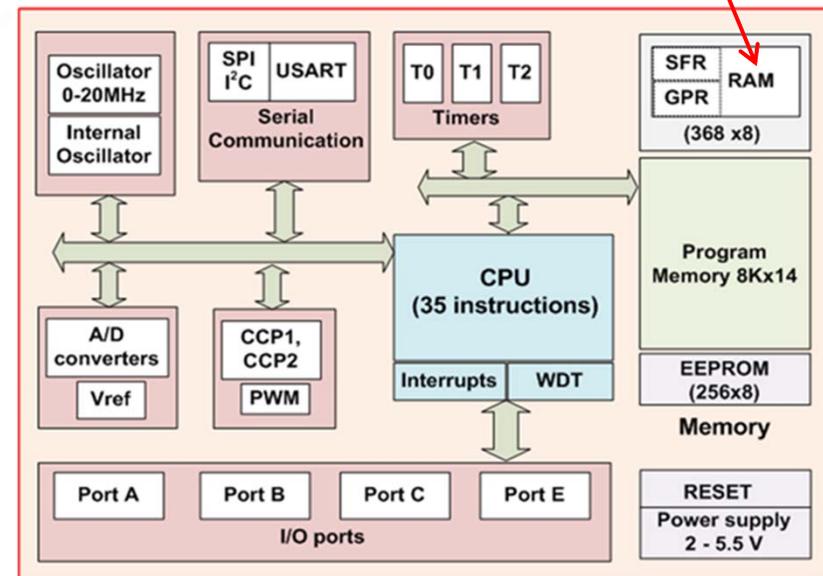
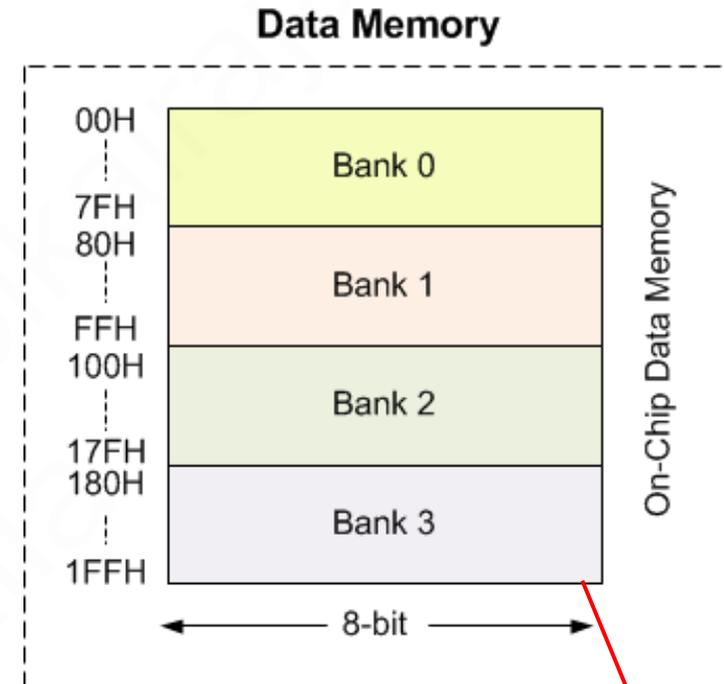


Data Memory (RAM) – 368 x 8

The **Data memory** is partitioned into four banks (Bank 0,1,2,& 3) which contain:

