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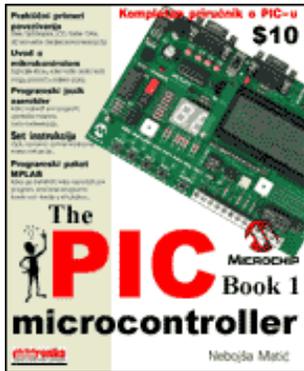
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PIC microcontrollers *for beginners,too!* **on-line,** **FREE!**

Author: Nebojsa Matic



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PIC microcontrollers; low-cost computers-in-a-chip; allows electronics designers and hobbyists add intelligence and functions that mimic big computers for almost any electronic product or project.

The purpose of this book is not to make a microcontroller expert out of you, but to make you equal to those who had someone to go to for their answers.

In this book you can find:

Practical connection samples for

Relays, Optocouplers, LCD's, Keys, Digits, A to D Converters, Serial communication etc.

Introduction to microcontrollers

Learn what they are, how they work, and how they can be helpful in your work.

Assembler language programming

How to write your first program, use of macros, addressing modes....

Instruction Set

Description, sample and purpose for using each instruction.....

MPLAB program package

How to install it, how to start the first program, following the program step by step in the simulator....

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CHAPTER 1

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Introduction

Circumstances that we find ourselves in today in the field of microcontrollers had their beginnings in the development of technology of integrated circuits. This development has made it possible to store hundreds of thousands of transistors into one chip. That was a prerequisite for production of microprocessors, and the first computers were made by adding external peripherals such as memory, input-output lines, timers and other. Further increasing of the volume of the package resulted in creation of integrated circuits. These integrated circuits contained both processor and peripherals. That is how the first chip containing a microcomputer, or what would later be known as a microcontroller came about.

History

It was year 1969, and a team of Japanese engineers from the BUSICOM company arrived to United States with a request that a few integrated circuits for calculators be made using their projects. The proposition was set to INTEL, and Marcian Hoff was responsible for the project. Since he was the one who has had experience in working with a computer (PC) PDP8, it occurred to him to suggest a fundamentally different solution instead of the suggested construction. This solution presumed that the function of the integrated circuit is determined by a program stored in it. That meant that configuration would be more simple, but that it would require far more memory than the project that was proposed by Japanese engineers would require. After a while, though Japanese engineers tried finding an easier solution, Marcian's idea won, and the first microprocessor was born. In transforming an idea into a ready made product, Federico Faggin was a major help to INTEL. He transferred to INTEL, and in only 9 months had succeeded in making a product from its first conception. INTEL obtained the rights to sell this integral block in 1971. First, they bought the license from the BUSICOM company who had no idea what treasure they had. During that year, there appeared on the market a microprocessor called 4004. That was the first 4-bit microprocessor with the speed of 6 000 operations per second. Not long after that, American company CTC requested from INTEL and Texas Instruments to make an 8-bit microprocessor for use in terminals. Even though CTC gave up this idea in the end, Intel and Texas Instruments kept working on the microprocessor and in April of 1972, first 8-bit microprocessor appeared on the market under a name 8008. It was able to address 16Kb of memory, and it had 45 instructions and the

speed of 300 000 operations per second. That microprocessor was the predecessor of all today's microprocessors. Intel kept their developments up in April of 1974, and they put on the market the 8-bit processor under a name 8080 which was able to address 64Kb of memory, and which had 75 instructions, and the price began at \$360.

In another American company Motorola, they realized quickly what was happening, so they put out on the market an 8-bit microprocessor 6800. Chief constructor was Chuck Peddle, and along with the processor itself, Motorola was the first company to make other peripherals such as 6820 and 6850. At that time many companies recognized greater importance of microprocessors and began their own developments. Chuck Peddle leaved Motorola to join MOS Technology and kept working intensively on developing microprocessors.

At the WESCON exhibit in United States in 1975, a critical event took place in the history of microprocessors. The MOS Technology announced it was marketing microprocessors 6501 and 6502 at \$25 each, which buyers could purchase immediately. This was so sensational that many thought it was some kind of a scam, considering that competitors were selling 8080 and 6800 at \$179 each. As an answer to its competitor, both Intel and Motorola lowered their prices on the first day of the exhibit down to \$69.95 per microprocessor. Motorola quickly brought suit against MOS Technology and Chuck Peddle for copying the protected 6800. MOS Technology stopped making 6501, but kept producing 6502. The 6502 was a 8-bit microprocessor with 56 instructions and a capability of directly addressing 64Kb of memory. Due to low cost , 6502 becomes very popular, so it was installed into computers such as: KIM-1, Apple I, Apple II, Atari, Comodore, Acorn, Oric, Galeb, Orao, Ultra, and many others. Soon appeared several makers of 6502 (Rockwell, Sznertek, GTE, NCR, Ricoh, and Comodore takes over MOS Technology) which was at the time of its prosperity sold at a rate of 15 million processors a year!

Others were not giving up though. Frederico Faggin leaves Intel, and starts his own Zilog Inc.

In 1976 Zilog announced the Z80. During the making of this microprocessor, Faggin made a pivotal decision. Knowing that a great deal of programs have been already developed for 8080, Faggin realized that many would stay faithful to that microprocessor because of great expenditure which redoing of all of the programs would result in. Thus he decided that a new processor had to be compatible with 8080, or that it had to be capable of performing all of the programs which had already been written for 8080. Beside these characteristics, many new ones have been added, so that Z80 was a very powerful microprocessor in its time. It was able to address directly 64 Kb of memory, it had 176 instructions, a large number of registers, a built in option for refreshing the dynamic RAM memory, single-supply, greater speed of work etc. Z80 was a great success and everybody converted from 8080 to Z80. It could be said that Z80 was without a doubt commercially most successful 8-bit microprocessor of that time. Besides Zilog, other new manufacturers like Mostek, NEC, SHARP, and SGS also appeared. Z80 was the heart of many computers like Spectrum, Partner, TRS703, Z-3 .

In 1976, Intel came up with an improved version of 8-bit microprocessor named 8085. However, Z80 was so much better that Intel soon lost the battle. Although a few more processors appeared on the market (6809, 2650, SC/MP etc.), everything was actually already decided. There weren't any more great improvements to make manufacturers convert to something new, so 6502 and Z80 along with 6800 remained as main representatives of the 8-bit microprocessors of that time.

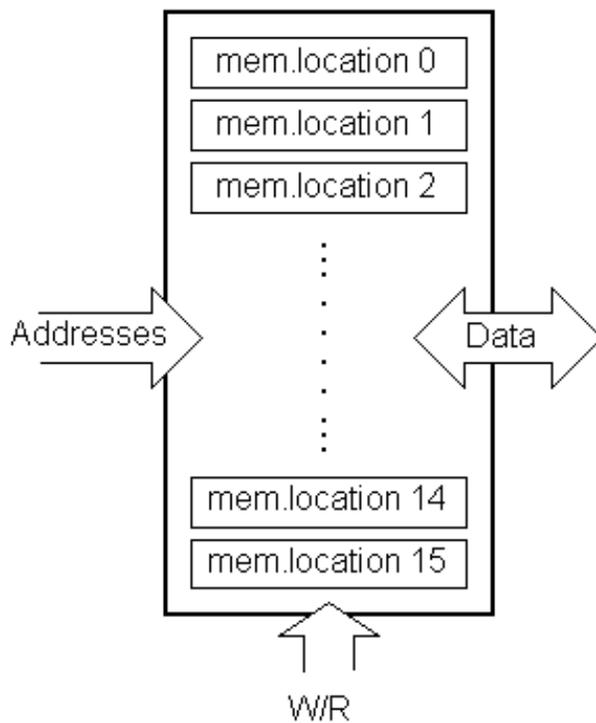
Microcontrollers versus Microprocessors

Microcontroller differs from a microprocessor in many ways. First and the most important is its functionality. In order for a microprocessor to be used, other components such as memory, or components for receiving and sending data must be added to it. In short that means that microprocessor is the very heart of the computer. On the other hand, microcontroller is designed to be all of that in one. No other external components are needed for its application because all necessary peripherals are already built into it. Thus, we save the time and space needed to construct devices.

1.1 Memory unit

Memory is part of the microcontroller whose function is to store data.

The easiest way to explain it is to describe it as one big closet with lots of drawers. If we suppose that we marked the drawers in such a way that they can not be confused, any of their contents will then be easily accessible. It is enough to know the designation of the drawer and so its contents will be known to us for sure.

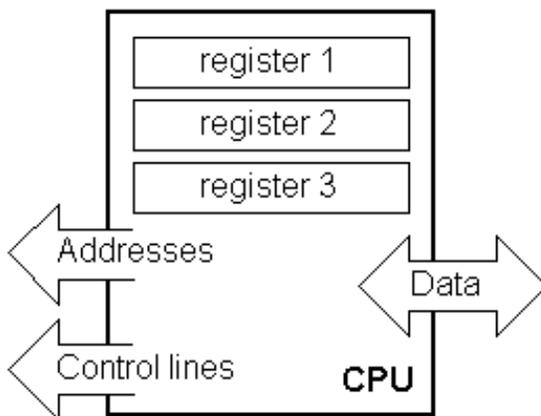


Example of simplified model of a memory unit. For a specific input we get a corresponding output. Line R/W determines whether we are reading from or writing to memory

Memory components are exactly like that. For a certain input we get the contents of a certain addressed memory location and that's all. Two new concepts are brought to us: addressing and memory location. Memory consists of all memory locations, and addressing is nothing but selecting one of them. This means that we need to select the desired memory location on one hand, and on the other hand we need to wait for the contents of that location. Beside reading from a memory location, memory must also provide for writing onto it. This is done by supplying an additional line called control line. We will designate this line as R/W (read/write). Control line is used in the following way: if $r/w=1$, reading is done, and if opposite is true then writing is done on the memory location. Memory is the first element, and we need a few operations of our microcontroller .

1.2 Central Processing Unit

Let add 3 more memory locations to a specific block that will have a built in capability to multiply, divide, subtract, and move its contents from one memory location onto another. The part we just added in is called "central processing unit" (CPU). Its memory locations are called registers.



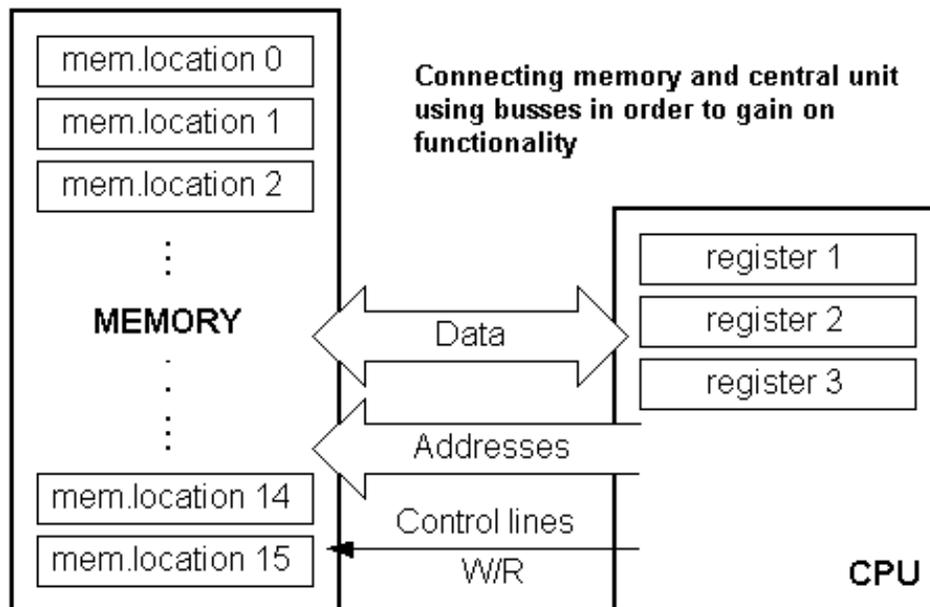
Example of simplified central processing unit with three registers

Registers are therefore memory locations whose role is to help with performing various mathematical operations or any other operations with data wherever data can be found. Look at the current situation. We have two independent entities (memory and CPU) which are interconnected, and thus any exchange of data is hindered, as well as its functionality. If, for example, we wish to add the contents of two memory locations and return the result again back to memory, we would need a connection between memory and CPU. Simply stated, we must have some "way" through data goes from one block to another.

1.3 Bus

That "way" is called "bus". Physically, it represents a group of 8, 16, or more wires

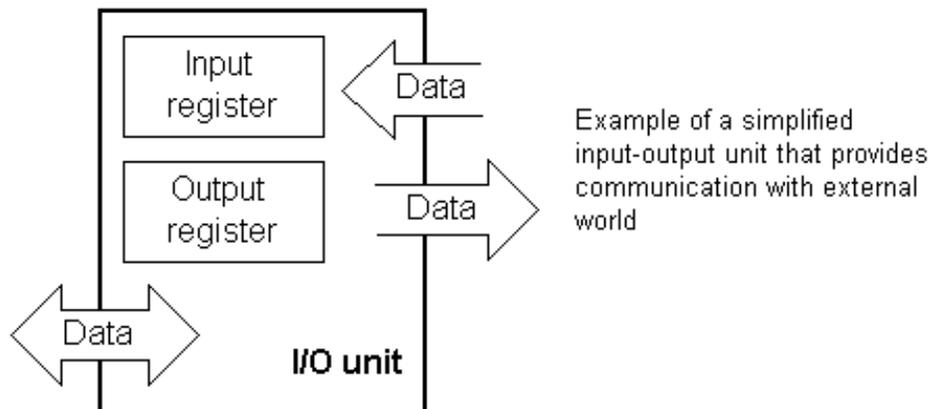
There are two types of buses: address and data bus. The first one consists of as many lines as the amount of memory we wish to address, and the other one is as wide as data, in our case 8 bits or the connection line. First one serves to transmit address from CPU memory, and the second to connect all blocks inside the microcontroller.



As far as functionality, the situation has improved, but a new problem has also appeared: we have a unit that's capable of working by itself, but which does not have any contact with the outside world, or with us! In order to remove this deficiency, let's add a block which contains several memory locations whose one end is connected to the data bus, and the other has connection with the output lines on the microcontroller which can be seen as pins on the electronic component.

1.4 Input-output unit

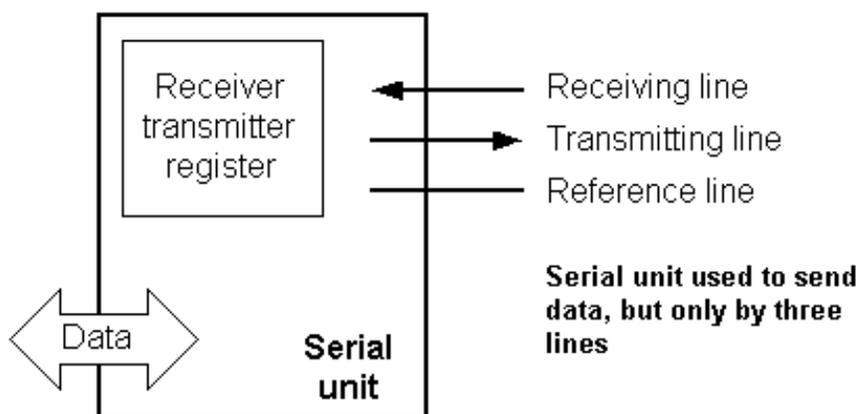
Those locations we've just added are called "ports". There are several types of ports : input, output or bidirectional ports. When working with ports, first of all it is necessary to choose which port we need to work with, and then to send data to, or take it from the port.



When working with it the port acts like a memory location. Something is simply being written into or read from it, and it could be noticed on the pins of the microcontroller.

1.5 Serial communication

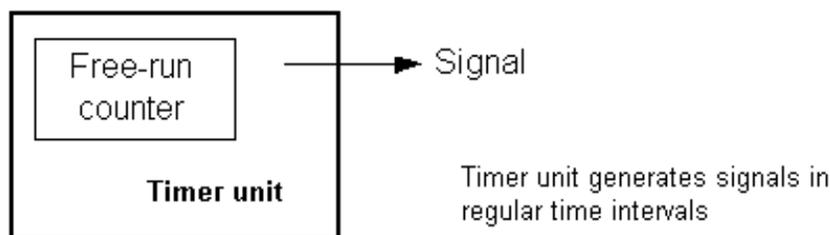
Beside stated above we've added to the already existing unit the possibility of communication with an outside world. However, this way of communicating has its drawbacks. One of the basic drawbacks is the number of lines which need to be used in order to transfer data. What if it is being transferred to a distance of several kilometers? The number of lines times number of kilometers doesn't promise the economy of the project. It leaves us having to reduce the number of lines in such a way that we don't lessen its functionality. Suppose we are working with three lines only, and that one line is used for sending data, other for receiving, and the third one is used as a reference line for both the input and the output side. In order for this to work, we need to set the rules of exchange of data. These rules are called protocol. Protocol is therefore defined in advance so there wouldn't be any misunderstanding between the sides that are communicating with each other. For example, if one man is speaking in French, and the other in English, it is highly unlikely that they will quickly and effectively understand each other. Let's suppose we have the following protocol. The logical unit "1" is set up on the transmitting line until transfer begins. Once the transfer starts, we lower the transmission line to logical "0" for a period of time (which we will designate as T), so the receiving side will know that it is receiving data, and so it will activate its mechanism for reception. Let's go back now to the transmission side and start putting logic zeros and ones onto the transmitter line in the order from a bit of the lowest value to a bit of the highest value. Let each bit stay on line for a time period which is equal to T, and in the end, or after the 8th bit, let us bring the logical unit "1" back on the line which will mark the end of the transmission of one data. The protocol we've just described is called in professional literature NRZ (Non-Return to Zero).



As we have separate lines for receiving and sending, it is possible to receive and send data (info.) at the same time. So called full-duplex mode block which enables this way of communication is called a serial communication block. Unlike the parallel transmission, data moves here bit by bit, or in a series of bits what defines the term serial communication comes from. After the reception of data we need to read it from the receiving location and store it in memory as opposed to sending where the process is reversed. Data goes from memory through the bus to the sending location, and then to the receiving unit according to the protocol.

1.6 Timer unit

Since we have the serial communication explained, we can receive, send and process data.



However, in order to utilize it in industry we need a few additionally blocks. One of those is the timer block which is significant to us because it can give us information about time, duration, protocol etc. The basic unit of the timer is a free-run counter which is in fact a register whose numeric value increments by one in even intervals, so that by taking its value during periods T1 and T2 and on the basis of their difference we can determine how much time has elapsed. This is a very important part of the microcontroller whose understanding requires most of our time.

1.7 Watchdog

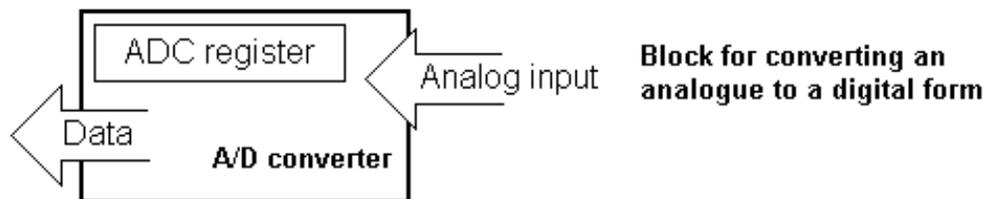
One more thing is requiring our attention is a flawless functioning of the microcontroller during its run-time. Suppose that as a result of some interference (which often does occur in industry) our microcontroller stops executing the program, or worse, it starts working incorrectly.



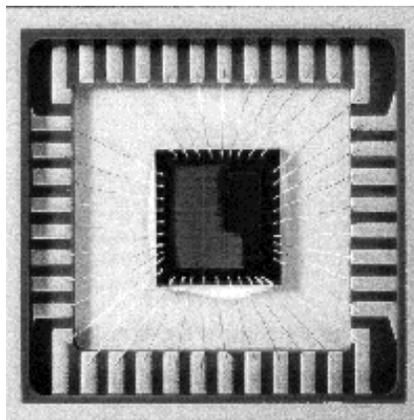
Of course, when this happens with a computer, we simply reset it and it will keep working. However, there is no reset button we can push on the microcontroller and thus solve our problem. To overcome this obstacle, we need to introduce one more block called watchdog. This block is in fact another free-run counter where our program needs to write a zero in every time it executes correctly. In case that program gets "stuck", zero will not be written in, and counter alone will reset the microcontroller upon achieving its maximum value. This will result in executing the program again, and correctly this time around. That is an important element of every program to be reliable without man's supervision.

1.8 Analog to Digital Converter

As the peripheral signals usually are substantially different from the ones that microcontroller can understand (zero and one), they have to be converted into a pattern which can be comprehended by a microcontroller. This task is performed by a block for analog to digital conversion or by an ADC. This block is responsible for converting an information about some analog value to a binary number and for follow it through to a CPU block so that CPU block can further process it.

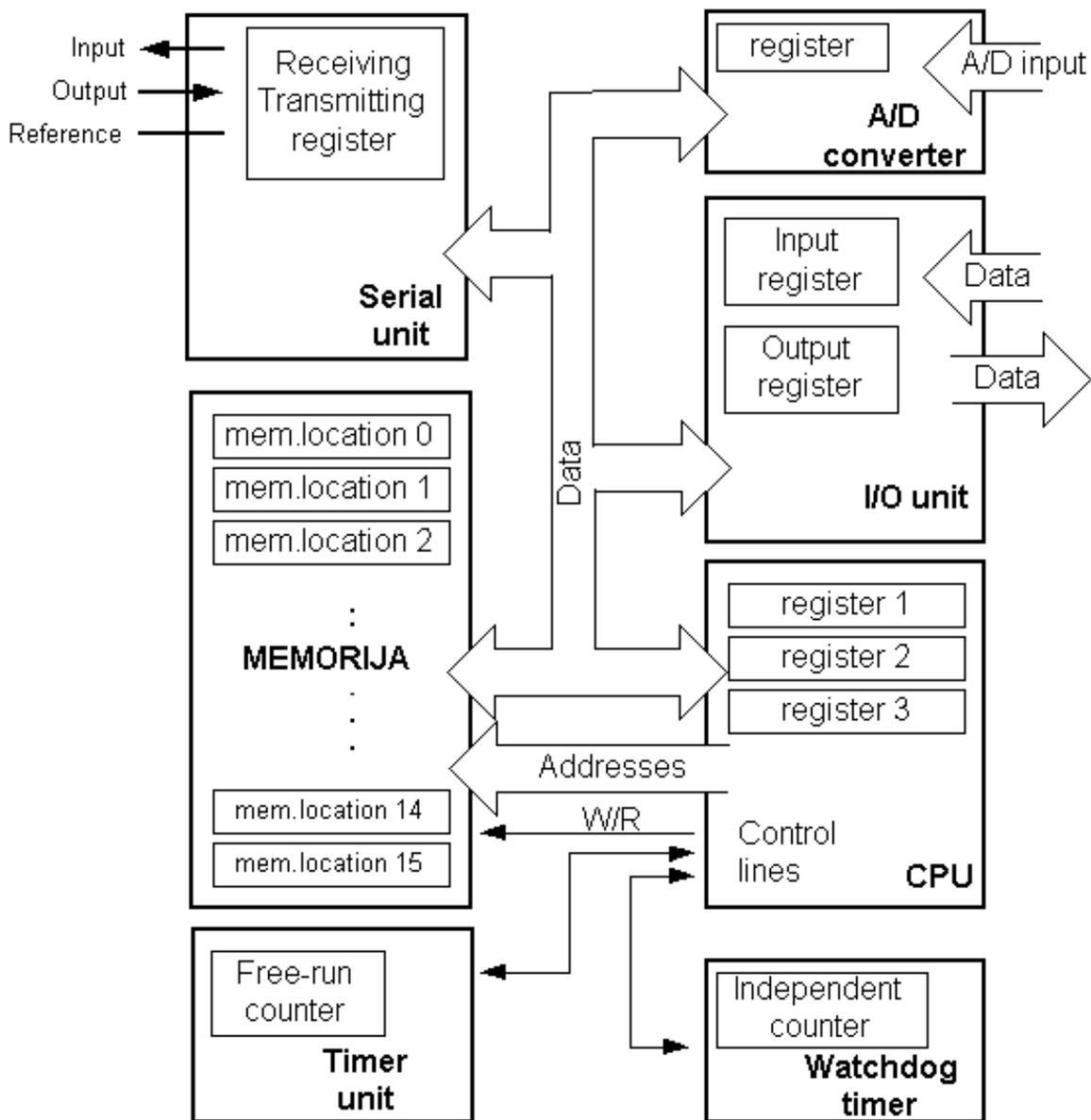


Finally, the microcontroller is now completed, and all we need to do now is to assemble it into an electronic component where it will access inner blocks through the outside pins. The picture below shows what a microcontroller looks like inside.



Physical configuration of the interior of a microcontroller

Thin lines which lead from the center towards the sides of the microcontroller represent wires connecting inner blocks with the pins on the housing of the microcontroller so called bonding lines. Chart on the following page represents the center section of a microcontroller.



Microcontroller outline with its basic elements and internal connections

For a real application, a microcontroller alone is not enough. Beside a microcontroller, we need a program that would be executed, and a few more elements which make up a interface logic towards the elements of regulation (which will be discussed in later chapters).

1.9 Program

Program writing is a special field of work with microcontrollers and is called "programming". Try to write a small program in a language that we will make up ourselves first and then would be understood by anyone.

```

START
REGISTER1=MEMORY LOCATION_A
REGISTER2=MEMORY LOCATION_B
PORTA=REGISTER1 + REGISTER2

```

END

The program adds the contents of two memory locations, and views their sum on port A. The first line of the program stands for moving the contents of memory location "A" into one of the registers of central processing unit. As we need the other data as well, we will also move it into the other register of the central processing unit. The next instruction instructs the central processing unit to add the contents of those two registers and send a result to port A, so that sum of that addition would be visible to the outside world. For a more complex problem, program that works on its solution will be

bigger.

Programming can be done in several languages such as Assembler, C and Basic which are most commonly used languages. Assembler belongs to lower level languages that are programmed slowly, but take up the least amount of space in memory and gives the best results where the speed of program execution is concerned. As it is the most commonly used language in programming microcontrollers it will be discussed in a later chapter. Programs in C language are easier to be written, easier to be understood, but are slower in executing from assembler programs. Basic is the easiest one to learn, and its instructions are nearest a man's way of reasoning, but like C programming language it is also slower than assembler. In any case, before you make up your mind about one of these languages you need to consider carefully the demands for execution speed, for the size of memory and for the amount of time available for its assembly.

After the program is written, we would install the microcontroller into a device and run it. In order to do this we need to add a few more external components necessary for its work. First we must give life to a microcontroller by connecting it to a power supply (power needed for operation of all electronic instruments) and oscillator whose role is similar to the role that heart plays in a human body. Based on its clocks microcontroller executes instructions of a program. As it receives supply microcontroller will perform a small check up on itself, look up the beginning of the program and start executing it. How the device will work depends on many parameters, the most important of which is the skillfulness of the developer of hardware, and on programmer's expertise in getting the maximum out of the device with his program.

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Introduction

PIC16F84 belongs to a class of 8-bit microcontrollers of RISC architecture. Its general structure is shown on the following map representing basic blocks.

Program memory (FLASH)- for storing a written program.

Since memory made in FLASH technology can be programmed and cleared more than once, it makes this microcontroller suitable for device development.

EEPROM - data memory that needs to be saved when there is no supply.

It is usually used for storing important data that must not be lost if power supply suddenly stops. For instance, one such data is an assigned temperature in temperature regulators. If during a loss of power supply this data was lost, we would have to make the adjustment once again upon return of supply. Thus our device loses on self-reliance.

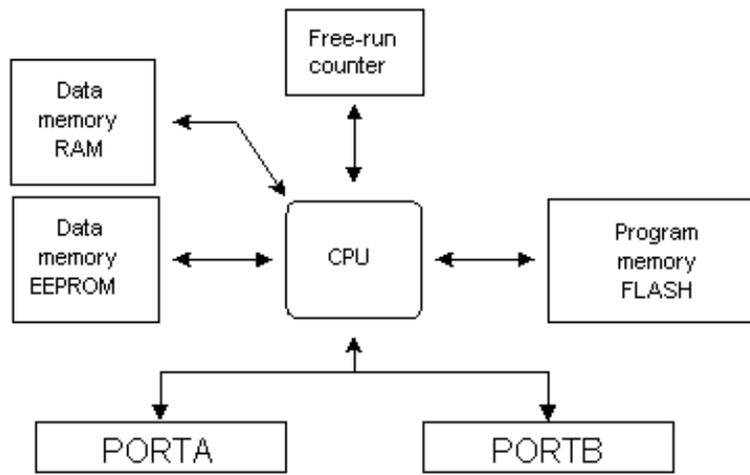
RAM - data memory used by a program during its execution.

In RAM are stored all inter-results or temporary data during run-time.

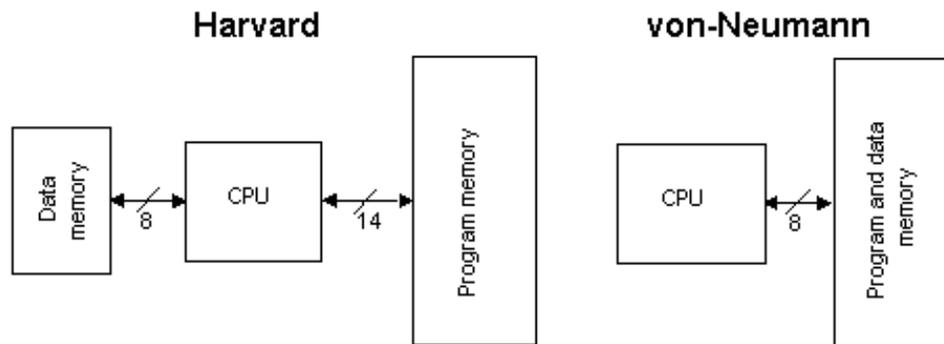
PORTA and PORTB are physical connections between the microcontroller and the outside world. Port A has five, and port B eight pins.

FREE-RUN TIMER is an 8-bit register inside a microcontroller that works independently of the program. On every fourth clock of the oscillator it increments its value until it reaches the maximum (255), and then it starts counting over again from zero. As we know the exact timing between each two increments of the timer contents, timer can be used for measuring time which is very useful with some devices.

CENTRAL PROCESSING UNIT has a role of connective element between other blocks in the microcontroller. It coordinates the work of other blocks and executes the user program.



PIC16F84 microcontroller outline



Harvard vs. von Neuman Block Architectures

CISC, RISC

It has already been said that PIC16F84 has a RISC architecture. This term is often found in computer literature, and it needs to be explained here in more detail. Harvard architecture is a newer concept than von-Neumann's. It rose out of the need to speed up the work of a microcontroller. In Harvard architecture, data bus and address bus are separate. Thus a greater flow of data is possible through the central processing unit, and of course, a greater speed of work. Separating a program from data memory makes it further possible for instructions not to have to be 8-bit words. PIC16F84 uses 14 bits for instructions which allows for all instructions to be one word instructions. It is also typical for Harvard architecture to have fewer instructions than von-Neumann's, and to have instructions usually executed in one cycle.

Microcontrollers with Harvard architecture are also called "RISC microcontrollers". RISC stands for Reduced Instruction Set Computer. Microcontrollers with von-Neumann's architecture are called 'CISC microcontrollers'. Title CISC stands for Complex Instruction Set Computer.

Since PIC16F84 is a RISC microcontroller, that means that it has a reduced set of instructions, more precisely 35 instructions. (ex. Intel's and Motorola's microcontrollers have over hundred instructions) All of these instructions are executed in one cycle except for jump and branch instructions. According to what its maker says, PIC16F84 usually reaches results of 2:1 in code compression and 4:1 in speed in relation to other 8-bit microcontrollers in its class.

Applications

PIC16F84 perfectly fits many uses, from automotive industries and controlling home appliances to industrial instruments, remote sensors, electrical doorlocks and safety devices. It is also ideal for smart cards as well as for battery supplied devices

because of its low consumption.

EEPROM memory makes it easier to apply microcontrollers to devices where permanent storage of various parameters is needed (codes for transmitters, motor speed, receiver frequencies, etc.). Low cost, low consumption, easy handling and flexibility make PIC16F84 applicable even in areas where microcontrollers had not previously been considered (example: timer functions, interface replacement in larger systems, coprocessor applications, etc.).

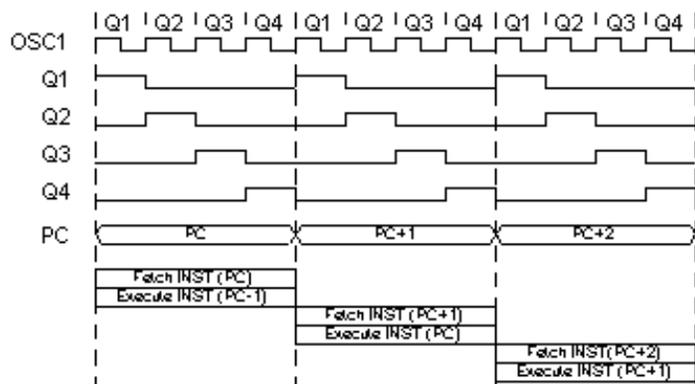
In System Programmability of this chip (along with using only two pins in data transfer) makes possible the flexibility of a product, after assembling and testing have been completed. This capability can be used to create assembly-line production, to store calibration data available only after final testing, or it can be used to improve programs on finished products.

Clock / instruction cycle

Clock is microcontroller's main starter, and is obtained from an external component called an "oscillator". If we want to compare a microcontroller with a time clock, our "clock" would then be a ticking sound we hear from the time clock. In that case, oscillator could be compared to a spring that is wound so time clock can run. Also, force used to wind the time clock can be compared to an electrical supply.

Clock from the oscillator enters a microcontroller via OSC1 pin where internal circuit of a microcontroller divides the clock into four even clocks Q1, Q2, Q3, and Q4 which do not overlap. These four clocks make up one instruction cycle (also called machine cycle) during which one instruction is executed.

Execution of instruction starts by calling an instruction that is next in string. Instruction is called from program memory on every Q1 and is written in instruction register on Q4. Decoding and execution of instruction are done between the next Q1 and Q4 cycles. On the following diagram we can see the relationship between instruction cycle and clock of the oscillator (OSC1) as well as that of internal clocks Q1-Q4. Program counter (PC) holds information about the address of the next instruction.

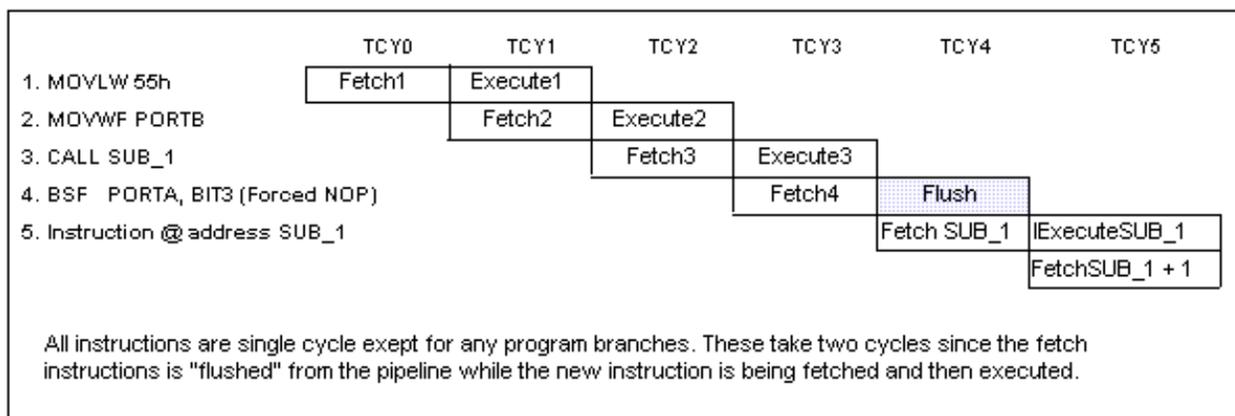


Clock/Instruction Cycle

Pipelining

Instruction cycle consists of cycles Q1, Q2, Q3 and Q4. Cycles of calling and executing instructions are connected in such a way that in order to make a call, one instruction cycle is needed, and one more is needed for decoding and execution.

However, due to pipelining, each instruction is effectively executed in one cycle. If instruction causes a change on program counter, and PC doesn't point to the following but to some other address (which can be the case with jumps or with calling subprograms), two cycles are needed for executing an instruction. This is so because instruction must be processed again, but this time from the right address. Cycle of calling begins with Q1 clock, by writing into instruction register (IR). Decoding and executing begins with Q2, Q3 and Q4 clocks.

**Instruction Pipeline Flow**

TCY0 reads in instruction MOVLW 55h (it doesn't matter to us what instruction was executed, because there is no rectangle pictured on the bottom).

TCY1 executes instruction MOVLW 55h and reads in MOVWF PORTB.

TCY2 executes MOVWF PORTB and reads in CALL SUB_1.

TCY3 executes a call of a subprogram CALL SUB_1, and reads in instruction BSF PORTA, BIT3. As this instruction is not the one we need, or is not the first instruction of a subprogram SUB_1 whose execution is next in order, instruction must be read in again. This is a good example of an instruction needing more than one cycle.

TCY4 instruction cycle is totally used up for reading in the first instruction from a subprogram at address SUB_1.

TCY5 executes the first instruction from a subprogram SUB_1 and reads in the next one.

Pin description

PIC16F84 has a total of 18 pins. It is most frequently found in a DIP18 type of case but can also be found in SMD case which is smaller from a DIP. DIP is an abbreviation for Dual In Package. SMD is an abbreviation for Surface Mount Devices suggesting that holes for pins to go through when mounting, aren't necessary in soldering this type of a component.



Pins on PIC16F84 microcontroller have the following meaning:

Pin no.1 **RA2** Second pin on port A. Has no additional function

Pin no.2 **RA3** Third pin on port A. Has no additional function.

Pin no.3 **RA4** Fourth pin on port A. TOCK1 which functions as a timer is also found on this pin

Pin no.4 **MCLR** Reset input and Vpp programming voltage of a microcontroller

Pin no.5 **Vss** Ground of power supply.

Pin no.6 **RB0** Zero pin on port B. Interrupt input is an additional function.

Pin no.7 **RB1** First pin on port B. No additional function.

Pin no.8 **RB2** Second pin on port B. No additional function.

Pin no.9 **RB3** Third pin on port B. No additional function.

Pin no.10 **RB4** Fourth pin on port B. No additional function.

Pin no.11 **RB5** Fifth pin on port B. No additional function.

- Pin no.12 **RB6** Sixth pin on port B. 'Clock' line in program mode.
- Pin no.13 **RB7** Seventh pin on port B. 'Data' line in program mode.
- Pin no.14 **Vdd** Positive power supply pole.
- Pin no.15 **OSC2** Pin assigned for connecting with an oscillator
- Pin no.16 **OSC1** Pin assigned for connecting with an oscillator
- Pin no.17 **RA2** Second pin on port A. No additional function
- Pin no.18 **RA1** First pin on port A. No additional function.

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2.1 Clock generator - oscillator

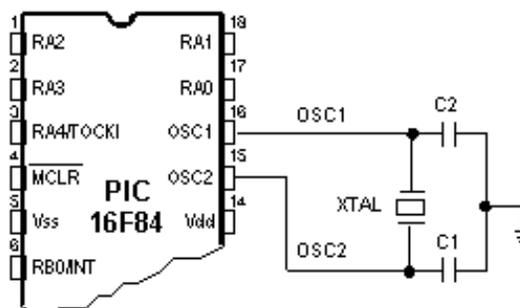
Oscillator circuit is used for providing a microcontroller with a clock. Clock is needed so that microcontroller could execute a program or program instructions.

Types of oscillators

PIC16F84 can work with four different configurations of an oscillator. Since configurations with crystal oscillator and resistor-capacitor (RC) are the ones that are used most frequently, these are the only ones we will mention here. Microcontroller type with a crystal oscillator has in its designation XT, and a microcontroller with resistor-capacitor pair has a designation RC. This is important because you need to mention the type of oscillator when buying a microcontroller.

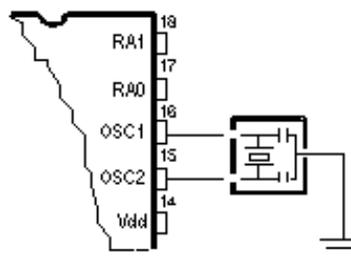
XT Oscillator

Crystal oscillator is kept in metal housing with two pins where you have written down the frequency at which crystal oscillates. One ceramic capacitor of 30pF whose other end is connected to the ground needs to be connected with each pin.



Connecting the quartz oscillator to give clock to a microcontroller

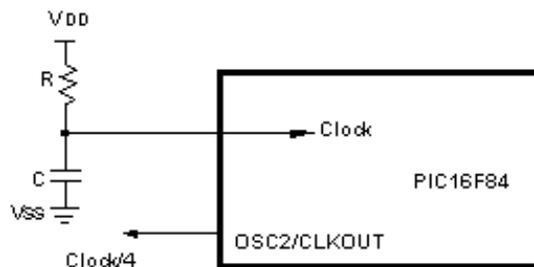
Oscillator and capacitors can be packed in joint case with three pins. Such element is called ceramic resonator and is represented in charts like the one below. Center pins of the element is the ground, while end pins are connected with OSC1 and OSC2 pins on the microcontroller. When designing a device, the rule is to place an oscillator nearer a microcontroller, so as to avoid any interference on lines on which microcontroller is receiving a clock.



Connecting a resonator onto a microcontroller

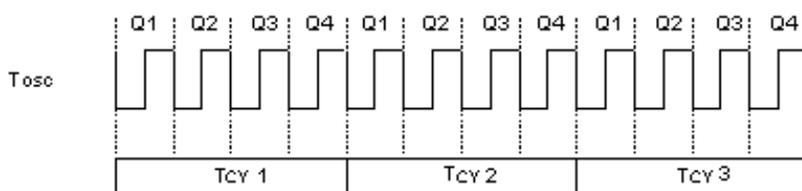
RC Oscillator

In applications where great time precision is not necessary, RC oscillator offers additional savings during purchase. Resonant frequency of RC oscillator depends on supply voltage rate, resistance R, capacity C and working temperature. It should be mentioned here that resonant frequency is also influenced by normal variations in process parameters, by tolerance of external R and C components, etc.



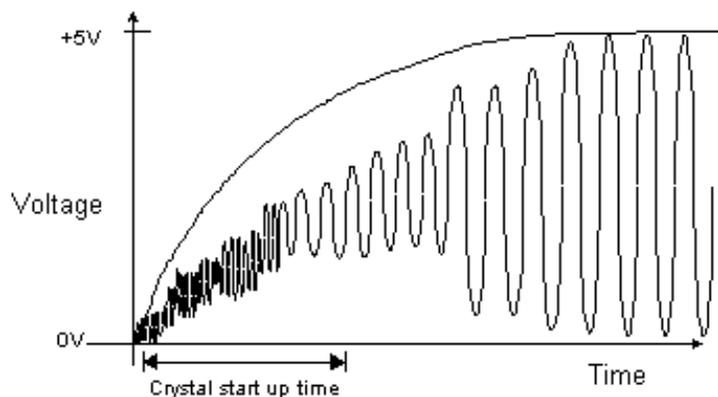
Note: This pin can be configured as input/output pin

Above diagram shows how RC oscillator is connected with PIC16F84. With value of resistor R being below 2.2k, oscillator can become unstable, or it can even stop the oscillation. With very high value of R (ex.1M) oscillator becomes very sensitive to noise and humidity. It is recommended that value of resistor R should be between 3 and 100k. Even though oscillator will work without an external capacitor(C=0pF), capacitor above 20pF should still be used for noise and stability. No matter which oscillator is being used, in order to get a clock that microcontroller works upon, a clock of the oscillator must be divided by 4. Oscillator clock divided by 4 can also be obtained on OSC2/CLKOUT pin, and can be used for testing or synchronizing other logical circuits.



Relationship between a clock and a number of instruction cycles

Following a supply, oscillator starts oscillating. Oscillation at first has an unstable period and amplitude, but after some period of time it becomes stabilized.



Signal of an oscillator clock after receiving the supply of a microcontroller

To prevent such inaccurate clock from influencing microcontroller's performance, we need to keep the microcontroller in reset state during stabilization of oscillator's clock. Above diagram shows a typical shape of a signal which microcontroller gets from the quartz oscillator following a supply.



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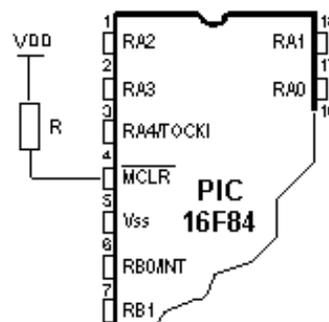
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2.2 Reset

Reset is used for putting the microcontroller into a 'known' condition. That practically means that microcontroller can behave rather inaccurately under certain undesirable conditions. In order to continue its proper functioning it has to be reset, meaning all registers would be placed in a starting position. Reset is not only used when microcontroller doesn't behave the way we want it to, but can also be used when trying out a device as an interrupt in program execution, or to get a microcontroller ready when reading in a program.

In order to prevent from bringing a logical zero to MCLR pin accidentally (line above it means that reset is activated by a logical zero), MCLR has to be connected via resistor to the positive supply pole. Resistor should be between 5 and 10K. This kind of resistor whose function is to keep a certain line on a logical one as a preventive, is called a pull up.



Using the internal reset circuit

Microcontroller PIC16F84 knows several sources of resets:

- a) Reset during power on, POR (Power-On Reset)
- b) Reset during regular work by bringing logical zero to MCLR microcontroller's pin.
- c) Reset during SLEEP regime
- d) Reset at watchdog timer (WDT) overflow
- e) Reset during at WDT overflow during SLEEP work regime.

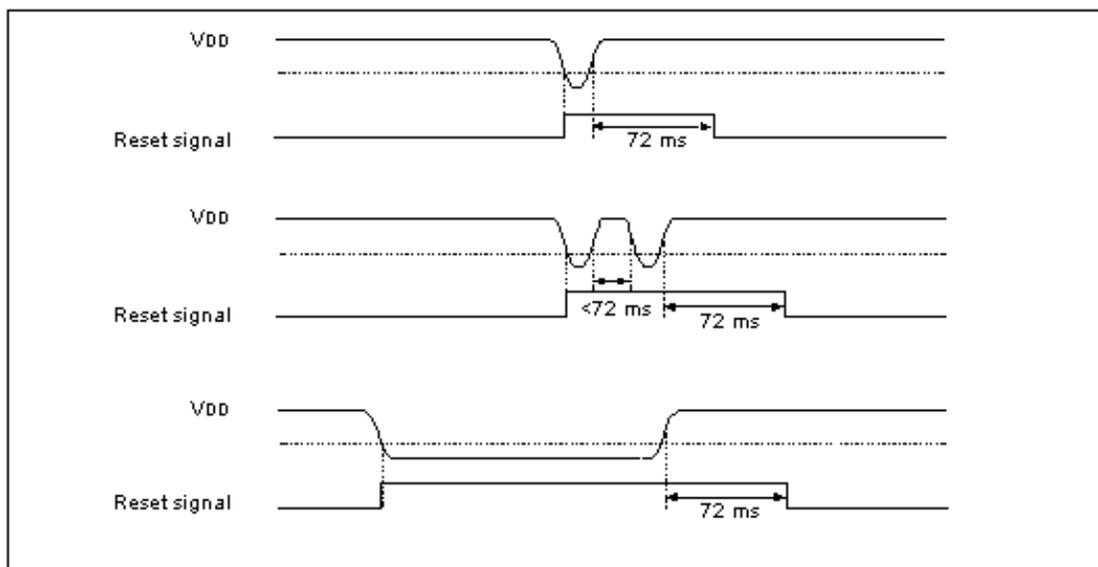
The most important reset sources are a) and b). The first one occurs each time a power supply is brought to the microcontroller and serves to bring all registers to a starting position initial state. The second one is a product of purposeful bringing in of a logical zero to MCLR pin during normal operation of the microcontroller. This second one is often used in program development.

During a reset, RAM memory locations are not being reset. They are unknown during a power up and are not changed at any reset. Unlike these, SFR registers are reset to a starting position initial state. One of the most important effects of a reset is setting a program counter (PC) to zero (0000h), which enables the program to start executing from the first written instruction.

Reset at supply voltage drop below the permissible (Brown-out Reset)

Impulse for resetting during voltage voltage-up is generated by microcontroller itself when it detects an increase in supply Vdd (in a range from 1.2V to 1.8V). That impulse lasts 72ms which is enough time for an oscillator to get stabilized. These 72ms are provided by an internal PWRT timer which has its own RC oscillator. Microcontroller is in a reset mode as long as PWRT is active. However, as device is working, problem arises when supply doesn't drop to zero but falls below the limit that guarantees microcontroller's proper functioning. This is a likely case in practice, especially in industrial environment where disturbances and instability of supply are an everyday occurrence. To solve this problem we need to make sure that

microcontroller is in a reset state each time supply falls below the approved limit.



Examples of voltage supply drop below the proper level

If, according to electrical specification, internal reset circuit of a microcontroller can not satisfy the needs, special electronic components can be used which are capable of generating the desired reset signal. Beside this function, they can also function in watching over supply voltage. If voltage drops below specified level, a logical zero would appear on MCLR pin which holds the microcontroller in reset state until voltage is not within limits that guarantee correct functioning.

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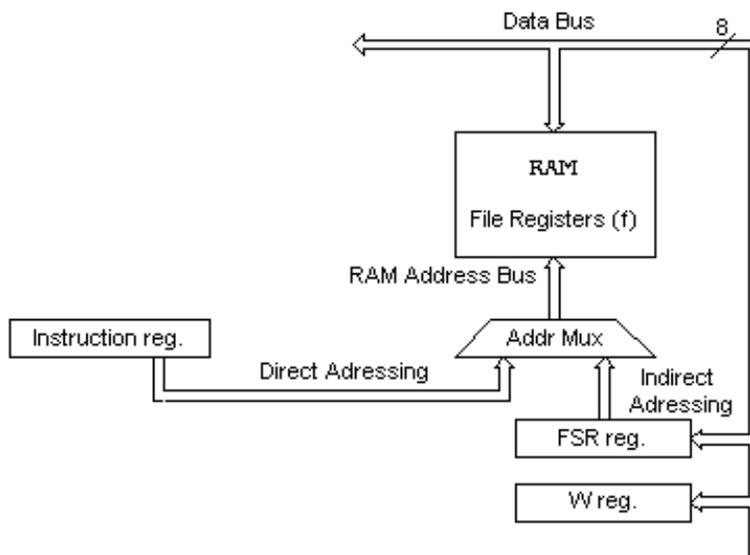
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2.3 Central Processing Unit

Central processing unit (CPU) is the brain of a microcontroller. That part is responsible for finding and fetching the right instruction which needs to be executed, for decoding that instruction, and finally for its execution.

