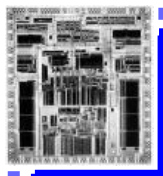
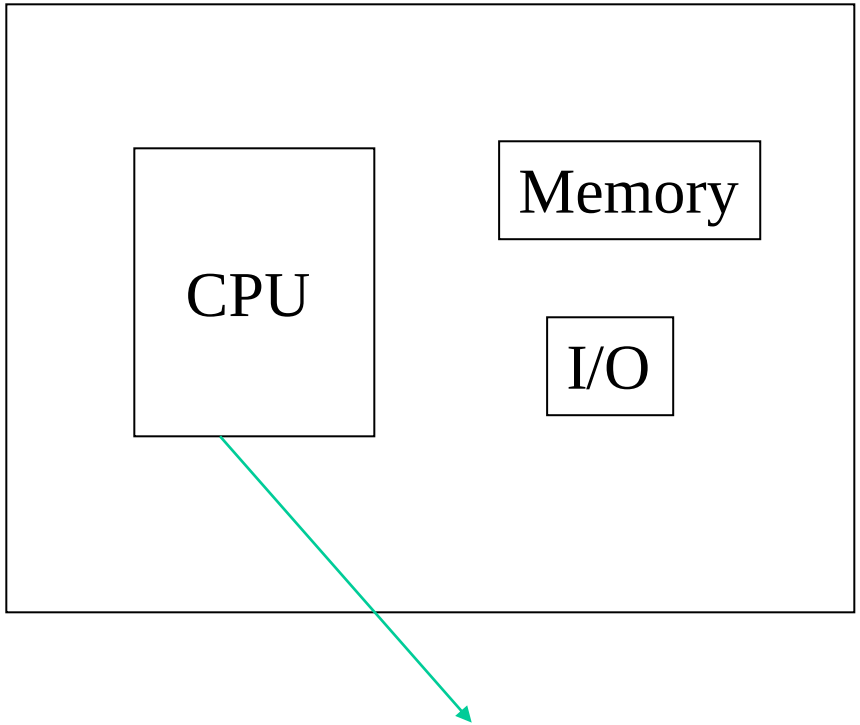


Embedded Systems

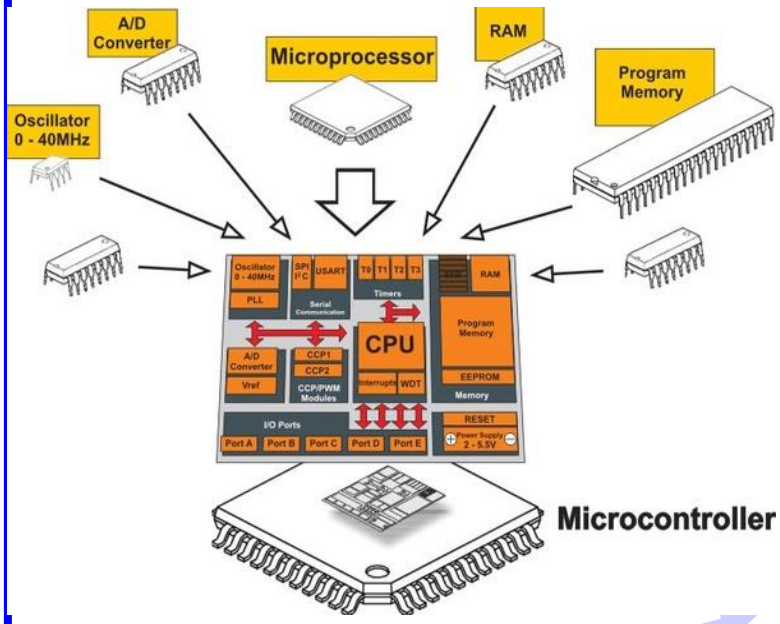
Basic Components of Computer

- CPU
- Memory
- I/O

Motherboard



Microcontrollers



A single chip (SoC)

CPU

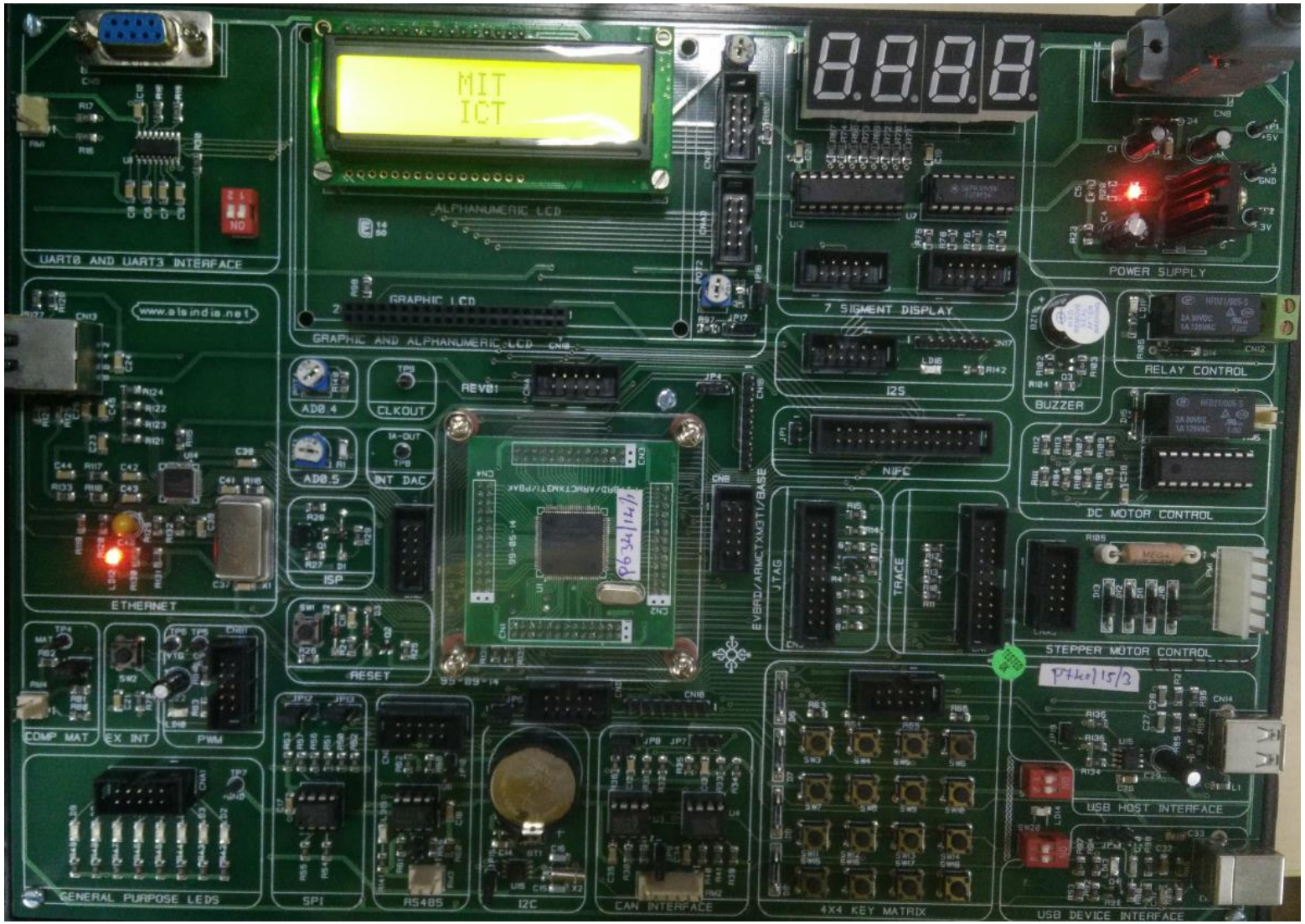
Memory

ROM	RAM

I/O

Subsystems:
Timers, Counters, Analog Interfaces, I/O interfaces

LPC 1768


MIT
ICT
ALPHANUMERIC LCD
GRAPHIC LCD
GRAPHIC AND ALPHANUMERIC LCD
UART0 AND UART3 INTERFACE
www.elsindia.net
ETHERNET
POWER SUPPLY
7 SEGMENT DISPLAY
RELAY CONTROL
BUZZER
I2S
NIFC
DC MOTOR CONTROL
STEPPER MOTOR CONTROL
USB HOST INTERFACE
USB DEVICE INTERFACE
4X4 KEY MATRIX
CAN INTERFACE
I2C
RS485
SPI
GENERAL PURPOSE LEDS
COMP MAT
EX INT
PWM
RESET
ISP
INT DAC
CLKOUT
AD0.4
AD0.5
JTAG
TRACE
EVBRD/ARMCTXM3T1/BASE
REV01

Microprocessor vs Microcontroller

Sl.no	Microprocessor	Microcontroller
1	General purpose processor	Specific application controller
2	Contains no RAM, no ROM, no I/O ports on chip itself.	Contains RAM, ROM, I/O ports on chip itself
3	Size of RAM/ROM can vary	Size of RAM/ROM is fixed
4	Makes the system bulkier	Make the system compact
5	More expensive	Less expensive
6	It has less bit handling instructions	It has more bit handling instructions
7	Less number of pins have multiplexed functions	more number of pins have multiplexed functions
8	More flexible in designer point of view	Less flexible in designer point of view
9	Limited power saving options compared to microcontrollers	Includes lot of power saving features
10	Eg: Desktop PC, 8086, i7	Eg: Digital Camera, 8051, msp430
11	Execution faster	Compared to µp slower
12	More general purpose registers	Less number of gen purpose registers
13	More addressing modes	Less addressing modes
14	Design time is more	Application design time less
15	Microprocessors are based on von Neumann model/architecture where program and data are stored in same memory module	Micro controllers are based on Harvard architecture where program memory and Data memory are separate
16	Cannot be used in compact systems and hence inefficient	Can be used in compact systems and hence it is an efficient technique

17	Example code:
	`ADD AX,BX`
	`ADD AX,CX`
	`ADD AX,DX`
		Example code:
		`MOV A,#2fh`
		`MOV B,#2fh`
		`ADD A,B`

18	It cannot be used as stand alone	Can be used as stand alone.
19	May or may not be real-time application oriented	Real-time application oriented
20	Fig : a	Fig :b

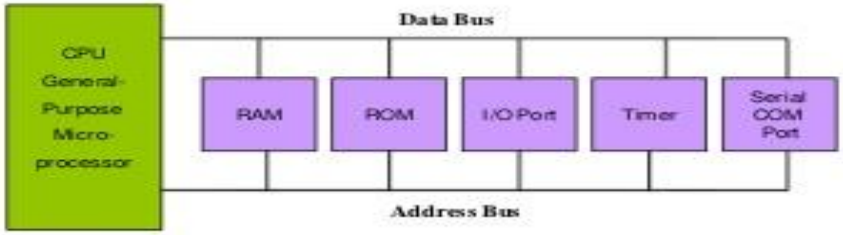


Fig : (a) Microprocessor

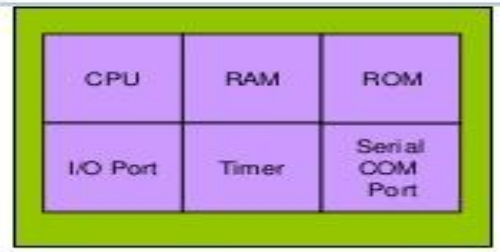
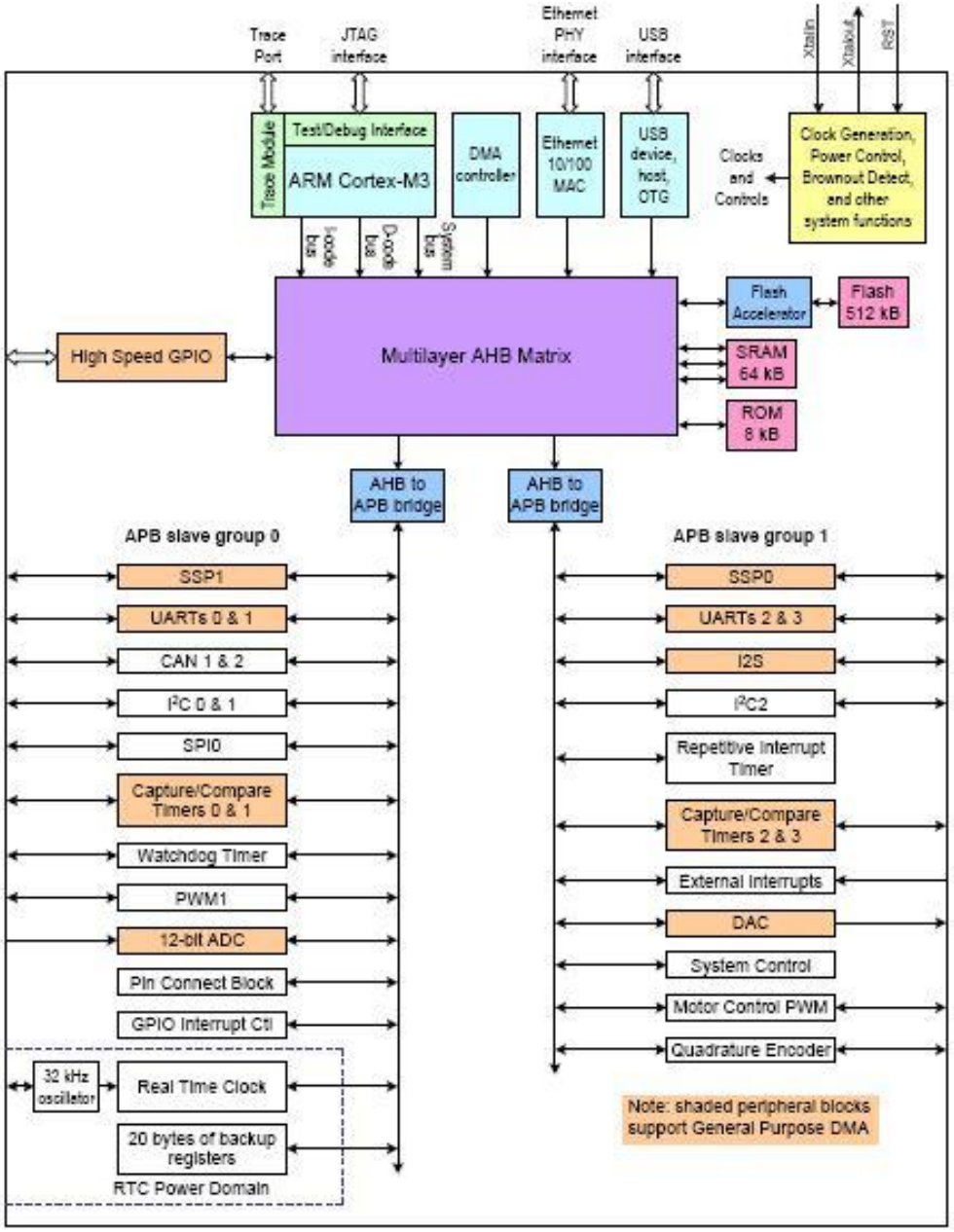
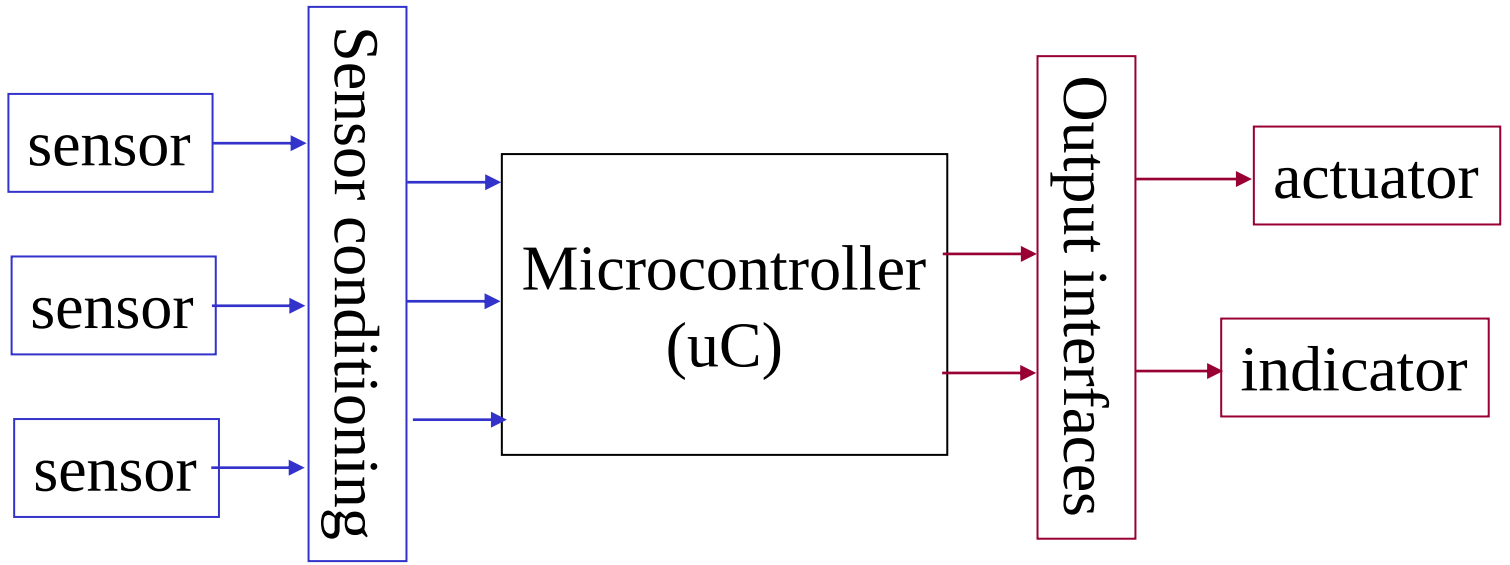


Fig : (b) Microcontroller

Microcontrollers

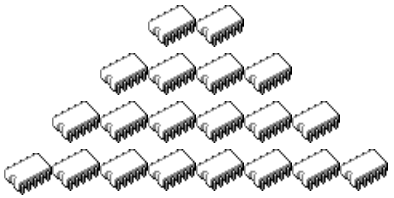


Embedded System General Block Diagram

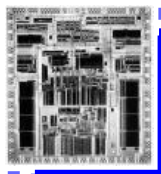


Embedded systems overview

- Embedded computing systems
  - Computing systems embedded within electronic devices
  - Nearly any computing system other than a desktop computer
  - Billions of units produced yearly, versus millions of desktop units



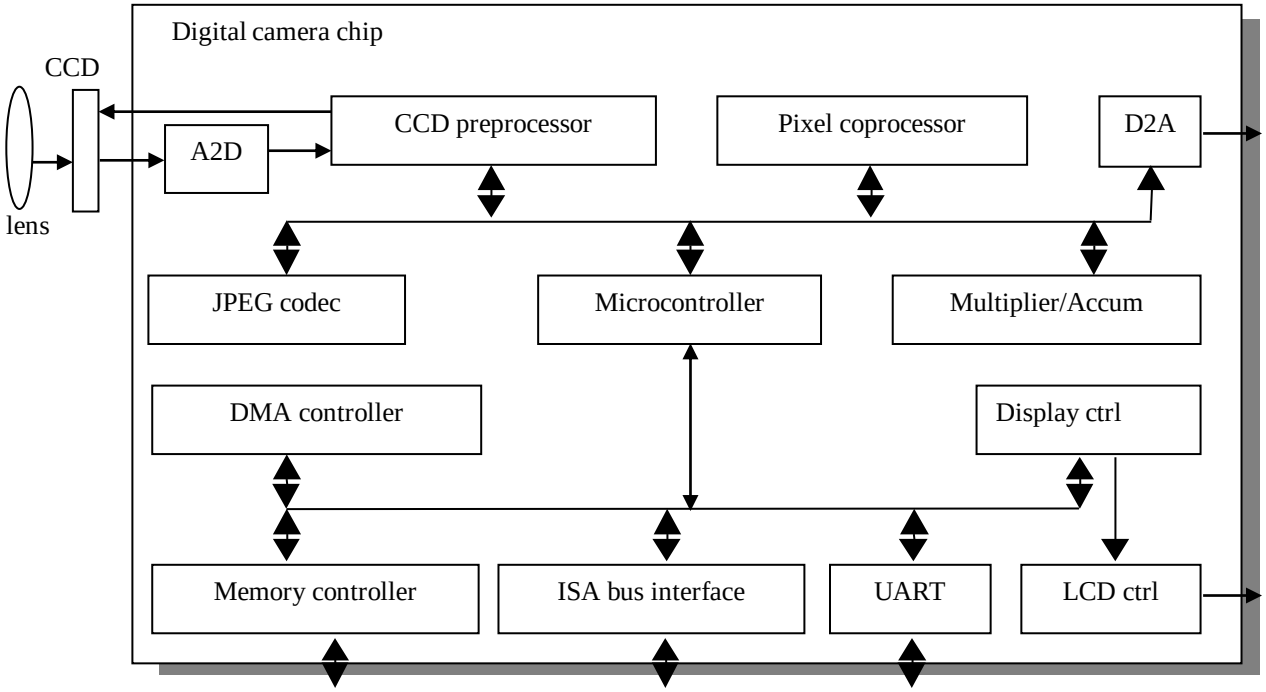
Lots more of these, though they cost a lot less each.

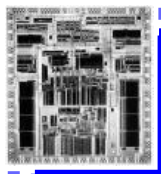


Some common characteristics of embedded systems

- Single-functioned
  - Executes a single program, repeatedly
- Tightly-constrained
  - Low cost, low power, small, fast, etc.
- Reactive and real-time
  - Continually reacts to changes in the system's environment
  - Must compute certain results in real-time without delay

An embedded system example -- a digital camera





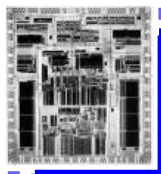
RISC vs CISC

What is RISC?

- A reduced instruction set computer is a computer that only uses simple commands that can be divided into several instructions that achieve low-level operation within a single CLK cycle, as its name proposes “Reduced Instruction Set”.

What is CISC?

- A complex instruction set computer is a computer where single instructions can perform numerous low-level operations like a load from memory, an arithmetic operation, and a memory store or are accomplished by multi-step processes or addressing modes in single instructions, as its name proposes “Complex Instruction Set ”.

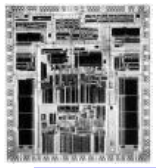


RISC vs CISC

RISC – Reduced Instruction Set Computer
CISC – Complex Instruction Set Computer

1. One of the major characteristics of RISC architecture is a large number of registers. All RISC architectures have at least 8 or 16 registers. Of these 16 registers, only a few are assigned to a dedicated function. One advantage of a large number of registers is that it avoids the need for a large stack to store parameters.

2. RISC processors have a fixed instruction size. In a CISC microprocessors such as the x86, instructions can be 1, 2, 3, or even 5 bytes. For example, look at the following instructions in the x86:

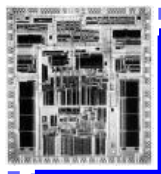


RISC vs CISC

3. RISC processors have a small instruction set. RISC processors have only basic instructions such as ADD, SUB, MUL, LOAD, STORE, AND, OR, EOR, CALL, JUMP, and so on.

The limited number of instructions is one of the criticisms leveled at the RISC processor because it makes the job of Assembly language programmers much more tedious and difficult compared to CISC Assembly language programming.

This is one reason that RISC is used more commonly in high-level language environments such as the C programming language rather than Assembly language environments.

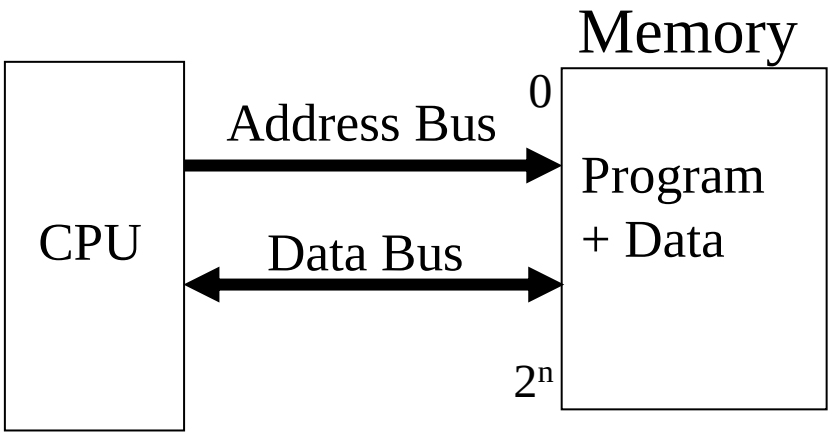


RISC vs CISC

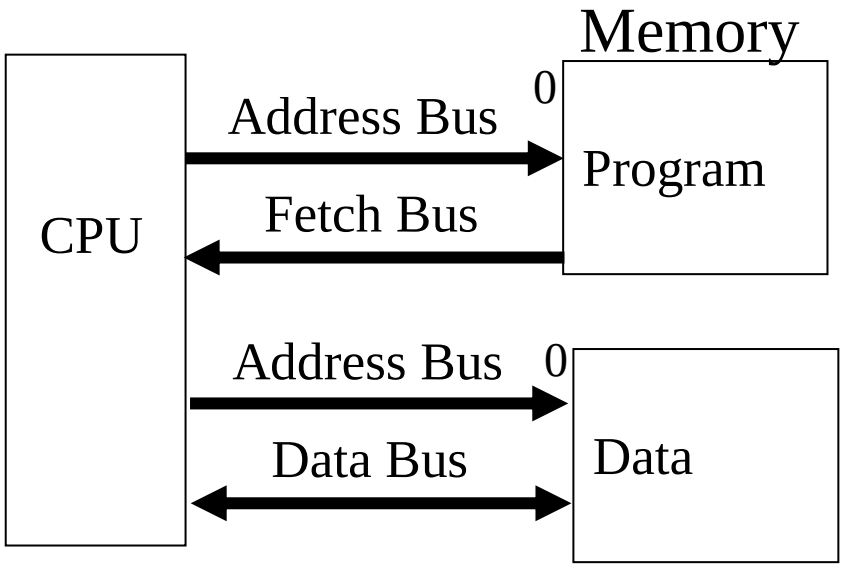
4. The most important characteristic of the RISC processor is that more than 99% of instructions are executed with only one clock cycle, in contrast to CISC instructions.

5. RISC processors have separate buses for data and code.

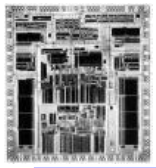
Microcontroller Architectures



Von Neumann
Architecture in CISC



Harvard
Architecture in RISC



RISC vs CISC

6. Because CISC has such a large number of instructions, each with so many different addressing modes, microinstructions (microcode) are used to implement them.

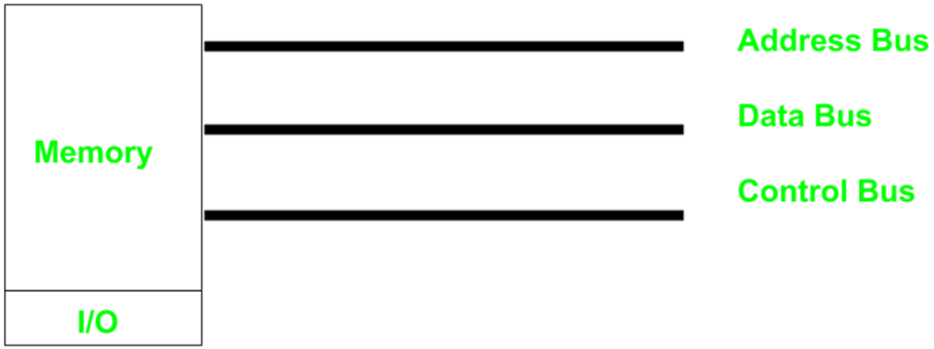
RISC instructions, however, due to the small set of instructions, are implemented using the hardwire method.

7. RISC uses load/ store architecture. In CISC microprocessors, data can be manipulated while it is still in memory.

8. Memory Mapped IO in RISC and IO mapped IO in CISC

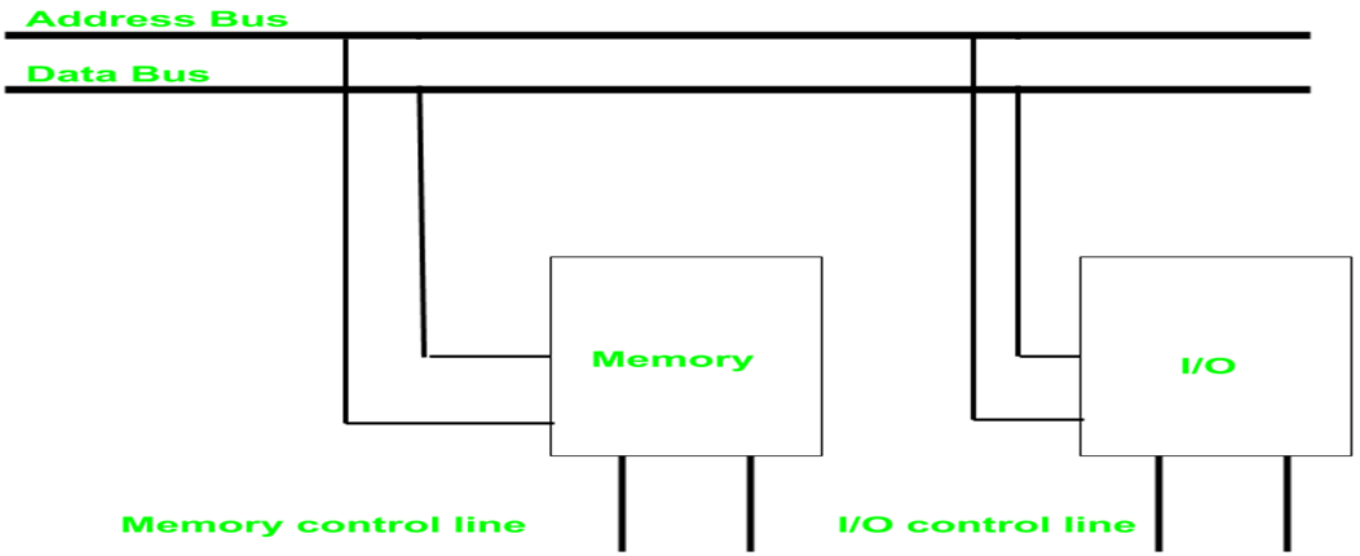
RISC vs CISC

- **Memory Mapped I/O**
- In this case every bus in common due to which the same set of instructions work for memory and I/O.

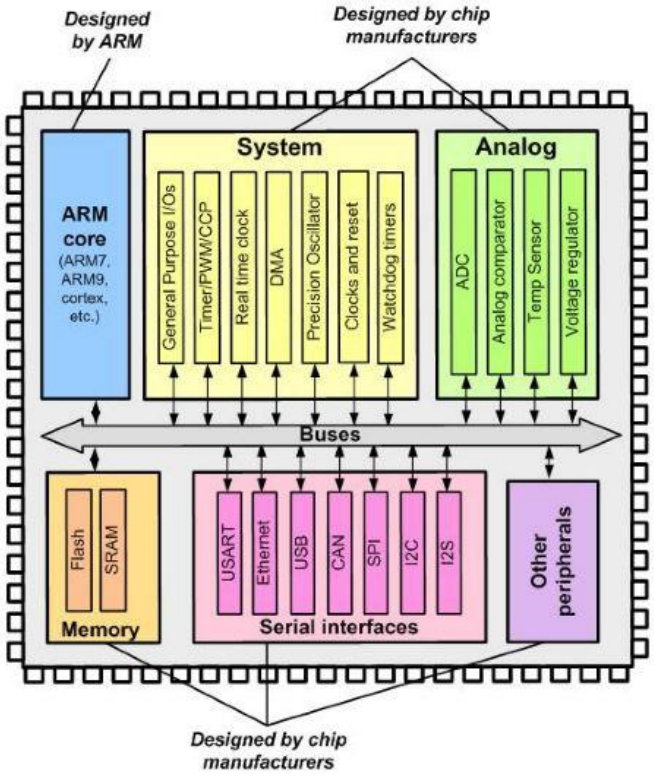


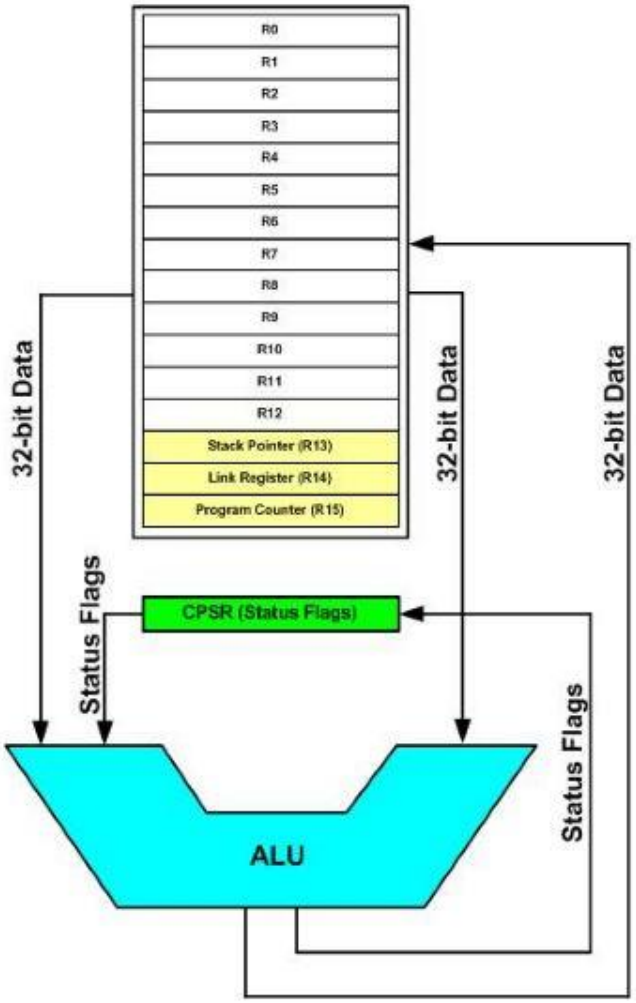
RISC vs CISC

IO mapped IO (Isolated I/O) In which we have common bus(data and address) for I/O and memory but separate read and write control lines for I/O.



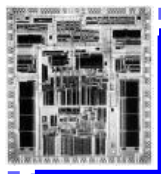
RISC vs CISC





N,Z,C,V flags

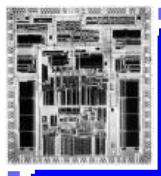
Bit No. 31, 30, 29. 28



Addressing Modes

The way in which an operand is specified in an instruction is called Addressing Mode

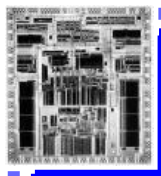
1. Register - MOV R0. R1
2. Immediate – MOV R0, #1
3. Register Indirect- LDR R0, [R1]
   STR R0, [R1]
4. Indexed



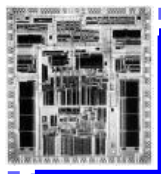
Addressing Modes

Addressing modes

Indexed Addressing Mode	Syntax	Pointing Location in Memory	Rm Value After Execution
Preindex	LDR Rd, [Rm,#k]	Rm+#k	Rm
Preindex with WB*	LDR Rd, [Rm,#k]!	Rm+#k	Rm + #k
Postindex	LDR Rd, [Rm],#k	Rm	Rm + #k
WB means Writeback* * Rd and Rm are any of registers and #k is a signed 12-bit immediate value between -4095 and +4095*			



Addressing Modes



Load/Store Byte/Half Word

LDRB – Load Byte

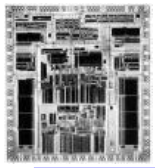
LDRH – Load Halfword

LDRSB – Load Signed byte

LDRSH – Load Signed Halfword

STRH – Store Halfword

Note : For all these instructions – Indirect/Indexed addressing modes are applicable)



MOV instruction

MOV Rd, Rn

MOV Rd, #0x12

MOVW Rd, #0x1234 (Move Word. i.e to the Lower 16 bit)

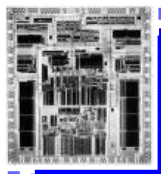
MOVT Rd, #0x1234 (Move Top. i.e. to higher 16 bit)

MVN Rd, Rn (Move Negative – 1’s compliment)

MVN Rd, #0x12

MSR Special_Function_Reg, Rn (Move SFR from Register)

MRS Rn, Special_Function_Reg (Move Register from SFR)



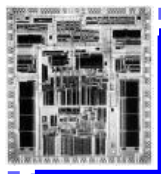
ADD instruction

ADD Rd, Rn, opr2 ; Rd ←Rn+opr2 (addition)

ADC Rd, Rn, opr2; Rd ← Rn + opr2 + C

Flags not affected.

Use S suffix to update flags: ADDS, ADCS



SUBTRACT

SUB Rd, Rn, opr2 ; Rd ←Rn-opr2 (Subtract)

SBC Rd, Rn, opr2; Rd ← Rn -opr2 – (1- C) (Subtract with Carry)

RSB Rd, Rn, opr2 ; Rd ←opr2-Rn (Reverse Subtract)

RSC Rd, Rn, opr2 ; Rd ←opr2-Rn – (1-C) (Reverse Subtract with Carry

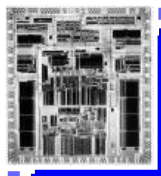
Flags not affected.

Use S suffix to update flags : SUBS, SBCS, RSBS, RSCS

MULTIPLICATION

MUL Rd, Rn, Rm ; Rd = Rn × Rm (Multiply)
MLA Rd, Rs1, Rs2, Rs3 ; Rd = (Rs1 × Rs2) + Rs3 (Multiply and Accumulate)
MLS Rd, Rm, Rs, Rn ; Rd = Rn -(Rs × Rm) (Multiply and Subtract)
UMULL RdLo, RdHi, Rn, Rm ; RdHi:RdLo = Rm × Rn (Unsigned Multiply Long)
UMLAL RdLo, RdHi, Rn, Rm ;RdHi:RdLo =(Rm × Rn) + (RdHi:RdLo) (Unsigned Multiply and Accumulate Long)
SMULL Rdlo, Rdhi, Rn, Rm ;Rdhi:Rdlo = Rm × Rn (Signed Multiply Long)
SMLAL Rdlo, Rdhi, Rn, Rm ;Rdhi:Rdlo =(Rm × Rn) + (Rdhi:Rdlo) (Signed Multiply and Accumulate Long)

Flags not affected.



MULTIPLICATION

LOGICAL INSTRUCTIONS

```
AND  Rd, Rn, Op2          ;Rd = Rn ANDed Op2
ORR Rd, Rn, Op2           ;Rd = Rn ORed with Op2
ORN Rd, Rn, Op2           ;Rd = Rn ORed with 1' s comp of Op2
EOR   Rd, Rn, Op2         ;Rd = Rn XORed Op2
```

Flags not affected.
Use S suffix to update flags

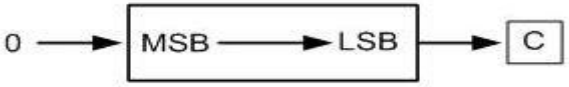
```
TEQ   Rn, Op2          ;performs Rn Ex-OR Op2
TST   Rn, Op2          ;performs Rn AND Op2
```

Flags N,Z affected

SHIFT AND ROTATE

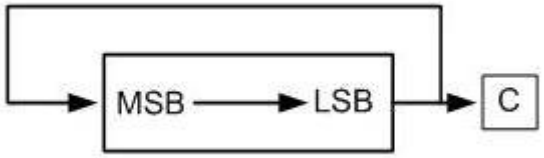
LSL Rd, Rn, Op2

LSR Rd, Rn, Op2

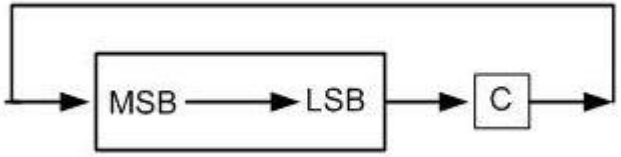


ASR Rd, Rn, Op2

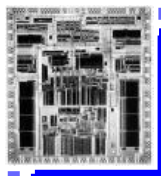
ROR Rd, Rn, Op2



RRX Rd, Rm ;Rd = rotate Rm right 1 bit position



Flags not affected.
Use S suffix to update flags



SHIFT AND ROTATE

BCD addition

```
        AREA    MYCODE, CODE, READONLY

      ENTRY
      EXPORT Reset_Handler


Reset_Handler
;;;;;;;;;;User Code Starts from the next line;;;;

        ldr r0,=res
        ldr r3,=num1
        ldr r4,=num2
        ldr r1,[r3]
        ldr r2,[r4]
        mov [redacted]
        mov r5,#0
        mov r8,#8
loop    mov r3,r1
        mov r4,r2
        and r3,#mask
        and r4,#mask
        add r6,r3,r4
        add r6,r6,r5
        cmp r6,#0x0a
        blo rcarry1
```

BCD addition

```
        mov r5,#1
        sub r6,#0x0a
        b next
rcarry1 mov r5,#0
next    lsr r1, #4
        lsr r2, #4
        orr r7,r6
        ror r7,#4
        sub r8,#1
        teq r8,#0
        bne loop
next1
        str r7,[r0],#4
        str r5,[r0]
stop    b stop
num1    DCD 0x99999999
num2    DCD 0x99999999
mask equ 0x0f
        AREA data1,DATA
res     DCD 0,0
        end
```

Compare Instructions

CMP Compare

Flags: Affected: V, N, Z, C.

Format: CMP Rn,Op2 ;sets flags as if "Rn-Op2"

CMN Compare Negative

Flags: Affected: V, N, Z,C.

Format: CMN Rn,Op2 ;sets flags as if "Rn + Op2"

BRANCH INSTRUCTIONS

B **Branch (unconditional jump)**

Flags: Unchanged.

Format: B target ;jump to target address

Bxx **Branch Conditional**

Flags: Unaffected.

Format: Bxx target ;jump to target upon condition

BRANCH INSTRUCTIONS

Instruction		Condition
BCS	Branch if Carry Set	jump if C=1
BCC	Branch if Carry Clear	jump if C=0
BEQ	Branch if Equal	jump if Z=1
BNE	Branch if Not Equal	jump if Z=0
BMI	Branch if Minus/Negative	jump if N=1
BPL	Branch if Plus/Positive	jump if N=0
BVS	Branch if Overflow	jump if V=1
BVC	Branch if No overflow	jump if V=0

Based on single flag

BRANCH INSTRUCTIONS

"B condition" where the condition refers to the comparison of unsigned numbers. After a compare (CMP Rn,Op2) instruction is executed, C and Z indicate the result of the comparison, as follows:

	C	Z
Rn > Op2	1	0
Rn = Op2	1	1
Rn < Op2	0	0

Based on multiple flags

BRANCH INSTRUCTIONS

Instruction		Condition
BHI	Branch if Higher	jump if C=1 and Z=0
BEQ	Branch if Equal	[redacted] Z=1
BLS	Branch if Lower or same	jump if C=0 or Z=1
BLO	Brach if lower	C=0 and Z=0
BHS	Brach if Higher or same	C=1 or Z=1

For unsigned comparison

BRANCH INSTRUCTIONS

Rn > Op2	V=N or Z=0
Rn = Op2	Z=1
Rn < Op2	V inverse of N

For the signed comparison

Instruction		
BGE	Branch Greater or Equal	V=N or Z=1
BLT	Branch Less than	V is inverse N and Z=0
BGT	Branch Greater than	V=N and Z=0
BLE	Branch Less or Equal	Vis inverse N or Z=1
BEQ	Branch if Equal	jump if Z = 1

BCD to HEX

```
        AREA    MYCODE, CODE, READONLY

        ENTRY

        EXPORT Reset_Handler


Reset_Handler
        ldr r0,=bcd
        ldr r1,[r0]
        and r2,r1,#0x000000f0
        lsr r2,r2,#4
        and r3,r1,#0x0000000f
        mov r4,#10 ; or ox0A
        mla r5,r2,r4,r3
        ldr r0,=hex
        str r5,[r0]

stop    B stop

bcd     DCD 0x98
        AREA data1,DATA
hex     dcd 0
        end
```

Function Call & Return

BL Branch with Link (this is Call instruction)

Flags: Unchanged.

Format: BL Subroutine_Addr ;transfer

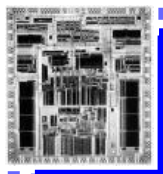
BX Branch Indirect (BX LR is used for Return)

Flags: Unchanged.

Format: BX Rm ;BX LR is used for Return from a subroutine

Function Call & Return

```
        BL HEX_BCD  ; call HEX_BCD
        MOV R0,R1
         ------
         -------
HERE B HERE

HEX_BCD MOV R4,R5
        ---------
        ---------
        BX LR ; Return
```



PUSH and POP

PUSH **PUSH register onto stack**

Flags: Unaffected.

Format: PUSH {reg_list} ;PUSH reg_list onto stack

POP **POP register from Stack**

Flags: Unaffected.

Format: POP {reg_list} ;reg_reg = words off top of stack

PUSH and POP

PUSH {R1,R3-R5}; same as PUSH {R1,R3,R4,R5}

POP {R1,R3-R5}

Example:

LDR R13,=0x10000010

LDR R1,=0x12345678

LDR R3,=0x89ABCDEF

LDR R4,=-2

LDR R5,=0x98765432

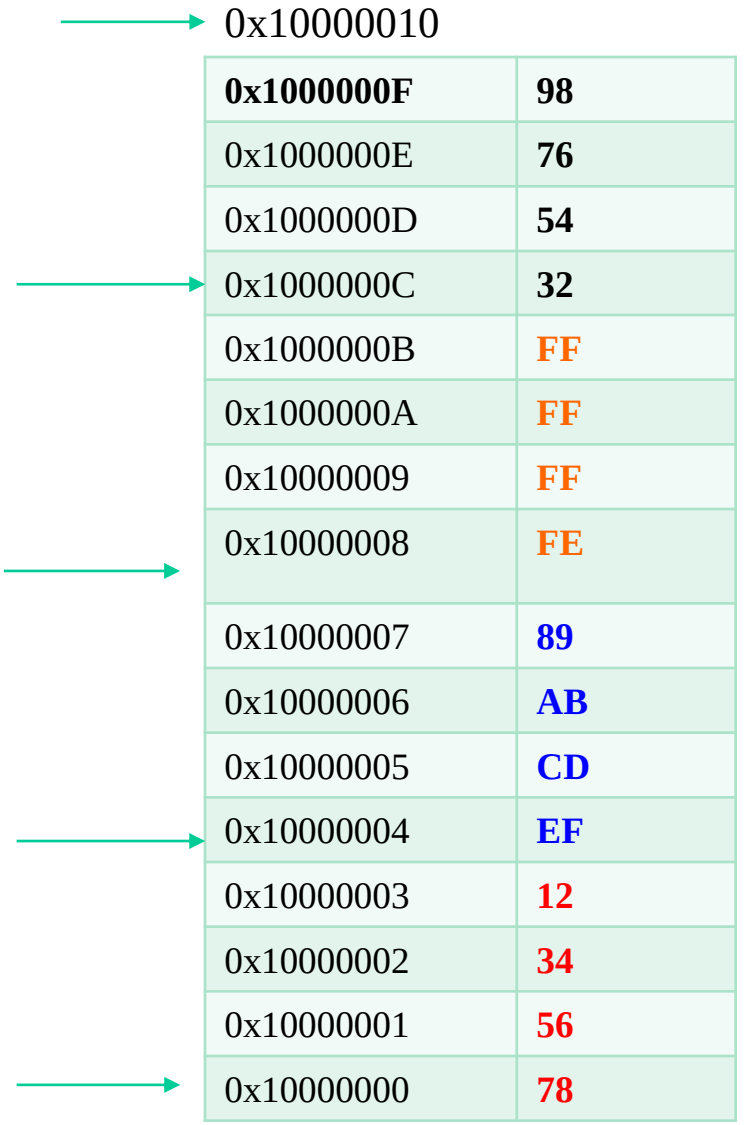
PUSH {R1,R3-R5}

POP {R2,R6-R8}

R13 = 0x10000000

R2= 0x12345678

R6=0x89ABCDEF…

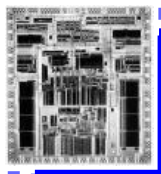


BCD addition

```
        AREA    MYCODE, CODE, READONLY

      ENTRY
      EXPORT Reset_Handler


Reset_Handler
;;;;;;;;;;User Code Starts from the next line;;;;

        ldr r0,=res
        ldr r3,=num1
        ldr r4,=num2
        ldr r1,[r3]
        ldr r2,[r4]
        mov [redacted]
        mov r5,#0
        mov r8,#8
loop    mov r3,r1
        mov r4,r2
        and r3,#mask
        and r4,#mask
        add r6,r3,r4
        add r6,r6,r5
        cmp r6,#0x0a
        blo rcarry1
```

BCD addition

```
        mov r5,#1
        sub r6,#0x0a
        b next
rcarry1 mov r5,#0
next    lsr r1, #4
        lsr r2, #4
        orr r7,r6
        ror r7,#4
        sub r8,#1
        teq r8,#0
        bne loop
next1
        str r7,[r0],#4
        str r5,[r0]
stop    b stop
num1    DCD 0x99999999
num2    DCD 0x99999999
mask equ 0x0f
        AREA data1,DATA
res     DCD 0,0
        end
```



HEX to BCD

```
AREA  Example4, CODE, READONLY
                        ENTRY

Reset_Handler
                        ldr r0,=hex
                        ldr r2,=rem
                        mov r5,#0
                        mov r7,#32
                        ldr r1,[r0]
up2                     bl divide
                        cmp r1,#0
                        bne up2
                        ldr r0,=bcd
                        lsr r5, r7
                        str r5,[r0]
stop        B stop
```

HEX to BCD

```
divide      mov r3,#0
up1                 cmp r1,#0x0a
                    blo down
                    sub r1,#0x0a
                    add r3,#1
                    b up1
down
                    orr r5, r1
                    ror r5,#4
                    mov r1,r3
                    sub r7,#4
                    bx lr
hex                 DCD 0xfffe
                    AREA data1,DATA
bcd                 DCD 0
```

Convert NEG to POSITIVE in array

```
    LDR R0, =ARRAY
    MOV R1,#10
UP  LDR R2, [R0], #4
    CMP R2, #0
    RSBLT R2, #0
    STRLT R2, [R0, #-4]
    SUB R1, #0
    TEQ R1, #0
    BNE UP
```

Factorial using Recursion

```
AREA  Example4, CODE, READONLY
                ENTRY
Reset_Handler
                ldr r1,num
                ldr r13,=0x10001000
                bl fact1
                ldr r1,=fact
                str r2,[r1]
stop            b stop
fact1           cmp r1,#1
                beq exit
                push {r1}
                push {lr}
                sub r1, #1
                bl fact1
```

Factorial using Recursion

```
                pop {lr}
                pop {r1}
                mul r2,r1,r2
                bx lr
exit            mov r2,#1
                bx lr
num     DCD 0x07

                AREA data1,DATA
fact    DCD 0
                                end
```

GCD

```
        LDR R0, =NUM1
        LDR R1, =NUM2
        LDR R0,[R0]
        LDR R1,[R1]
UP      CMP R0, R1
        BEQ EXIT
        SUBHI R0,R1
        SUBLO R1,R0
        B UP
EXIT    LDR R2,=GCD
        STR R0, [R2]
```

```
While (a != b)
{
If (a > b)
    a = a-b;
Else if (b > a)
     b = b-a;
}
```

Load and Store Multiple

LDM Load Multiple registers

Flags: Unaffected.