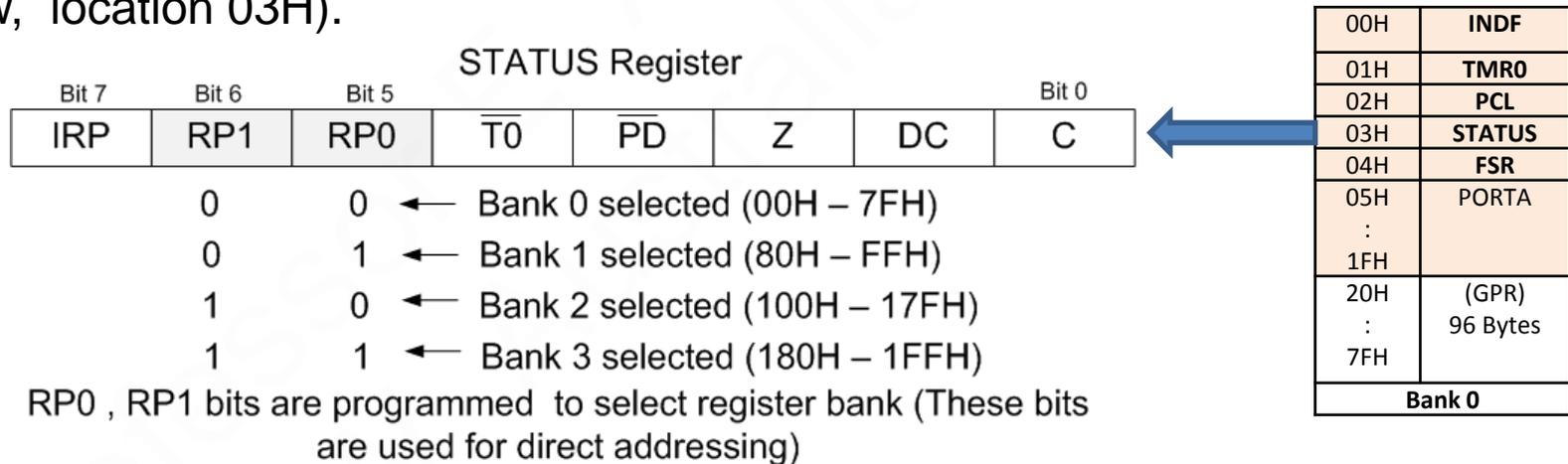
- ✓ **General Purpose Registers (GPR)** implemented as static RAM are located in the last 96 locations of each bank and are used for storing temporary data and results during a calculation.
- ✓ **Special Function Registers (SFR)** are used by CPU and peripheral functions for controlling devices and located in the first 32 locations of each bank.
- ❑ Prior to accessing a register during program writing or reading, it is necessary to select the bank which contains that register.

❑ Unimplemented data memory locations, read as '0'



Data Memory Addressing

- It is known that the larger the memory, we need more bits for the address bus. One way to avoid this problem is to divide the memory into a number of small blocks of equal size known as “Banks” and hence a smaller address bus can be used. Note that only one bank can be used at any one time.
- PIC16F886 microcontroller uses a banked RAM structure, having 4 banks with a 7-bit RAM address.
- The bank is selected by bits 5 and 6 of STATUS register (see, Bank 0 below, location 03H).



- The programmer must set the bits 5 and 6 of the STATUS register before accessing the Banked RAM (default setting is Bank 0)