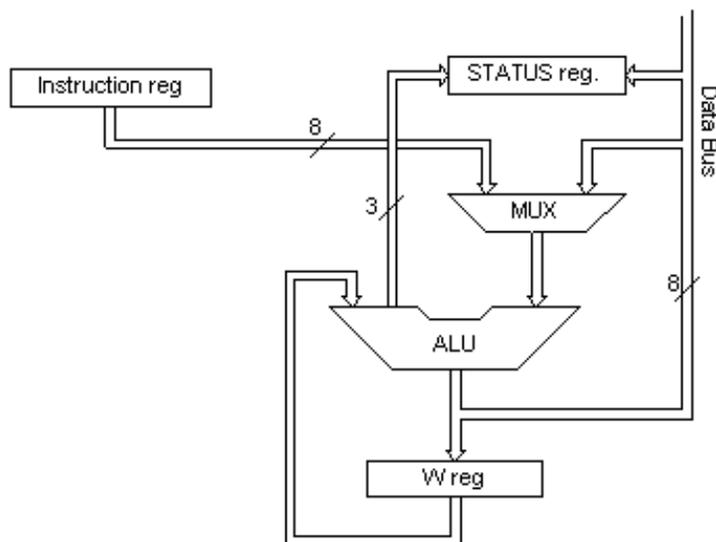


Outline of the central processing unit-CPU

Central processing unit connects all parts of the microcontroller into one whole. Surely, its most important function is to decode program instructions. When programmer writes a program, instructions have a clear form like `MOVLW 0x20`. However, in order for a microcontroller to understand that, this 'letter' form of an instruction must be translated into a series of zeros and ones which is called an 'opcode'. This transition from a letter to binary form is done by translators such as assembler translator (also known as an assembler). Instruction thus fetched from program memory must be decoded by a central processing unit. We can then select from the table of all the instructions a set of actions which execute a assigned task defined by instruction. As instructions may within themselves contain assignments which require different transfers of data from one memory into another, from memory onto ports, or some other calculations, CPU must be connected with all parts of the microcontroller. This is made possible through a data bus and an address bus.

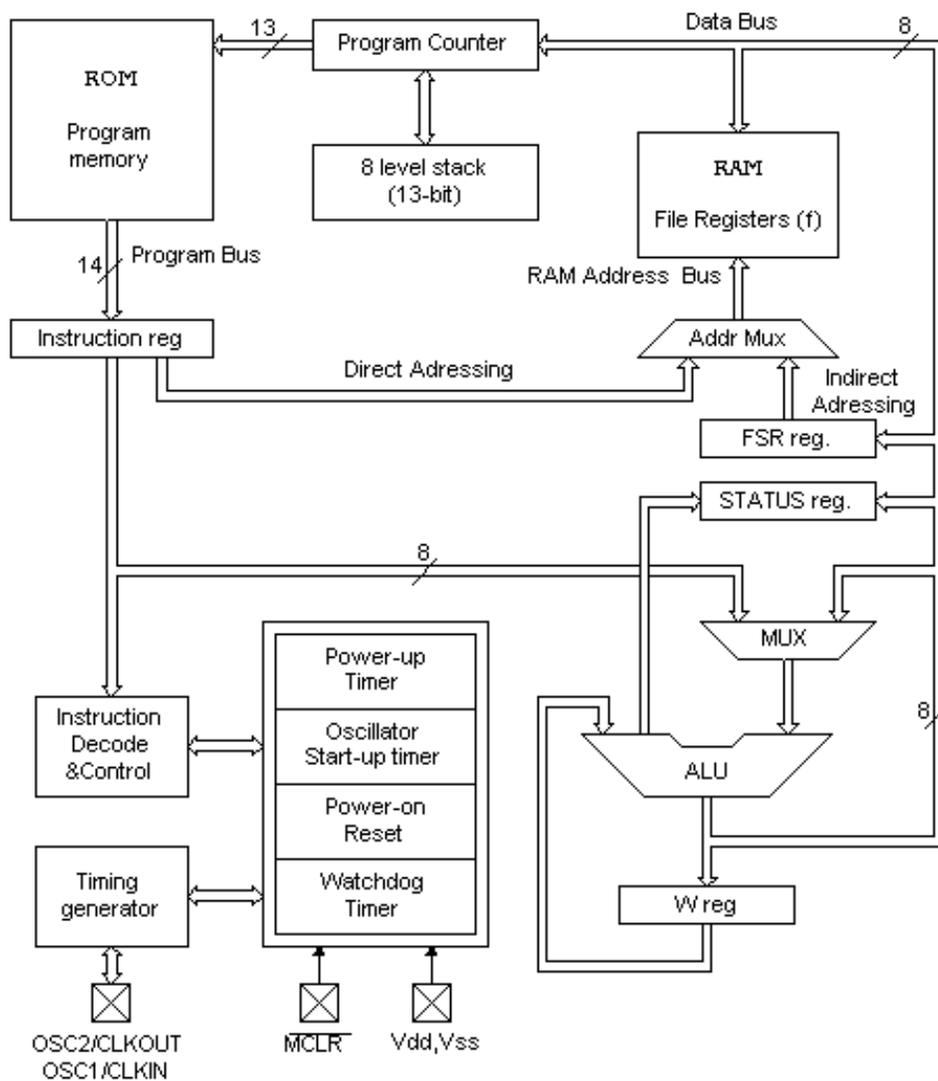
Arithmetic Logic Unit (ALU)

Arithmetic logic unit is responsible for performing operations of adding, subtracting, moving (left or right within a register) and logic operations. Moving data inside a register is also known as 'shifting'. PIC16F84 contains an 8-bit arithmetic logic unit and 8-bit work registers.



Arithmetic-logic unit and how it works

In instructions with two operands, ordinarily one operand is in work register (W register), and the other is one of the registers or a constant. By operand we mean the contents on which some operation is being done, and a register is any one of the GPR or SFR registers. GPR is an abbreviation for 'General Purposes Registers', and SFR for 'Special Function Registers'. In instructions with one operand, an operand is either W register or one of the registers. As an addition in doing operations in arithmetic and logic, ALU controls status bits (bits found in STATUS register). Execution of some instructions affects status bits, which depends on the result itself. Depending on which instruction is being executed, ALU can affect values of Carry (C), Digit Carry (DC), and Zero (Z) bits in STATUS register.



OSC2/CLKOUT
OSC1/CLKIN

MCLR Vdd,Vss

More detailed block outline of PIC16F84 microcontroller

STATUS Register

R/W-0	R/W-0	R/W-0	R/W-1	R/W-1	R/W-x	R/W-x	R/W-x
IRP	RP1	RP0	\overline{TO}	\overline{PD}	Z	DC	C

bit7

Legend:
R = Readable bit **W** = Writable bit

U = Unimplemented bit, read as '00' - n = Value at power-on reset

bit 0 C (Carry) Transfer

Bit that is affected by operations of addition, subtraction and shifting.

1= transfer occurred from the highest resulting bit

0=transfer did not occur

C bit is affected by ADDWF, ADDLW, SUBLW, SUBWF instructions.

bit 1 DC (Digit Carry) DC Transfer

Bit affected by operations of addition, subtraction and shifting. Unlike C bit, this bit represents transfer from the fourth resulting place. It is set by addition when occurs carry from bit3 to bit4, or by subtraction when occurs borrow from bit4 to bit3, or by shifting in both direction.

1=transfer occurred on the fourth bit according to the order of the result

0=transfer did not occur

DC bit is affected by ADDWF, ADDLW, SUBLW, SUBWF instructions.

bit 2 Z (Zero bit) Indication of a zero result

This bit is set when the result of an executed arithmetic or logic operation is zero.

1=result equals zero

0=result does not equal zero

bit 3 PD (Power-down bit)

Bit which is set whenever power supply is brought to a microcontroller as it starts running, after each regular reset and after execution of instruction CLRWDT. Instruction SLEEP resets it when microcontroller falls into low consumption/usage regime. Its repeated setting is possible via reset or by turning the supply on, or off. Setting can be triggered also by a signal on RBO/INT pin, change on RB port, completion of writing in internal DATA EEPROM, and by a watchdog, too.

1=after supply has been turned on

0= executing SLEEP instruction

bit 4 TO Time-out ; Watchdog overflow.

Bit is set after turning on the supply and execution of CLRWDT and SLEEP instructions. Bit is reset when watchdog gets to the end signaling that something is not right.

1=overflow did not occur

0=overflow did occur

bit6: 5 RP1:RP0 (Register Bank Select bits)

These two bits are upper part of the address for direct addressing. Since instructions which address the memory directly have only seven bits, they need one more bit in order to address all 256 bytes which is how many bytes PIC16F84 has. RP1 bit is not used, but is left for some future expansions of this microcontroller.

01=first bank

00=zero bank

bit 7 IRP (Register Bank Select bit)

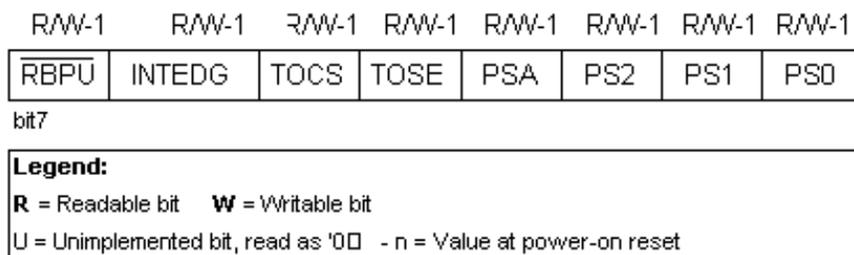
Bit whose role is to be an eighth bit for indirect addressing of internal RAM.

1=bank 2 and 3

0=bank 0 and 1 (from 00h to FFh)

STATUS register contains arithmetic status ALU (C, DC, Z), RESET status (TO, PD) and bits for selecting of memory bank (IRP, RP1, RP0). Considering that selection of memory bank is controlled through this register, it has to be present in each bank. Memory bank will be discussed in more detail in Memory organization chapter. STATUS register can be a destination for any instruction, with any other register. If STATUS register is a destination for instructions which affect Z, DC or C bits, then writing to these three bits is not possible.

OPTION register



bit 0:2 **PS0, PS1, PS2** (Prescaler Rate Select bit)

These three bits define prescaler rate select bit. What a prescaler is and how these bits can affect the work of a microcontroller will be explained in section on TMRO.

Bits	TMRO	WDT
000	1 : 2	1 : 1
001	1 : 4	1 : 2
010	1 : 8	1 : 4
011	1 : 16	1 : 8
100	1 : 32	1 : 16
101	1 : 64	1 : 32
110	1 : 128	1 : 64
111	1 : 256	1 : 128

bit 3 **PSA** (Prescaler Assignment bit)

Bit which assigns prescaler between TMRO and watchdog.

1=prescaler is assigned to watchdog

0=prescaler is assigned to a free-run timer TMRO

bit 4 **TOSE** (TMRO Source Edge Select bit)

If it is allowed to trigger TMRO by impulses from the pin RA4/TOCKI, this bit determines whether this will be to the falling or rising edge of a signal.

1=falling edge

0=rising edge

bit 5 **TOCS** (TMRO Clock Source Select bit)

This pin enables free-run timer to increment its state either from internal oscillator on every $\frac{1}{4}$ of oscillator clock, or through external impulses on RA4/TOCKI pin.

1=external impulses

0=1/4 internal clock

bit 6 **INTEDG** (Interrupt Edge Select bit)

If interrupt is enabled possible this bit will determine the edge at which an interrupt will be activated on pin RB0/INT.

1=rising edge

0=falling edge

bit 7 **RBP $\overline{\text{U}}$** (PORTB Pull-up Enable bit)

This bit turns on and off internal 'pull-up' resistors on port B.

1= "pull-up" resistors turned off

0= "pull-up" resistors turned on

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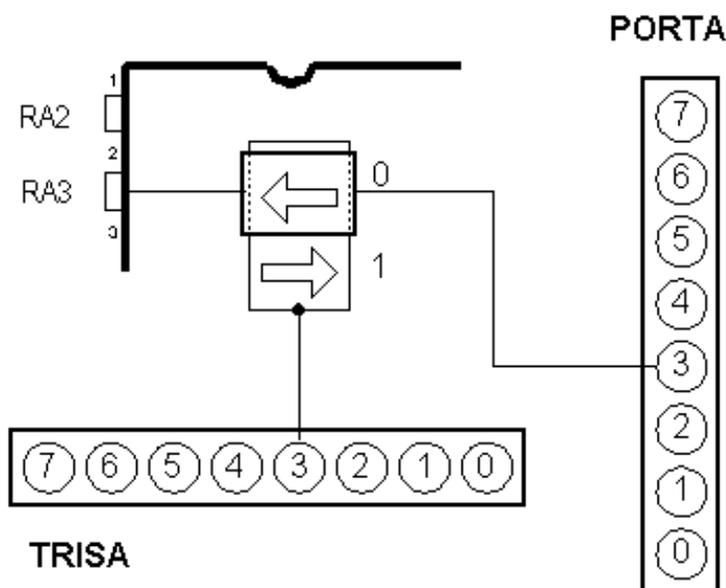
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2.4 Ports

Port refers to a group of pins on a microcontroller which can be accessed simultaneously, or on which we can set the desired combination of zeros and ones, or read from them an existing status. Physically, port is a register inside a microcontroller which is connected by wires to the pins of a microcontroller. Ports represent physical connection of Central Processing Unit with an outside world. Microcontroller uses them in order to monitor or control other components or devices. Due to functionality, some pins have twofold roles like PA4/TOCKI for instance, which is simultaneously the fourth bit of port A and an external input for free-run counter. Selection of one of these two pin functions is done in one of the configurational registers. An illustration of this is the fifth bit TOCS in OPTION register. By selecting one of the functions the other one is disabled.



Relationship between TRISA and PORTA register

All port pins can be defined as input or output, according to the needs of a device that's being developed. In order to define a pin as input or output pin, the right combination of zeros and ones must be written in TRIS register. If at the appropriate place in TRIS register a logical "1" is written, then that pin is an input pin, and if the opposite is true, it's an output pin. Every port has its proper TRIS register. Thus, port A has TRISA at address 85h, and port B has TRISB at address 86h.

PORTB

PORTB has 8 pins joined to it. The appropriate register for direction of data is TRISB at address 86h. Setting a bit in TRISB register defines the corresponding port pin as an input pin, and resetting a bit in TRISB register defines the corresponding port pin as the output pin. Each pin on PORTB has a weak internal pull-up resistor (resistor which defines a line to logic one) which can be activated by resetting the seventh bit RBPU in OPTION register. These 'pull-up' resistors are automatically being turned off when port pin is configured as an output. When a microcontroller is started, pull-up's are disabled.

Four pins PORTB, RB7:RB4 can cause an interrupt which occurs when their status changes from logical one into logical zero and opposite. Only pins configured as input can cause this interrupt to occur (if any RB7:RB4 pin is configured as an output, an interrupt won't be generated at the change of status.) This interrupt option along with internal pull-up resistors makes it easier to solve common problems we find in practice like for instance that of matrix keyboard. If rows on the keyboard are connected to these pins, each push on a key will then cause an interrupt. A microcontroller will determine which key is at hand while processing an interrupt. It is not recommended to refer to port B at the same time that interrupt is being

processed.

```

    clrf  STATUS      ;Bank0
    clrf  PORTB       ;PORTB=0
    bsf   STATUS,RPO  ;Bank1
    movlw 0x0F        ;Defining input and output pins
    movwf TRISB       ;Writing to TRISB register

```

The above example shows how pins 0, 1, 2, and 3 are declared for input, and pins 4, 5, 6, and 7 for output.

PORTA

PORTA has 5 pins joined to it. The corresponding register for data direction is TRISA at address 85h. Like with port B, setting a bit in TRISA register defines also the corresponding port pin as an input pin, and clearing a bit in TRISA register defines the corresponding port pin as an output pin.

The fifth pin of port A has dual function. On that pin is also situated an external input for timer TMR0. One of these two options is chosen by setting or resetting the TOCS bit (TMR0 Clock Source Select bit). This pin enables the timer TMR0 to increase its status either from internal oscillator or via external impulses on RA4/TOCKI pin.

```

    bcf   STATUS,RPO  ;Bank0
    clrf  PORTA       ;PORTA=0
    bsf   STATUS,RPO  ;Bank1
    movlw 0x1F        ;Defining input and output pins pinova
    movwf TRISA       ;Writing to TRISA register

```

Example shows how pins 0, 1, 2, 3, and 4 are declared to be input, and pins 5, 6, and 7 to be output pins.

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2.5 Memory organization

PIC16F84 has two separate memory blocks, one for data and the other for program. EEPROM memory and GPR registers in RAM memory make up a data block, and FLASH memory makes up a program block.

Program memory

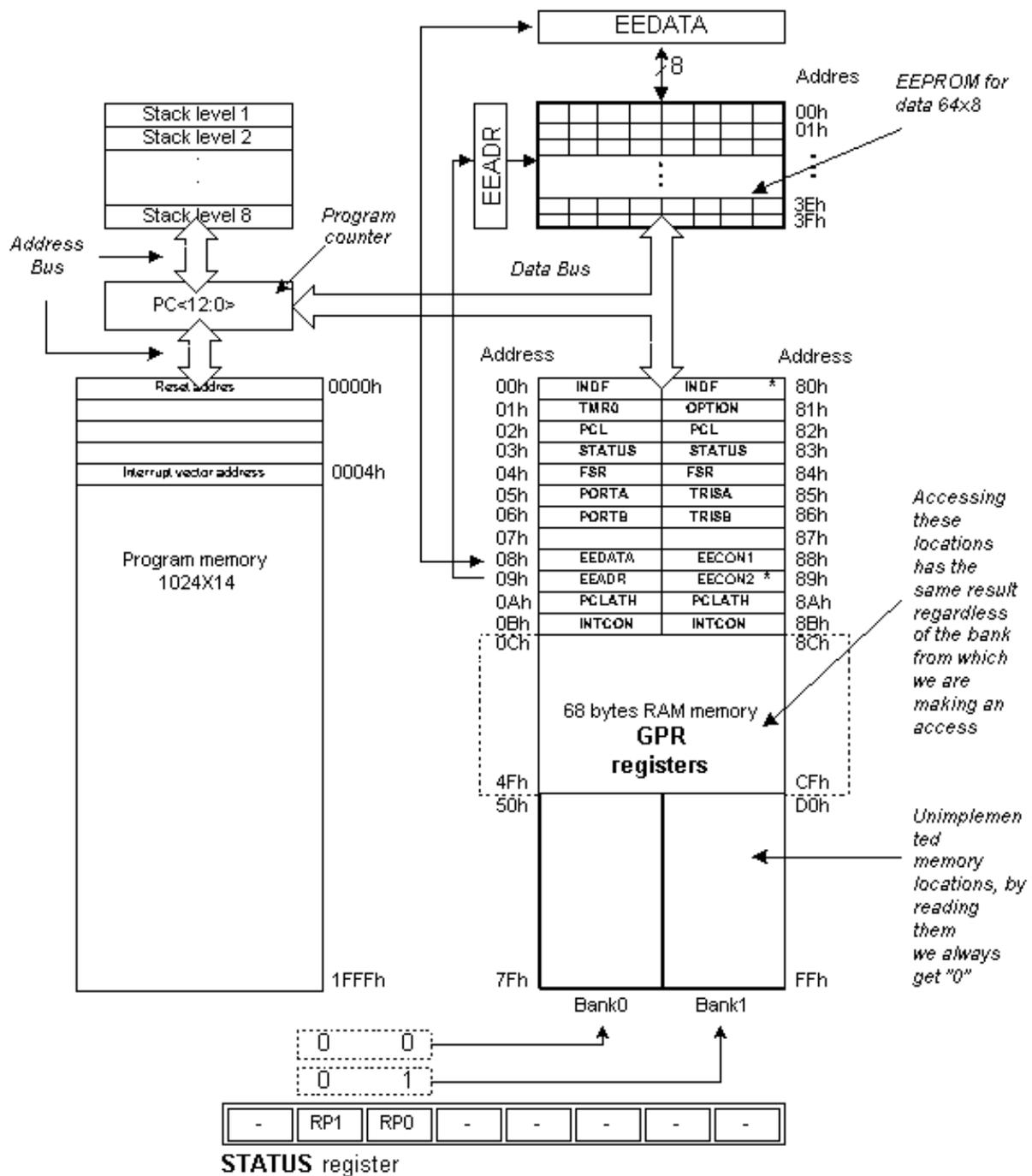
Program memory has been realized in FLASH technology which makes it possible to program a microcontroller many times before it's installed into a device, and even after its installment if eventual changes in program or process parameters should occur. The size of program memory is 1024 locations with 14 bits width where locations zero and four are reserved for reset and interrupt vector.

Data memory

Data memory consists of EEPROM and RAM memories. EEPROM memory consists of 64 eight bit locations whose contents is not lost during loosing of power supply. EEPROM is not directly addressible, but is accessed indirectly through EEADR and EEDATA registers. As EEPROM memory usually serves for storing important parameters (for example, of a given temperature in temperature regulators) , there is a strict procedure for writing in EEPROM which must be followed in order to avoid accidental writing. RAM memory for data occupies space on a memory map from location 0x0C to 0x4F which comes to 68 locations. Locations of RAM memory are also called GPR registers which is an abbreviation for General Purpose Registers. GPR registers can be accessed regardless of which bank is selected at the moment.

SFR registers

Registers which take up first 12 locations in banks 0 and 1 are registers of specialized function assigned with certain blocks of the microcontroller. These are called Special Function Registers.



Memory organization of microcontroller PIC16F84

Memory Banks

Beside this 'length' division to SFR and GPR registers, memory map is also divided in 'width' (see preceding map) to two areas called 'banks'. Selecting one of the banks is done via RP0 and RP1 bits in STATUS register.

Example:

```
bcf STATUS, RP0
```

Instruction BCF clears bit RP0 (RP0=0) in STATUS register and thus sets up bank 0.

```
bsf STATUS, RP0
```

Instruction BSF sets the bit RP0 (RP0= 1) in STATUS register and thus sets up bank1.

Usually, groups of instructions that are often in use, are connected into one unit which can easily be recalled in a program,

and whose name has a clear meaning, so called Macros. With their use, selection between two banks becomes more clear and the program itself more legible.

```
BANK0 macro
    Bcf STATUS, RP0    ;Select memory bank 0
Endm

BANK1 macro
    Bsf STATUS, RP0    ;Select memory bank 1
Endm
```



Locations 0Ch - 4Fh are general purpose registers (GPR) which are used as RAM memory. When locations 8Ch - CFh in Bank 1 are accessed, we actually access the exact same locations in Bank 0. In other words, whenever you wish to access one of the GPR registers, there is no need to worry about which bank we are in!

Program Counter

Program counter (PC) is a 13 bit register that contains the address of the instruction being executed. By its incrementing or change (ex. in case of jumps) microcontroller executes program instructions step-by-step.

Stack

PIC16F84 has a 13-bit stack with 8 levels, or in other words, a group of 8 memory locations of 13 -bits width with special function. Its basic role is to keep the value of program counter after a jump from the main program to an address of a subprogram. In order for a program to know how to go back to the point where it started from, it has to return the value of a program counter from a stack. When moving from a program to a subprogram, program counter is being pushed onto a stack (example of this is CALL instruction). When executing instructions such as RETURN, RETLW or RETFIE which were executed at the end of a subprogram, program counter was taken from a stack so that program could continue where was stopped before it was interrupted. These operations of placing on and taking off from a program counter stack are called PUSH and POP, and are named according similar instructions on some bigger microcontrollers.

In System Programming

In order to program a program memory, microcontroller must be set to special working mode by bringing up MCLR pin to 13.5V, and supply voltage Vdd has to be stabilized between 4.5V to 5.5V. Program memory can be programmed serially using two 'data/clock' pins which must previously be separated from device lines, so that errors wouldn't come up during programming.

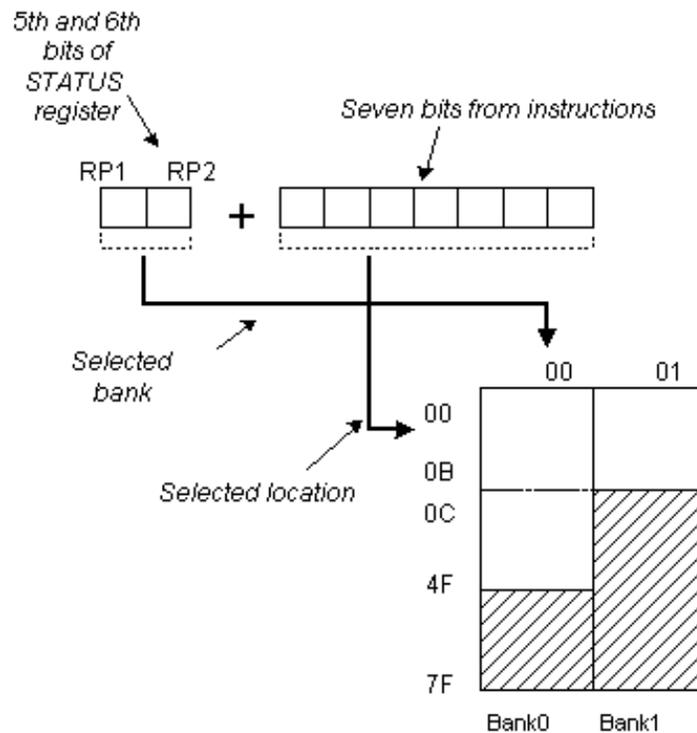
Addressing modes

RAM memory locations can be accessed directly or indirectly.

Direct Addressing

Direct Addressing is done through a 9-bit address. This address is obtained by connecting 7th bit of direct address of an instruction with two bits (RP1, RP0) from STATUS register as is shown on the following picture. Any access to SFR registers can be an example of direct addressing.

```
Bsf STATUS, RP0 ;Bank1
movlw 0xFF      ;w=0xFF
movwf TRISA     ;address of TRISA register is taken from
                ;instruction movwf
```

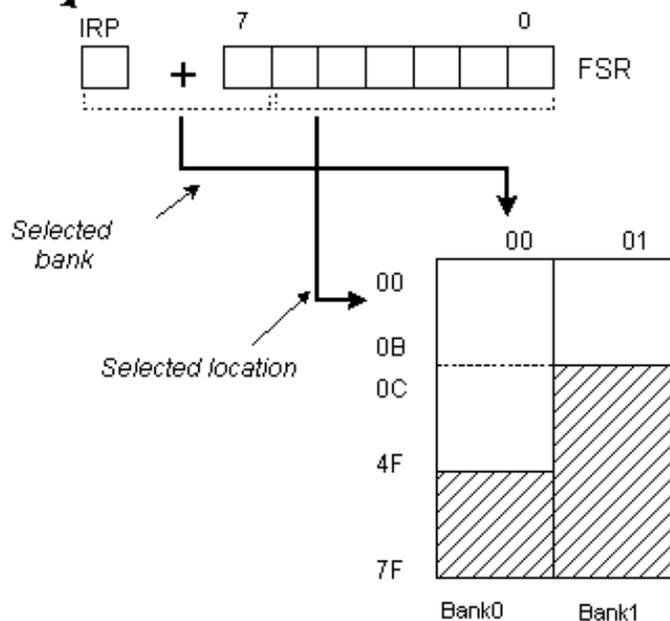


Direct addressing

Indirect Addressing

Indirect unlike direct addressing does not take an address from an instruction but makes it with the help of IRP bit of STATUS and FSR registers. Addressed location is accessed via INDF register which in fact holds the address indicated by a FSR. In other words, any instruction which uses INDF as its register in reality accesses data indicated by a FSR register. Let's say, for instance, that one general purpose register (GPR) at address 0Fh contains a value of 20. By writing a value of 0Fh in FSR register we will get a register indicator at address 0Fh, and by reading from INDF register, we will get a value of 20, which means that we have read from the first register its value without accessing it directly (but via FSR and INDF). It appears that this type of addressing does not have any advantages over direct addressing, but certain needs do exist during programming which can be solved smoothly only through indirect addressing.

Seventh bit of
STATUS
register



Indirect addressing

An of such example can be sending a set of data via serial communication, working with buffers and indicators (which will be discussed further in a chapter with examples), or erasing a part of RAM memory (16 locations) as in the following instance.

```

        Movlw 0x0C          ;initialization of starting address
        Movwf FSR          ;FSR indicates address 0x0C
LOOP    clrf INDF          ;INDF = 0
        incf FSR           ;address = initial address + 1
        btfss FSR,4        ;are all locations erased
        goto loop          ;no, go through a loop again
CONTINUE
        :                  ; yes, continue with program

```

Reading data from INDF register when the contents of FSR register is equal to zero returns the value of zero, and writing to it results in NOP operation (no operation).

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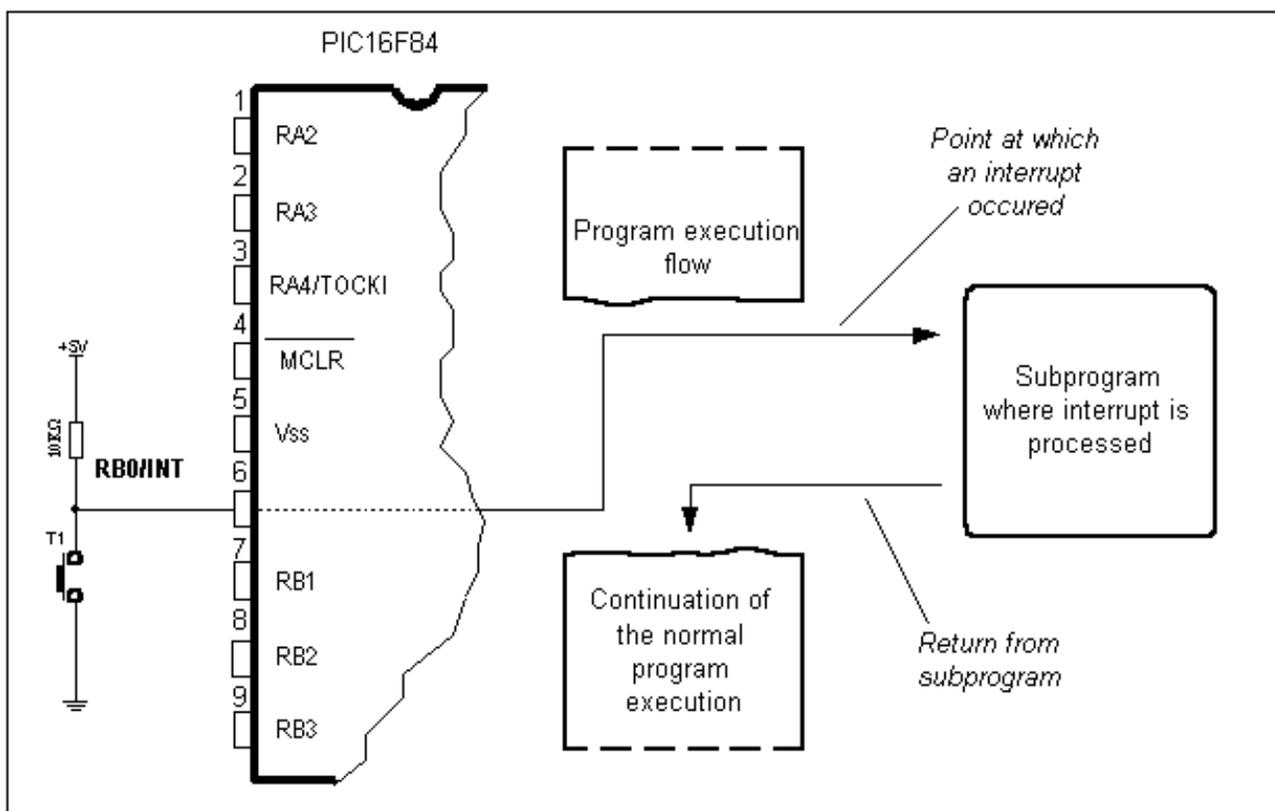
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2.6 Interrupts

Interrupts are a mechanism of a microcontroller which enables it to respond to some events at the moment when they occur, regardless of what microcontroller is doing at the time. This is a very important part, because it provides connection between a microcontroller and environment which surrounds it. Generally, each interrupt changes the program flow, interrupts it and after executing an interrupt subprogram (interrupt routine) it continues from that same point on.



One of the possible sources of an interrupt and how it affects the main program

One of the possible sources of an interrupt and how it affects the main program

Control register of an interrupt is called INTCON and is found at 0Bh address. Its role is to allow or disallowed interrupts, and in case they are not allowed, it registers single interrupt requests through its own bits.

INTCON Register

R/W-0 R/W-0 R/W-0 R/W-0 R/W-0 R/W-0 R/W-0 R/W-0

GIE	EEIE	TOIE	INTE	RBIE	TOIF	INTF	RBIF
-----	------	------	------	------	------	------	------

bit7

Legend:**R** = Readable bit **W** = Writable bit**U** = Unimplemented bit, read as '0' - n = Value at power-on reset

bit 0 RBIF (RB Port Change Interrupt Flag bit) Bit which informs about changes on pins 4, 5, 6 and 7 of port B.
1=at least one pin has changed its status
0=no change occurred on any of the pins

bit 1 INTF (INT External Interrupt Flag bit) External interrupt occurred.
1=interrupt occurred
0=interrupt did not occur

If a rising or falling edge was detected on pin RB0/INT, (which is defined with bit INTEDG in OPTION register), bit INTF is set. Bit must be cleared in interrupt subprogram in order to detect the next interrupt.

bit 2 TOIF (TMR0 Overflow Interrupt Flag bit) Overflow of counter TMR0.
1= counter changed its status from FFh to 00h
0=overflow did not occur
Bit must be cleared in program in order for an interrupt to be detected.

bit 3 RBIE (RB port change Interrupt Enable bit) Enables interrupts to occur at the change of status of pins 4, 5, 6, and 7 of port B.
1= enables interrupts at the change of status
0=interrupts disabled at the change of status
If RBIE and RBIF were simultaneously set, an interrupt would occur.

bit 4 INTE (INT External Interrupt Enable bit) Bit which enables external interrupt from pin RB0/INT.
1=external interrupt enabled
0=external interrupt disabled
If INTE and INTF were set simultaneously, an interrupt would occur.

bit 5 TOIE (TMR0 Overflow Interrupt Enable bit) Bit which enables interrupts during counter TMR0 overflow.
1=interrupt enabled
0=interrupt disabled
If TOIE and TOIF were set simultaneously, interrupt would occur.

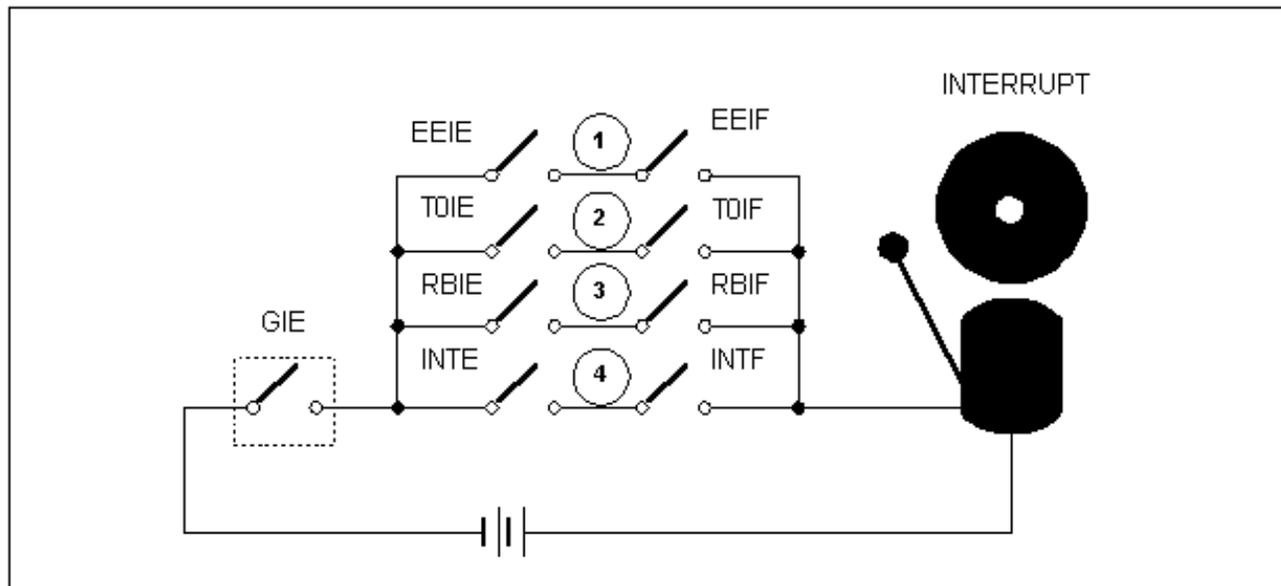
Bit 6 EEIE (EEPROM Write Complete Interrupt Enable bit) Bit which enables an interrupt at the end of a writing routine to EEPROM
1=interrupt enabled
0=interrupt disabled
If EEIE and EEIF (which is in EECON1 register) were set simultaneously, an interrupt would occur.

Bit 7 GIE (Global Interrupt Enable bit) Bit which enables or disables all interrupts.
1=all interrupts are enabled
0=all interrupts are disabled

PIC16F84 has four interrupt sources:

1. Termination of writing data to EEPROM
2. TMR0 interrupt caused by timer overflow
3. Interrupt during alteration on RB4, RB5, RB6 and RB7 pins of port B.
4. External interrupt from RB0/INT pin of microcontroller

Generally speaking, each interrupt source has two bits joined to it. One enables interrupts, and the other detects when interrupts occur. There is one common bit called GIE which can be used to disallow or enable all interrupts simultaneously. This bit is very useful when writing a program because it allows for all interrupts to be disabled for a period of time, so that execution of some important part of a program would not be interrupted. When instruction which resets GIE bit was executed (GIE=0, all interrupts disallowed), any interrupt that remained unsolved should be ignored.



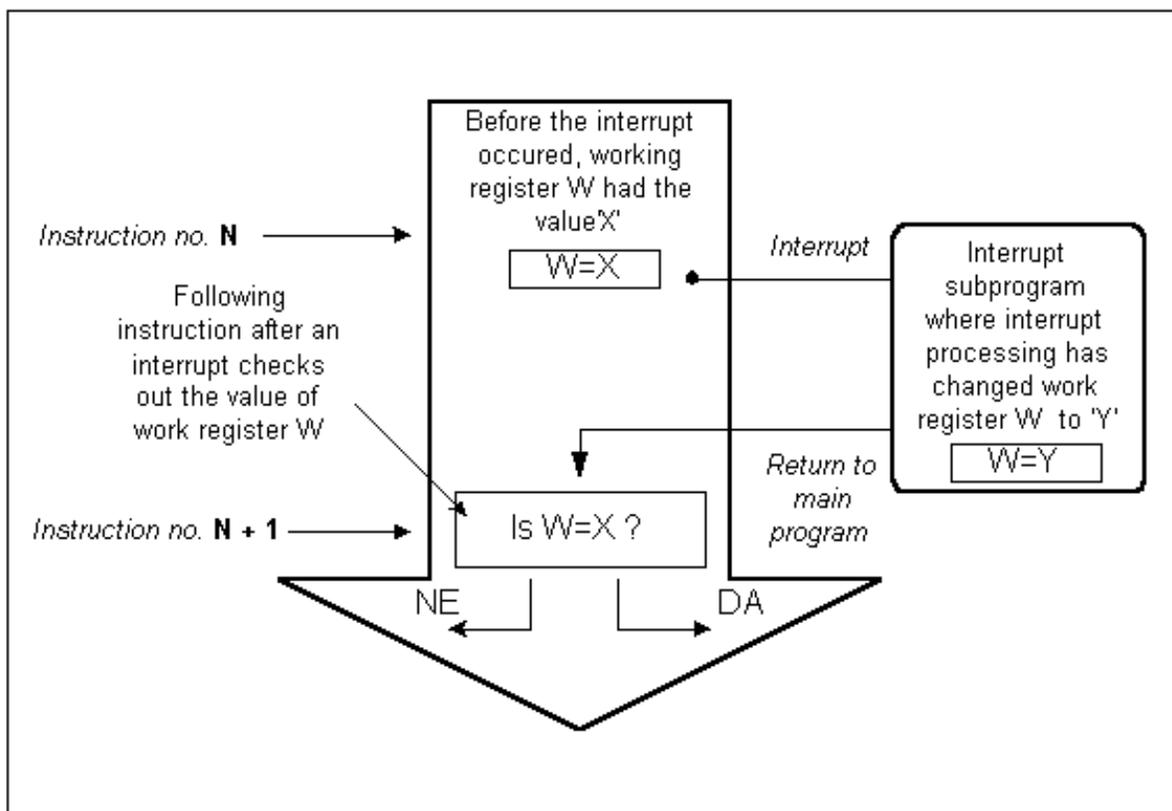
Simplified outline of PIC16F84 microcontroller interrupt

Interrupts which remained unsolved and were ignored, are processed when GIE bit (GIE= 1, all interrupts allowed) would be cleared. When interrupt was answered, GIE bit was cleared so that any additional interrupts would be disabled, return address was pushed onto stack and address 0004h was written in program counter - only after this does replying to an interrupt begin! After interrupt is processed, bit whose setting caused an interrupt must be cleared, or interrupt routine would automatically be processed over again during a return to the main program.

Keeping the contents of important registers

Only return value of program counter is stored on a stack during an interrupt (by return value of program counter we mean the address of the instruction which was to be executed, but wasn't because interrupt occurred). Keeping only the value of program counter is often not enough. Some registers which are already in use in the main program can also be in use in interrupt routine. If they were not retained, main program would during a return from an interrupt routine get completely different values in those registers, which would cause an error in the program. One example for such a case is contents of the work register W. If we suppose that main program was using work register W for some of its operations, and if it had stored in it some value that's important for the following instruction, then an interrupt which occurs before that instruction would change the value of work register W which would directly be influenced the main program.

Procedure of recording important registers before going to an interrupt routine is called PUSH, while the procedure which brings recorded values back, is called POP. PUSH and POP are instructions with some other microcontrollers (Intel), but are so widely accepted that a whole operation is named after them. PIC16F84 does not have instructions like PUSH and POP, and they have to be programmed.



One of the possible cases of errors if saving was not done when going to a subprogram of an interrupt

One of the possible cases of errors if saving was not done when going to a subprogram of an interrupt

Due to simplicity and frequent usage, these parts of the program can be made as macros. The concept of a Macro is explained in "Program assembly language". In the following example, contents of W and STATUS registers are stored in W_TEMP and STATUS_TEMP variables prior to interrupt routine. At the beginning of PUSH routine we need to check presently selected bank because W_TEMP and STATUS_TEMP are found in bank 0. For exchange of data between these registers, SWAPF instruction is used instead of MOVF because it does not affect the status of STATUS register bits.

Example is a program assembler for following steps:

1. Testing the current bank
2. Storing W register regardless of the current bank
3. Storing STATUS register in bank 0.
4. Executing interrupt routine for interrupt processing (ISR)
5. Restores STATUS register
6. Restores W register

If there are some more variables or registers that need to be stored, then they need to be kept after storing STATUS register (step 3), and brought back before STATUS register is restored (step 5).

```

Push
    BTFSS STATUS, RPO          ; Bank 0
    GOTO RPOCLEAR             ; Yes
    BCF STATUS, RPO           ; NO, go to Bank 0
    MOVWF W_TEMP               ; Save W register
    SWAPF STATUS, W           ; W <- STATUS
    MOVWF STATUS_TEMP         ; STATUS_TEMP <- W
    BSF STATUS_TEMP, 1        ; RPO(STATUS_TEMP)=1
    GOTO ISR_Code             ; Push completed
RPOCLEAR
    MOVWF W_TEMP               ; Save W register
    SWAPF STATUS, W           ; W <- STATUS
    MOVWF STATUS_TEMP         ; STATUS_TEMP <- W
;
ISR_Code
    ;
    ; (Interrupt subprogram)
    ;
;
Pop
    SWAPF STATUS_TEMP, W      ; W <- STATUS_TEMP
    MOVWF STATUS               ; STATUS <- W
    BTFSS STATUS, RPO         ; Bank 1?
    GOTO Return_WREG          ; NO,
    BCF STATUS, RPO           ; YES, go to Bank 0
    SWAPF W_TEMP, F           ; Return contents of W register
    SWAPF W_TEMP, W           ;
    BSF STATUS, RPO           ; Return to Bank 1
    RETFIE                     ; POP complete
Return_WREG
    SWAPF W_TEMP, F           ; Return contents of W register
    SWAPF W_TEMP, W           ;
    RETFIE                     ; POP completed

```

The same example can be realized by using macros, thus getting a more legible program. Macros that are already defined can be used for writing new macros. Macros BANK1 and BANK0 which are explained in "Memory organization" chapter are used with macros 'push' and 'pop'.

```

push    macro
    movwf W_Temp               ;W_Temp <- W
    swapf W_Temp,F             ;Swap them
    BANK1                       ;Macro for switching to Bank1
    swapf OPTION_REG,W         ;W <- OPTION_REG
    movwf Option_Temp          ;Option_Temp <- W
    BANK0                       ;macro for switching to Bank0
    swapf STATUS,W             ;W <- STATUS
    movwf Stat_Temp            ;Stat_Temp <-W
    endm                        ;End of push macro

pop     macro
    swapf Stat_Temp,W          ;W <- Stat_Temp
    movwf STATUS               ;STATUS <- W
    BANK1                       ;Macro for switching to Bank1
    swapf Option_Temp,W        ;W <- Option_Temp
    movwf OPTION_REG           ;OPTION_REG <- W
    BANK0                       ;Macro for switching to Bank0
    swapf W_Temp,W             ;W <- W_Temp
    endm                        ;End of a pop macro

```

External interrupt on RB0/INT pin of microcontroller

External interrupt on RB0/INT pin is triggered by rising signal edge (if bit INTEDG=1 in OPTION<6> register), or falling edge (if INTEDG=0). When correct signal appears on INT pin, INTF bit is set in INTCON register. INTF bit (INTCON<1>) must be

reset in interrupt routine, so that interrupt wouldn't occur again while going back to the main program. This is an important part of the program which programmer must not forget, or program will constantly go into interrupt routine. Interrupt can be turned off by resetting INTE control bit (INTCON<4>).

Interrupt during a TMRO counter overflow

Overflow of TMRO counter (from FFh to 00h) will set TOIF (INTCON<2>) bit. This is very important interrupt because many real problems can be solved using this interrupt. One of the examples is time measurement. If we know how much time counter needs in order to complete one cycle from 00h to FFh, then a number of interrupts multiplied by that amount of time will yield the total of elapsed time. In interrupt routine some variable would be incremented in RAM memory, value of that variable multiplied by the amount of time the counter needs to count through a whole cycle, would yield total elapsed time. Interrupt can be turned on/off by setting/resetting TOIE (INTCON<5>) bit.

Interrupt during a change on pins 4, 5, 6 and 7 of port B

Change of input signal on PORTB <7:4> sets RBIF (INTCON<0>) bit. Four pins RB7, RB6, RB5 and RB4 of port B, can trigger an interrupt which occurs when status on them changes from logic one to logic zero, or vice versa. For pins to be sensitive to this change, they must be defined as input. If any one of them is defined as output, interrupt will not be generated at the change of status. If they are defined as input, their current state is compared to the old value which was stored at the last reading from port B. Interrupt can be turned on/off by setting/resetting RBIE bit in INTCON register.

Interrupt upon finishing write-subroutine to EEPROM

This interrupt is of practical nature only. Since writing to one EEPROM location takes about 10ms (which is a long time in the notion of a microcontroller), it doesn't pay off to a microcontroller to wait for writing to end. Thus interrupt mechanism is added which allows the microcontroller to continue executing the main program, while writing in EEPROM is being done in the background. When writing is completed, interrupt informs the microcontroller that writing has ended. EEIF bit, through which this informing is done, is found in EECON1 register. Occurrence of an interrupt can be disabled by resetting the EEIE bit in INTCON register.

Interrupt initialization

In order to use an interrupt mechanism of a microcontroller, some preparatory tasks need to be performed. These procedures are in short called "initialization". By initialization we define to what interrupts the microcontroller will respond, and which ones it will ignore. If we do not set the bit that allows a certain interrupt, program will not execute an interrupt subprogram. Through this we can obtain control over interrupt occurrence, which is very useful.

```

    clrf INTCON           ; all interrupts disabled
    movlw B'00010000'    ; external interrupt only is enabled
    bsf INTCON, GIE      ; occurrence of interrupts allowed

```

The above example shows initialization of external interrupt on RB0 pin of a microcontroller. Where we see one being set, that means that interrupt is enabled. Occurrence of other interrupts is not allowed, and all interrupts together are disallowed until GIE bit is keeping to one.

The following example shows a typical way of handling interrupts. PIC16F84 has only one location where the address of an interrupt subprogram is stored. This means that first we need to detect which interrupt is at hand (if more than one interrupt source is available), and then we can execute that part of a program which refers to that interrupt.

```

org ISR_ADDR           ;ISR_ADDR is interrupt routine address
btfsc INTCON, GIE      ;GIE bit turned off?
goto ISR_ADDR         ;no, go back to the beginning
PUSH                   ;keep the contents of important registers
btfsc INTCON, RBIF     ;change on pins 4, 5, 6 and 7 of port B?
goto ISR_PORTB        ;jump to that section
btfsc INTCON,INTF      ;external interrupt occurred?
goto ISR_RBO          ;jump to that part
btfsc INTCON, TOIF     ;overflow of timer TMRO?
goto ISR_TMRO         ;jump to that section
BANK1                  ;Bank1 because of EECON1
Btfsc EECON1, EEIF     ;writing to EEPROM completed?
goto ISR_EEPROM       ;jump to that section
BANK0                  ;Bank0

ISR_PORTB
:                      ;section of code which is processed by an
:                      ;interrupt ?
:
:                      ;jump to the exit of an interrupt
goto END_ISR
ISR_RBO
:                      ;section of code processing an interrupt?
:
:                      ;jump to exit of an interrupt.
goto END_ISR
ISR_TMRO
:                      ;section of code processing an interrupt
:
:                      ;jump to the exit of an interrupt
goto END_ISR
ISR_EEPROM
:                      ;section of code which processes an interrupt
:
:                      ;jump to an exit from an interrupt.
goto END_ISR
END_ISR
:
POP                    ;bringing back the contents of important
:                      ;registers
RETFIE                 ;return and setting of GIE bit

```



Return from interrupt routine can be accomplished with instructions RETURN, RETLW and RETFIE. It is recommended that instruction RETFIE be used because that instruction is the only one which automatically sets the GIE bit which allows new interrupts to occur.