Format: LDM Rn, {Rx,Ry,..}

STM Store Multiple

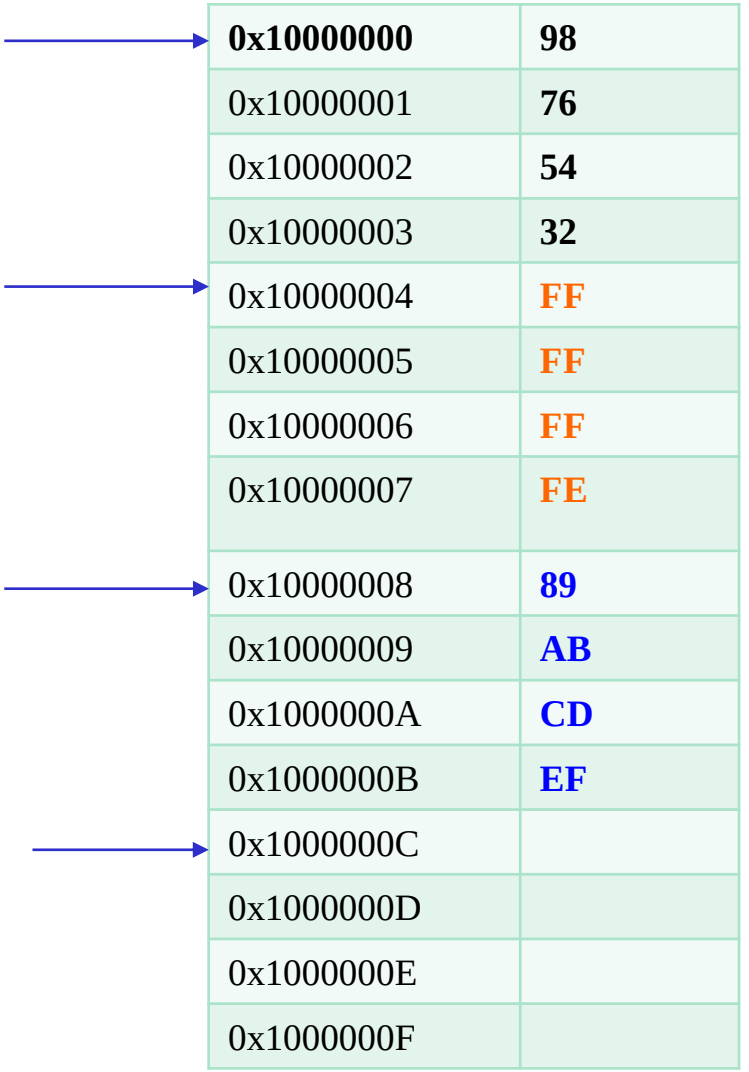
Flags: Unaffected.

Format: STM Rn, {Rx,Ry,...}

Load and Store Multiple

LDR R1, =0x10000000
LDM R1, {R2,R4,R6}
R2 = 0x32547698
R4 = 0xFEFFFFFF
R6 = 0xEFCDAB89
R1= 0x10000000

In case of !
LDM R1!, {R2,R4,R6}
R1=0x1000000C

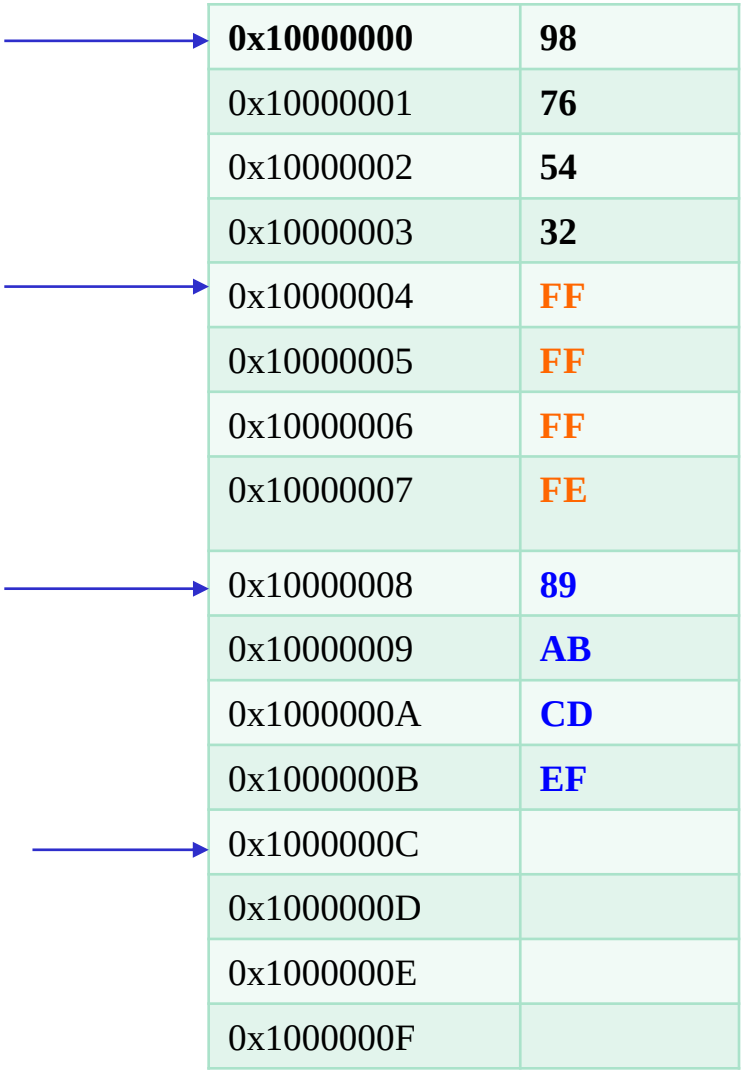


0x10000000	**98**
0x10000001	**76**
0x10000002	**54**
0x10000003	**32**
0x10000004	**FF**
0x10000005	**FF**
0x10000006	**FF**
0x10000007	**FE**
0x10000008	**89**
0x10000009	**AB**
0x1000000A	**CD**
0x1000000B	**EF**
0x1000000C	
0x1000000D	
0x1000000E	
0x1000000F	

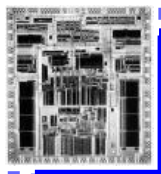
Load and Store Multiple

LDR R1, =0x10000000
LDR R2, = 0x32547698
LDR R4, =0xFEFFFFFF
LDR R6, = 0xEFCDAB89
STM R1, {R2,R4,R6}
R1= 0x10000000

In case of !
STM R1!, {R2,R4,R6}
R1=0x1000000C



0x10000000	**98**
0x10000001	**76**
0x10000002	**54**
0x10000003	**32**
0x10000004	**FF**
0x10000005	**FF**
0x10000006	**FF**
0x10000007	**FE**
0x10000008	**89**
0x10000009	**AB**
0x1000000A	**CD**
0x1000000B	**EF**
0x1000000C	
0x1000000D	
0x1000000E	
0x1000000F	



Load and Store Multiple

LDMDB **Load Multiple registers and Decrement Before each access**

Flags: Unaffected.

Format: LDMDB Rn, {Rx,Ry,...}

STMDB **Store Multiple register and Decrement Before**

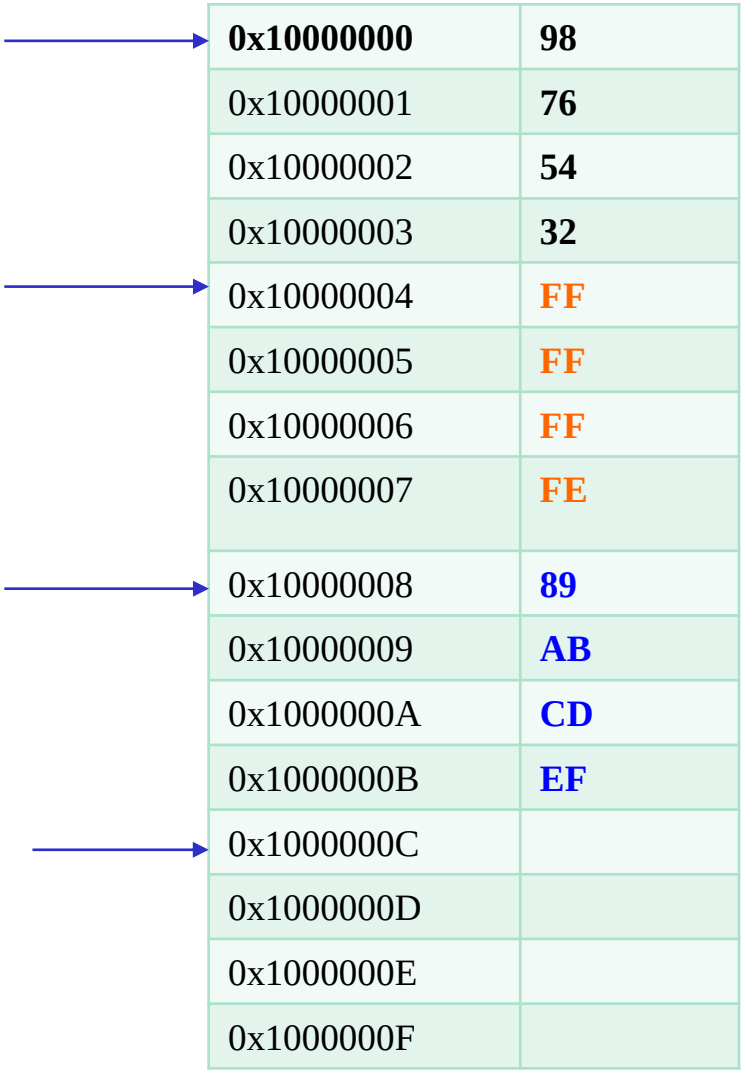
Flags: Unaffected.

Format: STMDB Rn,{Rx,Ry,...}

Load and Store Multiple

LDR R1, =0x1000000C
LDMDB R1, {R2,R4,R6}
R2 = 0x32547698
R4 = 0xFEFFFFFF
R6 = 0xEFCDAB89
R1= 0x1000000C

In case of !
LDMDB R1!, {R2,R4,R6}
R1=0x10000000

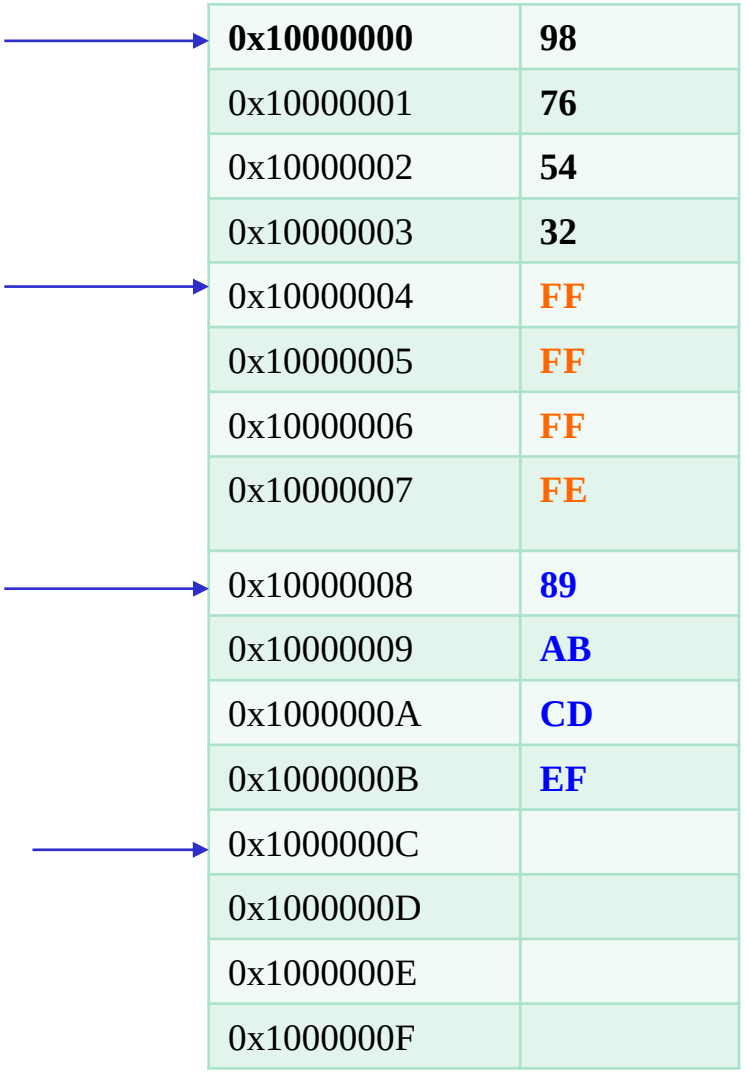


0x10000000	**98**
0x10000001	**76**
0x10000002	**54**
0x10000003	**32**
0x10000004	**FF**
0x10000005	**FF**
0x10000006	**FF**
0x10000007	**FE**
0x10000008	**89**
0x10000009	**AB**
0x1000000A	**CD**
0x1000000B	**EF**
0x1000000C	
0x1000000D	
0x1000000E	
0x1000000F	

Load and Store Multiple

LDR R1, =0x1000000C
LDR R2, = 0x32547698
LDR R4, =0xFEFFFFFF
LDR R6, = 0x32547698
STMDB R1, {R2,R4,R6}
R1= 0x1000000C

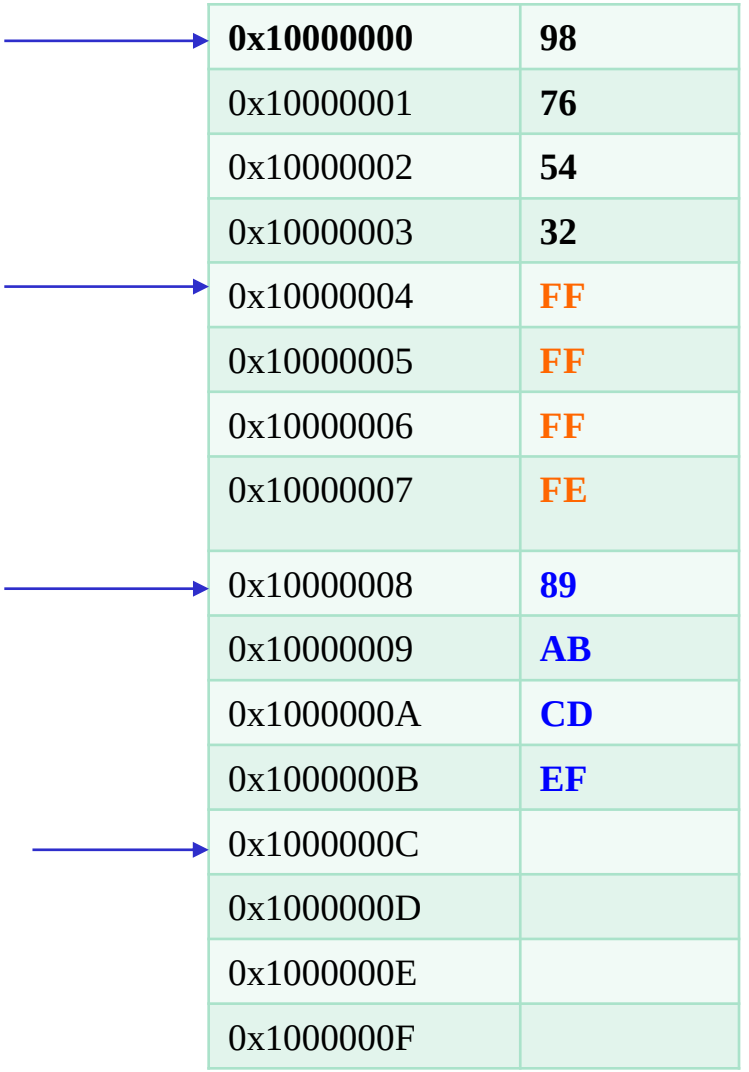
In case of !
STMDB R1!, {R2,R4,R6}
R1=0x10000000



0x10000000	**98**
0x10000001	**76**
0x10000002	**54**
0x10000003	**32**
0x10000004	**FF**
0x10000005	**FF**
0x10000006	**FF**
0x10000007	**FE**
0x10000008	**89**
0x10000009	**AB**
0x1000000A	**CD**
0x1000000B	**EF**
0x1000000C	
0x1000000D	
0x1000000E	
0x1000000F	

Fully Ascending Stack

```
LDR R13, =0x10000000
LDR R2, = 0x32547698
LDR R4, =0xFEFFFFFF
LDR R6, = 0x32547698
STM R13!, {R2,R4,R6}
R13= 0x1000000C
MOV R2, #0
MOV R4, #0
MOV R6, #0
LDMDB R13!, {R2,R4,R6}
R13=0x10000000
```



0x10000000	**98**
0x10000001	**76**
0x10000002	**54**
0x10000003	**32**
0x10000004	**FF**
0x10000005	**FF**
0x10000006	**FF**
0x10000007	**FE**
0x10000008	**89**
0x10000009	**AB**
0x1000000A	**CD**
0x1000000B	**EF**
0x1000000C	
0x1000000D	
0x1000000E	
0x1000000F	

SP increments for PUSH

SP decrements for POP

Fully Descending Stack

```
LDR R13, =0x1000000C
LDR R2, = 0x32547698
LDR R4, =0xFEFFFFFF
LDR R6, = 0x32547698
STMDB R13!, {R2,R4,R6}
```

R13= 0x10000000

```
MOV R2, #0
MOV R4, #0
MOV R6, #0
LDM R13!, {R2,R4,R6}
```

R13=0x1000000C

0x10000000	**98**
0x10000001	**76**
0x10000002	**54**
0x10000003	**32**
0x10000004	**FF**
0x10000005	**FF**
0x10000006	**FF**
0x10000007	**FE**
0x10000008	**89**
0x10000009	**AB**
0x1000000A	**CD**
0x1000000B	**EF**
0x1000000C	
0x1000000D	
0x1000000E	
0x1000000F	

SP decrements for PUSH

SP increments for POP

ARM LPC1768
ASM Programs

ARM – ASM Programming

Bubble Sort

Bubble Sort Algorithm

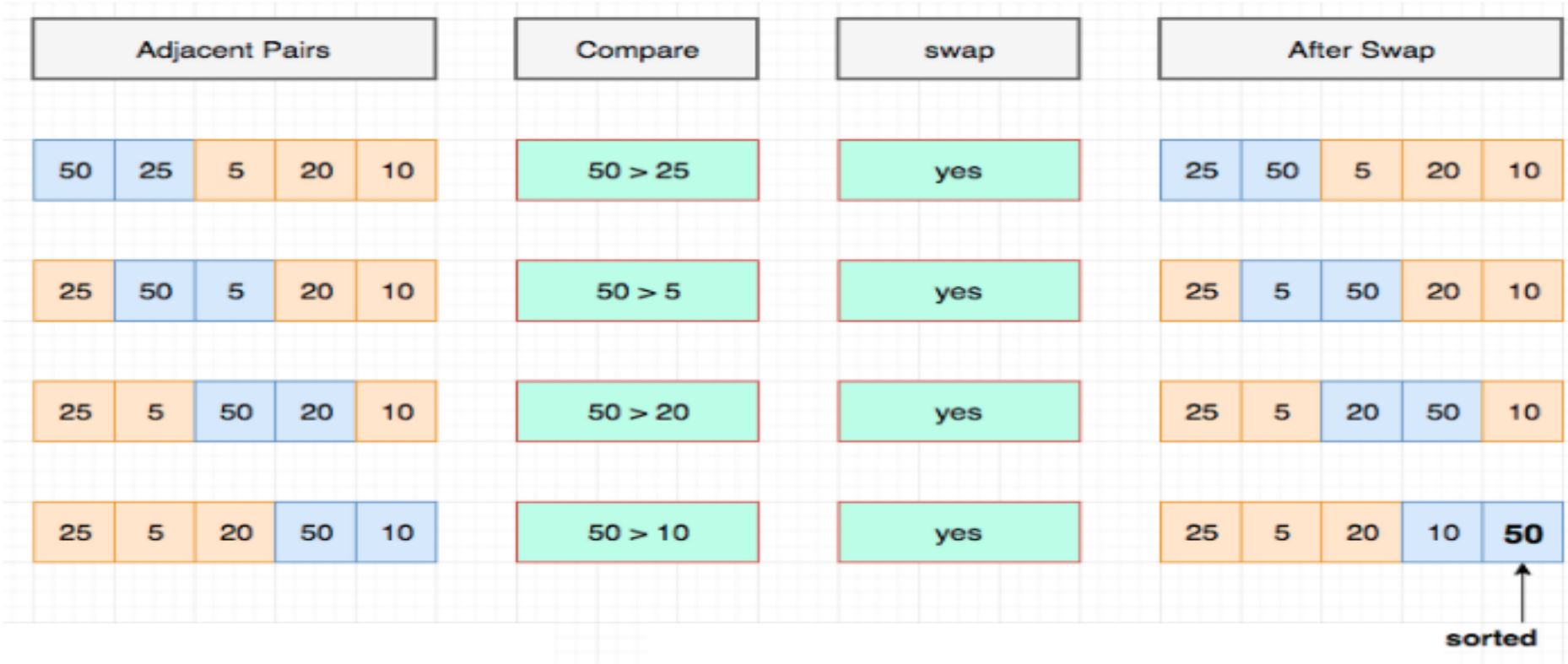
- Two successive elements are compared with each other, and if the left element is larger than the right one, they are swapped.

- These comparison and swap operations are performed from left to right across all elements. Therefore, after the first pass, the largest element is positioned on the far right.

- Ex: Let's take an array of 5 elements = {50, 25, 5, 20, 10}

Bubble Sort Algorithm

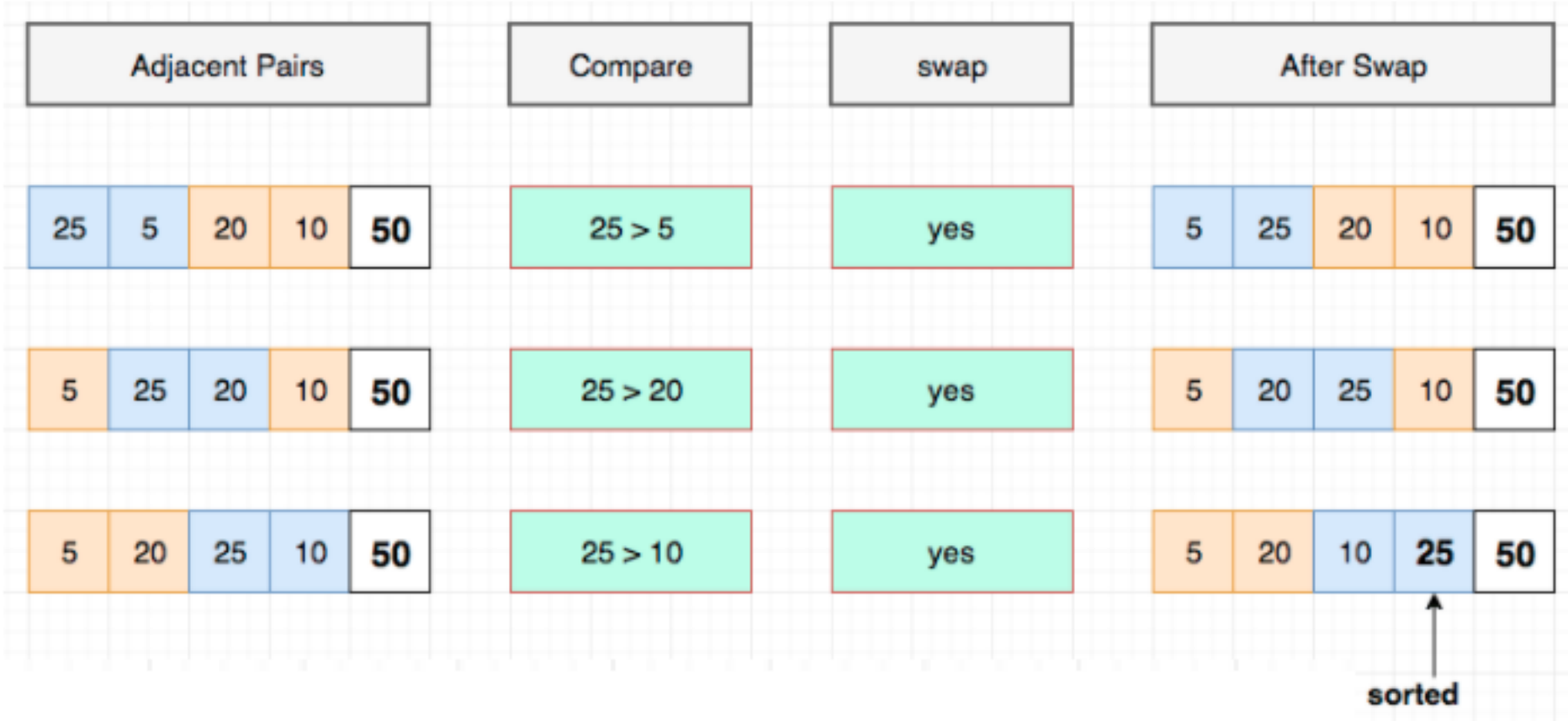
Step 1



- We can notice that one element has been sorted after the above process.
- In general, to sort N element using bubble sort, we need to do the same process N-1 times.
- From next iteration onwards, we can skip the sorted elements. i.e. 50

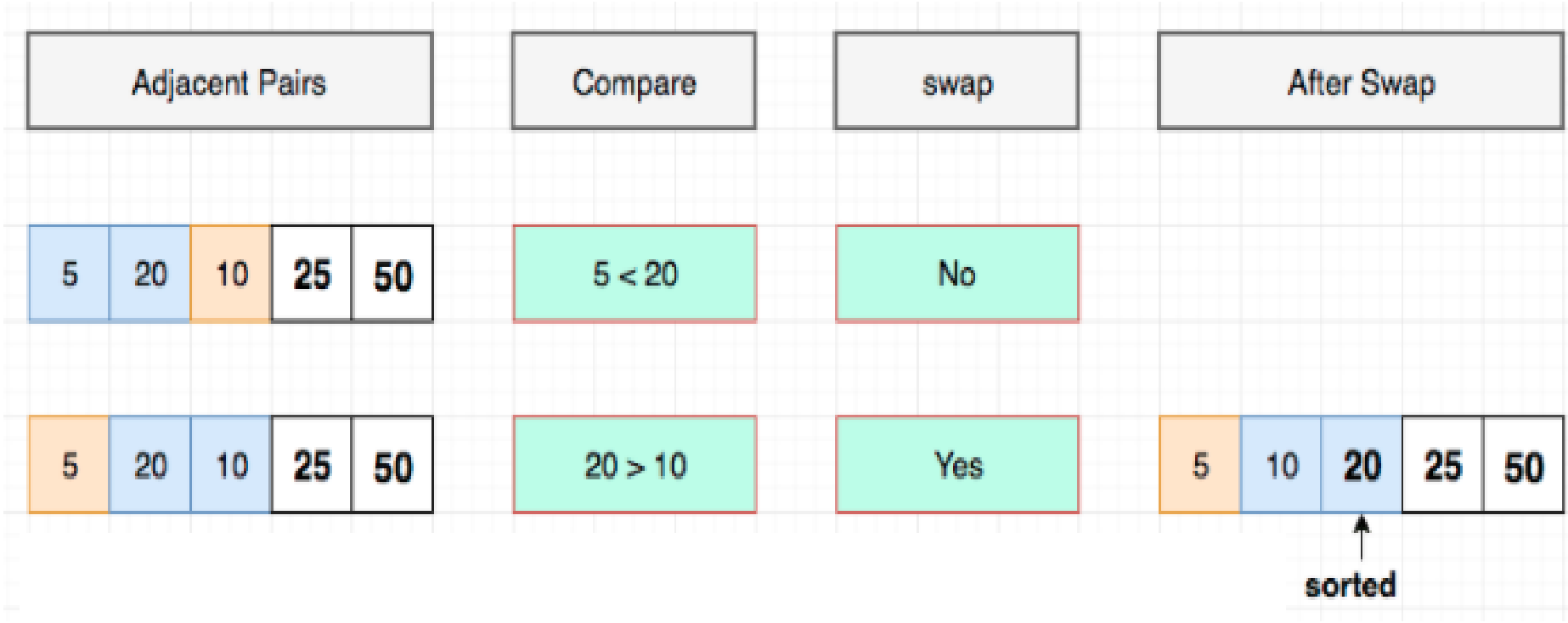
Bubble Sort Algorithm

Step 2



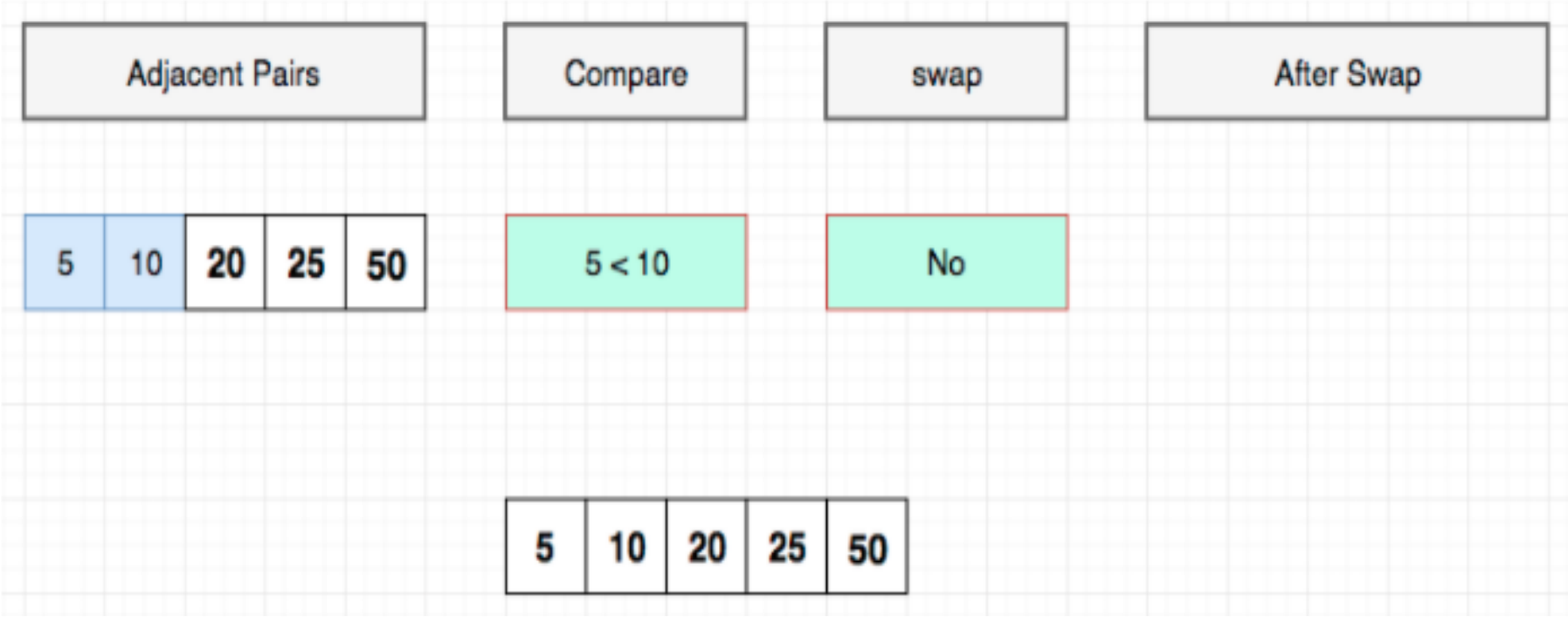
Bubble Sort Algorithm

Step 3



Bubble Sort Algorithm

Step 4



ARM – ASM Programming

Hex to ASCII & ASCII to Hex Conversion

Hexadecimal System (Hex System)

- The hexadecimal system (shortly hex), uses the number 16 as its base (radix).
- As a base-16 numeral system, it uses 16 symbols:- 10 decimal digits (0, 1, 2, 3, 4, 5, 6, 7, 8, 9) and the first six letters of the English alphabet (A, B, C, D, E, F).
- Hex is used in mathematics and information technologies as a more friendly way to represent binary numbers.
- Each hex digit represents four binary digits; therefore, hex is a language to write binary in an abbreviated form.
- Application:- In html programming, colours can be represented by a 6-digit hexadecimal number: FFFFFF represents white whereas 000000 represents black.

ASCII Text

- ASCII abbreviated as American Standard Code for Information Interchange.
- ASCII is one of the most common character encoding standards widely used in electronic communication for conveying text.
- As computers can only understand numbers, the ASCII code represents text (characters) with different numbers. This is how a computer 'understands' and shows text.
- ASCII is based on 128 characters. These are the 26 letters of the English alphabet (both in lower and upper cases); numbers from 0 to 9; and various punctuation marks.
- In the ASCII code, each of these characters are assigned a decimal number from 0 to 127.
- Ex:- ASCII representation of upper case A is 65 and the lower case a is 97.

ASCII Table

Dec	Hex	Name	Char	Ctrl-char	Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char
0	0	Null	NUL	CTRL-@	32	20	Space	64	40	@	96	60	`
1	1	Start of heading	SOH	CTRL-A	33	21	!	65	41	A	97	61	a
2	2	Start of text	STX	CTRL-B	34	22	"	66	42	B	98	62	b
3	3	End of text	ETX	CTRL-C	35	23	#	67	43	C	99	63	c
4	4	End of xmit	EOT	CTRL-D	36	24	$	68	44	D	100	64	d
5	5	Enquiry	ENQ	CTRL-E	37	25	%	69	45	E	101	65	e
6	6	Acknowledge	ACK	CTRL-F	38	26	&	70	46	F	102	66	f
7	7	Bell	BEL	CTRL-G	39	27	'	71	47	G	103	67	g
8	8	Backspace	BS	CTRL-H	40	28	(	72	48	H	104	68	h
9	9	Horizontal tab	HT	CTRL-I	41	29	)	73	49	I	105	69	i
10	0A	Line feed	LF	CTRL-J	42	2A	*	74	4A	J	106	6A	j
11	0B	Vertical tab	VT	CTRL-K	43	2B	+	75	4B	K	107	6B	k
12	0C	Form feed	FF	CTRL-L	44	2C	,	76	4C	L	108	6C	l
13	0D	Carriage feed	CR	CTRL-M	45	2D	-	77	4D	M	109	6D	m
14	0E	Shift out	SO	CTRL-N	46	2E	.	78	4E	N	110	6E	n
15	0F	Shift in	SI	CTRL-O	47	2F	/	79	4F	O	111	6F	o
16	10	Data line escape	DLE	CTRL-P	48	30	0	80	50	P	112	70	p
17	11	Device control 1	DC1	CTRL-Q	49	31	1	81	51	Q	113	71	q
18	12	Device control 2	DC2	CTRL-R	50	32	2	82	52	R	114	72	r
19	13	Device control 3	DC3	CTRL-S	51	33	3	83	53	S	115	73	s
20	14	Device control 4	DC4	CTRL-T	52	34	4	84	54	T	116	74	t
21	15	Neg acknowledge	NAK	CTRL-U	53	35	5	85	55	U	117	75	u
22	16	Synchronous idle	SYN	CTRL-V	54	36	6	86	56	V	118	76	v
23	17	End of xmit block	ETB	CTRL-W	55	37	7	87	57	W	119	77	w
24	18	Cancel	CAN	CTRL-X	56	38	8	88	58	X	120	78	x
25	19	End of medium	EM	CTRL-Y	57	39	9	89	59	Y	121	79	y
26	1A	Substitute	SUB	CTRL-Z	58	3A	:	90	5A	Z	122	7A	z
27	1B	Escape	ESC	CTRL-[	59	3B	;	91	5B	[	123	7B	{
28	1C	File separator	FS	CTRL-\	60	3C	<	92	5C	\	124	7C	|
29	1D	Group separator	GS	CTRL-]	61	3D	=	93	5D	]	125	7D	}
30	1E	Record separator	RS	CTRL-^	62	3E	>	94	5E	^	126	7E	~
31	1F	Unit separator	US	CTRL-_	63	3F	?	95	5F	_	127	7F	DEL

ASCII Encoding of a Text using Hex Codes

HEX Code	ASCII String
68 65 6C 6C 6F	hello
47 6F 6F 64 20 6D 6F 72 6E 69 6E 67	Good morning
4D 41 48 45	MAHE
4D 61 69 70 61 6C	Manipal

ASCII - Hex Mapping

Hexadecimal Number	ASCII number (Hexadecimal)
0	30
1	31
2	32
3	33
4	34
5	35
6	36
7	37
8	38
9	39
A	41
B	42
C	43
D	44
E	45
F	46

Steps to Convert Hexadecimal number to ASCII equivalent

- **Example 1.** Hexadecimal number =1

Corresponding ASCII value =Hexadecimal number + $30_{(16)}$

$= 31_{(16)}$

- **Example 2.** Hexadecimal number =D

Corresponding ASCII value =Hexadecimal number + $37_{(16)}$

$= D_{(16)} + 37_{(16)}$

$= 13_{(10)} + 55_{(10)}$

$= 68_{(10)}$

$= 44_{(16)}$

Steps to Convert ASCII to Hexadecimal equivalent number

- **Example 1**: ASCII number $=36_{(16)}$

Corresponding Hexadecimal number $= 36_{(16)} - 30_{(16)}$

$=6$

- **Example 2**: ASCII number $=45_{(16)}$

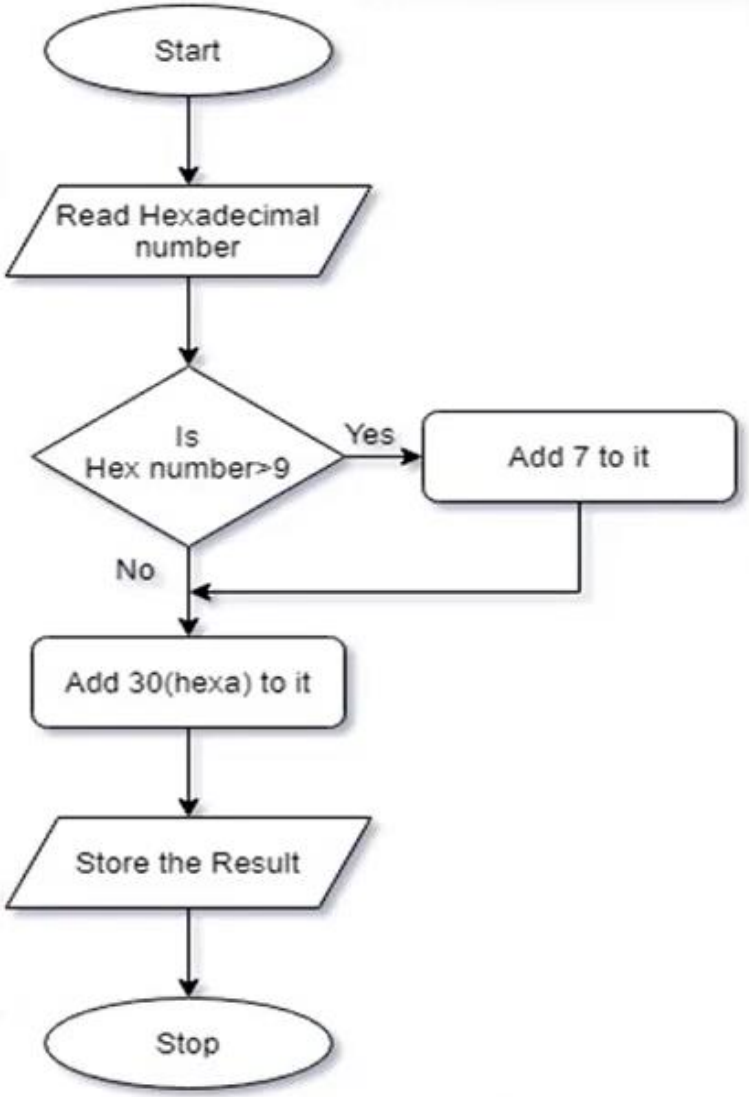
Corresponding Hexadecimal number $= 45_{(16)} - 37_{(16)}$

$=69_{(10)} - 55_{(10)}$

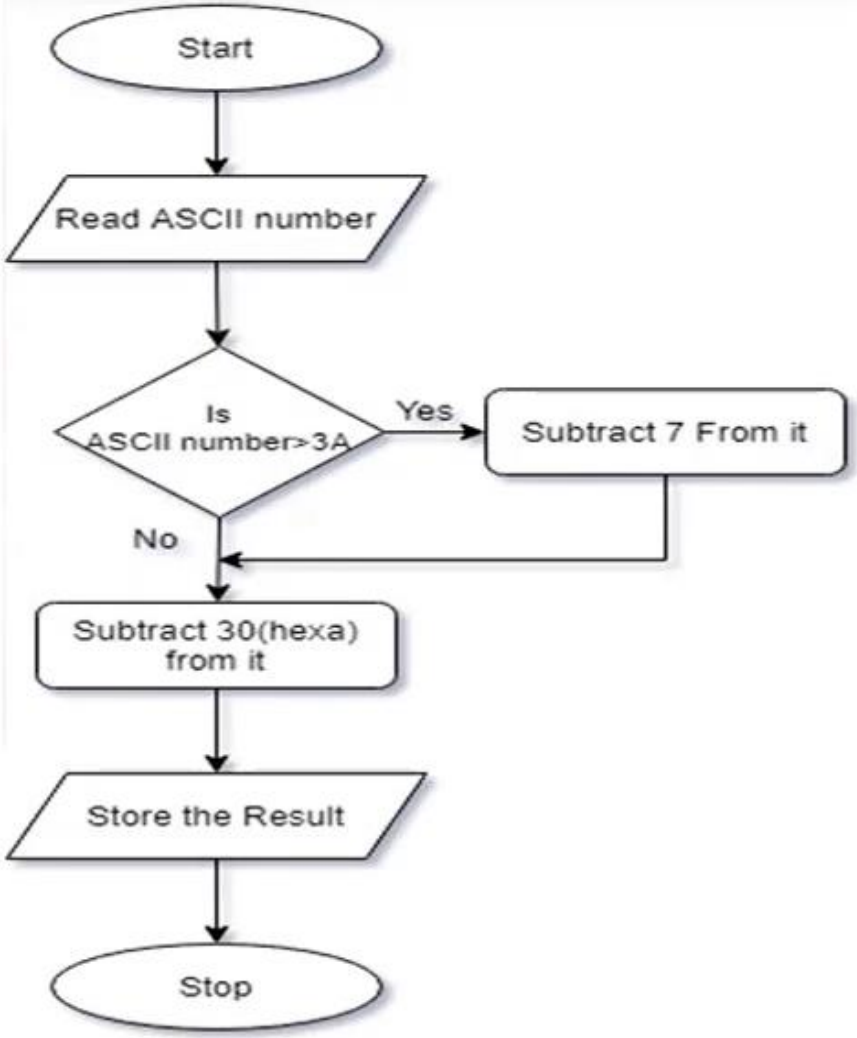
$=14_{(10)} = E_{(16)}$

Flow Chart

Hexadecimal to ASCII



ASCII to Hexadecimal



Puzzle

- What is the minimum number of square towels that can be cut from a ream of cloth 20 meters in length and 16 meters wide without wasting any cloth ?
- The measurement of one side of required square towel is GCD(20,16) = 4 meters.
- The area of ONE square towel is 4 x 4 = 16 sqm
- The area of full ream = 20 x 16 = 320 sqm
- Minimum number of towels possible is: 320/16 = 20 towels.

ARM – ASM Programming

GCD of Two Numbers

GCD of Two Numbers

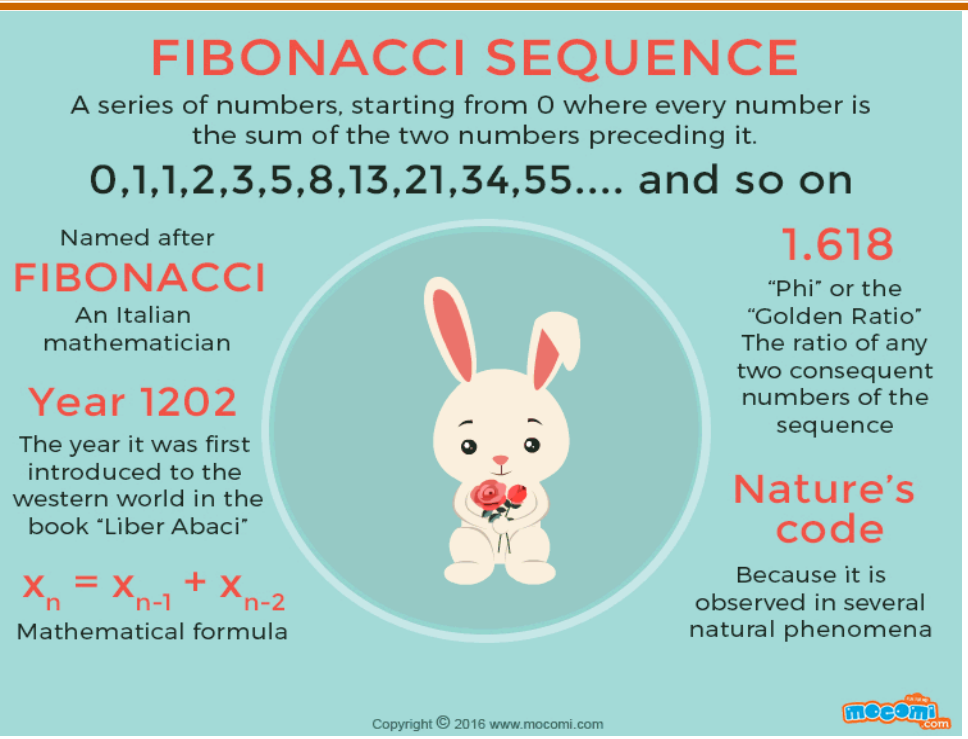
- The Greatest Common Divisor (GCD) refers to the greatest positive integer that is a common divisor for a given set of positive integers.
- It is also termed as the Highest Common Factor (HCF) or the Greatest Common Factor (GCF).
- Application: Encryption Algorithms, Linear Algebra etc.

