# Design of an 8 Bit General Purpose Microcontroller with Sea-of-Gates Design Style

Nalan Erdas*, Mustafa Gündüzalp*

***Abstract*-- This study includes the VLSI design of an eight bit general purpose microcontroller with Sea-of-Gates design style and 1.6μ double metal CMOS technology. The system blocks and the behaviour of these blocks are defined and the logical design is implemented in gate level in the design phase. Then, the logic circuits are simulated and all of the subunits are converted into VLSI layout with Ocean Design System, prepared by Delft University-Netherlands, in a PC using Linux operating system. Finally, in order to construct the microcontroller these units are placed in the floorplan and simulated with analog and digital, logic and switch level simulator. The results of the simulations indicates that the microcontroller can run 31 instructions which can be divided into six subgroups: Transfer instructions, arithmetic and logic instructions, rotate and shift instructions, branch instructions, input/output instructions, control instructions. The external bus of the microcontroller is 16 bit. It includes approximately 10,000 transistors and runs in 25MHz. Its power consumption is 82.5mW for 5V bias voltage. In this paper, the properties of the microcontroller, the design steps and the obtained results are explained.**

**Index Terms-- Microcontroller, logic design, sea-of-gates design.**

## I. Introduction

The integrated circuit technology is the one of the most important fields of the electronics since it minimizes the area of the circuit, parasitic effects and the cost. Furthermore, these devices are more reliable than the circuits that are set up of the discrete components. Therefore, the interest in this subject is increasing day by day. In this study, a general-purpose 8-bit microcontroller is designed using Very Large Scale Integrated Circuit design methods. The technology used for the design is 1.6μ, double metal CMOS technology. CMOS technology is preferred because of its low power dissipation and high integration density. Furthermore, the symmetrical structure of CMOS makes the design easier.

The design style of the integrated circuit is sea-of-gates design style that includes some basic architectures such as transistors, gates, and in order to construct a circuit designer makes interconnections between these units. Therefore, the design time that will be consumed for the system is minimized. However, the basic image presents some limitations. For example, the interconnection paths or the feature sizes of the transistors can not be changed.

The design work is performed on a PC using Linux operating system. The sea-of-gate design system Ocean is used for the design and simulation. It has various tools for layout design, simulation and extraction of the designed circuit with graphical user interface.

## II. Method

The control method that is used by the microcontroller is microprogram method. In this method, a memory called control memory holds the microinstructions that would produce the control signals for the microoperations. The microoperations are the operations that are executed by the subunits of the microcontroller in one machine cycle. [5], [6], [7].

The architecture of the microcontroller is bus oriented which means that it has a main data bus that connects all subunits. Thus, the data flow among the subunits is faster than a microcontroller that has a unidirectional bus. Basically, the subunits of the microcontroller can be grouped into four main blocks. These are processing unit, memory unit, input/output unit and the control unit (Fig. 1). The processing unit consists of arithmetic and logic unit (ALU), shifter and two data registers A and B. The memory unit includes memory address register (MAR) and RAM block. The memory address register is four bits wide and latches the internal RAM address from the bus in order to read from or write to memory. RAM block consists of a 4 to 16 decoder and 16x8 bit static memory cells. The input-output unit provides the connection between the internal bus and the external buses. Finally, the control unit produces the necessary signal for the proper operation of the microcontroller [7], [8], [9].

The instruction set of the microcontroller consists six types of instructions: Transfer instructions, Arithmetic and Logic Instructions, Rotate and Shift Instructions, Branch Instructions, Input/Output Instructions, Control Instructions.

The operation of the microcontroller can be explained in the following way: The instructions are read from the external memory through external data bus and the input latch, Din. Then, the instruction is decoded by control logic

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circuitry and the control unit produces control signals for the microoperations. Additionally, the bus control logic controls the access of the subunits to internal data bus. After decoding, one of the possible operations is followed according to the type of the instruction. For the transfer, arithmetic-logic and shift operations, the operand that is needed for the instruction is read from the external program memory in immediate addressing mode case, or from internal memory in direct addressing mode case, or from registers in register addressing mode case. Then, the desired operation is performed upon the operand in the processing unit and finally the result is written into the destination. For branch instructions, the least significant byte of the branch address is read from the external program memory and it is written to least significant byte of the program counter. Additionally, if the branch instruction is conditional, the status flags are controlled to determine the next operation. For output instructions, the data is transferred to the out of the microcontroller through data output latch $D_{out}$ and I/O port [9].