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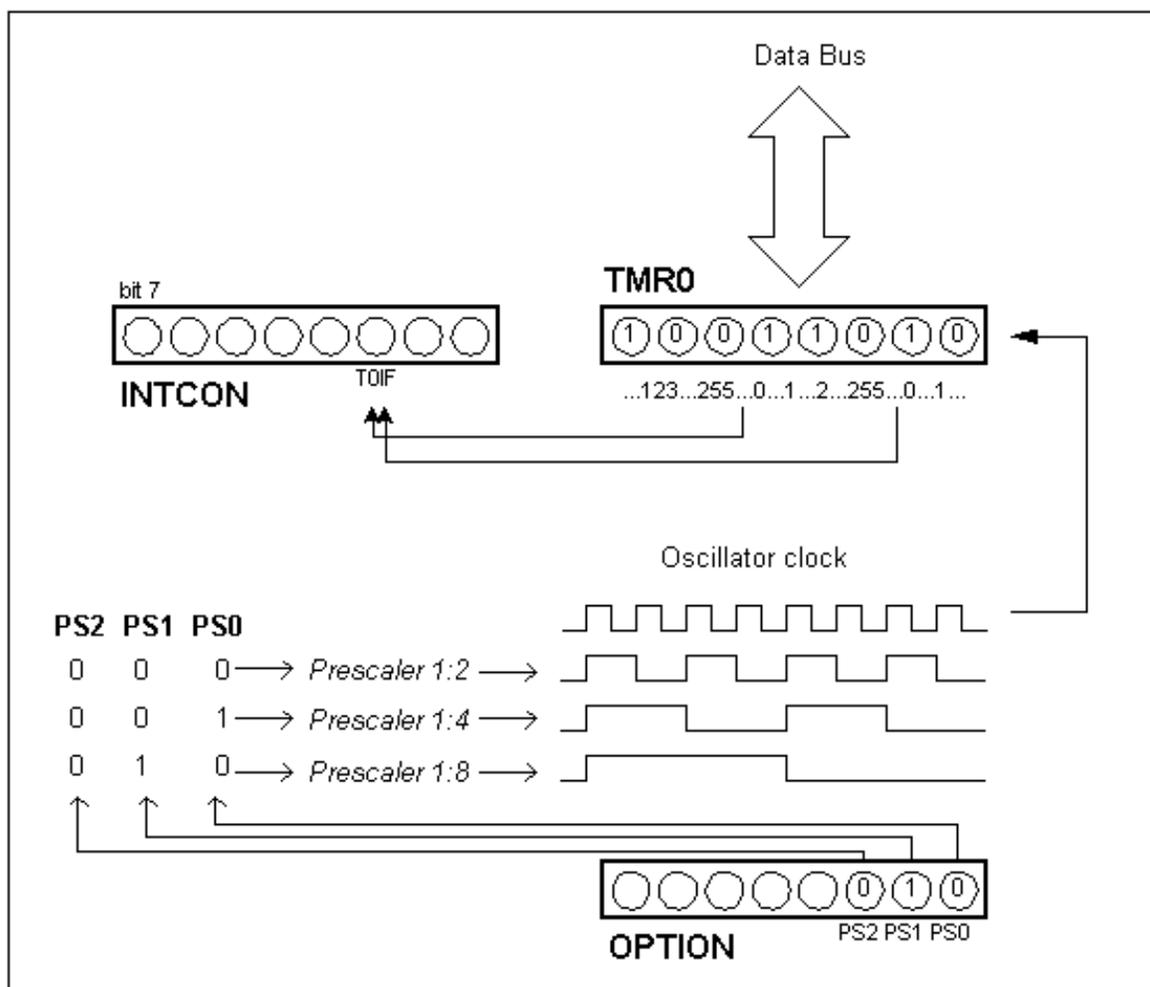
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2.7 Free-run timer TMR0

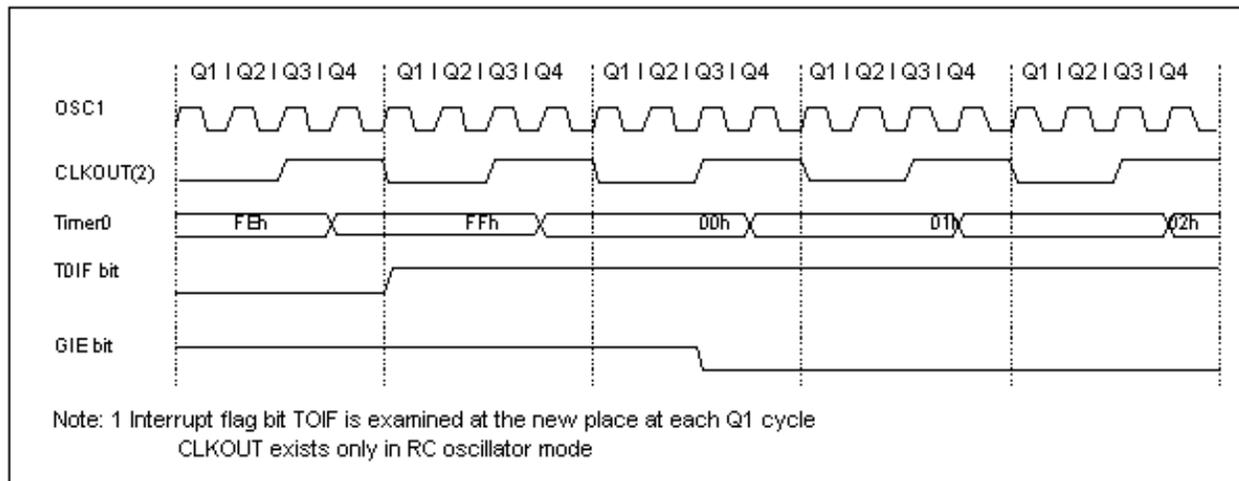
Timers are usually most complicated parts of a microcontroller, so it is necessary to set aside more time for their explaining. With their application it is possible to create relations between a real dimension such as "time" and a variable which represents status of a timer within a microcontroller. Physically, timer is a register whose value is continually increasing to 255, and then it starts all over again: 0, 1, 2, 3, 4...255...0, 1, 2, 3.....etc.



Relation between the timer TMR0 and prescaler

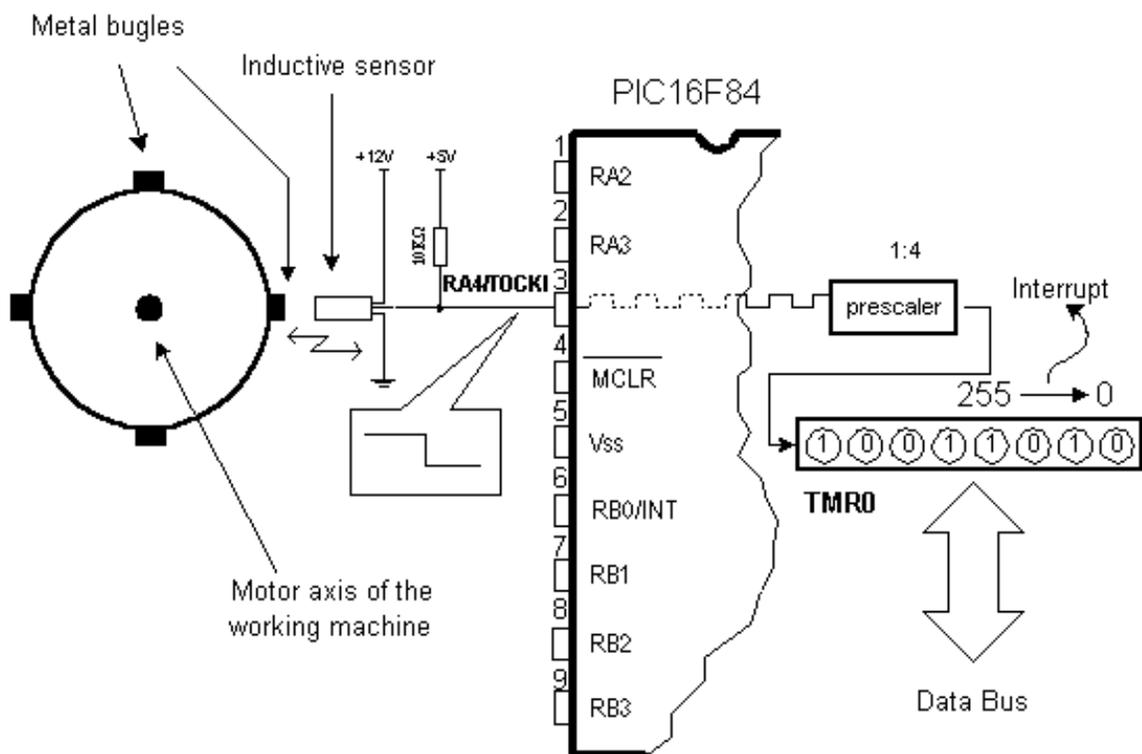
This incrementing is done in the background of everything a microcontroller does. It is up to programmer to "think up a way" how he will take advantage of this characteristic for his needs. One of the ways is increasing some variable on each timer overflow. If we know how much time a timer needs to make one complete round, then multiplying the value of a variable by that time will yield the total amount of elapsed time.

PIC16F84 has an 8-bit timer. Number of bits determines what value timer counts to before starting to count from zero again. In the case of an 8-bit timer, that number is 256. A simplified scheme of relation between a timer and a prescaler is represented on the previous diagram. Prescaler is a name for the part of a microcontroller which divides oscillator clock before it will reach logic that increases timer status. Number which divides a clock is defined through first three bits in **OPTION** register. The highest divisor is 256. This actually means that only at every 256th clock, timer value would increase by one. This provides us with the ability to measure longer timer periods.



Time diagram of interrupt occurrence with TMR0 timer

After each count up to 255, timer resets its value to zero and starts with a new cycle of counting to 255. During each transition from 255 to zero, TOIF bit in INTCOM register is set. If interrupts are allowed to occur, this can be taken advantage of in generating interrupts and in processing interrupt routine. It is up to programmer to reset TOIF bit in interrupt routine, so that new interrupt, or new overflow could be detected. Beside the internal oscillator clock, timer status can also be increased by the external clock on RA4/TOCKI pin. Choosing one of these two options is done in OPTION register through T0CS bit. If this option of external clock was selected, it would be possible to define the edge of a signal (rising or falling), on which timer would increase its value.



Determining a number of full axis turns of the motor

In practice, one of the typical example that is solved via external clock and a timer is counting full turns of an axis of some production machine, like transformer winder for instance. Let's wind four metal screws on the axis of a winder. These four screws will represent metal convexity. Let's place now the inductive sensor at a distance of 5mm from the head of a screw. Inductive sensor will generate the falling signal every time the head of the screw is parallel with sensor head. Each signal will represent one fourth of a full turn, and the sum of all full turns will be found in TMR0 timer. Program can easily read this data from the timer through a data bus.

The following example illustrates how to initialize timer to signal falling edges from external clock source with a prescaler 1:4. Timer works in "polig" mode.

```

    clrf TMRO          ;TMRO=0
    clrf INTCON        ;Interrupts and TOIF=0 disallowed
    bsf STATUS,RPO     ;Bank1 because of OPTION_REG
    movlw B'00110001' ;prescaler 1:4, falling edge selected external
                        ;clock source and pull up ;selected resistors
                        ;on port B activated
    movwf OPTION_REG ;OPTION_REG <- W
TO_OVFL
    btfss INTCON, TOIF ;testing overflow bit
    goto TO_OVFL      ;interrupt has not occurred yet, wait
;
; (Part of the program which processes data regarding a number of turns)
;
goto TO_OVFL          ;waiting for new overflow

```

The same example can be realized through an interrupt in the following way:

```

push macro
    movwf W_Temp          ;W_Temp <- W
    swapf W_Temp,F        ;Swap them
    BANK1                 ;Macro for switching to Bank1
    swapf OPTION_REG,W    ;W <- OPTION_REG
    movwf Option_Temp     ;Option_Temp <- W
    BANK0                 ;macro for switching to Bank0
    swapf STATUS,W        ;W <- STATUS
    movwf Stat_Temp       ;Stat_Temp <-W
endm                      ;End of push macro

pop macro
    swapf Stat_Temp,W     ;W <- Stat_Temp
    movwf STATUS          ;STATUS <- W
    BANK1                 ;Macro for switching to Bank1
    swapf Option_Temp,W   ;W <- Option_Temp
    movwf OPTION_REG      ;OPTION_REG <- W
    BANK0                 ;Macro for switching to Bank0
    swapf W_Temp,W        ;W <- W_Temp
endm                      ;End of a pop macro

```

Prescaler can be assigned either timer TMRO or a watchdog. Watchdog is a mechanism which microcontroller uses to defend itself against programs getting stuck. As with any other electrical circuit, so with a microcontroller too can occur failure, or some work impairment. Unfortunately, microcontroller also has program where problems can occur as well. When this happens, microcontroller will stop working and will remain in that state until someone resets it. Because of this, watchdog mechanism has been introduced. After a certain period of time, watchdog resets the microcontroller (microcontroller in fact resets itself). Watchdog works on a simple principle: if timer overflow occurs, microcontroller is reset, and it starts executing a program all over again. In this way, reset will occur in case of both correct and incorrect functioning. Next step is preventing reset in case of correct functioning, which is done by writing zero in WDT register (instruction CLRWDT) every time it nears its overflow. Thus program will prevent a reset as long as it's executing correctly. Once it gets stuck, zero will not be written, overflow of WDT timer and a reset will occur which will bring the microcontroller back to correct functioning again.

Prescaler is accorded to timer TMRO, or to watchdog timer through PSA bit in OPTION register. By clearing PSA bit, prescaler will be accorded to timer TMRO. When prescaler is accorded to timer TMRO, all instructions of writing to TMRO register (CLRF TMRO, MOVWF TMRO, BSF TMRO,...) will clear prescaler. When prescaler is assigned to a watchdog timer, only CLRWDT instruction will clear a prescaler and watchdog timer at the same time. Prescaler change is completely under programmer's control, and can be changed while program is running.



There is only one prescaler and one timer. Depending on the needs, they are assigned either to timer TMRO or to a watchdog.

OPTION Control Register

R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
RBP ^U	INTE ^{DG}	TOCS	TOSE	PSA	PS2	PS1	PS0
bit 7							bit 0

Legend:
R = Readable bit **W** = Writable bit
U = Unimplemented bit, read as '0' -n = Value at POR reset

Bit 0:2 PS0, PS1, PS2 (Prescaler Rate Select bit)

The subject of a prescaler, and how these bits affect the work of a microcontroller will be covered in section on TMRO.

Bits	TMRO	WDT
000	1 : 2	1 : 1
001	1 : 4	1 : 2
010	1 : 8	1 : 4
011	1 : 16	1 : 8
100	1 : 32	1 : 16
101	1 : 64	1 : 32
110	1 : 128	1 : 64
111	1 : 256	1 : 128

bit 3 PSA (Prescaler Assignment bit)

Bit which assigns prescaler between TMRO and watchdog timer.

1= prescaler is assigned to watchdog timer.

0= prescaler is assigned to free timer TMRO

bit 4 TOSE (TMRO Source Edge Select bit)

If trigger TMRO was enabled with impulses from a RA4/TOCKI pin, this bit would determine whether it would be on the rising or falling edge of a signal.

1= falling edge

0= rising edge

bit 5 TOCS (TMRO Clock Source Select bit)

This pin enables a free-run timer to increment its value either from an internal oscillator, i.e. every 1/4 of oscillator clock, or via external impulses on RA4/TOCKI pin.

1= external impulses

0= 1/4 internal clock

bit 6 INTE^{DG} (Interrupt Edge Select bit)

If occurrence of interrupts was enabled, this bit would determine at what edge interrupt on RB0/INT pin would occur.

1= rising edge

0= falling edge

bit 7 RBPU (PORTB Pull-up Enable bit)

This bit turns internal pull-up resistors on port B on or off.

1= 'pull-up' resistors turned on

0= 'pull-up' resistors turned off



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2.8 EEPROM Data memory

PIC16F84 has 64 bytes of EEPROM memory locations on addresses from 00h to 63h those can be written to or read from. The most important characteristic of this memory is that it does not lose its contents during power supply turned off. That practically means that what was written to it will be remaining even if microcontroller is turned off. Data can be retained in EEPROM without power supply for up to 40 years (as manufacturer of PIC16F84 microcontroller states), and up to 10000 cycles of writing can be executed.

In practice, EEPROM memory is used for storing important data or some process parameters. One such parameter is a given temperature, assigned when setting up a temperature regulator to some process. If that data wasn't retained, it would be necessary to adjust a given temperature after each loss of supply. Since this is very impractical (and even dangerous), manufacturers of microcontrollers have began installing one smaller type of EEPROM memory.

EEPROM memory is placed in a special memory space and can be accessed through special registers. These registers are:

- **EEDATA** at address 08h, which holds read data or that to be written.
- **EEADR** at address 09h, which contains an address of EEPROM location being accessed.
- **EECON1** at address 88h, which contains control bits.
- **EECON2** at address 89h. This register does not exist physically and serves to protect EEPROM from accidental writing.

EECON1 register at address 88h is a control register with five implemented bits.

Bits 5, 6 and 7 are not used, and by reading always are zero. Interpretation of EECON1 register bits follows.

EECON1 Register

U-0	U-0	U-0	R/W-1	R/W-1	R/W-x	R/S-0	R/S-x	
—	—	—	EEIF (1)	WRERR	WREN	WR	RD	
bit 7								bit 0

Legend:
R = Readable bit **W** = Writable bit
U = Unimplemented bit, read as '0' -n = Value at POR reset

bit 0 **RD** (Read Control bit)

Setting this bit initializes transfer of data from address defined in EEADR to EEDATA register. Since time is not as essential in reading data as in writing, data from EEDATA can already be used further in the next instruction.

1=initializes reading

0=does not initialize reading

bit 1 **WR** (Write Control bit)

Setting of this bit initializes writing data from EEDATA register to the address specified through EEADR register.

1=initializes writing

0=does not initialize writing

bit 2 **WREN** (EEPROM Write Enable bit) Enables writing to EEPROM

If this bit was not set, microcontroller would not allow writing to EEPROM.

1=writing allowed

0=writing disallowed

bit 3 **WRERR** (Write EEPROM Error Flag) Error during writing to EEPROM

This bit was set only in cases when writing to EEPROM had been interrupted by a reset signal or by running out of time in watchdog timer (if it's activated).

1=error occurred

0=error did not occur

bit 4 **EEIF** (EEPROM Write Operation Interrupt Flag bit) Bit used to inform that writing data to EEPROM has ended. When writing has terminated, this bit would be set automatically. Programmer must clear EEIF bit in his program in order to detect new termination of writing.

1=writing terminated

0=writing not terminated yet, or has not started

Reading from EEPROM Memory

Setting the RD bit initializes transfer of data from address found in EEADR register to EEDATA register. As in reading data we don't need so much time as in writing, data taken over from EEDATA register can already be used further in the next instruction.

Sample of the part of a program which reads data in EEPROM, could look something like the following:

```

bcf    STATUS, RPO           ;bank0, because EEADR is at 09h
movlw  0x00                  ;address of location being read
movwf  EEADR                 ;address transferred to EEADR
bsf    STATUS, RPO           ;bank1 because EECON1 is at 88h
bsf    EECON1, RD            ;reading from EEPROM
bcf    STATUS, RPO           ;Bank0 because EEDATA is at 08h
movf   EEDATA, W             ;W <-- EEDATA

```

After the last program instruction, contents from an EEPROM address zero can be found in working register w.

Writing to EEPROM Memory

In order to write data to EEPROM location, programmer must first write address to EEADR register and data to EEDATA register. Only then is it useful to set WR bit which sets the whole action in motion. WR bit will be reset, and EEIF bit set following a writing what may be used in processing interrupts. Values 55h and AAh are the first and the second key whose disallow for accidental writing to EEPROM to occur. These two values are written to EECON2 which serves only that purpose, to receive these two values and thus prevent any accidental writing to EEPROM memory. Program lines marked as 1, 2, 3, and 4 must be executed in that order in even time intervals. Therefore, it is very important to turn off interrupts which could change the timing needed for executing instructions. After writing, interrupts can be enabled again .

Example of the part of a program which writes data 0xEE to first location in EEPROM memory could look something like the following:

```

bcf    STATUS, RPO           ;bank0, because EEADR is at 09h
movlw  0x00                  ;address of location being
                               ;written to
movwf  EEADR                 ;address being transferred to
                               ;EEADR
movlw  0xEE                  ;write the value 0xEE
movwf  EEDATA                ;data goes to EEDATA register
bsf    STATUS, RPO           ;Bank1 because EEADR is at 09h
bcf    INTCON, GIE           ;all interrupts are disabled
bsf    EECON1, WREN          ;writing enabled
movlw  55h
1)    movwf EECON2            ;first key 55h --> EECON2
2)    movlw AAh
3)    movwf EECON2            ;second key AAh --> EECON2
4)    bsf  EECON1, WR         ;initializes writing
      bsf  INTCON, GIE        ;interrupts are enabled

```



*It is recommended that WREN be turned off the whole time except when writing data to EEPROM, so that possibility of accidental writing would be minimal.
All writing to EEPROM will automatically clear a location prior to writing a new!*

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CHAPTER 3

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Introduction

We have already mentioned that microcontroller is not like any other integrated circuit. When they come out of production most integrated circuits are ready to be built into devices which is not the case with microcontrollers. In order to "make" microcontroller perform a task, we have to tell it exactly what to do, or in other words we must write the program microcontroller will execute. We will describe in this chapter instructions which make up the assembler, or lower-level program language for PIC microcontrollers.

Instruction Set in PIC16Cxx Microcontroller Family

Complete set which includes 35 instructions is given in the following table. A reason for such a small number of instructions lies primarily in the fact that we are talking about a RISC microcontroller whose instructions are well optimized considering the speed of work, architectural simplicity and code compactness. The only drawback is that programmer is expected to master "uncomfortable" technique of using a reduced set of 35 instructions.

Data transfer

Transfer of data in a microcontroller is done between work (W) register and an 'f' register that represents any location in internal RAM (regardless whether those are special or general purpose registers).

First three instructions (look at the following table) provide for a constant being written in W register (MOVLW is short for MOVE Literal to W), and for data to be copied from W register onto RAM and data from RAM to be copied onto W register (or on the same RAM location, at which point only the status of Z flag changes). Instruction CLRF writes constant 0 in 'f' register, and CLRW writes constant 0 in register W. SWAPF instruction exchanges places of the 4-bit nibbles field inside a register.

Arithmetic and logic

Of all arithmetic operations, PIC like most microcontrollers supports only subtraction and addition. Flags C, DC and Z are set depending on a result of addition or subtraction, but with one exception: since subtraction is performed like addition of a negative value, C flag is inverse following a subtraction. In other words, it is set if operation is possible, and reset if larger number was subtracted from a smaller one.

Logic unit of PIC has capability of performing operations AND, OR, EX-OR, complementing (COMF) and rotation (RLF and RRF).

Instructions which rotate the register contents move bits inside a register through flag C by one space to the left (toward bit 7), or to the right (toward bit 0). Bit which "comes out" of a register is written in flag C, and value of C flag is written in a bit on the "opposite side" of the register.

Bit operations

Instructions BCF and BSF do setting or cleaning of one bit anywhere in the memory. Even though this seems like a simple operation, it is executed so that CPU first reads the whole byte, changes one bit in it and then writes in the entire byte at the same place.

Directing a program flow

Instructions GOTO, CALL and RETURN are executed the same way as on all other microcontrollers, only stack is independent of internal RAM and limited to eight levels.

'RETLW k' instruction is identical with RETURN instruction, except that before coming back from a subprogram a constant defined by instruction operand is written in W register. This instruction enables us to design easily the Look-up tables (lists). Mostly we use them by determining data position on our table adding it to the address at which the table begins, and then we read data from that location (which is usually found in program memory).

Table can be formed as a subprogram which consists of a series of 'RETLW k' instructions, where 'k' constants are members of the table.

```

Main      molov 2
          call Lookup
Lookup    addwf PCL, f
          retlw k
          retlw k1
          retlw k2
          :
          :
          retlw kn

```

We write the position of a member of our table in W register, and using CALL instruction we call a subprogram which creates the table. First subprogram line ADDWF PCL, f adds the position of a W register member to the starting address of our table, found in PCL register, and so we get the real data address in program memory. When returning from a subprogram we will have in W register the contents of an addressed table member. In a previous example, constant 'k2' will be in W register following a return from a subprogram.

RETFIE (RETurn From Interrupt - Interrupt Enable) is a return from interrupt routine and differs from a RETURN only in that it automatically sets GIE (Global Interrupt Enable) bit. Upon an interrupt, this bit is automatically cleared. As interrupt begins, only the value of program counter is put at the top of a stack. No automatic storing of register values and status is provided.

Conditional jumps are synthesized into two instructions: BTFSC and BTFSS. Depending on a bit status in 'f' register that is being tested, instructions skip or don't skip over the next program instruction.

Instruction Execution Period

All instructions are executed in one cycle except for conditional branch instructions if condition was true, or if the contents of program counter was changed by some instruction. In that case, execution requires two instruction cycles, and the second cycle is executed as NOP (No Operation). Four oscillator clocks make up one instruction cycle. If we are using an oscillator with 4MHz frequency, the normal time for executing an instruction is 1 μ s, and in case of conditional branching, execution

period is 2 μ s.

Word list

f any memory location in a microcontroller

W work register

b bit position in 'f' register

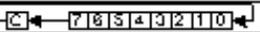
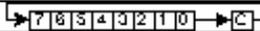
d destination bit

label group of eight characters which marks the beginning of a part of the program

TOS top of stack

[] option

<> bit position inside register

Mnemonic		Description	Operation	Flag	Cycle	Notes
Data transfer						
MOVLW	k	Move constant to W	$k \rightarrow W$		1	
MOVWF	f	Move W to f	$W \rightarrow f$		1	
MOVF	f, d	Move f	$f \rightarrow d$	Z	1	1,2
CLRW	-	Clear W	$0 \rightarrow W$	Z	1	
CLRF	f	Clear f	$0 \rightarrow f$	Z	1	2
SWAPF	f, d	Swap nibbles in f	$f(7:4), (3:0) \rightarrow f(3:0), (7:4)$		1	1,2
Arithmetic and logic						
ADDLW	k	Add constant and W	$W+1 \rightarrow W$	C,DC,Z	1	
ADDWF	f, d	Add W and f	$W+f \rightarrow d$	C,DC,Z	1	1,2
SUBLW	k	Subtract W from constant	$W-k \rightarrow W$	C,DC,Z	1	
SUBWF	f, d	Subtract W from f	$W-f \rightarrow d$	C,DC,Z	1	1,2
ANDLW	k	AND constant with W	$W.AND.k \rightarrow W$	Z	1	
ANDWF	f, d	AND W with f	$W.AND.f \rightarrow d$	Z	1	1,2
IORLW	k	OR constant with W	$W.OR.k \rightarrow W$	Z	1	
IORWF	f, d	OR W with f	$W.OR.f \rightarrow d$	Z	1	1,2
XORLW	k	Exclusive OR constant with W	$W.XOR.k \rightarrow W$	Z	1	1,2
XORWF	f, d	Exclusive OR W with f	$W.XOR.f \rightarrow d$	Z	1	
INCF	f, d	Increment f	$f+1 \rightarrow f$	Z	1	1,2
DECF	f, d	Decrement f	$f-1 \rightarrow f$	Z	1	1,2
RLF	f, d	Rotate Left f through carry		C	1	1,2
RRF	f, d	Rotate Right f through carry		C	1	1,2
COMF	f, d	Complement f	$F \rightarrow d$	Z	1	1,2
Bit operations						
BCF	f, b	Bit Clear f	$0 \rightarrow f(b)$		1	1,2
BSF	f, b	Bit Set f	$1 \rightarrow f(b)$		1	1,2
Directing a program flow						
BTFSZ	f, b	Bit Test f, Skip if Clear	jump if $f(b)=0$		1 (2)	3
BTSSZ	f, b	Bit Test f, Skip if Set	jump if $f(b)=1$		1 (2)	3
DECFSZ	f, d	Decrement f, Skip if 0	$f-1 \rightarrow d$, jump if $Z=1$		1(2)	1,2,3
INCFSZ	f, d	Increment f, Skip if 0	$f+1 \rightarrow d$, jump if $Z=0$		1(2)	1,2,3
GOTO	k	Go to address	$W.AND.k \rightarrow W$		2	
CALL	k	Call subroutine	$W.AND.f \rightarrow d$		2	
RETURN	-	Return from Subroutine	$W.OR.k \rightarrow W$		2	
RETLW	k	Return with constant in W	$W.OR.f \rightarrow d$		2	
RETFIE	-	Return from interrupt	$W.XOR.k \rightarrow W$		2	
Other instructions						
NOP	-	No Operation			1	
CLRWDAT	-	Clear Watchdog Timer	$0 \rightarrow WDT, 1 \rightarrow TO, 1 \rightarrow PD$	$\overline{TO}, \overline{PD}$	1	
SLEEP	-	Go into standby mode	$0 \rightarrow WDT, 1 \rightarrow TO, 0 \rightarrow PD$	$\overline{TO}, \overline{PD}$	1	

CLRWDT	-	Clear Watchdog Timer	0 → WDT, 1 → TO, 1 → PD	$\overline{TO}, \overline{PD}$	1	
SLEEP	-	Go into standby mode	0 → WDT, 1 → TO, 0 → PD	$\overline{TO}, \overline{PD}$	1	

*1 If I/O port is source operand, status on microcontroller pins is read

*2 If this instruction is executed on TMR register and if d= 1, prescaler assigned to that timer will automatically be cleared

*3 If PC was modified, or test result = 1, instruction was executed in two cycles.

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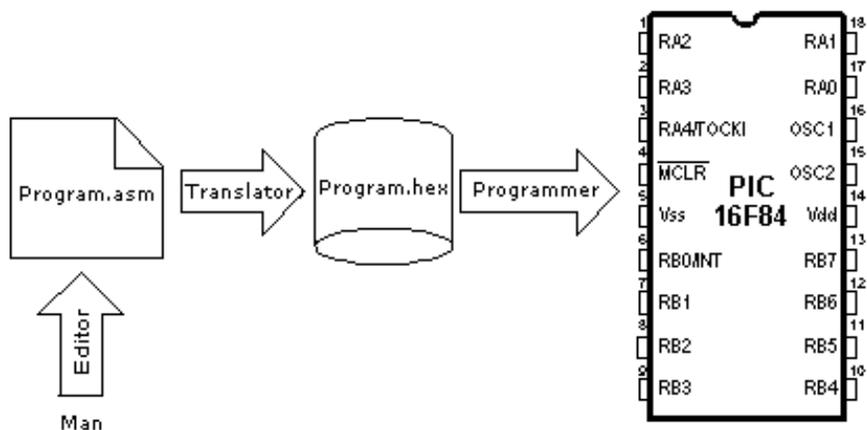
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Introduction

The ability to communicate is of great importance in any field. However, it is only possible if both communication partners know the same language, i.e follow the same rules during communication. Using these principles as a starting point, we can also define communication that occurs between microcontrollers and man . Language that microcontroller and man use to communicate is called "assembly language". The title itself has no deeper meaning, and is analogue to names of other languages , ex. English or French. More precisely, "assembly language" is just a passing solution. Programs written in assembly language must be translated into a "language of zeros and ones" in order for a microcontroller to understand it. "Assembly language" and "assembler" are two different notions. The first represents a set of rules used in writing a program for a microcontroller, and the other is a program on the personal computer which translates assembly language into a language of zeros and ones. A program that is translated into "zeros" and "ones" is also called "machine language".



The process of communication between a man and a microcontroller

Physically, "**Program**" represents a file on the computer disc (or in the memory if it is read in a microcontroller), and is written according to the rules of assembler or some other language for microcontroller programming. Man can understand assembler language as it consists of alphabet signs and words. When writing a program, certain rules must be followed in order to reach a desired effect. A **Translator** interprets each instruction written in assembly language as a series of zeros and ones which have a meaning for the internal logic of the microcontroller.

Lets take for instance the instruction "RETURN" that a microcontroller uses to return from a sub-program.

When the assembler translates it, we get a 14-bit series of zeros and ones which the microcontroller knows how to interpret.

Example: RETURN 00 0000 0000 1000

Similar to the above instance, each assembler instruction is interpreted as corresponding to a series of zeros and ones. The place where this translation of assembly language is found, is called an "execution" file. We will often meet the name "HEX" file. This name comes from a hexadecimal representation of that file, as well as from the suffix "hex" in the title, ex. "test.hex". Once it is generated, the execution file is read in a microcontroller through a programmer.

An **Assembly Language** program is written in a program for text processing (editor) and is capable of producing an ASCII file on the computer disc or in specialized surroundings such as MPLAB - to be explained in the next chapter.

Assembly language

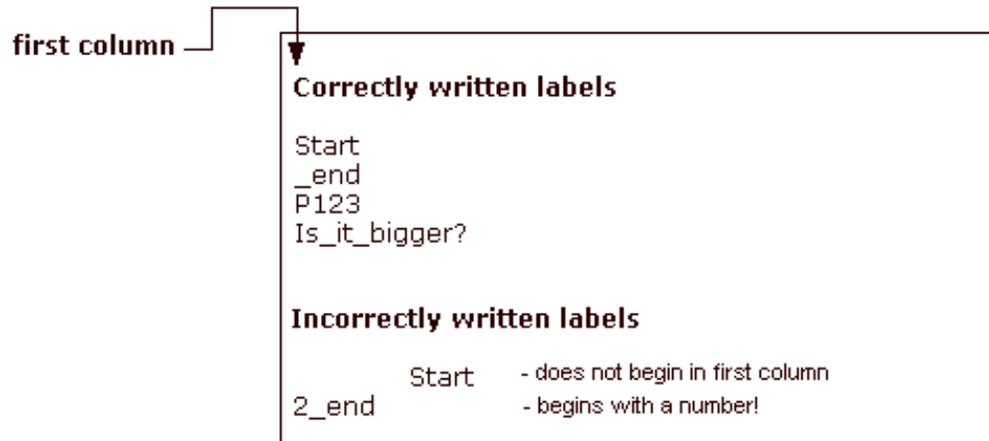
Basic elements of assembly language are:

- Labels
- Instructions
- Operands

- Directives
- Comments

Labels

A **Label** is a textual designation (generally an easy-to-read word) for a line in a program, or section of a program where the micro can jump to - or even the beginning of set of lines of a program. It can also be used to execute program branching (such as Goto) and the program can even have a condition that must be met for the Goto instruction to be executed. It is important for a label to start with a letter of the alphabet or with an underline "_". The length of the label can be up to 32 characters. It is also important that a label starts in the first column.



Instructions

Instructions are already defined by the use of a specific microcontroller, so it only remains for us to follow the instructions for their use in assembly language. The way we write an instruction is also called instruction "syntax". In the following example, we can recognize a mistake in writing because instructions movlp and gotto do not exist for the PIC16F84 microcontroller.

Correctly written instructions

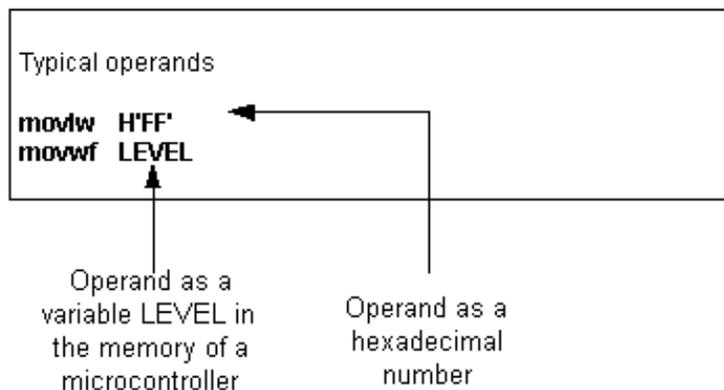
```
movlw   H'01FF'
goto    Start
```

Incorrectly written instructions

```
movlp   H'01FF'
gotto   Start
```

Operands

Operands are the instruction elements for the instruction is being executed. They are usually **registers** or **variables** or **constants**.



Comments

Comment is a series of words that a programmer writes to make the program more clear and legible. It is placed after an instruction, and must start with a semicolon ";".

Directives

A **directive** is similar to an instruction, but unlike an instruction it is independent on the microcontroller model, and represents a characteristic of the assembly language itself. Directives are usually given purposeful meanings via variables or registers. For example, LEVEL can be a designation for a variable in RAM memory at address 0Dh. In this way, the variable at that address can be accessed via LEVEL designation. This is far easier for a programmer to understand than for him to try to remember address 0Dh contains information about LEVEL.

Some frequently used directives:

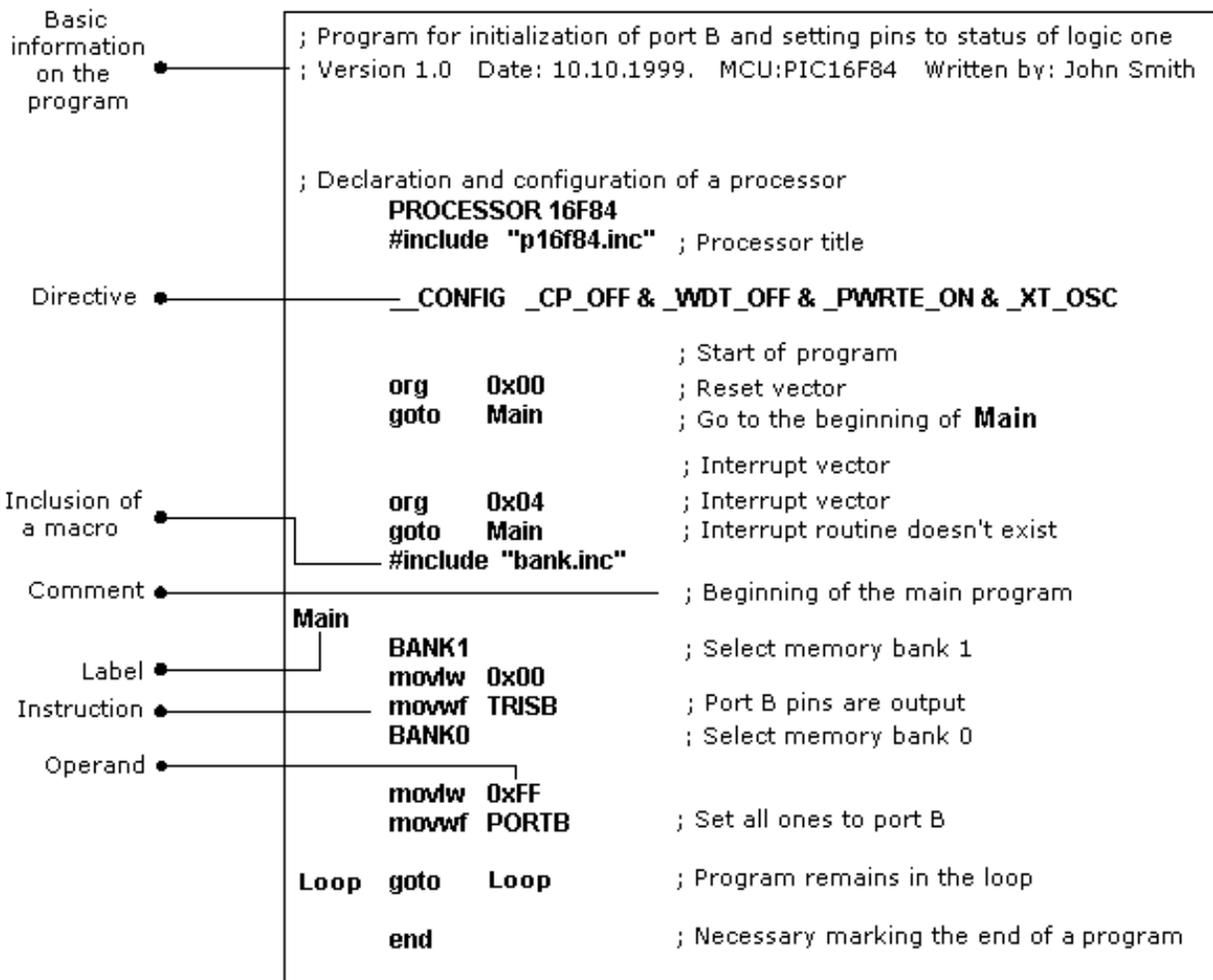
```
PROCESSOR 16F84
#include "p16f84.inc"

__CONFIG _CP_OFF & _WDT_OFF & _PWRTE_ON & _XT_OSC
```

An example of a writing program

The following example illustrates a simple program written in assembly language respecting the basic rules.

When writing a program, beside mandatory rules, there are also some rules that are not written down but need to be followed. One of them is to write the name of the program at the beginning, what the program does, its version, date when it was written, type of microcontroller it was written for, and the programmer's name.



Since this data isn't important for the assembly translator, it is written as **comments**. It should be noted that a comment always begins with a semicolon and it can be placed in a new row or it can follow an instruction. After the opening comment has been written, the **directive** must be included. This is shown in the example above.

In order to function properly, we must define several microcontroller parameters such as: - type of oscillator, - whether watchdog timer is turned on, and - whether internal reset circuit is enabled. All this is defined by the following directive:

```
_CONFIG _CP_OFF&_WDT_OFF&PWRTE_ON&XT_OSC
```

When all the needed elements have been defined, we can start writing a program.

First, it is necessary to determine an address from which the microcontroller starts, following a power supply start-up. This is (org 0x00).

The address from which the program starts if an interrupt occurs is (org 0x04).

Since this is a simple program, it will be enough to direct the microcontroller to the beginning of a program with a "**goto Main**" instruction.

The instructions found in the **Main** select memory bank 1 (BANK1) in order to access TRISB register, so that port B can be declared as an output (movlw 0x00, movwf TRISB).

The next step is to select memory bank 0 and place status of logic one on port B (movlw 0xFF, movwf PORTB), and thus the main program is finished.

We need to make another loop where the micro will be held so it doesn't "wander" if an error occurs. For that purpose, one infinite loop is made where the micro is retained while power is connected. The necessary "end" at the end of each program informs the assembly translator that no more instructions are in the program.

Control directives

4.1 #DEFINE Exchanges one part of text for another

Syntax:

```
#define<text> [<another text>]
```

Description:

Each time <text> appears in the program, it will be exchanged for <another text >.

Example:

```
#define turned_on 1
#define turned_off 0
```

Similar directives: #UNDEFINE, IFDEF,IFNDEF

4.2 INCLUDE Include an additional file in a program

Syntax:

```
#include <file_name>
#include "file_name"
```

Description:

An application of this directive has the effect as though the entire file was copied to a place where the "include" directive was found. If the file name is in the square brackets, we are dealing with a system file, and if it is inside quotation marks, we are dealing with a user file. The directive "include" contributes to a better layout of the main program.

Example:

```
#include <regs.h>
#include "subprog.asm"
```

4.3 CONSTANT Gives a constant numeric value to the textual designation

Syntax:

```
Constant <name>=<value>
```

Description:

Each time that <name> appears in program, it will be replaced with <value>.

Example:

```
Constant MAXIMUM=100
Constant Length=30
```

Similar directives: SET, VARIABLE

4.4 VARIABLE Gives a variable numeric value to textual designation

Syntax:

```
Variable<name>=<value>
```

Description:

By using this directive, textual designation changes with particular value.

It differs from CONSTANT directive in that after applying the directive, the value of textual designation can be changed.

Example:

```
variable level=20
variable time=13
```

Similar directives: SET, CONSTANT

4.5 SET Defining assembler variable

Syntax:

```
<name_variable>set<value>
```

Description:

To the variable <name_variable> is added expression <value>. SET directive is similar to EQU, but with SET directive name of the variable can be redefined following a definition.

Example:

```
level set 0
length set 12
level set 45
```

Similar directives: EQU, VARIABLE

4.6 EQU Defining assembler constant

Syntax:

```
<name_constant> equ <value>
```

Description:

To the name of a constant <name_constant> is added value <value>

Example:

```
five equ 5
six equ 6
seven equ 7
```

Similar instructions: SET

4.7 ORG Defines an address from which the program is stored in microcontroller memory

Syntax:

```
<label>org<value>
```

Description:

This is the most frequently used directive. With the help of this directive we define where some part of a program will be start in the program memory.

Example:

```
Start org 0x00
    movlw 0xFF
    movwf PORTB
```

The first two instructions following the first 'org' directive are stored from address 00, and the other two from address 10.

4.8 END End of program

Syntax:

```
end
```

Description:

At the end of each program it is necessary to place 'end' directive so that assembly translator would know that there are no more instructions in the program.

Example:

```
.
.
movlw 0xFF
movwf PORTB
end
```

Conditional instructions

4.9 IF Conditional program branching

Syntax:

```
if< conditional_term>
```

Description:

If condition in <conditional_term> was met, part of the program which follows IF directive would be executed. And if it wasn't, then the part following ELSE or ENDIF directive would be executed.

Example:

```
if level=100
goto FILL
else
goto DISCHARGE
endif
```

Similar directives: #ELSE, ENDIF

4.10 ELSE The alternative to 'IF' program block with conditional terms

Syntax:

```
Else
```

Description:

Used with IF directive as an alternative if conditional term is incorrect.

Example:

```
If time< 50
goto SPEED UP
else goto SLOW DOWN
endif
```

Similar instructions: ENDIF, IF

4.11 ENDIF End of conditional program section

Syntax:

```
endif
```

Description:

Directive is written at the end of a conditional block to inform the assembly translator that it is the end of the conditional block

Example:

```
If level=100
goto LOADS
else
goto UNLOADS
endif
```

Similar directives: ELSE, IF

4.12 WHILE Execution of program section as long as condition is met

Syntax:

```
while<condition>
```

```
.
endw
```

Description:

Program lines between WHILE and ENDW would be executed as long as condition was met. If a condition stopped being valid, program would continue executing instructions following ENDW line. Number of instructions between WHILE and ENDW can be 100 at the most, and number of executions 256.

Example:

```
While i<10
i=i+1
endw
```

4.13 ENDW End of conditional part of the program

Syntax:

```
endw
```

Description:

Instruction is written at the end of the conditional WHILE block, so that assembly translator would know that it is the end of the conditional block

Example:

```
while i<10
i=i+1

endw
```

Similar directives: WHILE

4.14 IFDEF Execution of a part of the program if symbol was defined

Syntax:

```
ifdef<designation>
```

Description:

If designation <designation> was previously defined (most commonly by #DEFINE instruction), instructions which follow would be executed until ELSE or ENDIF directives are not would be reached.

Example:

```
#define test
.
ifdef test ;how the test was defined
.....; instructions from these lines would execute
endif
```

Similar directives: #DEFINE, ELSE, ENDIF, IFNDEF, #UNDEFINE

4.15 IFNDEF Execution of a part of the program if symbol was defined

Syntax:

```
ifndef<designation>
```

Description:

If designation <designation> was not previously defined, or if its definition was erased with directive #UNDEFINE, instructions which follow would be executed until ELSE or ENDIF directives would be reached.

Example:

```
#define test
.....
#undefine test
.....
ifndef test ;how the test was undefined
..... ; instructions from these lines would execute
endif
```

Similar directives: #DEFINE, ELSE, ENDIF, IFDEF, #UNDEFINE

Data Directives

4.16 CBLOCK Defining a block for the named constants

Syntax:

```
Cblock [<term>]
    <label>[:<increment>], <label>[:<increment>],.....
endc
```

Description:

Directive is used to give values to named constants. Each following term receives a value greater by one than its precursor. If <increment> parameter is also given, then value given in <increment> parameter is added to the following constant. Value of <term> parameter is the starting value. If it is not given, it is considered to be zero.

Example:

```
Cblock 0x02
First, second, third ;first=0x02, second=0x03, third=0x04
endc

cblock 0x02
first : 4, second : 2, third ;first=0x06, second=0x08, third=0x09
endc
```

Similar directives: ENDC

4.17 ENDC End of constant block definition

Syntax:

```
endc
```

Description:

Directive was used at the end of a definition of a block of constants so assembly translator could know that there are no more constants.

Similar directives: CBLOCK

4.18 DB Defining one byte data

Syntax:

```
[<label>]db <term> [, <term> ,....., <term> ]
```

Description:

Directive reserves a byte in program memory. When there are more terms which need to be assigned a byte each, they will be assigned one after another.

Example:

```
db 't', 0x0f, 'e', 's', 0x12
```

Similar instructions: DE, DT

4.19 DE Defining the EEPROM memory byte

Syntax:

```
[<term>] de <term> [, <term> ,....., <term> ]
```

Description:

Directive is used for defining EEPROM memory byte. Even though it was first intended only for EEPROM memory, it could be used for any other location in any memory.

Example:

```
org H'2100'
de "Version 1.0" , 0
```

Similar instructions: DB, DT

4.20 DT Defining the data table

Syntax:

```
[<label>] dt <term> [, <term>,....., <term>]
```

Description:

Directive generates RETLW series of instructions, one instruction per each term.

Example:

```
dt "Message", 0
dt first, second, third
```

Similar directives: DB, DE

Configurational directives

4.21 _CONFIG Setting the configurational bits

Syntax:

```
_ _config<term> or_ _config<address>,<term>
```

Description:

Oscillator, watchdog timer application and internal reset circuit are defined. Before using this directive, the processor must be defined using PROCESSOR directive.

Example:

```
_CONFIG _CP_OFF&_WDT_OFF&_PWRTE_ON&_XT_OSC
```

Similar directives: _IDLOCS, PROCESSOR

4.22 PROCESSOR Defining microcontroller model

Syntax:

```
Processor <microcontroller_type>
```

Description:

Instruction sets the type of microcontroller where programming is done.