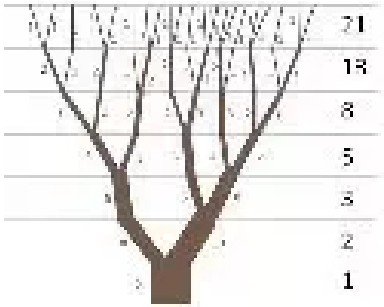
```
While (a != b)
{
If (a > b)
    a = a-b;
Else if (b > a)
    b = b-a;
}
```

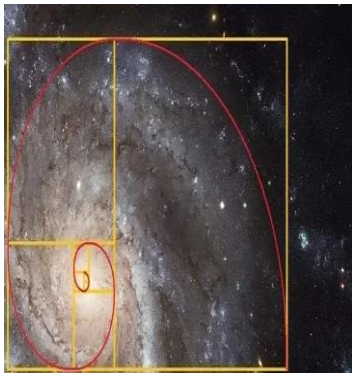
ARM – ASM Programming

Fibonacci series

Fibonacci series







- Fibonacci numbers are used in Fibonacci heaps, which are a data structure that can be used to speed up some very practical algorithms.
- They are used in charting analysis (technical analysis) in stock trading to estimate the price fall and rise.

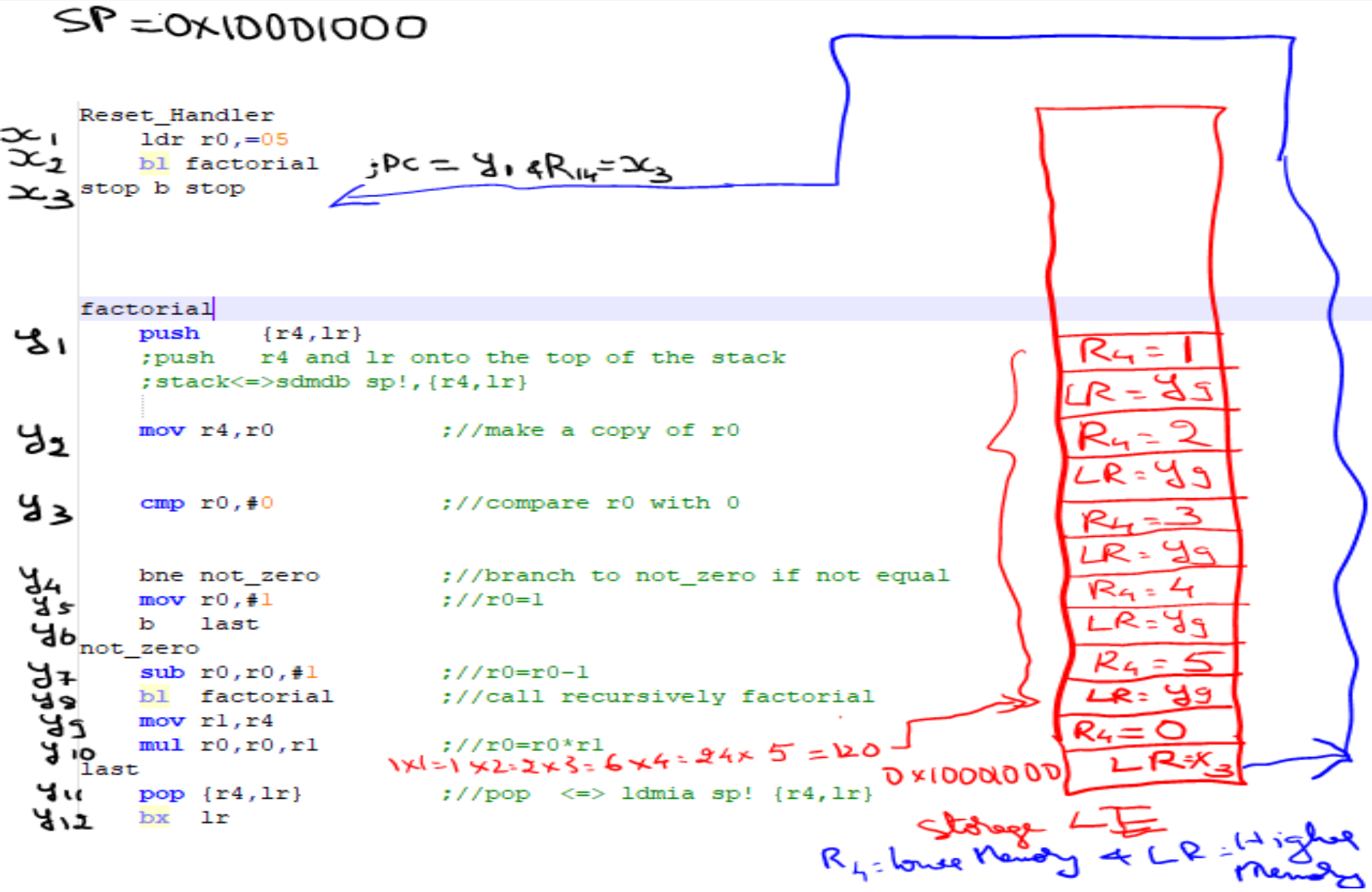
ARM – ASM Programming

Factorial of a Number

Factorial of a Number

- In programming terms, a recursive function can be defined as a routine that calls itself directly or indirectly.
- Types:
  - Function calling itself(Direct way): Here the function calls itself.
  - Recursion using mutual function call(Indirect way): Here, a function [funA()] can call another function [funB()] which in turn calls [funA()] which is the the former function.
- Application: Encryption Algorithms.

Factorial


SP = 0x10001000
Reset_Handler
ldr r0,=05
bl factorial
stop b stop
;PC = y1 & R14 = x3
factorial
push {r4,lr}
;push r4 and lr onto the top of the stack
;stack<=>sdmdb sp!,{r4,lr}
mov r4,r0 ;//make a copy of r0
cmp r0,#0 ;//compare r0 with 0
bne not_zero ;//branch to not_zero if not equal
mov r0,#1 ;//r0=1
b last
not_zero
sub r0,r0,#1 ;//r0=r0-1
bl factorial ;//call recursively factorial
mov r1,r4
mul r0,r0,r1 ;//r0=r0*r1
last
pop {r4,lr} ;//pop <=> ldmia sp! {r4,lr}
bx lr
1x1=1 x2=2x3=6x4=24x5=120
0x10001000
R4=1
LR=y9
R4=2
LR=y9
R4=3
LR=y9
R4=4
LR=y9
R4=5
LR=y9
R4=0
LR=x3
Stack LE
R4: lower Memory & LR: Higher Memory

ARM – ASM Programming

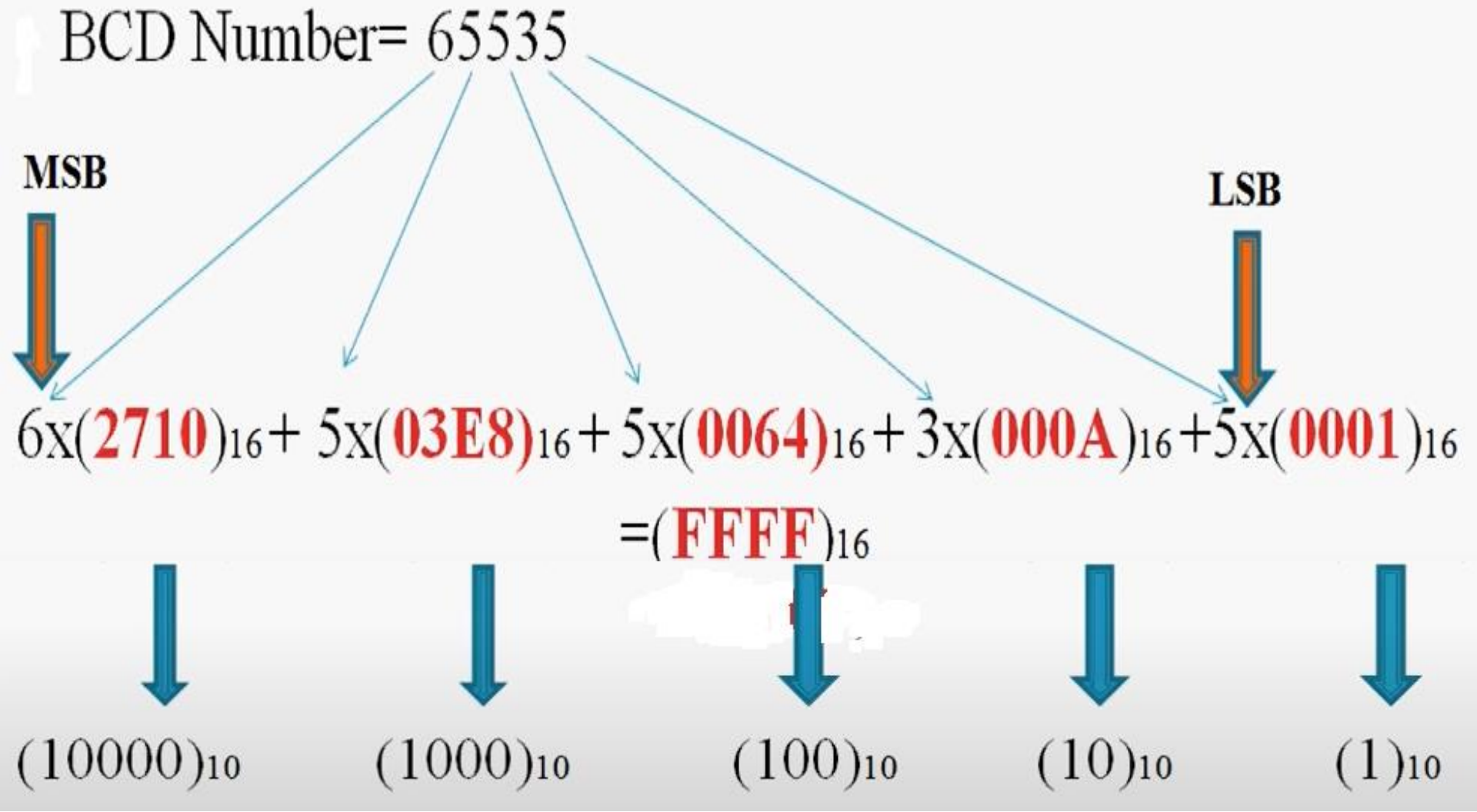
BCD to Hexadecimal Convertion

BCD - Hexadecimal

- In BCD each digit of number is coded separately using fixed number of bits usually 4.
- 29 = 0010 1001

2 9

BCD - Hexadecimal



Note: Here we need to perform positional multiplication.

ARM – ASM Programming

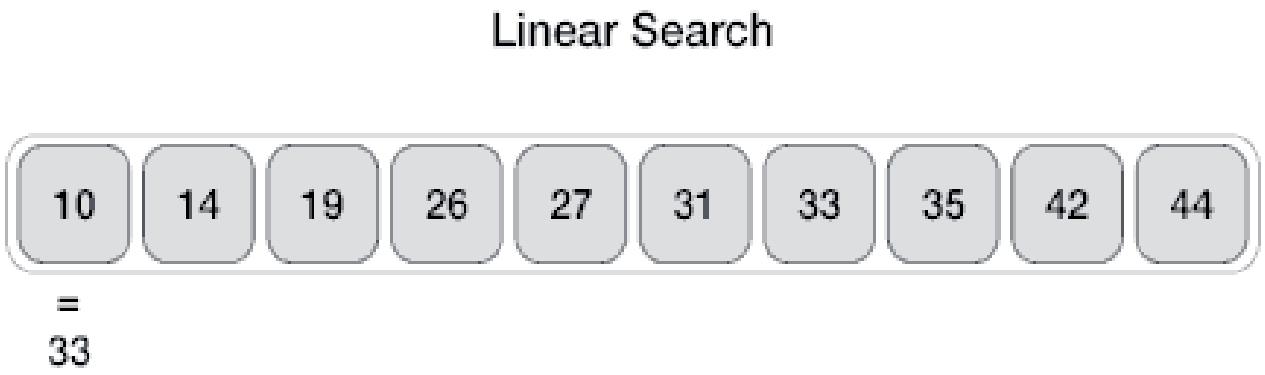
Hex-BCD

ARM – ASM Programming

Linear search

Linear Search

- Here, a sequential search is made over all items one by one.
- Every item is checked and if a match is found then that particular item is store on to the data memory.



ARM LPC1768
External Hardware Interrupt

External HW interrupts

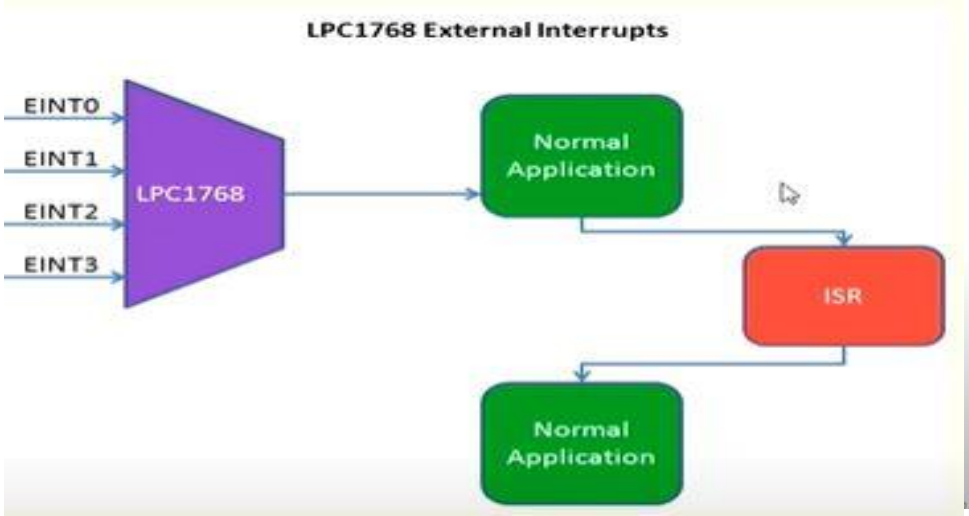
- What are Interrupts?!
- System Control block of Arm has SFR's to handle external hardware interrupts.
- LPC1768 has Four External Hardware Interrupts: EINT0 – EINT3 in general represented as EINTx Pins mapped to multifunctional pins of port 2 as shown

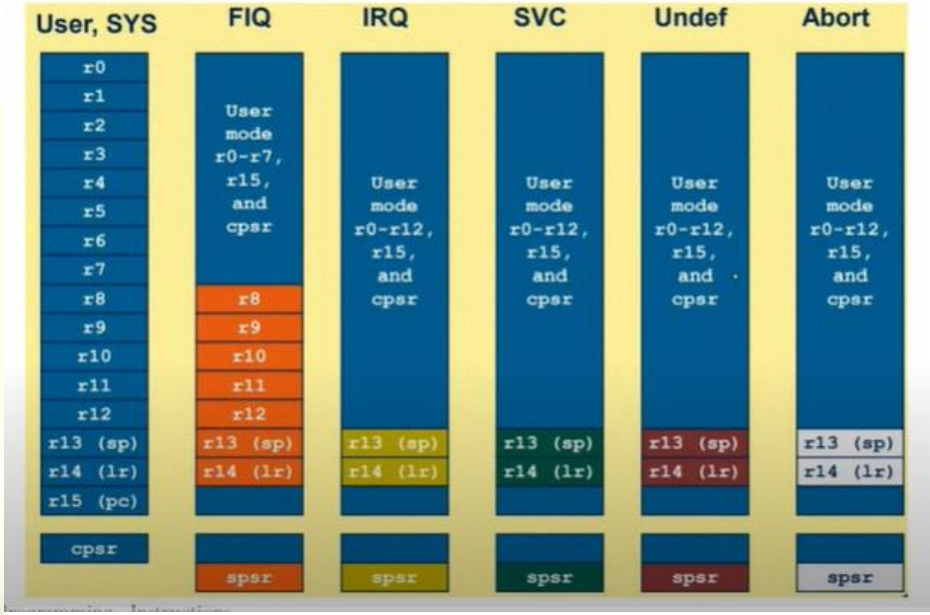
Port Pin	PINSEL_FUNC_0	PINSEL_FUNC_1	PINSEL_FUNC_2	PINSEL_FUNC_3
P2.10	GPIO	EINT0	NMI	
P2.11	GPIO	EINT1	I2STX_CLK	
P2.12	GPIO	EINT2	I2STX_WS	
P2.13	GPIO	EINT3	I2STX_SDA	

External HW interrupts

- **There are two types of interrupt triggers namely:**
  - **Level Triggered:** Level 0 or Level 1
  - **Edge Triggered:** Rising or Falling Edge

- **Operational Logic:**





External HW interrupts

- Since we are accessing system control block for EHI we write **LPC_SC** similar to accessing GPIO as we write **LPC_GPIO** to access SFR's associated with External Hardware Interrupts (EHI).
- Registers associated with EHI are

EINT Registers

Register	Description
PINSELx	To configure the pins as External Interrupts
EXTINT	External Interrupt Flag Register contains interrupt flags for EINT0,EINT1, EINT2 & EINT3.
EXTMODE	External Interrupt Mode register(Level/Edge Triggered)
EXTPOLAR	External Interrupt Polarity(Falling/Rising Edge, Active Low/High)

External HW interrupts Registers

EXTINT				
31:4	3	2	1	0
RESERVED	EINT3	EINT2	EINT1	EINT0

EINTx: Bits will be set whenever the interrupt is detected on the particular interrupt pin. If the interrupts are enabled then the control goes to ISR.

Writing one to specific bit will clear the corresponding interrupt.

EXTMODE				
31:4	3	2	1	0
RESERVED	EXTMODE3	EXTMODE2	EXTMODE1	EXTMODE0

EXTMODEx: These bits are used to select whether the EINTx pin is level or edge Triggered

0: EINTx is Level Triggered.
1: EINTx is Edge Triggered.

External HW interrupts Registers

EXTPOLAR				
31:4	3	2	1	0
RESERVED	EXTPOLAR3	EXTPOLAR2	EXTPOLAR1	EXTPOLAR0

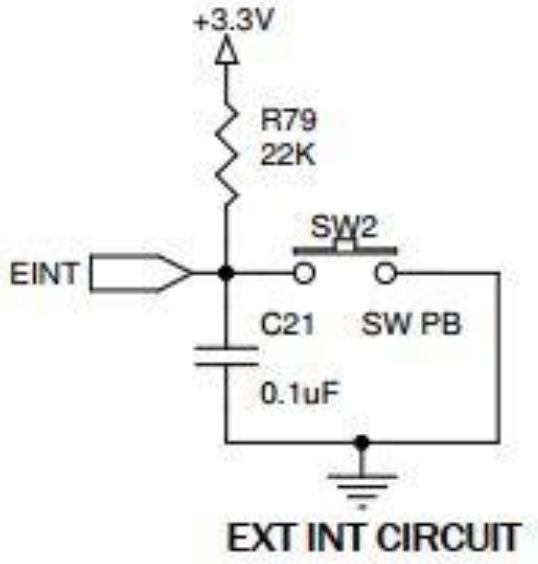
EXTPOLARx: These bits are used to select polarity(LOW/HIGH, FALLING/RISING) of the EINTx interrupt depending on the EXTMODE register.
0: EINTx is Active Low or Falling Edge (depending on EXTMODEx).
1: EINTx is Active High or Rising Edge (depending on EXTMODEx).

EXTMODEx	EXTPOLARx	EINTx
0	0	Level 0
0	1	Level 1
1	0	Falling Edge
1	1	Rising Edge

External HW interrupts

Steps to Configure External Hardware Interrupts:

- Configure the pins as external interrupts in PINSELx register.
- Configure the EINTx as Edge/Level triggered in EXTMODE register.
- Select the polarity(Falling/Rising Edge, Active Low/High) of the interrupt in EXTPOLAR register.
- Enable the interrupts by calling NVIC_EnableIRQ(EINTx_IRQn)
- Clear any pending interrupts in EXTINT on entering ISR.



EXT INT CIRCUIT

External HW interrupts - Programming

Toggle LED connected to P1.23 at each negative edge of the input applied at P2.12 (EINT2, Function-01)

```
include<LPC17xx.h>
 void EINT2_IRQHandler(void);
 int main(void)
 {

        SystemInit();
        SystemCoreClockUpdate();

        LPC_PINCON->PINSEL4 |= (1<<24);          //P2.12 as EINT2 i.e FUNCTION-01
        LPC_GPIO1->FIODIR = 0x00800000;          //P1.23 is assigned output
        LPC_SC->EXTMODE = 0x00000004;            //EINT2 is initiated as edge senitive, 0 for level
        LPC_SC->EXTPOLAR = 0x00000000;           //EINT2 is falling edge sensitive, 1 for rising edge
        NVIC_EnableIRQ(EINT2_IRQn);
        while(1) ;
         }

 void EINT2_IRQHandler(void)
 {
LPC_SC->EXTINT = 0x00000004;    //cleares the interrupt
LPC_GPIO1->FIOPIN = ~ LPC_GPIO1->FIOPIN ;

 }
```

External HW interrupts - Programming

```
#include<LPC17xx.h>
void EINT3_IRQHandler(void);
unsigned char int3_flag=0;
int main(void)
{
   LPC_PINCON->PINSEL4 |= 0x04000000;          //P2.13 as EINT3
   LPC_PINCON->PINSEL4 &= 0xFCFFFFFF;          //P2.12 GPIO for LED
   LPC_GPIO2->FIODIR = 0x00001000;             //P2.12 is assigned output
   LPC_GPIO2->FIOSET = 0x00001000;             //Initially LED is kept on
   LPC_SC->EXTINT = 0x00000008;          //writing 1 clears the interrupt, get set if there is interrupt
   LPC_SC->EXTMODE = 0x00000008;        //EINT3 is initiated as edge sensitive, 0 for level sensitive
   LPC_SC->EXTPOLAR = 0x00000000;       //EINT3 is falling edge sensitive, 1 for rising edge
   NVIC_EnableIRQ(EINT3_IRQn);                                  //core_cm3.h
    while(1);
}
```

PINSEL4 – bit 26 and 27 – P2.13- EINT3 is the first alternate function – value is 01
PINSEL4- Value 0xFCFFFFFF –
C- 1100 making P2.12 as GPIO – bit 25 and 24 with 00, while not altering 26 and 27

Switch pressed

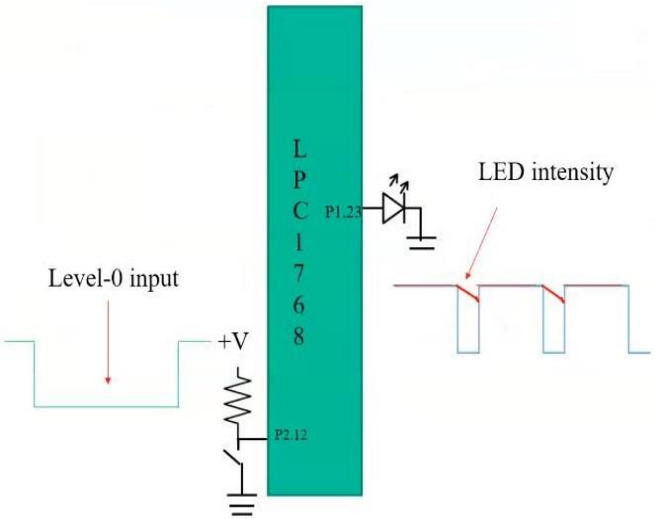
External HW interrupts - Programming

```
void EINT3_IRQHandler(void)
{  LPC_SC->EXTINT = 0x00000008;                    //cleares the interrupt
   if(int3_flag == 0x00)                          //when flag is '0' off the LED
         {
               LPC_GPIO2->FIOCLR = 0x00001000;
               int3_flag = 0xff;
         }
         else
                                                        //when flag is FF on the LED
         {
               LPC_GPIO2->FIOSET = 0x00001000;
               int3_flag = 0;
         }
}
```

External HW interrupts - Programming

Toggle LED connected to P1.23 whenever the switch connected to P2.12 (EINT2, Function-01) is pressed LED remains ON as long as the switch is pressed (Assume, when the switch is pressed Logic-0 is INPUT.

```
#include<LPC17xx.h>
 void EINT2_IRQHandler(void);
 int main(void)
 {
        LPC_PINCON->PINSEL4 |= (1<<24);          //P2.12 as EINT2 i.e FUNCTION-01
        LPC_GPIO1->FIODIR = 0x00800000;          //P1.23 is assigned output
        LPC_SC->EXTMODE = 0x00000000;            //EINT2 i as level-0 sensitive
        LPC_SC->EXTPOLAR = 0x00000000;
        NVIC_EnableIRQ(EINT2_IRQn);
        while(1) ;

 }
 void EINT2_IRQHandler(void)
 {
        LPC_SC->EXTINT = 0x00000004;    //clear the interrupt
        LPC_GPIO1->FIOSET = 1<<23; //LED ON
        for (i=0;i<255;i++);
        LPC_GPIO1->FIOCLR = 1<<23; LED OFF

 }
```



External HW interrupts - Programming

Program to Stop Displaying Hex digits on seven segment Display on Button Pressed

Reference: https://www.youtube.com/watch?v=FuAyGjmTNdc&ab_channel=AnandHD

ARM LPC1768
IO Interrupt

GPIO Interrupts

- The **GPIO interrupt** is only available to **PORT 0 & PORT 2** of LPC1768 Microcontroller.
- The GPIO interrupts are edge triggered.

Falling Edge Interrupt

- **Register LPC_GPIOINT –> IOxIntEnF**

is used to enable falling edge detected interrupt, in which 'x' is the group number, either 0 or 2. To turn on falling edge interrupt of pin, set the corresponding pin to '1'.

- Example:
  - To enable Pin 0.3 falling edge interrupt
  - LPC_GPIOINT –> IO0IntEnF |= (1<<3);

Rising Edge Interrupt

- **Register LPC_GPIOINT –> IOxIntEnR**

is used to enable rising edge detected interrupt. In which 'x' is the group number to turn on rising edge interrupt of a pins set the corresponding pin to '1'.

- Example:

  To enable Pin 0.3 and 0.5 rising edge interrupt

  LPC_GPIOINT –> IO0IntEnR |= ((1<<3) | (1<<5));

All **GPIO interrupt are connected to EINT3 interrupt source**.
You need to turn EINT3_IRQn ON in order to use GPIO interrupt. NVIC_EnableIRQ(EINT3_IRQn);

GPIO Interrupt Register Map (SFR's)

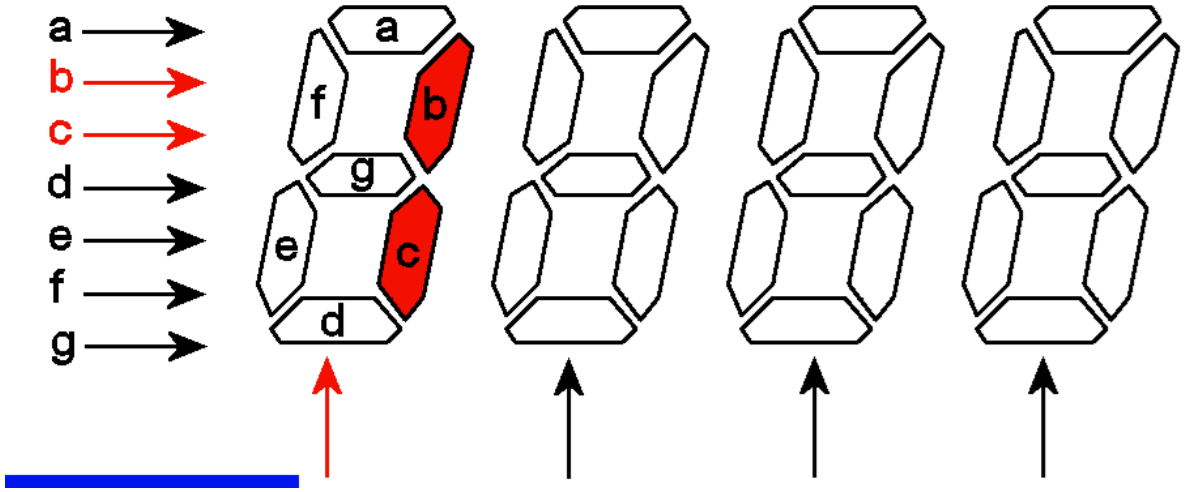
- IntStatus ➔ GPIO overall Interrupt status.
- IntEnR ➔ GPIO Interrupt Enable for Rising Edge.
- IntEnF ➔ GPIO interrupt enable for falling edge.
- IntStatR ➔ GPIO interrupt status for rising edge.
- IntStatF ➔ GPIO interrupt status for falling edge.
- IntClr ➔ GPIO Interrupt Clear.

- **Note:** GPIO Interrupts are applicable only on Input port and on output port.

GPIO Interrupt Programming

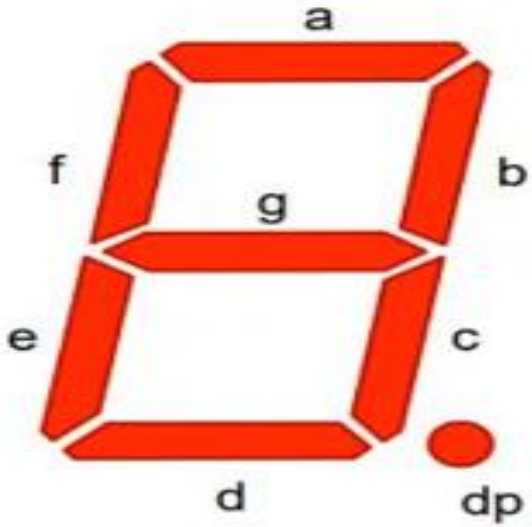
GPIO Interrupt Programming

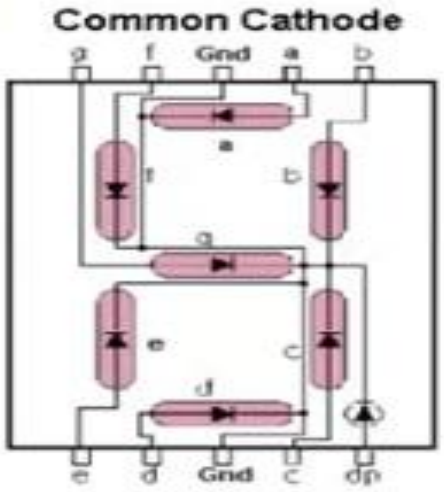
ARM LPC1768 – Seven Segment Display Interfacing

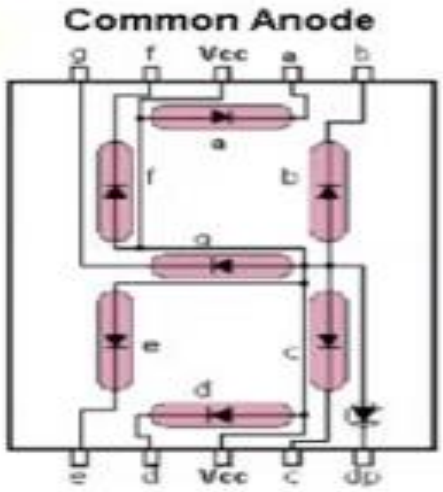


Seven Segment Display

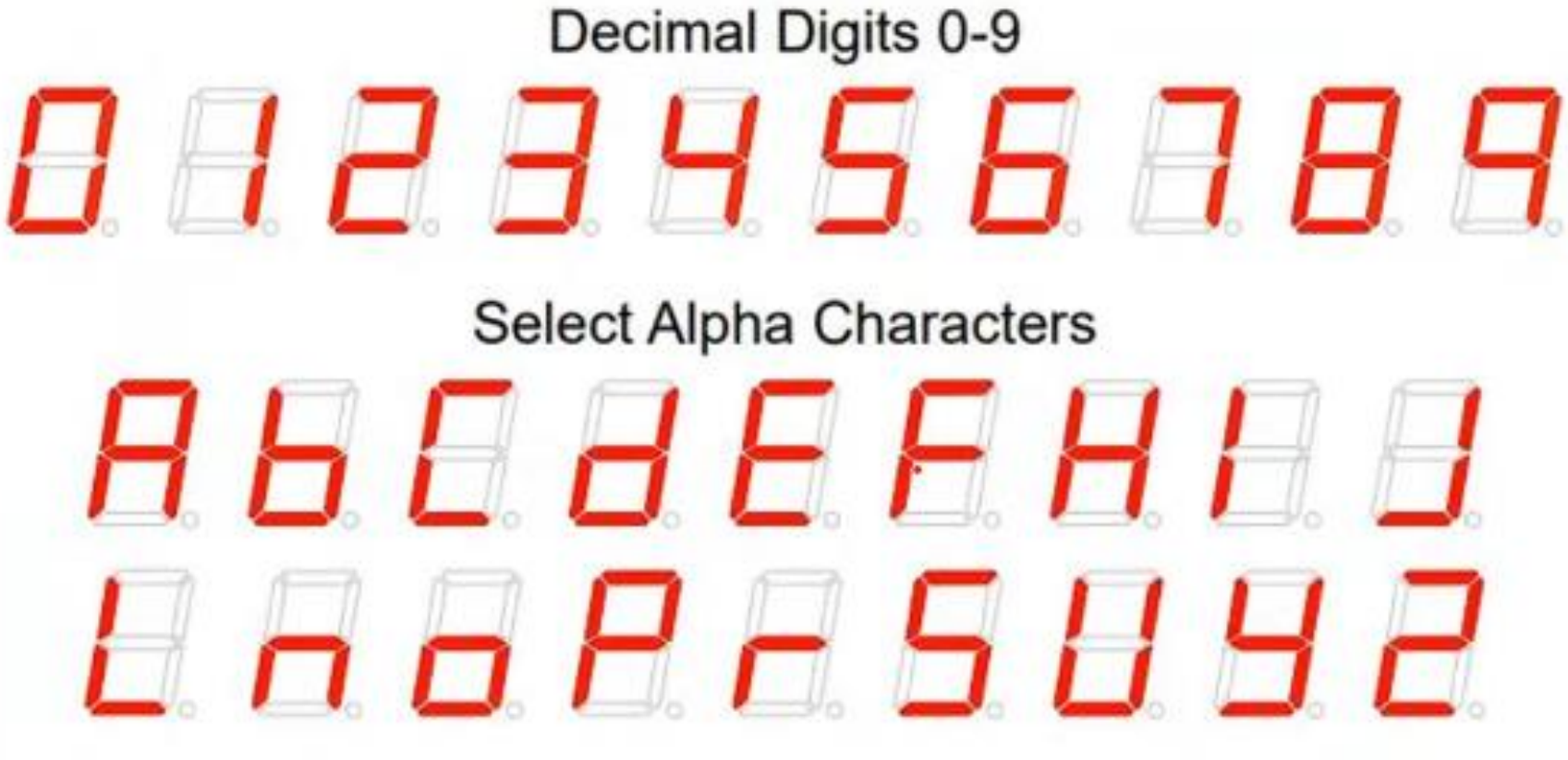
- Common Cathode (all LED cathodes are connected)
- Common Anode (all LED anodes are connected)







Seven Segment Display



Seven Segment Display

Here,
CNA
P0.11 – P0.4

FRC Cable
----→

'7' Segment
h ------- a

Seven Segment Display

Number	h g f e d c b a	Hex Code
0	0 0111111	3F
1	0 0000110	06
2	1011011	5B
3	1001111	4F
4	1100110	66
5	1101101	6D
6	1111101	7D
7	0000111	07
8	1111111	7F
9	1001111	4F

Pin CNA	PIN LPC1768	Description
1	81	P0.4/I2SRX_CLK/RD2/CAP2.0
2	80	P0.5/I2SRX_WS/TD2/CAP2.1
3	79	P0.6/I2SRX_SDA/SSEL1/MAT2.0
4	78	P0.7/I2STX_CLK/SCK1//MAT2.1
5	77	P0.8/I2STX_WS/MISO1/MAT2.2
6	76	P0.9/I2STX_SDA/MOSI1/MAT2.3
7	48	P0.10/TXD2/SDA2/MAT3.0
8	49	P0.11/RXD2/SCL2/MAT3.1
9	-	No connection
10	-	Ground

Pin CNB	Pin LPC1768	Description
1	37	P1.23/MCI1/PWM1.4/MISO0
2	38	P1.24/MCI2/PWM1.5/MOSI0
3	39	P1.25/MCOA1/MAT1.1
4	40	P1.26/MCOB1/PWM1.6/CAP0.0
5	53	P2.10/EINT0/NMI
6	52	P2.11/EINT1/I2STX_CLK
7	51	P2.12/EINT2/I2STX_WS
8	50	P2.13/EINT3/I2STX_SDA
9	-	No connection
10	-	Ground

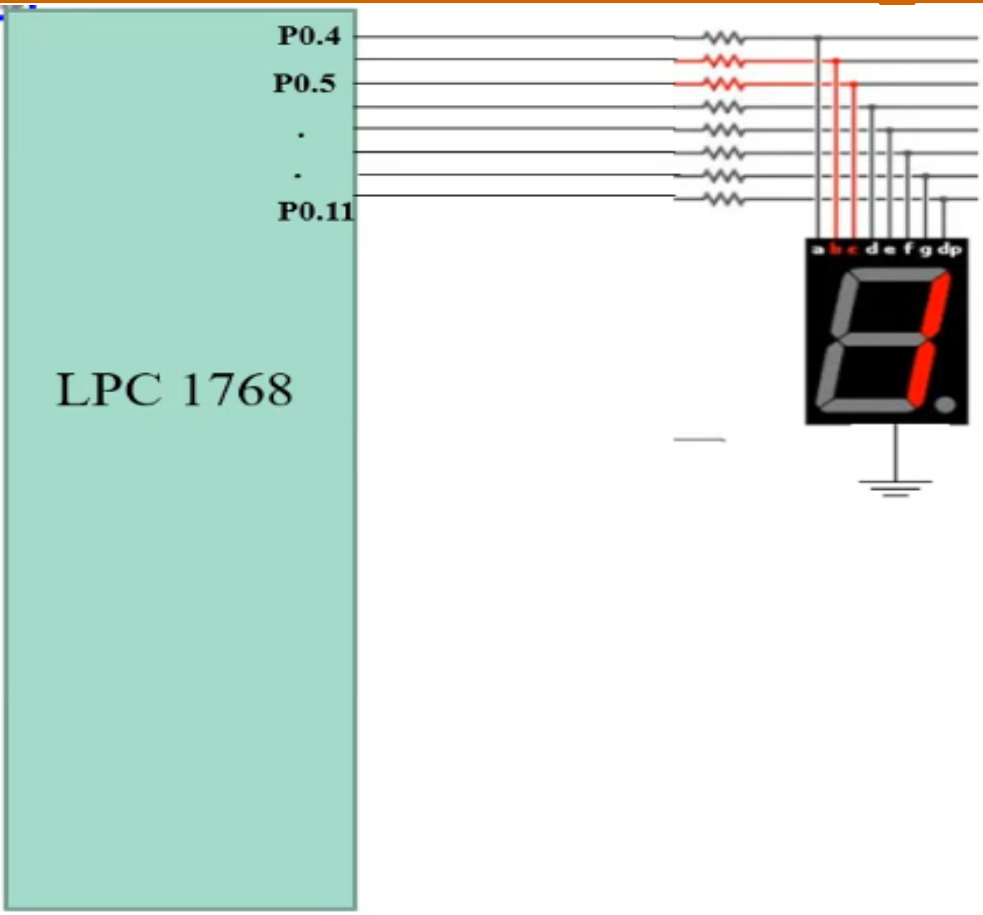
Pin CNC	Pin LPC1768	Description
1	62	P0.15/TXD1/SCK0/SCK
2	63	P0.16/RXD1/SSEL0/SSEL
3	61	P0.17/CTS1/MISO0/MISO
4	60	P0.18/DCD1/MOSI0/MOSI
5	59	P0.19/DSR1/SDA1
6	58	P0.20/DTR1/SCL1
7	57	P0.21/RI1/RD1
8	56	P0.22/RTS1/TD1
9	50	P2.13/I2STX_SDA
10	-	Ground

Pin CND	Pin LPC1768	Description
1	9	P0.23/AD0.0/I2SRX_CLK/CAP3.0
2	8	P0.24/AD0.1/I2SRX_WS/CAP3.1
3	7	P0.25/AD0.2/I2SRX_SDA/TXD3
4	6	P0.26/AD0.3/AOUT/RXD3
5	25	P0.27/SDA0/USB/SDA
6	24	P0.28/SCL0/USB_SCL
7	75	P2.0/PWM1.1/TXD1
8	74	P2.1/PWM1.2/RXD1
9	-	No connection
10	-	Ground

Assumption:

1. Common Cathode.
2. ‘h’ is MS bit (P0.11) & ‘a’ is LS bit (P0.4)

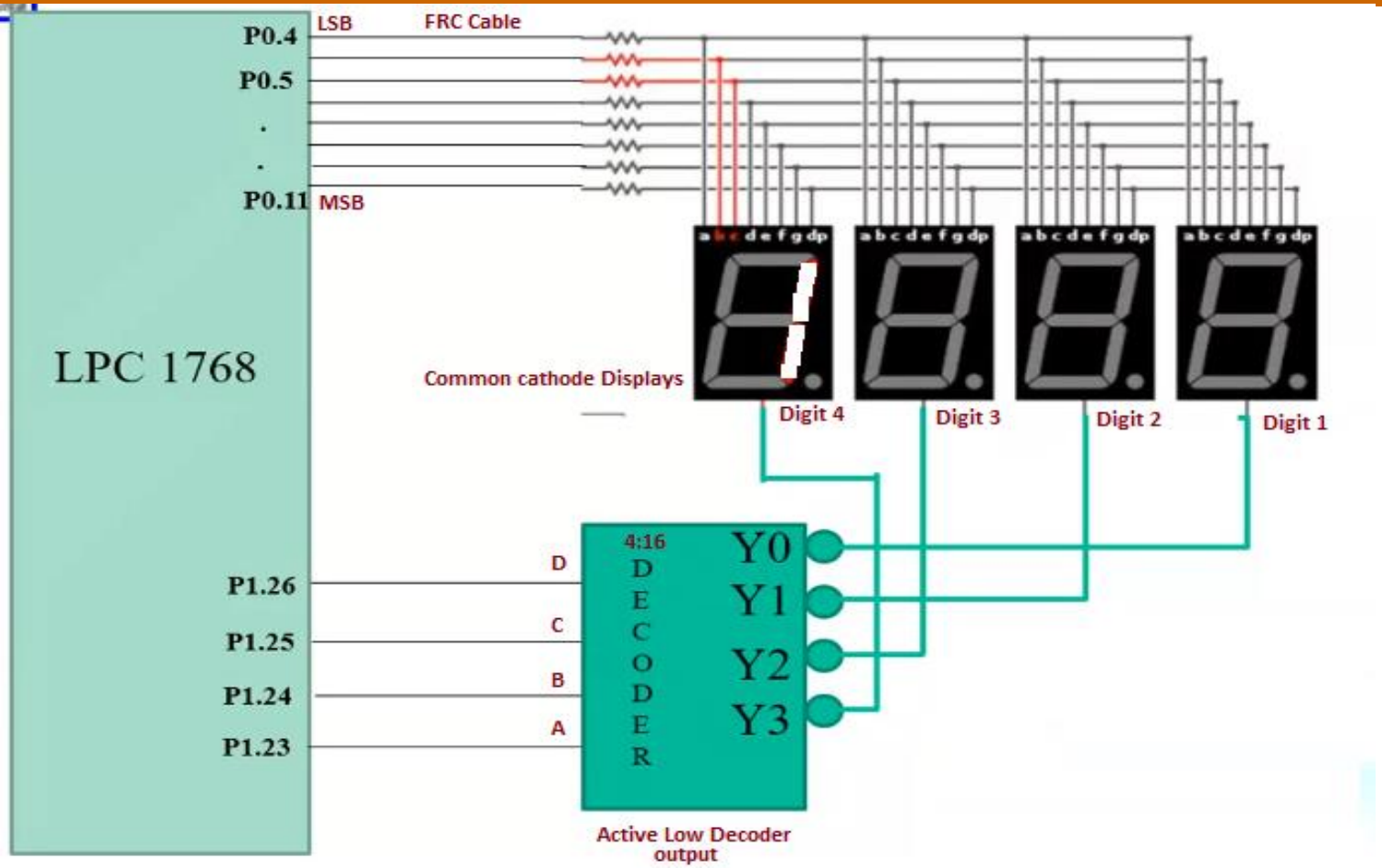
Seven Segment Display Interfacing

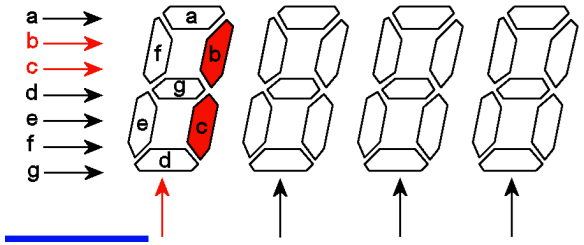


Seven Segment Display Programming

```
#include<lpc17xx.h>
unsigned char seven_seg[10]={0x3F,0x06,0x5B,0x4F,0x66,0x6D,0x7D,0x07,0x7F,0x6F};
unsigned int i,j;
void delay(void);
int main(void)
 {
        SystemInit();
        SystemCoreClockUpdate();

        LPC_PINCON->PINSEL0 = 0     //P0.4 to P0.11 GPIO data lines
        LPC_GPIO0->FIODIR |= 0x00000FF0;       //P0.4 to P0.11 output
        while (1)
          {
            for(i=0; i<10; i++)
              {
               LPC_GPIO0->FIOPIN = seven_seg[i ] << 4;
               delay();
              }
          }
    }
void  delay(void)
{
 for(j=0;j<10000;j++);
}
```

Multiplexed Seven Segment Display





Multiplexed Seven Segment Display Programming – Display a Number

```
#include <LPC17xx.h>
#include <stdio.h>

#define   FIRST_SEG         0<<23
#define   SECOND_SEG        1<<23
#define   THIRD_SEG         2<<23
#define   FOURTH_SEG        3<<23


 unsigned int dig_count;
 unsigned int digit_value = {0, 4, 3, 2, 1}
 unsigned int select_segment = {0, 0 << 23, 1<<23. 2<<23. 3<<23};
 unsigned char seven_seg[10]={0x3F,0x06,0x5B,0x4F,0x66,0x6D,0x7D,0x07,0x7F,0x6F};
 unsigned long int temp1,temp2 ,i=0;

void Display(void);
void delay(void);
int main(void)
{
        SystemInit();
        SystemCoreClockUpdate();

        LPC_PINCON->PINSEL0 = 0;    //P0.4 to P0.11 GPIO data lines
        LPC_PINCON->PINSEL3 = 0;    //P1.23 to P1.26 GPIO enable lines

        LPC_GPIO0->FIODIR = 0x00000FF0;       //P0.4 to P0.11 output
        LPC_GPIO1->FIODIR = 0x07800000;       //P1.23 to P1.26 output
```

Multiplexed Seven Segment Display Programming – Display a Number

```
        while(1)
        {
                delay();

                dig_count +=1;
                if(dig_count == 0x05)
                        dig_count = 0x01;

                Display();

        } //end of while(1)

}//end of main


 void Display(void)     //To Display on 7-segments
{

        LPC_GPIO1->FIOPIN = select_segment[dig_count];
        LPC_GPIO0->FIOPIN = seven_seg[digit_value[dig_count]] << 4;
        for(i=0;i<500;i++);
        LPC_GPIO0->FIOCLR = 0x00000FF0;
}
void delay(void)
{
for i=0;i<500;i++);
}
```

```
while(1)
{
        delay();

        dig_count +=1;
        if(dig_count == 0x05)
                dig_count = 0x01;

        Display();

} //end of while(1)

}//end of main


 void Display(void)     //To Display on 7-segments
{

        LPC_GPIO1->FIOPIN = select_segment[dig_count];
        LPC_GPIO0->FIOPIN = seven_seg[digit_value[dig_count]] << 4;
        for(i=0;i<500;i++);
        LPC_GPIO0->FIOCLR = 0x00000FF0;
}
void delay(void)
{
for i=0;i<500;i++);
```

For every second update the digits

After one second, set Flag

```
void delay(void)
{
for i=0;i<500;i++);

if(count ==N)
        {
                flag = 0xFF;
                count = 0;
        }
        else count += 1;
}
```

After one second, set Flag

```
if(flag == 0xFF)
        {
                flag = 0;
                digit_value[1] +=1;

                if(digit_value[1] == 0x0A)
                {
                        digit_value[1] = 0;
                        digit_value[2] +=1;

                        if(digit_value[2] == 0x0A)
                        {
                                digit_value[2]= 0;
                                digit_value[3] +=1;

                                if(digit_value[3] == 0x0A)
                                {
                                        digit_value[3] = 0;
                                        digit_value[4] += 1;

                                        if(digit_value[4]== 0x0A)
                                        {
                                                digit_value[4]= 0;
                                        } //end of dig4

                                } //end of dig3

                        } //end of dig2

                } //end of dig1

        } //end of one_sec if
```

For every second update the digits

PINSELECT Registers

PIN CONNECT BLOCK

Register	Controls
PINSEL0	P0[15:0]
PINSEL1	P0 [31:16]
PINSEL2	P1 [15:0] (Ethernet)
PINSEL3	P1 [31:16]
PINSEL4	P2 [15:0]
PINSEL5	P2 [31:16]
PINSEL6	P3 [15:0]
PINSEL7	P3 [31:16]
PINSEL8	P4 [15:0]
PINSEL9	P4 [31:16]

PINSEL0 to PINSEL9 Values	Function
00	Primary (default) function, typically GPIO port
01	First alternate function
10	Second alternate function
11	Third alternate function

GPIO Registers

FIODIR	Fast GPIO Port Direction control register. This register individually controls the direction of each port pin.
FIOPIN	Fast Port Pin value register using FIOMASK. The current state of digital port pins can be read from this register, regardless of pin direction or alternate function selection (as long as pins are not configured as an input to ADC). The value read is masked by ANDing with inverted FIOMASK. Writing to this register places corresponding values in all bits enabled by zeros in FIOMASK. **Important:** if an FIOPIN register is read, its bit(s) masked with 1 in the FIOMASK register will be read as 0 regardless of the physical pin state.
FIOSET	Fast Port Output Set register using FIOMASK. This register controls the state of output pins. Writing 1s produces highs at the corresponding port pins. Writing 0s has no effect. Reading this register returns the current contents of the port output register. Only bits enabled by 0 in FIOMASK can be altered.
FIOCLR	Fast Port Output Clear register using FIOMASK. This register controls the state of output pins. Writing 1s produces lows at the corresponding port pins. Writing 0s has no effect. Only bits enabled by 0 in FIOMASK can be altered.
FIOMASK	Fast Mask register for port. Writes, sets, clears, and reads to port (done via writes to FIOPIN, FIOSET, and FIOCLR, and reads of FIOPIN) alter or return only the bits enabled by zeros in this register.