PIC16F886: Special Function Registers (SFRs)- Data Memory Bank 0

Address	Name	Bit7 (MSB)	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0 (LSB)
00H	INDF	Indirect Register (Addressing this location uses contents of FSR to address data memory)							
01H	TMR0	Timer T0 Module Register							
02H	PCL	Least Significant Byte of Program Counter (PC)							
03H	STATUS	IRP	RP1	RP0	\overline{TO}	\overline{PD}	Z	DC	C
04H	FSR	Indirect Data Memory Address Pointer							
05H	PORTA	RA7	RA6	RA5	RA4	RA3	RA2	RA1	RA0
06H	PORTB	RB7	RB6	RB5	RB4	RB3	RB2	RB1	RB0
07H	PORTC	RC7	RC6	RC5	RC4	RC3	RC2	RC1	RC0
08H	-	-	-	-	-	-	-	-	-
09H	PORTE	-	-	-	-	RE3	RE2	RE1	RE0
0AH	PCLATH	-	-	-	Write buffer for Upper 5 bits of Program Counter				
0BH	INTCON	GIE	PEIE	TOIE	INTE	RBIE	TOIF	INTF	RBIF
0CH	PIR1	-	ADIF	RCIF	TXIF	SSPIF	CCP1IF	TMR2IF	TMR1IF
0DH	PIR2	OSFIF	C2IF	C1IF	EEIF	BCLIF	ULPWUIF	-	CCP2IF
0EH	TMR1L	Holding Register for the Least Significant Byte of the 16-bit Timer TMR1							
0FH	TMR1H	Holding Register for the Most Significant Byte of the 16-bit Timer TMR1							
10H	T1CON	T1GINV	TMR1GE	T1CKPS1	T1CKPS0	T1OSCEN	$\overline{T1SYNC}$	TMR1CS	TMR1ON
11H	TMR2	Timer T2 Module Register							
12H	T2CON	-	TOUTPS3	TOUTPS2	TOUTPS1	TOUTPS0	TMR2ON	T2CKPS1	T2CKPS0
13H	SSPBUF	Synchronous Serial Port Receive Buffer/Transmit Register							
14H	SSPCON	WCOL	SSPOV	SSPEN	CKP	SSPM3	SSPM2	SSPM1	SSPM0
15H	CCPR1L	Capture/Compare PWM Register 1 Low Byte (LSB)							
16H	CCPR1H	Capture/Compare PWM Register 1 High Byte (LSB)							
17H	CCP1CON	P1M1	P1M0	DC1B1	DC1B0	CCP1M3	CCP1M2	CCP1M1	CCP1M0
18H	RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D
19H	TXREG	EUSART Transmit Data Register							
1AH	RCREG	EUSART Receive Data Register							
1BH	CCPR2L	Capture/Compare PWM Register 2 Low Byte (LSB)							
1CH	CCPR2H	Capture/Compare PWM Register 2 High Byte (LSB)							
1DH	CCP2CON	-	-	DC2B1	DC2B0	CCP2M3	CCP2M2	CCP2M1	CCP2M0
1EH	ADRESH	A/D Result Register High Byte							
1FH	ADCON0	ADCS1	ADCS0	CHS3	CHS2	CHS1	CHS0	$\overline{GO/DONE}$	ADON

PIC16F886: Special Function Registers (SFRs)- Data Memory Bank 1

Address	Name	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
80H	INDF	Indirect Register							
81H	OPTION_REG	RBPU	INTEDG	TOCS	TOSE	PSA	PS2	PS1	PS0
82H	PCL	Least Significant Byte of Program Counter							
83H	STATUS	IRP	RP1	RP0	\overline{TO}	\overline{PD}	Z	DC	C
84H	FSR	Indirect Data Memory Address Pointer							
85H	TRISA	TRISA7	TRISA6	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0
86H	TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0
87H	TRISC	TRISC7	TRISC6	TRISC5	TRISC4	TRISC3	TRISC2	TRISC1	TRISCO
88H	-	-	-	-	-	-	-	-	-
89H	TRISE	-	-	-	-	TRISE3	TRISE2	TRISE1	TRISE0
8AH	PCLATH	-	-	-	Upper 5 bits of the Program Counter				
8BH	INTCON	GIE	PEIE	TOIE	INTE	RBIE	TOIF	INTF	RBIF
8CH	PIE1	-	ADIE	RCIE	TXIE	SSPIE	CCP1IE	TMR2IE	TMR1IE
8DH	PIE2	OSFIE	C2IE	C1IE	EEIE	BCLIE	ULPWUIE	-	CCP2IE
8EH	PCON	-	-	ULPWUE	SBOREN	-	-	POR	BOR
8FH	OSCCON	-	IRCF2	IRCF1	IRCF0	OSTS	HTS	LTS	SCS
90H	OSCTUNE	-	-	-	TUN4	TUN3	TUN2	TUN1	TUN0
91H	SSPCON2	GCEN	ACKSTAT	ACKDT	ACKEN	RCEN	PEN	RSEN	SEN
92H	PR2	Timer T2 Period Register							
93H	SSPADD	Synchronous Serial Port (I ² C mode) Address Register							
93H	SSPMSK	MSK7	MSK6	MSK5	MSK4	MSK3	MSK2	MSK1	MSK0
94H	SSPSTAT	SMP	CKE	D/A	P	S	R/W	UA	BF
95H	WPUB	WPUB7	WPUB6	WPUB5	WPUB4	WPUB3	WPUB2	WPUB1	WPUB0
96H	IOCB	IOCB7	IOCB6	IOCB5	IOCB4	IOCB3	IOCB2	IOCB1	IOCB0
97H	VRCON	VREN	VROE	VRR	VRSS	VR3	VR2	VR1	VR0
98H	TXSTA	CSRC	TX9	TXEN	SYNC	SENDB	BRGH	TRMT	TX9D
99H	SPBRG	BRG7	BRG6	BRG5	BRG4	BRG3	BRG2	BRG1	BRG0
9AH	SPBRGH	BRG15	BRG14	BRG13	BRG12	BRG11	BRG10	BRG9	BRG8
9BH	PWM1CON	PRSEN	PDC6	PDC5	PDC4	PDC3	PDC2	PDC1	PDC0
9CH	ECCPAS	ECCPASE	ECCPAS2	ECCPAS1	ECCPAS0	PSSAC1	PSSAC0	PSSBD1	PSSBD0
9DH	PSTRCON	-	-	-	STRSYNC	STRD	STRC	STRB	STRA
9EH	ADRESL	A/D Result Register Low Byte							
9FH	ADCON1	ADFM	-	VCFG1	VCFG0	-	-	-	-