Example:

```
processor 16F84
```

Assembler arithmetic operators

Operator Description Example

Operator	Description	Example
\$	Current status of program counter	goto \$ + 3
(Left bracket	1 + (d * 4)
)	Right bracket	(Length + 1) * 256
!	NE (logic complement)	if ! (a - b)
-	Complement	flags = -flags
-	Negation (second complement)	-1 * Length
high	Returns higher byte	movlw high CTR_Table
low	Returns lower byte	movlw low CTR_Table
*	Multiplying	a = b * c
/	Subdividing	a = b / c
%	Subdividing by module	entry_len = tot_len % 16
+	Addition	tot_len = entry_len * 8 + 1
-	Subtraction	entry_len = (tot - 1) / 8
<<	Moving to the left	val = flags << 1
>>	Moving to the right	val = flags >> 1
>=	Higher than, or equal	if entry_idx >= num_entries
>	Higher than	if entry_idx > num_entries
<	Lesser than	if entry_idx < num_entries
<=	Lesser than, or equal	if entry_idx <= num_entries
==	Equal	if entry_idx == num_entries
!=	Not equal	if entry_idx != num_entries
&	Operation AND on bits	flags = flags & ERROR_BIT
^	Exclusive OR on bits	flags = flags ^ ERROR_BIT
	Logic OR on bits	flags = flags ERROR_BIT
&&	Logic AND	if (len == 512) && (b == c)
	Logic OR	if (len == 512) (b == c)
=	Equal	entry_index = 0
+=	Add and assign	entry_index += 1
-=	Subtract and assign	entry_index -= 1
*=	Multiply and assign	entry_index *= entry_length
/=	Divide and assign	entry_total /= entry_length
%=	Divide at module and assign	entry_index %= 8
<<=	Move to the left and assign	flags <<= 3
>>=	Move to the right and assign	flags >>= 3
&=	Logic AND and assign	flags &= ERROR_FLAG
=	Logic OR on bits and assign	flags = ERROR_FLAG
^=	Exclusive OR on bits and assign	flags ^= ERROR_FLAG
++	Increment by one	i ++
--	Decrease by one	i --

Files created as a result of program translation

As a result of the process of translating a program written in assembler language we get files like:

- Executing file (Program_Name.HEX)

- Program errors file (Program_Name.ERR)
- List file (Program_Name.LST)

The first file contains translated program which was read in microcontroller by programming. Its contents can not give any information to programmer, so it will not be considered any further.

The second file contains possible errors that were made in the process of writing, and which were noticed by assembly translator during translation process. Errors can be discovered in a "list" file as well. This file is more suitable though when program is big and viewing the 'list' file takes longer.

The third file is the most useful to programmer. Much information is contained in it, like information about positioning instructions and variables in memory, or error signalization.

Example of 'list' file for the program in this chapter follows. At the top of each page is stated information about the file name, date when it was translated, and page number. First column contains an address in program memory where a instruction from that row is placed. Second column contains a value of any variable defined by one of the directives : SET, EQU, VARIABLE, CONSTANT or CBLOCK. Third column is reserved for the form of a translated instruction which PIC is executing. The fourth column contains assembler instructions and programmer's comments. Possible errors will appear between rows following a line in which the error occurred.



Makro: Proba.lst

```

MPASM 02.40Released          PROBA.ASM    4-26-2000  7:18:17          PAGE 1

LOC  OBJECT CODE          LINE SOURCE TEXT
VALUE

          00001  ;Program for initialization of port B and setting its pins
          00002  ;to the state of logic one
          00003  ;Version: 1.0 Date: 10.05.2000.      MCU: PIC16F84 Written
          00004  ;by: Petar Petrovic
          00005
          00006  ;Declaration and configuration of the processor
          00007  PROCESSOR 16F84
          00008  #include "p16f84.inc" ;Processor title
          00001  LIST
          00002  ;P16F84.INC Standard Header File, Version 2.00 Microchip
          ;Technology, Inc.
          00136  LIST
          00009
2007 3FF1          00010  __CONFIG  __CP_OFF & __WDT_OFF & __PWRTE_ON & __XT_OSC
          00011
000C          00012  CONSTANT BASE = 0x0c
          00013
          00014  ;Start of a program
0000          00015  org 0x00      ;Reset vector
0000 2805          00016  goto Main    ;Go to the beginning of the main program
          00017
          00018  ;Interrupt vector
0004          00019  org 0x04    ;Interrupt vector
0004 2805          00020  goto Main    ;Interrupt routine does not exist
          00021
          00022  ;Beginning of the main program
          00023  #include "Bank.inc" ; File with macros
          00001  ;*****
          00002  ;      Makros BANK0 and BANK1
          00003  ;*****
          00004
0000 0010          00005  W_Temp      set    BASE+4
0000 0011          00006  Stat_Temp   set    BASE+5
0000 0012          00007  Option_Temp set    BASE+6
          00008
          00009
          00010  BANK0 macro
          00011  bcf STATUS,RPO ; Select memory bank 0
          00012  endm
          00013
          00014  BANK1 macro
          00015  bsf STATUS,RPO ; Select memory bank 1
          00016  endm
          00017

```

```

00016  endm
00017
0005   00024  Main
00025  BANK1           ; Select memory bank 1
0005   1683  M      bsf   STATUS,RPO   ; Select memory bank 1
0006   3000  00026  movlw  0x00
Message[302]: Register in operand not in bank 0. Ensure that bank bits are
correct.
0007   0086  00027  movwf  TRISB       ;Port B pins are output
00028
00029  BANK0           ;Select memory bank 0
0008   1283  M      bcf   STATUS,RPO   ;Select memory bank 0
0009   30FF  00030  movlw  0xFF
000A   0086  00031  movwf  PORTB       ;Set all ones to port B
00032
000B   280B  00033  Loop   goto   Loop   ; Program stays in the loop
00034
00035  END             ;Necessary marking the end of a program

MEMORY USAGE MAP ('X' = Used, '-' = Unused)

0000 : X---XXXXXXXX-----
2000 : -----X-----

All other memory blocks unused.

Program Memory Words Used:    9
Program Memory Words Free:   1015

Errors:      0
Warnings:    0 reported,      0 suppressed
Messages:    1 reported,      0 suppressed

```

At the end of the "list" file there is a table of symbols used in a program. Useful element of 'list' file is a graph of memory utilization. At the very end, there is an error statistic as well as the amount of remaining program memory.

Macros

Macros are a very useful element in assembly language. They could briefly be described as "user defined group of instructions which will enter assembler program where macro was called". It is possible to write a program even without using macros. But with their use written program is much more readable, especially if more programmers are working on the same program together. Macros have the same purpose as functions of higher program languages.

How to write them:

```
<label> macro [<argument1>,<argument2>,<argumentN> ]
```

```
.....
.....
endm
```

From the way they were written, we could be seen that macros can accept arguments, too which is also very useful in programming. Whenever argument appears in the body of a macro, it will be replaced with the <argumentN> value.

Example:

```

NA_PORTB      macro ARG1
                BANK0           ;Select memory bank 0
                movlw ARG1       ;Value from ARG1 argument
                                ;is stored in working register
                movwf PORTB      ;value from ARG1
                                ; argument placed on port B
                endm             ;macro ended

```

The above example shows a macro whose purpose is to place on port B the ARG1 argument that was defined while macro

was called. Its use in the program would be limited to writing one line: `ON_PORTB 0xFF` , and thus we would place value `0xFF` on `PORTB`. In order to use a macro in the program, it is necessary to include macro file in the main program with instruction `include "macro_name.inc"`. Contents of a macro is automatically copied onto a place where this instruction was written. This can be best seen in a previous list file where file with macros "`bank.inc`" was copied below the line `#include"bank.inc"`

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CHAPTER 5

MPLAB

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[5.3 Choosing the development mode](#)

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[5.5 Designing new assembler file](#)

[5.6 Writing a program](#)

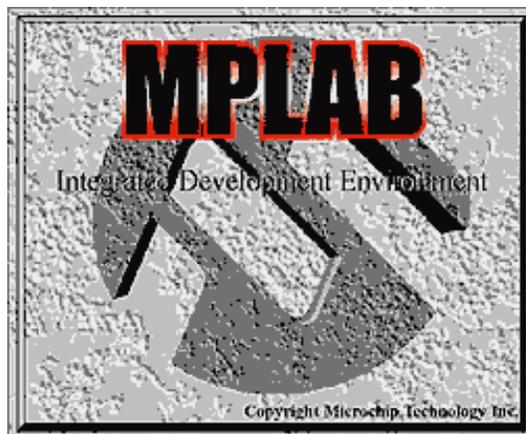
[5.7 MPSIM simulator](#)

[5.8 Toolbar](#)

Introduction

MPLAB is a Windows program package that makes writing and developing a program easier. It could best be described as developing environment for some standard program language that is intended for programming a PC computer. Some operations which were done from the instruction line with a large number of parameters until the discovery of IDE "Integrated Development Environment" are now made easier by using the MPLAB. Still, our tastes differ, so even today some programmers prefer the standard editors and compilers from instruction line. In any case, the written program is legible, and well documented help is also available.

5.1 Installing the program -MPLAB



MPLAB consists of several parts:

- Grouping the projects files into one project (Project Manager)
- Generating and processing a program (Text Editor)

- Simulator of the written program used for simulating program function on the microcontroller.

Besides these, there are support systems for Microchip products such as PICStart Plus and ICD (In Circuit Debugger). As this book does not cover these, they will be mentioned only as options.

Minimal computer requirements for starting the MPLAB are:

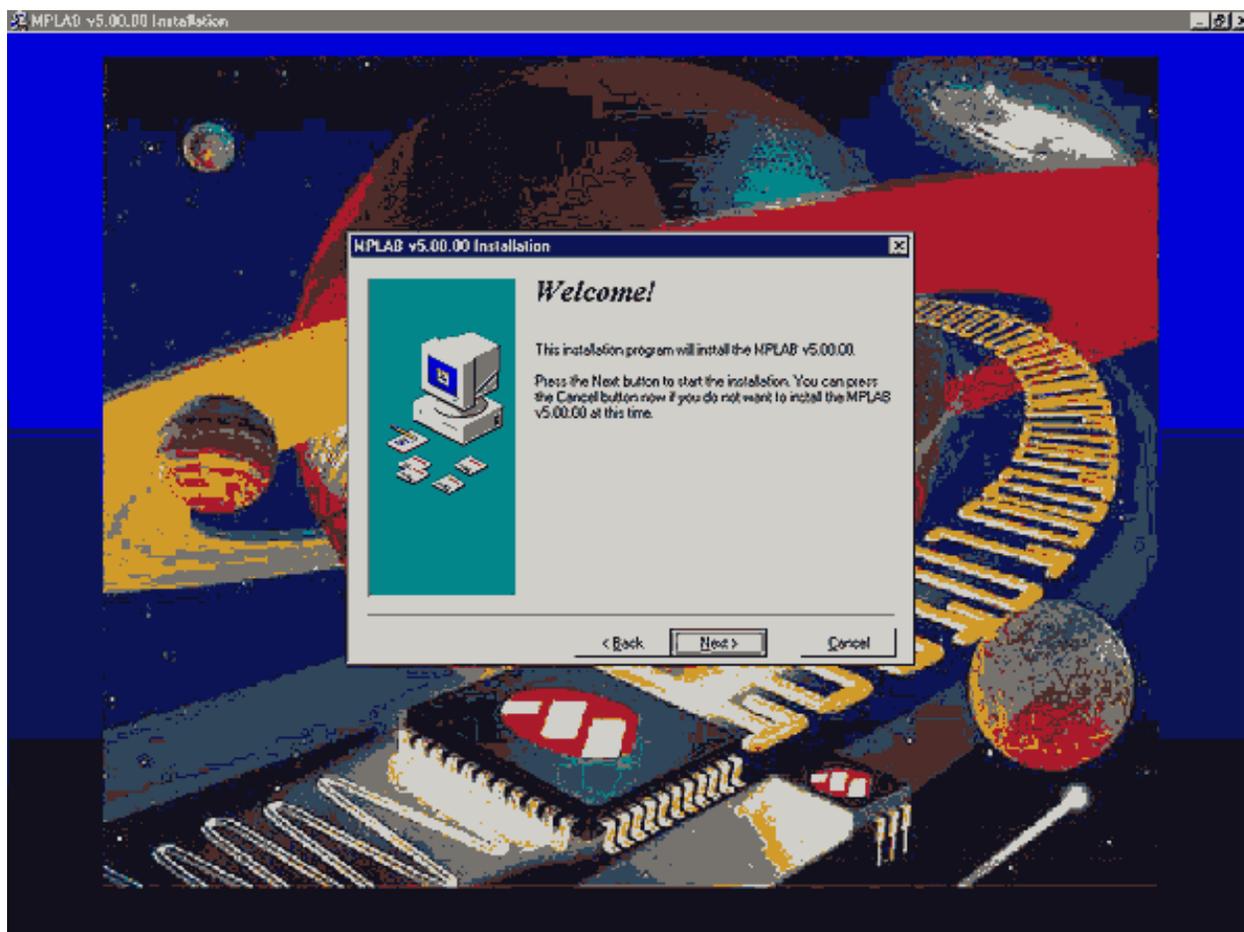
- PC compatible computer 486 or higher
- Microsoft Windows 3.1x or Windows 95 and new versions of the Windows operating system
- VGA graphic card
- 8MB memory (32MB recommended)
- 20MB space on hard disc
- Mouse

In order to start the MPLAB we need to install it first. Installing is a process of copying MPLAB files from the CD onto a hard disc of your computer. There is an option on each new window which helps you return to a previous one, so errors should not present a problem or become a stressful experience. Installment itself works much the same as installment of most Windows programs. First you get the Welcome screen, then you can choose the options followed by installment itself, and, at the end, you get the message which says your installed program is ready to start.

Steps for installing MPLAB:

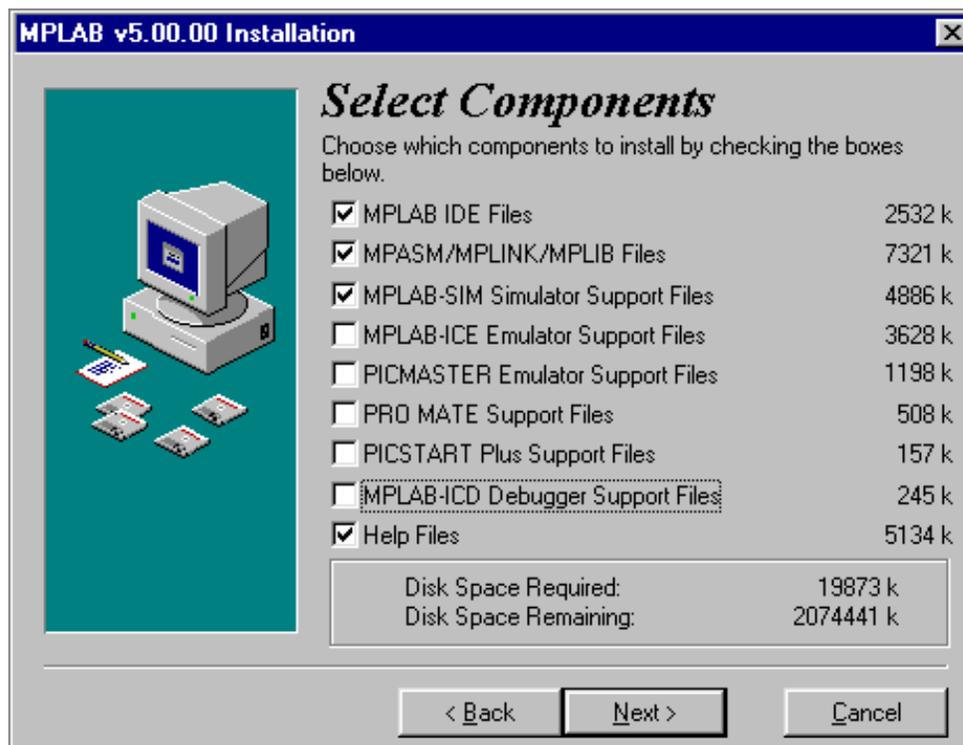
1. Start-up the Microsoft Windows
2. Put the Microchip CD disc into CD ROM
3. Click on START in the bottom left corner of the screen and choose the RUN option
4. Click on BROWSE and select CD ROM drive of your computer.
5. Find directory called MPLAB on your CD ROM
6. Click on SETUP.EXE and then on OK .
7. Click again on OK in your RUN window

Installing begins after these seven steps. The following pictures explain the meaning of certain installment steps.



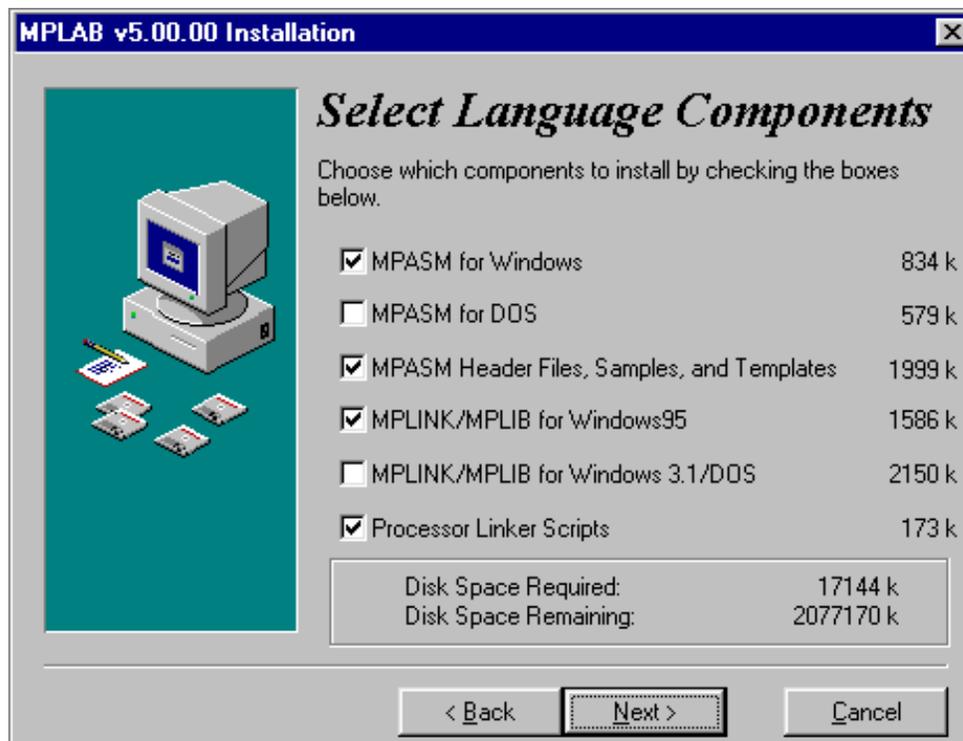
Welcome screen at the beginning of MPLAB installment

At the very beginning, it is necessary to select those MPLAB components we will be working with. Since we don't have any original Microchip hardware components such as programmers or emulators, we will only install MPLAB environment, Assembler, Simulator and the instructions.



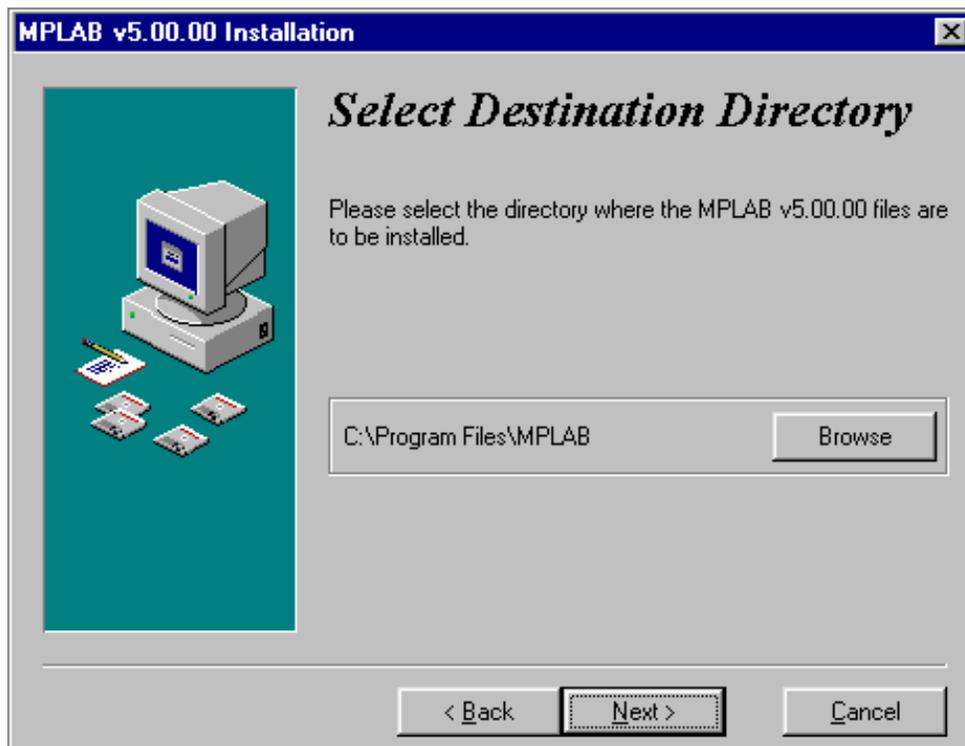
Selecting components of MPLAB developing environment

As it is assumed you will work in Windows 95 (or a newer operating system), everything in connection with DOS operating system has been taken out during selection of assembler language. However, if you still wish to work in DOS, you need to deselect all options connected with Windows, and choose the components appropriate for DOS.



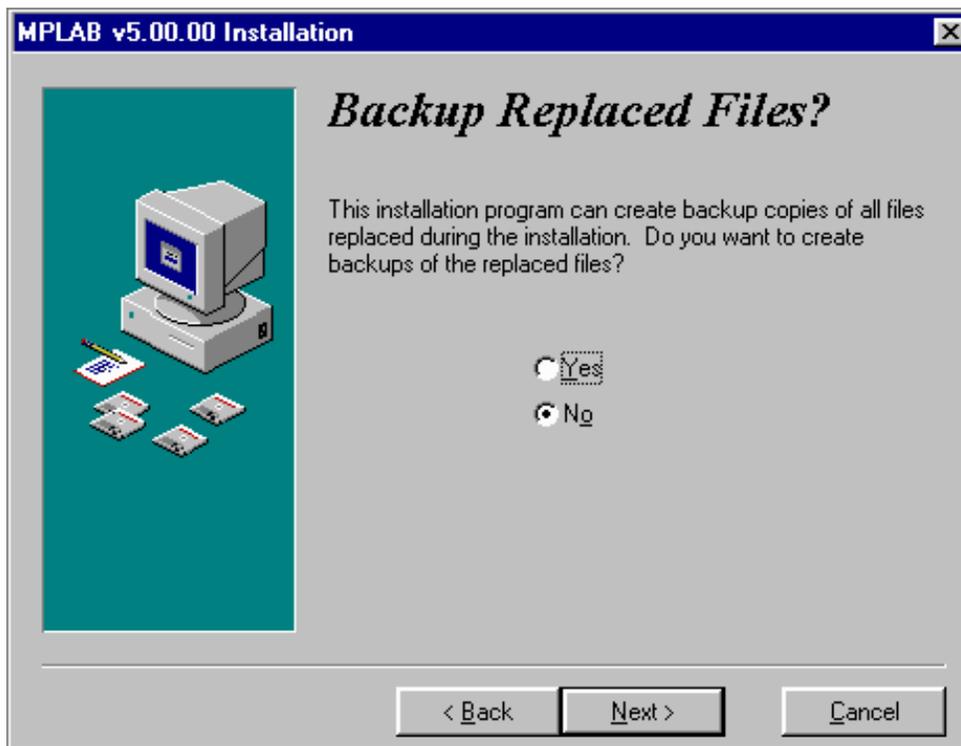
Selecting the assembler and the operating system

Like any other program, MPLAB should be installed into some directory. This option could be moved into any directory on any hard disc of your computer. If you didn't have a more pressing need, it should be left at selected place.



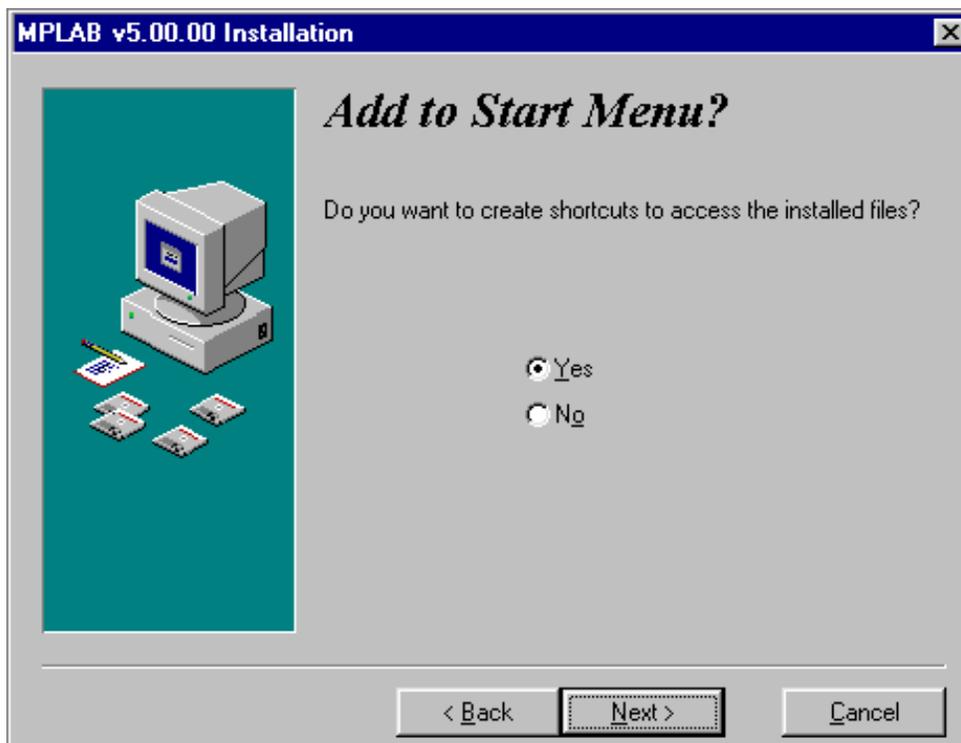
Choosing the directory where MPLAB will be installed

Users who have already had MPLAB (older version than this one) need the following option. The purpose of this option is to save copies of all files which will be modified during a changeover to a new MPLAB version. In our case we should leave selected NO because of presumption that this is your first installment of MPLAB on your computer.



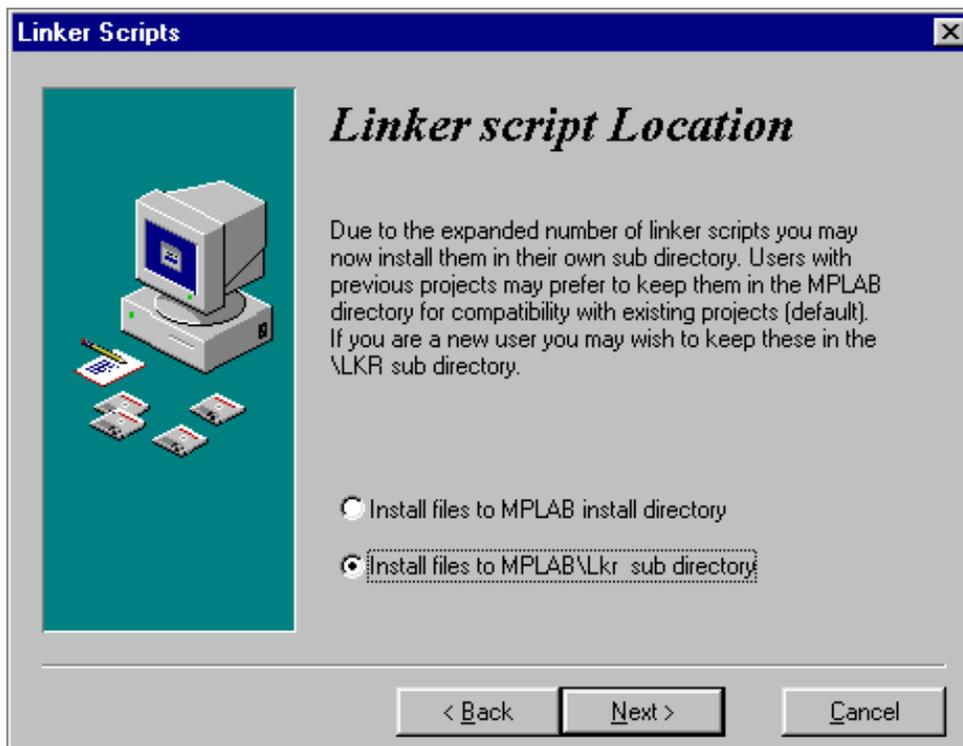
Option for users who are installing a new version over an already installed MPLAB

Start menu is a group of program pointers, and is selected by clicking on START option in the lower left corner of the screen. Since MPLAB will be started from here, we need to leave this option as it is.



Adding the MPLAB to the start menu

Location that will be mentioned from here on, has to do with a part of MPLAB whose explanation we don't need to get into. By selecting a special directory, MPLAB will keep all files in connection with the linker in a separate directory.



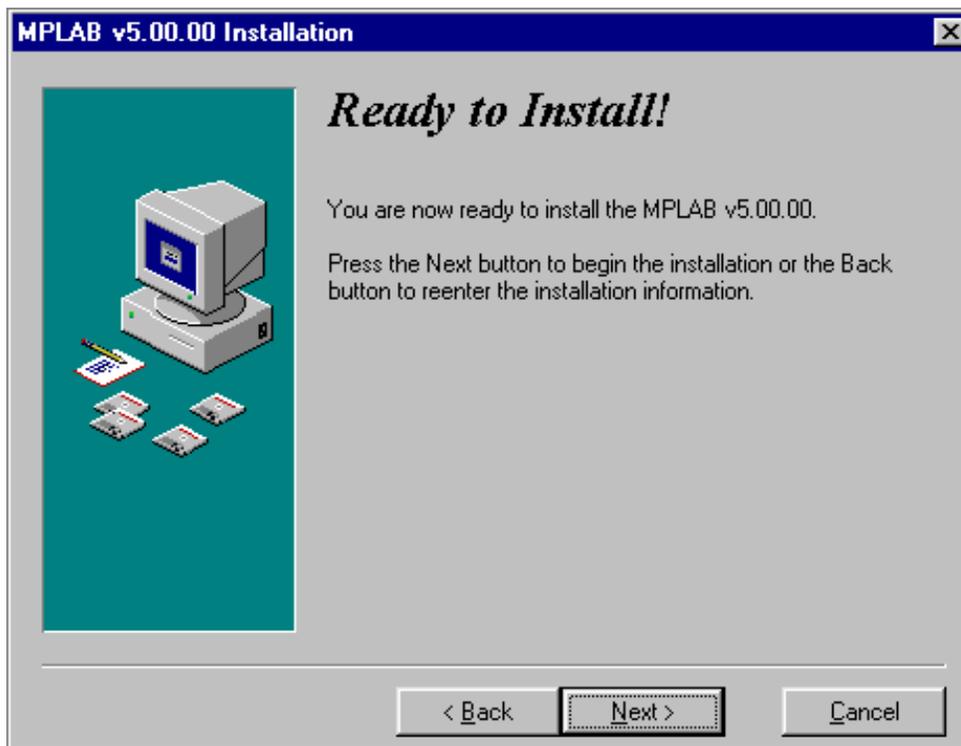
Determining a directory for linker files

Every Windows program has system files usually stored in a directory containing Windows program. After a number of different installments, the Windows directory becomes overcrowded and too big. Thus, some programs allow for their system files to be kept in same directories with programs. MPLAB is an example of such program, and the bottom option should be selected.



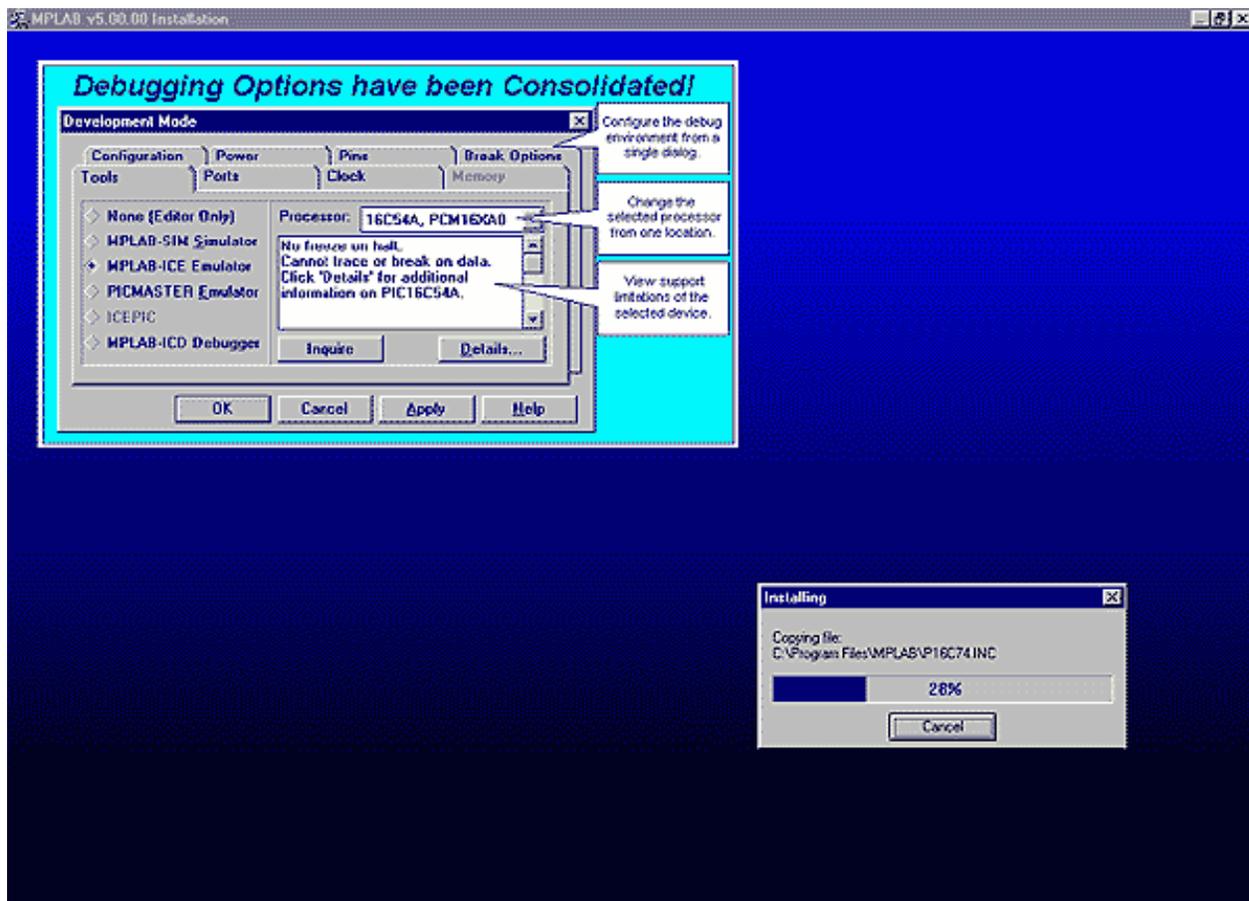
Selecting a directory for system files

After all of the above steps, installment begins by clicking on 'Next'.



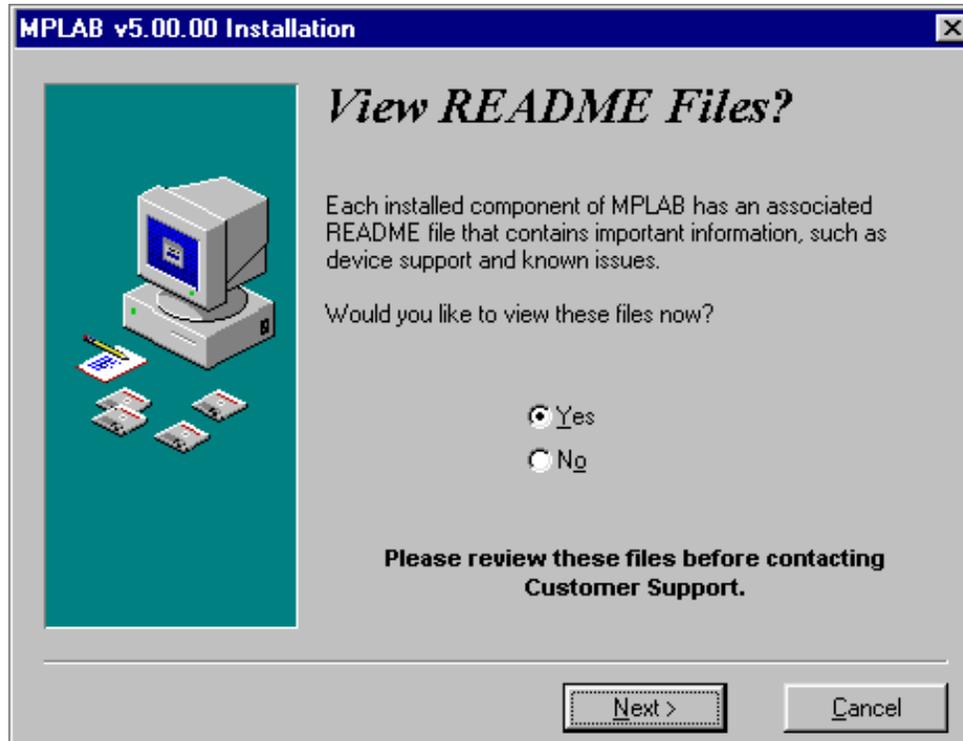
Screen prior to installment

Installment doesn't take long, and the process of copying the files can be viewed on a small window in the right corner of the screen.



Installment flow

After installment have been completed, there are two dialog screens, one for the last minute information regarding program versions and corrections, and the other is a welcome screen. If text files (Readme.txt) have opened, they would need to be closed.



Last minute information regarding program versions and corrections.

By clicking on Finish, installment of MPLAB is finished.

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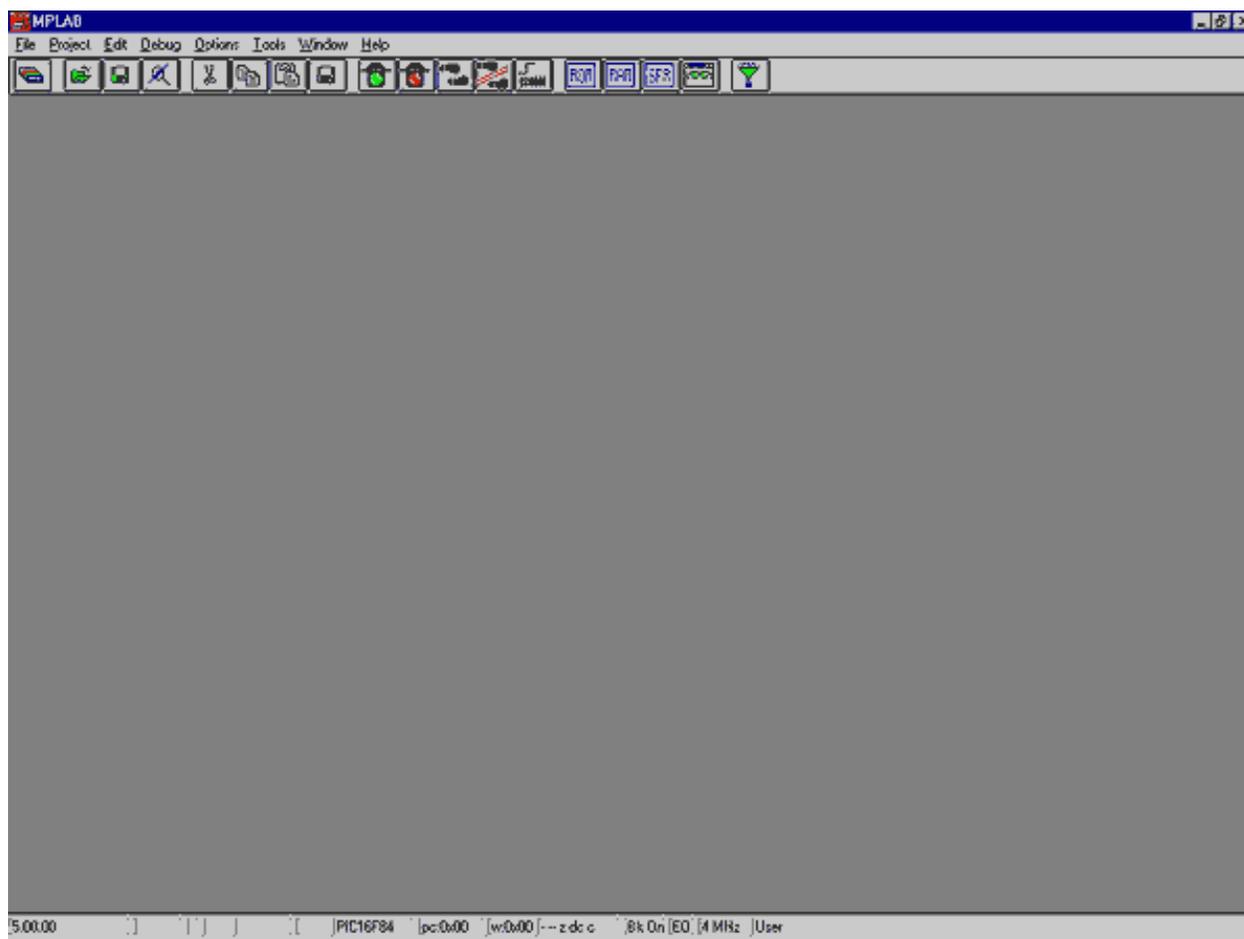
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5.2 MPLAB

Following the installment procedure, you will get a screen of the program itself. As you can see, MPLAB looks like most of the Windows programs. Near working area there is a "menu" (upper blue colored area with options File, Edit..etc.), "toolbar" (an area with illustrations the size of small squares), and status line on the bottom of the window. There is a rule in Windows of taking some of the most frequently used program options and placing them below the menu, too. Thus we can access them easier and speed up the work. In other words, what you have in the toolbar you also have in the menu.



The screen after starting the MPLAB

The purpose of this chapter is for you to become familiar with MPLAB developing environment and with basic elements of MPLAB such as:

- Choosing a developing mode
- Designing a project
- Designing a file for the original program
- Writing an elementary program in assembler program language
- Translating a program into executive code
- Starting the program
- Opening a new window for a simulator
- Opening a new window for variables whose values we watch (Watch Window)
- Saving a window with variables whose values we are watching

Setting the break points in a simulator (Break point)

Preparing a program to be read in a microcontroller can boil down to several basic steps:

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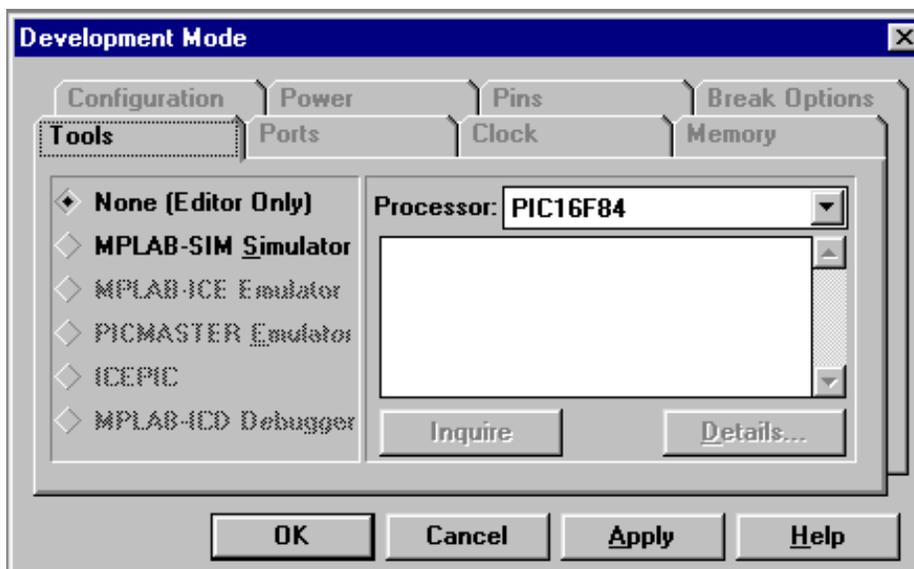
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5.3 Choosing the development mode

Setting a developing mode is necessary so that MPLAB can know what tools will be used to execute the written program. In our case, we need to set up the simulator as a tool that's being used. By clicking on OPTIONS---> DEVELOPMENT MODE, a new window will appear as in the picture below:



Setting a developing mode

We should select the 'MPLAB-SIM Simulator' option because that is where the program will be tried out. Beside this option, the 'Editor Only' option is also available. This option is used only if we want to write a program and by programmer write 'hex file' in a microcontroller. Selection of the microcontroller model is done on the right hand side. Since this book is based on the PIC16F84, this model should be selected.

Usually when we start working with microcontrollers, we use a simulator. As the level of knowledge will have increased, program will be written in a microcontroller right after translation. Our advice is that you always use the simulator. Though program will seem to develop slower, it will pay off in the end.

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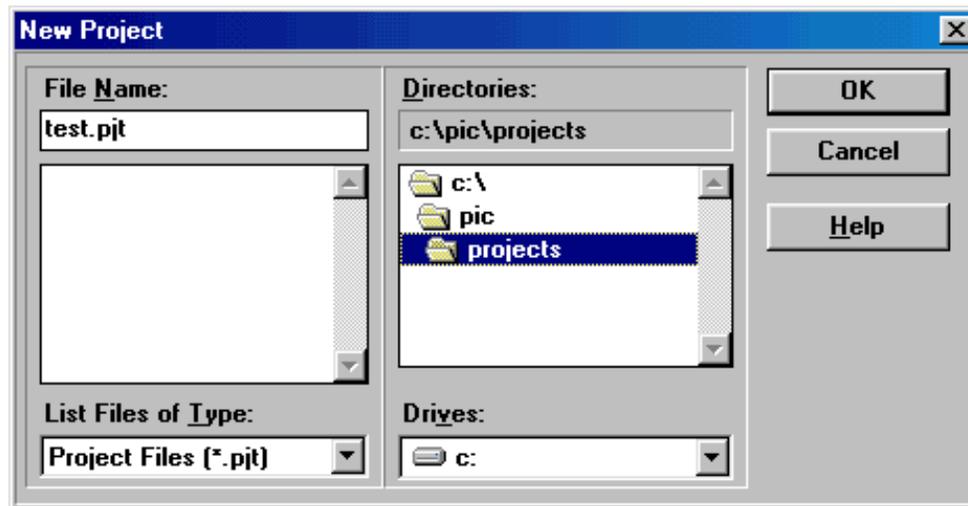
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5.4 Designing a project

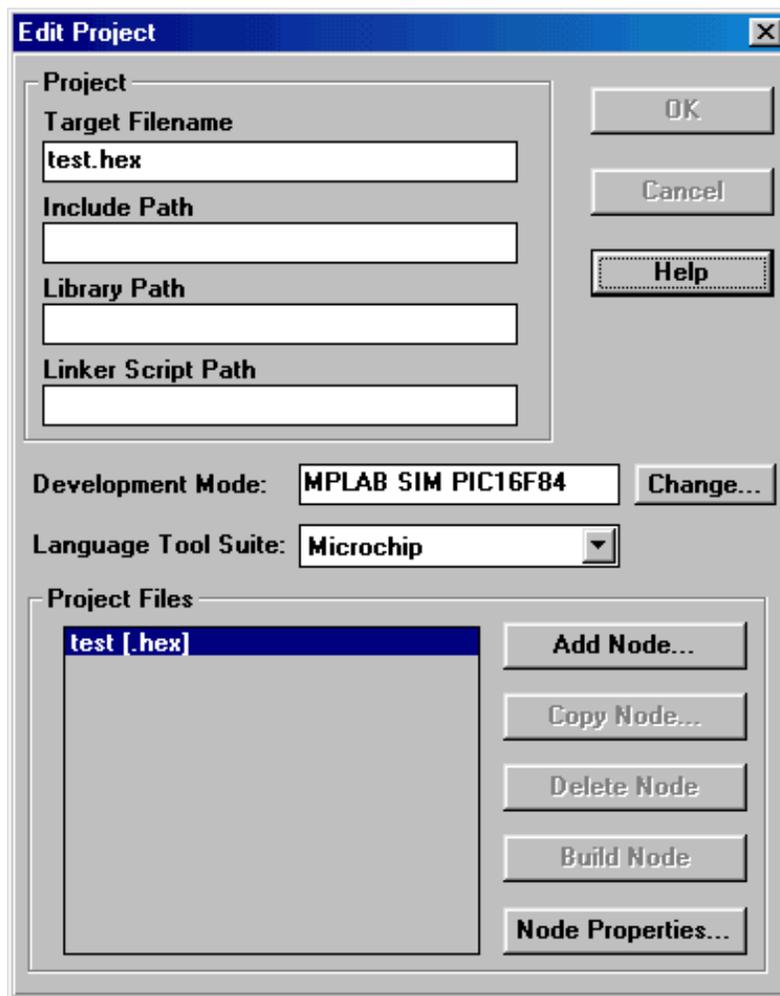
In order to start writing a program you need to create a project first. By clicking on PROJECT --> NEW PROJECT you are able to name your project and store it in a directory of your choice. In the picture below, a project named 'test.pjt' is being created and stored in c:\PIC\PROJEKTS\ directory.

This directory is chosen because authors had such directory set up of on their computer. Generally speaking, directory with files is usually placed in a larger directory whose name is unmistakably associated with its contents.