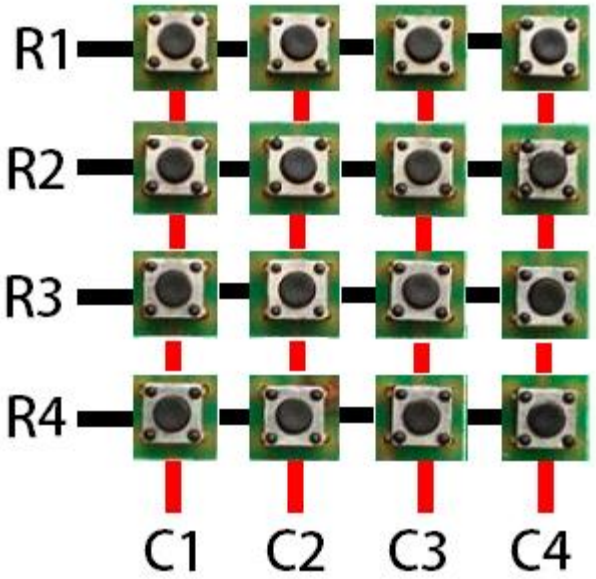
0	Controlled pin is input.
1	Controlled pin is output.

0	Controlled pin output is unchanged.
1	Controlled pin output is set to HIGH.

0	Controlled pin output is unchanged.
1	Controlled pin output is set to LOW.

0	Controlled pin is affected by writes to the port's FIOxSET, FIOxCLR, and FIOxPIN register(s). Current state of the pin can be read from the FIOxPIN register.
1	Controlled pin is not affected by writes into the port's FIOxSET, FIOxCLR and FIOxPIN register(s). When the FIOxPIN register is read, this bit will not be updated with the state of the physical pin.

ARM LPC1768 – Hex keypad Interfacing

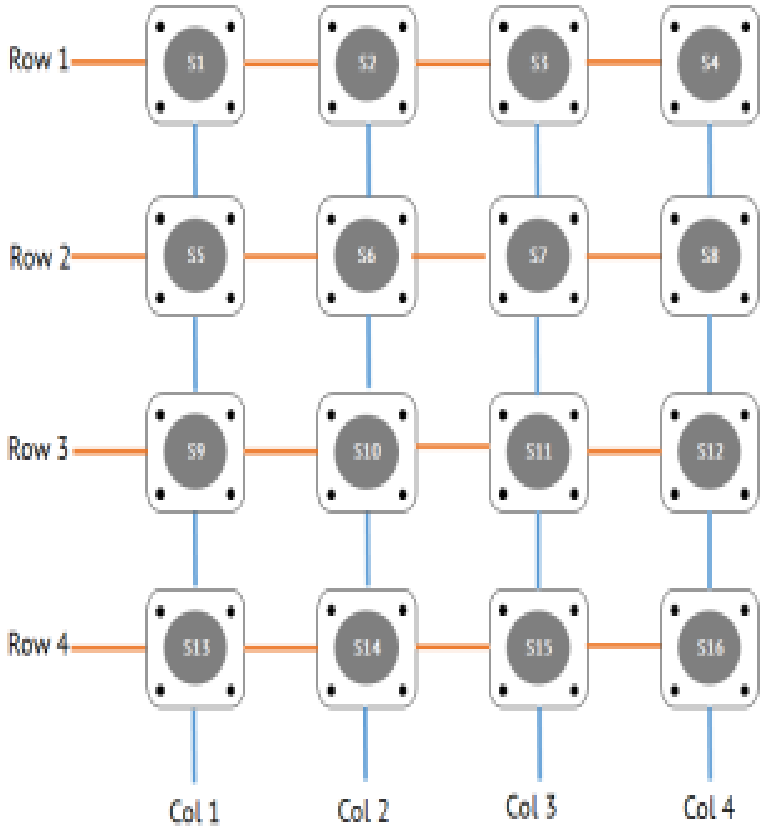


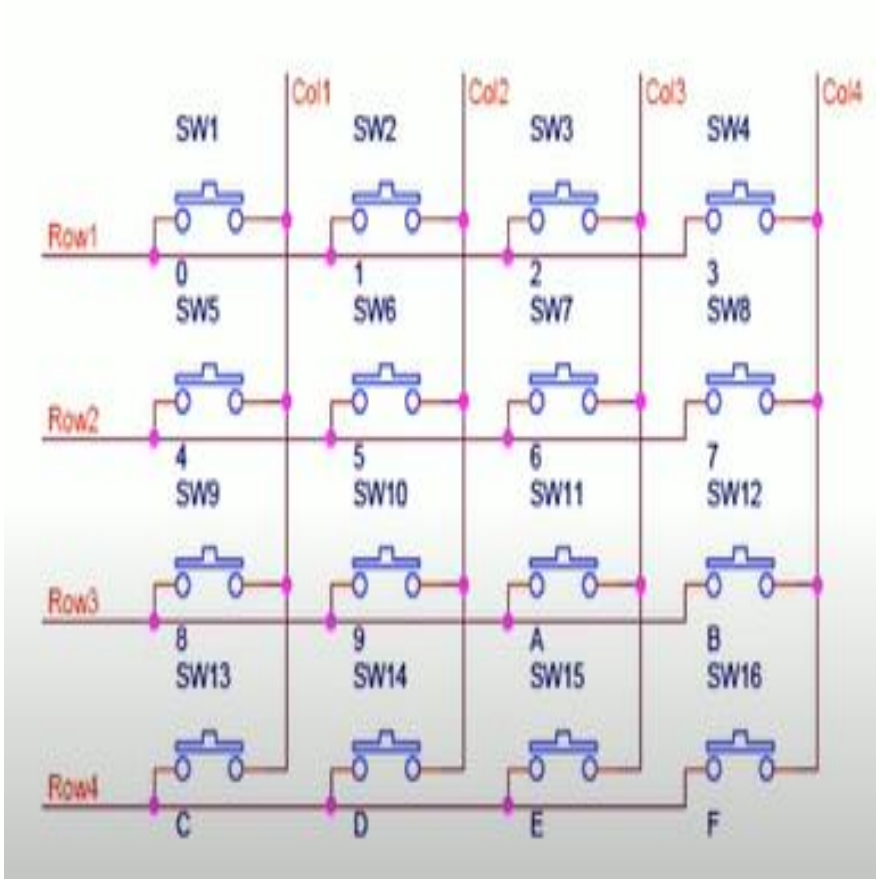
Hex keypad

- Used to
  - Give multiple Inputs
  - Each input can have particular significance
- Easy to Interface
- Easy to procure

Hex keypad Introduction

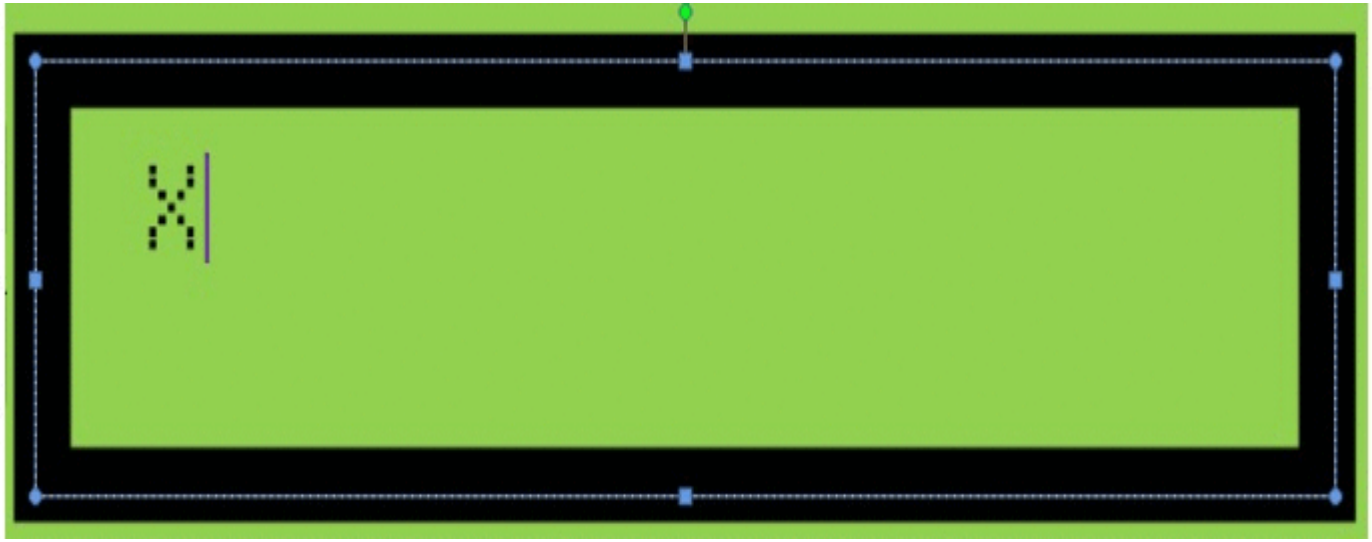
Hex keypad


Row 1
Row 2
Row 3
Row 4
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
S13
S14
S15
S16
Col 1
Col 2
Col 3
Col 4


Col1
Col2
Col3
Col4
SW1
SW2
SW3
SW4
Row1
0
SW5
1
SW6
2
SW7
3
SW8
Row2
4
SW9
5
SW10
6
SW11
7
SW12
Row3
8
SW13
9
SW14
A
SW15
B
SW16
Row4
C
D
E
F

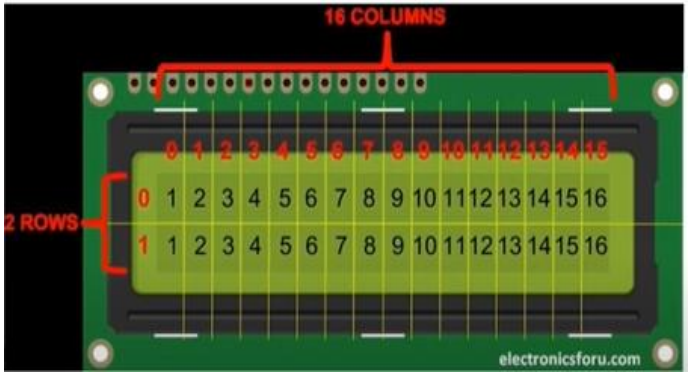
Hex keypad Programming

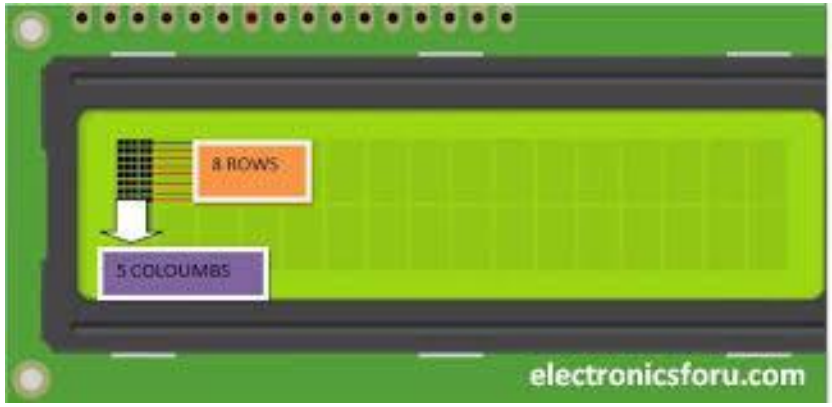
ARM LPC1768 – LCD Display Interfacing

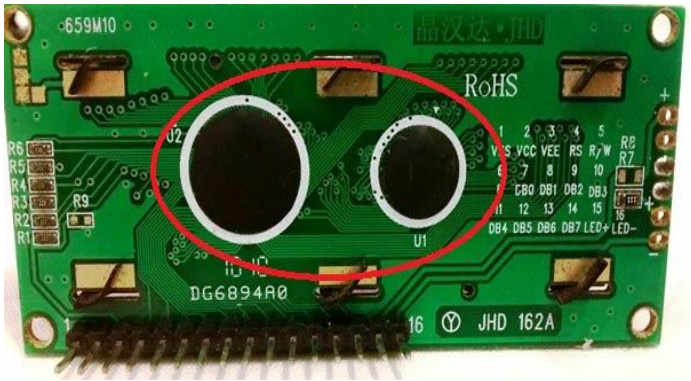


LCD 16 x 2 Features

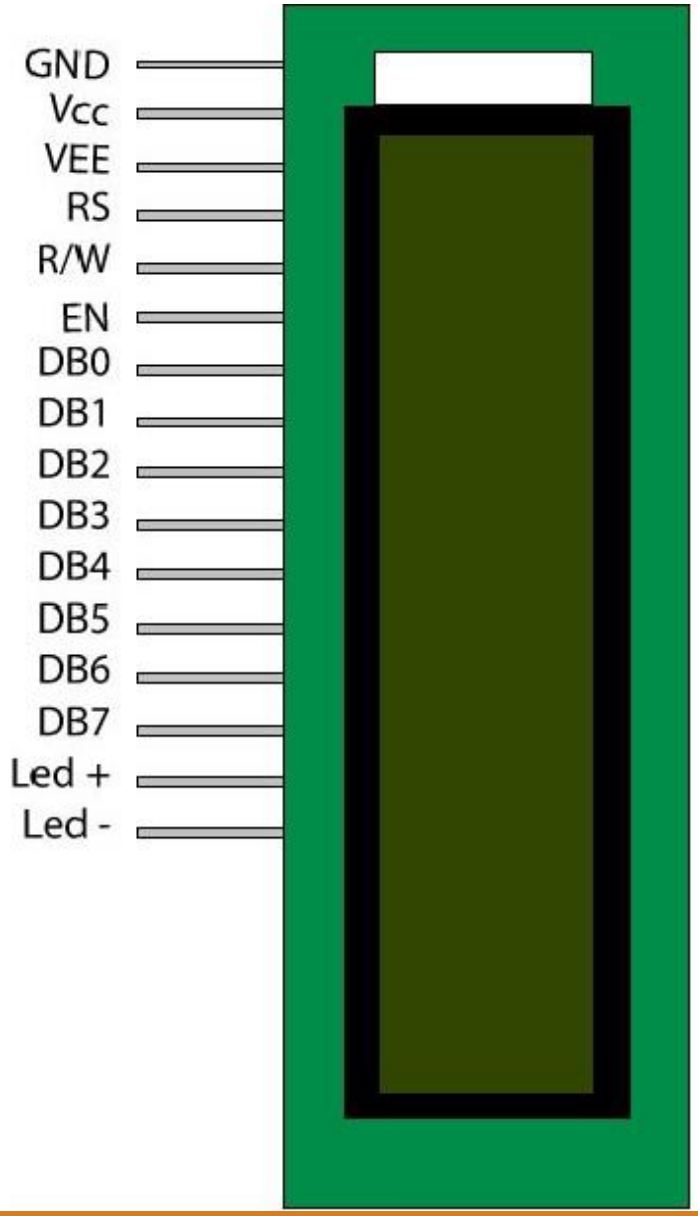
- The operating voltage of this LCD is 4.7V-5.3V.
- It includes two rows where each row can produce 16-characters.
- The utilization of current is 1mA with no backlight.
- Every character can be built with a 5×8 pixel box.
- The alphanumeric LCDs alphabets & numbers.
- Is display can work on two modes like 4-bit & 8-bit.
- These are obtainable in Blue & Green Backlight.
- It displays a few custom generated characters.







LCD Pinouts



Pin No.	Symbol	Function
1	Vss	Ground
2	Vdd	+5V
3	Vo	LCD contrast adjust
4	RS	Register select
5	R/W	Read / write
6	E	Enable
7	DB0	Data bit 0
8	DB1	Data bit 1
9	DB2	Data bit 2
10	DB3	Data bit 3
11	DB4	Data bit 4
12	DB5	Data bit 5
13	DB6	Data bit 6
14	DB7	Data bit 7
+	BL+	Power Supply for BL+
-	BL-	Power Supply for BL-

LCD Pinouts

- RS – Register Select

  RS=0 - Command Register

  RS=1 - Data Register

- RW- Read/Write

  RW=0 - Write

- EN- Enable the LCD

  EN=1 for Enable

LCD Commands

- For Hex Code-01, the LCD command will be Clearing the Display Screen
- For Hex Code-02, the LCD command will be returning home
- For Hex Code-04, the LCD command will be decrement cursor
- For Hex Code-06, the LCD command will be Increment cursor
- For Hex Code-05, the LCD command will be Shift display right
- For Hex Code-07, the LCD command will be Shift display left
- For Hex Code-08, the LCD command will be Display off, cursor off
- For Hex Code-0A, the LCD command will be cursor on and display off
- For Hex Code-0C, the LCD command will be cursor off, display on
- For Hex Code-0E, the LCD command will be cursor blinking, Display on
- For Hex Code-0F, the LCD command will be cursor blinking, Display on
- For Hex Code-10, the LCD command will be Shift cursor position to left
- For Hex Code-14, the LCD command will be Shift cursor position to the right
- For Hex Code-18, the LCD command will be Shift the entire display to the left
- For Hex Code-1C, the LCD command will be Shift the entire display to the right
- For Hex Code-80, the LCD command will be Force cursor to the beginning (1st line)
- For Hex Code-C0, the LCD command will be Force cursor to the beginning (2nd line)
- For Hex Code-38, the LCD command will be 2 lines and 5×7 matrix

LCD Commands

Instruction	Code RS	R/$\overline{W}$	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0	Description	Execution Time (max) (when f_{cp} or f_{osc} is 270 kHz)
Clear display	0	0	0	0	0	0	0	0	0	1	Clears entire display and sets DDRAM address 0 in address counter.	
Return home	0	0	0	0	0	0	0	0	1	—	Sets DDRAM address 0 in address counter. Also returns display from being shifted to original position. DDRAM contents remain unchanged.	1.52 ms
Entry mode set	0	0	0	0	0	0	0	1	I/D	S	Sets cursor move direction and specifies display shift. These operations are performed during data write and read.	37 µs
Display on/off control	0	0	0	0	0	0	1	D	C	B	Sets entire display (D) on/off, cursor on/off (C), and blinking of cursor position character (B).	37 µs
Cursor or display shift	0	0	0	0	0	1	S/C	R/L	—	—	Moves cursor and shifts display without changing DDRAM contents.	37 µs
Function set	0	0	0	0	1	DL	N	F	—	—	Sets interface data length (DL), number of display lines (N), and character font (F).	37 µs
Set CGRAM address	0	0	0	1	ACG	ACG	ACG	ACG	ACG	ACG	Sets CGRAM address. CGRAM data is sent and received after this setting.	37 µs
Set DDRAM address	0	0	1	ADD	ADD	ADD	ADD	ADD	ADD	ADD	Sets DDRAM address. DDRAM data is sent and received after this setting.	37 µs
Read busy flag & address	0	1	BF	AC	AC	AC	AC	AC	AC	AC	Reads busy flag (BF) indicating internal operation is being performed and reads address counter contents.	0 µs

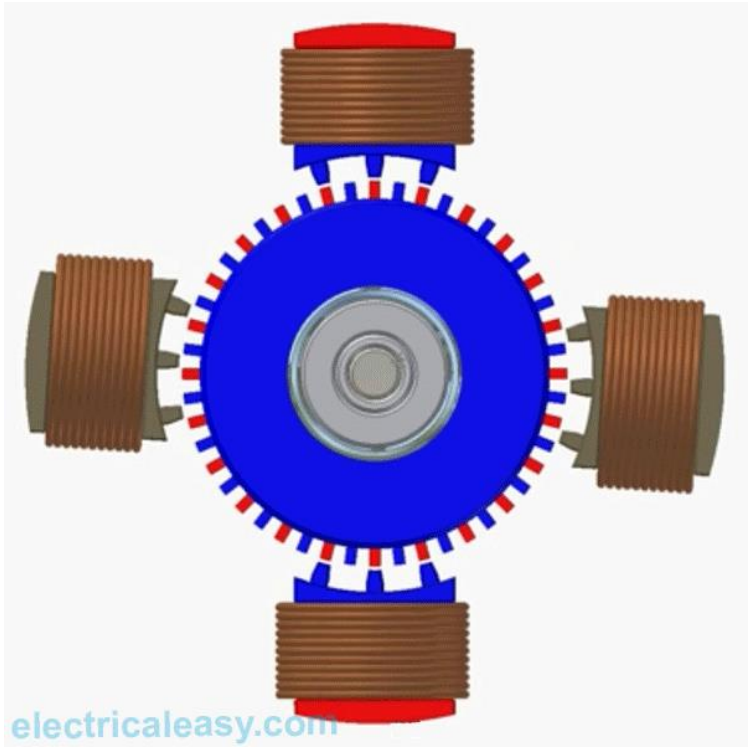
LCD Commands

Instruction	Code RS	R/$\overline{W}$	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0	Description	Execution Time (max) (when f_{cp} or f_{OSC} is 270 kHz)
Write data to CG or DDRAM	1	0	Write data								Writes data into DDRAM or CGRAM.	37 µs t_{ADD} = 4 µs*
Read data from CG or DDRAM	1	1	Read data								Reads data from DDRAM or CGRAM.	37 µs t_{ADD} = 4 µs*
	I/D = 1: Increment I/D = 0: Decrement S = 1: Accompanies display shift S/C = 1: Display shift S/C = 0: Cursor move R/L = 1: Shift to the right R/L = 0: Shift to the left DL = 1: 8 bits, DL = 0: 4 bits N = 1: 2 lines, N = 0: 1 line F = 1: 5 × 10 dots, F = 0: 5 × 8 dots BF = 1: Internally operating BF = 0: Instructions acceptable										DDRAM: Display data RAM CGRAM: Character generator RAM ACG: CGRAM address ADD: DDRAM address (corresponds to cursor address) AC: Address counter used for both DD and CGRAM addresses	Execution time changes when frequency changes Example: When f_{cp} or f_{osc} is 250 kHz, $37\ \mu s \times \frac{270}{250} = 40\ \mu s$

Note: — indicates no effect.

* After execution of the CGRAM/DDRAM data write or read instruction, the RAM address counter is incremented or decremented by 1. The RAM address counter is updated after the busy flag turns off. In Figure 10, t_{ADD} is the time elapsed after the busy flag turns off until the address counter is updated.

ARM LPC1768 – Stepper Motor Interfacing

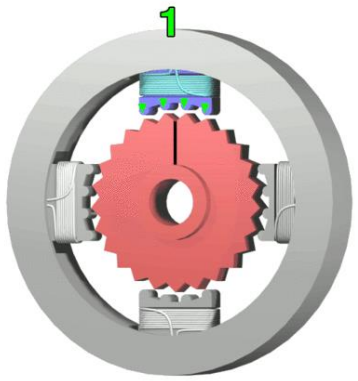


Stepper Motor Introduction

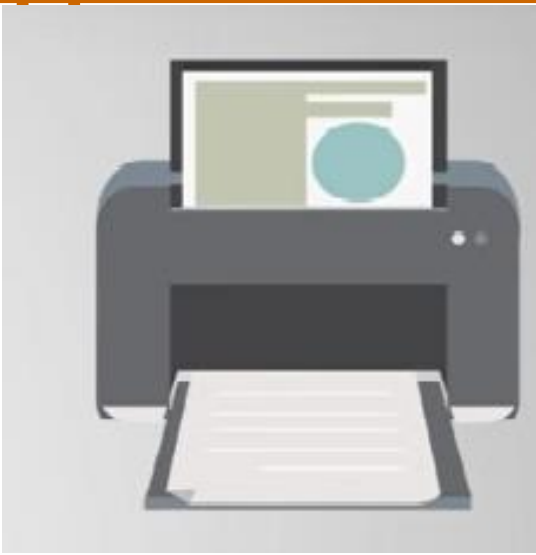
- A stepper motor (also referred to as step or stepping motor) is an electromechanical device achieving mechanical movements through conversion of electrical pulses.

- Typically, all winding in the motor are part of the stator, and the rotor is either a permanent magnet or, in the case of variable reluctance motors, a toothed block of some magnetically soft material.

- All of the commutation must be handled externally by the motor controller, and typically, the motors and controllers are designed so that the motor may be held in any fixed position as well as being rotated one way or the other.

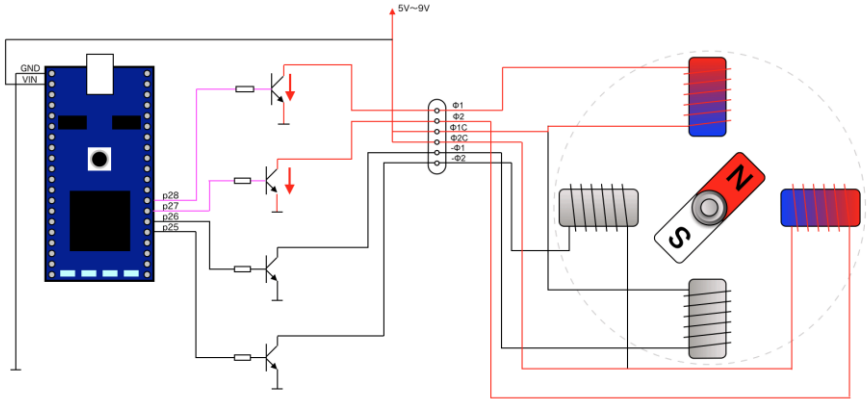


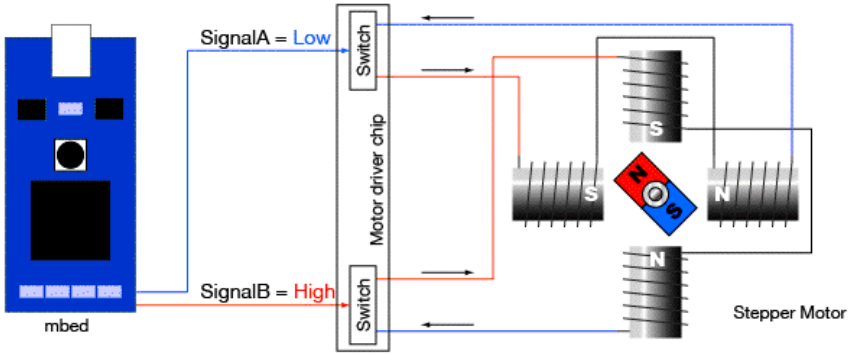
Applications



Stepper Motor - Working

- Stepper motors are driven by digital pulses rather than by a continuous applied voltage.
- Unlike conventional electric motors which rotate continuously, stepper motors rotate or step in fixed angular increments.
- A stepper motor is most commonly used for position control.
- Most steppers can be stepped at audio frequencies, allowing them to spin quite quickly, and with an appropriate controller, they may be started and stopped at controlled orientations.

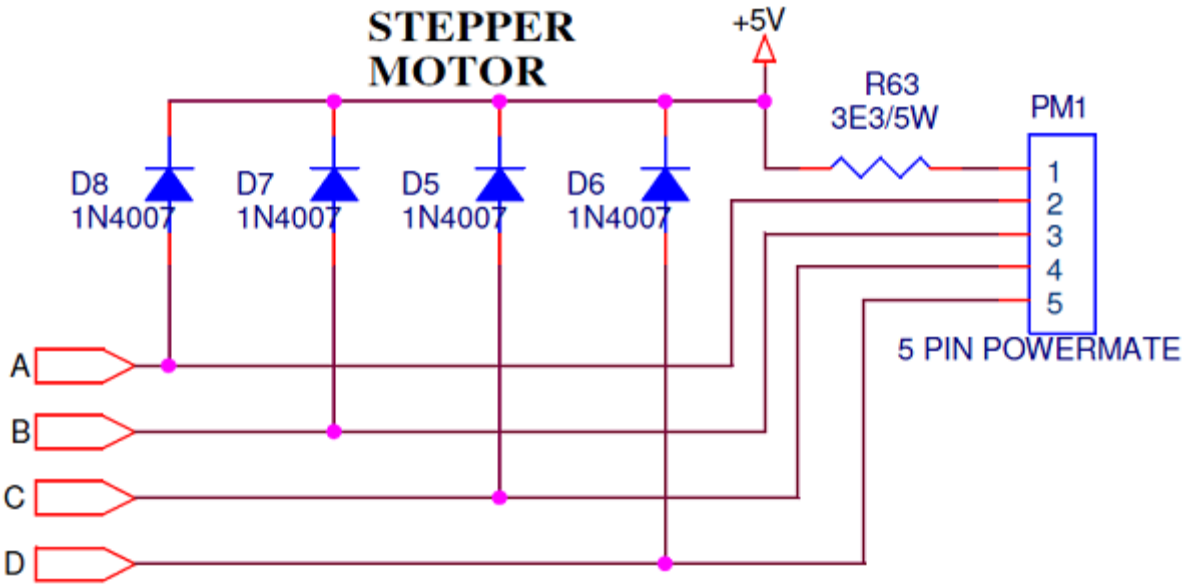




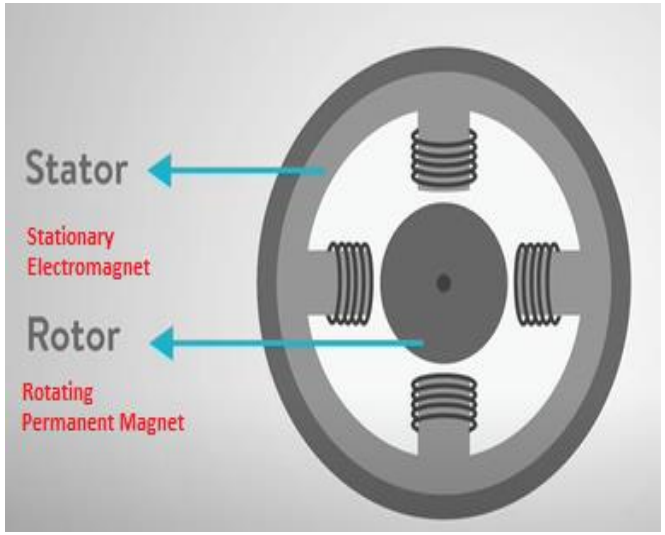
Stepper Motor - Working

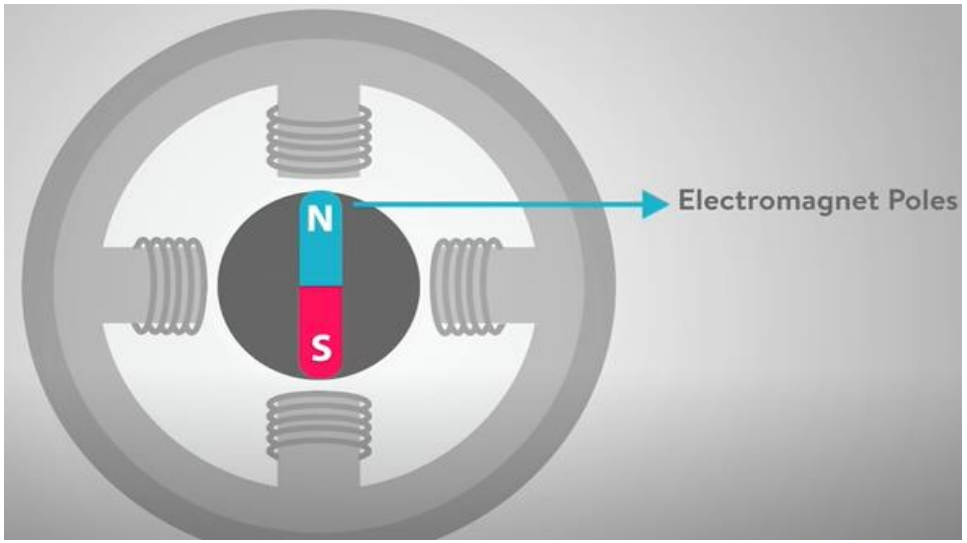
- In this lab, we'll use a so called "five wire stepper" shown in the figure below. This 28BYJ48 stepper motor is driven via a driver board that contains 4 Darlington drivers (ULN2003) and 4 LEDs.
- PM1 – it's a 5 pin straight male power mate.

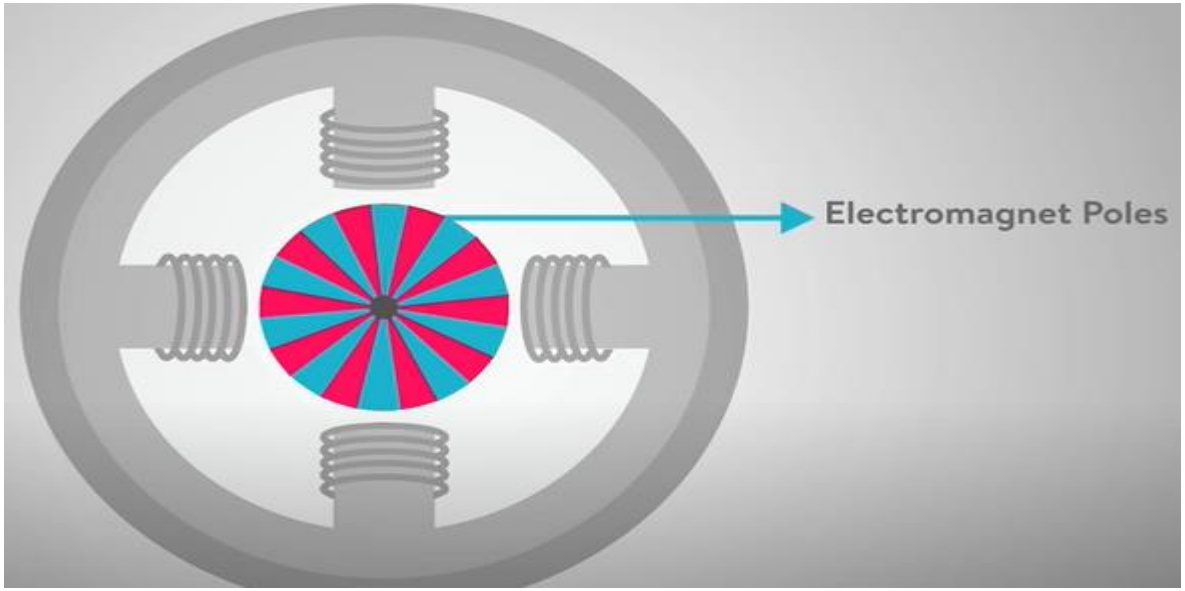
Pin no	Description
1	+5v supply
2	Phase A
3	Phase B
4	Phase C
5	Phase D