PIC16F886: Special Function Registers (SFRs)- Data Memory Bank 2

Address	Name	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
100H	INDF	Indirect Register							
101H	TMR0	Timer T0 Register							
102H	PCL	Least Significant Byte of Program Counter							
103H	STATUS	IRP	RP1	RP0	\overline{TO}	\overline{PD}	Z	DC	C
104H	FSR	Indirect Data Memory Address Pointer							
105H	WDTCON	-	-	-	WDTPS3	WDTPS2	WDTPS1	WDTPS0	SWDTEN
106H	PORTB	RB7	RB6	RB5	RB4	RB3	RB2	RB1	RB0
107H	CM1CON0	C1ON	C1OUT	C1OE	C1POL	-	C1R	C1CH1	C1CH0
108H	CM2CON0	C2ON	C2OUT	C2OE	C2POL	-	C2R	C2CH1	C2CH0
109H	CM2CON1	MC1OUT	MC2OUT	C1RSEL	C2RSEL	-	-	T1GSS	C2SYNC
10AH	PCLATH	-	-	-	Upper 5 bits of the Program Counter				
10BH	INTCON	GIE	PEIE	TOIE	INTE	RBIE	TOIF	INTF	RBIF
10CH	EEDAT	EEDAT7	EEDAT6	EEDAT5	EEDAT4	EEDAT3	EEDAT2	EEDAT1	EEDAT0
10DH	EEADR	EEADR7	EEADR6	EEADR5	EEADR4	EEADR3	EEADR2	EEADR1	EEADR0
10EH	EEDATH	-	-	EEDATH5	EEDATH4	EEDATH3	EEDATH2	EEDATH1	EEDATH0
10FH	EEADRH	-	-	-	EEADRH4	EEADRH3	EEADRH2	EEADRH1	EEADRH0