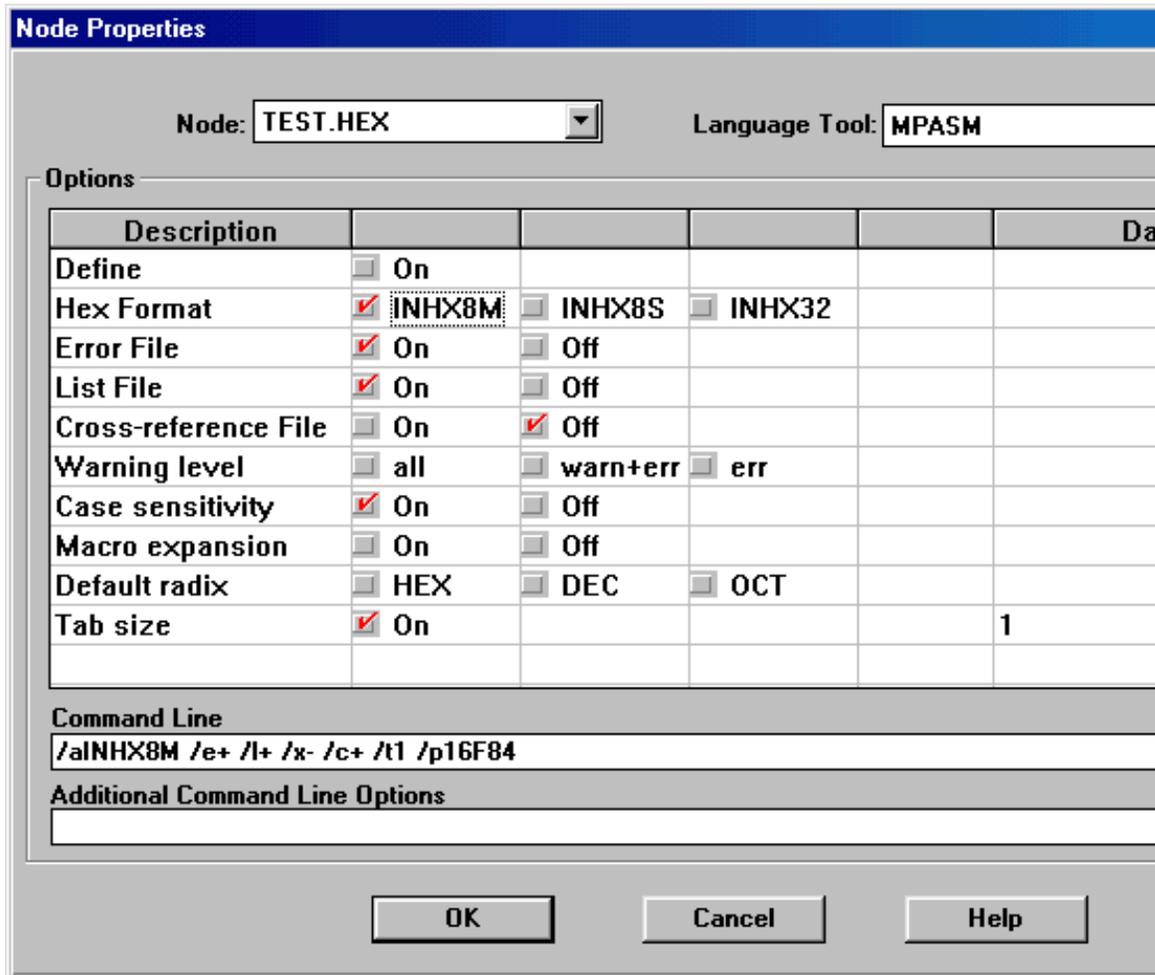
Opening a new project

After naming the project, click on OK. New window comes up as in the next picture.



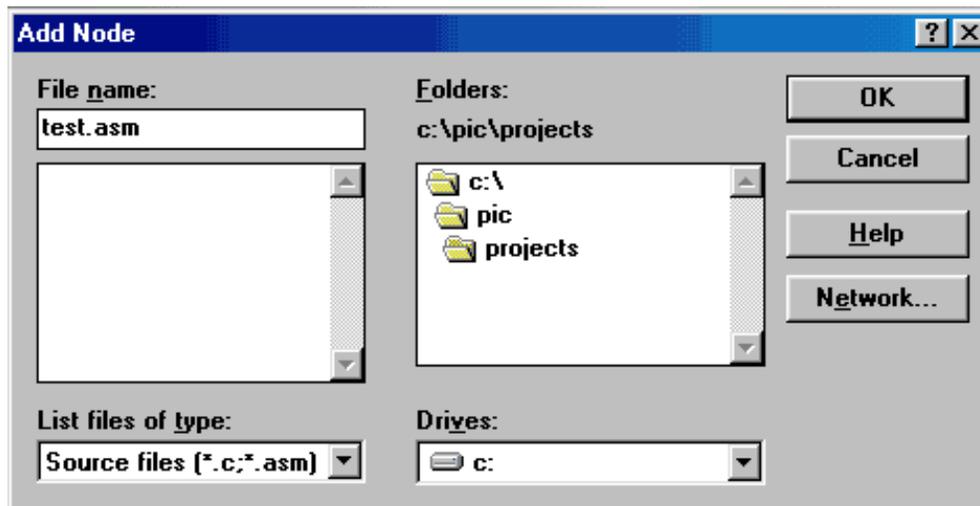
Adjusting project elements

Using a mouse click on "test [.hex]" which activates 'Node properties' option in the bottom right corner of a window. By clicking on it you get the following window.



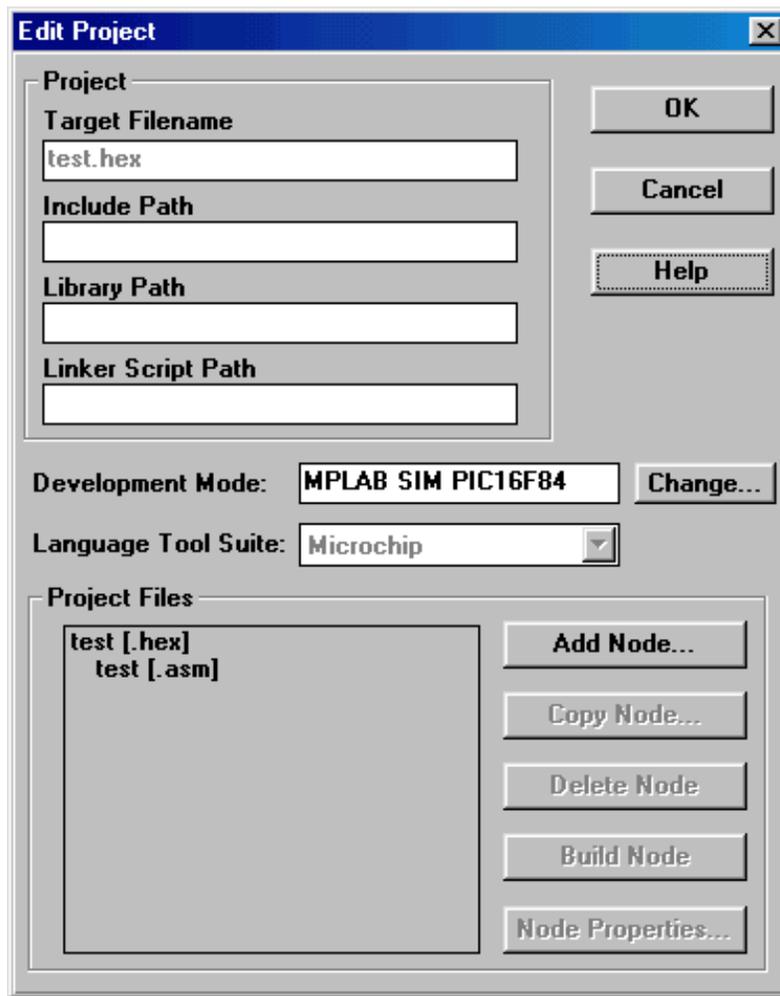
Defining parameters of MPASM assembler

From the picture we see that there are many different parameters. Each kind corresponds to one parameter in "Command line" . As memorizing these parameters is very uncomfortable, even forbidding for beginners, graphic adjustment has been introduced. From the picture we see which options need to be turned on. By clicking on OK we go back to previous window where "Add node" is an active option. By clicking on it we get the following window where we name our assembler program. Let's name it "Test.asm" since this is our first program in MPLAB.



Opening a new project

By clicking on OK we go back to the starting window where we see added an assembler file.



Assembler file added

By clicking on OK we return to MPLAB environment.

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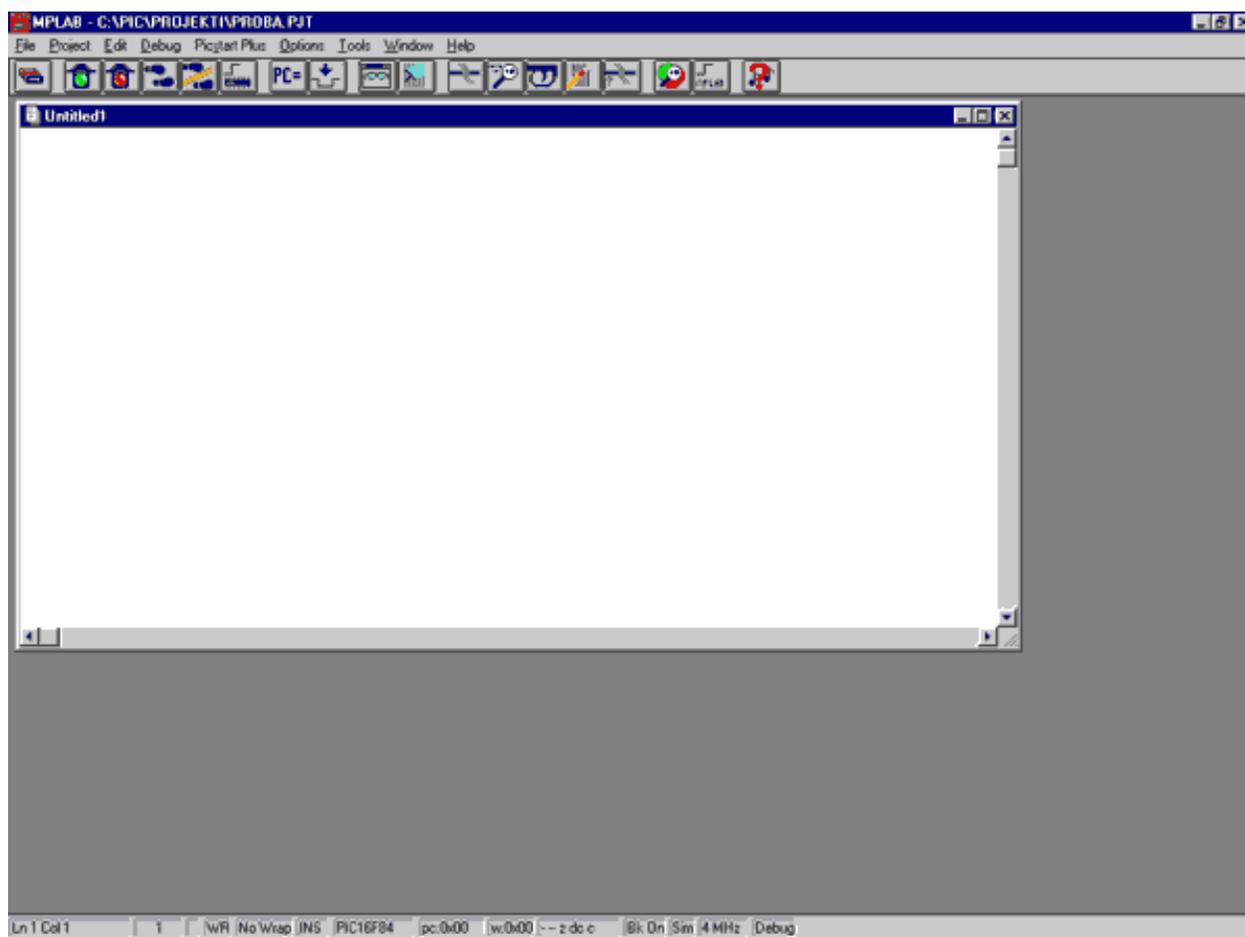
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5.5 Designing a new assembler file (writing a new program)

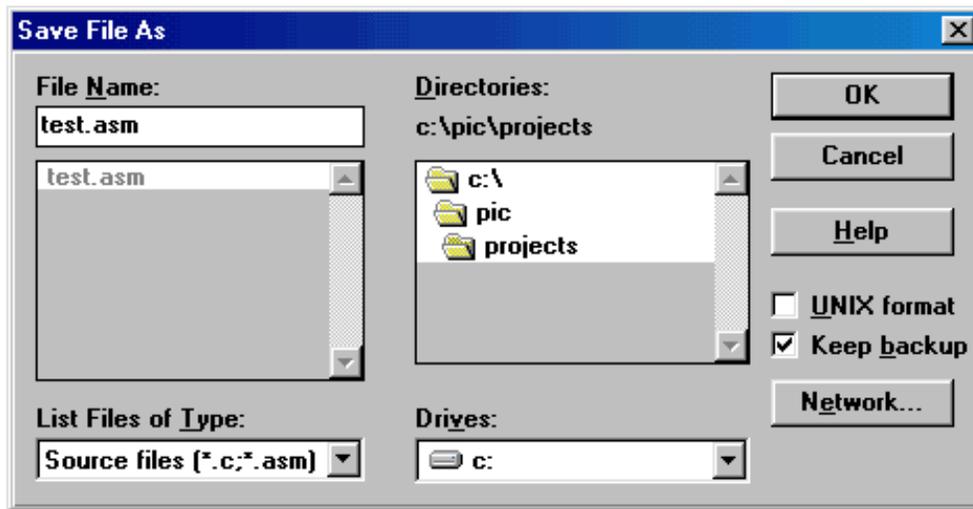
When "project" part of the work is finished, we need to start writing a program. In other words, new file must be opened, and will be named "test.asm". In our case, file has to be named "test.asm" because in projects which have only one file (such as ours), name of the project and name of the source file have to be the same.

New file is opened by clicking on FILE>NEW. Thus we get a text window inside MPLAB work space.



New assembler file opened

New window represents a file where program will be written. Since our assembler file has to be named "test.asm", we will name it so. Naming is done (as with all Windows programs) by clicking on FILE>SAVE AS. Then we get a window like the following picture.



Naming and saving a new assembler file

When we get this window, we need to write 'test.asm' below 'File name:', and click on OK. After that, we will see 'test.asm' file name at the top of our window.

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5.6 Writing a program

Only after all of the preceding operations have been completed we are able to start writing a program. Since a simple program has already been written in "Assembly Language Programming" section of the book, so we will use that same program here, too.



Program: Proba.asm

```

;Program for initialization of port B and setting its pins to
;state of logic one
;Version: 1.0 Date: 25.04.2000 MCU: PIC16F84 Written by: Petar
;Petrovic

;Declaration and configuration of processor

    PROCESSOR 16F84
    #include      "p16f84.inc"      ; Processor title

    __CONFIG    _CP_OFF & _WDT_OFF & _PWRTE_ON & _XT_OSC

    org    0x00          ; Reset vector
    goto   Main          ; Go to the beginning of the main
                        ; program

    org    0x04          ; Interrupt vector
    goto   Main          ; Interrupt routine does not exist

    #include "bank.inc" ; Macros BANK0 and BANK1

;Beginning of the main program

Main
    BANK1          ; Select memory bank 1
    movlw 0x00
    movwf TRISB    ; Port B pins are output
    BANK0          ; Select memory bank 0

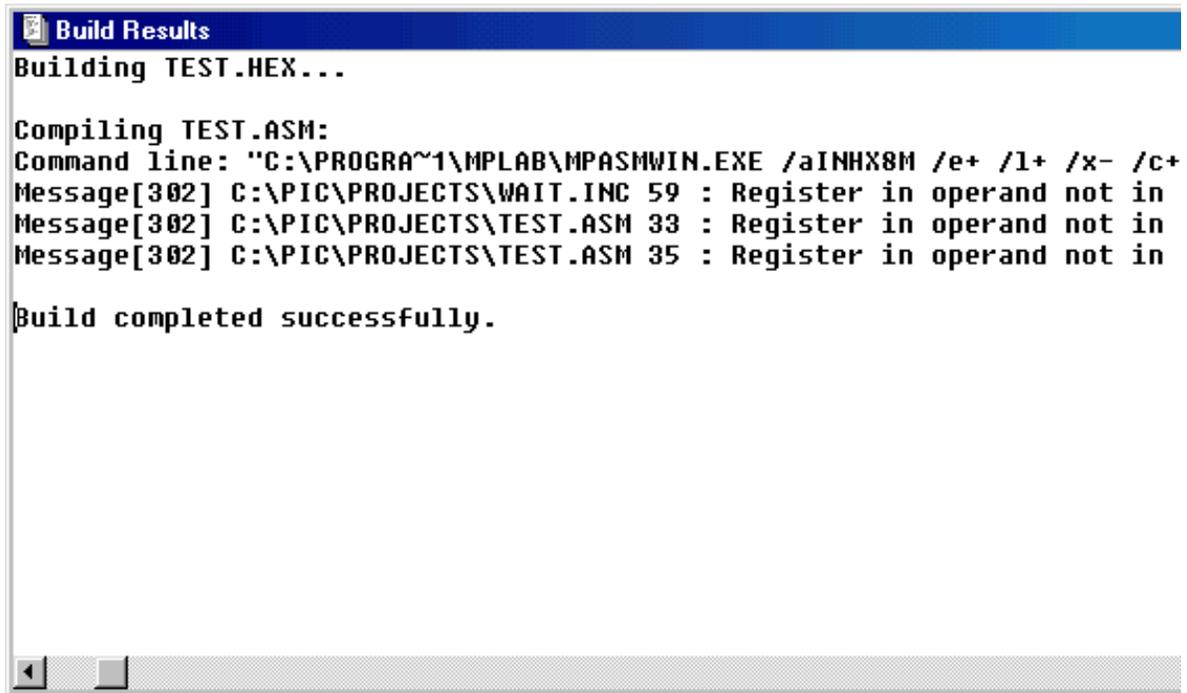
    movlw 0xFF
    movwf PORTB    ; Set all ones to port B

    Petlja goto   Petlja ; Program stays in the loop

    end            ; Necessary marking the end of a
                  ; program

```

Program has to be written to a window that's opened, or copied from a disc, or taken from MikroElektronika Internet presentation using options copy and paste. When the program is copied to "test.asm" window, we can use PROJECT -> BUILD ALL command (if there were no errors), and a new window would appear as in the next picture.



```
Build Results
Building TEST.HEX...

Compiling TEST.ASM:
Command line: "C:\PROGRA~1\MPLAB\MPASMWIN.EXE /aINHX8M /e+ /l+ /x- /c+
Message[302] C:\PIC\PROJECTS\WAIT.INC 59 : Register in operand not in
Message[302] C:\PIC\PROJECTS\TEST.ASM 33 : Register in operand not in
Message[302] C:\PIC\PROJECTS\TEST.ASM 35 : Register in operand not in

Build completed successfully.
```

Window with messages following a translation of assembler program

We can see from the picture that we get "test.hex" file as a result of translation process, that MPASMWIN program is used for translation, and that there is one message. In all that information, the last sentence in the window is the most important one because it shows whether translation was successful or not. 'Build completed successfully' is a message stating that translation was successful and that there were no errors.

In case an error shows up, we need to double click on error message in 'Build Results' window. This would automatically transfer you to assembler program and to the line where the error was.

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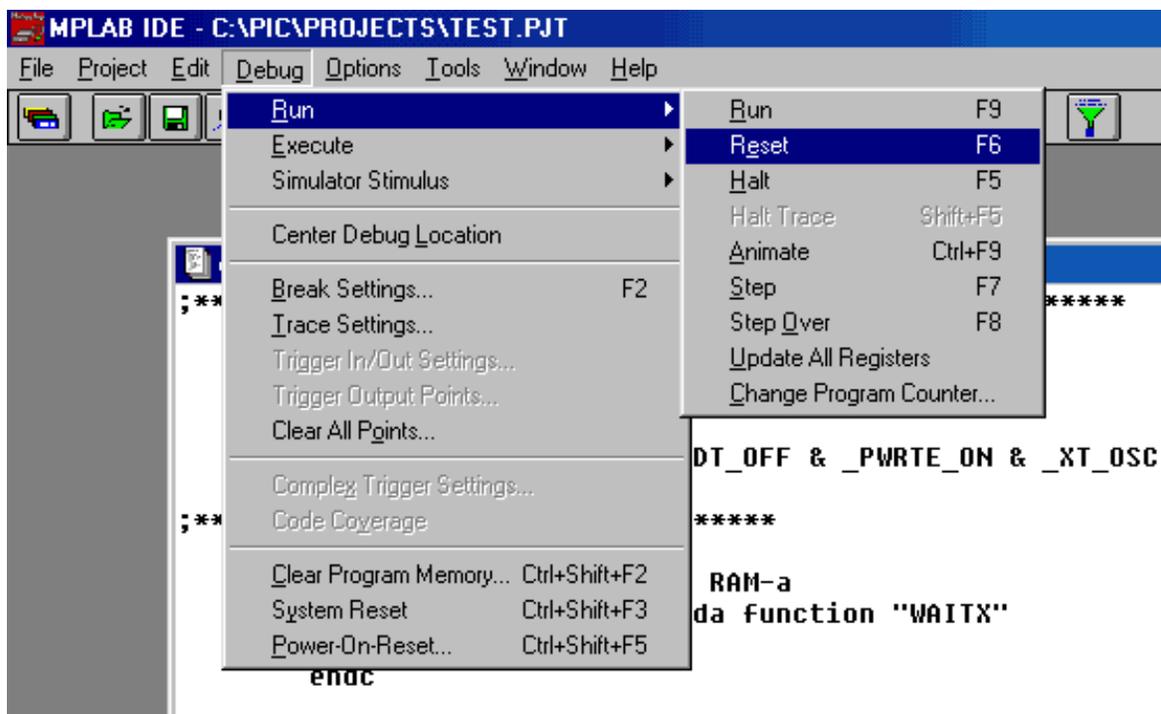
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5.7 MPSIM Simulator

Simulator is part of MPLAB environment which provides a better insight into the workings of a microcontroller. Through a simulator, we can monitor current variable values, register values and status of port pins. Truthfully, simulator does not have the same value in all programs. If a program is simple (like the one given here as an example), simulation is not of great importance because setting port B pins to logic one is not a difficult task. However, simulator can be of great help with more complicated programs which include timers, different conditions where something happens and other similar requirements (especially with mathematical operations). Simulation, as the name indicates "simulates the work of a microcontroller". As microcontroller executes instructions one by one, simulator is conceived - programmer moves through a program step-by-step (line-by-line) and follows what goes on with data within a microcontroller. When writing is completed, it is a good trait to, programmer's first check his program in a simulator, and then runs it out in a real situation. Unfortunately, as with many other good habits, man overflows this one too, more or less. Reasons for this are partly personality, and partly lack of good simulators.

First thing we need to do, as in a real situation, is to reset a microcontroller with `DEBUG > RUN > RESET` command. This command results in bold line positioned at the beginning of a program, and program counter is positioned at zero which can be seen in status line (`pc: 0x00`).



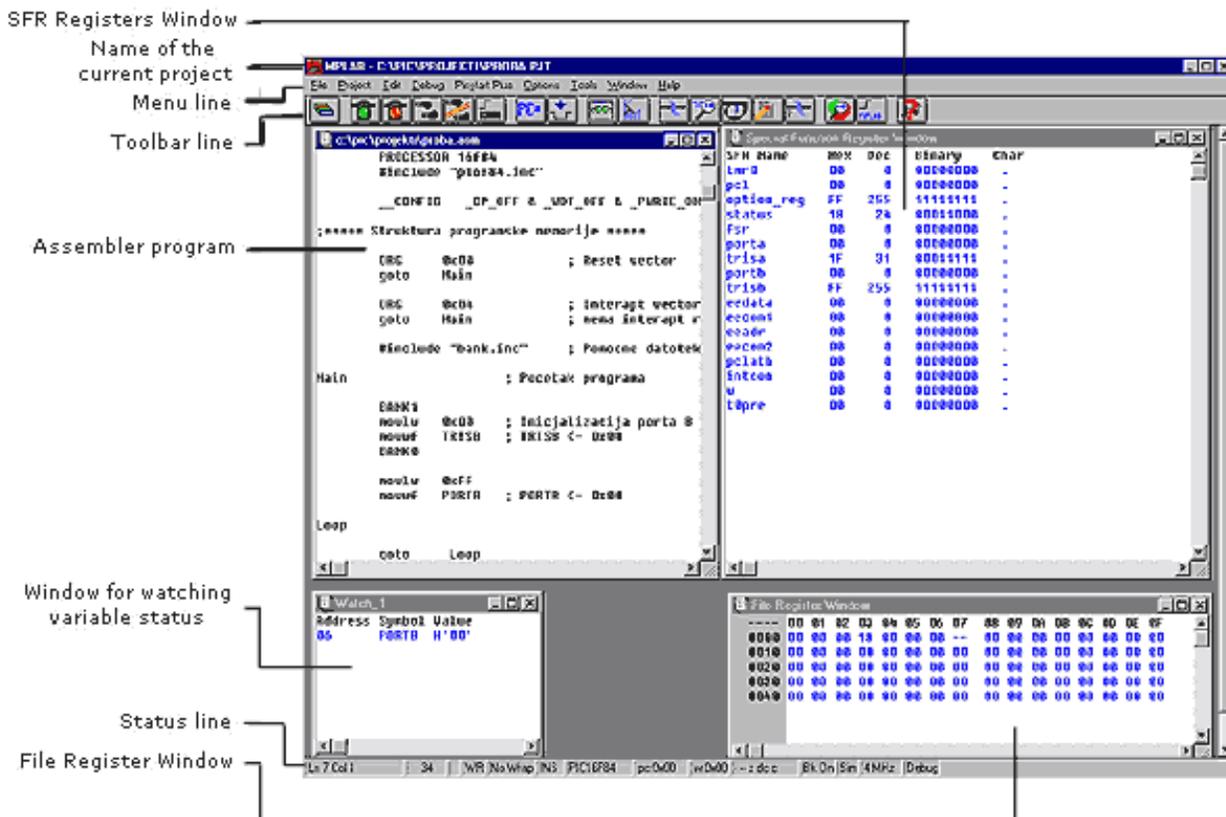
Beginning of program simulation, resetting a microcontroller

One of the main characteristics of a simulator is the ability to view register status within a microcontroller. These registers are also called special function registers, or SFR registers.

We can get a window with SFR registers by clicking on `WINDOW->SPECIAL FUNCTION REGISTERS`, or on SFR icon.

Beside SFR registers, it is useful to have an insight into file registers. Window with file registers can be opened by clicking on `WINDOW->FILE REGISTERS`.

If there are variables in the program, it is good to watch them, too. To each variable is assigned one window (Watch Windows) by clicking on `WINDOW->WATCH WINDOWS`.



Simulator with open windows for SFR registers, file registers and variables.

The next command in a simulator is `DEBUG>RUN>STEP` which starts our stepping through the program. The same command could have been assigned from a keyboard with `<F7>` key (generally speaking, all significant commands have keys assigned on the keyboard).

By using the `F7` key, program is executed step-by-step. When we get to a macro, file containing a macro is opened (Bank.inc), and we proceed to go through a macro. In a SFR registers window we can observe how W register receives value `0xFF` and delivers it to port B. By clicking on `F7` key again, we don't achieve anything because program has arrived to an "infinite loop". Infinite loop is a term we will meet often. It represents a loop from which a microcontroller can not get out until interrupt occurs (if it is used in a program), or until a microcontroller would be reset.

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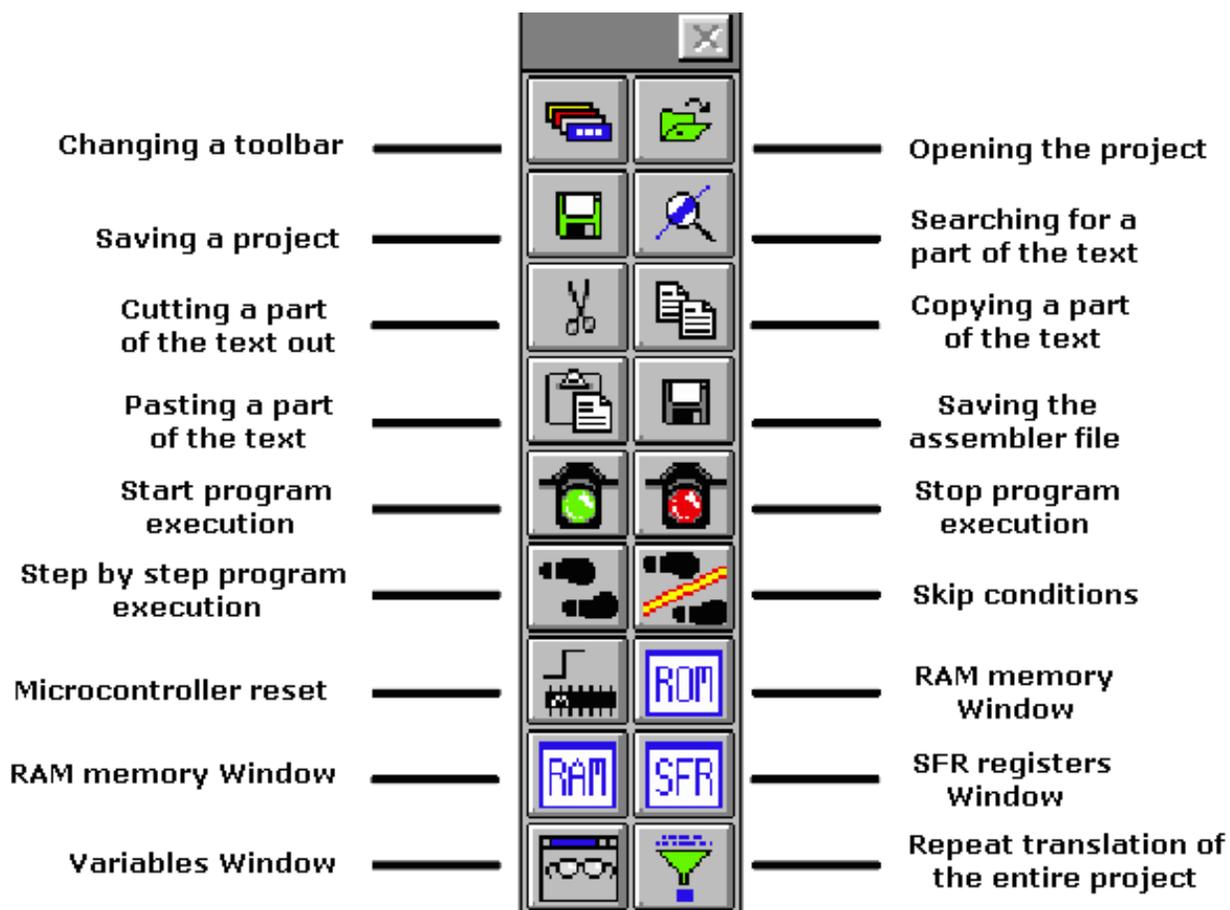
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5.8 Toolbar

Since MPLAB has more than one component, each of the components has its own toolbar. However, there is a toolbar which is some compilation of all toolbars, and can serve as a commonly used toolbar. This toolbar is enough for our needs, and it will be explained in more detail. In the picture below, we can see a toolbar we need with a brief explanation of each icon. Because of the limited format of this book, this toolbar is shown as a hanging toolbar. Generally, it is placed horizontally below the menu, over the entire length of the screen.



Universal toolbar with brief explanations of the icons

Toolbar icon description

	If the current toolbar for some reason does not respond to a click on this icon, the next one appears. Changeover is repeated so that on the fourth click we will get the same toolbar again.
	Icon for opening a project. Project opened in this way contains all screen adjustments and adjustment of all elements which are crucial to the current project.
	Icon for saving a project. Saved project will keep all window adjustments and all parameter adjustments. When we read in a program again, everything will return to the screen as when the project was closed.

	Searching for a part of the program, or words is operation we need when searching through bigger assembler or other programs. By using it, we can find quickly a part of the program, label, macro, etc.
	Cutting a part of the text out. This one and the following three icons are standard in all programs that deal with processing textual files. Since each program is actually a common text file, those operations are useful.
	Copying a part of the text. There is a difference between this one and the previous icon. With cut operation, when you cut a part of the text out, it disappears from the screen (and from a program) and is copied afterwards. But with copy operation, text is copied but not cut out, and it remains on the screen.
	When a part of the text is copied, it is moved into a part of the memory which serves for transferring data in Windows operational system. Later, by clicking on this icon it can be 'pasted' in the text where the cursor is.
	Saving a program (assembler file).
	Start program execution in full speed. It is recognized by appearance of a yellow status line. With this kind of program execution, simulator executes a program in full speed until it is interrupted by clicking on the red traffic light icon.
	Stop program execution in full speed. After clicking on this icon, status line becomes gray again, and program execution can continue step by step.
	Step by step program execution. By clicking on this icon, we begin executing an instruction from the next program line in relation to the current one.
	Skip requirements. Since simulator is still a software simulation of real work, it is possible to simply skip over some program requirements. This is especially handy with instructions which are waiting for some requirement following which program can proceed further. That part of the program which follows a requirement is the part that's interesting to a programmer.
	Resetting a microcontroller. By clicking on this icon, program counter is positioned at the beginning of a program and simulation can start.
	By clicking on this icon we get a window with a program, but this time as program memory where we can see which instruction is found at which address.
	With the help of this icon we get a window with the contents of RAM memory of a microcontroller.
	By clicking on this icon, window with SFR register appears. Since SFR registers are used in every program, it is recommended that in simulator this window is always active.
	If a program contains variables whose values we need to keep track of (ex. counter), a window needs to be added for each of them, which is done by using this icon.
	When certain errors in a program are noticed during simulation process, program has to be corrected. Since simulator uses HEX file as its input, so we need to translate a program again so that all changes would be transferred to a simulator. By clicking on this icon, entire project is translated again, and we get the newest version of HEX file for the simulator.

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CHAPTER 6

The Samples

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 - [Input shift register](#)
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- [7-segment Displays \(multiplexing\)](#)
- [LCD display](#)
- [12-bit AD converter](#)
- [Serial communication](#)

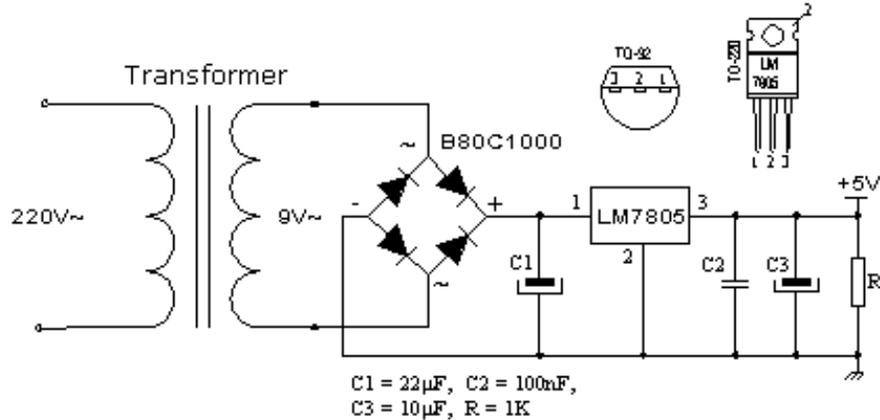
Introduction

Examples given in this chapter will show you how to connect the PIC microcontroller with other peripheral components or devices when developing your own microcontroller system. Each example contains detailed description of the hardware part with electrical outline and comments about the program. All programs can be taken directly from the from 'MikroElektronika' internet presentation.

Supplying the microcontroller

Generally speaking, the correct voltage supply is of utmost importance for the proper functioning of the microcontroller system. It can easily be compared to a man breathing in the air. It is more likely that a man who is breathing in fresh air will live longer than a man who's living in a polluted environment.

For a proper function of any microcontroller, it is necessary to provide a stable source of supply, a sure reset when you turn it on and an oscillator. According to technical specifications by the manufacturer of PIC microcontroller, supply voltage should move between 2.0V to 6.0V in all versions. The simplest solution to the source of supply is using the voltage stabilizer LM7805 which gives stable +5V on its output. One such source is shown in the picture below.



In order to function properly, or in order to have stable 5V at the output (pin 3), input voltage on pin 1 of LM7805 should be between 7V through 24V. Depending on current consumption of device we will use the appropriate type of voltage stabilizer LM7805. There are several versions of LM7805. For current consumption of up to 1A we should use the version in TO-220 case with the capability of additional cooling. If the total consumption is 50mA, we can use 78L05 (stabilizer version in small TO - 92 packaging for current of up to 100mA).

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Macros used in programs

Examples given in the following sections of this chapter often use macros WAIT, WAITX and PRINT, so they will be explained in more detail.

Macros WAIT, WAITX

File Wait.inc contains two macros WAIT and WAITX. Through these macros it is possible to assign time delays in different intervals. Both macros use the overflow of counter TMR0 as a basic interval. By changing the prescaler we can change the length of the overflow interval of the counter TMR0.



WAIT.inc

```

;**** Declaring constants ****

        CONSTANT PRESCstd = b'00000001' ; Standard prescaler value for TMR0

;**** Macros ****

WAIT    macro    timeconst_1

        movlw    timeconst_1
        call    WAITstd
        endm

WAITX   macro    timeconst_2, PRESCext

        movlw    timeconst_2
        movwf    WCYCLE           ; Set the delay time period
        movlw    PRESCext        ; Write specific prescaler value
        call    WAIT_x
        endm

;**** Subprograms ****

WAITstd
        movwf    WCYCLE           ; Set the delay time period
        movlw    PRESCstd        ; Write specific prescaler value

WAIT_x
        clrf    TMR0
        BANK1
        movwf    OPTION_REG      ; Assing the prescaler to TMR0 timer
        BANK0

WAITa
        bcf     INTCON,TDIF      ; Erase TMR0 Overflow Flag

WAITb
        btfss  INTCON,TDIF      ; Check whether it is erased, skip if isn't
        goto   WAITb            ; Wait loop
        decfsz WCYCLE,1         ; Repeat the loop if delay period has not run out

```

```

goto   WAITb           ; Wait loop
decfsz WCYCLE,1       ; Repeat the loop if delay period has not run out
goto   WAITa
RETURN

```

If we use the oscillator (resonator) of 4MHz, for prescaler values 0, 1, and 7 that divide the basic clock of the oscillator, the interval followed by an overflow of timer TMR0 will be 0.512, 1.02 and 65.3 mS. Practically, that means that the biggest delay would be 256x65.3mS which is equal to 16.72 seconds.

Prescaler	Divisor	Overflow
b'00000000'	1:2	0.512 ms
b'00000001'	1:4	1.02 ms
b'00000111'	1:256	65.3 ms

In order to use macros in the main program it is necessary do declare variables wcycle and prescWAIT as will be done in examples which follow in this chapter.

Macro WAIT has one argument. The standard value assigned to prescaler of this macro is 1 (1.02mS), and it can not be changed.

WAIT timeconst_1

timeconst_1 is number from 0 to 255. By multiplying that number with the overflow time period we get the total amount of the delay: TIME=timeconst_1 x 1.02mS.

Example: WAIT .100

Example shows how to make a delay of 100x1.02mS, or total of 102mS.

Unlike macro WAIT, macro WAITX has one more argument that can assign prescaler value. Macro WAITX has two arguments:

Timeconst_2 is number from 0 to 255. By multiplying that number with the overflow time period we get the total amount of the delay:

TIME=timeconst_1 x 1.02mS x PRESCext

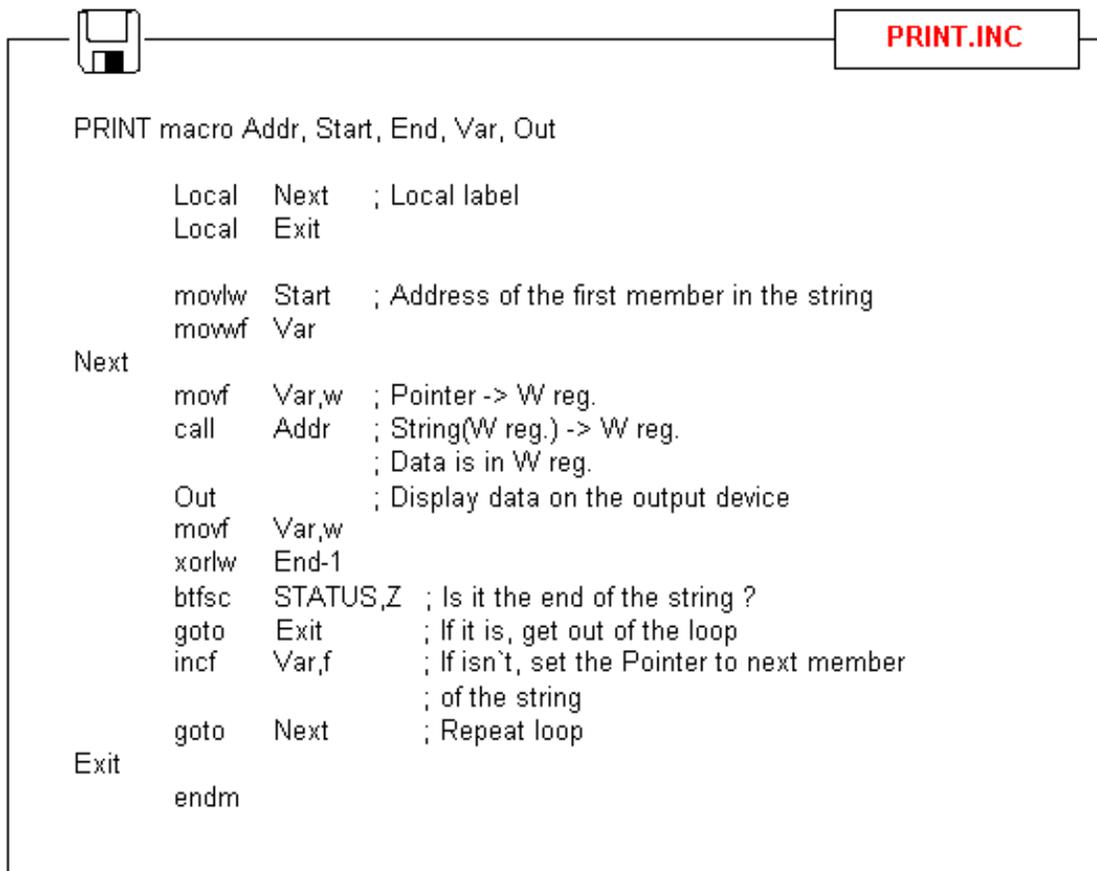
PRESCext is number from 0 to 7 which sets up the relationship between a clock and timer TMR0.

Example: WAITX .100,7

Example shows how to make a delay of 100x65.3 mS, or total of 653mS.

Macro PRINT

Macro PRINT is found in Print.inc file. It makes it easy to show a string of data on one of the output devices such as : LCD, RS232, matrix printer...etc. The easiest way to form a series is by using a dt (define table) directive. This instruction stores a series of data into program memory as a group of retlw instructions whose operand is data from the string.



How one such sequence is formed by using dt instruction is shown in the following example:

```

org 0x00
goto Main

String movwf PCL
String1 dt "this is 'ASCII' string"
String2 dt "Second string"
End
Main

movlw .5
call String
:

```

First instruction after label Main writes the position of a member of the string in w register. We jump with instruction call onto label string where position of a member of the string is added to the value of the program counter: $PCL = PCL + W$. Next we will have in the program counter an address of retlw instruction with the desired member of the string. When this instruction is executed, member of the string will be in w register, and address of the instruction that executed after the call instruction will be in the program counter. End label is an elegant way to mark the address at which the string ends.

Macro PRINT has five arguments:

PRINT macro Addr, Start, End, Var, Out

Addr is an address where one or more strings (which follow one by one) begin.

Start is an address of the first member of the string

End is an address where the string ends

Var is the variable which has a role of showing (pointing) the members of the string

Out is an argument we use to send the address of existing subprograms assigned to output devices such as : LCD, RS-232, etc.

```
Example:   org      0x00
             goto    Main

             Series  movwf PCL
             Message dt "mikroElektronika"
             End
```

```
Main
    PRINT Series, Message, End, Pointer, LCDw
    :
```

Macro PRINT writes out a string of ASCII characters for 'MikroElektronika' on LCD display. The string takes up one part of program memory beginning at address 0x03.

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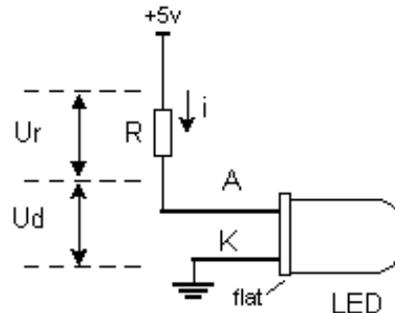
Samples

Light-Emitting Diodes - LEDs

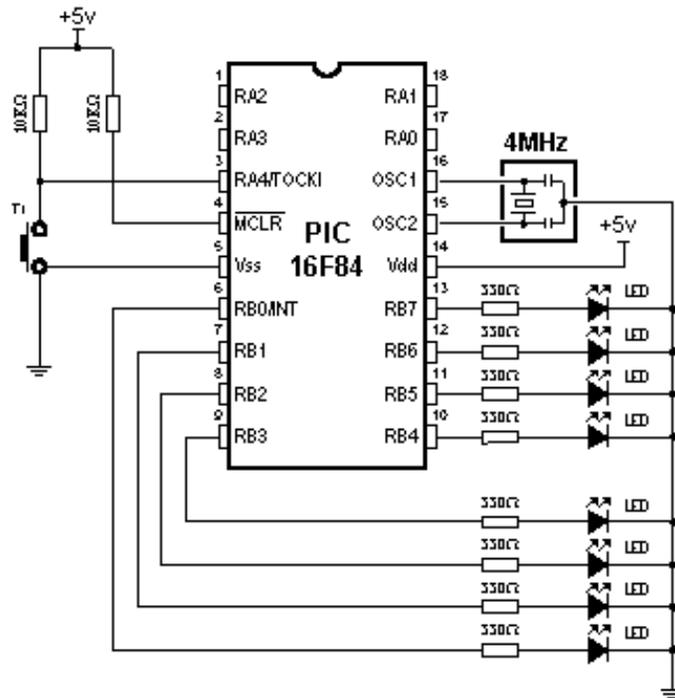
LEDs are surely one of the most commonly used elements in electronics. LED is an abbreviation for 'Light Emitting Diode'. When choosing a LED, several parameters should be looked at: diameter, which is usually 3 or 5 mm (millimeters), working current which is usually about 10mA (It can be as low as 2mA for LEDs with high efficiency - high light output), and color of course, which can be red or green though there are also orange, blue, yellow....

LEDs must be connected around the correct way, in order to emit light and the current-limiting resistor must be the correct value so that the LED is not damaged or burn out (overheated). The positive of the supply is taken to the anode, and the cathode goes to the negative or ground of the project (circuit). In order to identify each lead, the cathode is the shorter lead and the LED "bulb" usually has a cut or "flat" on the cathode side. Diodes will emit light only if current is flowing from anode to cathode. Otherwise, its PN junction is reverse biased and current won't flow. In order to connect a LED correctly, a resistor must be added in series that to limit the amount of current through the diode, so that it does not burn out. The value of the resistor is determined by the amount of current you want to flow through the LED. Maximum current flow through LED was defined by manufacturer. High-efficiency LEDs can produce a very good output with a current as low as 2mA.

To determine the value of the dropper-resistor, we need to know the value of the supply voltage. From this we subtract the characteristic voltage drop of a LED. This value will range from 1.2v to 1.6v depending on the color of the LED. The answer is the value of U_r . Using this value and the current we want to flow through the LED (0.002A to 0.01A) we can work out the value of the resistor from the formula $R = U_r / I$.



LEDs are connected to a microcontroller in two ways. One is to turn them on with logic zero, and other to turn them on with logic one. The first is called NEGATIVE logic and the other is called POSITIVE logic. The above diagram shows how they are connected for POSITIVE logic. Since POSITIVE logic provides a voltage of +5V to the diode and dropper resistor, it will emit light each time a pin of port B is provided with a logic 1 (1 = HIGH output). NEGATIVE logic requires the LED to be turned around the other way and the anodes connected together to the positive supply. When a LOW output from the microcontroller is delivered to the cathode and resistor, the LED will illuminate.



Connecting LED diodes to PORTB microcontroller

The following example initializes port B as output and sets logic one to each pin of port B to turn on all LEDs.