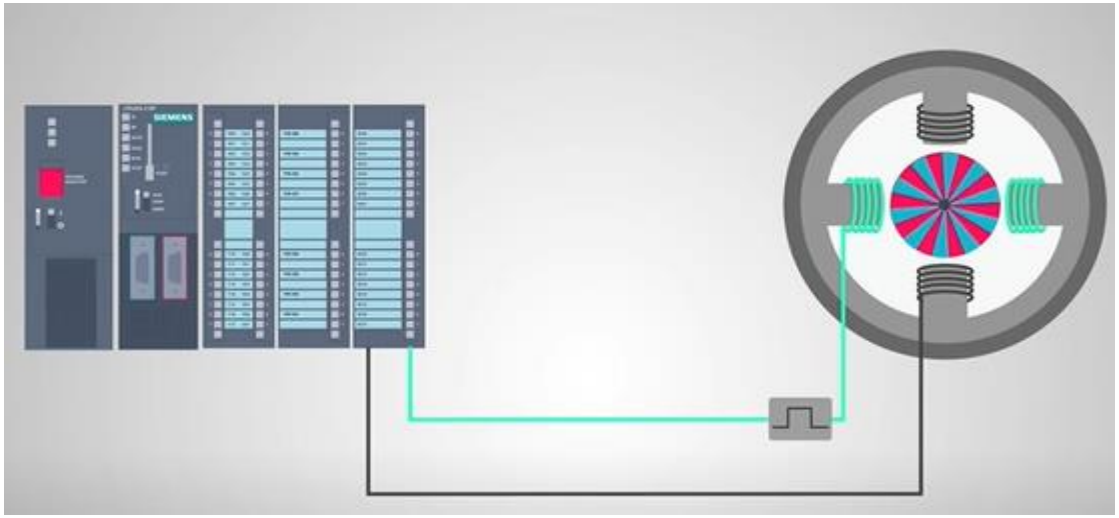
Construction

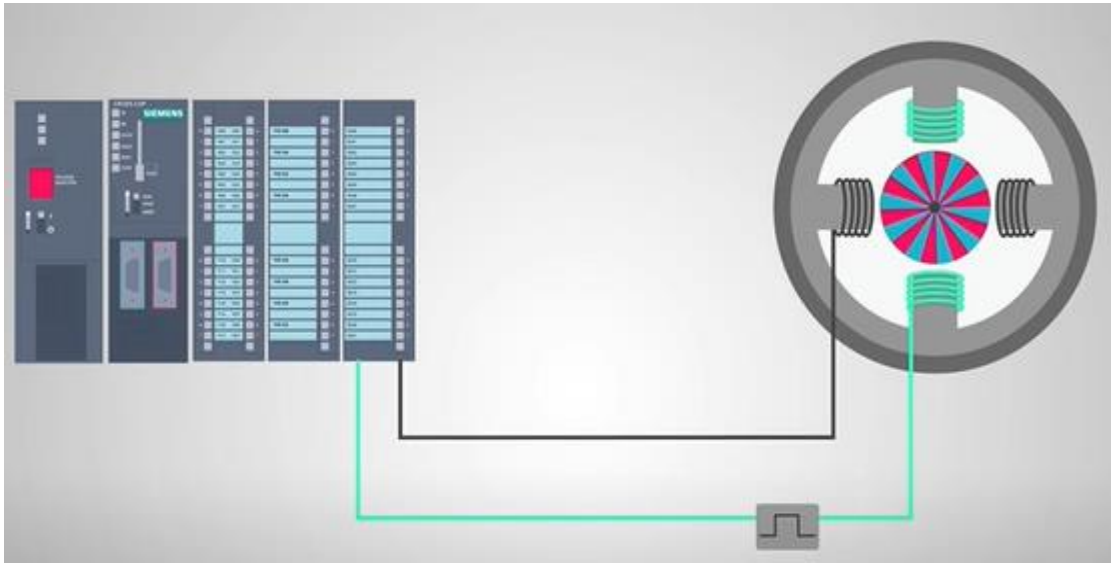




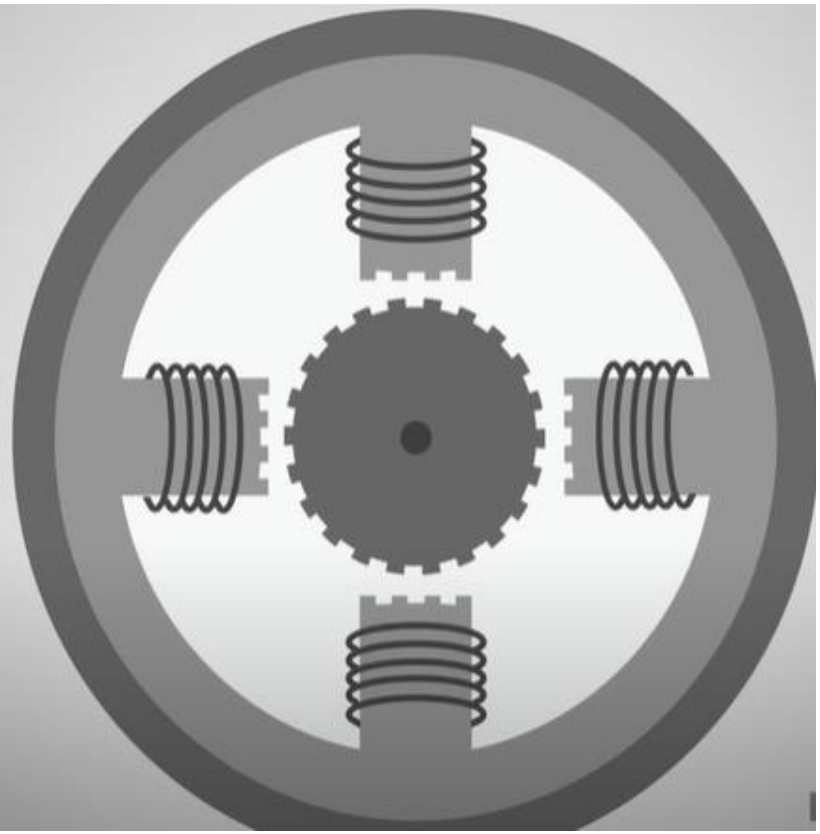


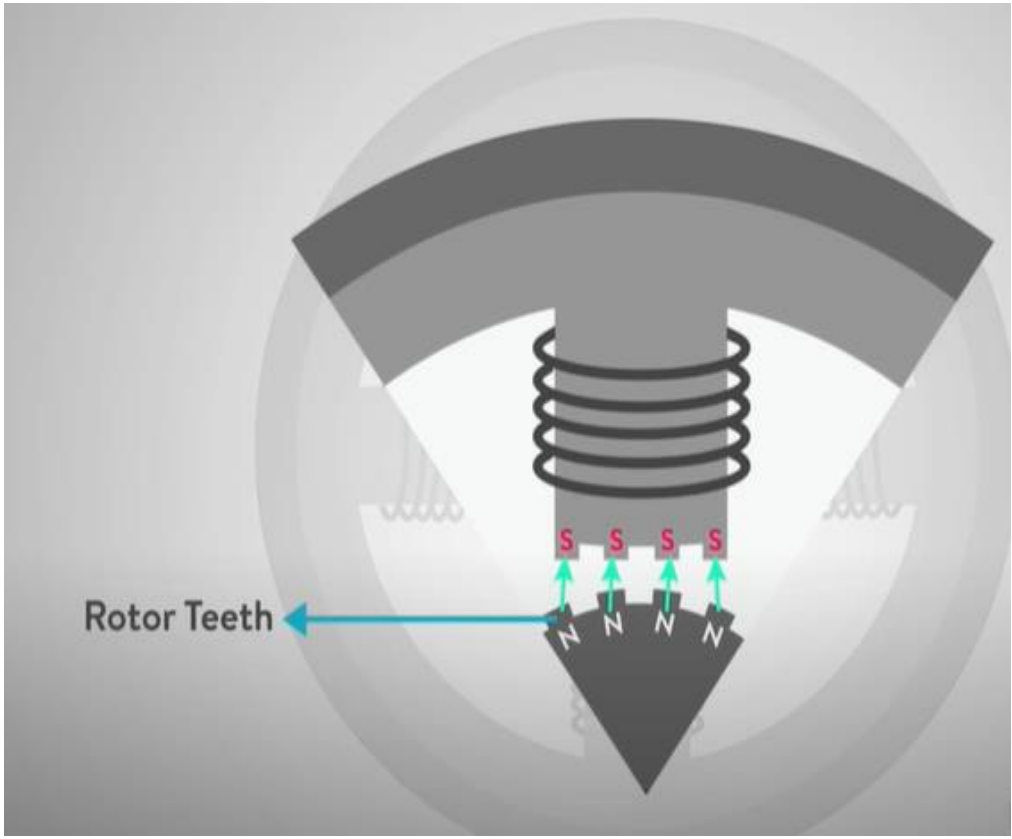
Working





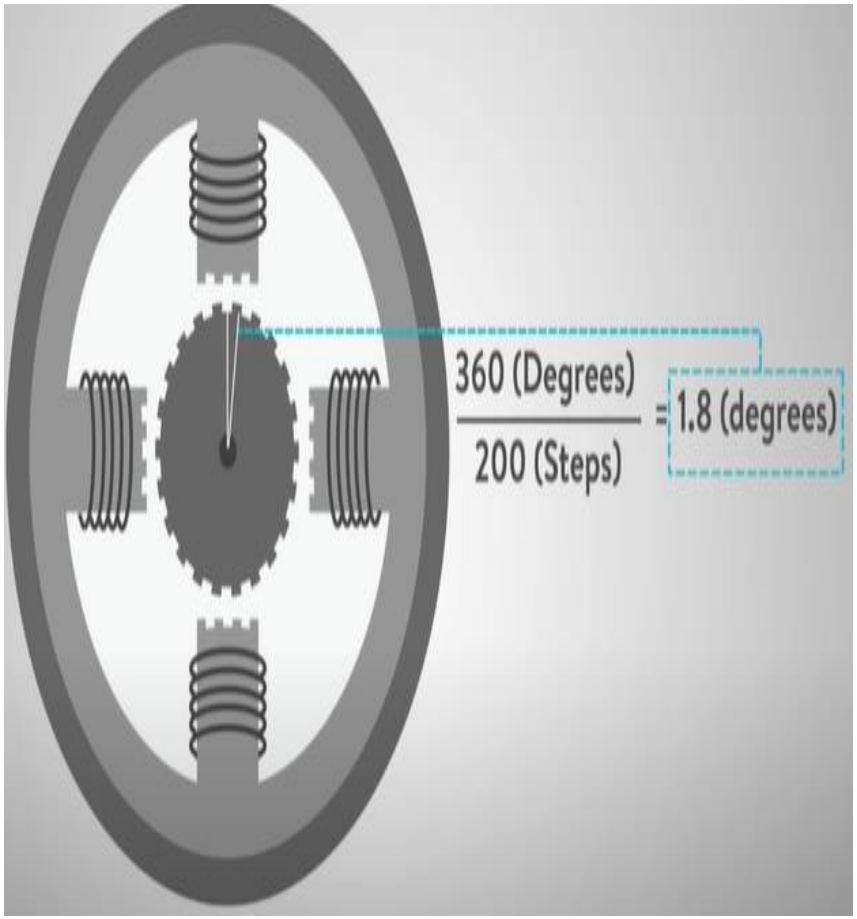
Working



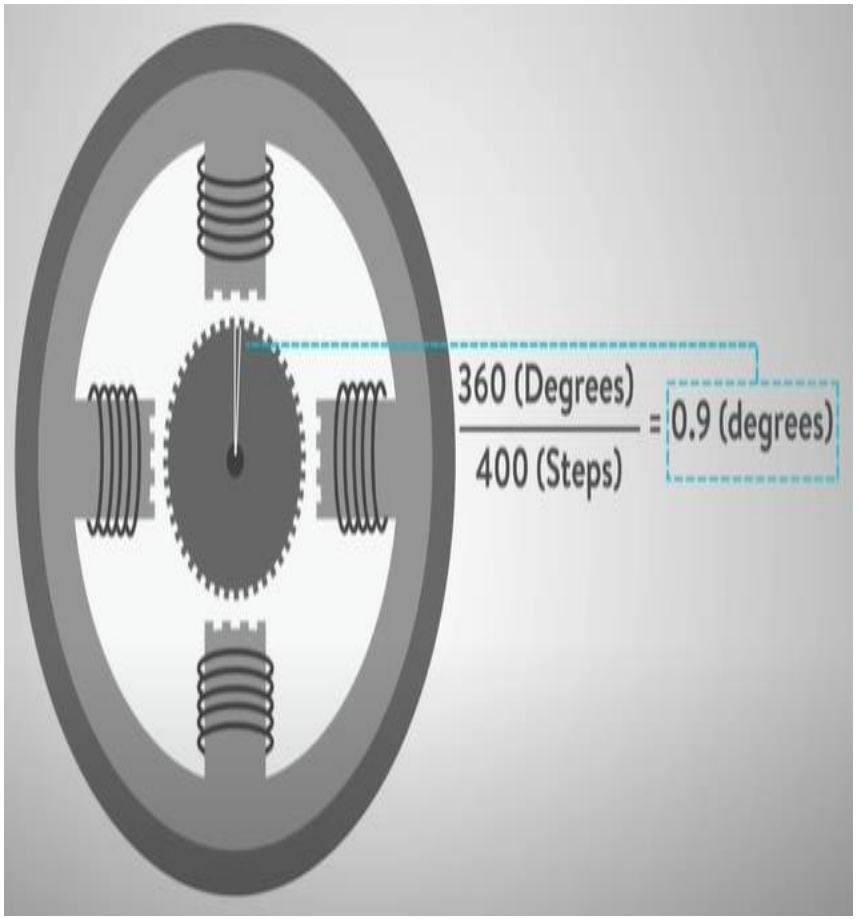


Step Angle Calculation

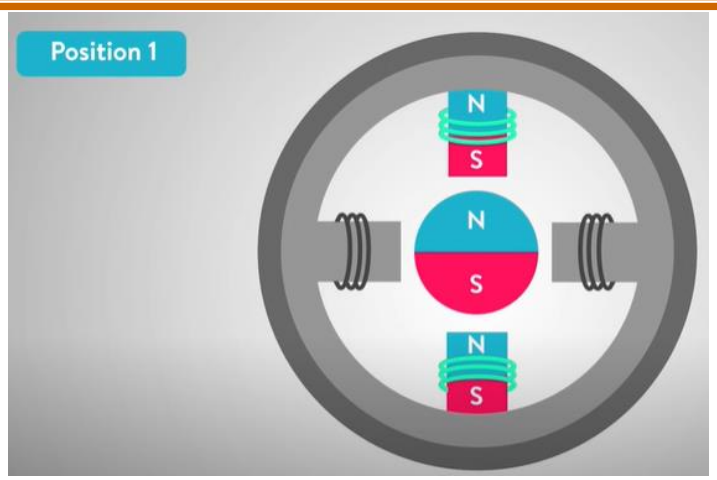
Full Step Rotation

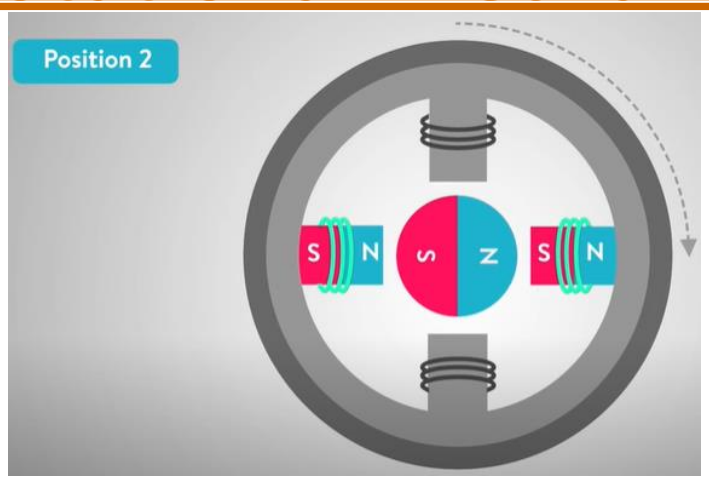


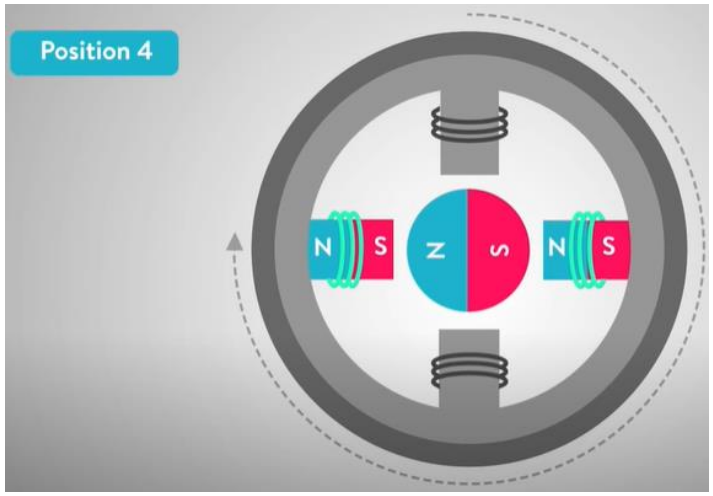
Half Step Rotation

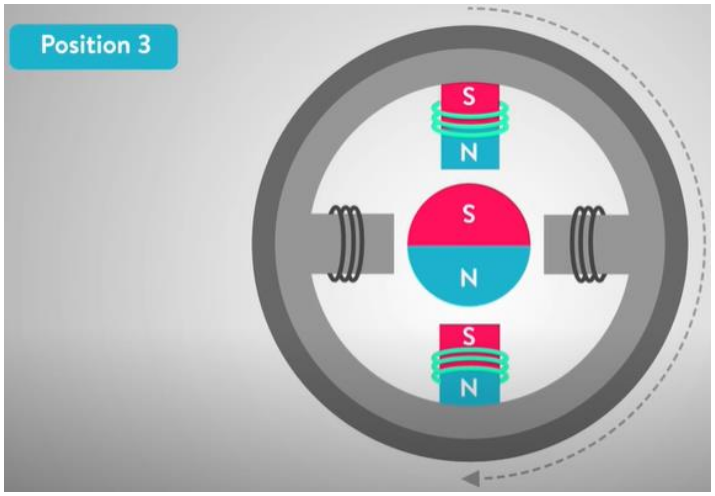


Rotational Mechanism

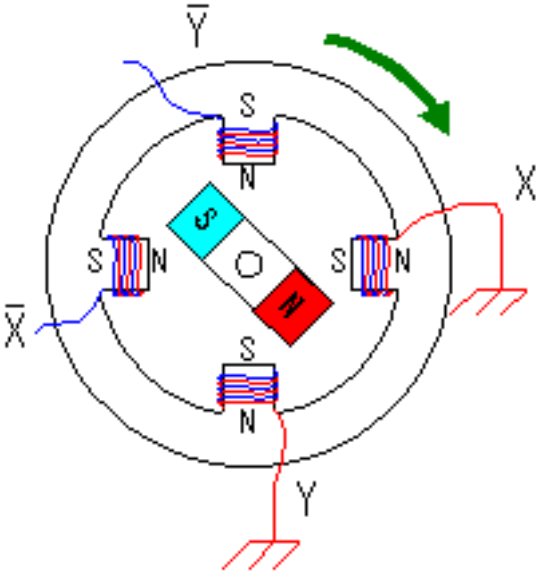








Rotational Mechanism – Clockwise



X	$\overline{X}$	Y	$\overline{Y}$
0	1	0	1
1	0	0	1
1	0	1	0
0	1	1	0

- **Clockwise control**

  X, $\overline{X}$, Y and $\overline{Y}$ are controlled in the following order.

X	$\overline{X}$	Y	$\overline{Y}$	Step angle
0	1	0	1	0°
1	0	0	1	90°
1	0	1	0	180°
0	1	1	0	270°

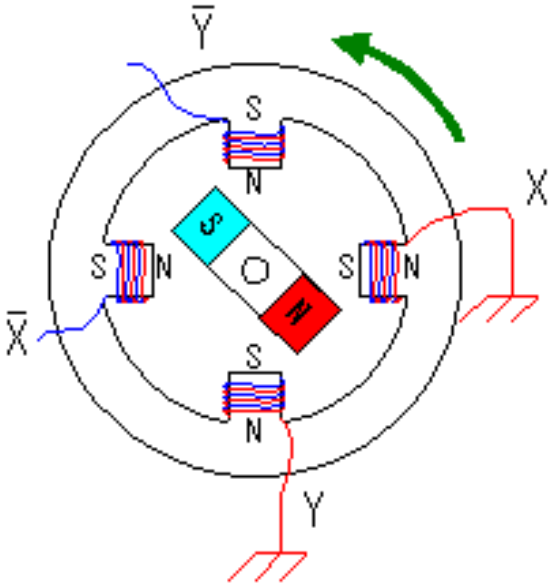
"0" means grounding.

Clockwise rotation – Excitation Codes

The case of the clockwise control is shown below.
The combination of X, $\overline{X}$, Y and $\overline{Y}$ repeats four patterns.

X	$\overline{X}$	Y	$\overline{Y}$	Step angle	X	$\overline{X}$	Y	$\overline{Y}$	Step angle
0	1	0	1	0.0°	0	1	0	1	180.0°
1	0	0	1	7.5°	1	0	0	1	187.5°
1	0	1	0	15.0°	1	0	1	0	195.0°
0	1	1	0	22.5°	0	1	1	0	202.5°
0	1	0	1	30.0°	0	1	0	1	210.0°
1	0	0	1	37.5°	1	0	0	1	217.5°
1	0	1	0	45.0°	1	0	1	0	225.0°
0	1	1	0	52.5°	0	1	1	0	232.5°
0	1	0	1	60.0°	0	1	0	1	240.0°
1	0	0	1	67.5°	1	0	0	1	247.5°
1	0	1	0	75.0°	1	0	1	0	255.0°
0	1	1	0	82.5°	0	1	1	0	262.5°
0	1	0	1	90.0°	0	1	0	1	270.0°
1	0	0	1	97.5°	1	0	0	1	277.5°
1	0	1	0	105.0°	1	0	1	0	285.0°
0	1	1	0	112.5°	0	1	1	0	292.5°
0	1	0	1	120.0°	0	1	0	1	300.0°
1	0	0	1	127.5°	1	0	0	1	307.5°
1	0	1	0	135.0°	1	0	1	0	315.0°
0	1	1	0	142.5°	0	1	1	0	322.5°
0	1	0	1	150.0°	0	1	0	1	330.0°
1	0	0	1	157.5°	1	0	0	1	337.5°
1	0	1	0	165.0°	1	0	1	0	345.0°
0	1	1	0	172.5°	0	1	1	0	352.5°

Rotational Mechanism – Anti-Clockwise



X	$\overline{X}$	Y	$\overline{Y}$
0	1	0	1
0	1	1	0
1	0	1	0
1	0	0	1

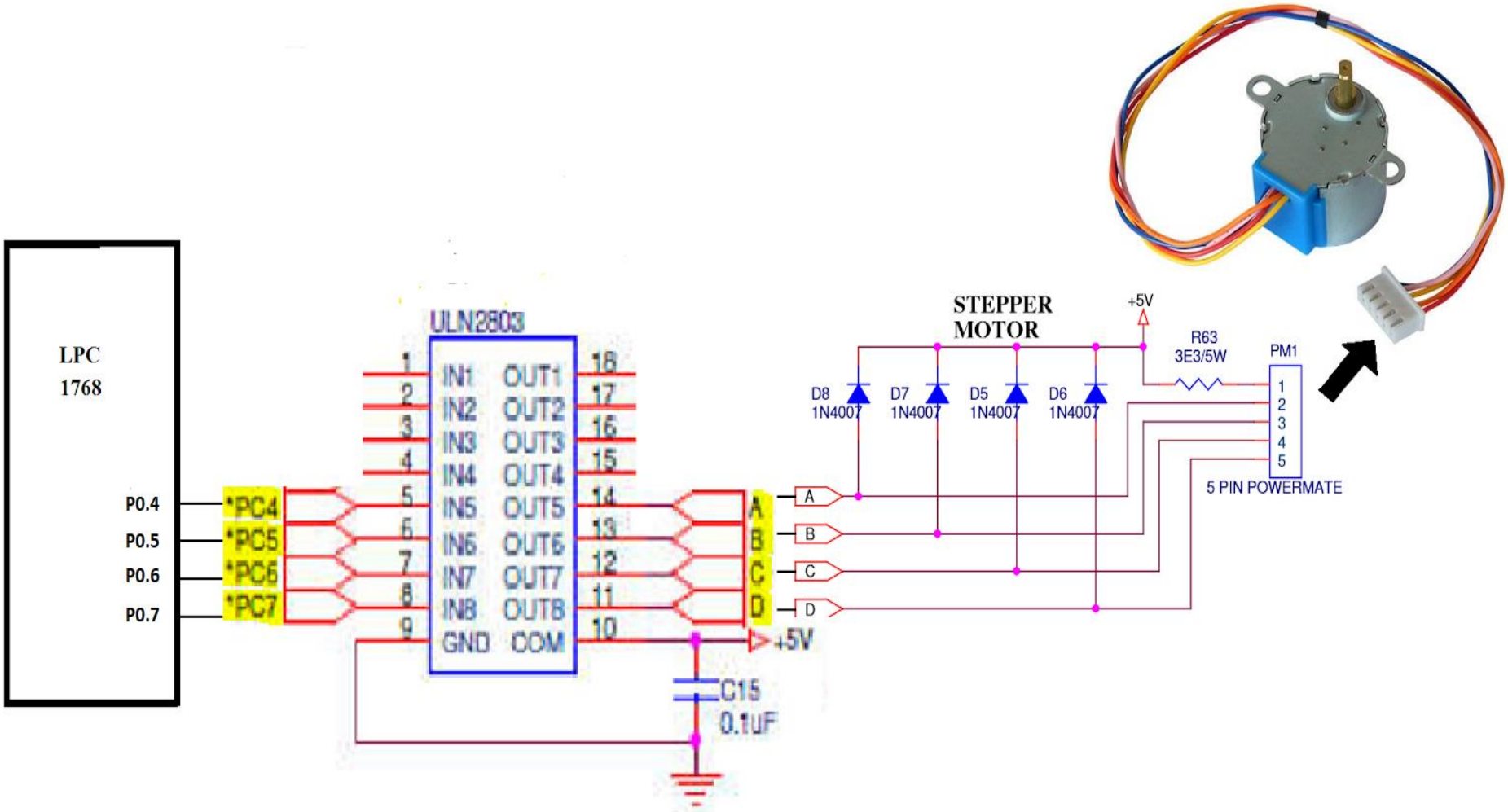
- **Counterclockwise control**

  X, $\overline{X}$, Y and $\overline{Y}$ are controlled in the following order.

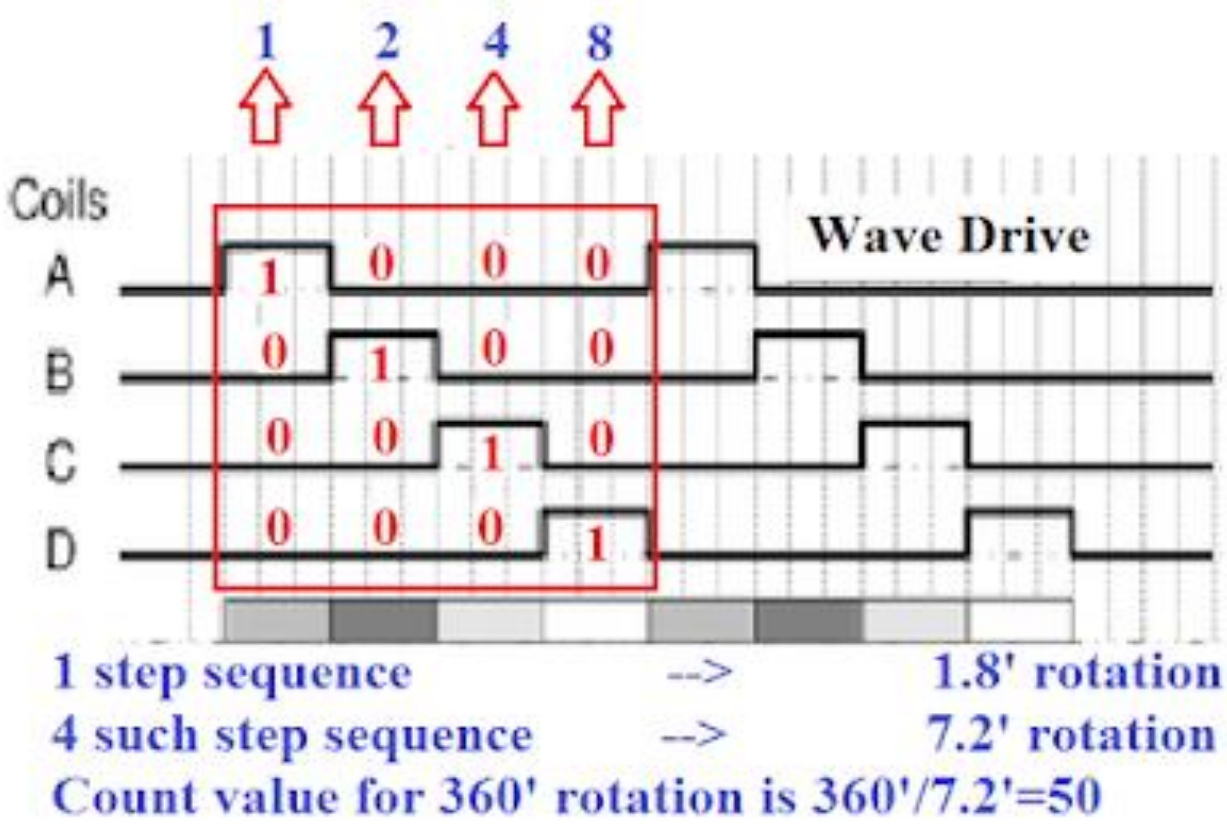
X	$\overline{X}$	Y	$\overline{Y}$	Step angle
0	1	0	1	0°
0	1	1	0	-90°
1	0	1	0	-180°
1	0	0	1	-270°

"0" means grounding.

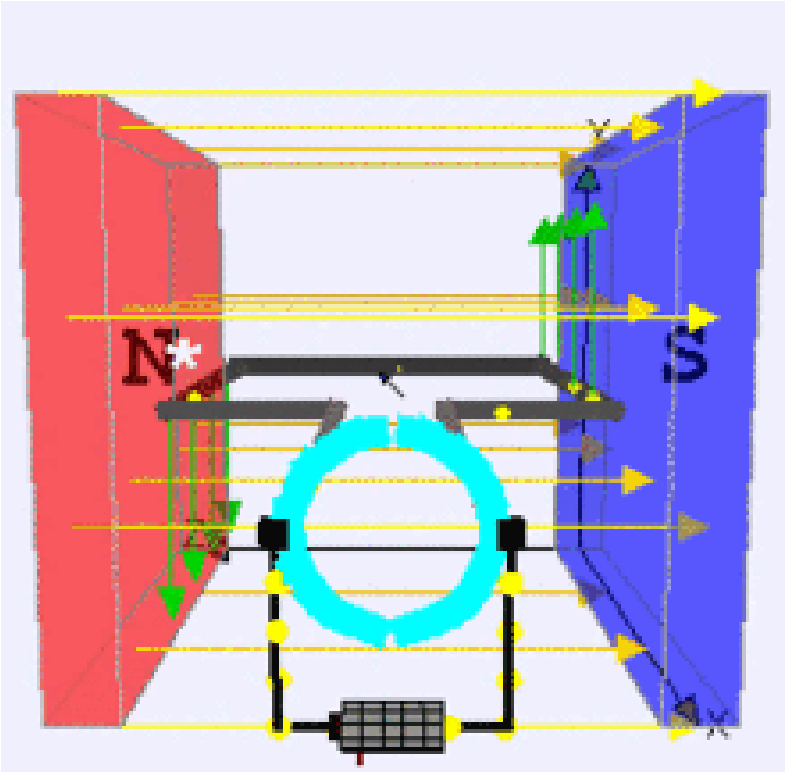
Interfacing Diagram

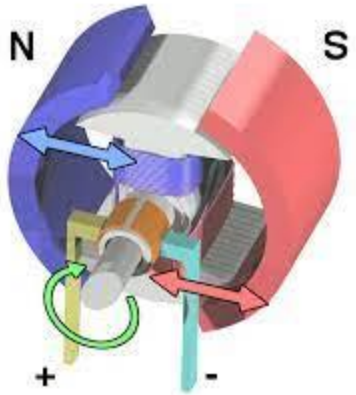


Interfacing Diagram



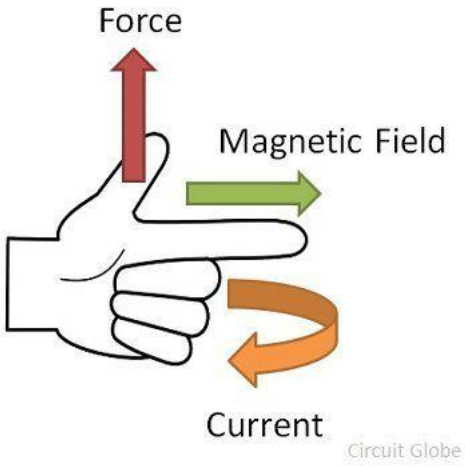
ARM LPC1768 – DC Motor Interfacing

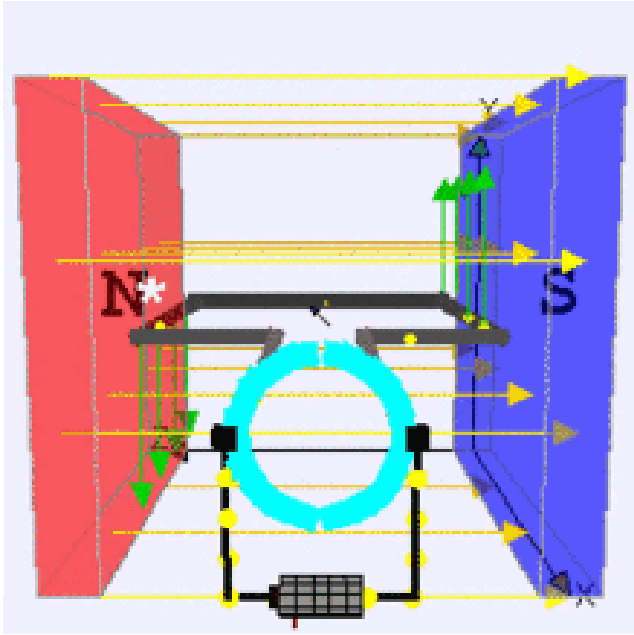




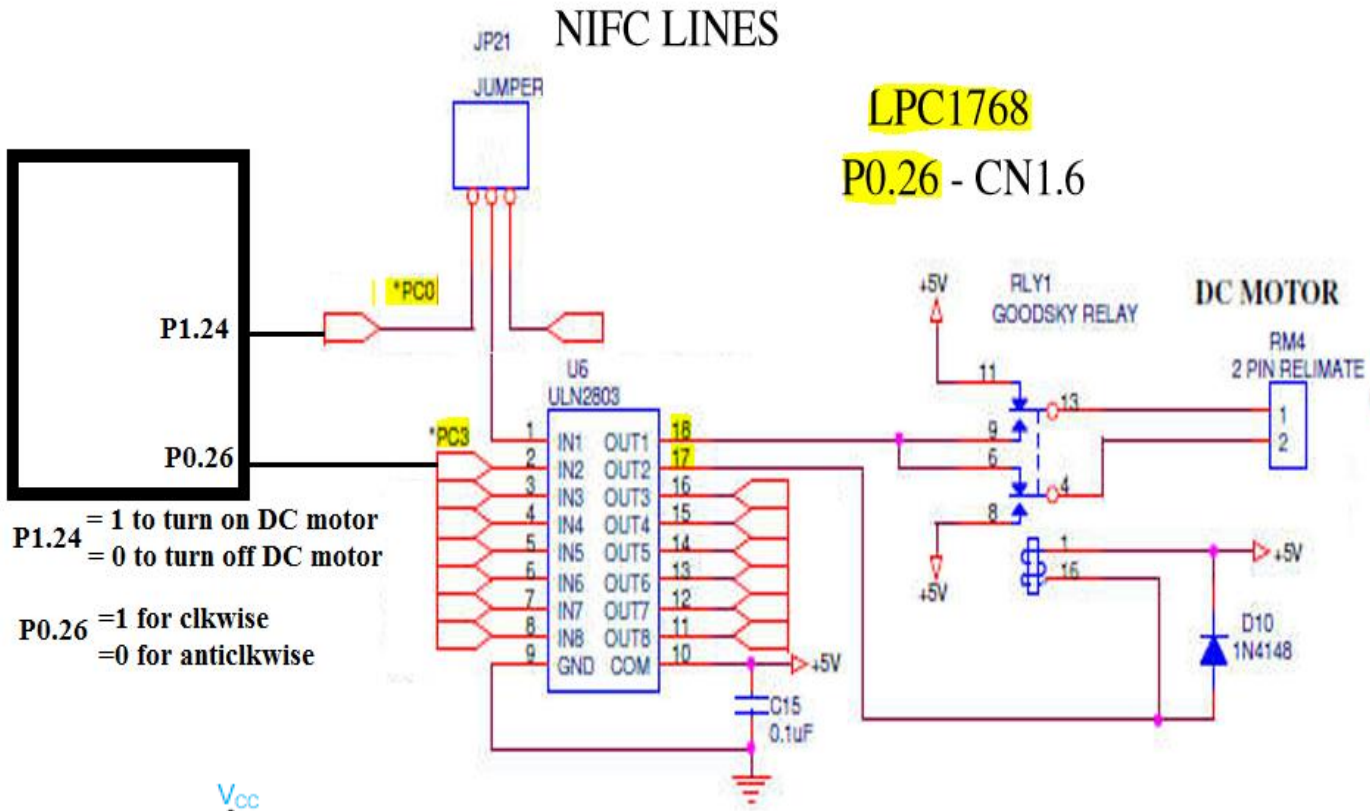
DC Motor - Introduction

- The DC motor is the device which converts the **Direct Current (DC) into the mechanical work**.
- It works on the principle of **Lorentz Law**, which states that "the current-carrying conductor placed in a magnetic and electric field experience a force". The experienced force is called the Lorentz force.
- The Flemming left-hand rule gives the direction of the force.





DC Motor - Interfacing



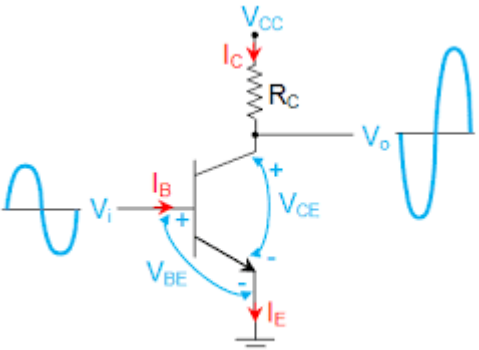
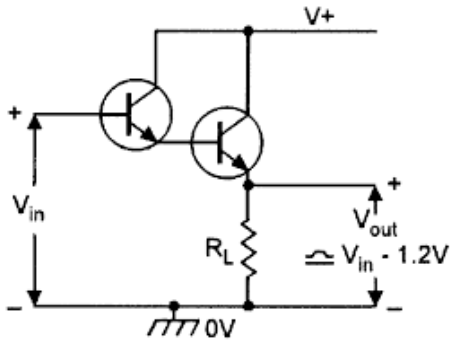
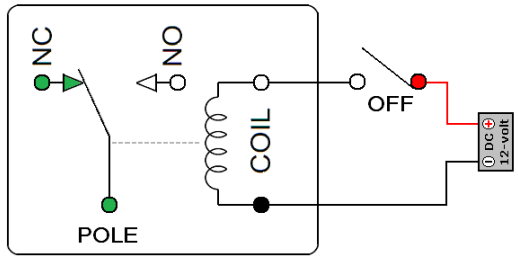
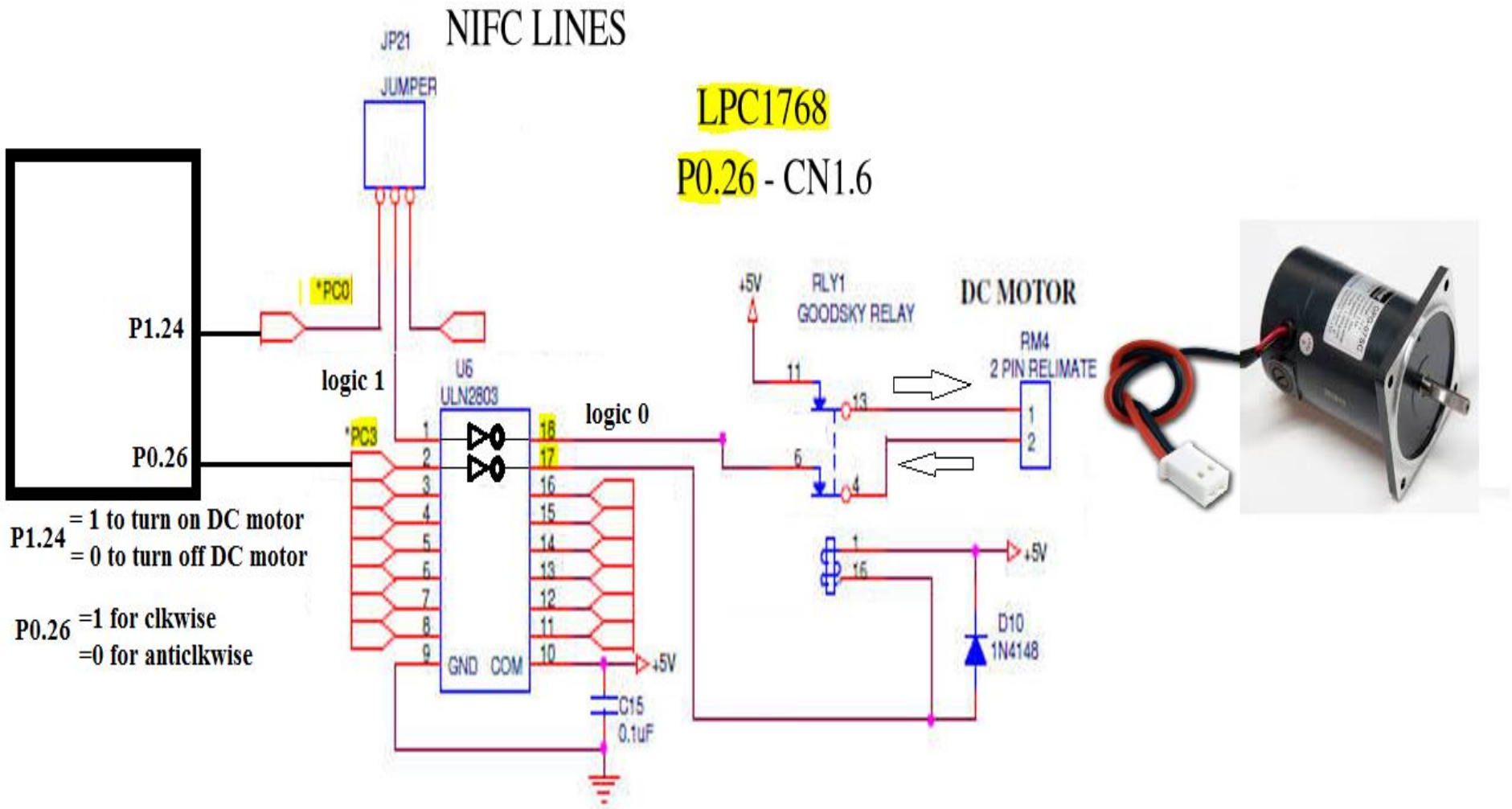


Figure 1 A Simple Common Emitter Amplifier

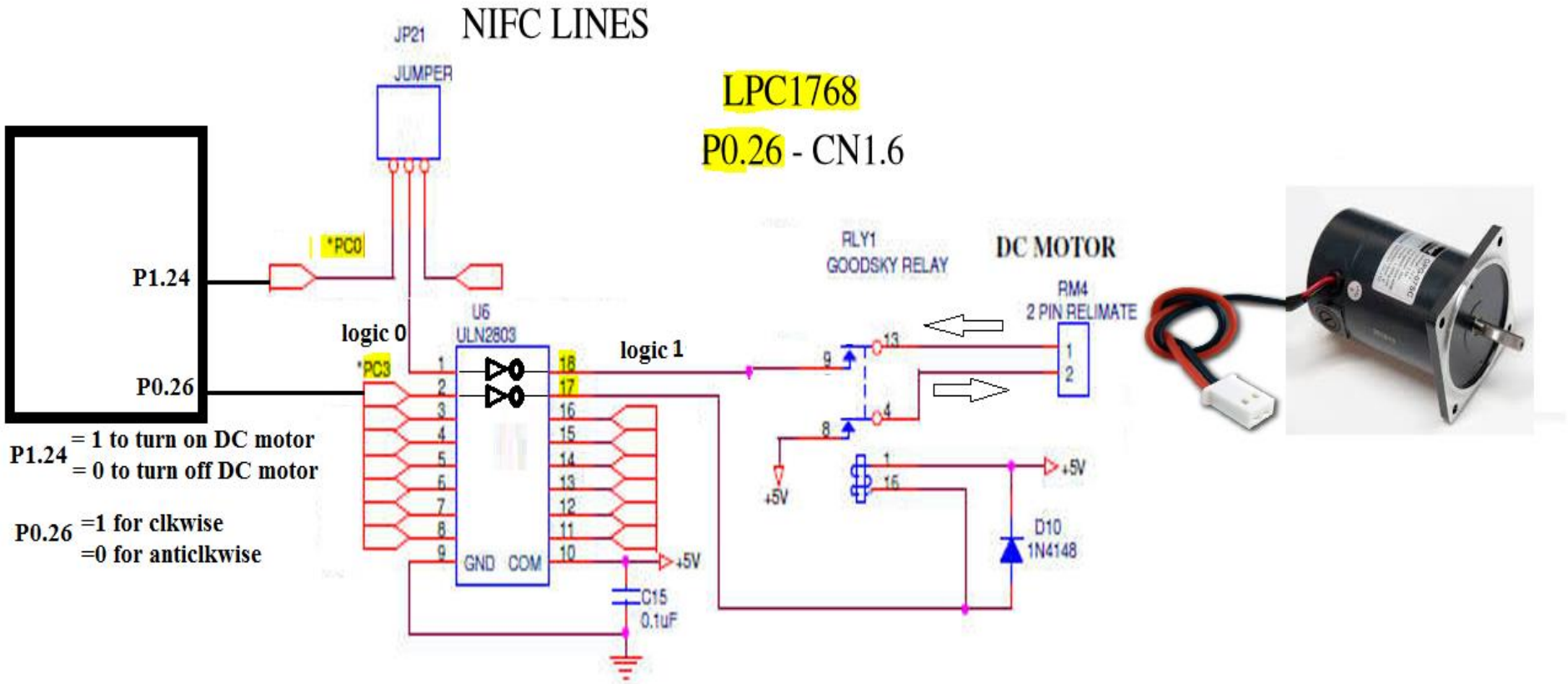




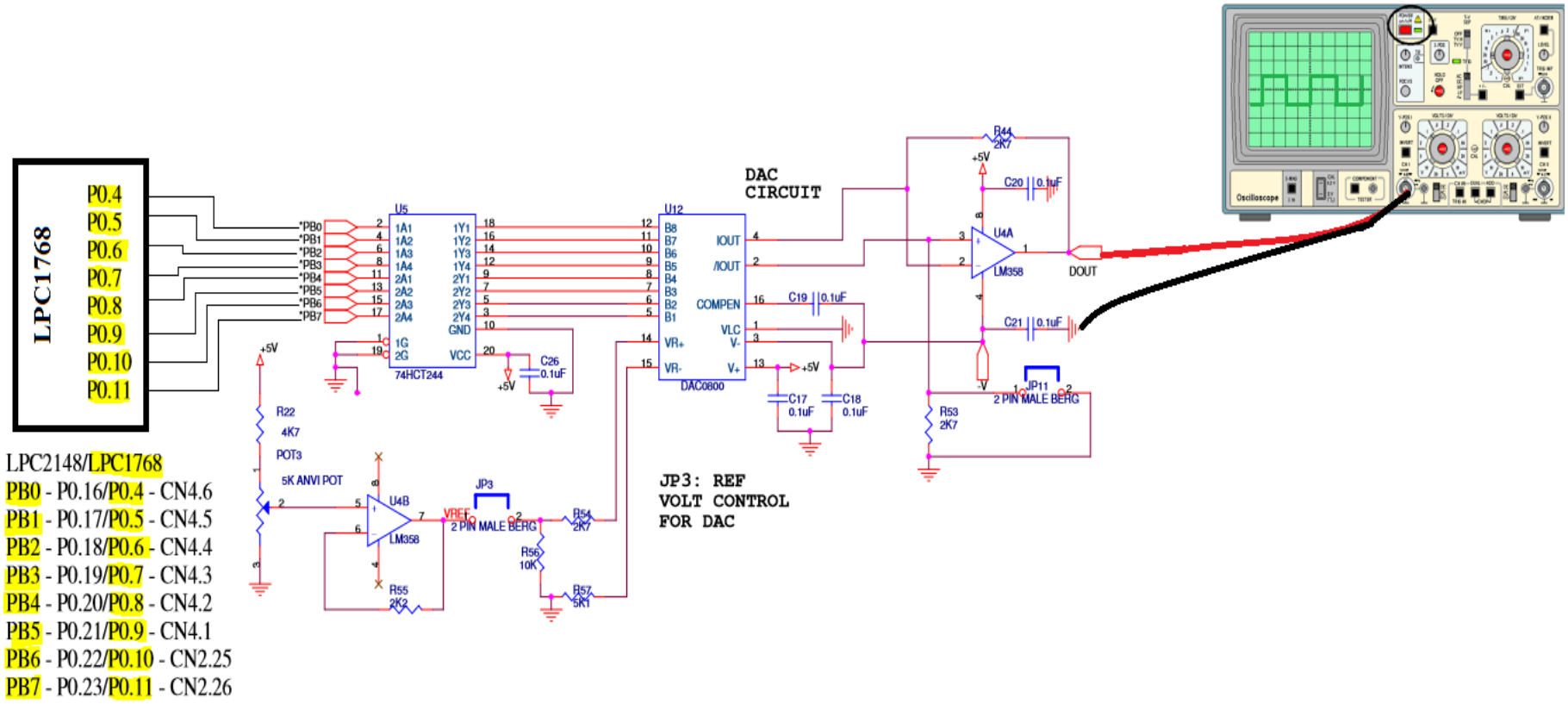
DC Motor – Interfacing – Case 1 : Clockwise



DC Motor – Interfacing – Case 2 : Anti-Clockwise



ARM LPC1768 – Digital to Analog Converter



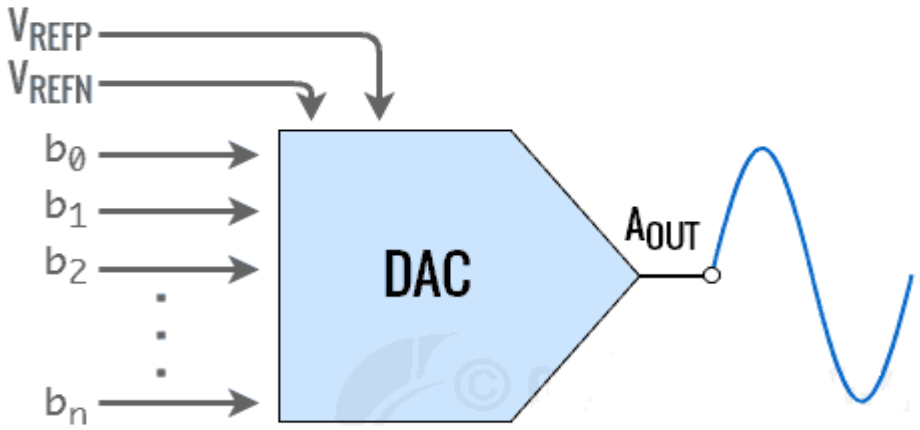
DAC Introduction

- DAC is abbreviated for Digital to Analog Converter. It is quite opposite to an ADC (Analog to Digital Converter).
- DACs are used in audio equipment like Music Players to convert the digital data into analog audio signals. Similarly, there are video DACs, for converting digital video data into analog video signals to be displayed on a screen.
- Types of **DAC implementations**: Switched Resistor DAC, R – 2R Ladder DAC, Successive Approximation DAC, etc.
- One of the simplest ways to implement a DAC is to using the PWM Functionality of a Timer Peripheral (if dedicated DAC unit is nor present).
- Similar to an ADC, a DAC also has **resolution**. It indicated the number of possible values a DAC unit can produce between the voltage extremes.
- E.x: 8-bit DAC can produce (2^8) 256 different levels for a voltage range.

LPC1768 - DAC

- DAC is abbreviated for Digital to Analog Converter. It is quite opposite to an ADC (Analog to Digital Converter).
- It contains a 10-bit DAC peripheral based on Resistor String and the maximum update rate is 1 MHz.
- The resolution of the DAC in LPC1768 is 10-bit, it can produce (2^10) 1024 different values between the positive and the negative reference voltage levels.

DAC Channel	Port Pin	Pin Functions	Associated PINSEL Register
Aout	P0.26	0-GPIO, 1-AD0[3], 2-**AOUT** , 3-RXD3	20,21 bits of PINSEL1



DAC Calculations

- The Analog voltage at the output of this pin is given as:

$$V_{AOUT} = \frac{VALUE * (V_{REFP} - V_{REFN})}{1024} + V_{REFN}$$

- Here,
  - VAOUT = Output Analog Voltage of DAC
  - VREFP = Positive Reference Voltage of DAC
  - VREFN = Negative Reference Voltage of DAC
  - VALUE = 10-bit digital value, which must be converted to analog voltage.

- When we have VREFN = 0, the equation boils down to:

$$V_{AOUT} = \frac{VALUE * V_{REFP}}{1024}$$

Pins Associated with DAC

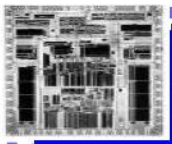
- LPC1768 has only a single channel DAC, only one output pin of the DAC Peripheral. The remaining pins related to power.
- Table gives an overview of pins associated with DAC peripheral of LPC1768 MCU

Pin	Function	Description
AOUT – P0.26	Analog Output	Provides the analog output voltage with reference to the analog GND (V_{SSA}).
V_{REFP}, V_{REFN}	Voltage References	These pins provide the positive and negative reference voltages for DAC and ADC. Usually isolated 3.3V and 0V.
V_{DDA}, V_{SSA}	Analog Power and GND	Same as V_{DD} and V_{SS} but isolated to minimize noise.

LPC1768 DAC Registers

- There are totally **three registers for DAC in LPC1768**. They are DACR, DACCTRL and DACCNTVAL.
- The DACCTRL and DACCNTVAL registers are associated with DMA operations in DAC.
- **DACR – D/A Converter Register:** It contains the digital value that must be converted to analog value. Also, this register contains a bit for a trade-off between power and performance.
- The field containing bits [15:6] is used to feed a digital value which needs to be converted and bit 16 is used to select settling time.
  - Bit[5:0]: Reserved.
  - **Bit[15:6] – VALUE**: After a new VALUE is written to this field, given settling time selected using BIAS has elapsed, we get the converted Analog voltage at the output. The formula for analog voltage at AOUT pin is as shown above.
  - **Bit[16] – BIAS**: Setting this bit to 0 selects settling time of 1us max with max current consumption of 700uA at max 1Mhz update rate. Setting it to 1 will select settling time of 2.5us but with reduce max current consumption of 300uA at max 400Khz update rate.
  - Bits[31:17]: Reserved

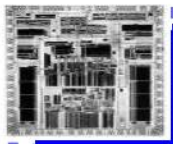
THANK YOU…



Timer/Counter Programming

Timer - Interval Timer to generate the intended delay . The Timer is designed to count cycles of the peripheral clock (PCLK)
Counter - Counting internal events. or an externally-supplied clock

There are four 32-bit Timers in LPC1768:
Timer0, Timer1, Timer2 and Timer3.



Timer/Counter Programming

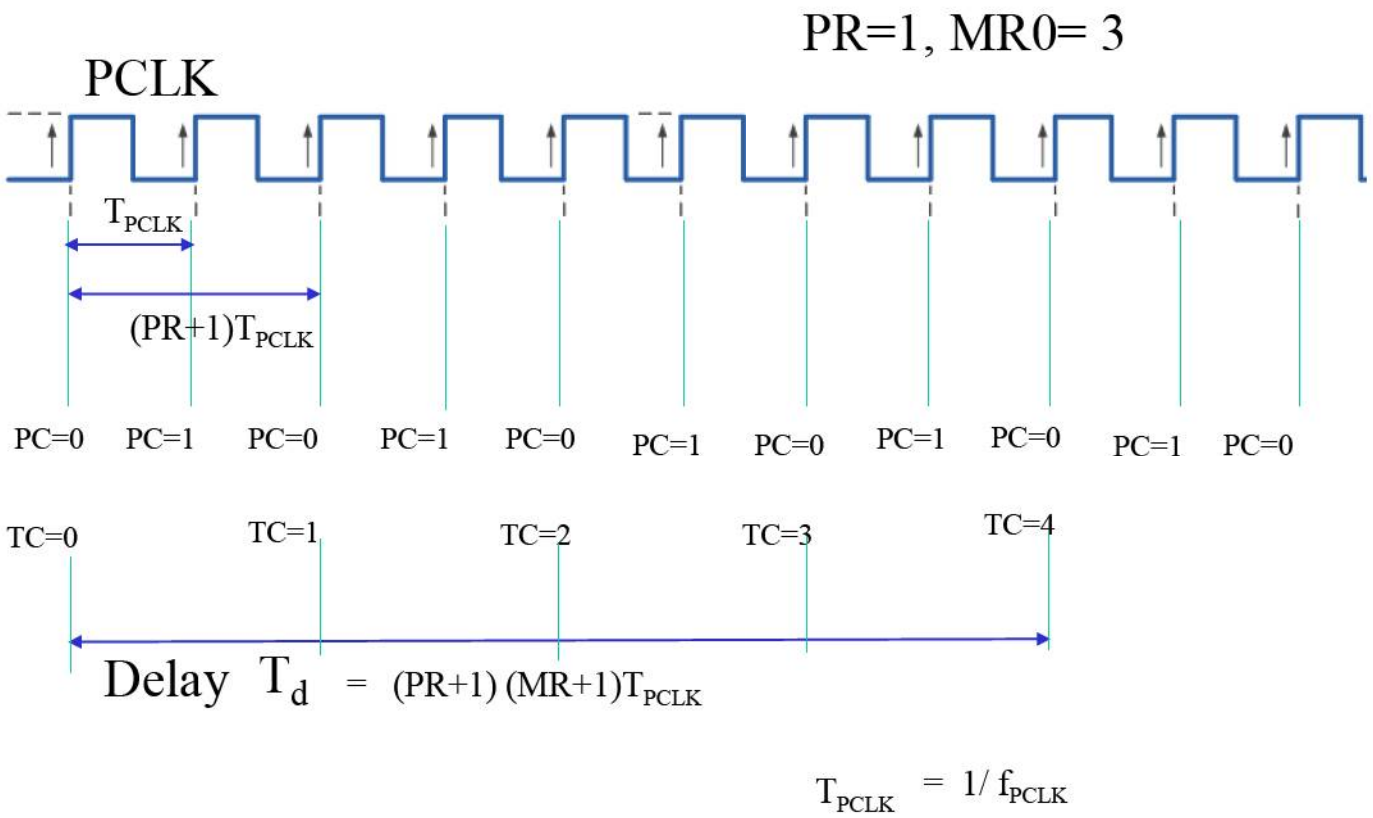
PC – Prescale Counter Register: It is a 32-bit register. The value in PC is incremented on every PCLK cycle and when its value matches the value in PR, the TC is incremented and the value in PC is RESET on the next PCLK cycle.