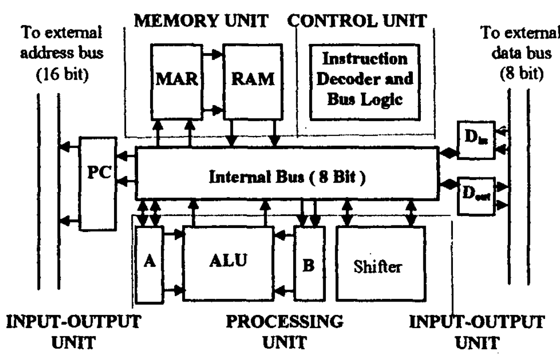


Fig. 1. The Block diagram of the microcontroller

## III. DESIGN OF THE MICROCONTROLLER

The regularity is a key factor in the design. By finding a standard cell, the desired function is implemented replicating these cells. Therefore, in this design, the leaf cells are searched and realized as a first step. After the simulation of the standard cells they are connected to build the subsystem units if the results are acceptable. Finally, the subsystem is simulated. In this section the design steps and the results will be introduced.

### *A. Processing Unit*

The processing unit is the unit that achieves data manipulations on the operands. These operations can be transfer, arithmetic, logic and shift operations. The subunits of the processing unit are the Arithmetic and Logic Unit, Data Registers and Shift Register.

The most important part of the ALU is a full adder. It is used to implement both arithmetic functions, such as addition, subtraction, incrementing and decrementing, and logic functions, such as AND, OR, NOT functions. The other parts are the status flags Carry and Zero, arithmetic output latch and logic output latch. The expressions of the sum and output carry of the used full adder can be expressed as follows [1], [2], [6]:

Sum $$S=\overline{C_1}\cdot(I_0+I_1+C_0)+I_0\cdot I_1\cdot C_0 \quad (1)$$

Carry $$C_1=(I_0+I_1)\cdot C_0+I_0\cdot I_1 \quad (2)$$

The data registers A and B are used to hold the operands for ALU operations. The basic elements of the registers are memory cells, consisting two inverters and two transmission gates [1], [10].

The shifter having parallel loading, left shift, right shift and rotate capability is used for shift and rotate instructions. It is constructed using D type flip flops and logic gates.

### *B. Memory Unit*

It is designed to store necessary bits that can be changed during system operation and program flow. The memory unit includes 16x8 RAM matrix, a 4-to-16 decoder and memory address register.

In the design phase of the RAM circuitry, first a static memory cell is designed. The cell includes cross-coupled two inverters and two pass transistors. Additionally, current mirror differential sense amplifier is prepared for reading operation [11], [12]. However, the feature size of the transistors in the fishbone image is constant, therefore the tuning of the aspect ratios for reading operation cannot be done and the circuit did not work. As a result the register cells are used for RAM. In order to select any one of the 8 bit row of the memory, a 4 to 16 row decoder consisting logic gates is used. During read and write operations the memory address should be hold stable. For this purpose a register called memory address register is constructed of D type flip flops.

### *C. Input-Output Unit*

The Input/Output Unit of the microcontroller is used to provide an interface between the external world and the chip. This unit includes the data input and output latches and the port structure. The data input and output latches are used to store the data that is transferred between the external data bus and the internal bus. The bidirectional three-state port circuitry including 12 transistors is used for ports, as introduced in [12].

### *D. Control Unit*

The control unit is the unit that controls all the operations that are performed by the microcontroller using microprogram method. Basically, there are three elements of the control unit. These are the control address register, control memory and the program counter.

The control memory is constructed of Read Only Memory Cells [11], [13]. Since microcontroller has totally 25 control variables and 75 microoperations, the control memory includes 25 columns and 75 rows. The control decoder is similar to the memory address decoder and its used to address the rows of the control memory. [9].

The control address register actually is an 8 bit counter with parallel loading capability. It is designed using D type flip flops and logic gates. The control address register has 3 functions: Reset for reaching the fetch commands in first rows of the control memory, incrementing to implement the next microoperation and loading for reaching opcodes of the fetched instruction. [9]

The program counter is a 16 bit counter that addresses the external program memory. It is constructed of the counters designed for control address registers and has six functions to implement the instructions including conditional and unconditional branch instructions [9].