TEST.asm

```

;***** Declaring and configuring a microcontroller *****

PROCESSOR 16f84
#include "p16f84.inc"

    _CONFIG _CP_OFF & _WDT_OFF & _PWRTE_ON & _XT_OSC

;***** Declaring variables *****

Cblock 0x0C                ; Beginning of RAM
WCYCLE                    ; Belongs to 'WAITX' macro
PRESCwait
endc

;***** Structure of program memory *****

ORG 0x00                  ; Reset vector
goto Main

ORG 0x04                  ; Interrupt vector
goto Main                 ; No interrupt routine

#include "bank.inc"       ; Assistant files

Main                      ; Beginning of the program

```

```
Main                                ; Beginning of the program

    BANK1
    movlw 0xff                       ;Port A initialization
    movwf TRISA                      ; TRISA <- 0xff all input
    movlw 0x00                       ; PORTB initialization
    movwf TRISB                      ; TRISB <- 0xff
    movlw 0x00                       ; PORTB initialization
    BANK0

    movlw 0xff
    movwf PORTB                      ;Turn on all leds

Loop
    goto  Loop                       ; Repeat loop

End                                  ; End of program
```

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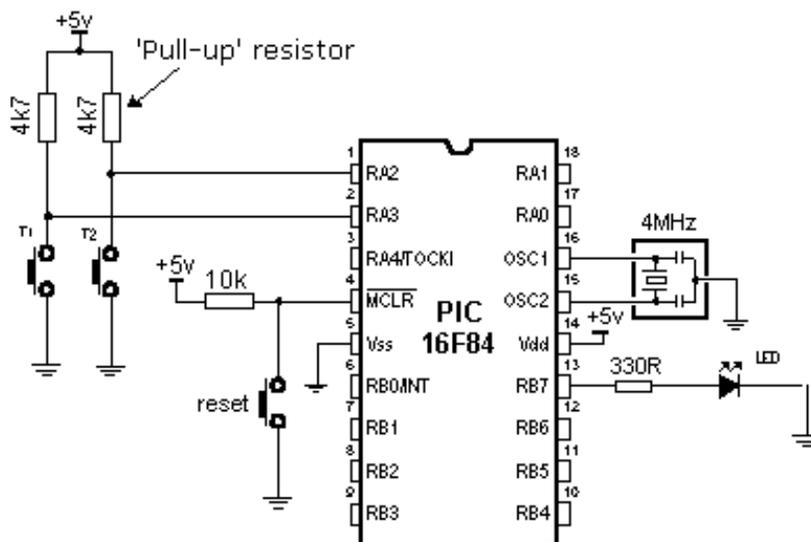
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Keyboard

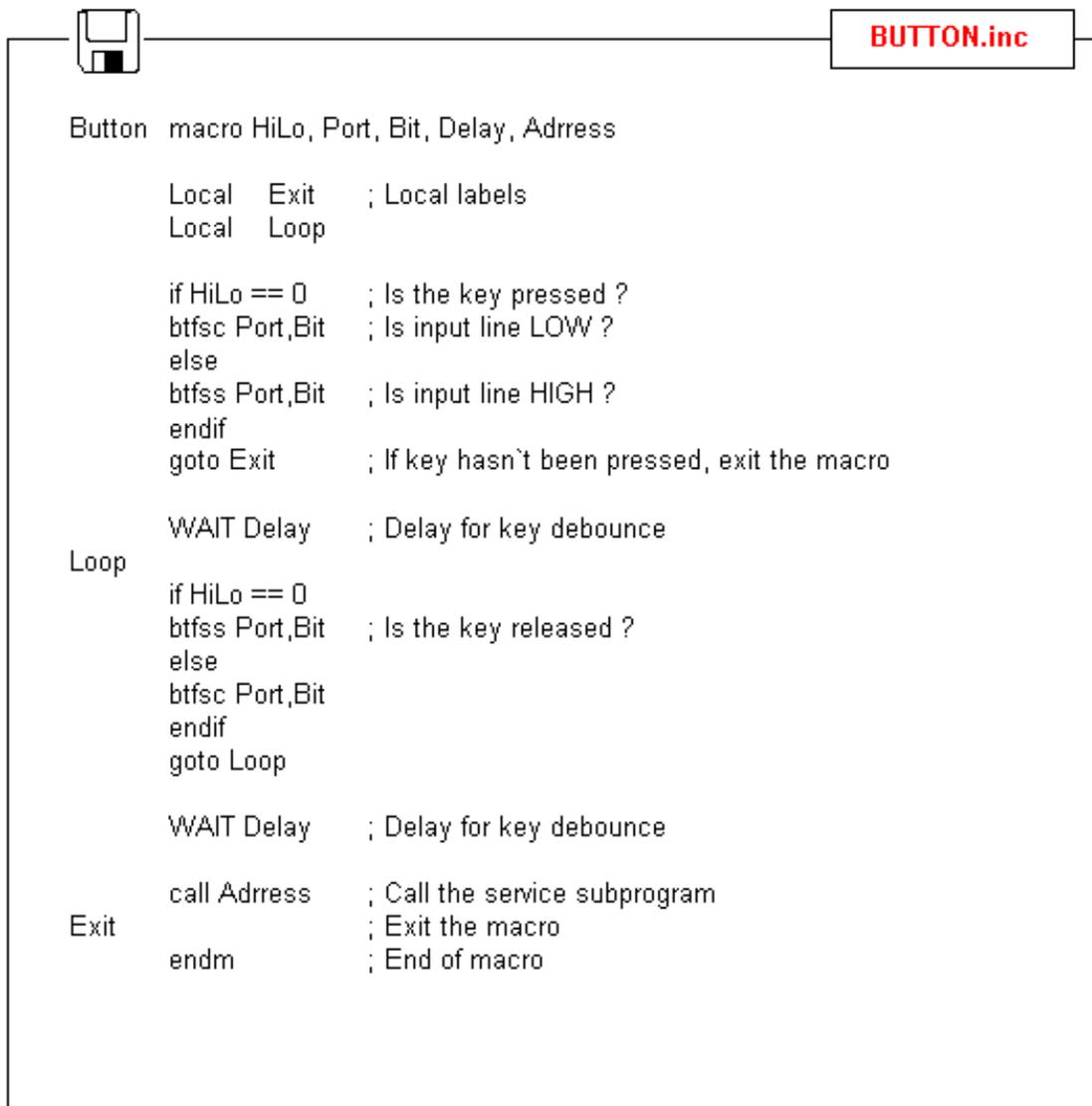
Keyboards are mechanical devices used to execute a break or make connection between two points. They come in different sizes and with different purposes. Keys that are used here are also called "dip-keys". They are soldered directly onto a printed board and are often found in electronics. They have four pins (two for each contact) which give them mechanical stability.



Example of connecting keys to microcontroller pins.

Key function is simple. When we press a key, two contacts are joined together and connection is made. Still, it isn't all that simple. The problem lies in the nature of voltage as an electrical dimension, and in the imperfection of mechanical contacts. That is to say, before contact is made or cut off, there is a short time period when vibration (oscillation) can occur as a result of unevenness of mechanical contacts, or as a result of the different speed in pressing a key (this depends on person who presses the key). The term given to this phenomena is called SWITCH (CONTACT) DEBOUNCE. If this is overlooked when program is written, an error can occur, or the program can produce more than one output pulse for a single key press. In order to avoid this, we can introduce a small delay when we detect the closing of a contact. This will ensure that the press of a key is interpreted as a single pulse. The debounce delay is produced in software and the length of the delay depends on the key, and the purpose of the key. The problem can be partially solved by adding a capacitor across the key, but a well-designed program is a much-better answer. The program can be adjusted until false detection is completely eliminated. In some case a simple delay will be adequate but if you want the program to be attending to a number of things at the same time, a simple delay will mean the processor is "doing-nothing" for a long period of time and may miss other inputs or be taken away from outputting to a display.

The solution is to have a program that looks for the press of a key and also the release of a key. The macro below can be used for keypress debounce.



The above macro has several arguments that need to be explained:

BUTTON macro HiLo, Port, Bit, Delay, Address

HiLo can be '0' or '1' which represents rising or falling edge where service subprogram will be executed when you press a key.

Port is a microcontroller's port to which a key is connected. In the case of a PIC16F84 microcontroller, it can be PORTA or PORTB.

Bit is port's pin to which the key is connected.

Delay is a number from 0 to 255, used to assign the time needed for key debounce detection - contact oscillation - to stop. It is calculated as $TIME = Delay \times 1ms$.

Address is the address where the micro goes after a key is detected. The sub-routine at the address carries out the required instruction for the keypress.

Example 1: BUTTON 0, PORTA, 3, .100, Tester1_above

Key-1 is connected to RA0 (the first output of port A) with a delay of 100 microseconds and a reaction to logic zero. Subprogram that processes key is found at address of label Tester1_above.

Example2: BUTTON 0, PORTA, 2, .200, Tester2_below

Key-2 is connected to RA1 (the second output of port A) with 200 mS delay and a reaction to logic one. Subprogram that processes key is found at address of label Tester2_below.

The next example shows the use of macros in a program. BUTTON.ASM turns LED on and off. The LED is connected to the seventh output of port B. Key-1 is used to turn LED on. Key-2 turns LED off.



```

;***** Declaring and configuring a microcontroller *****

PROCESSOR 16F84
#include "p16F84.inc"

    __CONFIG    _CP_OFF & _WDT_OFF & _PWRTE_ON & _XT_OSC

;***** Declaring variables *****

    Cblock 0x0C          ; Beginning of RAM
    WCYCLE              ; Belongs to 'WAITX' macro
    PRESCwait
    endc

;***** Structure of program memory *****

    ORG    0x00          ; Reset vector
    goto   Main

    ORG    0x04          ; Interrupt vector
    goto   Main          ; No interrupt routine

#include "bank.inc"      ; Assistant files
#include "button.inc"
#include "wait.inc"

Main                      ; Beginning of the program
    BANK1
    movlw 0xff           ; PORTA initialization
    movwf TRISA          ; TRISA <- 0xff
    movlw 0x00           ; PORTB initialization
    movwf TRISB          ; TRISB <- 0x00
    BANK0

    clrf   PORTB         ; PORTB <- 0x00

Loop
    Button 0, PORTA, 2, .100, On ; Button 1
    Button 0, PORTA, 3, .100, Off ; Button 2
    goto   Loop

On
    bsf   PORTB,7        ; Turn on LED
    return

Off
    bcf   PORTB,7        ; Turn off LED
    return

End          ; End of program

```

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Optocoupler

Optocoupler combine a LED and photo-transistor in the same case. The purpose of an optocoupler is to separate two parts of a circuit.

This is done for a number of reasons:

- **Interference.** One part of a circuit may be in a location where it picks up a lot of interference (such as from electric motors, welding equipment, petrol motors etc.) If the output of this circuit goes through an optocoupler to another circuit, only the intended signals will pass through the optocoupler. The interference signals will not have enough "strength" to activate the LED in the optocoupler and thus they are eliminated. To protect a section of the device. Typical examples are industrial units with lots of interferences which affect signals in the wires. If these interferences affect the function of control section, errors will occur and the unit will stop working.
- **Simultaneous separation and intensification of a signal.** A signal as low as 3v is able to activate an optocoupler and the output of the optocoupler can be connected to an input line of a microcontroller. The microcontroller requires an input swing of 5v and in this case the 3v signal is amplified to 5v. It can also be used to amplify the current of a signal. See below for use on the output line of a microcontroller for current amplification.
- **High Voltage Separation.** Optocouplers have inherent high voltage separation qualities. Since the LED is completely separate from the photo-transistor, optocouplers can exhibit voltage isolation of 3kv or higher.

Optocouplers can be used as input or output device. They can have additional functions such as Schmitt triggering (the output of a Schmitt trigger is either 0 or 1 - it changes slow rising and falling waveforms into definite low or high values). Optocouplers are packaged as a single unit or in groups of two or more in one housing. They are also called PHOTO INTERRUPTERS where a spoked wheel is inserted in a slot between the LED and phototransistor and each time the light is interrupted, the transistor produces a pulse.

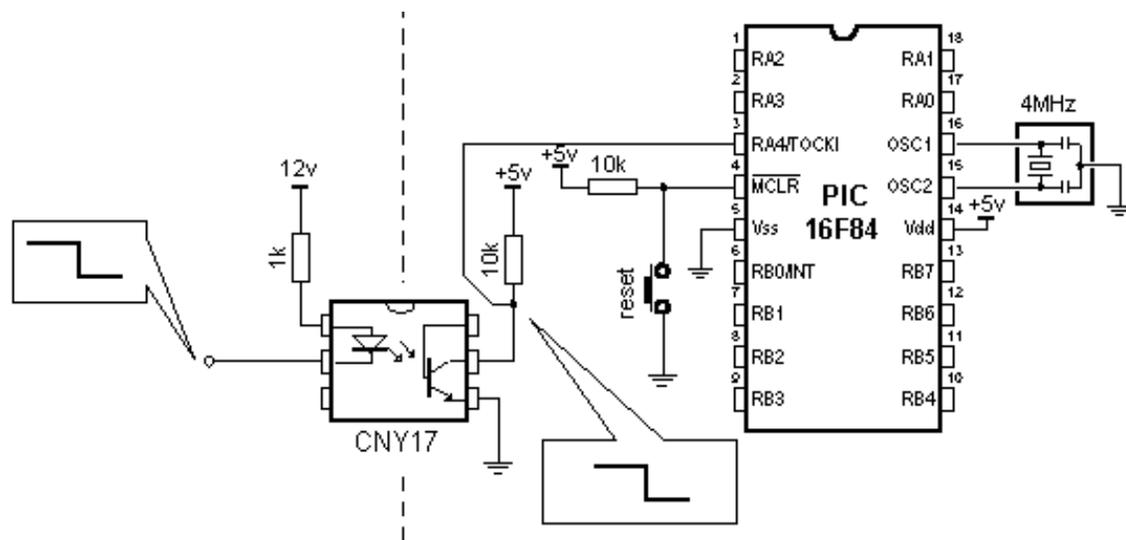
Each optocoupler needs two supplies in order to function. They can be used with one supply, but the voltage isolation feature is lost.

Optocoupler on an input line

The way it works is simple: when a signal arrives, the LED within the optocoupler is turned on, and it shines on the base of a photo-transistor within the same case. When the transistor is activated, the voltage between collector and emitter falls to 0.5V or less and the microcontroller sees this as a logic zero on its RA4 pin.

The example below is a counter, used for counting products on production line, determining motor speed, counting the number of revolutions of an axis etc.

Let the sensor be a micro-switch. Each time the switch is closed, the LED is illuminated. The LED 'transfers' the signal to the phototransistor and the operation of the photo-transistor delivers a LOW to input RA4 of a microcontroller. A program in the microcontroller will be needed to prevent false counting and an indicator connected to any of the outputs of the microcontroller will shows the current state of the counter.



Input line optocoupler example



OPTO_IN.asm

```

;***** Declaring and configuring a microcontroller *****

PROCESSOR 16f84
#include "p16f84.inc"

    _CONFIG_CP_OFF & _WDT_OFF & _PWRTE_ON & _XT_OSC

;***** Structure of program memory *****

ORG 0x00           ; Reset vector
goto Main

ORG 0x04           ; Interrupt vector
goto Main          ; No interrupt routine

#include "bank.inc" ; Assistant files

Main              ; Beginning of the program
BANK1
movlw 0xff        ; PORTA initialization
movwf TRISA       ; TRISA <- 0xff (input)
movlw 0x00        ; PORTB initialization
movwf TRISB       ; TRISB <- 0x00 (output)
movlw b'00110000' ; RA4 -> TMR0,
movwf OPTION_REG ; Increment TMR0 on falling edge
BANK0

clrf PORTB ; PORTB <- 0
clrf TMR0  ; TMR0 <- 0

Loop

movf TMR0,w      ; Copy TMR0 in W reg.
movwf PORTB      ; send value of W reg. on PORTB
goto Loop        ; Repeat the loop

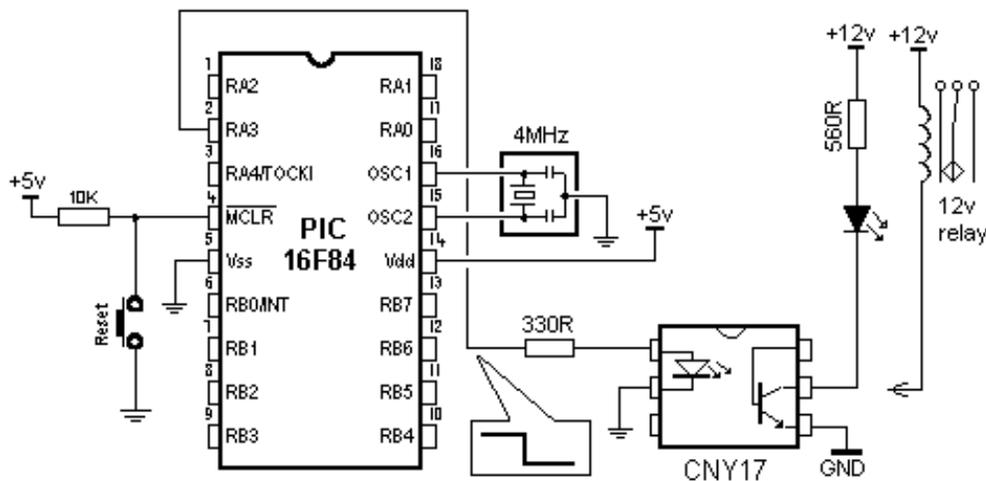
End              ; End of program

```

```
End ; End of program
```

Optocoupler on an output line

An Optocoupler can be used to separate the output signal of a microcontroller from an output device. This may be needed for high voltage separation or current amplification. The output of some microcontrollers is limited to 25mA. The optocoupler will take the low-current signal from the microcontroller and its output transistor will drive a LED or relay, as shown below:



Output line optocoupler example

The program for this example is simple. By delivering a logic '1' to the fourth pin of port A, the LED will be turned on and the transistor will be activated in the optocoupler. Any device connected to the output of the optocoupler will be activated. The transistor current-limit is about 250mA.

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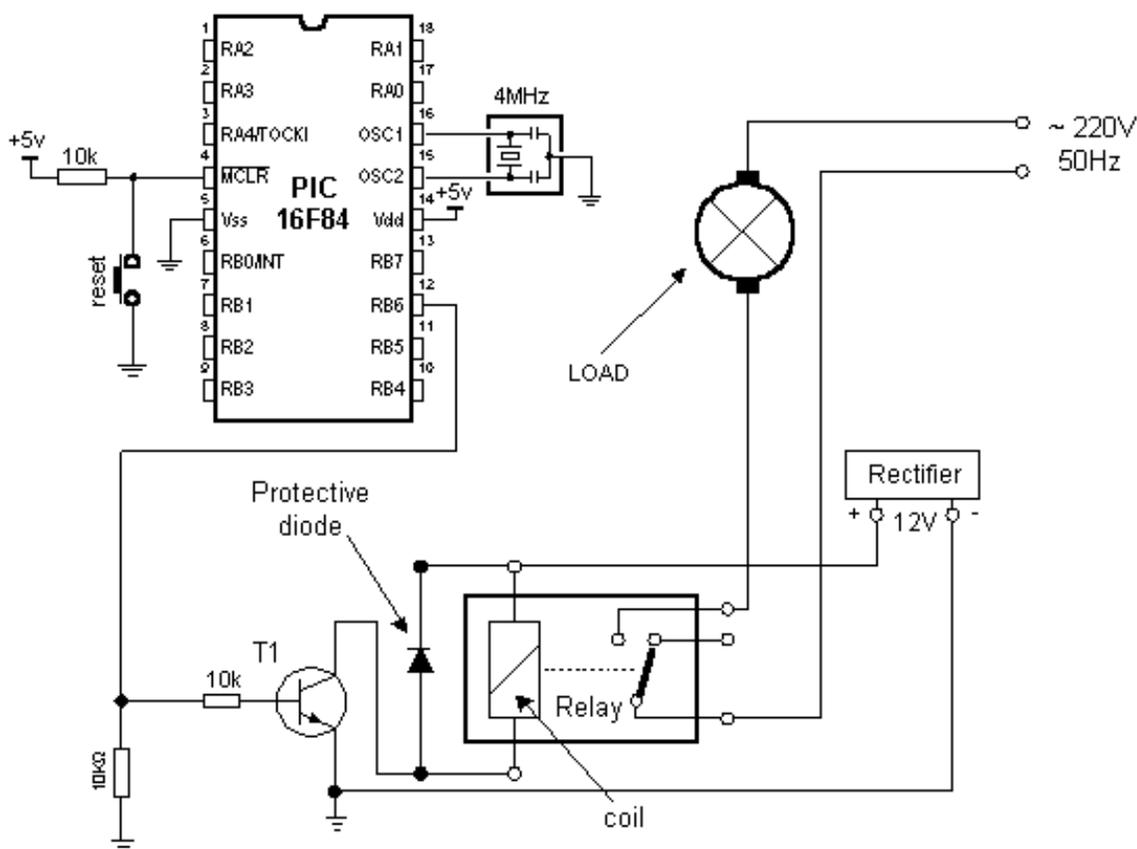
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The Relay

The relay is an electromechanical device, which transforms an electrical signal into mechanical movement. It consists of a coil of insulated wire on a metal core, and a metal armature with one or more contacts.

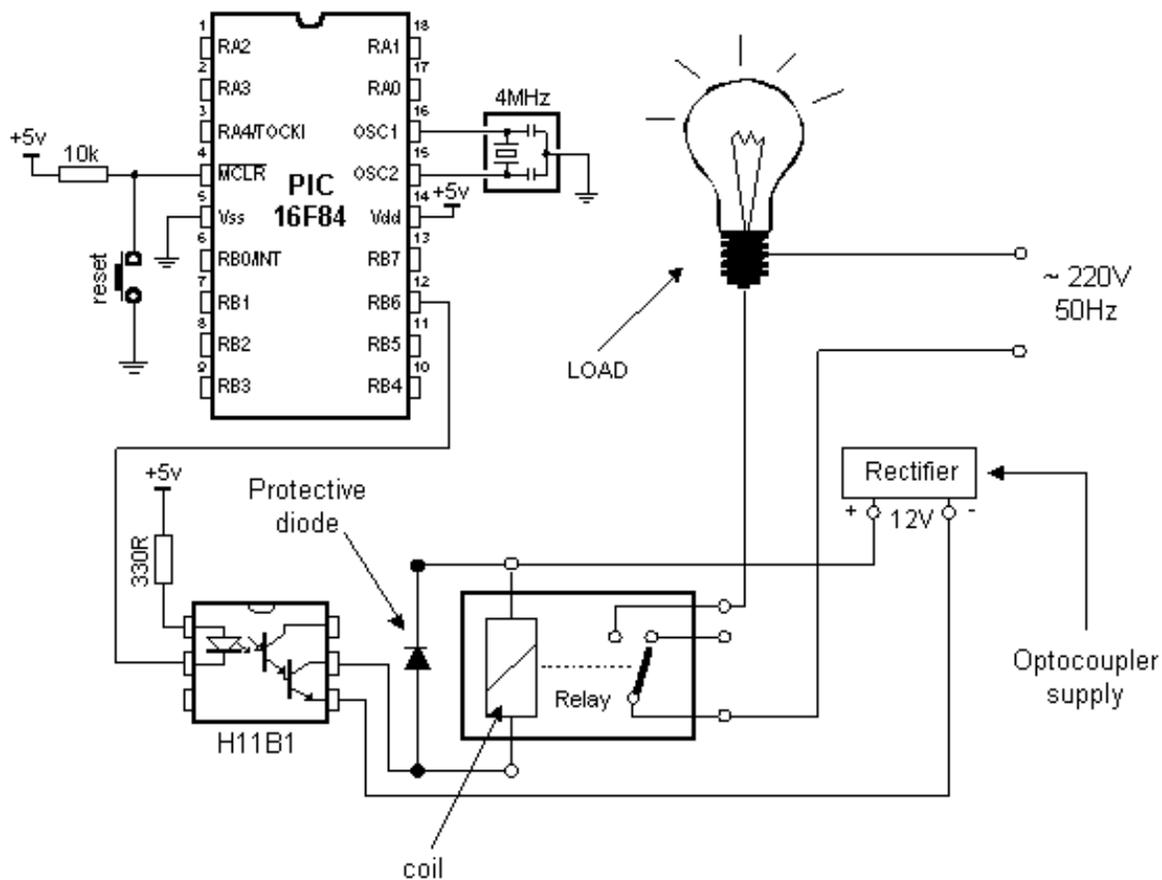
When a supply voltage was delivered to the coil, current would flow and a magnetic field would be produced that moves the armature to close one set of contacts and/or open another set. When power is removed from the relay, the magnetic flux in the coil collapses and produces a fairly high voltage in the opposite direction. This voltage can damage the driver transistor and thus a reverse-biased diode is connected across the coil to "short-out" the spike when it occurs.



Connecting a relay to the microcontroller via a transistor

Many microcontrollers cannot drive a relay directly and so a driver transistor is required. A HIGH on the base of the transistor turns the transistor ON and this activates the relay. The relay can be connected to any electrical device via the contacts.

The 10k resistor on the base of the transistor limits the current from the microcontroller to that required by the transistor. The 10k between base and the negative rail prevents noise on the base from activating the relay. Thus only a clear signal from the microcontroller will activate the relay.

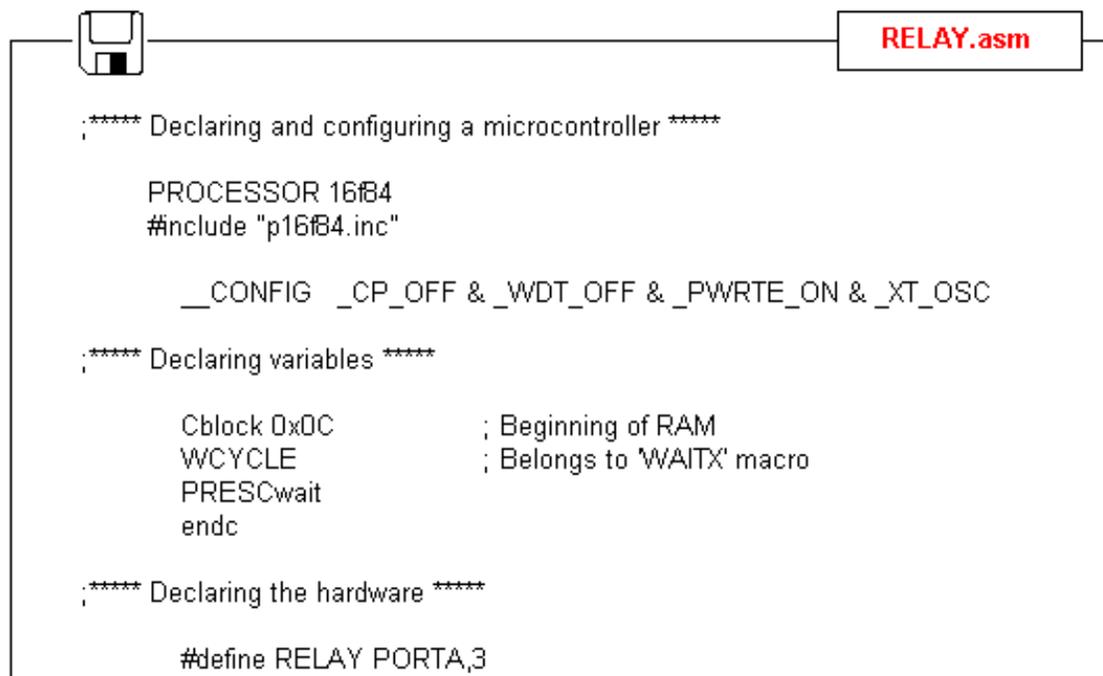


Connecting the optocoupler and relay to a microcontroller

A relay can also be activated via an optocoupler which at the same time amplifies the current related to the output of the microcontroller and provides a high degree of isolation. High current optocouplers usually contain a 'darlington' output transistor to provide high output current.

Connecting via an optocoupler is recommended especially for microcontroller applications, where motors are activated as the commutator noise from the motor can get back to the microcontroller via the supply lines. The optocoupler drives a relay and the relay activates the motor.

The figure below shows the program needed to activate the relay, and includes some of the already discussed macros.



```

        #define RELAY PORTA,3

;***** Structure of program memory *****

        ORG    0x00            ; Reset vector
        goto  Main

        ORG    0x04            ; Interrupt vector
        goto  Main            ; No interrupt routine

#include "bank.inc"           ; Assistant files
#include "button.inc"
#include "wait.inc"

Main                                     ; Beginning of the program
    BANK1
    movlw 0x17                    ; PORTA initialization
    movwf TRISA                   ; TRISA <- 0x17
    movlw 0x00                    ; PORTB initialization
    movwf TRISB                   ; TRISB <- 0x00
    BANK0

    clrf  PORTB                    ; PORTB <- 0x00

Loop
    Button 0, PORTA, 0, .100, On   ; Button 0
    Button 0, PORTA, 1, .100, Off ; Button 1

    goto  Loop                    ; Repeat the loop

On
    bsf RELAY                      ; Turn on relay
    return

Off
    bcf RELAY                      ; Turn off relay
    return

End                                     ; End of program

```

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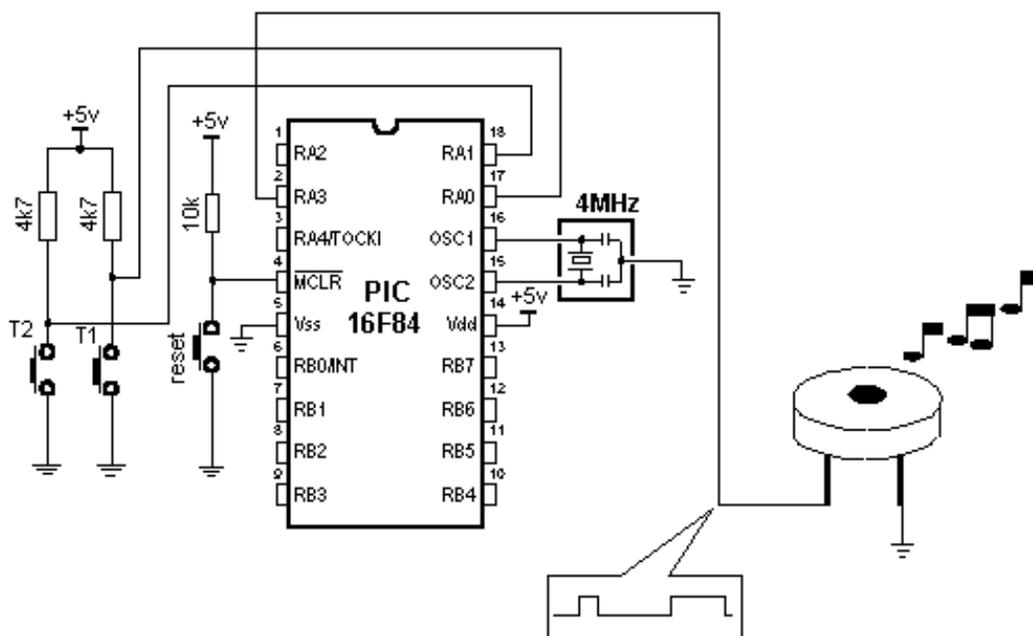
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Generating a sound

A Piezo diaphragm can be added to an output line of a microcontroller to deliver a "speaker" tones, beeps and signals. It is important to know there are two main types of piezo sound-emitting devices. One has active components inside the case and only requires a DC supply for the "speaker" to emit a tone or beep. Generally the tones or beeps emitted by these "speaker" or "beepers" cannot be changed - they are fixed by the internal circuitry. This is not the type we are discussing in this article.

The other type consists of a piezo diaphragm and requires a signal to be delivered to it for it to function. Depending on the frequency of the waveform, the output can be a tone, tune, alarm or even voice messages. In order for them to work we must deliver a cycle consisting of a HIGH and LOW. It is the change from HIGH to LOW or LOW to HIGH that causes the diaphragm to "dish" (move) to produce the characteristic "tinny" sound. The waveform can be a smooth change from one value to the other (called a sine wave) or a fast change (called a SQUARE WAVE). A computer is ideal for producing a square wave. The square wave delivery produces a slightly harsher output. Connecting a piezo diaphragm is very simple. One pin is connected to the negative rail and the other to an output of a microcontroller, as shown in the diagram below. This will deliver a 5v waveform to the piezo diaphragm. To produce a higher output, the waveform must be increased and this requires a driver transistor and inductor.



Connecting a piezo diaphragm to a microcontroller

As with a key, you can employ a macro that will deliver a BEEP ROUTINE into a program when needed.

BEEP **macro** freq , duration:

freq: frequency of the sound. The higher number produces higher frequency
duration: sound duration. The higher the number, the longer the sound.

Example 1: BEEP 0xFF, 0x02

The output of the piezo diaphragm has the highest frequency and duration at 2 cycles per 65.3mS which gives 130.6 mS

Example2: BEEP 0x90, 0x05

The output of the piezo diaphragm has a frequency of 0x90 and duration of 5 cycles per 65.3mS. It is best to determine these macro arguments through experimentation and select the sound that best suits the application.

The following is the BEEP Macro listing:



BEEP.inc

```

;***** Declaring constants *****

        CONSTANT PRESCbeep = b00000111'           ; 65,3 ms per cycle

;***** Macros *****

BEEP    macro    freq,duration

        movlw    freq
        movwf    Beep_TEMP1
        movlw    duration
        call     BEEPsub
        endm

BEEPinit macro

        bcf     BEEPport
        BANK1
        bcf     BEEPtris
        BANK0
        endm

;***** Subroutines *****

BEEPsub
        movwf    Beep_TEMP2           ; Set the value of sound duration
        clrf     TMR0                 ; Initialize the counter
        bcf     BEEPport
        BANK1
        bcf     BEEPport
        movlw    PRESCbeep           ; Set the prescaler for TMR0
        movwf    OPTION_REG         ; OPTION <- W
        BANK0

BEEPa
        bcf     INTCON,T0IF          ; Erase TMR0 Overflow Fleg

BEEPb
        bsf     BEEPport
        call    B_Wait               ; Duration of logic "1"
        bcf     BEEPport
        call    B_Wait               ; Duration of logic "0"
        btfsz  INTCON,T0IF          ; Check the TMR0 Overflow Fleg,
        goto    BEEPb               ; Skip of it is set
        decfsz Beep_TEMP2,1         ; Is the Beep_TEMP2 = 0 ?
        goto    BEEPa               ; If not, jump to BEEP again
        RETURN

B_Wait
        movfw   Beep_TEMP1
        movwf   Beep_TEMP3

B_Waita
        decfsz Beep_TEMP3,1

```

```

B_Waita
    decfsz Beep_TEMP3,1
    goto   B_Waita
    RETURN

```

The following example shows the use of a macro in a program. The program produces two melodies which are obtained by pressing T1 or T2. Some of the previously discussed macros are included in the program.


BEEP.asm

```

;***** Declaring and configuring a microcontroller *****

PROCESSOR 16f84
#include "p16f84.inc"

    __CONFIG _CP_OFF & _WDT_OFF & _PWRTE_ON & _XT_OSC

;***** Declaring variables *****

Cblock 0x0C           ; Beginning of RAM-a
WCYCLE             ; Belongs to 'WAITX' macro
PRESCwait
Beep_TEMP1        ; Belongs to 'BEEP' macro
Beep_TEMP2
Beep_TEMP3
endc

;***** Declaring the hardware *****

#define BEEPport PORTA,3 ; Port and pin for mini speaker
#define BEEPtris TRISA,3

;***** Structure of program memory *****

ORG 0x00           ; Reset vector
goto Main

ORG 0x04           ; Interrupt vector
goto Main          ; No interrupt routine

#include "bank.inc" ; Assistant files
#include "button.inc"
#include "wait.inc"
#include "beep.inc"

Main              ; Beginning of the program
BANK1
movlw 0x17        ; Port A initialization
movwf TRISA      ; TRISA <- 0x00
movlw 0x00
movwf TRISB
BANK0

BEEPinit         ; Mini speaker initialization

```

```
        clrf    PORTB

Loop    Button 0, PORTA, 0, .100, Play1    ; Button 1
        Button 0, PORTA, 1, .100, Play2    ; Button 2
        goto   Loop

Play1   BEEP 0xFF, 0x02
        BEEP 0x90, 0x05
        BEEP 0xC0, 0x03
        BEEP 0xFF, 0x03                    ; First melody
        return

Play2   BEEP 0xbb, 0x02
        BEEP 0x87, 0x05
        BEEP 0xa2, 0x03
        BEEP 0x98, 0x03                    ; Second melody
        return

End     ; End of program
```

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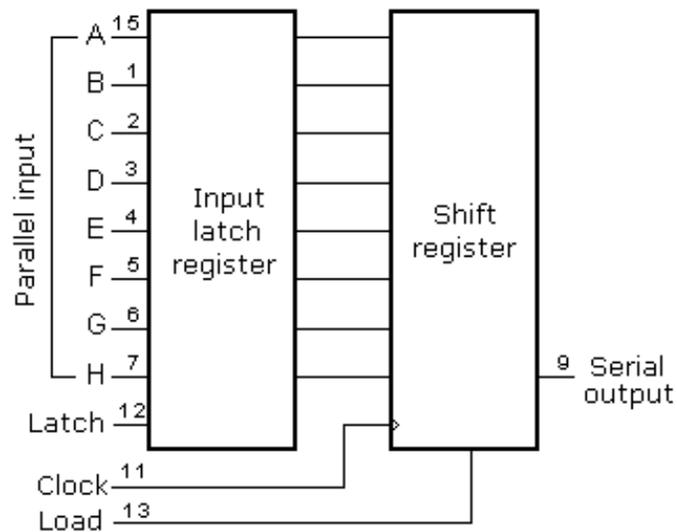
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Shift registers

There are two types of shift registers: **input and output**. **Input shift registers** receive data in parallel, through 8 lines and then send it serially through two lines to a microcontroller. **Output shift registers** work in the opposite direction; they receive serial data and on a "latch" line signal, they turn it into parallel data. Shift registers are generally used to expand the number of input-output lines of a microcontroller. They are not so much in use any more though, because most modern microcontrollers have a large number of input/output lines. However, their use with microcontrollers such as PIC16F84 is very important.

Input shift register 74HC597

Input shift registers transform parallel data into serial data and transfer it to a microcontroller. Their working is quite simple. There are four lines for the transfer of data: **clock, latch, load and data**. Data is first read from the input pins by an internal register through a 'latch' signal. Then, with a 'load' signal, data is transferred from the input latch register to the shift register, and from there it is serially transferred to a microcontroller via 'data' and 'clock' lines.



An outline of the connection of the shift register 74HC597 to a micro, is shown below.



HC597.inc

```

HC597 macro Var,Var1

    Local Loop           ; Local label

    movlw .8             ; transfer eight bits
    mowwf Var1           ; Counter initialization

    bsf Latch            ; Read pins at input latch
    nop
    bcf Latch            ; Transfer content from input latch

    bcf Load             ; to shift register
    nop
    bsf Load

Loop rlf Var,f          ; Rotate 'Var' one space to left

    btfss Data           ; Is Data line = '1' ?
    bcf Var,0            ; If not, erase bit '0' at Var variable
    btfsc Data           ; Is Data line = '0' ?
    bsf Var,0            ; If not, set bit '0'

    bsf Clock            ; Make one clock
    nop
    bcf Clock

    decfsz Var1,f        ; Are 8 bits received ?
    goto Loop           ; If not, repeat

endm

```

Example of how to use the HC597 macro is given in the following program. Program receives data from a parallel input of the shift register and moves it serially into the RX variable of the microcontroller. LEDs connected to port B will indicate the result of the data input.



HC597.asm

```

;***** Declaring and configuring a microcontroller *****

PROCESSOR 16f84
#include "p16f84.inc"

    __CONFIG _CP_OFF & _WDT_OFF & _PWRTE_ON & _XT_OSC

;***** Declaring variables *****

Cblock 0x0C           ; Beginning of RAM
RX
CountSPI
endc

```

```

        enum

;***** Declaring the hardware *****

        #define Data    PORTA,0
        #define Clock   PORTA,1
        #define Latch   PORTA,2
        #define Load    PORTA,3

;***** Program memory structure *****

        ORG    0x00          ; Reset vector
        goto   Main

        ORG    0x04          ; Interrupt vector
        goto   Main          ; No interrupt routine

        #include "bank.inc"  ; Assistant files
        #include "hc597.inc"

Main
        ; Beginning of the program
        BANK1
        movlw  b'00010001'   ; Port A initialization
        movwf  TRISA         ; TRISA <- 0x11
        clrf   TRISB
        BANK0

        clrf   PORTA        ; PORTA <- 0x00

        bsf    Load         ; Enable SHIFT register

Loop
        HC597  RX, CountSPI

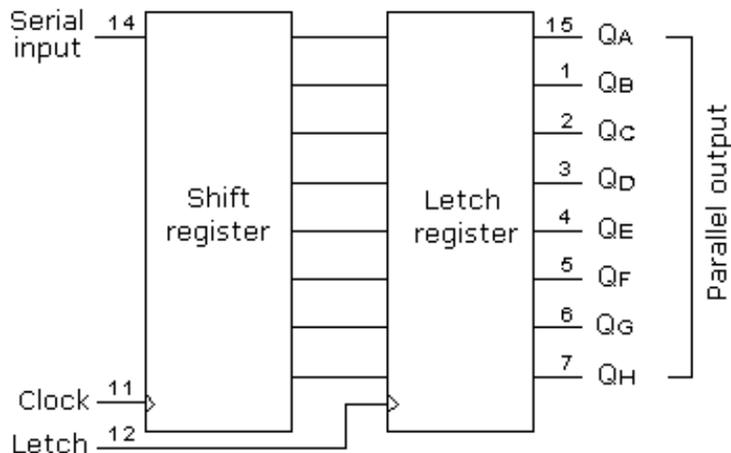
        ; Status of input pins of SHIFT register
        movf   RX,W          ; are found in variable RX
        movwf  PORTB         ; Set the contents of RX variable to port B
        goto   Loop          ; Repeat the loop

        End                ; End of program

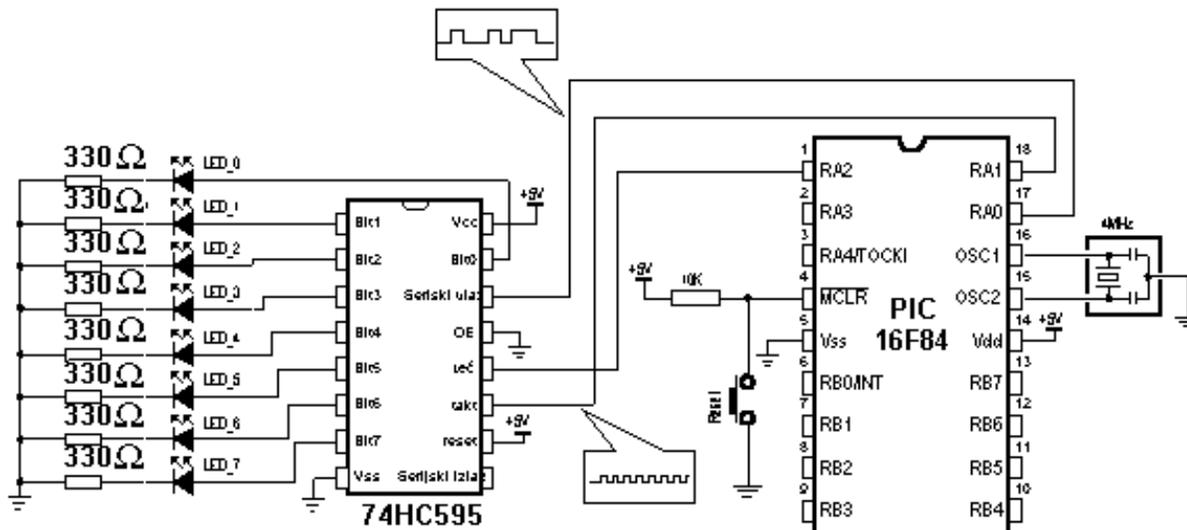
```

Output shift register

Output shift registers transform serial data into parallel data. On every rising edge of the clock, the shift register reads the value from data line, stores it in temporary register, and then repeats this cycle 8 times. On a signal from 'latch' line, data is copied from the shift register to input register, thus data is transformed from serial into parallel data.



An outline of the 74HC595 shift register connections is shown on the diagram below:



Connecting an output shift register to a microcontroller

Macro used in this example is found in hc595.inc file, and is called HC595.

Macro HC595 has two arguments:

HC595 macro Var, Var1

Var variable whose contents is transferred to outputs of shift register.

Var1 loop counter

Example: HC595 Data, counter

The data we want to transfer is stored in data variable, and counter variable is used as a loop counter.



HC595.inc

```

HC595 macro Var,Var1

    Local   Loop           ; Local label

    movlw  .8              ; transfer eight bits
    mowwf  Var1            ; Counter initialization

Loop  rlf    Var,f         ; Rotate 'Var' one space to left

    btfss  STATUS,C       ; Is carry = '1' ?
    bcf    Data          ; If not, set Data line to '0'
    btfsc  STATUS,C       ; Is carry = '0' ?
    bsf    Data          ; If not, set Data line to '1'

    bsf    Clock         ; Make one clock
    nop
    bcf    Clock

    decfsz Var1,f        ; Are eight bits sent ?
    goto  Loop          ; If not, repeat

    bsf    Latch         ; If all 8 bits have been sent, move the
    nop    ; contents from SHIFT register to output latch
    bcf    Latch

    endm

```

An example of how to use the HC595 macro is given in the following program. Data from variable TX is serially transferred to shift register. LEDs connected to the parallel output of the shift register will indicate the state of the lines. In this example value 0xCB (1100 1011) is sent so that the eighth, seventh, fourth, second and first LEDs are illuminated.



```

;***** Declaring and configuring a microcontroller *****

PROCESSOR 16f84
#include "p16f84.inc"

    __CONFIG _CP_OFF & _WDT_OFF & _PWRTE_ON & _XT_OSC

;***** Declaring variables *****

    Cblock 0x0C          ; Beginning of RAM
    TX                ; Belongs to 'HC595' macro
    CountSPI
    endc

;***** Declaring the hardware *****

    #define Data      PORTA,0
    #define Clock     PORTA,1
    #define Latch     PORTA,2

;***** Structure of program memory *****

    ORG 0x00          ; Reset vector
    goto Main

    ORG 0x04          ; Interrupt vector
    goto Main        ; No interrupt routine

#include "bank.inc"   ; Assistant files
#include "hc595.inc"

Main                ; Beginning of the program

    BANK1
    movlw 0x18        ; Port A initialization
    movwf TRISA       ; TRISA <- 0x18
    BANK0

    clrf PORTA        ; PORTA <- 0x00

    movlw 0xCB        ; Fill the TX buffer
    movwf TX          ; TX <- '11001011'

    HC595 TX, CountSPI

    Loop goto Loop   ; Infinite loop

    End              ; End of program

```

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Seven-Segment Display (multiplexing)

The segments in a 7-segment display are arranged to form a single digit from 0 to F as shown in the animation:



We can display a multi-digit number by connecting additional displays. Even though LCD displays are more comfortable to work with, 7-segment displays are still standard in the industry. This is due to their temperature robustness, visibility and wide viewing angle. Segments are marked with non-capital letters: a, b, c, d, e, f, g and dp, where dp is the decimal point. The 8 LEDs inside each display can be arranged with a common cathode or common anode. With a common cathode display, the common cathode must be connected to the 0V rail and the LEDs are turned on with a logic one. Common anode displays must have the common anode connected to the +5V rail. The segments are turned on with a logic zero.

The size of a display is measured in millimeters, the height of the digit itself (not the housing, but the digit!). Displays are available with a digit height of 7, 10, 13.5, 20, or 25 millimeters. They come in different colors, including: red, orange, and green.

The simplest way to drive a display is via a display driver. These are available for up to 4 displays.

Alternatively displays can be driven by a microcontroller and if more than one display is required, the method of driving them is called "multiplexing."

The main difference between the two methods is the number of "drive lines." A special driver may need only a single "clock" line and the driver chip will access all the segments and increment the display.

If a single display is to be driven from a microcontroller, 7 lines will be needed plus one for the decimal point. For each additional display, only one extra line is needed.

To produce a 4, 5 or 6 digit display, all the 7-segment displays are connected in parallel.

The common line (the common-cathode line) is taken out separately and this line is taken low for a short period of time to turn on the display.

Each display is turned on at a rate above 100 times per second, and it will appear that all the displays are turned on at the same time.

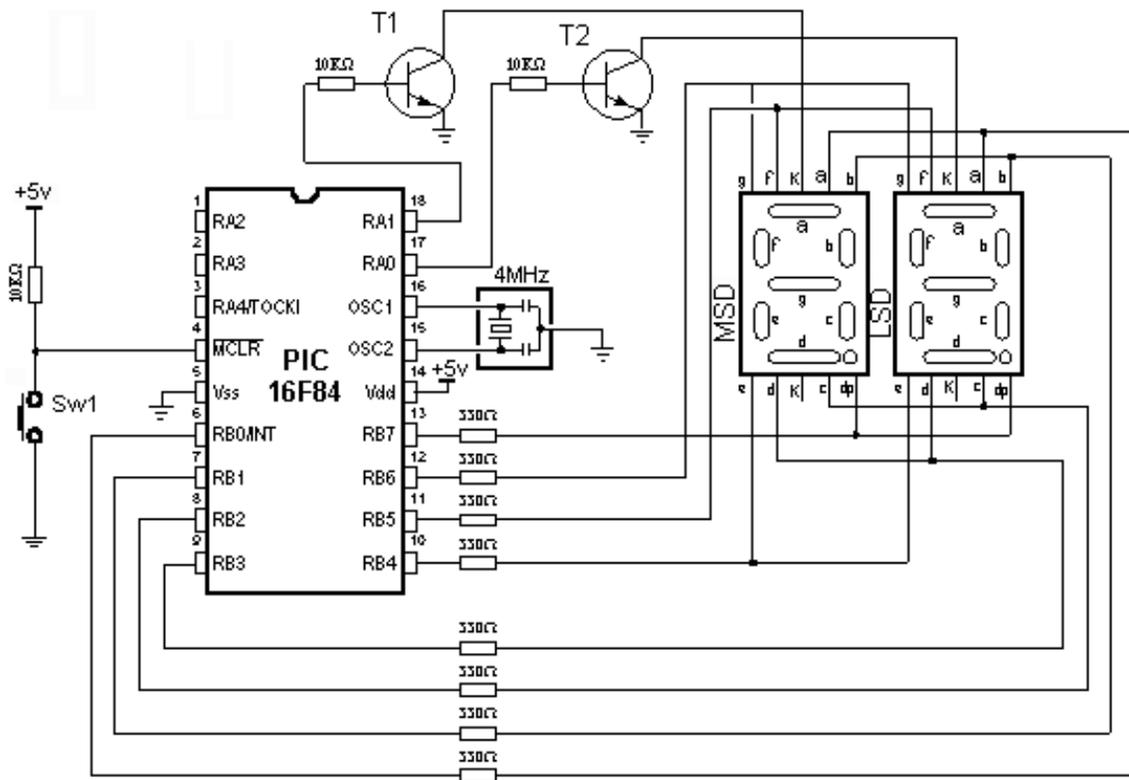
As each display is turned on, the appropriate information must be delivered to it so that it will give the correct reading.

Up to 6 displays can be accessed like this without the brightness of each display being affected. Each display is turned on very hard for one-sixth the time and the POV (persistence of vision) of our eye thinks the display is turned on the whole time.

All the timing signals for the display are produced by the program, the advantage of a microcontroller driving the display is flexibility.

The display can be configured as an up-counter, down-counter, and can produce a number of messages using letters of the alphabet that can be readily displayed.

The example below shows how to drive two displays.



Connecting a microcontroller to 7-segment displays in multiplex mode

File Led.inc contains two macros: LED_Init and LED_Dis2. The first macro is used for display initialization. That is where display refreshment period is defined as well as microcontroller pins used for connecting the displays. The second macro is used for displaying numbers from 0 to 99 on two displays.

Macro LED_Dis2 has one argument:

LED_Dis2 first macro

first is the number from 0 to 99 to be displayed on Msd and Lsd digit.