PIC16F886: Special Function Registers (SFRs)- Data Memory Bank 3

Address	Name	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
180H	INDF	Indirect Register							
181H	OPTION_REG	RBPU	INTEDG	TOCS	TOSE	PSA	PS2	PS1	PS0
182H	PCL	Least Significant Byte of the Program Counter							
183H	STATUS	IRP	RP1	RP0	\overline{TO}	\overline{PD}	Z	DC	C
184H	FSR	Indirect Data Memory Address Pointer							
185H	SRCON	SR1	SR0	C1SEN	C2REN	PULSS	PULSR	-	FVREN
186H	TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0
187H	BAUDCTL	ABDOVF	RCIDL	-	SCKP	BRG16	-	WUE	ABDEN
188H	ANSEL	ANS7	ANS6	ANS5	ANS4	ANS3	ANS2	ANS1	ANS0
189H	ANSELH	-	-	ANS13	ANS12	ANS11	ANS10	ANS9	ANS8
19AH	PCLATH	-	-	-	Upper 5 bits of the Program Counter				
19BH	INTCON	GIE	PEIE	TOIE	INTE	RBIE	TOIF	INTF	RBIF
19CH	EECON1	EEPGD	-	-	-	WRERR	WREN	WR	RD
19DH	EECON2	EEPROM Control Register 2							

The Core CPU Registers – STATUS Register

- The STATUS register contains:
 - The arithmetic status of the ALU
 - The reset Status
 - The bank select bits for data memory

STATUS Register

Bit 7	Bit 6	Bit 5	Bit 6	Bit 5	Bit 2	Bit 1	Bit 0
IRP	RP1	RP0	$\overline{T0}$	\overline{PD}	Z	DC	C
R/W (0)	R/W (0)	R/W (0)	R(1)	R(1)	R/W (x)	R/W (x)	R/W (x)

R/W – Readable/Writable bit, R – Readable bit only

(0) – After the microcontroller is reset, bit is cleared, (1) - After the microcontroller is reset, bit is set

(x) -After the microcontroller is reset, bit is unknown

STATUS Register

Bit 7	Bit 6	Bit 5	Bit 6	Bit 5	Bit 2	Bit 1	Bit 0
IRP	RP1	RP0	$\overline{T0}$	\overline{PD}	Z	DC	C
R/W (0)	R/W (0)	R/W (0)	R(1)	R(1)	R/W (x)	R/W (x)	R/W (x)

IRP – Bit selects register bank. It is used for **indirect addressing**

1 - Banks 2 and 3 are active (memory location 100h-1FFh)

0 - Banks 0 and 1 are active (memory location 00h-FFh)

$\overline{T0}$ – Time-out bit

1 – After power-up or CLRWDT instruction or SLEEP instruction

0 – After watch-dog timer time-out has occurred

\overline{PD} – Power - down bit

1 – After power-up or after executing CLRWDT instruction which resets the watch-dog timer

0 – After executing the SLEEP instruction, which sets the microcontroller into low-power consumption mode.

Z – Zero bit

1 – The result of an arithmetic or logic operation is zero

0 – The result of an arithmetic or logic operation is NOT zero

DC – Digit Carry bit

1 – A carry-out from the 4th low-order bit of the result occurred

0 – NO carry-out from the 4th low-order bit of the result

C – Carry bit

1 – A carry-out from the Most significant bit of the result occurred

0 – NO carry-out from the Most Significant bit of the result

Chapter 2: Exercise 1

- What are the differences between the Harvard architecture and the conventional von Neumann architecture?
- Explain the differences between microprocessors and microcontrollers.
- What is the size of the program counter of the PIC16F886 ? How many bits are allocated to Opcode?
- What is the size of the program memory of PIC16F886? Draw a block diagram to show the program memory organisation.
- What is the purpose of the Special Function Registers (SFR)? What are the functions of General Purpose Registers? Briefly explain these functions.
- What is the purpose of the hardware stack in a microcontroller? How is it used by the microcontroller? Briefly explain using a block diagram.
- What is the purpose of the STATUS register? Which memory bank holds the STATUS register?
- Using the datasheet of PIC16F886, find out the value of the following registers on power-up: (a) STATUS (b) PCL (c) Program Counter (PC) (d) TMR0
- State the value of the STATUS register bits Z, DC, and C after each 8-bit addition of the following decimal numbers in 2's complement representation:
(a) +39 and +62 (b) +67 and -99, (c) -25 and -40 (d) -21 and +21

ELEC2117: References

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<http://www.mikroe.com/products/view/11/book-pic-microcontrollers/>
3. PIC 16F886 Data Sheet (2007), Microchip Technology; www.microchip.com