## IV. RESULTS

An important aspect in integrated circuit design is to prepare the floorplan and distributing clock signal without causing clock skew and hazards. There are numerous approaches for clock distributions inside a VLSI chip [1], [2], [12], [14], After the structure of the microcontroller and available clock schemes are considered, buffered clock distribution tree is decided. In order to drive internal data bus, input and output of each subunit is buffered. By isolating each unit from the other, desired signal levels are obtained. After the subunits of the microcontroller are placed in the floorplan, the complete system is simulated to obtain the performance of the microcontroller. For the simulation, the control signals are generated in the input file of the simulator. Some of the results are shown in the figures below.

The Fig. 2 illustrates the output of the sample program. The a0-a7 stands for arithmetical outputs of ALU while l0-l7 shows logical outputs.

| Sample Program | |
|---|---|
| YUK A, 00H | Load A register with 00H |
| YUK B, FFH | Load B register with FFH |
| ETP A,B | Adds B to A with carry |
| YUK A,22H | Load A register with 22H |
| YUK B, FFH | Load B register with FFH |
| TOP A,B | Adds B to A without carry |
| DUR | Stops the program |

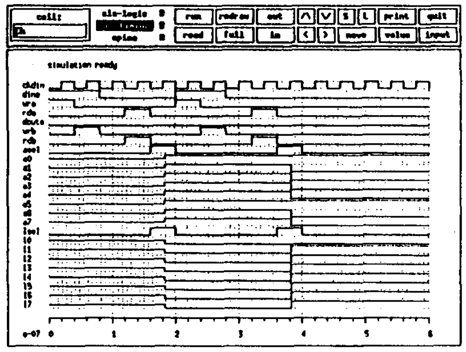

Fig. 2. The outputs for the sample program

The simulation results for shifter is shown in Fig. 3 and Fig.4. In the first figure the shifter is loaded with 01H and sequential shift left operations are implemented. Similarly, the A register is loaded with 80H and sequential rotate right operation are performed (Fig. 4)

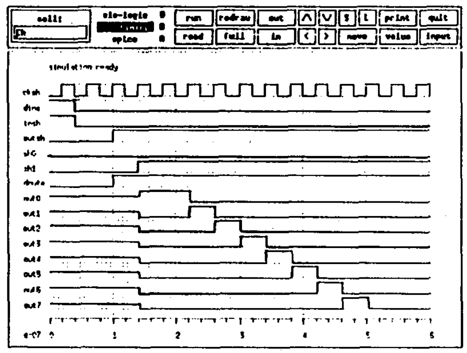

Fig. 3. Simulation results for shift operation

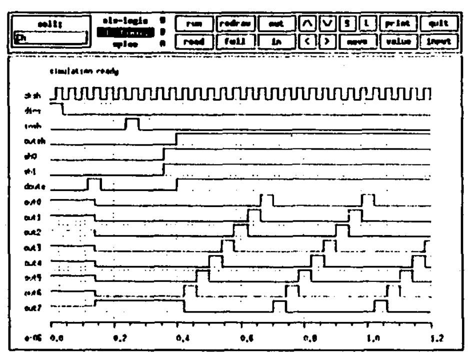

Fig. 4. Simulation results for rotate operation

## V. CONCLUSION

Minimizing the size of an electronic component while increasing its capability and reliability is one of the most important goals of the today's electronics world. Thus, there is a great trend to the design of very large scale and even ultra large scale integrated circuits. There is an increasing interest in integrated circuit technology also in our country and some design projects are performed by educational institutions. Therefore, in order to be a part of this progress, a general purpose 8 bit microcontroller is designed for industrial applications.

At design process, the microcontroller is divided into building blocks. Each subunit is designed and simulated individually. Finally, the subunits are located in the floorplan, the interconnections are completed and the system is simulated as a whole. The microcontroller has a capability of running 31 instructions including conditional and unconditional branch instructions. The other instructions can also be arranged to operate depending on status flags. Although the main instructions are used in the microcontroller, the instruction set can be expanded with some hardware additions.

The external address bus of the microcontroller is 16 bit. It includes approximately 10,000 transistors. The microcontroller works at 25MHz and the total power consumption is 82.5mW for 5V bias voltage.

The designed microcontroller can run the programs with loops consisting arithmetical, logical, rotate and shift operations. Thus, it can be used in some industrial applications by adding an external program memory and supplying with a clock signal. Also, the system can easily be expanded with some application-specific hardware.

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