Example: LED_Dis2 0x34

Number 34 will be shown on the display

Realization of a macro is given in the following listing.



```

;***** Subprograms *****

InitPorts
    BANK1
    clrf LEDtrisA           ; Pins RA0-4 are output
    clrf LEDtrisB           ; Port B is output
    BANK0
    clrf LEDportA           ; Set all outputs to '0'
    clrf LEDportB           ;      /
    bsf  LEDportA,3         ; Turn on MSD display

    RETURN

InitTimers
    BANK1
    movlw B'10000100'       ; Move the prescaler to TMR0
    movwf OPTION_REG        ; ps = 32
    BANK0
    movlw B'00100000'       ; Enable TMR0 interrupt
    movwf INTCON             ;
    movlw .96                ;
    movwf TMR0               ; Start the timer

    RETFIE

;***** ISR - Interrup service routine *****

ISR
    bcf  INTCON,GIE         ; Disable all interrupts
    btfsc INTCON,GIE        ; Check whether they are disabled
    goto ISR

    movlw .96                ; Initialize the TMR0
    movwf TMR0
    bcf  INTCON,TDIF        ; Erase the TDIF flag
    call UpdateDisplay      ; "Refresh" display

    RETFIE

UpdateDisplay
    movf  LEDportA,W        ; Display status -> w register
    clrf  LEDportA          ; Turn off all 7-seg. displays
    andlw 0x0f              ; Separate the lower halfbyte
    movwf TempC             ; Save display status in TempC
    bsf  TempC,4             ; Beginning status of LSD display
    rrf  TempC,F            ; Set the status of the next display
    btfss STATUS,C ; c=1 ?
    bcf  TempC,3             ; If not, turn off the LSD display
    btfsc TempC,0           ; If it is, check the status of MSD display
    goto UpdateMsd         ; If it is turned on, display the MSD digit

UpdateLsd
    call  ChkMsdZero        ; msd = 0 ?
    btfss STATUS,Z         ; If it is, skip
    movf  LO,W              ; Third LSD digit -> W
    andlw 0x0f              ;      /
    goto  DisplayOut       ; Show it on the display

UpdateMsd
    swapf LO,W              ; Msd digit -> W
    andlw 0x0f              ;      /

```

```

swapf  LO,W           ; Msd digit -> W
andlw  0x0f           ; /
btfsc  STATUS,Z      ; msd != 0 ?
movlw  0x0a           ; If it is, skip

DisplayOut
call   LedTable       ; Take the mask for a digit
mowwf  LEDportB       ; Set the mask on port B
movf   TempC,W        ; Turn on displays
mowwf  LEDportA

RETURN

LedTable
addwf  PCL, F
retlw  B'00111111'    ; mask for digit 0
retlw  B'00000110'    ; mask for digit 1
retlw  B'01011011'    ; mask for digit 2
retlw  B'01001111'    ; mask for digit 3
retlw  B'01100110'    ; mask for digit 4
retlw  B'01101101'    ; mask for digit 5
retlw  B'01111101'    ; mask for digit 6
retlw  B'00000111'    ; mask for digit 7
retlw  B'01111111'    ; mask for digit 8
retlw  B'01101111'    ; mask for digit 9
retlw  B'00000000'    ; no digit.....

ChkMsdZero           ; Checking the leading zero
movf   LO,W          ; Msd digit -> W
btfss  STATUS,Z      ; = 0 ? skip
RETURN              ; If it is, skip
retlw  .10           ; If not, go back from 10 to W reg.

```

The following example shows the use of macros in a program. Program displays number '21' in two 7-segment digits.



```

;***** Declaring and configuring a microcontroller *****

PROCESSOR 16f84
#include "p16f84.inc"

    __CONFIG _CP_OFF & _WDT_OFF & _PWRTE_ON & _XT_OSC

;***** Declaring variables *****

    Cblock 0x0C           ; Beginning of RAM
    TempC                ; Belongs to "LED_Dis2" macro
    LO
    endc

;***** Declaring the hardware *****

    LEDtrisA equ    TRISA
    LEDportA equ    PORTA

    LEDtrisB equ    TRISB
    LEDportB equ    PORTB

;***** Structure of program memory *****

    ORG    0x00           ; Reset vector
    goto   Main

    ORG    0x04           ; Interrupt vector
    goto   ISR           ; Interapt rutina is found
                        ; in 7-seg.inc file

#include "bank.inc"      ; Assistant files
#include "7-seg.inc"

Main                    ; Beginning of the program
    LED_Init

    LED_Dis2 0x21       ; Display on two 7-seg. displays
                        ; broj "21"
loop    goto    loop    ; Stay here

    End                ; End of program

```




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LCD Display

More microcontroller devices are using 'smart LCD' displays to output visual information. The following discussion covers the connection of a **Hitachi LCD display** to a PIC microcontroller. LCD displays designed around Hitachi's LCD HD44780 module, are inexpensive, easy to use, and it is even possible to produce a readout using the 8 x 80 pixels of the display. Hitachi LCD displays have a standard ASCII set of characters plus Japanese, Greek and mathematical symbols.



A 16x2 line Hitachi HD44780 display

Each of the 640 pixels of the display must be accessed individually and this is done with a number of surface-mount driver/controller chips mounted on the back of the display. This saves an enormous amount of wiring and controlling so that only a few lines are required to access the display to the outside world. We can communicate to the display via an 8-bit data bus or 4-bit data bus.

For a 8-bit data bus, the display requires a +5V supply plus 11 I/O lines. For a 4-bit data bus it only requires the supply lines plus seven extra lines. When the LCD display is not enabled, data lines are tri-state which means they are in a state of high impedance (as though they are disconnected) and this means they do not interfere with the operation of the microcontroller when the display is not being addressed.

The LCD also requires 3 "control" lines from the microcontroller.

The **Enable (E)** line allows access to the display through R/W and RS lines. When this line is low, the LCD is disabled and ignores signals from R/W and RS. When (E) line is high, the LCD checks the state of the two control lines and responds accordingly.

The **Read.Write (R/W)** line determines the direction of data between the LCD and microcontroller. When it is low, data is written to the LCD. When it is high, data is read from the LCD.

With the help of the **Register select (RS)** line, the LCD interprets the type of data on data lines. When it is low, an instruction is being written to the LCD. When it is high, a character is being written to the LCD.

Logic status on control lines:

E 0 Access to LCD disabled
1 Access to LCD enabled

R/W 0 Writing data to LCD
1 Reading data from LCD

RS 0 Instruction
1 Character

Writing data to the LCD is done in several steps:

Set R/W bit to low
Set RS bit to logic 0 or 1 (instruction or character)
Set data to data lines (if it is writing)
Set E line to high
Set E line to low
Read data from data lines (if it is reading)

Reading data from the LCD is done in the same way, but control line R/W has to be high. When we send a high to the LCD, it will reset and wait for instructions. Typical instructions sent to LCD display after a reset are: turning on a display, turning on a cursor and writing characters from left to right.

When the LCD is initialized, it is ready to continue receiving data or instructions. If it receives a character, it will write it on

the display and move the cursor one space to the right. The Cursor marks the next location where a character will be written. When we want to write a string of characters, first we need to set up the starting address, and then send one character at a time. Characters that can be shown on the display are stored in data display (DD) RAM. The size of DDRAM is 80 bytes.

The LCD display also possesses 64 bytes of Character-Generator (CG) RAM. This memory is used for characters defined by the user. Data in CG RAM is represented as an 8-bit character bit-map.

Each character takes up 8 bytes of CG RAM, so the total number of characters, which the user can define is eight. In order to read in the character bit-map to the LCD display, we must first set the CG RAM address to starting point (usually 0), and then write data to the display. The definition of a 'special' character is given in the picture .

CG RAM address	Bit map	Data
0000		01010
0001		00100
0010		01110
0011		10001
0100		10000
0101		10001
0110		01110
0111		00000

Before we access DD RAM after defining a special character, the program must set the DD RAM address. Writing and reading data from any LCD memory is done from the last address which was set up using set-address instruction. Once the address of DD RAM is set, a new written character will be displayed at the appropriate place on the screen.

Until now we discussed the operation of writing and reading to an LCD as if it were an ordinary memory. But this is not so. The LCD controller needs 40 to 120 microseconds (uS) for writing and reading. Other operations can take up to 5 mS.

During that time, the microcontroller can not access the LCD, so a program needs to know when the LCD is busy. We can solve this in two ways.

Set DD RAM address

RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	0	1	A	A	A	A	A	A	A

Set CG RAM address

RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	0	0	1	A	A	A	A	A	A

Write in data to RAM

RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
1	0	D	D	D	D	D	D	D	D

Read data from RAM

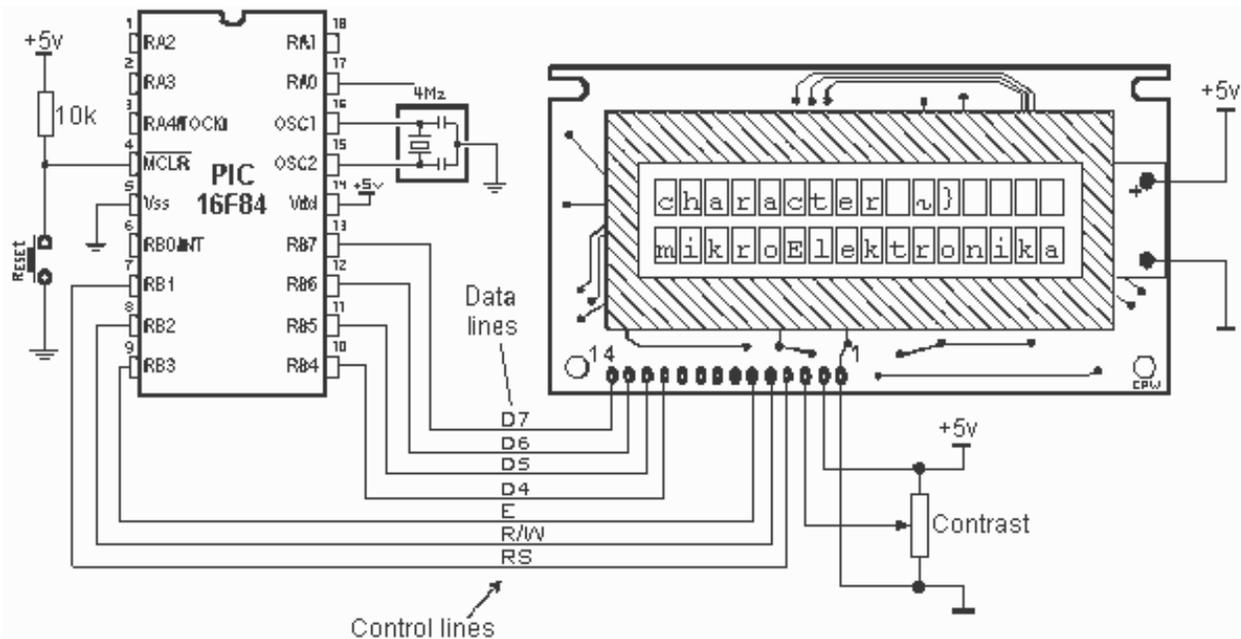
RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
1	1	D	D	D	D	D	D	D	D

A=address

D=data

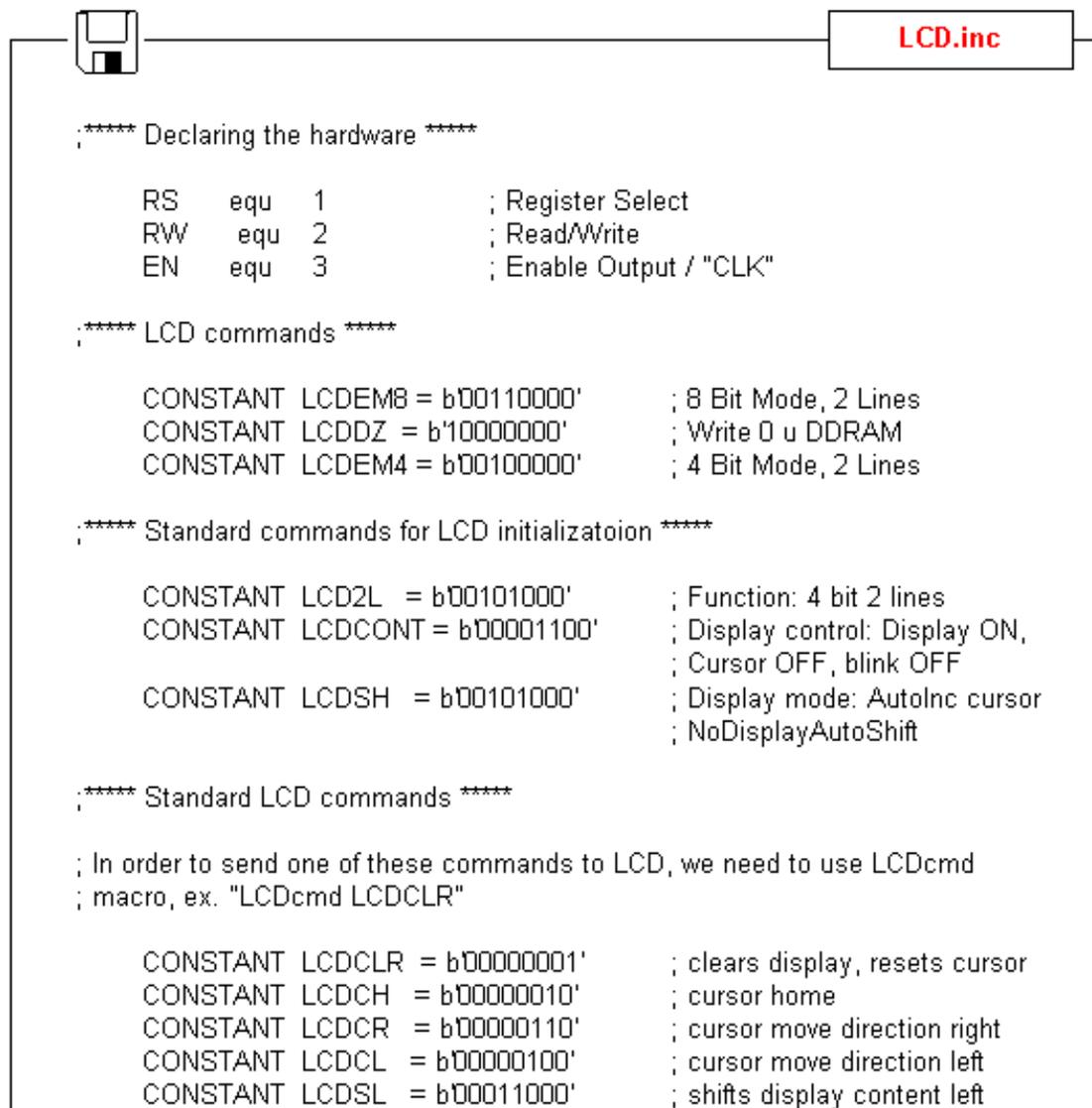
One way is to check the BUSY bit found on data line D7. This is not the best method because LCD's can get stuck, and program will then stay forever in a loop checking the BUSY bit. The other way is to introduce a delay in the program. The delay has to be long enough for the LCD to finish the operation in process. Instructions for writing to and reading from an LCD memory are shown in the previous table.

At the beginning we mentioned that we needed 11 I/O lines to communicate with an LCD. However, we can communicate with an LCD through a 4-bit data bus. Thus we can reduce the total number of communication lines to seven. The wiring for connection via a 4-bit data bus is shown in the diagram below. In this example we use an LCD display with 2x16 characters, labelled LM16X212 by Japanese maker SHARP. The message 'character' is written in the first row: and two special characters '~' and '}' are displayed. In the second row we have produced the word 'mikroElektronika'.



Connecting an LCD display to a microcontroller

File **LCD.inc** contains a group of macros for use when working with LCD displays.



```

CONSTANT LCDCL = b'00000100' ; cursor move direction left
CONSTANT LCDSL = b'00011000' ; shifts display content left
CONSTANT LCDSR = b'00011100' ; shifts display content right
CONSTANT LCDL1 = b'10000000' ; selects line 1
CONSTANT LCDL2 = b'11000000' ; selects line 2

;**** Macros ****

LCDinit macro
    call LCD_init ; LCD initialization
endm

LCDchar macro LCDarg ; write out the character on LCD
    movlw LCDarg
    call LCDdata
endm

LCDw macro
    call LCDdata
endm

LCDcmd macro LCDcommand ; send the command to LCD
    movlw LCDcommand
    call LCDcomd
endm

LCDline macro line_num
    IF (line_num == 1)
        LCDcmd LCDL1 ; Start macro with "First Line" instruction
    ELSE
        IF (line_num == 2)
            LCDcmd LCDL2 ; Start macro with "Second Line" instruction
        ELSE
            ENDIF
    ENDIF
endm

LCD_DDAdr macro DDRamAddress
    Local value = DDRamAddress | b'10000000' ; Beginning of DDRAM
    IF (DDRamAddress > 0x67)
        ERROR "Wrong DDRAM address in LCD_DDAdr"
    ELSE
        movlw value
        call LCDcomd
    ENDIF
endm

LCD_CGAdr macro CGRamAddress
    Local value = CGRamAddress | b'01000000' ; Beginning of CGRAM
    IF (CGRamAddress > b'00111111')
        ERROR "Wrong CGRAM address in LCD_CGAdr"
    ELSE
        movlw value
        call LCDcomd
    ENDIF
endm

```

```

;***** Subprograms *****

LCDcomd clrf LCDbuf      ; Clear Data flag
        goto LCDwrr

LCDdata clrf LCDbuf
        bsf LCDbuf,RS    ; Set Data flag

LCDwrr movwf LCDtemp     ; Command/Data in Temp
        andlw b'11110000' ; set aside the upper halfbyte
        iorwf LCDbuf,0    ; set aside Data flag
        movwf LCDport    ; send the upper halfbyte to LCD port
        call LCDclk
        clrf LCDport
        swapf LCDtemp,0  ; exchange the upper and lower halfbyte
                        ; again
        andlw b'11110000' ; set aside the lower halfbyte
        iorwf LCDbuf,0    ; set aside the Data flag
        movwf LCDport    ; send the low half byte to LCD port
        call LCDclk
        clrf LCDport
        RETURN

LCDclk WAITX 0x02,0x00  ; Enable access to LCD for data and
                        ; commands to be written in

        bsf LCDport,EN
        bcf LCDport,EN
        WAIT 0x02
        RETURN

LCD_init
        clrf LCDport     ; Prepare LCDport
        BANK1
        clrf OPTION_REG
        movlw b'00000000'
        movwf LCDtris
        BANK0
        WAIT 0x02

        movlw LCDEM8     ; Start initialization
        movwf LCDport   ; with "8-bit mode"
        call LCDclk
        clrf LCDport
        WAIT 0x02

        movlw LCDDZ      ; write 0 in DDRAM
        movwf LCDport
        call LCDclk
        clrf LCDport

        movlw LCDEM4     ; go to 4 bit mode
        movwf LCDport
        call LCDclk
        clrf LCDport

        LCDcmd LCD2L    ; Function: 2 lines, 4-bit mode
        LCDcmd LCDCONT ; Display ON, no cursor

```

```

LCDcmd LCD2L           ; Function: 2 lines, 4-bit mode
LCDcmd LCDCONT        ; Display ON, no cursor
LCDcmd LCDSH          ; Mode displaying AutoInc, NoAutoShift
LCDcmd LCDCLR         ; Clear display, address counter to zero
call  LCDspecialChars ; read in characters defined by the user
                          ; to CGRAM

RETURN

LCDspecialChars          ; Maximum number of characters
                          ; that user can define is 8

; *** first special Character is "C" at the position 0x00 ***
; *** is called form "LCDchar 0x00" ***

LCD_CGAdr 0x00          ; Send CGRAM address
LCDchar b'00001010'    ; Write data to CGRAM address
LCD_CGAdr 0x01
LCDchar b'00000100'
LCD_CGAdr 0x02
LCDchar b'00001110'
LCD_CGAdr 0x03
LCDchar b'00010001'
LCD_CGAdr 0x04
LCDchar b'00010000'
LCD_CGAdr 0x05
LCDchar b'00010001'
LCD_CGAdr 0x06
LCDchar b'00001110'
LCD_CGAdr 0x07
LCDchar b'00000000'

; *** first special Character is "C" at the position 0x01 ***
; *** is called form "LCDchar 0x01" ***

LCD_CGAdr 0x08
LCDchar b'00000010'
LCD_CGAdr 0x09
LCDchar b'00000100'
LCD_CGAdr 0x0A
LCDchar b'00001110'
LCD_CGAdr 0x0B
LCDchar b'00010001'
LCD_CGAdr 0x0C
LCDchar b'00010000'
LCD_CGAdr 0x0D
LCDchar b'00010001'
LCD_CGAdr 0x0E
LCDchar b'00001110'
LCD_CGAdr 0x0F
LCDchar b'00000000'

LCD_DDAAdr 0x00        ; Reset DDRAM

RETURN

```

Macro for LCD support

LCDinit macro used to initialize port connected to LCD. LCD is configured to work in four-bit mode.

Example: LCDinit

LCDchar LCDarg Write ASCII character. Argument is ASCII character.

Example: LCDChar 'd'

LCDw Write character found in W register.

Example: movlw 'p'
LCDw

LCDcmd LCDcommand Sending command instructions

Example: LCDcmd LCDCH

LCD_DDAdr DDRamAddress Set DD RAM address.

Example: LCD_DDAdr .3

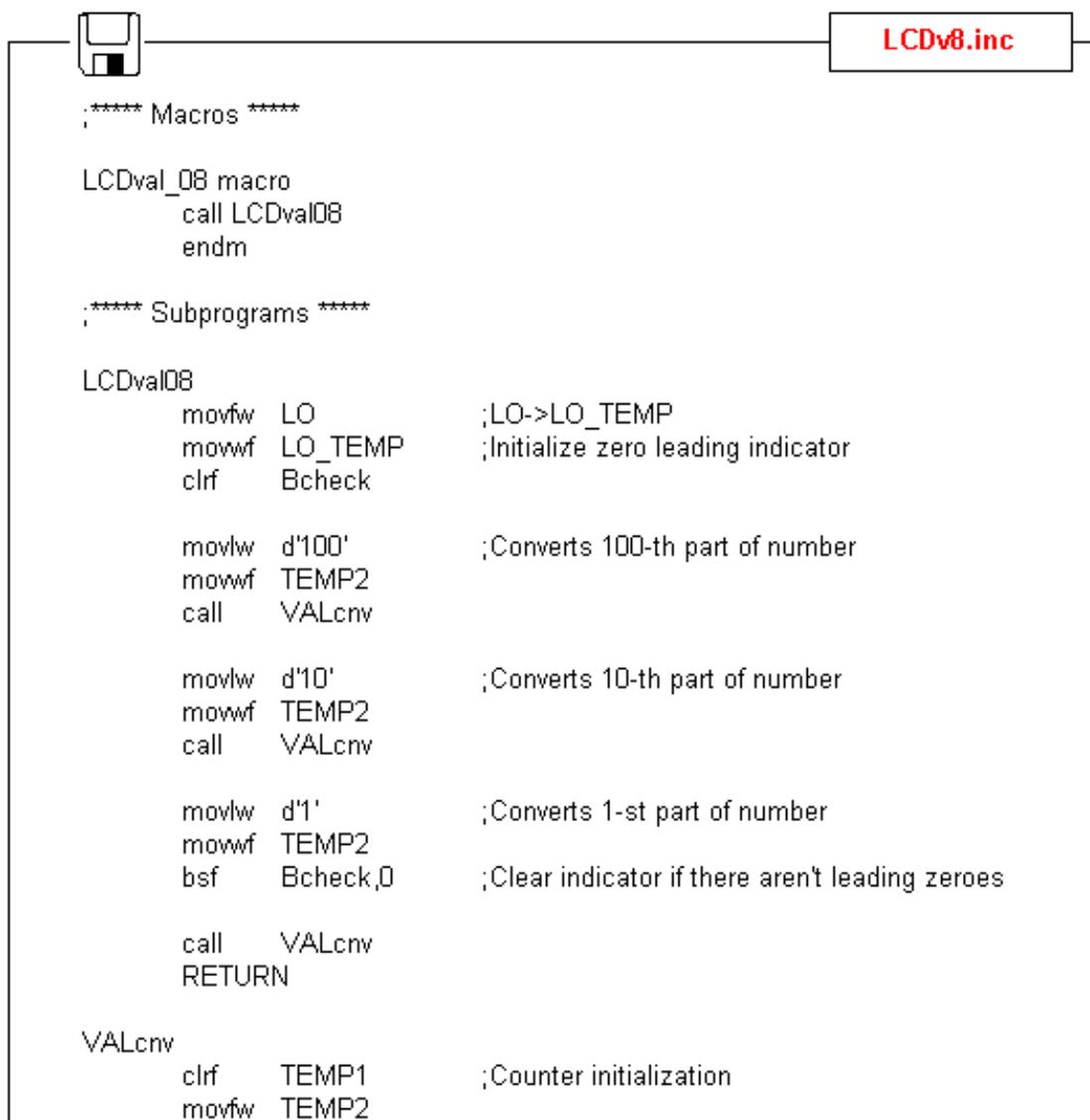
LCDline line_num Set cursor to the beginning of 1st or 2nd row

Example: LCDline 2

When working with a microcontroller the numbers are presented in a binary form.

As such, they cannot be displayed on a display. That's why it is necessary to change the numbers from a binary system into a decimal system so they can be easily understood. Listings of two macros **LCDval_08** and **LCDval_16** are given below.

Macro **LCDval_08** converts an eight-bit binary number into a decimal number from 0 to 255 and displays it on the LCD display. It is necessary to declare the following variables in the main program: TEMP1, TEMP2, LO, LO_TEMP, Bcheck. An eight-bit binary number is found in variable LO. When a macro was executed, the decimal equivalent of its number would be displayed on the LCD display. The leading zeros before the number will not be displayed.



```

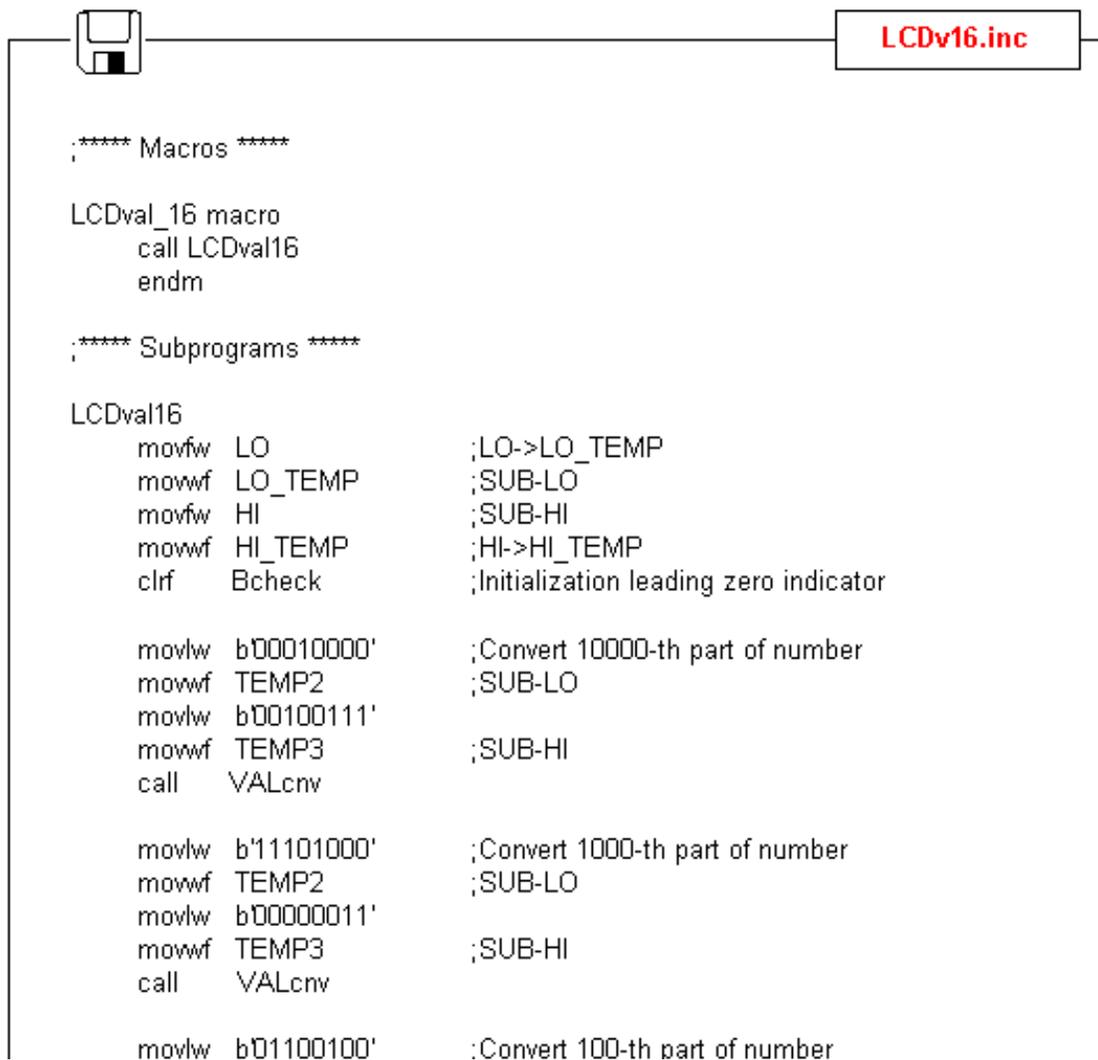
    clrf    TEMP1           ;Counter initialization
    movfw  TEMP2
VALc01
    subwf  LO_TEMP,0      ;Test if LO>99, set carry (negative result)
    skpc
    goto  LCDval2        ;Exit if c is not set (negative result)

    incf   TEMP1,1       ;Increment counter
    movfw  TEMP2
    subwf  LO_TEMP,1     ;Store TEMP1=TEMP1-100
    bsf    Bcheck,0
    goto  VALc01

    LCDval2 movlw '0'      ;Writing a digit on LCD
    addwf  TEMP1,0       ;Add to counter
    btfss  Bcheck,0
    movlw  ' '           ;Clear leading zero
    LCDw
    RETURN

```

Macro **LCDval_16** converts 16-bit binary number into decimal number from 0 to 65535 and displays it on LCD display. The following variables need to be declared in the main program: TEMP1, TEMP2, TEMP3, LO, HI, LO_TEMP, HI_TEMP, Bcheck. A 16-bit binary number is found in variables LO and HI. When a macro was executed, a decimal equivalent of this number would be displayed on LCD display. The leading zeros before the number would not be displayed.



```

movlw b01100100'      ;Convert 100-th part of number
movwf TEMP2           ;SUB-LO
clrf TEMP3            ;SUB-HI if zero
call VALcnv

movlw b00001010'     ;Convert 10-th part of number
movwf TEMP2           ;SUB-LO
clrf TEMP3
call VALcnv

movlw b00000001'     ;Convert 1st part of number
movwf TEMP2           ;SUB-LO
clrf TEMP3
bsf Bcheck,0         ;Clear indicator if there aren't leading zeroes

call VALcnv
RETURN

VALcnv                ;Counter initialization
clrf TEMP1

Vcnv1
movfw TEMP3
subwf HI_TEMP,0
skpc                  ;Skip if HI>=0
goto LCDval2         ;Exit if not
bnz Vcnv2

movfw TEMP2
subwf LO_TEMP,0
skpc                  ;Skip if LO>=0
goto LCDval2         ;Exit if not

Vcnv2
movfw TEMP3
subwf HI_TEMP,1      ;HI=HI-TEMP3
movfw TEMP2
subwf LO_TEMP,1      ;LO=LO-TEMP2
skpc                  ;Skip if LO>=0
decf HI_TEMP,1       ;Decrement HI
incf TEMP1,1         ;Increment counter
bsf Bcheck,0
goto Vcnv1

LCDval2 movlw '0'      ;Writing a number at LCD
addwf TEMP1,0        ;Add offset to counter
btfss Bcheck,0
movlw ''
LCDw
RETURN

```

The main program is a demonstration of using the LCD display and generate new characters. At the beginning of a program, we need to declare variables **LCDbuf** and **LCDtemp** used by subprograms for the LCD as well as the microcontroller port connected to the LCD.

The program writes the message 'characters:' on the first row and shows two special characters '~' and '}'. In the second row, 'mikroElektronika' is displayed.



LCD.asm

```

;***** Declaring and configuring a microcontroller *****

PROCESSOR 16f84
#include "p16f84.inc"

    __CONFIG _CP_OFF & _WDT_OFF & _PWRTE_ON & _XT_OSC

;***** Declaring variables *****

Cblock 0xDC          ; Beginning of RAM
LCDbuf              ; Belongs to 'LCDxxx' macros
LCDtemp
WCYCLE              ; Belongs to 'WAITX' macro
PRESCwait
Pointer             ; Pointer on characters in message
endc

;***** Declaring the hardware *****

LCDtris equ    TRISB
LCDport equ    PORTB

;***** Structure of program memory *****

ORG    0x00    ; Reset vector
goto   Main

ORG    0x04    ; Interrupt vector
goto   Main    ; No interrupt routine

Messages          ; Beginning of the messages

    movwf PCL

                ; Display messages

Message1 dt "mikRoEleKtrOnlKa"
Message2 dt "bla, bla"
Message3 dt "example"

END_messages          ; End of messages

#include "bank.inc"    ; Assistant files
#include "wait.inc"
#include "lcd.inc"
#include "print.inc"

Main                ; Beginning of the program

    bcf PORTB,2

    LCDinit          ; LCD initialization

```

```
LCDinit      ; LCD initialization

LCDchar 'C'  ; Display character on LCD
LCDchar 'a'
LCDchar 'r'
LCDchar 'a'
LCDchar 'c'
LCDchar 't'
LCDchar 'e'
LCDchar 'r'
LCDchar 's'
LCDchar ':'
LCDchar ''

LCDchar      0x00 ; Display special characters
LCDchar      0x01

LCDline 2    ; Second line

; Display message1 on LCD

PRINT Messages, Message1, Message2, Pointer, LCDw

Loop  goto  Loop ; Infinite loop

End      ; End of program
```

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12-bit Analog to Digital converter

Since everything in the microcontroller world is represented with "0's" and "1's", how do we cater for a signal that is 0.5 or 0.77?

Most of the world outside a computer consists of analogue signals. Apart from speech and music, there are many quantities that need to be fed into a computer. Humidity, temperature, air pressure, colour, turbidity, and methane levels, are just a few.

The answer is to take a number of digital lines and combine them so they can "read" an analogue value. An analogue value is any value **between** 0 and 1. You can also call it a "fractional value." All the above quantities must now be converted to a value between 0 and 1 so they can be fed into a computer.

This is the broad concept. It becomes a little more complex in application.

If we take 8 lines and arrange them so they accept binary values, the total count will be 256 (this is obtained by a count to 255 plus the value 0).

If we connect these 8 lines into a "black box," they will be called output lines and so we must provide a single input line.

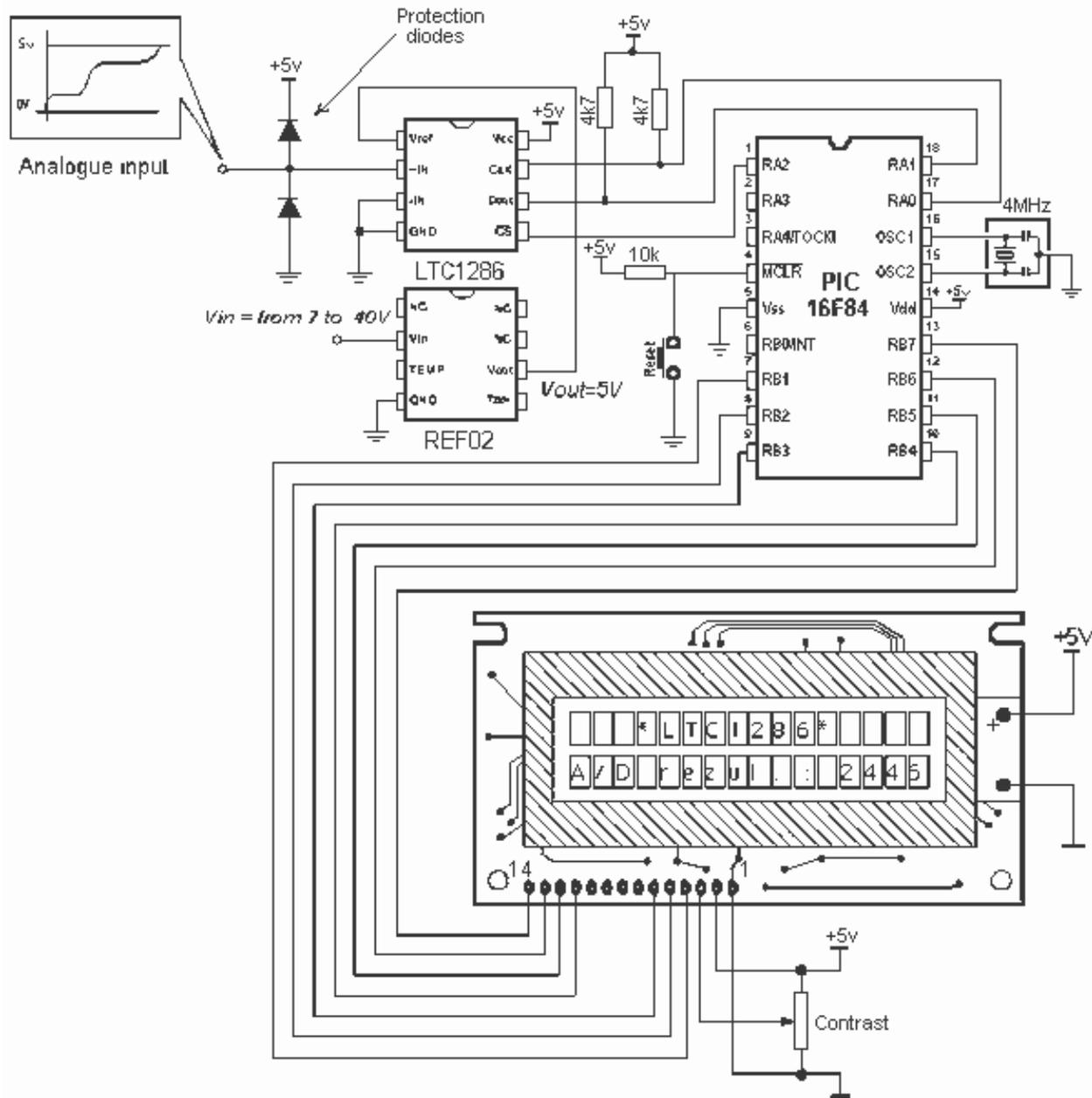
With this arrangement we can detect up to 255 increments between "0" and "1." This black box is called a CONVERTER and since we are converting from Analogue to Digital, the converter is called an **A-to-D converter** or **ADC**.

AD converters can be classified according to different parameters. The most important parameters are **precision** and **mode of data transfer**. As to precision, the range is: 8-bit, 10-bit, 12-bit, 14-bit, 16-bit. Since 12-bit conversion is an industrial standard, the example we have provided below was done with a 12-bit ADC. The other important parameter is the way data is transferred to a microcontroller. It can be parallel or serial. Parallel transmission is faster. However, these converters are usually more expensive. Serial transmission is slower, but in terms of cost and fewer input lines to a microcontroller, it is the favourite for many applications.

Analogue signals can sometimes go above the allowed input limit of an ADC. This may damage the converter. To protect the input, two diodes are connected as shown in the diagram. This will protect from voltages above 5V and below 0V.

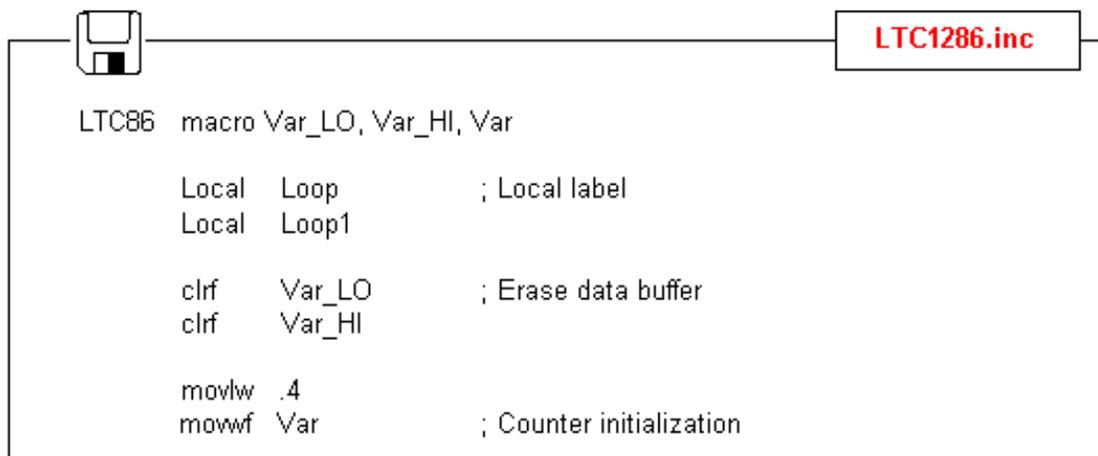
In our example we used a LTC1286 12-bit ADC (Linear Technology). The converter is connected to the microcontroller via three lines: data, clock and CS (Chip Select). The CS line is used to select an input device as it is possible to connect other input devices (eg: input shift register, output shift register, serial ADC) to the same lines of the microcontroller.

The circuit below shows how to connect an ADC, reference and LCD display to a micro. The LCD display has been added to show the result of the AD conversion.



Connecting an AD converter with voltage reference to a microcontroller

The Macro used in this example is LTC86 and is found in LTC1286.inc file.



```

        movwf Var          ; Counter initialization

        bcf    CS          ; Enable AD coverter

        call   CLK        ; Enable Dout line
        call   CLK        ;          /
        call   CLK        ; NULL bit

Loop    rlf    Var_HI,f   ; RRotate 'Var_HI' one space to left

        btfss Data       ; is Dout line = '1' ?
        bcf    Var_HI,0   ; if not, clear bit '0' in Var_HI variable
        btfsc Data       ; is Dout line = '0' ?
        bsf    Var_HI,0   ; if not, set bit '0' in Var_HI variable

        call   CLK

        decfsz Var,f     ; Are 4 bits received ?
        goto  Loop      ; If not, repeat

        movlw  .8
        movwf Var       ; Counter initialization

Loop1   rlf    Var_LO,f   ; Rotate 'Var_LO' one space to left

        btfss Data       ; is Dout line = '1' ?
        bcf    Var_LO,0   ; if not, clear bit '0' in Var_LO variable
        btfsc Data       ; is Dout line = '0' ?
        bsf    Var_LO,0   ; if not, set bit '0' in Var_LO variable

        call   CLK

        decfsz Var,f     ; Are 8 bits received ?
        goto  Loop1     ; If not, repeat

        bsf    CS        ; Disable AD converter

        endm

CLK
        bsf    Clock     ; Make one clock
        nop
        nop
        nop
        bcf    Clock

        return

```

The LTC86 Macro has three arguments:

LTC86 macro Var_LO, Var_HI, Var

Var_LO variable is where the result of **lower byte conversion** is stored

Var_HI variable is where the result of **higher byte conversion** is stored

Var loop counter

Example: LTC86 LO, HI, Count

The four bits of the highest value are in variable **HI**, and first eight bits of conversion result are in variable **LO**. **Count** is an assistant variable to count the passes through loops.

The following example shows how macros are used in the program. The program reads the value from an ADC and displays it on the LCD display. The result is given in quantums. Eg: for 0V the result is 0, and for 5V it is 4095.

LTC1286.asm

```

;**** Declaring and configuring a microcontroller ****
PROCESSOR 16f84
#include "p16f84.inc"

    _CONFIG_CP_OFF & _WDT_OFF & _PWRTE_ON & _XT_OSC

;**** Declaring variables ****

Cblock 0x0C                ; Beginning of RAM
LCDbuf                    ; Belongs to 'LCDxxx' macros
LCDtemp
WCYCLE                    ; Belongs to 'WAITX' macro
PRESCwait

TEMP1                      ; Belongs to "LCDval_16" macro
TEMP2
TEMP3
LO                          ; LO_Data buffer
HI                          ; HI_Data buffer
LO_TEMP
HI_TEMP
Bcheck

Count                      ; Belongs to "LTC86" macro
Pointer                    ; Pointer on characters in message
endc

;**** Declaring the hardware ****

#define Data    PORTA,0
#define Clock   PORTA,1
#define CS      PORTA,2

LCDtris equ    TRISB
LCDport equ    PORTB

;**** Structure of program memory ****

ORG    0x00                ; Reset vector
goto   Main

ORG    0x04                ; Interrupt vector
goto   Main                ; No interrupt routine

Messages                ; Beginning of the messages

mowf   PCL

                                ; Display messages

```

```

; Display messages
Message0 dt "** LTC1286 *"
Message1 dt "A/D rezul.:"

END_messages ; End of messages

#include "bank.inc" ; Assistant files
#include "ltc1286.inc"
#include "wait.inc"
#include "lcd.inc"
#include "lcdv16.inc"
#include "print.inc"

Main ; Beginning of the program
BANK1
movlw 0xf1 ; Port A initialization
mowwf TRISA ; TRISA <- 0xf1
BANK0

LCDinit ; LCD initialization

clrf PORTA ; PORTA <- 0x00

LCD_DDAdr .3

PRINT Messages, Message0, Message1, Pointer, LCDw
; Read value on AD coverter input

Loop
LTC86 LO, HI, Count

call Out ; Display AD result
; on LCD display

goto Loop ; Repeat loop

Out
LCDline 2 ; Second line

PRINT Messages, Message1, END_messages, Pointer, LCDw

LCDval_16

return

End ; End of program

```

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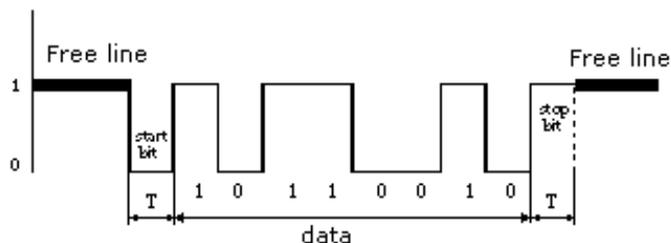
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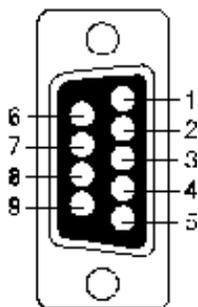
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Serial Communication

SCI is an abbreviation for Serial Communication Interface and, as a special subsystem, it exists on most microcontrollers. When it is not available, as is the case with PIC16F84, it can be created in software.



As with hardware communication, we use standard NRZ (Non Return to Zero) format also known as 8 (9)-N-1, or 8 or 9 data bits, without parity bit and with one stop bit. **Free line** is defined as the status of **logic one**. Start of transmission - **Start Bit**, has the status of **logic zero**. The data bits follow the start bit (the first bit is the low significant bit), and after the bits we place the **Stop Bit** of **logic one**. The duration of the stop bit 'T' depends on the speed of transmission and is adjusted according to the needs of the transmission. For the transmission speed of 9600 baud, T is 104 μ S.