PR – Prescale Register: It is a 32-bit register and specifies the maximum value for the Prescale Counter (PC).

TC – Timer Counter Register: It is a 32-bit register and is incremented at every PR+1 cycles of PCLK.

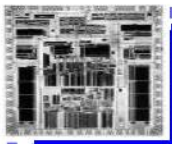
MR0 – MR3 – Match Registers: Contains user loaded values to be compared with TC. When value in Match Register matches with TC, appropriate action can be performed.

Timer/Counter Programming



$$T_{PCLK} = 1/f_{PCLK}$$

Ex: For frequency 3MHz, to get 1 second delay: PR= 999, MR0= 2999
PR= 2999, MR0= 999 etc.



Timer/Counter Programming

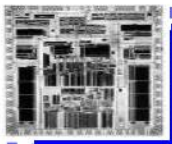
TCR – Timer Control register: Used to control Timer Counter functions i.e. enable, disable and reset.

Bit 0	Counter Enable	When 1, TC and PC are enabled for counting. When 0, TC and PC are disabled.
Bit 1	Counter Reset	When 1, TC and PC are reset on next positive edge of PCLK. The counters remain reset until this bit is returned to 0.

Timer/Counter Programming

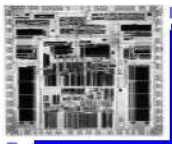
CTCR (Counter/Timer Control Register) is used to select between Timer and Counter mode, and in Counter mode to select the pin and edge(s) for counting.

Bit	Symbol	Value	Description
1:0	Counter/ Timer Mode		This field selects which rising PCLK edges can increment the Timer's Prescale Counter (PC), or clear the PC and increment the Timer Counter (TC).
		00	Timer Mode: the TC is incremented when the Prescale Counter matches the Prescale Register. The Prescale Counter is incremented on every rising PCLK edge.
		01	Counter Mode: TC is incremented on rising edges on the CAP input selected by bits 3:2.
		10	Counter Mode: TC is incremented on falling edges on the CAP input selected by bits 3:2.
		11	Counter Mode: TC is incremented on both edges on the CAP input selected by bits 3:2.
3:2	Count Input Select		When bits 1:0 in this register are not 00, these bits select which CAP pin is sampled for clocking.
		00	CAPn.0 for TIMERn
		01	CAPn.1 for TIMERn
		10	Reserved
		11	Reserved



Timer/Counter Programming

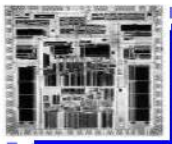
CAP0.0	P1.26
CAP0.1	P1.27
CAP1.0	P1.18 / P1.28 / P2.6
CAP1.1	P1.19 / P1.29
CAP2.0	P0.4
CAP2.1	P0.5
CAP3.0	P0.23
CAP3.1	P0.24
MAT0.0	P1.28 / P3.25
MAT0.1	P1.29 / P3.26
MAT1.0	P1.22
MAT1.1	P1.25
MAT2.0	P0.6 / P4.28
MAT2.1	P0.7 / P4.29
MAT2.2	P0.8
MAT2.3	P0.9
MAT3.0	P0.10
MAT3.1	P0.11



Timer/Counter Programming

Match Registers (MR0 - MR3)

- The Match register values are continuously compared to the Timer Counter value.
- When the two values are equal, actions can be triggered automatically.
- The action possibilities are to generate an interrupt, reset the Timer Counter, or stop the timer. Actions are controlled by the settings in the MCR register.

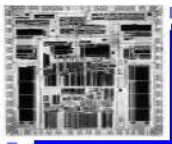


Timer/Counter Programming

Match Control Register (MCR)

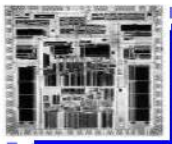
The Match Control Register is used to control what operations are performed when one of the Match Registers matches the Timer Counter.

Bit	Symbol	Value	Description
0	MR0I	1	Interrupt on MR0: an interrupt is generated when MR0 matches the value in the TC.
		0	This interrupt is disabled
1	MR0R	1	Reset on MR0: the TC will be reset if MR0 matches it.
		0	Feature disabled.
2	MR0S	1	Stop on MR0: the TC and PC will be stopped and TCR[0] will be set to 0 if MR0 matches the TC.
		0	Feature disabled.
3	MR1I	1	Interrupt on MR1: an interrupt is generated when MR1 matches the value in the TC.
		0	This interrupt is disabled
4	MR1R	1	Reset on MR1: the TC will be reset if MR1 matches it.
		0	Feature disabled.
5	MR1S	1	Stop on MR1: the TC and PC will be stopped and TCR[0] will be set to 0 if MR1 matches the TC.
		0	Feature disabled.



Timer/Counter Programming

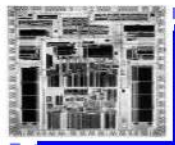
MR2I	1	Interrupt on MR2: an interrupt is generated when MR2 matches the value in the TC.
	0	This interrupt is disabled
MR2R	1	Reset on MR2: the TC will be reset if MR2 matches it.
	0	Feature disabled.
MR2S	1	Stop on MR2: the TC and PC will be stopped and TCR[0] will be set to 0 if MR2 matches the TC.
	0	Feature disabled.
MR3I	1	Interrupt on MR3: an interrupt is generated when MR3 matches the value in the TC.
	0	This interrupt is disabled
MR3R	1	Reset on MR3: the TC will be reset if MR3 matches it.
	0	Feature disabled.
MR3S	1	Stop on MR3: the TC and PC will be stopped and TCR[0] will be set to 0 if MR3 matches the TC.
	0	Feature disabled.
-		Reserved, user software should not write ones to reserved bits. The value read from a reserved bit is not defined.



Timer/Counter Programming

External Match Register (EMR): It provides Match Outputs. Also, the External Match Register provides both control and status of the external match pins.

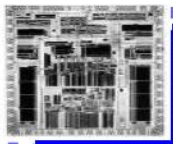
Bit	Symbol	Description
0	EM0	External Match 0. When a match occurs between the TC and MR0, this bit can either toggle, go low, go high, or do nothing, depending on bits 5:4 of this register. This bit can be driven onto a MATn.0 pin, in a positive-logic manner (0 = low, 1 = high).
1	EM1	External Match 1. When a match occurs between the TC and MR1, this bit can either toggle, go low, go high, or do nothing, depending on bits 7:6 of this register. This bit can be driven onto a MATn.1 pin, in a positive-logic manner (0 = low, 1 = high).
2	EM2	External Match 2. When a match occurs between the TC and MR2, this bit can either toggle, go low, go high, or do nothing, depending on bits 9:8 of this register. This bit can be driven onto a MATn.2 pin, in a positive-logic manner (0 = low, 1 = high).
3	EM3	External Match 3. When a match occurs between the TC and MR3, this bit can either toggle, go low, go high, or do nothing, depending on bits 11:10 of this register. This bit can be driven onto a MATn.3 pin, in a positive-logic manner (0 = low, 1 = high).
5:4	EMC0	External Match Control 0. Determines the functionality of External Match 0. Table 433 shows the encoding of these bits.
7:6	EMC1	External Match Control 1. Determines the functionality of External Match 1. Table 433 shows the encoding of these bits.
9:8	EMC2	External Match Control 2. Determines the functionality of External Match 2. Table 433 shows the encoding of these bits.
11:10	EMC3	External Match Control 3. Determines the functionality of External Match 3. Table 433 shows the encoding of these bits.



Timer/Counter Programming

EMR[11:10], EMR[9:8], EMR[7:6], or EMR[5:4]	Function
00	Do Nothing.
01	Clear the corresponding External Match bit/output to 0 (MATn.m pin is LOW if pinned out).
10	Set the corresponding External Match bit/output to 1 (MATn.m pin is HIGH if pinned out).
11	Toggle the corresponding External Match bit/output.

MAT0.0	P1.28 / P3.25
MAT0.1	P1.29 / P3.26
MAT1.0	P1.22
MAT1.1	P1.25
MAT2.0	P0.6 / P4.28
MAT2.1	P0.7 / P4.29
MAT2.2	P0.8
MAT2.3	P0.9
MAT3.0	P0.10
MAT3.1	P0.11



Timer/Counter Programming

```
#include<stdio.h>
#include<LPC17xx.h>
void delay(void)
{
        LPC_TIM0->TCR = 0x00000002;     // Timer0 Reset
        LPC_TIM0->EMR = 0X20;//Set match bit upon match
        LPC_TIM0->PR = 1000; /
        LPC_TIM0->MR0 = 3000;          //for 1 second
        LPC_TIM0->MCR = 0x00000004;     // stop PC and TC on MR0
        LPC_TIM0->TCR = 0x00000001;     // Timer0 Enable
        while ( !(LPC_TIM0->EMR & 0x01)); // wait until match

        return;
        }


int main(void)
{
        LPC_GPIO0->FIODIR=0x00000004;

                while(1)
        {


                LPC_GPIO0->FIOSET=0x4;
                delay();

                LPC_GPIO0->FIOCLR=0x4;
                delay();
        }
}
```

Toggle LED connected to P0.2 every second.i.e generate square wave with period 2 seconds

```
LPC_GPIO0->FIOPIN=~(LPC_GPIO0->FIOPIN & 0x00000004);
Delay();
```

Timer/Counter Programming

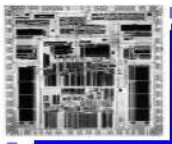
Generate square wave of period 2 seconds with 75% duty cycle on P0.2

```
#include<stdio.h>
#include<LPC17xx.h>
void delay(void)
{
        //LPC_SC->PCONP |= (1<<1);   //powers the T0
        LPC_TIM0->TCR = 0x00000002;    // Timer0 Reset
        LPC_TIM0->EMR = 0X20; //Set EM0 upon match
        LPC_TIM0->PR = 2999;
        LPC_TIM0->MCR = 0x00000004;    // stop PC and TC on MR0
        LPC_TIM0->TCR = 0x00000001;    // Timer0 Enable
        while ( !(LPC_TIM0->EMR & 0x01));// Wait until EM0 is set
        return;
        }
int main(void)
{
        LPC_GPIO0->FIODIR=0x00000004;
                while(1)
        {
                LPC_GPIO0->FIOPIN=0x00000004;
                LPC_TIM0->MR0 = 1500; //For 1.5 seconds
                delay();
                LPC_GPIO0->FIOPIN=0x00000000;
                LPC_TIM0->MR0 = 500; //For 0.5 seconds
                delay();
}
}
```

Timer/Counter Programming

Square waveform on MAT 0.0 output line by taking EM0 on the output pin.

```
#include<stdio.h>
#include<LPC17xx.h>
void delay(void)
{
        LPC_TIM0->TCR = 0x00000002;    // Timer0 Reset
        LPC_TIM0->CTCR = 0x00000000;
        LPC_TIM0->EMR = 0X30;//Toggle bit upon match
        LPC_TIM0->PR = 0; //
        LPC_TIM0->MR0 = 3000000;       //
        LPC_TIM0->MCR = 0x00000002;    // Reset TC
        LPC_TIM0->TCR = 0x00000001;    // Timer0 Enable
        return;
        }
int main(void)
{
            LPC_PINCON->PINSEL3 |= (3<<24);//Get EM0 on MAT0.0 (P1.28) line
            delay();
            while(1);
}
```



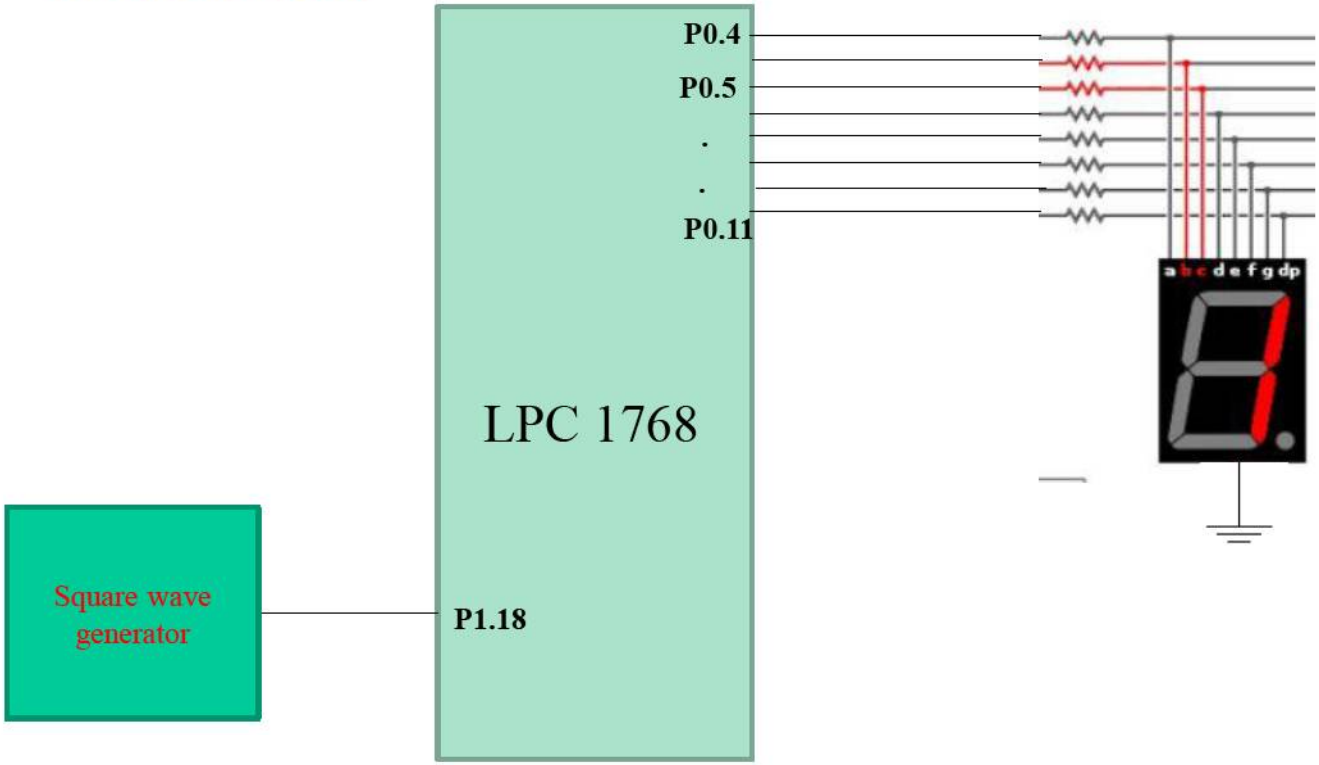
Timer/Counter Programming

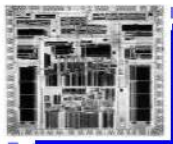
MAT 1.1(P1.25) toggles whenever count reaches 3. CAP 1.0 (P1.18) is counter clock. i.e Divide the frequency of the square waveform input at P1.18 by a factor of 8 on P1.25

```
#include<stdio.h>
#include<LPC17xx.h>
void init_timer1(void)
{
        LPC_PINCON->PINSEL3 |=(3<<18 | 3<<4);//  MAT 1.1(P1.25) and CAP 1.0 (P1.18)
        LPC_TIM1->TCR=2;//Reset Counter1
        LPC_TIM1->CTCR = 0x2; // Counter at -ve edge of CAP1.0
        LPC_TIM1->MR1=0x03; //To count 4 clock pulses
        LPC_TIM1->MCR=0x10;//Clear TC upon Match1
        LPC_TIM1->EMR=0xC0;//Toggle EM1 upon Match
        LPC_TIM1->TCR=1;//Start Counter1
}
int  main(void)
{
        init_timer1();
        while(1);
}
```

Timer/Counter Programming

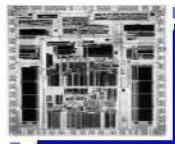
Assume that output of a square wave generator (Frequency < 10Hz) is connected to P1.18 (CAP1.0, Function-3) , write aprogram to display the frequency of this square waveform on the seven segment connected to P011-P0.4.





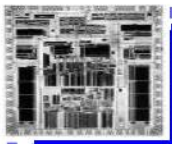
Timer/Counter Programming

```
#include<stdio.h>
#include<LPC17xx.h>
unsigned char seven_seg[10]={0x3F,0x06,0x5B,0x4F,0x66,0x6D,0x7D,0x07,0x7F,0x6F};
void delay(void)
{
        LPC_TIM0->TCR = 0x00000002;    // Timer0 Reset
        LPC_TIM0->EMR = 0X20;//Set match bit upon match
        LPC_TIM0->PR = 3000; //for 1 ms
        LPC_TIM0->MR0 = 1000;          //for 1 second
        LPC_TIM0->MCR = 0x00000004;    // stop PC and TC on MR0
        LPC_TIM0->TCR = 0x00000001;    // Timer0 Enable
        while ( !(LPC_TIM0->EMR & 0x01)); // wait until match
        }
void init_counter1(void)
{
        LPC_PINCON->PINSEL3 = (3<<4);//  cap 1.0 (P1.18)
        LPC_TIM1->CTCR = 0x01; // Counter at +ve edge of CAP1.0
}
```



Timer/Counter Programming

```
int  main(void)
{
        LPC_PINCON->PINSEL0 = 0          //P0.4 to P0.11 GPIO data lines
        LPC_GPIO0->FIODIR = 0x00000FF0;          //P0.4 to P0.11 output
        init_counter1();
while(1)
        {
        LPC_TIM1->TCR=2;//Reset Counter1
        LPC_TIM1->TCR=1;//Start Counter1
        Delay(); // wait for 1 second
        LPC_GPIO0->FIOPIN = seven_seg[LPC_TIM1->TC ] << 4; Counter1 on the
seven segment
        }

}
```

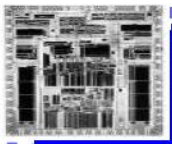


Timer/Counter Programming

Capture Registers (CR0 - CR1)

Each Capture register is associated with a device pin and may be loaded with the Timer Counter value when a specified event occurs on that pin.

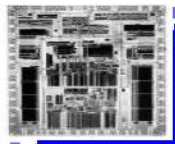
The settings in the Capture Control Register determine whether the capture function is enabled, and whether a capture event happens on the rising edge of the associated pin, the falling edge, or on both edges.



Timer/Counter Programming

Capture Control Register (CCR)

The Capture Control Register is used to control whether one of the four Capture Registers is loaded with the value in the Timer Counter when the capture event occurs, and whether an interrupt is generated by the capture event.



Timer/Counter Programming

Capture Control Register (CCR)

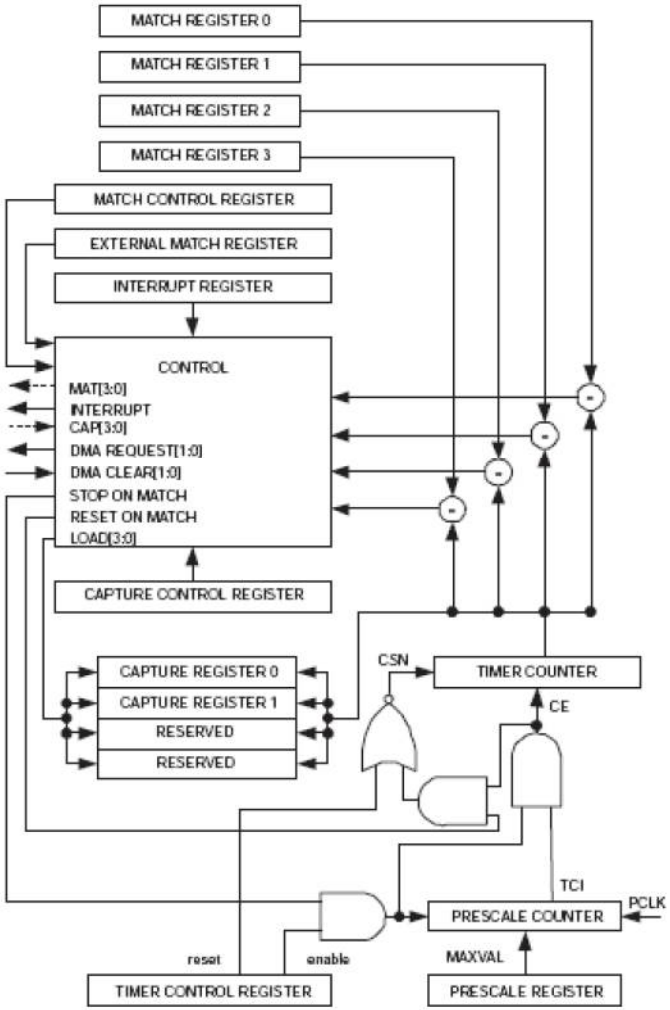
Bit	Symbol	Value	Description
0	CAP0RE	1	Capture on CAPn.0 rising edge: a sequence of 0 then 1 on CAPn.0 will cause CR0 to be loaded with the contents of TC.
		0	This feature is disabled.
1	CAP0FE	1	Capture on CAPn.0 falling edge: a sequence of 1 then 0 on CAPn.0 will cause CR0 to be loaded with the contents of TC.
		0	This feature is disabled.
2	CAP0I	1	Interrupt on CAPn.0 event: a CR0 load due to a CAPn.0 event will generate an interrupt.
		0	This feature is disabled.
3	CAP1RE	1	Capture on CAPn.1 rising edge: a sequence of 0 then 1 on CAPn.1 will cause CR1 to be loaded with the contents of TC.
		0	This feature is disabled.
4	CAP1FE	1	Capture on CAPn.1 falling edge: a sequence of 1 then 0 on CAPn.1 will cause CR1 to be loaded with the contents of TC.
		0	This feature is disabled.
5	CAP1I	1	Interrupt on CAPn.1 event: a CR1 load due to a CAPn.1 event will generate an interrupt.
		0	This feature is disabled.

Timer/Counter Programming

Capture TC into TC when +ve edge is applied to CAP0.0 (P1.26) or CAP0.1(P1.27)

```
#include<stdio.h>
#include<LPC17xx.h>
void delay(void)
{
        //LPC_SC->PCONP |= (1<<1);    //powers the T0
        LPC_TIM0->CCR=9;//capture on positive edge
        LPC_TIM0->TCR = 0x00000002;     // Timer0 Reset
        LPC_TIM0->EMR = 0X20;//Set match bit upon match
        LPC_TIM0->PR = 3000; //for 1 ms
        LPC_TIM0->MR0 = 1000;                 //for 1 second
        LPC_TIM0->MCR = 0x00000004;     // stop PC and TC on MR0
        LPC_TIM0->TCR = 0x00000001;     // Timer0 Enable
        while ( !(LPC_TIM0->EMR & 0x01)); // wait until match
        return;
        }

int main(void)
{
        LPC_GPIO0->FIODIR=0x00000004;
        LPC_PINCON->PINSEL3 |=(3<<20) | (3<<22);//select cap 0.0 and cap 0.1
                                while(1)
        {
                LPC_GPIO0->FIOPIN=~(LPC_GPIO0->FIOPIN & 0x00000004);//toggle p0.2
                delay();

        }
}
```

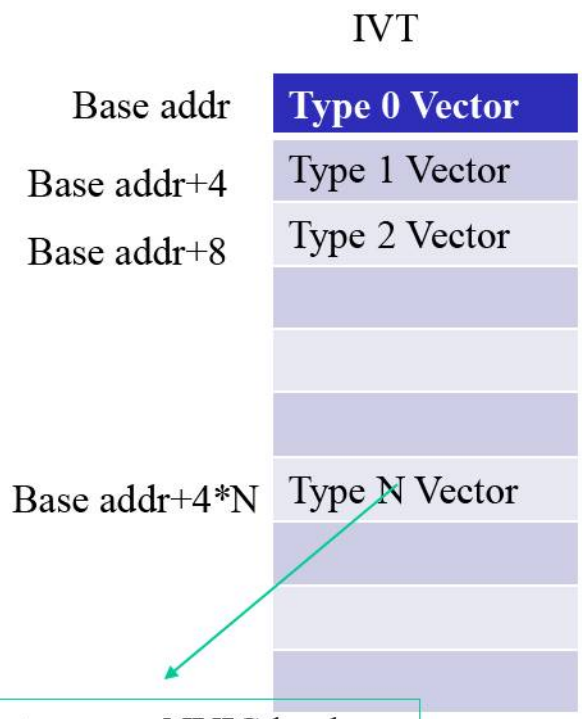
Timer/Counter Programming



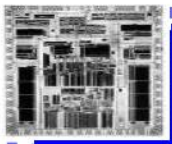
Timer Block diagram

Nested Vectored Interrupt Controller(NVIC)

- Controls system exceptions and peripheral interrupts
- In the LPC176x, the NVIC supports 35 vectored interrupts
- Each peripheral device may have one or more interrupt lines to the Vectored Interrupt Controller.
- Interrupt numbers relate to where entries are stored in the Interrupt vector table.
- Interrupt Vector – Is the address of Interrupt Service Subroutine (ISR)
- Interrupt vector of Interrupt Type N is stored at an offset N*4 from the base address of Interrupt Vector Table(IVT)
- If the peripheral device is enabled to generate Interrupt when some event

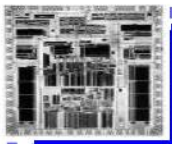


When Interrupt occurs, NVIC loads vector to PC and executes the ISR to provide the service to peripheral



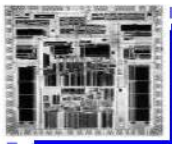
Nested Vectored Interrupt Controller(NVIC)

- If the peripheral device is enabled to generate Interrupt when some event occurs, the INTR request is sent to NVIC
- If NVIC is enabled to service the INTR request from the peripheral, it services the INTR request by executing ISR pertaining to the peripheral.(i.e Save the return address, Get the Interrupt Vector from IVT and load that address to PC. Upon completion of ISR execution resumes the calling function)



Nested Vectored Interrupt Controller(NVIC)

- In case of Timer, there are 6 INTR enable flags (4 in MCR and 2 in CCR. i.e 4 Match events and 2 Capture events can generate the Interrupt when the event occurs)
- When the event occurs the corresponding bit is set automatically in the IR register. This indicates the NVIC about the event
- If the NVIC is enabled to service the Timer Interrupt, it executes the corresponding ISR and gives the desired service to the Timer.
- In the ISR, clear the corresponding bit, by writing back 1.



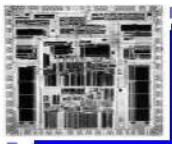
Timer/Counter Interrupt Programming

Interrupt Register (IR)

The Interrupt Register consists of 4 bits for the match interrupts and 2 bits for the capture interrupts. If an interrupt is generated then the corresponding bit in the IR will be high. Otherwise, the bit will be low.

Writing a logic one to the corresponding IR bit will reset the interrupt. Writing a zero has no effect.

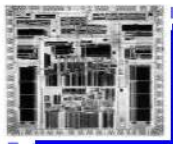
Bit	Symbol	Description
0	MR0 Interrupt	Interrupt flag for match channel 0.
1	MR1 Interrupt	Interrupt flag for match channel 1.
2	MR2 Interrupt	Interrupt flag for match channel 2.
3	MR3 Interrupt	Interrupt flag for match channel 3.
4	CR0 Interrupt	Interrupt flag for capture channel 0 event.
5	CR1 Interrupt	Interrupt flag for capture channel 1 event.



Timer/Counter Interrupt Programming

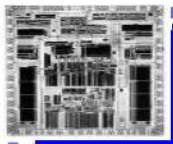
```
#include<stdio.h>
#include<LPC17xx.h>
unsigned int ticks=0,x;
void TIMER0_IRQHandler(void)
{
LPC_TIM0->IR = 1;
                ticks++;
                if(ticks==1000)
                {
                                ticks=0;
                                LPC_GPIO0->FIOPIN=~(LPC_GPIO0->FIOPIN & 0x00000004);
                }
                                }
void init_timer0(void)
{
                LPC_TIM0->TCR = 0x00000002;     // Timer0 Reset
                LPC_TIM0->CTCR =0x00;//Timer
                LPC_TIM0->MR0 = 2999; //  For 1ms
                LPC_TIM0->EMR = 0X00;//Do nothing for EM0
                LPC_TIM0->PR = 0;
                LPC_TIM0->MCR = 0x00000003;   //Reset TC upon Match-0 and generate INTR
                LPC_TIM0->TCR = 0x00000001;     // Timer0 Enable

                return;
```

Toggle LED connected to p0.2 every second while displaying the status of switch connected to P1.0 on the LED connected to P2.0



Timer/Counter Interrupt Programming

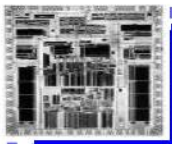
```
int main(void)
{
        LPC_GPIO0->FIODIR=0x00000004;
        LPC_GPIO2->FIODIR=0x00000001;
        init_timer0();
        NVIC_EnableIRQ(TIMER0_IRQn);//timer 0 intr enabled in NVIC
                while(1)
                {
                        LPC_GPIO2->FIOPIN=(LPC_GPIO1->FIOPIN & 0x01) ;
                }

}
```



Timer/Counter Interrupt Programming

Toggle P0.2 whenever counter value reaches 3. I. e for every 4 edges using counter interrupt.

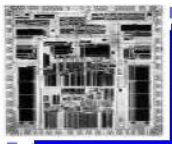
```
#include<stdio.h>
#include<LPC17xx.h>
void TIMER0_IRQHandler(void)
{
                        LPC_TIM0->IR = 1; //Clear the interrupt
                        LPC_GPIO0->FIOPIN=~(LPC_GPIO0->FIOPIN & 0x00000004);

}
void init_timer0(void)
{       LPC_TIM0->TCR = 0x00000002;     // Timer0 Reset
        LPC_TIM0->CTCR =0x05; // Counter at +ve edge of CAP0.1
        LPC_TIM0->MR0 = 3;
        LPC_TIM0->EMR = 0X00;
        LPC_TIM0->PR = 0;
        LPC_TIM0->MCR = 0x00000003;
        LPC_TIM0->TCR = 0x00000001;     // Timer0 Enable
        return;
        }

int main(void)
{
        LPC_GPIO0->FIODIR=0x00000004;
        LPC_PINCON->PINSEL3 |=((3<<22)|(3<<24));
        init_timer0();
        NVIC_EnableIRQ(TIMER0_IRQn);
        while(1);
}
```



Timer/Counter Interrupt Programming

Timer interrupt for rectangular waveform generation (1.5 second HIGH and 0.5 second LOW)

```
include<stdio.h>
#include<LPC17xx.h>
unsigned char flag=1;
void TIMER0_IRQHandler(void)
{
LPC_TIM0->IR = 1;

if(flag)
        {
                flag=0;
                LPC_TIM0->TCR = 0x00000002;    // Timer0 Reset
                LPC_GPIO0->FIOCLR=0x00000004;
                LPC_TIM0->MR0 = 500;
                LPC_TIM0->TCR = 0x00000001;    // Timer0 Enable
        }
        else
                {
                flag=1;
                LPC_TIM0->TCR = 0x00000002;    // Timer0 Reset
                LPC_GPIO0->FIOSET=0x00000004;
                LPC_TIM0->MR0 = 1500;
                LPC_TIM0->TCR = 0x00000001;    // Timer0 Enable
                }

}
```



Timer/Counter Interrupt Programming

```
void init_timer0(void)
{
        LPC_TIM0->TCR = 0x00000002;     // Timer0 Reset
        LPC_TIM0->CTCR =0x00;
        LPC_TIM0->MR0 = 1500;
        LPC_TIM0->EMR = 0X00;
        LPC_TIM0->PR = 3000;
        LPC_TIM0->MCR = 0x00000005;
        LPC_TIM0->TCR = 0x00000001;     // Timer0 Enable
        LPC_GPIO0->FIOSET=0x00000004;
        return;
}
int main(void)
{
        LPC_GPIO0->FIODIR=0x00000004;
        init_timer0();
        NVIC_EnableIRQ(TIMER0_IRQn);
        while(1);
}
```

XIAMEN AMOTEC DISPLAY CO.,LTD

SPECIFICATIONS OF LCD MODULE

MODULE NO : ADM1602K-NSW-FBS/3.3V

DOC.REVISION: 00

	SIGNATURE	DATE
PREPARED BY (RD ENGINEER)	QIU	2008-10-29
CHECKED BY	Chen	2008-10-29
APPROVED BY	yf	2008-10-29

DOCUMENT REVISION HISTORY

VERSINO	DATE	DESCRIPTION	CHANGED BY
00	Oct-29-2008	First issue	

CONTENTS

1. Features

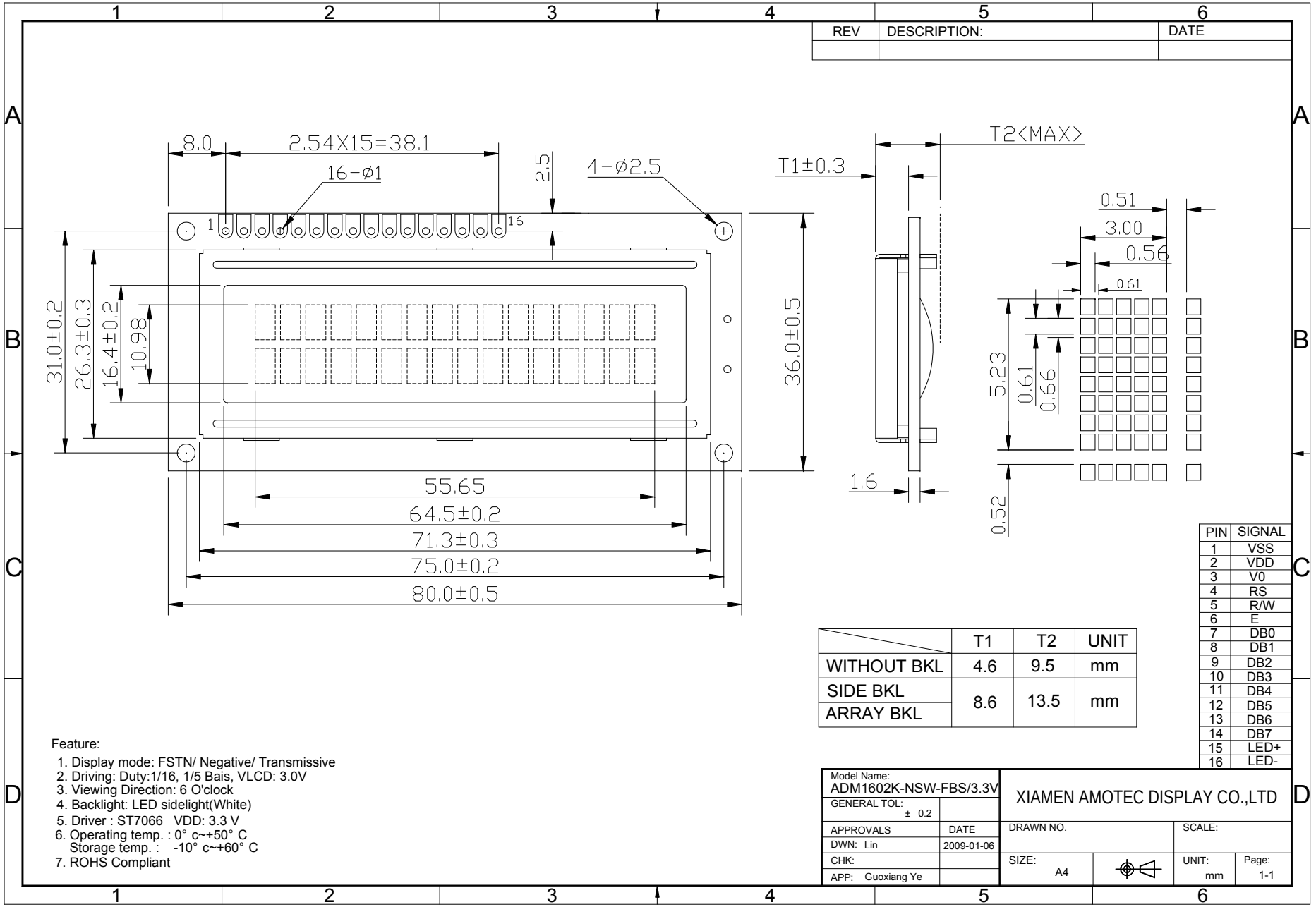
1. 5x8 dots with cursor
2. 16characters *2lines display
3. 4-bit or 8-bit MPU interfaces
4. Built-in controller (ST7066 or equivalent)
5. Display Mode & Backlight Variations
6. ROHS Compliant

LCD type	☐TN			
	☐FSTN	☑FSTN Negative		
	☐STN Yellow Green	☐STN Gray	☐STN Blue Negative	
View direction	☑6 O'clock	☐12 O'clock		
Rear Polarizer	☐Reflective	☐Transflective	☑Transmissive	
Backlight Type	☑LED	☐EL	☐Internal Power	☑3.3V Input
		☐CCFL	☑External Power	☐5.0V Input
Backlight Color	☑White	☐ Blue	☐ Amber	☐Yellow-Green
Temperature Range	☑Normal	☐Wide		☐Super Wide
DC to DC circuit	☐Build-in		☑Not Build-in	
Touch screen	☐With		☑Without	
Font type	☑English-Japanese	☐English-Europen	☐English-Russian	☐other

2. MECHANICAL SPECIFICATIONS

Module size	80.0mm(L)*36.0mm(W)* Max13.5(H)mm
Viewing area	64.5mm(L)*16.4mm(W)
Character size	3.00mm(L)*5.23mm(W)
Character pitch	3.51mm(L)*5.75mm(W)
Weight	Approx.

3. Outline dimension



	T1	T2	UNIT
WITHOUT BKL	4.6	9.5	mm
SIDE BKL / ARRAY BKL	8.6	13.5	mm

PIN	SIGNAL
1	VSS
2	VDD
3	V0
4	RS
5	R/W
6	E
7	DB0
8	DB1
9	DB2
10	DB3
11	DB4
12	DB5
13	DB6
14	DB7
15	LED+
16	LED-

Feature:

1. Display mode: FSTN/ Negative/ Transmissive
2. Driving: Duty:1/16, 1/5 Bais, VLCD: 3.0V
3. Viewing Direction: 6 O'clock
4. Backlight: LED sidelight(White)
5. Driver : ST7066 VDD: 3.3 V
6. Operating temp. : 0° c~+50° C
   Storage temp. : -10° c~+60° C
7. ROHS Compliant

Model Name:	ADM1602K-NSW-FBS/3.3V
GENERAL TOL: ± 0.2	
APPROVALS	DATE
DWN: Lin	2009-01-06
CHK:	
APP: Guoxiang Ye	

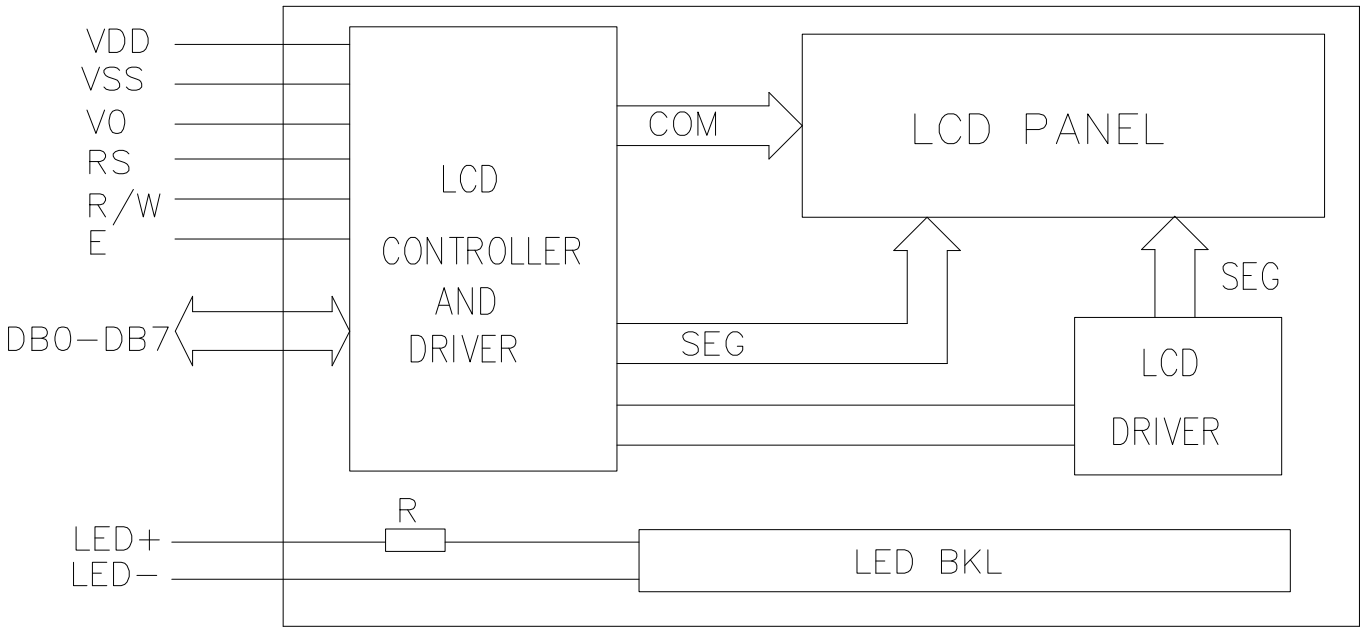
XIAMEN AMOTEC DISPLAY CO.,LTD

DRAWN NO.		SCALE:	
SIZE: A4		UNIT: mm	Page: 1-1

4. Absolute maximum ratings

Item	Symbol	Standard			Unit
Power voltage	V_{DD}-V_{SS}	0	-	7.0	V
Input voltage	V_{IN}	VSS	-	VDD	
Operating temperature range	V_{OP}	0	-	+50	℃
Storage temperature range	V_{ST}	-10	-	+60	

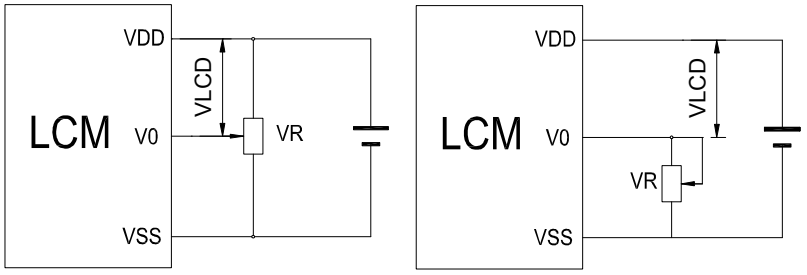
5. Block diagram



6. Interface pin description

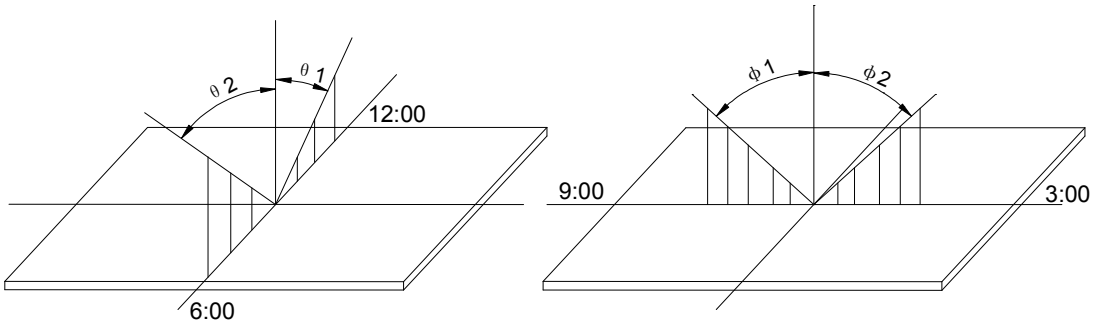
Pin no.	Symbol	External connection	Function
1	Vss	Power supply	Signal ground for LCM
2	V_{DD}		Power supply for logic for LCM
3	V_0		Contrast adjust
4	RS	MPU	Register select signal
5	R/W	MPU	Read/write select signal
6	E	MPU	Operation (data read/write) enable signal
7~10	DB0~DB3	MPU	Four low order bi-directional three-state data bus lines. Used for data transfer between the MPU and the LCM. These four are not used during 4-bit operation.
11~14	DB4~DB7	MPU	Four high order bi-directional three-state data bus lines. Used for data transfer between the MPU
15	LED+	LED BKL power supply	Power supply for BKL
16	LED-		Power supply for BKL

7. Contrast adjust



V_{DD}~V_0: LCD Driving voltage VR: 10k~20k

8. Optical characteristics



STN type display module (Ta=25℃, VDD=3.3V)

Item	Symbol	Condition	Min.	Typ.	Max.	Unit
Viewing angle	θ 1	$C_r \geqslant 3$		20		deg
	θ 2			40		
	Φ 1			35		
	Φ 2			35		
Contrast ratio	C_r		-	10	-	-
Response time (rise)	T_r	-	-	200	250	ms
Response time (fall)	T_r	-	-	300	350	

9. Electrical characteristics

DC characteristics

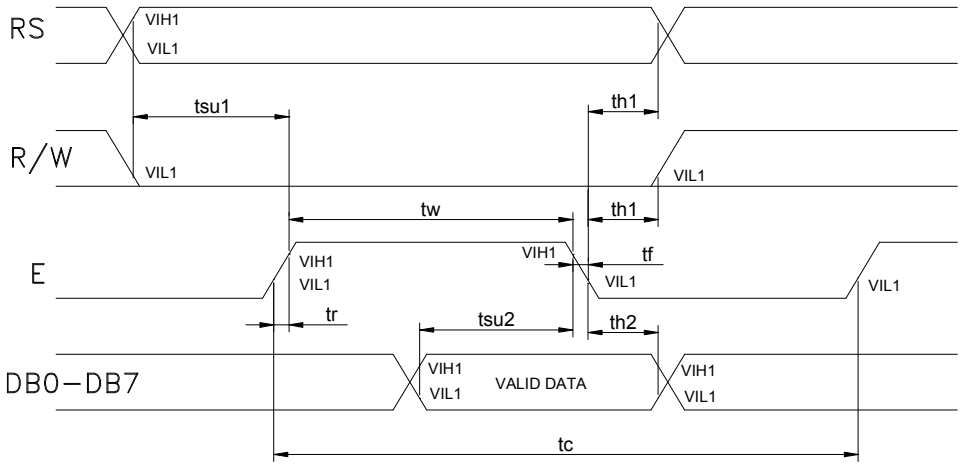
Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Supply voltage for LCD	V_{DD}-V_0	Ta =25℃	-	3.0	-	V
Input voltage	V_{DD}		3.1	3.3	3.5	
Supply current	I_{DD}	Ta=25℃, V_{DD}=3.3V	-	1.5	2.5	mA
Input leakage current	I_{LKG}		-	-	1.0	uA
“H” level input voltage	V_{IH}		2.2	-	V_{DD}	V
“L” level input voltage	V_{IL}	Twice initial value or less	0	-	0.6	
“H” level output voltage	V_{OH}	LOH=-0.25mA	2.4	-	-	
“L” level output voltage	V_{OL}	LOH=1.6mA	-	-	0.4	
Backlight supply voltage	V_F		-	3.0		
Backlight supply current	I_{LED}	V_{LED}=3.3 V R=25 Ω			16	mA

10. Timing Characteristics

Write cycle (Ta=25℃, VDD=3.3V)

Parameter	Symbol	Test pin	Min.	Typ.	Max.	Unit
Enable cycle time	t_c	E	500	-	-	ns
Enable pulse width	t_w		300	-	-	
Enable rise/fall time	t_r, t_f		-	-	25	
RS; R/W setup time	t_{su1}	RS; R/W	100	-	-	
RS; R/W address hold time	t_{h1}	RS; R/W	10	-	-	
Read data output delay	t_{su2}	DB0~DB7	60	-	-	
Read data hold time	t_{h2}		10	-	-	

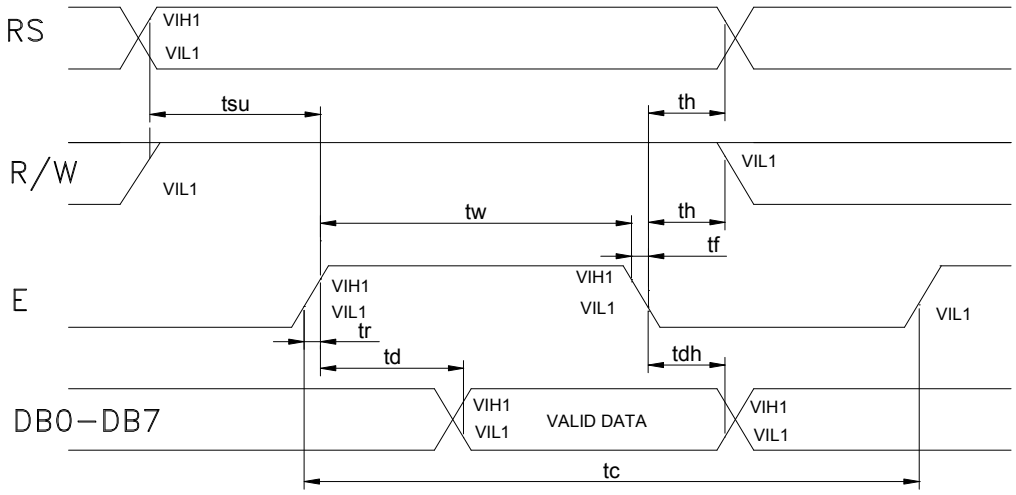
Write mode timing diagram



Read cycle (Ta=25℃, VDD=3.3V)

Parameter	Symbol	Test pin	Min.	Typ.	Max.	Unit
Enable cycle time	t_c	E	500	-	-	ns
Enable pulse width	t_w		300	-	-	
Enable rise/fall time	t_r, t_f		-	-	25	
RS; R/W setup time	t_{su}	RS; R/W	100	-	-	
RS; R/W address hold time	t_h	RS; R/W	10	-	-	
Read data output delay	t_d	DB0~DB7	60	-	90	
Read data hold time	t_{dh}		20	-	-	

Read mode timing diagram



11. FUNCTION DESCRIPTION

11.1 System Interface

This chip has all two kinds of interface type with MPU : 4-bit bus and 8-bit bus. 4-bit bus and 8-bit bus is selected by DL bit in the instruction register.