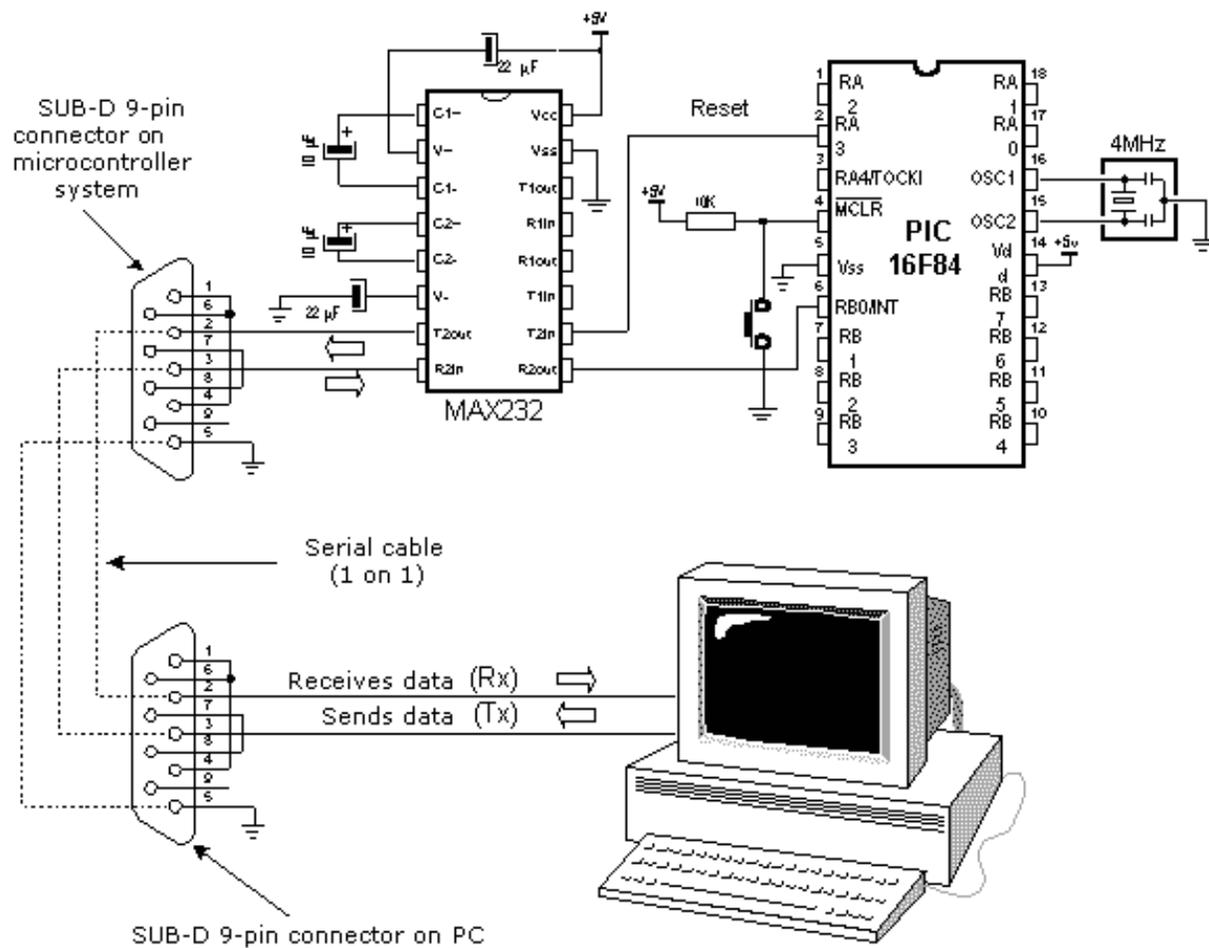


1. CD (Carrier Detect)
2. RXD (Receive Data)
3. TXD (Transmit Data)
4. DTR (Data terminal Ready)
5. GND (Ground)
6. DSR (Data Set Ready)
7. RTS (Request To Send)
8. CTS (Clear To Send)
9. RI (Ring Indicator)

Pin designations on RS232 connector

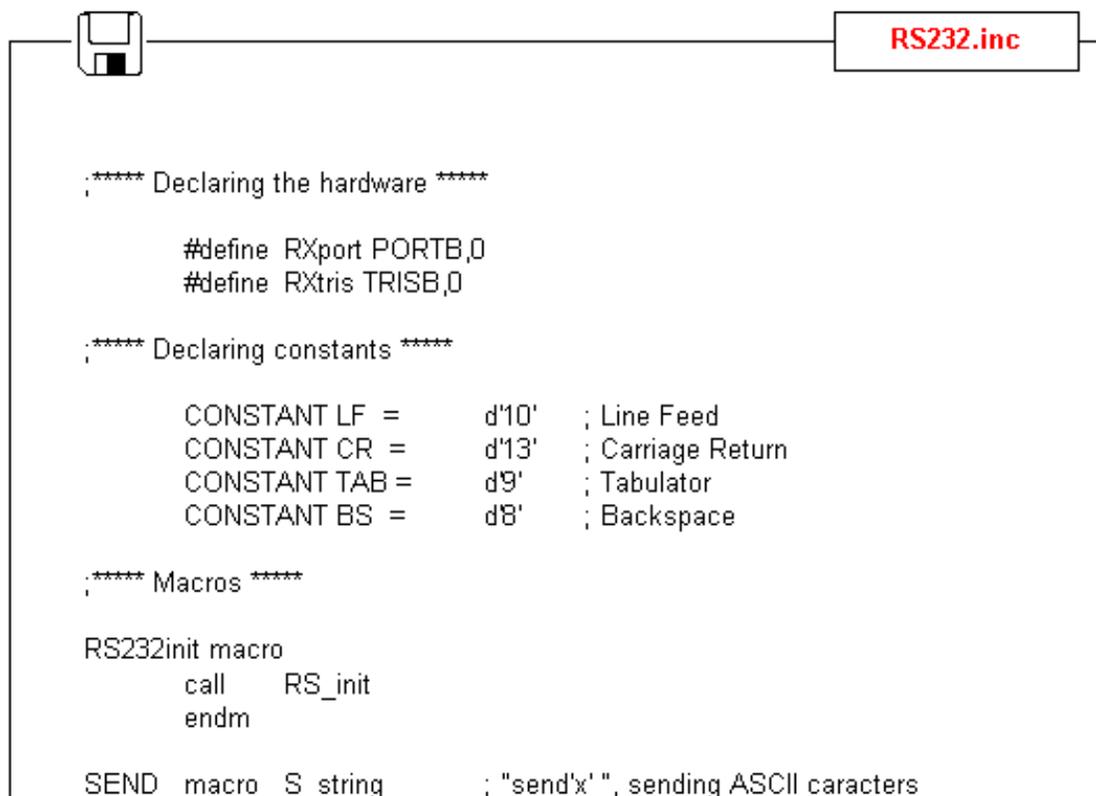
In order to connect a microcontroller to a serial port on a PC computer, we need to adjust the level of the signals so communicating can take place. The signal level on a PC is -10V for logic zero, and +10V for logic one. Since the signal level on the microcontroller is +5V for logic one, and 0V for logic zero, we need an intermediary stage that will convert the levels. One chip specially designed for this task is MAX232. This chip receives signals from -10 to +10V and converts them into 0 and 5V.

The circuit for this interface is shown in the diagram below:



Connecting a microcontroller to a PC via a MAX232 line interface chip.

File RS232.inc contains a group of macros used for serial communication.



```

SEND macro S_string ; "send'x'", sending ASCII characters
    movlw S_string
    call SENDsub
endm

SENDw macro
    call SENDsub
endm

RECEIVE macro
    call RECsub
endm

;***** Subprograms *****

RS_init bcf TXport
        BANK1
        clrf OPTION_REG
        bcf TXtris ;Tx pin
        bsf RXtris ;Rx input with pull-up
        BANK0
        bsf TXport ;The beginning state onTX line :logic "1"
        movlw b'10010000'
        movwf INTCON ;Enable RBO -interrupt
        RETURN

SENDsub movwf TXD ;Tx data register
        bcf TXport ;Start bit
        movlw 0x08
        movwf RS_TEMP1 ;The number of bit to send 9600-8-N-1
        call S_Wait
SENDa btfsc TXD,0 ;Send LSB first
        goto SENDb
        bcf TXport
        goto SENDc
SENDb bsf TXport
SENDc rrf TXD,1
        call S_Wait
        decfsz RS_TEMP1,1
        goto SENDa
        goto SENDd
SENDd bsf TXport ;Stop bit
        call S_Wait
        call S_Wait ;Re-synchronization
        RETURN

S_Wait movlw 0x1E ;Pause between two bits
        movwf RS_TEMP2 ;9600 baud => 104uS in sending
        goto X_Wait

Rs_Wait movlw 0x0C ;Pause 52uS for start bit
        movwf RS_TEMP2 ;in receiving
        goto X_Wait

R_Wait movlw 0x1D ;Pause between two bits in receiving
        movwf RS_TEMP2
        goto X_Wait

X_Wait decfsz RS_TEMP2,1

```

```

X_Wait decfsz RS_TEMP2,1
       goto  X_Wait
       RETURN

RECSUB      call    Rs_Wait
           btfsc  RXport
           goto  REENTRY          ;Not start bit
           movlw  0x08
           movwf  RS_TEMP1        ;The number receiving bits 9600-8-N-1
           goto  RECa            ;Pause
RECa       call    R_Wait
           btfss  RXport
           goto  RECb
           bsf    RXD,0x07
           goto  RECC
RECb       bcf    RXD,0x07
RECC       decfsz RS_TEMP1,0      ;Skip if RS_TEMP=1
           rrf    RXD,1          ;Repeat this seven times
           decfsz RS_TEMP1,1
           goto  RECa
           call   R_Wait
           btfss  RXport        ;Check if stop bit
           clrf  RXD
           RETURN

REENTRY    clrf  RXD            ;Invalid data
           goto  ISRend

```

Using the macro:

RS232init Macro for initializing RB0 pin and line for transmitting data (TX-pin).

Example: RS232init

SEND S_string Sending ASCII character. Argument is ASCII sign.

Example: SEND 'g'

SENDw Sending data found in W register.

Example: movlw 't'

SENDw

RECEIVE macro in interrupt routine receives data for RS232 and stores it in RXD register

Example:

```

ORG     0x04
       goto  ISR
ISR     bcf    INTCON,GIE
       btfsc INTCON,GIE
       goto  ISR
       RECEIVE
       :
       :
ISRend bcf    INTCON,INTF
       RETFIE

```

At the beginning of the main program, we need to declare variables RS_TEMP1, RE_TEMP2, TXD, RXD and TX pin on

microcontroller. After resetting a microcontroller the program sends a greeting message to PC computer: **\$ PIC16F84 on line \$**, and is ready to receive data from RX line.

We can send and receive data from PC computer from some communication program. When microcontroller receives data, it will send a message: Character received from PIC16F84: x, thus confirming that reception was successful.

Main program:



RS232.asm

```

;***** Declaring and configuring a microcontroller *****

PROCESSOR 16F84
#include "p16f84.inc"

    __CONFIG_CP_OFF & _WDT_OFF & _PWRTE_ON & _XT_OSC

;***** Declaring variables *****

    Cblock 0x0C      ; Beginning of RAM
    RS_TEMP1      ; Belongs to 'RS232' functions
    RS_TEMP2
    TXD
    RXD
    Pointer      ; Pointer to message's characters
    endc

;***** Deklaracija hardvera *****

    #define TXport PORTA,3
    #define TXtris TRISA,3

    LCDtris equ TRISB
    LCDport equ PORTB

;***** Structure of program memory *****

    ORG 0x00      ; Reset vector
    goto Main

    ORG 0x04      ; Interrupt vector
    goto ISR      ; Jump on interrupt routine

Messages

    mowf PCL      ; Messages to be shown at LCD
                  ; sent by RS232

Message0 dt "Received character from PIC16F84: "
Message1 dt "$ PIC16F84 on line $"

END_messages      ; End of messages

#include "bank.inc" ; Assistant files
#include "rs232.inc"
#include "print.inc"

;***** Interrupt routine *****

```

```

;***** Interrupt routine *****

ISR    bcf    INTCON,GIE      ; Disable all interrupts
       btfsz  INTCON,GIE     ; Check if disabled
       goto  ISR

       RECEIVE      ; Store received data in RX variable

       SEND TAB          ; Send message 0 trough RS232 line

       PRINT Messages, Message0, Message1, Pointer, SENDw

       movfw  RXD        ; Return back received data as confirmation
       SENDw          ; of successful receiving

       SEND  CR        ; Carriage Return
       SEND  LF        ; Line Feed
       SEND  LF

ISRend bcf INTCON,INTF ; Clear interrupt fleg RBO/INT
       RETFIE         ; Enable all interrupts

Main          ; Start of the program

       RS232init      ; RS232 initialization

                   ; Send message 1

       PRINT Messages, Message1, END_messages, Pointer, SENDw

       SEND  CR        ; Carriage Return
       SEND  LF        ; Line Feed
       SEND  LF

Loop    goto    Loop    ; Infinite loop
End     End      ; End of program

```

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Appendix A

Instruction Set

Introduction

Appendix contains all instructions presented separately with examples for their use. Syntax, description and its effects on status bits are given for each instruction.

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- [A.2 MOVWF](#)
- [A.3 MOVF](#)
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A.1 MOVLW Write constant in W register

Syntax: `[label] MOVLW k`
Description: 8-bit constant **k** is written in **W** register.
Operation: $k \Rightarrow (W)$
Operand: $0 \leq k \leq 255$
Flag: -
Number of words: 1
Number of cycles: 1

Example 1 `MOVLW 0x5A`

After instruction: `W=0x5A`

Example 2 `MOVLW REGISTAR`

Before instruction: `W=0x10` and `REGISTAR=0x40`

After instruction: `W=0x40`

A.2 MOVWF Copy W to f

Syntax: `[label] MOVWF f`
Description: Contents of **W** register is copied to **f** register.
Operation: $W \Rightarrow (f)$
Operand: $0 \leq f \leq 127$
Flag: -
Number of words: 1
Number of cycles: 1

Example 1 `MOVWF OPTION_REG`

Before instruction: `OPTION_REG=0x20`
`W=0x40`

After instruction: `OPTION_REG=0x40`
`W=0x40`

Example 2 `MOVWF INDF`

Before instruction: `W=0x17`
`FSR=0xC2`
 address contents `0xC2=0x00`

After instruction: `W=0x17`
`FSR=0xC2`
 address contents `0xC2=0x17`

A.3 MOVF Copy f to d

Syntax: `[/label] MOVF f, d`
Description: Contents of **f** register is stored in location determined by **d** operand.
 If **d=0**, destination is **W** register.
 If **d=1**, destination is **f** register itself.
 Option **d=1** is used for testing the contents of **f** register because execution of this instruction affects Z flag in STATUS register.

Operation: $f \Rightarrow (d)$
Operand: $0 \leq f \leq 127$
 $d \in [0, 1]$
Flag: Z
Number of words: 1
Number of cycles: 1

Example 1 `MOVF FSR, 0`

Before instruction: `FSR=0xC2`
`W=0x00`
 After instruction: `W=0xC2`
`Z=0`

Example 2 `MOVF INDF, 0`

Before instruction: `W=0x17`
`FSR=0xC2`
`address contents 0xC2=0x00`
 After instruction: `W=0x17`
`FSR=0xC2`
`address contents 0xC2=0x00`
`Z=1`

A.4 CLRW Write 0 in W

Syntax: `[/label] CLRW`
Description: Contents of **W** register evens out to zero, and Z flag in STATUS register is set to one.
Operation: $0 \Rightarrow (W)$
Operand: -
Flag: Z
Number of words: 1
Number of cycles: 1

Example `CLRW`

Before instruction: `W=0x55`
 After instruction: `W=0x00`
`Z=1`

A.5 Write 0 in f

Syntax: `[label] CRLF f`
Description: Contents of 'f' register evens out to zero, and Z flag in status register is set to one.
Operation: $0 \Rightarrow f$
Operand: $0 \leq f \leq 127$
Flag: Z
Number of words: 1
Number of cycles: 1

Example 1 CRLF STATUS

Before instruction: STATUS=0xC2
 After instruction: STATUS=0x00
 Z=1

Example 2 CLRF INDF

Before instruction: FSR=0xC2
 address contents 0xC2=0x33
 After instruction: FSR=0xC2
 address contents 0xC2=0x00
 Z=1

A.6 SWAPF Copy the nibbles from f to d crosswise

Syntax: `[label] SWAPF f, d`
Description: Upper and lower half of f register exchange places.
 If **d=0**, result is stored in **W** register.
 If **d=1**, result is stored in **f** register.

Operation: $f\langle 0:3 \rangle \Rightarrow d\langle 4:7 \rangle, f\langle 4:7 \rangle \Rightarrow d\langle 0:3 \rangle;$
Operand: $0 \leq f \leq 127$
 $d \in [0, 1]$
Flag: -
Number of words: 1
Number of cycles: 1

Example 1 SWAP REG, 0

Before instruction: REG=0xF3
 After instruction: REG=0xF3
 W=0x3F

Example 2 SWAP REG, 1

Before instruction: REG=0xF3
 After instruction: REG=0x3F

A.7 ADDLW Add W to a constant

Syntax: `[label] ADDLW k`
Description: Contents of **W** register is added to 8-bit constant **k** and result is stored in **W** register.
Operation: $(W) + k \Rightarrow W$
Operand: $0 \leq k \leq 255$
Flag: C, DC, Z
Number of words: 1
Number of cycles: 1

Example 1 `ADDLW 0x15`

Before instruction: `W=0x10`
 After instruction: `W=0x25`

Example 2 `ADDLW REG`

Before instruction: `W=0x10`
 register contents `REG=0x37`
 After instruction: `W=0x47`

A.8 ADDWF Add W to f

Syntax: `[label] ADDWF f, d`
Description: Add contents of register **W** to register **f**.
 If **d=0**, result is stored in **W** register.
 If **d=1**, result is stored in **f** register.
Operation: $(W) + (f) \Rightarrow d$
 $d \in [0, 1]$
Operand: $0 \leq f \leq 127$
Flag: C, DC, Z
Number of words: 1
Number of cycles: 1

Example 1 `ADDWF FSR, 0`

Before instruction: `W=0x17`
 `FSR=0xC2`
 After instruction: `W=0xD9`
 `FSR=0xC2`

Example 2 `ADDLW INDF, 1`

Before instruction: `W=0x17`
 `FSR=0xC0`
 address contents `0xC2=0x20`
 After instruction: `W=0x17`
 `FSR=0xC2`
 address contents `0xC2=0x37`

A.9 SUBLW Subtract W from a constant

Syntax: `[label] SUBLW k`
Description: Contents of **W** register is subtracted from **k** constant, and result is stored in **W** register.
Operation: $k - (W) \Rightarrow W$
Operand: $0 \leq k \leq 255$
Flag: C, DC, Z
Number of words: 1
Number of cycles: 1

Example 1 SUBLW 0x03

Before instruction: W=0x01, C=x, Z=x
 After instruction: W=0x02, C=1, Z=0 Result > 0

Before instruction: W=0x03, C=x, Z=x
 After instruction: W=0x00, C=1, Z=1 Result = 0

Before instruction: W=0x04, C=x, Z=x
 After instruction: W=0xFF, C=0, Z=0 Result < 0

Example 2 SUBLW REG

Before instruction: W=0x10
 contents REG=0x37
 After instruction: W=0x27
 C=1 Result > 0

A.10 SUBWF Subtract W from f

Syntax: `[label] SUBWF f, d`
Description: Contents of **W** register is subtracted from the contents of **f** register.
 If **d=0**, result is stored in **W** register.
 If **d=1**, result is stored in **f** register.
Operation: $(f) - (W) \Rightarrow d$
Operand: $0 \leq f \leq 127$
 $d \in [0, 1]$
Flag: C, DC, Z
Number of words: 1
Number of cycles: 1

Example 1 SUBWF REG, 1

Before instruction: REG=3, W=2, C=x, Z=x
 After instruction: REG=1, W=2, C=1, Z=0 Result > 0

Before instruction: REG=2, W=2, C=x, Z=x
 After instruction: REG=0, W=2, C=1, Z=1 Result = 0

Before instruction: REG=1, W=2, C=x, Z=x
 After instruction: REG=0xFF, W=2, C=0, Z=0 Result < 0

A.11 ANDLW Logic AND W with constant

Syntax: `[label] ANDLW k`
Description: Performs operation logic AND over the contents of **W** register and constant **k**.
 Result is stored in **W** register.
Operation: $(W) \text{ .AND. } k \Rightarrow W$
Operand: $0 \leq k \leq 255$
Flag: Z
Number of words: 1
Number of cycles: 1

Example 1 ANDLW 0x5F

```
Before instruction:  W=0xA3           ; 0101 1111 (0x5F)
After instruction:  W=0x03           ; 1010 0011 (0xA3)
                   -----
                   ; 0000 0011 (0x03)
```

Example 2 ANDLW REG

```
Before instruction:  W=0xA3           ; 1010 0011 (0xA3)
                   REG=0x37          ; 0011 0111 (0x37)
After instruction:  W=0x23           ; 0010 0011 (0x23)
                   -----
                   ; 0010 0011 (0x23)
```

A.12 ANDWF Logic AND W with f

Syntax: `[label] ANDWF f, d`
Description: Performs operation of logic AND over the contents of **W** and **f** registers.
 If **d=0**, result is stored in **W** register.
 If **d=1**, result is stored in **f** register.
Operation: $(W) \text{ .AND. } f \Rightarrow d$
Operand: $0 \leq f \leq 127$
 $d \in [0, 1]$
Flag: Z
Number of words: 1
Number of cycles: 1

Example 1 ANDWF FSR, 1

```
Before instruction:  W=0x17, FSR=0xC2 ; 0001 0111 (0x17)
After instruction:  W=0x17, FSR=02    ; 1100 0010 (0xC2)
                   -----
                   ; 0000 0010 (0x02)
```

Example 2 ANDWF FSR, 0

```
Before instruction:  W=0x17, FSR=0xC2 ; 0001 0111 (0x17)
After instruction:  W=0x02, FSR=0xC2  ; 1100 0010 (0xC2)
                   -----
                   ; 0000 0010 (0x02)
```

A.13 IORLW Logic OR W with constant

Syntax: `[/label] IORLW k`
Description: Operation logic OR is performed over the contents of **W** register and over 8-bit constant **k**, and result is stored in **W** register.
Operation: $(W) .OR. (k) \Rightarrow W$
Operand: $0 \leq k \leq 255$
Flag: Z
Number of words: 1
Number of cycles: 1

Example 1 IORLW 0x35

Before instruction: W=0x9A
 After instruction: W=0xBF
 Z=0

Example 2 IORLW REG

Before instruction: W=0x9A
 content REG=0x37
 After instruction: W=0x9F
 Z=0

A.14 IORWF Logic OR W with f

Syntax: `[/label] IORWF f, d`
Description: Operation logic OR is performed over the contents of **W** and **f** registers.
 If **d=0**, result is stored in **W** register.
 If **d=1**, result is stored in **f** register.
Operation: $(W) .OR. (f) \Rightarrow d$
Operand: $0 \leq f \leq 127$
 $d \in [0,1]$
Flag: Z
Number of words: 1
Number of cycles: 1

Example 1 IORWF REG, 0

Before instruction: REG=0x13, W=0x91
 After instruction: REG=0x13, W=0x93
 Z=0

Example 2 IORWF REG, 1

Before instruction: REG=0x13, W=0x91
 After instruction: REG=0x93, W=0x91
 Z=0

A.15 XORLW Logic exclusive OR W with constant

Syntax: `[/label] XORLW k`
Description: Operation exclusive OR (XOR) is done over the contents of **W** register and constant **k**, and result is stored in **W** register.
Operation: $(W) .XOR. k \Rightarrow W$
Operand: $0 \leq k \leq 255$
Flag: Z
Number of words: 1
Number of cycles: 1

Example 1 XORLW 0xAF

Before instruction:	W=0xB5		; 1010 1111 (0xAF)
After instruction:	W=0x1A		; 1011 0101 (0xB5)

			; 0001 1010 (0x1A)

Example 2 XORLW REG

Before instruction:	W=0xAF		; 1010 1111 (0xA3)
	REG=0x37		; 0011 0111 (0x37)
After instruction:	W=0x18		-----
	Z=0		; 0001 1000 (0x18)

A.16 XORWF Logic exclusive OR W with f

Syntax: `[/label] XORWF f, d`
Description: Operation exclusive OR is performed over the contents of **W** and **f** registers.
 If **d=0**, result is stored in **W** register.
 If **d=1**, result is stored in **f** register.
Operation: $(W) .XOR. (f) \Rightarrow d$
Operand: $0 \leq f \leq 127$
 $d \in [0,1]$
Flag: Z
Number of words: 1
Number of cycles: 1

Example 1 XORWF REG, 1

Before instruction:	REG=0xAF, W=0xB5		; 1010 1111 (0xAF)
After instruction:	REG=0x1A, W=0xB5		; 1011 0101 (0xB5)

			; 0001 1010 (0x1A)

Example 2 XORWF REG, 0

Before instruction:	REG=0xAF, W=0xB5		; 1010 1111 (0xAF)
After instruction:	REG=0xAF, W=0x1A		; 1011 0101 (0xB5)

			; 0001 1010 (0x1A)

A.17 INCF Increment f

Syntax: `[/label] INCF f, d`
Description: Increments f register by one.
 If **d=0**, result is stored in **W** register.
 If **d=1**, result is stored in **f** register.
Operation: $(f) + 1 \Rightarrow d$
Operand: $0 \leq f \leq 127$
 $d \in [0,1]$
Flag: Z
Number of words: 1
Number of cycles: 1

Example 1 `INCF REG, 1`

Before instruction: `REG=0xFF`
`Z=0`
 After instruction: `REG=0x00`
`Z=1`

Example 2 `INCF REG, 0`

Before instruction: `REG=0x10`
`W=x`
`Z=0`
 After instruction: `REG=0x10`
`W=0x11`
`Z=0`

A.18 DECF Decrement f

Syntax: `[/label] DECF f, d`
Description: Decrements f register by one.
 If **d=0**, result is stored in **W** register.
 If **d=1**, result is stored in **f** register.
Operation: $(f) - 1 \Rightarrow d$
Operand: $0 \leq f \leq 127$
 $d \in [0,1]$
Flag: Z
Number of words: 1
Number of cycles: 1

Example 1 `DECF REG, 1`

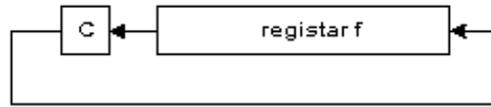
Before instruction: `REG=0x01`
`Z=0`
 After instruction: `REG=0x00`
`Z=1`

Example 2 `DECF REG, 0`

Before instruction: `REG=0x13`
`W=x`
`Z=0`
 After instruction: `REG=0x13`
`W=0x12`
`Z=0`

A.19 RLF Rotate f to the left through CARRY

Syntax: `[label] RLF f, d`
Description: Contents of **f** register is rotated by one space to the left through C (Carry) flag.
 If **d=0**, result is stored in **W** register.
 If **d=1**, result is stored in **f** register.
Operation: $(f\langle n \rangle) \Rightarrow d\langle n+1 \rangle, f\langle 7 \rangle \Rightarrow C, C \Rightarrow d\langle 0 \rangle$;
Operand: $0 \leq f \leq 127$
 $d \in [0,1]$
Flag: C
Number of words: 1
Number of cycles: 1



Example 1 `RLF REG, 0`

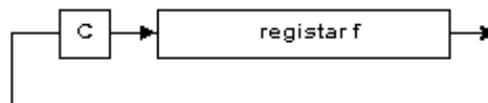
Before instruction: REG=1110 0110
 C=0
 After instruction: REG=1110 0110
 W=1100 1100
 C=1

Example 2 `RLF REG, 1`

Before instruction: REG=1110 0110
 C=0
 After instruction: REG=1100 1100
 C=1

A.20 RRF Rotate f to the right through CARRY

Syntax: `[label] RRF f, d`
Description: Contents of **f** register is rotated by one space to the right through C (Carry) flag.
 If **d=0**, result is stored in **W** register.
 If **d=1**, result is stored in **f** register.
Operation: $(f\langle n \rangle) \Rightarrow d\langle n-1 \rangle, f\langle 0 \rangle \Rightarrow C, C \Rightarrow d\langle 7 \rangle$;
Operand: $0 \leq f \leq 127$
 $d \in [0,1]$
Flag: C
Number of words: 1
Number of cycles: 1



Example 1 `RRF REG, 0`

Before instruction: REG=1110 0110
 W=x
 C=0
 After instruction: REG=1110 0110
 W=0111 0011
 C=0

Example 2 `RRF REG, 1`

Before instruction: REG=1110 0110
 C=0
 After instruction: REG=0111 0011
 C=0

A.21 COMF Complement f

Syntax: `[label] COMF f, d`
Description: Contents of **f** register is complemented.
 If **d=0**, result is stored in **W** register.
 If **d=1**, result is stored in **f** register.
Operation: $\overline{(f)} \Rightarrow d$
Operand: $0 \leq f \leq 127$
 $d \in [0, 1]$
Flag: Z
Number of words: 1
Number of cycles: 1

Example 1 COMF REG, 0

Before instruction:	REG=0×13		; 0001 0011 (0×13)
After instruction:	REG=0×13		; complement
	W=0×EC	-----	
			; 1110 1100 (0×EC)

Example 2 COMF INDF, 1

Before instruction:	FSR=0×C2		
	address contents (FSR)=0×AA		
After instruction:	FSR=0×C2		
	address contents (FSR)=0×55		

A.22 BCF Reset bit b in f

Syntax: `[label] BCF f, b`
Description: Reset bit **b** in **f** register.
Operation: $(0) \Rightarrow f\langle b \rangle$
Operand: $0 \leq f \leq 127$
 $0 \leq b \leq 7$
Flag: -
Number of words: 1
Number of cycles: 1

Example 1 BCF REG, 7

Before instruction:	REG=0×C7		; 1100 0111 (0×C7)
After instruction:	REG=0×47		; 0100 0111 (0×47)

Example 2 BCF INDF, 3

Before instruction:	W=0×17		
	FSR=0×C2		
	address contents (FSR)=0×2F		
After instruction:	W=0×17		
	FSR=0×C2		
	address contents (FSR)=0×27		

A.23 BSF Set bit b in f

Syntax: `[/label] BSF f, b`
Description: Set bit **b** in **f** register.
Operation: $1 \Rightarrow f\langle b \rangle$
Operand: $0 \leq f \leq 127$
 $0 \leq b \leq 7$
Flag: -
Number of words: 1
Number of cycles: 1

Example 1 `BSF REG, 7`

Before instruction: `REG=0x07` ; 0000 0111 (0x07)
 After instruction: `REG=0x17` ; 1000 0111 (0x17)

Example 2 `BCF INDF, 3`

Before instruction: `W=0x17`
`FSR=0xC2`
 address contents (FSR)=0x20
 After instruction: `W=0x17`
`FSR=0xC2`
 address contents (FSR)=0x28

A.24 BTFSC Test bit b in f, skip if it = 0

Syntax: `[/label] BTFSC f, b`
Description: If bit **b** in **f** register equals zero, then we skip the next instruction. If bit **b** equals zero, during execution of the current instruction, execution of the next one is disabled, and NOP instruction executes instead thus making the current one a two-cycle instruction.
Operation: Skip next instruction if $(f\langle b \rangle) = 0$
Operand: $0 \leq f \leq 127$
 $0 \leq b \leq 7$
Flag: -
Number of words: 1
Number of cycles: 1 or 2 depending on a **b** bit

Example

```
LAB_01    BTFSC REG,1    ;Test bit no.1 in REG
LAB_02    .....       ;Skip this line if =0
LAB_03    .....       ;Skip here if =1
```

Before instruction, program counter was at address LAB_01.

After instruction, if the first bit in REG register was zero, program counter points to address LAB_03.

If the first bit in REG register was one, program counter points to address LAB_02.

A.25 BTFSS Test bit b in f, skip if = 1

Syntax: `[/label] BTFSS f, b`
Description: If bit **b** in **f** register equals one, then skip over the next instruction. If bit **b** equals one, during execution of the current instruction, the next one is disabled, and NOP instruction is executed instead, thus making the current one a two-cycle instruction.
Operation: Skip next instruction if $(f \ll b) = 1$
Operand: $0 \leq f \leq 127$
 $0 \leq b \leq 7$
Flag: -
Number of words: 1
Number of cycles: 1 or 2 depending on a **b** bit

Example

```
LAB_01    BTFSS REG,1      ;Test bit no.1 in REG
LAB_02    . . . . .      ;Skip this line if =1
LAB_03    . . . . .      ;Skip here if =0
```

Before instruction, program counter was at address LAB_01

After instruction, if the first bit in REG register was one, program counter points to address LAB_03.

If the first bit in REG register was zero, program counter points to address LAB_02.

A.26 INCFSZ Increment f, skip if= 0

Syntax: `[/label] INCFSZ f, d`
Description: Contents of **f** register is incremented by one. If **d=0**, result is stored in **W** register. If **d=1**, result is stored in **f** register. If result =0, the next instruction is executed as NOP making the current one a two-cycle instruction.
Operation: $(f) + 1 \Rightarrow d$
Operand: $0 \leq f \leq 127$
 $d \in [0,1]$
Flag: -
Number of words: 1
Number of cycles: 1 or 2 depending on a result

Example

```
LAB_01    INCFSZ REG, 1   ; Increase the contents REG by one.
LAB_02    . . . . .      ; Skip this line if =0
LAB_03    . . . . .      ; Skip here if =0
```

The contents of program counter before instruction, PC=address LAB_01

The contents of REG register after executing an instruction $REG=REG+1$, if $REG=0$, program counter points to label address LAB_03. Otherwise, program counter points to address of the next instruction or to LAB_02.

A.27 DECFSZ Decrement f, skip if = 0

Syntax: `[label] DECFSZ f, d`
Description: Contents of **f** register is decremented by one.
 If **d=0**, result is stored in **W** register.
 If **d=1**, result is stored in **f** register.
 If result = 0, next instruction is executed as NOP, thus making the current one, a two-cycle instruction.
Operation: $(f) - 1 \Rightarrow d$
Operand: $0 \leq f \leq 127$
 $d \in [0,1]$
Flag: -
Number of words: 1
Number of cycles: 1 or 2 depending on a result

Example

```
LAB_01    DECFSZ CNT, 1           ; Decrement the contents REG by one.
LAB_02    .....                ; Skip this line if = 0
LAB_03    .....                ; Skip here if = 1
```

The contents of program counter before instruction, PC=address LAB_01

The contents of CNT register after executing an instruction CNT=CNT-1, if CNT=0, program counter points to address of label LAB_03. Otherwise, program counter points to address of the following instruction, or to LAB_02.

A.28 GOTO Jump to address

Syntax: `[label] GOTO k`
Description: Unconditional jump to address **k**.
Operation: $k \Rightarrow PC<10:0>$, $(PCLATH<4:3>) \Rightarrow PC<12:11>$
Operand: $0 \leq k \leq 2048$
Flag: -
Number of words: 1
Number of cycles: 2

Example

```
LAB_00    GOTO LAB_01           ; Jump to LAB_01
          :
          :
LAB_01    .....
```

Before instruction: PC=address LAB_00

After instruction: PC=address LAB_01

A.29 CALL Call a program

Syntax: `[/label] CALL k`
Description: Instruction calls a subprogram. First, return address (PC+1) is stored on stack, then 11-bit direct operand **k**, which contains the subprogram address, is stored in program counter.
Operation: (PC) + 1 ⇒ Top Of Stack (TOS)
k ⇒ PC<10:0>, (PCLATH<4:3>) ⇒ PC<12:11>
Operand: $0 \leq k \leq 2048$
Flag: -
Number of words: 1
Number of cycles: 2

Example

```
LAB_01    CALL LAB_02           ; Call subroutine LAB_02
          :
          :
LAB_02    . . . . .
```

Before instruction: PC=address LAB_01
TOS=x
After instruction: PC=address LAB_02
TOS=LAB_01

A.30 RETURN Return from a subprogram

Syntax: `[/label] RETURN`
Description: Contents from the top of a stack is stored in program counter.
Operation: TOS ⇒ program counter PC
Operand: -
Flag: -
Number of words: 1
Number of cycles: 2

Example RETURN

Before instruction: PC=x
TOS=x
After instruction: PC=TOS
TOS=TOS-1

A.31 RETLW Return from a subprogram with constant in W

Syntax: `[label] RETLW k`
Description: 8-bit constant **k** is stored in **W** register. Value off the top of a stack is stored in program counter.
Operation: $(k) \Rightarrow W$; $TOS \Rightarrow PC$
Operand: $0 \leq k \leq 255$
Flag: -
Number of words: 1
Number of cycles: 2

Example `RETLW 0x43`

Before instruction: `W=x`
`PC=x`
`TOS=x`
 After instruction: `W=0x43`
`PC=TOS`
`TOS=TOS-1`

A.32 RETFIE Return from interrupt routine

Syntax: `[label] RETFIE`
Description: Return from a subprogram. Value from TOS is stored in program counter PC. Interrupts are enabled by setting a GIE (Global interrupt Enable) bit.
Operation: $TOS \Rightarrow PC$; $1 \Rightarrow GIE$
Operand: -
Flag: -
Number of words: 1
Number of cycles: 2

Example `RETFIE`

Before instruction: `PC=x`
`GIE=0`
 After instruction: `PC=TOS`

A.33 NOP No operation

Syntax: `[label] NOP`
Description: Does not execute any operation or affect any flag.
Operation: -
Operand: -
Flag: -
Number of words: 1
Number of cycles: 1

Example `NOP`

Before instruction: `PC=x`
 After instruction: `PC=x+1`

A.34 CLRWDT Initialize watchdog timer

Syntax: `[label] CLRWDT`
Description: Watchdog timer is reset. Prescaler of the Watchdog timer is also reset, and status bits \overline{TO} and \overline{PD} are set also.
Operation: 0 \Rightarrow WDT
 0 \Rightarrow WDT prescaler
 1 \Rightarrow \overline{TO}
 1 \Rightarrow \overline{PD}
Operand: -
Flag: \overline{TO} , \overline{PD}
Number of words: 1
Number of cycles: 1

Example CLRWDT

Before instruction: WDT counter= \times
 WDT prescaler=1:128
 After instruction: WDT counter=0 \times 00
 WDT prescaler counter=0
 \overline{TO} =1
 \overline{PD} =1
 WDT prescaler=1:128

A.35 SLEEP Stand by mode

Syntax: `[label] SLEEP`
Description: Processor goes into low consumption mode. Oscillator is stopped. \overline{PD} (Power Down) status bit is reset. \overline{TO} (Timer Out) bit is set. WDT (Watchdog) timer and its prescaler are reset.
Operation: 0 \Rightarrow WDT
 0 \Rightarrow WDT prescaler
 1 \Rightarrow \overline{TO}
 0 \Rightarrow \overline{PD}
Operand: -
Flag: \overline{TO} , \overline{PD}
Number of words: 1
Number of cycles: 1

Example SLEEP

Before instruction: WDT counter= \times
 WDT prescaler= \times
 After instruction: WDT counter=0 \times 00
 WDT prescaler=0
 \overline{TO} =1
 \overline{PD} =0

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Appendix B

Numerical Systems

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Introduction

It was always difficult for people to accept the fact that some things differ from them or their way of thinking. That is probably one of the reasons why numerical systems which differ from a decimal are still hard to understand. Still, whether we want it or not, reality is different. Decimal numerical system that people use in everyday life is so far behind the binary system used by millions of computers around the world.

Each numerical system are based on some basis. With a decimal numerical system, that basis is 10, with binary 2, and with a hexadecimal system 16. The value of each decimal is determined by its position in relation to the whole number represented in the given numerical system. The sum of values of each decimal gives the value of the whole number. Binary and hexadecimal numerical systems are especially interesting for the subject of this book. Beside these, we will also discuss a decimal system, in order to compare it with the other two. Even though a decimal numerical system is a subject we are well acquainted with, we will discuss it here because of its relatedness to other numerical systems.

B.1 Decimal numerical system

Decimal numerical system is defined by its basis 10 and decimal space that is counted from right to left, and consists of numbers 0,1, 2, 3, 4, 5, 6, 7, 8, 9. That means that the end right digit of the total sum is multiplied by 1, next one by 10, next by 100, etc.

Example:

$$\begin{array}{r}
 4631 \\
 \begin{array}{l}
 | \\
 | \\
 | \\
 | \\
 \hline
 \end{array}
 \begin{array}{l}
 1 * 10^0 = 1 \\
 3 * 10^1 = 30 \\
 6 * 10^2 = 600 \\
 4 * 10^3 = 4000 \\
 \hline
 \text{Result} = 4631
 \end{array}
 \end{array}$$

Operations of addition, subtraction, division, and multiplication in a decimal numerical system are used in a way that is already known to us, so we won't discuss it further.

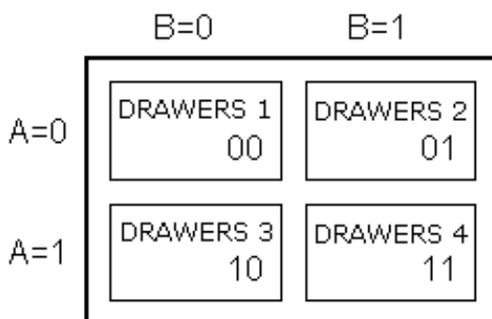
B.2 Binary numerical system

Binary numerical system differs in many aspects from the decimal system we are used to in our everyday lives. Its numerical basis is 2, and each number can have only two values, '1' or '0'. Binary numerical system is used in computers and microcontrollers because it is far more suitable for processing than a decimal system. Usually, binary number consists of binary digits 8, 16 or 32, and it is not important in view of the contents of our book to discuss why. It will be enough for now to adopt this information.

Example:

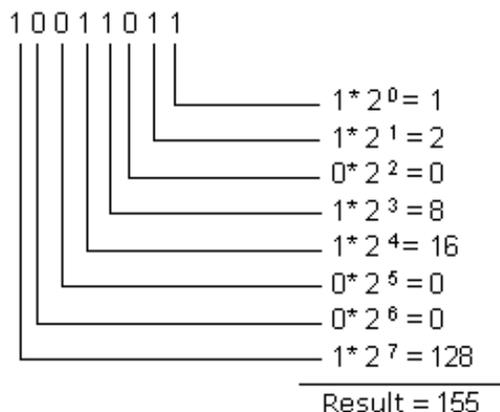
10011011 binary number with 8 digits

In order to understand the logic of binary numbers, we will consider an example. Let's say that we have a small chest with four drawers, and that we need to tell someone to bring something from one of the drawers to us. Nothing is more simple, we will say left side, bottom (drawer), and the desired drawer is clearly defined. However, if we had to do this without the use of instructions like left, right, beneath, above, etc., then we would have a problem. There are many solution to this problem, but we should look for one that is most beneficent and practical! Lets designate rows with A, and types with B. If A=1, it refers to the upper row of drawers, and for A=0, bottom row. Similarly with columns, B=1 represents the left column, and B=0, the right (next picture). Now it is already easier to explain from which drawer we need something. We simply need to state one of the four combinations: 00, 01, 10 or 11. This characteristic naming of each drawer individually is nothing but binary numerical representation, or conversion of common numbers from a decimal into binary form. In other words, references like "first, second, third and fourth" are exchanged with "00,01, 10 and 11".



What remains is for us to get acquainted with logic that is used with binary numerical system, or how to get a numerical value from a series of zeros and ones in a way we can understand, of course. This procedure is called conversion from a binary to a decimal number.

Example:



As you can see, converting a binary number into a decimal number is done by calculating the expression on the left side.

Depending on the position in a binary number, digits carry different values which are multiplied by themselves, and by adding them we get a decimal number we can understand. Let's further suppose that there are few marbles in each of the drawers: 2 in the first one, 4 in the second drawer, 7 in the third and 3 in the fourth drawer. Let's also say to the one who's opening the drawers to use binary representation in answer. Under these conditions, question would be as follows: "How many marbles are there in 01?", and the answer would be: "There are 100 marbles in 01." It should be noted that both question and the answer are very clear even though we did not use the standard terms. It should further be noted that for decimal numbers from 0 to 3 it is enough to have two binary digits, and that for all values above that we must add new binary digits. So, for numbers from 0 to 7 it is enough to have three digits, for numbers from 0 to 15, four, etc. Simply said, the biggest number that can be represented by a binary digit is the one obtained when basis 2 is graded onto a number of binary digits in a binary number and thus obtained number is decremented by one.

Example:

$$2^4 - 1 = 16 - 1 = 15$$

This means that it is possible to represent decimal numbers from 0 to 15 with 4 binary digits, including numbers '0' and '15', or 16 different values.

Operations which exist in decimal numerical system also exist in a binary system. For reasons of clarity and legibility, we will review addition and subtraction only in this chapter.

Basic rules that apply to binary addition are:

$$\begin{array}{r} 1 \\ + 0 \\ \hline 1 \end{array} \quad \begin{array}{r} 0 \\ + 1 \\ \hline 1 \end{array} \quad \begin{array}{r} 0 \\ + 0 \\ \hline 0 \end{array} \quad \begin{array}{r} 1 \\ + 1 \\ \hline 10 \end{array}$$

Addition is done so that digits in the same numerical positions are added, similar to the decimal numerical system. If both digits being added are zero, their sum remains zero, and if they are '0' and '1', result is '1'. The sum of two ones gives two, in binary representation it will be a zero, but with transferring '1' to a higher position that is added to digits from that position.

Example:

$$\begin{array}{r} 1010 \text{ First number} \\ - 1001 \text{ Second number} \\ \hline 10011 \text{ Result} \end{array}$$

We can check whether result is correct by transferring these number to decimal numerical system and by performing addition in it. With a transfer we get a value 10 as the first number, value 9 as the second, and value 19 as the sum. Thus we have proven that operation was done correctly. Trouble comes when sum is greater than what can be represented by a binary number with a given number of binary digits. Different solutions can be applied then, one of which is expanding the number of binary digits in the sum as in the previous example.

Subtraction, like addition is done on the same principle. The result of subtraction between two zeros, or two ones remains a zero. When subtracting one from zero, we have to borrow one from binary digit which has a higher value in the binary number.

Example:

$$\begin{array}{r} 1010 \text{ First number} \\ - 1001 \text{ Second number} \\ \hline 0001 \text{ Result} \end{array}$$

By checking the result as we did with addition, when we translate these binary numbers we get decimal numbers 10 and 9. Their difference corresponds to number 1 which is what we get in subtraction.

$$\begin{array}{r} \$2D46 \text{ First number} \\ + \$1752 \text{ Second number} \\ \hline \$15F4 \text{ Result} \end{array}$$

By checking this result, we get values 11590 for the first number and 5970 for the second, where their difference is 5620, which corresponds to a number \$15F4 after a transfer into a decimal numerical system.

Conclusion

Binary numerical system is still the one that is most in use, decimal the one that's easiest to understand, and a hexadecimal is somewhere between those two systems. It's easy conversion to a binary numerical system and easy memorization make it, along with binary and decimal systems, one of the most important numerical systems.

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Appendix C

Glossary

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Introduction

Since all the fields of man's activity are regularly based on adequate and already adopted terms (through which other notions and definitions become), so in the field of microcontrollers we can single out some frequently used terms. Ideas are often connected so that correct understanding of one notion is needed in order to get acquainted with one or more of the other ideas.

Microcontroller

Microprocessor with peripherals in one electronic component.

I/O pin

External microcontroller's connector pin which can be configured as input or output. In most cases I/O pin enables a microcontroller to communicate, control or read information.

Software

Information that microcontroller needs in order to be able to function. Software can not have any errors if we want the program and a device to function properly. Software can be written in different languages such as: Basic, C, pascal or assembler. Physically, that is a file on computer disc.

Hardware

Microcontroller, memory, supply, signal circuits and all components connected with microcontroller. The other way of viewing this (especially if it's not working) is, that, hardware is something you can kick.

Simulator

Software package for PC which simulates the internal function of microcontroller. It is ideal for checking software routines and all the parts of the code which do not have over demanding connections with an outside world. Options are installed to watch the code, movement around the program back and forth step by step, and debugging.

ICE

ICE (In Circuit Emulator), internal emulator, very useful part of the equipment which connects a PC instead of microcontroller on a device that is being developed. It enables software to function on the PC computer, but to appear as if a real microcontroller exists in the device. ICE enables you to move through program in real time, to see what is going on in the microcontroller and how it communicates with an outside world.

EPROM Emulator

EPROM Emulator is a device which does not emulate the entire microcontroller like ICE emulator, but it only emulates its memory. It is mostly used in microcontrollers that have external memory. By using it we avoid constant erasing and writing of EPROM memory.

Assembler

Software package which translates source code into a code which microcontroller can understand. It contains a section for discovering errors. This part is used when we debug a program from errors made when program was written.

HEX file

This is a file made by assembler translator when translating a source file, and has a form "understood" by microcontrollers. A continuation of the file is usually File_name.HEX where the name HEX file comes from.

List file

This is a file made by assembler translator and it contains all instructions from source file with addresses and comments programmer has written. This is a very useful file for keeping track of errors in the program. File extension is LST which is where its name comes from.

Source File

File written in the language understood by man and assembler translator. By translating the source file, we get HEX and LIST files.

Debugging

Error made in writing a program, which error we are not aware of. Errors can be quite simple such as typing errors, and quite complex such as incorrect use of program language. Assembler will find most of these errors and report them to '.LST' file. Other errors will need to be searched for by trying it out and watching how device functions.

ROM, EPROM, EEPROM, FLASH, RAM

Types of memories we meet with microcontroller use. First one can not be erased, what you write in it once, stays forever,

and can not be erased. The second is erasable with UV lamp. Third one can be erased electrically, using voltage which microcontroller operates on. Fourth one is electrically erasable, but unlike EEPROM memory it does not have such a great number of cycles of writing and erasing at memory locations. Fifth one is fast, but it does not hold back the contents as the previous when there is supply shortage. Thus, program is not stored in it, but it serves for different variables and inter-results.

Addressing

Determines and designates certain memory locations.

ASCII

Short for "American Standard Code for Information Interchange". It is widely accepted type of coding where each number and letter have their eight-bit code.

Carry

Transfer bit connected with arithmetic operations

Code

File, or section of a file which contains program instructions.

Byte, Kilobyte, Megabyte

Terms designating amounts of information. The basic unit is a byte, and it has 8 bits. Kilobyte has 1024 bytes, and megabyte has 1024 kilobytes.

Flag

Bits from a status register. By their activation, programmer is informed about certain actions. Program activates its response if necessary.

Interrupt vector or interrupts

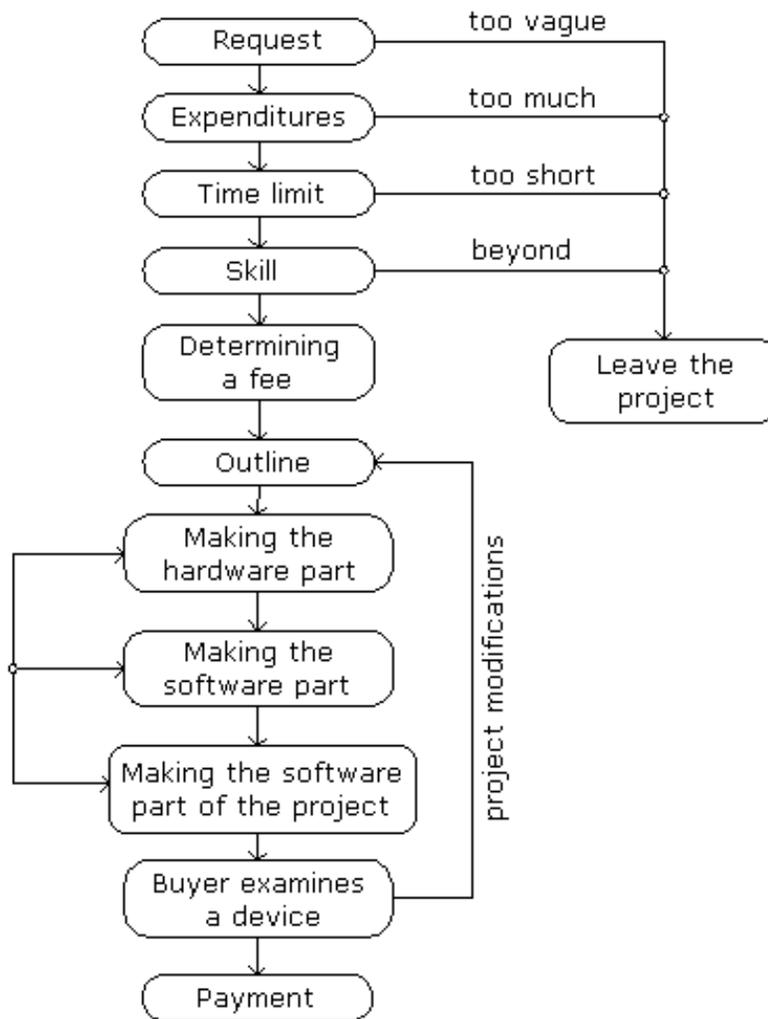
Location in microcontroller memory. Microcontroller takes from this location information about a section of the program that is to be executed as an answer to some event of interest to programmer and device.

Programmer

Device which makes it possible to write software in microcontroller memory, thus enabling the microcontroller to work independently. It consists of the hardware section usually connected with one of the ports and software section used on the computer as a program.

Product

Product development is a combination of luck and experience. Short terms, or time-limits for production should be avoided because even with most simple assignments, much time is needed to develop and improve. When creating a project, we need time, quiet, logical mind and most importantly, a thorough understanding of consumer's needs. Typical course in creating a product would have the following algorithm.



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