11.2 Busy Flag (BF)

When BF = “High”, it indicates that the internal operation is being processed. So during this time the next instruction cannot be accepted. BF can be read, when RS = Low and R/W = High (Read Instruction Operation), through DB7 port. Before executing the next instruction, be sure that BF is not high.

11.3 Address Counter (AC)

Address Counter (AC) stores DDRAM/CGRAM address, transferred from IR. After writing into (reading from) DDRAM/CGRAM, AC is automatically increased (decreased) by 1. When RS = “Low” and R/W = “High”, AC can be read through DB0 – DB6 ports.

11.4 Display Data RAM (DDRAM)

DDRAM stores display data of maximum 80 x 8 bits (80 characters). DDRAM address is set in the address counter (AC) as a hexadecimal number.

Display position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
DDRAM address	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F
DDRAM address	40	41	42	43	44	45	46	47	48	49	4A	4B	4C	4D	4E	4F

11.5 CGROM (Character Generator ROM)

CGROM has a 5 x 8 dots 204 characters pattern and a 5 x 10 dots 32 characters pattern. CGROM has 204 character patterns of 5 x 8 dots.

11.6 CGRAM (Character Generator RAM)

CGRAM has up to 5 ． 8 dot, 8 characters. By writing font data to CGRAM, user defined characters can be used.

Character Code (DDRAM Data)									CGRAM Address						Character Patterns (CGRAM Data)							
b8	b7	b6	b5	b4	b3	b2	b1	b0	b5	b4	b3	b2	b1	b0	b7	b6	b5	b4	b3	b2	b1	b0
0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	-	-	-	1	1	1	1	1
						0	0	0				0	0	1				0	0	1	0	0
						0	0	0				0	1	0				0	0	1	0	0
						0	0	0				0	1	1				0	0	1	0	0
						0	0	0				1	0	0				0	0	1	0	0
						0	0	0				1	0	1				0	0	1	0	0
						0	0	0				1	1	0				0	0	1	0	0
						0	0	0				1	1	1				0	0	0	0	0
0	0	0	0	0	-	0	0	1	0	0	1	0	0	0	-	-	-	1	1	1	1	0
						0	0	1				0	0	1				1	0	0	0	1
						0	0	1				0	1	0				1	0	0	0	1
						0	0	1				0	1	1				1	1	1	1	0
						0	0	1				1	0	0				1	0	1	0	0
						0	0	1				1	0	1				1	0	0	1	0
						0	0	1				1	1	0				1	0	0	0	1
						0	0	1				1	1	1				0	0	0	0	0

Relationship between CGRAM Addresses, Character Codes (DDRAM) and Character patterns (CGRAM Data)

Notes:

1. Character code bits 0 to 2 correspond to CGRAM address bits 3 to 5 (3 bits: 8 types).
2. CGRAM address bits 0 to 2 designate the character pattern line position. The 8th line is the cursor position

and its display is formed by a logical OR with the cursor. Maintain the 8th line data, corresponding to the cursor display position, at 0 as the cursor display. If the 8th line data is 1, 1 bit will light up the 8th line regardless of the cursor presence.
3. Character pattern row positions correspond to CGRAM data bits 0 to 4 (bit 4 being at the left).
4. As shown Table, CGRAM character patterns are selected when character code bits 4 to 7 are all 0. However, since character code bit 3 has no effect, the R display example above can be selected by either character code 00H or 08H.
5. 1 for CGRAM data corresponds to display selection and 0 to non-selection.
"-": Indicates no effect.

11.7 Cursor/Blink Control Circuit
It controls cursor/blink ON/OFF at cursor position.

11.8 Outline
To overcome the speed difference between the internal clock of ST7066 and the MPU clock, ST7066 performs internal operations by storing control in formations to IR or DR. The internal operation is determined according to the signal from MPU, composed of read/write and data bus (Refer to Table7).
Instructions can be divided largely into four groups:

1) ST7066 function set instructions (set display methods, set data length, etc.)
2) Address set instructions to internal RAM
3) Data transfer instructions with internal RAM
4) Others

The address of the internal RAM is automatically increased or decreased by 1.

Note: during internal operation, busy flag (DB7) is read "High".
Busy flag check must be preceded by the next instruction.

11.9 Instruction Table

Instruction	Instruction code										Description	Execution time (fosc= 270 KHZ
	RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0		
Clear Display	0	0	0	0	0	0	0	0	0	1	Write “20H” to DDRA and set DDRAM address to “00H” from AC	1.53ms
Return Home	0	0	0	0	0	0	0	0	1	-	Set DDRAM address to “00H” From AC and return cursor to Its original position if shifted. The contents of DDRAM are not changed.	1.53ms
Entry mode Set	0	0	0	0	0	0	0	1	I/D	SH	Assign cursor moving direction And blinking of entire display	39us
Display ON/ OFF control	0	0	0	0	0	0	1	D	C	B	Set display (D), cursor (C), and Blinking of cursor (B) on/off Control bit.	
Cursor or Display shift	0	0	0	0	0	1	S/C	R/L	-	-	Set cursor moving and display Shift control bit, and the Direction, without changing of DDRAM data.	39us
Function set	0	0	0	0	1	DL	N	F	-	-	Set interface data length (DL: 8- Bit/4-bit), numbers of display Line (N: =2-line/1-line) and, Display font type (F: 5x11/5x8)	39us
Set CGRAM Address	0	0	0	1	AC5	AC4	AC3	AC2	AC1	AC0	Set CGRAM address in address Counter.	39us
Set DDRAM Address	0	0	1	AC6	AC5	AC4	AC3	AC2	AC1	AC0	Set DDRAM address in address Counter.	39us
Read busy Flag and Address	0	1	BF	AC6	AC5	AC4	AC3	AC2	AC1	AC0	Whether during internal Operation or not can be known By reading BF. The contents of Address counter can also be read.	0us
Write data to Address	1	0	D7	D6	D5	D4	D3	D2	D1	D0	Write data into internal RAM (DDRAM/CGRAM).	43us
Read data From RAM	1	1	D7	D6	D5	D4	D3	D2	D1	D0	Read data from internal RAM (DDRAM/CGRAM).	43us

NOTE:

When an MPU program with checking the busy flag (DB7) is made, it must be necessary 1/2fosc is necessary for executing the next instruction by the falling edge of the “E” signal after the busy flag (DB7) goes to “Low”.

11.3Contents

1) Clear display

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

Clear all the display data by writing “20H” (space code) to all DDRAM address, and set DDRAM address to “00H” into AC (address counter).

Return cursor to the original status, namely, bring the cursor to the left edge on the fist line of the display.

Make the entry mode increment (I/D=“High”).

2) Return home

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

Return home is cursor return home instruction.

Set DDRAM address to “00H” into the address counter.
Return cursor to its original site and return display to its original status, if shifted.
Contents of DDRAM does not change.

3) Entry mode set

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

Set the moving direction of cursor and display.

I/D: increment / decrement of DDRAM address (cursor or blink)
When I/D=“high”, cursor/blink moves to right and DDRAM address is increased by 1.
When I/D=“Low”, cursor/blink moves to left and DDRAM address is increased by 1.
*CGRAM operates the same way as DDRAM, when reading from or writing to CGRAM.

SH: shift of entire display
When DDRAM read (CGRAM read/write) operation or SH=“Low”, shifting of entire display is not performed. If SH =“High” and DDRAM write operation, shift of entire display is performed according to I/D value. (I/D=“high”. shift left, I/D=“Low”. Shift right).

4) Display ON/OFF control

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

Control display/cursor/blink ON/OFF 1 bit register.

D: Display ON/OFF control bit
When D=“High”, entire display is turned on.
When D=“Low”, display is turned off, but display data remains in DDRAM.

C: cursor ON/OFF control bit
When D=“High”, cursor is turned on.
When D=“Low”, cursor is disappeared in current display, but I/D register preserves its data.

B: Cursor blink ON/OFF control bit
When B=“High”, cursor blink is on, which performs alternately between all the “High” data and display characters at the cursor position.
When B=“Low”, blink is off.

5) Cursor or display shift

RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	0	0	0	0	1	S/C	R/L	-	-

Shifting of right/left cursor position or display without writing or reading of display data.
This instruction is used to correct or search display data.
During 2-line mode display, cursor moves to the 2nd line after the 40th digit of the 1st line.
Note that display shift is performed simultaneously in all the lines.
When display data is shifted repeatedly, each line is shifted individually.
When display shift is performed, the contents of the address counter are not changed.

Shift patterns according to S/C and R/L bits

S/C	R/L	Operation
0	0	Shift cursor to the left, AC is decreased by 1
0	1	Shift cursor to the right, AC is increased by 1
1	0	Shift all the display to the left, cursor moves according to the display
1	1	Shift all the display to the right, cursor moves according to the display

6) Function set

RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	0	0	0	1	DL	N	F	-	-

DL: Interface data length control bit

When DL="High", it means 8-bit bus mode with MPU.
When DL="Low", it means 4-bit bus mode with MPU. Hence, DL is a signal to select 8-bit or 4-bit bus mode.
When 4-but bus mode, it needs to transfer 4-bit data twice.

N: Display line number control bit

When N="Low", 1-line display mode is set.
When N="High", 2-line display mode is set.

F: Display line number control bit

When F="Low", 5x8 dots format display mode is set.
When F="High", 5x11 dots format display mode.

7) Set CGRAM address

RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	0	0	1	AC5	AC4	AC3	AC2	AC1	AC0

Set CGRAM address to AC.
The instruction makes CGRAM data available from MPU.

8) Set DDRAM address

RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	0	1	AC6	AC5	AC4	AC3	AC2	AC1	AC0

Set DDRAM address to AC.
This instruction makes DDRAM data available form MPU.
When 1-line display mode (N=LOW), DDRAM address is form "00H" to "4FH".In 2-line display mode (N=High), DDRAM address in the 1st line form "00H" to "27H", and DDRAM address in the 2nd line is from "40H" to "67H".

9) Read busy flag & address

RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	1	BF	AC6	AC5	AC4	AC3	AC2	AC1	AC0

This instruction shows whether SPLC780D is in internal operation or not.
If the resultant BF is "High", internal operation is in progress and should wait BF is to be LOW, which by then the nest instruction can be performed. In this instruction you can also read the value of the address counter.

10) Write data to RAM

RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
1	0	D7	D6	D5	D4	D3	D2	D1	D0

Write binary 8-bit data to DDRAM/CGRAM.
The selection of RAM from DDRAM, and CGRAM, is set by the previous address set instruction (DDRAM address set, CGRAM address set).
RAM set instruction can also determine the AC direction to RAM.
After write operation. The address is automatically increased/decreased by 1, according to the entry mode.

11) Read data from RAM

RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
1	1	D7	D6	D5	D4	D3	D2	D1	D0

Read binary 8-bit data from DDRAM/CGRAM.

The selection of RAM is set by the previous address set instruction. If the address set instruction of RAM is not performed before this instruction, the data that has been read first is invalid, as the direction of AC is not yet determined. If RAM data is read several times without RAM address instructions set before, read operation, the correct RAM data can be obtained from the second. But the first data would be incorrect, as there is no time margin to transfer RAM data.

In case of DDRAM read operation, cursor shift instruction plays the same role as DDRAM address set

instruction, it also transfers RAM data to output data register.

After read operation, address counter is automatically increased/decreased by 1 according to the entry mode.

After CGRAM read operation, display shift may not be executed correctly.

NOTE: In case of RAM write operation, AC is increased/decreased by 1 as in read operation.

At this time, AC indicates next address position, but only the previous data can be read by the read instruction.

12.Standard character pattern

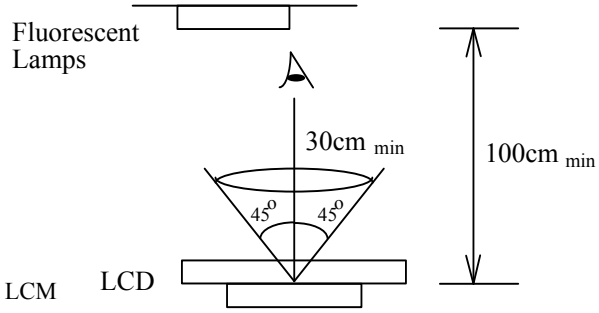
Upper 4bit / Lower 4bit	LLLL	LLLH	LLHL	LLHH	LHLL	LHLH	LHHL	LHHH	HLLL	HLLH	HLHL	HLHH	HHLL	HHLH	HHHL	HHHH
LLLL	CG RAM (1)															
LLLH	(2)															
LLHL	(3)															
LLHH	(4)															
LHLL	(5)															
LHLH	(6)															
LHHL	(7)															
LHHH	(8)															
HLLL	(1)															
HLLH	(2)															
HLHL	(3)															
HLHH	(4)															
HHLL	(5)															
HHLH	(6)															
HHHL	(7)															
HHHH	(8)															

13. QUALITY SPECIFICATIONS

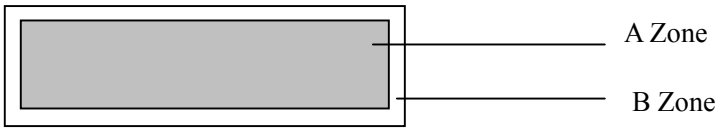
13.1 Standard of the product appearance test

Manner of appearance test: The inspection should be performed in using 20W x 2 fluorescent lamps. Distance between LCM and fluorescent lamps should be 100 cm or more. Distance between LCM and inspector eyes should be 30 cm or more.

Viewing direction for inspection is 45° from vertical against LCM.



Definition of zone:



A Zone: Active display area (minimum viewing area).
B Zone: Non-active display area (outside viewing area).

13.2 Specification of quality assurance

AQL inspection standard

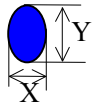
Sampling method: MIL-STD-105E, Level II, single sampling

Defect classification **(Note: * is not including)**

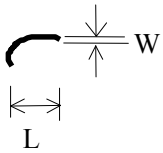
Classify	Item		Note	AQL
Major	Display state	Short or open circuit	1	0.65
		LC leakage		
		Flickering		
		No display		
		Wrong viewing direction		
		Contrast defect (dim, ghost)	2	
		Back-light	1,8	
	Non-display	Flat cable or pin reverse	10	
		Wrong or missing component	11	
Minor	Display state	Background color deviation	2	1.0
		Black spot and dust	3	
		Line defect, Scratch	4	
		Rainbow	5	
		Chip	6	
		Pin hole	7	
	Polarizer	Protruded	12	
		Bubble and foreign material	3	
	Soldering	Poor connection	9	
	Wire	Poor connection	10	
	TAB	Position, Bonding strength	13	

Note on defect classification

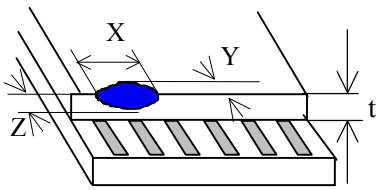
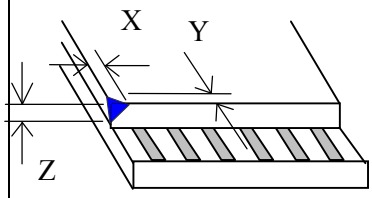
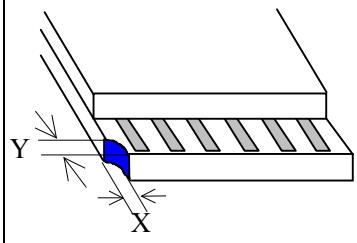
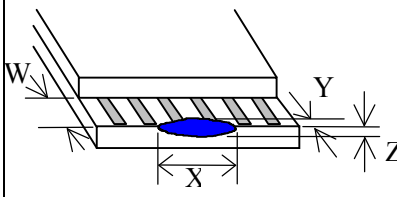
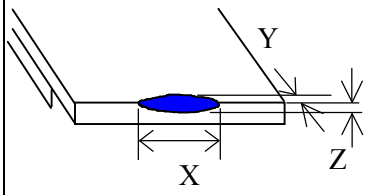
<table>
<tr><th>No.</th><th>Item</th><th>Criterion</th></tr>
<tr><td rowspan="6">1</td><td>Short or open circuit</td><td rowspan="6">Not allow</td></tr>
<tr><td>LC leakage</td></tr>
<tr><td>Flickering</td></tr>
<tr><td>No display</td></tr>
<tr><td>Wrong viewing direction</td></tr>
<tr><td>Wrong Back-light</td></tr>
<tr><td rowspan="2">2</td><td>Contrast defect</td><td rowspan="2">Refer to approval sample</td></tr>
<tr><td>Background color deviation</td></tr>
<tr><td>3</td><td>Point defect,
Black spot, dust
(including Polarizer)

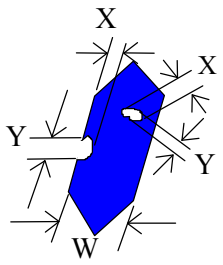
ϕ = (X+Y)/2</td><td> 

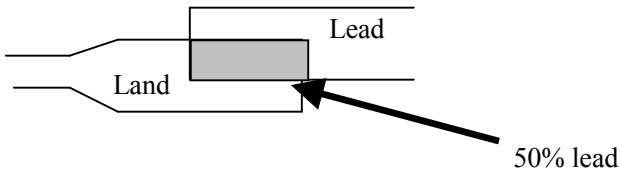
<table>
<tr><th>Point Size</th><th>Acceptable Qty.</th></tr>
<tr><td>ϕ≤0.10</td><td>Disregard</td></tr>
<tr><td>0.10<ϕ≤0.20</td><td>3</td></tr>
<tr><td>0.20<ϕ≤0.25</td><td>2</td></tr>
<tr><td>0.25<ϕ≤0.30</td><td>1</td></tr>
<tr><td>ϕ>0.30</td><td>0</td></tr>
</table>
Unit：mm</td></tr>
<tr><td>4</td><td>Line defect,

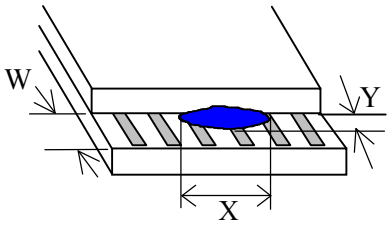
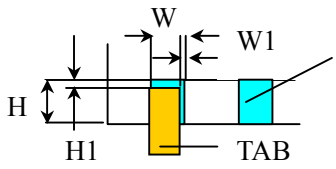
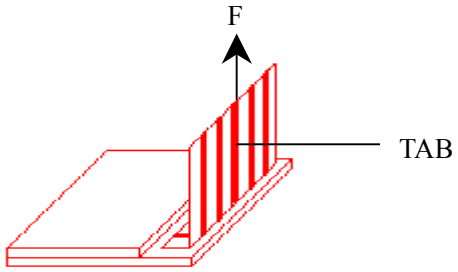
Scratch</td><td> 

<table>
<tr><th colspan="2">Line</th><th>Acceptable Qty.</th></tr>
<tr><td>L</td><td>W</td><td></td></tr>
<tr><td>---</td><td>0.015≥W</td><td>Disregard</td></tr>
<tr><td>3.0≥L</td><td>0.03≥W</td><td rowspan="2">2</td></tr>
<tr><td>2.0≥L</td><td>0.05≥W</td></tr>
<tr><td>1.0≥L</td><td>0.1＞W</td><td>1</td></tr>
<tr><td>---</td><td>0.05<W</td><td>Applied as point defect</td></tr>
</table>
Unit: mm</td></tr>
<tr><td>5</td><td>Rainbow</td><td>Not more than two color changes across the viewing area.</td></tr>
</table>

No	Item	Criterion
6	Chip Remark: X: Length direction Y: Short direction Z: Thickness direction t: Glass thickness W: Terminal Width	 Acceptable criterion X: ≤2; Y: 0.5mm; Z: ≤t/2  Acceptable criterion X: ≤2; Y: 0.5mm; Z: ≤t  Acceptable criterion X: ≤3; Y: ≤2; Z: ≤t shall not reach to ITO  Acceptable criterion X: Disregard; Y: ≤0.2; Z: ≤t  Acceptable criterion X: ≤5; Y: ≤2; Z: ≤t/3

<table>
<tr><th>No.</th><th>Item</th><th>Criterion</th></tr>
<tr><td>7</td><td>Segment
pattern
W = Segment width
ϕ = (X+Y)/2</td><td>(1) Pin hole
ϕ < 0.10mm is acceptable.
 

<table>
<tr><th>Point Size</th><th>Acceptable Qty</th></tr>
<tr><td>ϕ≤1/4W</td><td>Disregard</td></tr>
<tr><td>1/4W< ϕ≤1/2W</td><td>1</td></tr>
<tr><td>ϕ>1/2W</td><td>0</td></tr>
</table>
Unit: mm</td></tr>
<tr><td>8</td><td>Back-light</td><td>(1) The color of backlight should correspond its specification.
(2) Not allow flickering</td></tr>
<tr><td>9</td><td>Soldering</td><td>(1) Not allow heavy dirty and solder ball on PCB.
(The size of dirty refer to point and dust defect)
(2) Over 50% of lead should be solderedon Land.
 
</td></tr>
<tr><td>10</td><td>Wire</td><td>(1) Copper wire should not be rusted
(2) Not allow crack on copper wire connection.
(3) Not allow reversing the position of the flat cable.
(4) Not allow exposed copper wire inside the flat cable.</td></tr>
<tr><td>11*</td><td>PCB</td><td>(1) Not allow screw rust or damage.
(2) Not allow missing or wrong putting of component.</td></tr>
</table>

No	Item	Criterion
12	Protruded W: Terminal Width	 Acceptable criteria: Y ≤ 0.4
13	TAB	1. Position  W1≤1/3W H1≤1/3H 2 TAB bonding strength test  P (=F/TAB bonding width) ≥650gf/cm ,(speed rate: 1mm/min) 5pcs per SOA (shipment)
14	Total no. of acceptable Defect	A. Zone Maximum 2 minor non-conformities per one unit. Defect distance: each point to be separated over 10mm B. Zone It is acceptable when it is no trouble for quality and assembly in customer's end product.

13.3 Reliability of LCM

Reliability test condition:

Item	Condition	Time (hrs)	Assessment
High temp. Storage	80°C	48	No abnormalities in functions and appearance
High temp. Operating	70°C	48	
Low temp. Storage	-30°C	48	
Low temp. Operating	-20°C	48	
Humidity	40°C/ 90%RH	48	
Temp. Cycle	0°C ← 25°C→ 50°C (30 min ← 5 min → 30min)	10cycles	

Recovery time should be 24 hours minimum. Moreover, functions, performance and appearance shall be free from remarkable deterioration within 50,000 hours under ordinary operating and storage conditions room temperature (20±8°C), normal humidity (below 65% RH), and in the area not exposed to direct sun light.

13.4 Precaution for using LCD/LCM

LCD/LCM is assembled and adjusted with a high degree of precision. Do not attempt to make any alteration or modification. The followings should be noted.

General Precautions:

1. LCD panel is made of glass. Avoid excessive mechanical shock or applying strong pressure onto the surface of display area.
2. The polarizer used on the display surface is easily scratched and damaged. Extreme care should be taken when handling. To clean dust or dirt off the display surface, wipe gently with cotton, or other soft material soaked with isoproply alcohol, ethyl alcohol or trichlorotriflorothane, do not use water, ketone or aromatics and never scrub hard.
3. Do not tamper in any way with the tabs on the metal frame.
4. Do not make any modification on the PCB without consulting AMOTEC
5. When mounting a LCM, make sure that the PCB is not under any stress such as bending or twisting. Elastomer contacts are very delicate and missing pixels could result from slight dislocation of any of the elements.
6. Avoid pressing on the metal bezel, otherwise the elastomer connector could be deformed and lose contact, resulting in missing pixels and also cause rainbow on the display.
7. Be careful not to touch or swallow liquid crystal that might leak from a damaged cell. Any liquid crystal adheres to skin or clothes, wash it off immediately with soap and water.

Static Electricity Precautions:

1. CMOS LSI is used for the module circuit; therefore operators should be grounded whenever he/she comes into contact with the module.
2. Do not touch any of the conductive parts such as the LSI pads; the copper leads on the PCB and the interface terminals with any parts of the human body.

3. Do not touch the connection terminals of the display with bare hand; it will cause disconnection or defective insulation of terminals.
4. The modules should be kept in anti-static bags or other containers resistant to static for storage.
5. Only properly grounded soldering irons should be used.
6. If an electric screwdriver is used, it should be grounded and shielded to prevent sparks.
7. The normal static prevention measures should be observed for work clothes and working benches.
8. Since dry air is inductive to static, a relative humidity of 50-60% is recommended.

Soldering Precautions:

1. Soldering should be performed only on the I/O terminals.
2. Use soldering irons with proper grounding and no leakage.
3. Soldering temperature: 280°C±10°C
4. Soldering time: 3 to 4 second.
5. Use eutectic solder with resin flux filling.
6. If flux is used, the LCD surface should be protected to avoid spattering flux.
7. Flux residue should be removed.

Operation Precautions:

1. The viewing angle can be adjusted by varying the LCD driving voltage Vo.
2. Since applied DC voltage causes electro-chemical reactions, which deteriorate the display, the applied pulse waveform should be a symmetric waveform such that no DC component remains. Be sure to use the specified operating voltage.
3. Driving voltage should be kept within specified range; excess voltage will shorten display life.
4. Response time increases with decrease in temperature.
5. Display color may be affected at temperatures above its operational range.
6. Keep the temperature within the specified range usage and storage. Excessive temperature and humidity could cause polarization degradation, polarizer peel-off or generate bubbles.
7. For long-term storage over 40 C is required, the relative humidity should be kept below 60%,and avoid direct sunlight.

Limited Warranty

AMOTEC LCDs and modules are not consumer products, but may be incorporated by AMOTEC 's customers into consumer products or components thereof, AMOTEC does not warrant that its LCDs and components are fit for any such particular purpose.

1. The liability of AMOTEC is limited to repair or replacement on the terms set forth below. AMOTEC will not be responsible for any subsequent or consequential events or injury or damage to any personnel or user including third party personnel and/or user. Unless otherwise agreed in writing between AMOTEC and the customer, AMOTEC will only replace or repair any of its LCD which is found defective electrically or visually when inspected in accordance with AMOTEC general LCD inspection standard . (Copies available on request)
2. No warranty can be granted if any of the precautions state in handling liquid crystal display above has been disregarded. Broken glass, scratches on polarizer mechanical damages as well as defects that are caused accelerated environment tests are excluded from warranty.
3. In returning the LCD/LCM, they must be properly packaged; there should be detailed description of the failures or defect.

GPIO (General Purpose Input/Output)

Write an embedded C program to turn ON and OFF LEDs connected to P0.11 – P0.4

```
#include <LPC17xx.h>
 unsigned int j;
 unsigned long LED = 0x00000FF0;

int main(void)
{
        SystemInit();
        SystemCoreClockUpdate();

        LPC_PINCON->PINSEL0 =  0x00000000; // P0.15-P0.0 GPIO
        LPC_GPIO0->FIODIR = 0x00000FF0; // P0.11-P0.4 as output

        while(1)
        {
                LPC_GPIO0->FIOSET = LED; // SET P0.11-P0.4
                for(j=0;j<10000;j++); // Delay

                LPC_GPIO0->FIOCLR = LED; // CLEAR P0.11-P0.4
                for(j=0;j<10000;j++); //Delay

        }
}
```

```
LPC_GPIO0->FIOPIN= ~(LPC_GPIO0->FIOPIN & 0x00000FF0);
for(j=0;j<10000;j++); //Delay
```

GPIO (General Purpose Input/Output)

8 bit Johnson Counter on LEDs

Twisted ring counter

Mod -16

2 x 8

P0.11 – P0.4

why

00000000
00000001
00000011
00000111
00001111
00011111
00111111
01111111
11111111
11111110
11111100
11111000
11110000
11100000
11000000
10000000
00000000

ON

OFF

16 states

```
#include <LPC17xx.h>

 unsigned int i,j;
 unsigned long LED = 0x00000010;

 int main(void)
 {
   SystemInit()

   SystemCoreClockUpdate();

   LPC_PINCON->PINSEL0 = 0
                    ;Configure  Port0 pins  P0.4-P0.11 ;as GPIO

   LPC_GPIO0->FIODIR = 0x00000FF0;
                                    ;Configure P0.4-P0.11 as output
```

GPIO (General Purpose Input/Output)

```
while(1)
        {
                LED = 0x00000010; Initial value on LED
                for(i=1;i<9;i++)          //ON the LED's serially
                {
                 LPC_GPIO0->FIOSET = LED;

                 for(j=0;j<10000;j++);
                  LED <<= 1;
                }


                LED = 0x00000010;

                   for(i=1;i<9;i++)        //OFF the LED's serially
                              {
                   LPC_GPIO0->FIOCLR = LED
                    for(j=0;j<10000;j++);
                   LED <<= 1;
                              }

            }
             }
```

GPIO (General Purpose Input/Output)

Write an embedded C program to turn ON LEDs connected to P0.11 – P0.4 when key connected to P2.12 pressed, else turn OFF.

```
#include <LPC17xx.h>
unsigned int j;
unsigned long LED = 0x0000FF00;

int main(void)
{
        SystemInit();
        SystemCoreClockUpdate();

        LPC_PINCON->PINSEL0 =  0x00000000; // P0.15-P0.0 GPIO
        LPC_GPIO0->FIODIR = 0x00000FF0; // P0.11-P0.4 as output

        while(1)
        {
            if ( !(LPC_GPIO2->FIOPIN & 1<<12))

                LPC_GPIO0->FIOSET = LED; // SET P0.11-P0.4
           else

                LPC_GPIO0->FIOCLR = LED; // CLEAR P0.11-P0.4

        }
}
```

Display digits 0-9 in seven segment display.

Seven Segment Display Programming

```
#include<lpc17xx.h>
unsigned char seven_seg[10]={0x3F,0x06,0x5B,0x4F,0x66,0x6D,0x7D,0x07,0x7F,0x6F};
unsigned int i,j;
void delay(void);
int main(void)
 {
            SystemInit();
            SystemCoreClockUpdate();

            LPC_PINCON->PINSEL0 = 0     //P0.4 to P0.11 GPIO data lines
            LPC_GPIO0->FIODIR |= 0x00000FF0;       //P0.4 to P0.11 output
            while (1)
              {
                  for(i=0; i<10; i++)
                   {
                    LPC_GPIO0->FIOPIN = seven_seg[i ] << 4;
                    delay();
                   }
              }
    }
void  delay(void)
{
 for(j=0;j<10000;j++);
}
```

Display a number in multiplexed seven segment display (number is 1,2,3,4).

Multiplexed Seven Segment Display Programming – Display a Number

```
#include <LPC17xx.h>
#include <stdio.h>

 #define   FIRST_SEG          0<<23
 #define   SECOND_SEG         1<<23
 #define   THIRD_SEG          2<<23
 #define   FOURTH_SEG         3<<23


  unsigned int dig_count;
  unsigned int digit_value = {0, 4, 3, 2, 1}
  unsigned int select_segment = {0, 0 << 23, 1<<23. 2<<23. 3<<23};
  unsigned char seven_seg[10]={0x3F,0x06,0x5B,0x4F,0x66,0x6D,0x7D,0x07,0x7F,0x6F};
  unsigned long int temp1,temp2 ,i=0;

 void Display(void);
 void delay(void);
 int main(void)
 {
            SystemInit();
            SystemCoreClockUpdate();

            LPC_PINCON->PINSEL0 = 0;    //P0.4 to P0.11 GPIO data lines
            LPC_PINCON->PINSEL3 = 0;    //P1.23 to P1.26 GPIO enable lines

            LPC_GPIO0->FIODIR = 0x00000FF0;       //P0.4 to P0.11 output
            LPC_GPIO1->FIODIR = 0x07800000;       //P1.23 to P1.26 output
```

Multiplexed Seven Segment Display Programming – Display a Number

```
        while(1)
        {
                delay();

                dig_count +=1;
                if(dig_count == 0x05)
                        dig_count = 0x01;

                Display();

        } //end of while(1)

}//end of main


 void Display(void)     //To Display on 7-segments
{

        LPC_GPIO1->FIOPIN = select_segment[dig_count];
        LPC_GPIO0->FIOPIN = seven_seg[digit_value[dig_count]] << 4;
        for(i=0;i<500;i++);
        LPC_GPIO0->FIOCLR = 0x00000FF0;
}
void delay(void)
{
for i=0;i<500;i++);
}
```

Seven segment up counter

Multiplexed Seven Segment Display Programming – 4 Digit BCD UP Counter

```
void delay(void)
{
for i=0;i<500;i++);

if(count ==N)
        {
                flag = 0xFF;
                count = 0;
        }
        else count += 1;
}
```

After one second, set Flag

```
if(flag == 0xFF)
        {
                flag = 0;
                digit_value[1] +=1;

                if(digit_value[1] == 0x0A)
                {
                        digit_value[1] = 0;
                        digit_value[2] +=1;

                        if(digit_value[2] == 0x0A)
                        {
                                digit_value[2]= 0;
                                digit_value[3] +=1;

                                if(digit_value[3] == 0x0A)
                                {
                                        digit_value[3] = 0;
                                        digit_value[4] += 1;

                                        if(digit_value[4]== 0x0A)
                                        {
                                                digit_value[4]= 0;
                                        } //end of dig4

                                } //end of dig3

                        } //end of dig2

                } //end of dig1

        } //end of one_sec if
```

For every second update the digits

Hex Keypad Programming

```
#include <LPC17xx.h>
unsigned char col,row,flag,key;
unsigned long var;
void scan();
int main(void)
 {
        SystemInit();
        SystemCoreClockUpdate();

        LPC_PINCON->PINSEL3 &= 0xFFC03FFF; //P1.23 to P1.26 MADE
                                                    //GPIO
        LPC_PINCON->PINSEL4 &= 0xF00FFFFF; //P2.10 t P2.13 made
                                                    //GPIO
        LPC_GPIO2->FIODIR |= 0x00003C00; //made output P2.10 to
                                                    //P2.13 (rows)
        LPC_GPIO1->FIODIR &= 0xF87FFFFF; //made input P1.23 to
                                                    //P1.26 (cols)
        while(1)
        {
         for (row=0;row<4;row++)
         {
          LPC_GPIO2->FIOPIN=1<<(row+10);
                flag=0;
                  scan();
                if (flag==1)
                { key= 4*row+col;
                }
         }}
 }
 void scan()
 {
           var=LPC_GPIO1->FIOPIN &(0xf<<23);
         if(var)
         { flag=0x1;
                var=var>>23;
                switch(var)
                {
                        case 1 : col =0;
                        break;
                        case 2: col=1;
                                break;
                        case 4: col=2;
                                 break;
                        case 8: col=3;
                                break;
                }
         }
 }
```

LCD print a message program:

```
#include <lpc17xx.h>
#define RS_CTRL  0x08000000  //P0.27
#define EN_CTRL  0x10000000  //P0.28
#define DT_CTRL  0x07800000  //P0.23 to P0.26 data lines

 unsigned long int temp1=0, temp2=0,i,j ;
 unsigned char flag1 =0, flag2 =0;
 unsigned char msg[] = {"MITn 01manipal"};

void lcd_write(void);
void port_write(void);
void delay_lcd(unsigned int);
unsigned long int init_command[] = {0x30,0x30,0x30,0x20,0x28,0x0c,0x06,0x01,0xC0};
 int main(void)
 {
       SystemInit();
       SystemCoreClockUpdate();
                LPC_GPIO0->FIODIR = DT_CTRL | RS_CTRL | EN_CTRL;
                 flag1 =0;
        for (i=0; i<9;i++)
                 {
           temp1 = init_command[i];
           lcd_write();
                  }
                 flag1 =1;
       i =0;
       while (msg[i++] != '\0')
                  {
                   temp1 = msg[i];
                   lcd_write();
                   i+= 1;
                  }
       while(1);
 }


  void lcd_write(void)
                {
                 flag2 =  (flag1 == 1) ? 0 :((temp1 == 0x30) || (temp1 == 0x20)) ? 1 : 0;
                 temp2 = temp1 & 0xf0;//move data (26-8+1) times : 26 - HN place, 4 - Bits
       temp2 = temp2 << 19;//data lines from 23 to 26
       port_write();
                 if (!flag2)
                   {
          temp2 = temp1 & 0x0f; //26-4+1
          temp2 = temp2 << 23;
          port_write();
                  }
                }


 void port_write(void)
 {
       LPC_GPIO0->FIOPIN = 0;
       LPC_GPIO0->FIOPIN = temp2;
         if (flag1 == 0)
                 LPC_GPIO0->FIOCLR = RS_CTRL;
         else
                       LPC_GPIO0->FIOSET = RS_CTRL;

       LPC_GPIO0->FIOSET = EN_CTRL;
       delay_lcd(25);
       LPC_GPIO0->FIOCLR = EN_CTRL;
                 delay_lcd(30000);

  }

void delay_lcd(unsigned int r1)
 {
       unsigned int r;
       for(r=0;r<r1;r++);

    return;
 }
```

Display message in two lines in LCD display program

```
#include <lpc17xx.h>
#define RS  27 //P0.27
#define EN  28  //P0.28
#define DT  23  //P0.23 to P0.26 data lines

 unsigned long int temp1=0, temp2=0,i,j ;
 unsigned char flag1 =0, flag2 =0;
 unsigned char msg[] = {" Department of ICT MIT manipal"}; //As message is written in codes they are stored in ASCII values

void lcd_write(void);
void port_write(void);
void delay_lcd(unsigned int);
unsigned long int init_command[] = {0x30,0x30,0x30,0x20,0x28,0x0c,0x06,0x01,0x80};
int main(void)
 {
        SystemInit();
        SystemCoreClockUpdate();
                  LPC_GPIO0->FIODIR = 1<<RS|1<<EN|0XF<<DT;  //used to make all pins output
                   flag1 =0;    // flag1 = 0 all are command and flag1 = 1 all are data
         for (i=0; i<9;i++)
                    {
            temp1 = init_command[i];
            lcd_write();
                    }
                   flag1 =1;
        i =0;
        while (msg[i] != '\0')
                     {
                      temp1 = msg[i]; // char by char
                      lcd_write();
                      i+= 1;
                      if(i==16)  //check for 1 charactres in first line
                       {
                         flag1=0;  //if yes
                         temp1=0xc0; //configure second line in command register
                         lcd_write();
                         flag1=1;
                       }
                     }
        while(1);
 }
```

```
 void lcd_write(void)
               {
                flag2 =  (flag1 == 1) ? 0 :((temp1 == 0x30) || (temp1 == 0x20)) ? 1 : 0;
                temp2 = temp1 & 0xf0;//move data (26-8+1) times : 26 - HN place, 4 - Bits to extract MSB and then LSB as nedd to send 4 bit at a time
                                                                  temp2=temp2>>4;
      temp2 = temp2 << DT;//data lines from 23 to 26
      port_write();
                if (!flag2)
                  {
         temp2 = temp1 & 0x0f; //26-4+1
         temp2 = temp2 << DT;
         port_write();
                 }
               }


void port_write(void)
{
      LPC_GPIO0->FIOPIN = 0;
      LPC_GPIO0->FIOPIN = temp2;
        if (flag1 == 0)
               LPC_GPIO0->FIOCLR = 1<<RS;
        else
                     LPC_GPIO0->FIOSET = 1<<RS;

      LPC_GPIO0->FIOSET = 1<<EN;      //this and below 3 lines are used go give pulse for enable and wait for some time interval
      delay_lcd(25);
      LPC_GPIO0->FIOCLR = 1<<EN;
                delay_lcd(30000);                           // 3 mili sec highest delay

 }

void delay_lcd(unsigned int r1)
{
      unsigned int r;
      for(r=0;r<r1;r++);

   return;
}
```

Generate square wave with period 2 second

```
#include<stdio.h>
#include<LPC17xx.h>
void delay(void)
{
        LPC_TIM0->TCR = 0x00000002;    // Timer0 Reset
        LPC_TIM0->EMR = 0X20;//Set match bit upon match
        LPC_TIM0->PR = 1000; /
        LPC_TIM0->MR0 = 3000;         //for 1 second
        LPC_TIM0->MCR = 0x00000004;    // stop PC and TC on MR0
        LPC_TIM0->TCR = 0x00000001;    // Timer0 Enable
        while ( !(LPC_TIM0->EMR & 0x01)); // wait until match

        return;
        }


int main(void)
{
        LPC_GPIO0->FIODIR=0x00000004;

                while(1)
        {
                                                LPC_GPIO0->FIOPIN=~(LPC_GPIO0->FIOPIN & 0x00000004);
                                                Delay();
                LPC_GPIO0->FIOSET=0x4;
                delay();

                LPC_GPIO0->FIOCLR=0x4;
                delay();
        }
}
```

Toggle LED connected to P0.2 every second.i.e generate square wave with period 2 seconds

Generate square wave when duty cycle is given

Generate square wave of period 2 seconds with 75% duty cycle on P0.2

```
#include<stdio.h>
#include<LPC17xx.h>
void delay(void)
{
        //LPC_SC->PCONP |= (1<<1);   //powers the T0
        LPC_TIM0->TCR = 0x00000002;    // Timer0 Reset
        LPC_TIM0->EMR = 0X20; //Set EM0 upon match
        LPC_TIM0->PR = 2999;
        LPC_TIM0->MCR = 0x00000004;    // stop PC and TC on MR0
        LPC_TIM0->TCR = 0x00000001;    // Timer0 Enable
        while ( !(LPC_TIM0->EMR & 0x01));// Wait until EM0 is set
        return;
        }
int main(void)
{
        LPC_GPIO0->FIODIR=0x00000004;
                while(1)
        {
                LPC_GPIO0->FIOPIN=0x00000004;
                LPC_TIM0->MR0 = 1500; //For 1.5 seconds
                delay();
                LPC_GPIO0->FIOPIN=0x00000000;
                LPC_TIM0->MR0 = 500; //For 0.5 seconds
                delay();
}
}
```

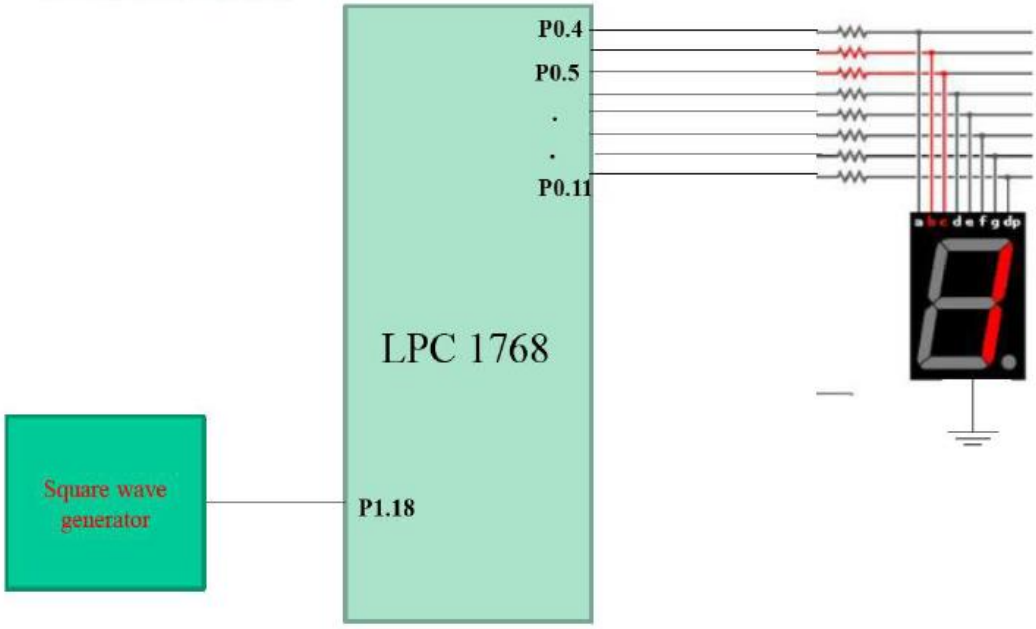
Square waveform on MAT 0.0 output line by taking EM0 on the output pin.

```
#include<stdio.h>
#include<LPC17xx.h>
void delay(void)
{
        LPC_TIM0->TCR = 0x00000002;    // Timer0 Reset
        LPC_TIM0->CTCR = 0x00000000;
        LPC_TIM0->EMR = 0X30;//Toggle bit upon match
        LPC_TIM0->PR = 0; //
        LPC_TIM0->MR0 = 3000000;       //
        LPC_TIM0->MCR = 0x00000002;    // Reset TC
        LPC_TIM0->TCR = 0x00000001;    // Timer0 Enable
        return;
        }
int main(void)
{
            LPC_PINCON->PINSEL3 |= (3<<24);//Get EM0 on MAT0.0 (P1.28) line
            delay();
            while(1);
}
```

MAT 1.1(P1.25) toggles whenever count reaches 3. CAP 1.0 (P1.18) is counter clock. i.e Divide the frequency of the square waveform input at P1.18 by a factor of 8 on P1.25

```
#include<stdio.h>
#include<LPC17xx.h>
void init_timer1(void)
{
        LPC_PINCON->PINSEL3 |=(3<<18 | 3<<4);//  MAT 1.1(P1.25) and CAP 1.0 (P1.18)
        LPC_TIM1->TCR=2;//Reset Counter1
        LPC_TIM1->CTCR = 0x2; // Counter at -ve edge of CAP1.0
        LPC_TIM1->MR1=0x03; //To count 4 clock pulses
        LPC_TIM1->MCR=0x10;//Clear TC upon Match1
        LPC_TIM1->EMR=0xC0;//Toggle EM1 upon Match
        LPC_TIM1->TCR=1;//Start Counter1
}
int  main(void)
{
        init_timer1();
        while(1);
}
```

Assume that output of a square wave generator (Frequency < 10Hz) is connected to P1.18 (CAP1.0, Function-3) , write aprogram to display the frequency of this square waveform on the seven segment connected to P011–P0.4.




```
#include<stdio.h>
#include<LPC17xx.h>
unsigned char seven_seg[10]={0x3F,0x06,0x5B,0x4F,0x66,0x6D,0x7D,0x07,0x7F,0x6F};
void delay(void)
{
        LPC_TIM0->TCR = 0x00000002;    // Timer0 Reset
        LPC_TIM0->EMR = 0X20;//Set match bit upon match
        LPC_TIM0->PR = 3000; //for 1 ms
        LPC_TIM0->MR0 = 1000;          //for 1 second
        LPC_TIM0->MCR = 0x00000004;    // stop PC and TC on MR0
        LPC_TIM0->TCR = 0x00000001;    // Timer0 Enable
        while ( !(LPC_TIM0->EMR & 0x01)); // wait until match
        }
void init_counter1(void)
{
        LPC_PINCON->PINSEL3 = (3<<4);//  cap 1.0 (P1.18)
        LPC_TIM1->CTCR = 0x01; // Counter at +ve edge of CAP1.0
}
```

```
int  main(void)
{
            LPC_PINCON->PINSEL0 = 0          //P0.4 to P0.11 GPIO data lines
            LPC_GPIO0->FIODIR = 0x00000FF0;            //P0.4 to P0.11 output
            init_counter1();
while(1)
        {
        LPC_TIM1->TCR=2;//Reset Counter1
        LPC_TIM1->TCR=1;//Start Counter1
        Delay(); // wait for 1 second
        LPC_GPIO0->FIOPIN = seven_seg[LPC_TIM1->TC ] << 4; Counter1 on the
seven segment
        }

}
```

Capture TC into TC when +ve edge is applied to CAP0.0 (P1.26) or CAP0.1(P1.27)

```
#include<stdio.h>
#include<LPC17xx.h>
void delay(void)
{
            //LPC_SC->PCONP |= (1<<1);   //powers the T0
            LPC_TIM0->CCR=9;//capture on positive edge
            LPC_TIM0->TCR = 0x00000002;    // Timer0 Reset
            LPC_TIM0->EMR = 0X20;//Set match bit upon match
            LPC_TIM0->PR = 3000; //for 1 ms
            LPC_TIM0->MR0 = 1000;              //for 1 second
            LPC_TIM0->MCR = 0x00000004;    // stop PC and TC on MR0
            LPC_TIM0->TCR = 0x00000001;    // Timer0 Enable
            while ( !(LPC_TIM0->EMR & 0x01)); // wait until match
            return;
            }

int main(void)
{
            LPC_GPIO0->FIODIR=0x00000004;
            LPC_PINCON->PINSEL3 |=(3<<20) | (3<<22);//select cap 0.0 and cap 0.1
                                    while(1)
            {
                        LPC_GPIO0->FIOPIN=~(LPC_GPIO0->FIOPIN & 0x00000004);//toggle p0.2
                        delay();

            }
}
```

Toggle LED connected to p0.2 every second while displaying the status of switch connected to P1.0 on the LED connected to P2.0

```
#include<stdio.h>
#include<LPC17xx.h>
unsigned int ticks=0,x;
void TIMER0_IRQHandler(void)
{
LPC_TIM0->IR = 1;
            ticks++;
            if(ticks==1000)
            {
                        ticks=0;
                        LPC_GPIO0->FIOPIN=~(LPC_GPIO0->FIOPIN & 0x00000004);
            }
                        }
void init_timer0(void)
{
            LPC_TIM0->TCR = 0x00000002;    // Timer0 Reset
            LPC_TIM0->CTCR =0x00;//Timer
            LPC_TIM0->MR0 = 2999; //  For 1ms
            LPC_TIM0->EMR = 0X00;//Do nothing for EM0
            LPC_TIM0->PR = 0;
            LPC_TIM0->MCR = 0x00000003;  //Reset TC upon Match-0 and generate INTR
            LPC_TIM0->TCR = 0x00000001;    // Timer0 Enable

            return;


int main(void)
{
            LPC_GPIO0->FIODIR=0x00000004;
            LPC_GPIO2->FIODIR=0x00000001;
            init_timer0();
            NVIC_EnableIRQ(TIMER0_IRQn);//timer 0 intr enabled in NVIC
                        while(1)
                        {
                                    LPC_GPIO2->FIOPIN=(LPC_GPIO1->FIOPIN & 0x01) ;
                        }

}
```

Toggle P0.2 whenever counter value reaches 3. I. e for every 4 edges using counter interrupt.

```
#include<stdio.h>
#include<LPC17xx.h>
void TIMER0_IRQHandler(void)
{
                        LPC_TIM0->IR = 1; //Clear the interrupt
                        LPC_GPIO0->FIOPIN=~(LPC_GPIO0->FIOPIN & 0x00000004);

}
void init_timer0(void)
{       LPC_TIM0->TCR = 0x00000002;    // Timer0 Reset
        LPC_TIM0->CTCR =0x05; // Counter at +ve edge of CAP0.1
        LPC_TIM0->MR0 = 3;
        LPC_TIM0->EMR = 0X00;
        LPC_TIM0->PR = 0;
        LPC_TIM0->MCR = 0x00000003;
        LPC_TIM0->TCR = 0x00000001;    // Timer0 Enable
        return;
        }

int main(void)
{
        LPC_GPIO0->FIODIR=0x00000004;
        LPC_PINCON->PINSEL3 |=((3<<22)|(3<<24));
        init_timer0();
        NVIC_EnableIRQ(TIMER0_IRQn);
        while(1);
}
```

Timer interrupt for rectangular waveform generation (1.5 second HIGH and 0.5 second LOW)

```
include<stdio.h>
#include<LPC17xx.h>
unsigned char flag=1;
void TIMER0_IRQHandler(void)
{
LPC_TIM0->IR = 1;

if(flag)
        {
                flag=0;
                LPC_TIM0->TCR = 0x00000002;    // Timer0 Reset
                LPC_GPIO0->FIOCLR=0x00000004;
                LPC_TIM0->MR0 = 500;
                LPC_TIM0->TCR = 0x00000001;    // Timer0 Enable
        }
        else
                {
                flag=1;
                LPC_TIM0->TCR = 0x00000002;    // Timer0 Reset
                LPC_GPIO0->FIOSET=0x00000004;
                LPC_TIM0->MR0 = 1500;
                LPC_TIM0->TCR = 0x00000001;    // Timer0 Enable
                }

}
```

```
void init_timer0(void)
{
        LPC_TIM0->TCR = 0x00000002;    // Timer0 Reset
        LPC_TIM0->CTCR =0x00;
        LPC_TIM0->MR0 = 1500;
        LPC_TIM0->EMR = 0X00;
        LPC_TIM0->PR = 3000;
        LPC_TIM0->MCR = 0x00000005;
        LPC_TIM0->TCR = 0x00000001;    // Timer0 Enable
        LPC_GPIO0->FIOSET=0x00000004;
        return;
}
int main(void)
{
        LPC_GPIO0->FIODIR=0x00000004;
        init_timer0();
        NVIC_EnableIRQ(TIMER0_IRQn);
        while(1);
}
```

ADC software mode for 2-channel concurrent conversion

```
#include<LPC17xx.h>
 #include<stdio.h>
int main(void)
{
        unsigned long temp4, temp5;
        unsigned int i;

        SystemInit();
        SystemCoreClockUpdate();
        LPC_PINCON->PINSEL3 = (3<<28) | (3<<30);          //P1.30 as AD0.4 and P1.31 as AD0.5
        LPC_ADC->ADINTEN = 0;
        while(1)
        {
                LPC_ADC->ADCR = (1<<4)|(1<<21)|(1<<24);//;          //ADC0.4, start conversion and operational
                while(((temp4=LPC_ADC->ADDR4) & (1<<31)) == 0);   //wait till 'done' bit is 1, indicates conversion complete
                temp4 = LPC_ADC->ADDR4;
                temp4 >>= 4;
                temp4  &= 0x00000FFF;                             //12 bit ADC

                LPC_ADC->ADCR = (1<<5)|(1<<21)|(1<<24);//          //ADC0.5, start conversion and operational
                for(i=0;i<2000;i++);                              //delay for conversion
                while(((temp5=LPC_ADC->ADDR5) & (1<<31)) == 0);   //wait till 'done' bit is 1, indicates conversion complete
                temp5 = LPC_ADC->ADDR5;
                temp5 >>= 4;
                temp5 &= 0x00000FFF;                              //12 bit ADC
//Now you can use temp4 and temp5 for further processing based on your requirement
        }
}
```

ADC burst mode for 2-channel concurrent conversion

```
#include<LPC17xx.h>
#include<stdio.h>
int main(void)

{                       SystemInit();
                        SystemCoreClockUpdate();
                        LPC_PINCON->PINSEL3 =(3<<28)|(3<<30);       //P1.30 as AD0.4 and P1.31 as AD0.5
                        LPC_ADC->ADCR = (1<<4) | (1<<5)|(1<<16) | (1<<21); //Enable CH 4 and 5 for BURST mode with ADC power ON
                        LPC_ADC->ADINTEN =(1<<4)|(1<<5); // Enable  DONE for INTR
                        NVIC_EnableIRQ(ADC_IRQn);
                        while(1);
}
void ADC_IRQHandler(void)
{
        int channel,temp,result;
        channel=(LPC_ADC->ADGDR >>24) & 0x07;
        result= ( LPC_ADC->ADGDR >>4) & 0xFFF;
        if(channel == 4)
        {
         temp4 = ( LPC_ADC->ADDR4 >>4) & 0xFFF ; //Read to Clear Done flag
         }
        else if(channel == 5)
        {
         temp5 = ( LPC_ADC->ADDR5 >>4) & 0xFFF ; //Read to Clear Done flag
//Now you can use temp4 and temp5 for further processing based on your requirement
 }
```

Input Analog voltage and display its digital equivalent on LCD

```
include<LPC17xx.h>
 #include<stdio.h>
 #define      Ref_Vtg                  3.300
 #define      Full_Scale   0xFFF//12 bit ADC
int main(void)
{
              unsigned long adc_temp;
              unsigned int i;
              float in_vtg;
              unsigned char vtg[7], dval[7];
              unsigned char Msg3[] = {"ANALOG IP:"};
              unsigned char Msg4[] = {"ADC OUTPUT:"};
              SystemInit();
              SystemCoreClockUpdate();
              lcd_init();//Initialize LCD
               LPC_PINCON->PINSEL3 |= 3<<30;//P1.31 as AD0.5
              LPC_SC->PCONP |= (1<<12);//enable the peripheral ADC
              flag1=0;//Command
              temp1 = 0x80;//Cursor at beginning of first line
              lcd_write();
              flag1=1;//Data
               i =0;
               while (Msg3[i++] != '\0')
                 {
                 temp1 = Msg3[i];
                 lcd_write();//Send data bytes
                }
```

```
flag1=0; //Command
    temp1 = 0xC0;//Cursor at beginning of second line
  lcd_write();
  flag1=1;
    i =0;
  while (Msg4[i++] != '\0')
   {
    temp1 = Msg4[i];
    lcd_write();//Send data bytes
    }
while(1)
{
        LPC_ADC->ADCR = (1<<5)|(1<<21)|(1<<24);//ADC0.5, start conversion and operational
          while(((adc_temp=LPC_ADC->ADGDR) & (1<<31)) == 0);
        adc_temp = LPC_ADC->ADGDR;
        adc_temp >>= 4;
        adc_temp &= 0x00000FFF;          //12 bit ADC
        in_vtg = (((float)adc_temp * (float)Ref_Vtg))/((float)Full_Scale);          //calculating input analog voltage
        sprintf(vtg,"%3.2fV",in_vtg);          //convert the readings into string to display on LCD
        sprintf(dval,"%x",adc_temp);
        flag1=0;;
        temp1 = 0x8A;
        lcd_write();
        flag1=1;
            i =0;
          while (vtg[i++] != '\0')
           {
            temp1 = vtg[i];
            lcd_write();//Send data bytes
            }
```

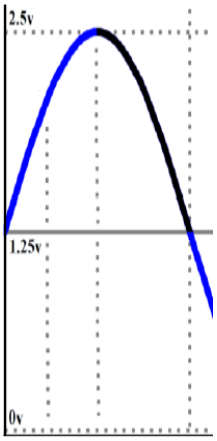
```
flag1=0;
temp1 = 0xCB;
lcd_write();
flag1=1;
  i =0;
 while (dval[i++] != '\0')
   {
    temp1 = dval[i];
    lcd_write();//Send data bytes
    }
   for(i=0;i<7;i++)
   vtg[i] = dval[i] = 0;
}
}
```

Generate a sawtooth waveform with peak to peak amplitude 3.3v at P0.26.

```
#include <lpc17xx.h>
 void DAC_Init(void);
 int main (void)
 {
            unsigned int m,i;
            SystemInit();
            SystemCoreClockUpdate();
            LPC_PINCON->PINSEL1 = 2<<20;// Analog Input P0.26
            LPC_DAC->DACCNTVAL = 0x0050; // DAC Counter for Double Buffering
            LPC_DAC->DACCTRL = (0x1<<1)|(0x1<<2); //Double buffering
            while ( 1 )
            {
                        LPC_DAC->DACR = (i << 6) ;
                        i++;
                        if ( i == 0x400 )                    //Maximum value is 0x3FF in 10 bit DAC
                        {
                        i = 0;
                        }
            }
 }
```

Generate a sinewave with peak to peak amplitude 2.5v at P0.26. (i.e. Vout = 1.25+1.25 sin θ)

```
#include <lpc17xx.h>
 void DAC_Init(void);
sinetable[]= { 388, 582,723, 776, 723,582, 388,194,52,0,52,194};
 int main (void)
 {
            unsigned int m,i;
            SystemInit();
            SystemCoreClockUpdate();
            LPC_PINCON->PINSEL1 = 2<<20;// Analog Input P0.26
            while ( 1 )
            {
                        for(i=0; i < 12; i++) // Assuming samples separated by 30 degrees
                         {
                          LPC_DAC->DACR = (sinetable[i % 12]<< 6) ;
                          delay(); // Call timer delay based on period. If period is 10 ms. Delay is  (10ms/12)
            }
 }
```



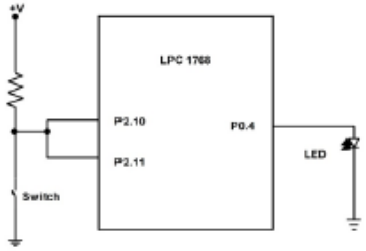
INSEM QUESTIONS:

Write an embedded C program using timer interrupt to generate a square waveform of frequency 100 kHz and duty cycle 75% on P2.3 using TIMER-0 (PCLK = 3 MHz)

```
#include<stdio.h>
#include<LPC17xx.h>
unsigned char flag=1;
void TIMER0_IRQHandler(void)
{

        if(flag)
        {
                flag=0;
                LPC_TIM0->TCR = 0x00000002;     // Timer0 Reset
                LPC_GPIO2->FIOCLR=0x00000008;
                LPC_TIM0->MR0 = 7;
                LPC_TIM0->TCR = 0x00000001;     // Timer0 Enable
        }
        else
                {
                flag=1;
                LPC_TIM0->TCR = 0x00000002;     // Timer0 Reset
                LPC_GPIO2->FIOSET=0x00000008;
                LPC_TIM0->MR0 = 22;
                LPC_TIM0->TCR = 0x00000001;     // Timer0 Enable
        }
                LPC_TIM0->IR = 1;
        }
void init_timer0(void)
{
        LPC_TIM0->TCR = 0x00000002;     // Timer0 Reset
        LPC_TIM0->CTCR =0x00;
        LPC_TIM0->MR0 = 22;
        LPC_TIM0->EMR = 0X30;
        LPC_TIM0->PR = 0;
        LPC_TIM0->MCR = 0x00000005;
        LPC_TIM0->TCR = 0x00000001;     // Timer0 Enable
        LPC_GPIO2->FIOSET=0x00000008;
        return;
        }


int main(void)
{
        LPC_GPIO2->FIODIR=0x00000008;
        init_timer0();
        NVIC_EnableIRQ(TIMER0_IRQn);
        while(1);}
```

Main-0.5, Timer init 1.5, ISS - 1

3. For the connections shown below, write an embedded C program using GPIO interrupt to turn ON the LED whenever the switch is pressed and turn OFF the LED whenever the switch is released.




```
#include<LPC17xx.h>

unsigned int x,y;
void EINT3_IRQHandler (void)
{
}
x = (LPC_GPIOINT->IO2IntStatR)>>10;
if (x== 0x01)
LPC_GPIO0->FIOCLR = 0x04;
y = (LPC_GPIOINT->IO2IntStatF)>>10;
if (y== 0x02)
LPC_GPIO0->FIOSET = 0x04;

LPC_GPIOINT->IO2IntClr = 0x03<<10;
}
void main(void)
{
LPC_PINCON -> PINSEL4 = (1<<20) | (1<<22) ;
LPC_GPIO0 ->FIODIR = 0x10;
LPC_GPIOINT->IO2IntEnR=0x01<<10; // P2.10 raising edge
LPC_GPIOINT->IO2IntEnF=0x01<<11; // P2.11 falling edge
NVIC_EnableIRQ(EINT3_IRQn);
while(1);
}
```

Functions – 1.5 each

5. Assume that output of a square wave generator (Frequency range 0-9 Hz) is connected to P2.12 (EINT-2, Function-1) input. Write an embedded C program using external hardware interrupt to display the frequency of this square waveform on the seven-segment display connected to P0.7-P0.0.

```
#include<LPC17xx.h>
unsigned int count =0;
unsigned char
seven_seg[10]={0x3F,0x06,0x5B,0x4F,0x66,0x6D,0x7D,0x07,0x7F,0x6F};
void EINT2_IRQHandler(void)
{
count++;
}
void delay(void)
{
        LPC_TIM0->TCR = 0x00000002;     // Timer0 Reset
        LPC_TIM0->EMR = 0X20;//Set match bit upon match
        LPC_TIM0->PR = 3000; //for 1 ms
        LPC_TIM0->MR0 = 1000;     //for 1 second
        LPC_TIM0->MCR = 0x00000004;     // stop PC and TC on MR0
        LPC_TIM0->TCR = 0x00000001;     // Timer0 Enable
        while ( !(LPC_TIM0->EMR & 0x01)); // wait until match

}
int  main(void)
{
LPC_GPIO0->FIODIR = 0x00000FF;
LPC_PINCON -> PINSEL4 = (1<<24);
LPC_SC ->EXTMODE =0x04;
LPC_SC ->EXTPOLAR = 0x04;
NVIC_EnableIRQ(EINT2_IRQn);
while(1)
        {
        LPC_TIM1->TCR=2;//Reset Counter1
         Delay(); // wait for 1 second
        LPC_GPIO0->FIOPIN = seven_seg[count ] << 4; Counter1 on the seven
segment
count=0;
        }
```

4

EINT ISS -1, Other functions – 1.5 each

6. With a neat diagram, explain how a 3-digit multiplexed 7 segment display can be interfaced to microcontroller. Write an embedded C program to display 123 on this

```
#include<LPC17xx.h>
#include<stdio.h>

#define FIRST_SEG 0<<23
#define SECOND_SEG 1<<23
#define THIRD_SEG 2<<23

unsigned int dig count;
unsigned int digit_value = (0, 3, 2, 1)
unsigned int select_segment = (0, 0 << 23. 1<<23. 2<<23);
unsigned char seven_seg[3]={0x06, 0x5B, 0x4F};
 unsigned long int temp1, temp2 ,i=0;

void Display(void);
void delay(void);
int main(void) ;
Systemlnit();
SystemCoreClockUpdate();

LPC _PINCON->PINSELO = 0; P0.4 to P0.11 GPIO data lines
```

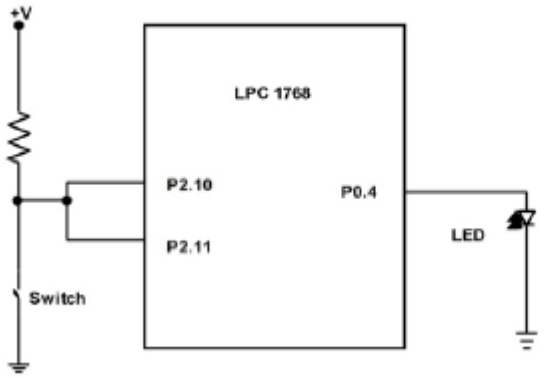
```
LPC PINCON•>PINSEL3 = 0;    P1.23 to P1.26 GPIO enable lines
LPC_GP100•>FIODIR = Ox00000FFO; P0.4 to P0.11 output
LPC_GP101->FIODIR = 0x07800000; HP1.23 to P1.26 output

while(1)
{
delay();
dig_count +=1;
if(dig_count == 0x04)
dig_count = Ox01:
Display()
} //end of while(1)
}//end of main

void Display(void) //To Display on 7•segmenb
{
LPC_GP101•>F1OPIN = select_segment[dig_count];
LPC_GP100•>FIOPIN = seven_seg_digit_value[dig_count]] << 4;
for(i=0;i<500;i++);
LPC_GP100->FIOCLR = Ox00000FFO;
}
void delay(void)
{
 for 1=0;i<500;i++);
}

void delay(void)
{
for i=0;i<500;i++);
if(count ==N)
{
flag = OxFF;
count = 0;
}
else count += 1;


  if(flag == 0XFF)
  {
   Flag = 0;
  Digit_value[1] ==3;
  Digit_value[2] ==2;
  Digit_value[3] ==1;

  }}
```

2. Assume that output of a square wave generator is connected to P1.29(CAP 1.1, Function-3). Write an embedded C program to generate a square waveform on the P1.25 (MAT 1.1, Function-3) whose frequency is one fourth of the frequency of the square wave input at P1.29.

```
#include<stdio.h>
#include<LPC17xx.h>
void init_timer1(void)
{

        LPC_PINCON->PINSEL3 |=(3<<18 | 3<<26);//  MAT 1.1(P1.25) and CAP 1.1 (P1.29)
        LPC_TIM1->TCR=2;//Reset Counter1
        LPC_TIM1->CTCR = 0x5; // Counter at +ve edge of CAP1.1
        LPC_TIM1->MR1=0x01; //To count 2 clock pulses in half cycle
        LPC_TIM1->MCR=0x10;//Clear TC upon Match1
        LPC_TIM1->EMR=0xC0;//Toggle EM1 upon Match
        LPC_TIM1->TCR=1;//Start Counter1
}
int  main(void)
{
        init_timer1();
        while(1);
}
```

(MR Value -1, Program 2)

3. For the connections shown below, write an embedded C program using external hardware interrupt to turn ON the LED whenever the switch is pressed and turn OFF the LED whenever the switch is released.



```
#include<LPC17xx.h>

void EINT0_IRQHandler(void)
{
LPC_GPIO0 ->FIOSET = 0x10;
LPC_SC -> EXTINT = 0x01;
}

void EINT1_IRQHandler(void)
{
LPC_GPIO0 ->FIOCLR = 0x10;
LPC_SC -> EXTINT = 0x2;

}


void main(void)
{
LPC_PINCON -> PINSEL4 = (1<<20) | (1<<22) ;
LPC_GPIO0 ->FIODIR = 0x10;
LPC_SC ->EXTMODE =0x03;
LPC_SC ->EXTPOLAR = 0x02;


NVIC_EnableIRQ(EINT0_IRQn);
NVIC_EnableIRQ(EINT1_IRQn);

while(1);}
```

Main -2, Functions – 1each

5. Assume that output of a square wave generator is connected to P2.12 input. Write an embedded C program using GPIO interrupt to generate a square waveform at P0.4 whose frequency is 0.125 times the frequency of the input square waveform at P2.12.

```
#include<LPC17xx.h>
unsigned int x;
void EINT3_IRQHandler (void)
{
}
x ++
if (x==4) // for frequency 1/8
{
x=0;
LPC_GPIO0->FIOPIN = ~ (LPC_GPIO0->FIOPIN & 1<<4);
}
LPC_GPIOINT->IO2IntClr = 1<<12;
}
void main(void)
{
LPC_GPIO0 ->FIODIR = 1<<4;
LPC_GPIOINT->IO2IntEnR=1<<12; // P2.12 raising edge
NVIC_EnableIRQ(EINT3_IRQn);
while(1);
}
```

Functions – 2each

4

6. With a neat diagram, explain how a 3x3 matrix keyboard can be interfaced to microcontroller. Write an embedded C program to display the keycode of the key pressed on the LEDs connected to P0.2-P0.0

4

Interfacing Diagram: 1 Mark
LPC Pin configuration : 0.5 Mark
Polling the key pressed with identification : 1+1.5 Mark

```
  Main(void)
{
Initialization for P1.0 to P1.5 (Key Pad:GPIO);
Initialization for P0.0 to P0.2 (LED's GPIO);

Setting Direction Port1 : Input (Key Pad);
Setting Direction Port0 : output (LED);

Int flag, row;

While(1)
{
 For row = 0; row<3; row++)
{
Making each row high one after other;
Flag = 0 ;
Scan();
If(flag = 1)
Break;
}

If(flag = 1)
{
Keypress = 3*row + col;
LEDdisplay(Keypress);
}}}


Voidscan()
{
X = LPC_GPIO1→ FIOPIN;
X = x&07;
If(x!=0)
{
Flag=1;

Using switch case finding the column;
}

Void LEDdisplay(Keypress)
{
Based on keypressvalues

Using if statement or switch and LPC_GPIO→FIOSET enable the LED's

}
```

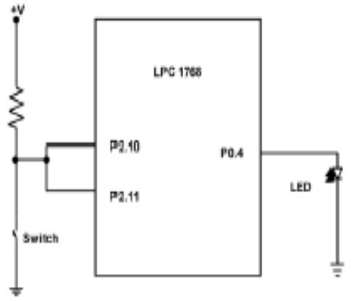
2. Write an embedded C program using timer interrupt to generate a square waveform of frequency 1 kHz and duty cycle 67% on P2.6 using TIMER-1 (PCLK = 6 MHz)

3

```
#include<stdio.h>
#include<LPC17xx.h>
unsigned char flag=1;
void TIMER1_IRQHandler(void)
{
        if(flag)
        {
                flag=0;
                LPC_TIM1->TCR = 0x00000002;     // Timer1 Reset
                LPC_GPIO2->FIOCLR=1<<6;
                LPC_TIM1->MR0 = 1980;
                LPC_TIM1->TCR = 0x00000001;     // Timer1 Enable

        }
        else
                {
                flag=1;
                LPC_TIM1->TCR = 0x00000002;     // Timer1 Reset
                LPC_GPIO2->FIOSET=1<<6;
                LPC_TIM1->MR0 = 4020;
                LPC_TIM1->TCR = 0x00000001;     // Timer1 Enable
        }
                LPC_TIM1->IR = 1;
        }
void init_timer1(void)
{

        LPC_TIM1->TCR = 0x00000002;     // Timer1 Reset
        LPC_TIM1->CTCR =0x00;
        LPC_TIM1->MR0 = 4020;
        LPC_TIM1->EMR = 0X30;
        LPC_TIM1->PR = 0;
        LPC_TIM1->MCR = 0x00000005;
        LPC_TIM1->TCR = 0x00000001;     // Timer1 Enable
        LPC_GPIO2->FIOSET=1<<6;
        return;
        }


int main(void)
{
        LPC_GPIO2->FIODIR=1<<6;
        init_timer1();
        NVIC_EnableIRQ(TIMER1_IRQn);
        while(1);}
```

Main-0.5, Timer init 1.5, ISS - 1

3. For the connections shown below, write an embedded C program using GPIO interrupt to turn ON the LED after pressing and releasing the Switch FOUR times.



3

```
#include<LPC17xx.h>
unsigned int x, count1, count2, y;
void EINT3_IRQHandler (void)
{
}
x = (LPC_GPIOINT->IO2IntStatR)>>10;
y = (LPC_GPIOINT->IO2IntStatF)>>10;
if (x== 0x01)
count1++;

if (y== 0x02)
count2++;
if (count1==4 && count2 ==4)
LPC_GPIO0->SET = 0x04;

LPC_GPIOINT->IO2IntClr = 0x03<<10;
}
void main(void)
{
LPC_PINCON -> PINSEL4 = (1<<20) | (1<<22) ;
LPC_GPIO0 ->FIODIR = 0x10;
LPC_GPIOINT->IO2IntEnR=0x01<<10; // P2.10 raising edge
LPC_GPIOINT->IO2IntEnF=0x01<<11; // P2.11 falling edge
NVIC_EnableIRQ(EINT3_IRQn);
while(1);
}
```

5. Assume that output of a square wave generator with 50% duty cycle is connected to P2.12 (EINT2, Function-1). Write an embedded C program using external hardware interrupt to generate a square waveform on P0.4 with frequency one eighth of the frequency of the input square waveform at P2.12 and duty cycle 75%.

```
#include<LPC17xx.h>
unsigned int count =0;
void EINT2_IRQHandler(void)
{
count++;
if (count==6)
LPC_GPIO0->FIOCLR = 1<<4;
if(count==8)
{
LPC_GPIO0->FIOSET = 1<<4;
count=0;
}
LPC_SC ->EXTINT = 0x04;
}
int  main(void)
{
LPC_GPIO0->FIODIR = 1<<4;
LPC_PINCON -> PINSEL4 = (1<<24);
LPC_SC ->EXTMODE =0x04;
LPC_SC ->EXTPOLAR = 0x04;
NVIC_EnableIRQ(EINT2_IRQn);
LPC_GPIO0->FIOSET = 1<<4;
while(1);
        }
```

EINT ISS -2, Main-2

4

6. With a neat diagram, explain how a 16x2 LCD can be interfaced to the microcontroller. Write an embedded C program to display the message "Best Wishes" 4

```
#include <lpc17xx.h>
#define RS  27 //P0.27
#define EN  28  //P0.28
#define DT  23  //P0.23 to P0.26 data lines

 unsigned long int temp1=0, temp2=0,i,j ;
 unsigned char flag1 =0, flag2 =0;
 unsigned char msg[] = {" Best Wishes "}; //As message is written in codes they are stored in
ASCII values

void lcd_write(void);
void port_write(void);
void delay_lcd(unsigned int);
unsigned long int init_command[] = {0x30,0x30,0x30,0x20,0x28,0x0c,0x06,0x01,0x80};
int main(void)
 {
        SystemInit();
        SystemCoreClockUpdate();
           LPC_GPIO0->FIODIR  =  1<<RS|1<<EN|0XF<<DT;   //used  to  make  all  pins
output
            flag1 =0;     // flag1 = 0 all are command and flag1 = 1 all are data
         for (i=0; i<9;i++)
             {
           temp1 = init_command[i];
           lcd_write();
             }
            flag1 =1;
        i =0;
        while (msg[i] != '\0')
              {
              temp1 = msg[i]; // char by char
              lcd_write();
                    i+= 1;

if(i==16)  //check for 1 charactres in first line
                                                                                {

         flag1=0;  //if yes

         temp1=0xc0; //configure second line in command register

         lcd_write();

         flag1=1;
                                                                                }
              }
        while(1);
```

```
}

 void lcd_write(void)
            {
                flag2 =  (flag1 == 1) ? 0 :((temp1 == 0x30) || (temp1 == 0x20)) ? 1 : 0;
              temp2 = temp1 & 0xf0;//move data (26-8+1) times : 26 - HN place, 4 - Bits to
extract MSB and then LSB as nedd to send 4 bit at a time
                                                                    temp2=temp2>>4;
          temp2 = temp2 << DT;//data lines from 23 to 26
          port_write();
             if (!flag2)
               {
            temp2 = temp1 & 0x0f; //26-4+1
            temp2 = temp2 << DT;
            port_write();
              }
             }


 void port_write(void)
 {
          LPC_GPIO0->FIOPIN = 0;
          LPC_GPIO0->FIOPIN = temp2;
        if (flag1 == 0)
             LPC_GPIO0->FIOCLR = 1<<RS;
        else
                   LPC_GPIO0->FIOSET = 1<<RS;

          LPC_GPIO0->FIOSET = 1<<EN;        //this and below 3 lines are used  give pulse
for enable and wait for some time interval
          delay_lcd(25);
          LPC_GPIO0->FIOCLR = 1<<EN;
             delay_lcd(30000);                              // 3 ms  highest delay

 }

void delay_lcd(unsigned int r1)
 {
          unsigned int r;
          for(r=0;r<r1;r++);

   return;
 }
```

MANIPAL INSTITUTE OF TECHNOLOGY
MANIPAL
(A constituent unit of MAHE, Manipal)

V SEMESTER B.TECH (IT) INTERNAL EXAMINATIONS NOV 2021

In-Semester (Online)

SUBJECT: EMBEDDED SYSTEMS [ICT 3158]

Date of Exam: **18/11/2021** Time of Exam: **4.00 PM - 5.20 PM** Max. Marks: **20**

Instructions to Candidates:

- Answer ALL the questions
- All the questions are pertaining to LPC1768 microcontroller.
- Upload the single PDF file of your answer booklet

1. Explain the following instructions with an example for each:

(a) MLS (b) TST (c) ORN

a. MLS:

Instruction Description :

Multiply with subtract

MLS{Cond} Rd, Rn, Rm, Ra; (Description of each entities)

Rd = Ra – Rn*Rm 0.5 Mark

Example:

Rn = 0X00 00 00 02

Rm = 0X00 00 00 03

Ra = 0X00 00 00 0A

Rd = 0X00 00 00 04

0.5 Mark

b. TST:

Instruction Description :

3

Test bits

TST{cond} Rn, Operand2; (Description of each entities)

0.5

Mark

Example:

TST R0, #0x3F8 ; Perform bitwise AND of R0 value to 0x3F8; APSR is updated but result is discarded

0.5 Mark

c. ORN:

Instruction Description :

Logical OR NOT

op{S}{cond} {Rd,} Rn, Operand2; (Description of each entities)

0.5 Mark

Example:

ORN R7, R11, R14, ROR #4; R7 = R11 OR (NOT(R14 ROR #4))

0.5 Mark

2. Write an embedded C program using timer interrupt to generate a square waveform of frequency 100 kHz and duty cycle 75% on P2.3 using TIMER-0 (PCLK = 3 MHz)

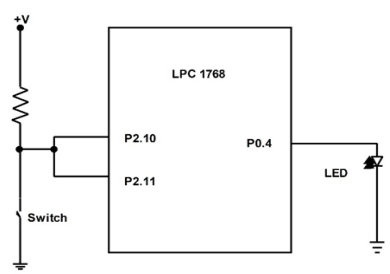
```
#include<stdio.h>
#include<LPC17xx.h>
unsigned char flag=1;
void TIMER0_IRQHandler(void)
{
```

3

```
        if(flag)
        {
                flag=0;
                LPC_TIM0->TCR = 0x00000002;     // Timer0 Reset
                LPC_GPIO2->FIOCLR=0x00000008;
                LPC_TIM0->MR0 = 7;
                LPC_TIM0->TCR = 0x00000001;     // Timer0 Enable
        }
        else
                {
                flag=1;
                LPC_TIM0->TCR = 0x00000002;     // Timer0 Reset
                LPC_GPIO2->FIOSET=0x00000008;
                LPC_TIM0->MR0 = 22;
                LPC_TIM0->TCR = 0x00000001;     // Timer0 Enable
        }
                LPC_TIM0->IR = 1;
        }
void init_timer0(void)
{
        LPC_TIM0->TCR = 0x00000002;     // Timer0 Reset
        LPC_TIM0->CTCR =0x00;
        LPC_TIM0->MR0 = 22;
        LPC_TIM0->EMR = 0X30;
        LPC_TIM0->PR = 0;
        LPC_TIM0->MCR = 0x00000005;
        LPC_TIM0->TCR = 0x00000001;     // Timer0 Enable
        LPC_GPIO2->FIOSET=0x00000008;
        return;
        }


int main(void)
{
        LPC_GPIO2->FIODIR=0x00000008;
        init_timer0();
        NVIC_EnableIRQ(TIMER0_IRQn);
        while(1);}
```

Main-0.5, Timer init 1.5, ISS - 1

3. For the connections shown below, write an embedded C program using GPIO interrupt to turn ON the LED whenever the switch is pressed and turn OFF the LED whenever the switch is released.



3

```
#include<LPC17xx.h>
```

```
unsigned int x,y;
void EINT3_IRQHandler (void)
{
}
x = (LPC_GPIOINT->IO2IntStatR)>>10;
if (x== 0x01)
LPC_GPIO0->FIOCLR = 0x04;
y = (LPC_GPIOINT->IO2IntStatF)>>10;
if (y== 0x02)
LPC_GPIO0->FIOSET = 0x04;

LPC_GPIOINT->IO2IntClr = 0x03<<10;
}
void main(void)
{
LPC_PINCON -> PINSEL4 = (1<<20) | (1<<22) ;
LPC_GPIO0 ->FIODIR = 0x10;
LPC_GPIOINT->IO2IntEnR=0x01<<10; // P2.10 raising edge
LPC_GPIOINT->IO2IntEnF=0x01<<11; // P2.11 falling edge
NVIC_EnableIRQ(EINT3_IRQn);
while(1);
}
```

Functions – 1.5 each

4. Write an assembly language program to find the product of two single digit BCD numbers available in the code memory and store the BCD result in the data memory.

Loading the data into register from code memory – 1 Mark
Finding the product of two single digit BCD numbers – 1 Mark
Storing the BCD result in the data memory – 1 Mark

```
   EXPORT  __Vectors

__Vectors
        DCD  0x40001000     ; stack pointer value when stack is empty
   DCD  Reset_Handler  ; reset vector

   ALIGN

        AREA mycode, CODE, READONLY                                    3
        ENTRY
        EXPORT Reset_Handler

Reset_Handler

        LDR R0, =VALUE1   ;pointer to the first value1
        LDR R1,[R0]           ;load the first value into R1 Assuming data is single
digit BCD
        LDR R0,=VALUE2    ;pointer to the second value
        LDR R3, [R0]          ;load  second number into r3
        MUL R6, R1,R3         ;MUL two numbers and store the result in r6
       Logic for BCD Conversion
        LDR R2, =RESULT
        STR R6,[R2]   ; ; CY IS NOT STORED IN MEMORY
```

```
STOP
        B STOP

VALUE1 DCD 0X00000003  ; First BCD digit
VALUE2 DCD 0X00000002 ; Second BCD digit

        AREA data, DATA, READWRITE
RESULT DCD 0
        END
```

5. Assume that output of a square wave generator (Frequency range 0-9 Hz) is connected to P2.12 (EINT-2, Function-1) input. Write an embedded C program using external hardware interrupt to display the frequency of this square waveform on the seven-segment display connected to P0.7-P0.0.

```
#include<LPC17xx.h>
unsigned int count =0;
unsigned char
seven_seg[10]={0x3F,0x06,0x5B,0x4F,0x66,0x6D,0x7D,0x07,0x7F,0x6F};
void EINT2_IRQHandler(void)
{
count++;
}
void delay(void)
{
        LPC_TIM0->TCR = 0x00000002;     // Timer0 Reset
        LPC_TIM0->EMR = 0X20;//Set match bit upon match
        LPC_TIM0->PR = 3000; //for 1 ms
        LPC_TIM0->MR0 = 1000;     //for 1 second
        LPC_TIM0->MCR = 0x00000004;     // stop PC and TC on MR0
        LPC_TIM0->TCR = 0x00000001;     // Timer0 Enable
        while ( !(LPC_TIM0->EMR & 0x01)); // wait until match

}
int  main(void)
{
LPC_GPIO0->FIODIR = 0x00000FF;
LPC_PINCON -> PINSEL4 = (1<<24);
LPC_SC ->EXTMODE =0x04;
LPC_SC ->EXTPOLAR = 0x04;
NVIC_EnableIRQ(EINT2_IRQn);
while(1)
         {
          LPC_TIM1->TCR=2;//Reset Counter1
           Delay(); // wait for 1 second
          LPC_GPIO0->FIOPIN = seven_seg[count ] << 4; Counter1 on the seven
segment
count=0;
          }
```

4

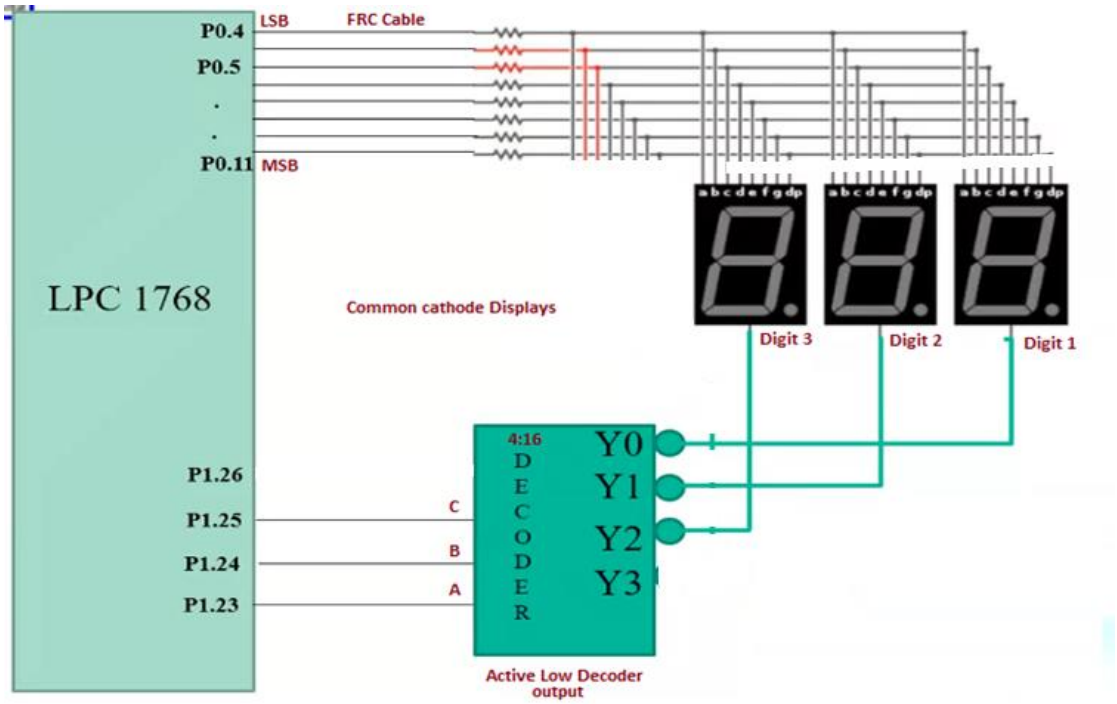
EINT ISS -1, Other functions – 1.5 each

6. With a neat diagram, explain how a 3-digit multiplexed 7 segment display can be interfaced to microcontroller. Write an embedded C program to display 123 on this

4

display.

Interfacing Diagram: 1 Mark
7 segment Initialization with Pin configuration: 1 Mark
Display Function to display 123 and delay: 2 Mark




```
#include<LPC17xx.h>
#include<stdio.h>

#define FIRST_SEG 0<<23
#define SECOND_SEG 1<<23
#define THIRD_SEG 2<<23

unsigned int dig count;
unsigned int digit_value = (0, 3, 2, 1)
unsigned int select_segment = (0, 0 << 23. 1<<23. 2<<23);
unsigned char seven_seg[3]={0x06, 0x5B, 0x4F};
 unsigned long int temp1, temp2 ,i=0;

void Display(void);
void delay(void);
int main(void) ;
Systemlnit();
SystemCoreClockUpdate();
```

LPC _PINCON->PINSELO = 0; P0.4 to P0.11 GPIO data lines

```
LPC PINCON•>PINSEL3 = 0;    P1.23 to P1.26 GPIO enable lines
LPC_GP100•>FIODIR = Ox00000FFO; P0.4 to P0.11 output
LPC_GP101->FIODIR = 0x07800000; HP1.23 to P1.26 output

while(1)
{
delay();
dig_count +=1;
if(dig_count == 0x04)
dig_count = Ox01:
Display()
} //end of while(1)
}//end of main

void Display(void) //To Display on 7•segmenb
{
LPC_GP101•>F1OPIN = select_segment[dig_count];
LPC_GP100•>FIOPIN = seven_seg_digit_value[dig_count]] << 4;
for(i=0;i<500;i++);
LPC_GP100->FIOCLR = Ox00000FFO;
}
void delay(void)
{
 for 1=0;i<500;i++);
}

void delay(void)
{
for i=0;i<500;i++);
if(count ==N)
{
flag = OxFF;
count = 0;
}
else count += 1;


if(flag == 0XFF)
{
 Flag = 0;
Digit_value[1] ==3;
Digit_value[2] ==2;
Digit_value[3] ==1;

}}
```

MANIPAL INSTITUTE OF TECHNOLOGY
MANIPAL
(A constituent unit of MAHE, Manipal)

V SEMESTER B.TECH (IT) INTERNAL EXAMINATIONS NOV 2021

In-Semester (Online)

SUBJECT: EMBEDDED SYSTEMS [ICT 3158]

Date of Exam: **18/11/2021** Time of Exam: **4.00 PM - 5.20 PM** Max. Marks: **20**

Instructions to Candidates:

- Answer ALL the questions
- All the questions are pertaining to LPC1768 microcontroller.
- Upload the single PDF file of your answer booklet

1. Explain the following instructions with an example for each:
(a) SMULL (b) TEQ (c) RRX

a. SMULL:

Instruction Description :

Signed Long Multiply

SMULL{cond}{S} RdLo, RdHi, Rm, Rs

The SMULL instruction interprets the values from Rs and Rs as two's complement signed integers. It multiplies these integers and places the least significant 32 bits of the result in RdLo, and the most significant 32 bits of the result in RdHi.

0.5 Mark

```
MOV R0,#0X11111111
MOV R1,#0X11111111

SMULL R4,R5,R0,R1
```

3

b. TEQ:

Instruction Description :

Test Equivalence

TEQ{cond} Rn, Operand2 (Instruction Description)

0.5 Mark

Example:

TEQEQ R10, R9 ; Conditionally test if value in R10 is equal to; value in R9, APSR is updated but result is discarded.

0.5 Mark

c. RRX:

Instruction Description :

Rotate Right Extended by 1 bit

0.5 Mark

Example: 0.5 Mark

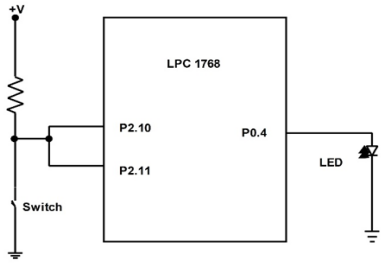
2. Assume that output of a square wave generator is connected to P1.29(CAP 1.1, Function-3). Write an embedded C program to generate a square waveform on the P1.25 (MAT 1.1, Function-3) whose frequency is one fourth of the frequency of the square wave input at P1.29. **3**

```
#include<stdio.h>
#include<LPC17xx.h>
void init_timer1(void)
{
```

```
        LPC_PINCON->PINSEL3 |=(3<<18 | 3<<26);//  MAT 1.1(P1.25) and CAP 1.1 (P1.29)
        LPC_TIM1->TCR=2;//Reset Counter1
        LPC_TIM1->CTCR = 0x5; // Counter at +ve edge of CAP1.1
        LPC_TIM1->MR1=0x01; //To count 2 clock pulses in half cycle
        LPC_TIM1->MCR=0x10;//Clear TC upon Match1
        LPC_TIM1->EMR=0xC0;//Toggle EM1 upon Match
        LPC_TIM1->TCR=1;//Start Counter1
}
int  main(void)
{
        init_timer1();
        while(1);
}
```

(MR Value -1, Program 2)

3. For the connections shown below, write an embedded C program using external hardware interrupt to turn ON the LED whenever the switch is pressed and turn OFF the LED whenever the switch is released.




```
#include<LPC17xx.h>

void EINT0_IRQHandler(void)
{
LPC_GPIO0 ->FIOSET = 0x10;
LPC_SC -> EXTINT = 0x01;
}

void EINT1_IRQHandler(void)
{
LPC_GPIO0 ->FIOCLR = 0x10;
LPC_SC -> EXTINT = 0x2;

}


void main(void)
{
LPC_PINCON -> PINSEL4 = (1<<20) | (1<<22) ;
LPC_GPIO0 ->FIODIR = 0x10;
LPC_SC ->EXTMODE =0x03;
LPC_SC ->EXTPOLAR = 0x02;
```

3

```
NVIC_EnableIRQ(EINT0_IRQn);
NVIC_EnableIRQ(EINT1_IRQn);

while(1);}
```

Main -2, Functions – 1each

4. Write an assembly language program to find the sum of all the digits of a 8-digit BCD number available in the code memory and store the BCD result in the data memory.

Loading the data into register from code memory – 0.5 Mark
find the sum of all the digits of a 8-digit BCD number – 1.5 Mark
Storing the BCD result in the data memory – 1 Mark

```
        AREA    RESET, DATA, READONLY
    EXPORT  __Vectors

__Vectors
        DCD  0x100000FF     ; stack pointer value when stack is empty
    DCD  Reset_Handler  ; reset vector

    ALIGN

        AREA mycode, CODE, READONLY
        EXPORT Reset_Handler
        ENTRY
Reset_Handler
        LDR R3, = NUM
        LDR R1, [R3]
```

3

```
MOV R5, R1
MOV R4, #8
MOV R7, #0 ; STORE SUM
LP:
AND R5, #0X0F
ADD R7,R5
CMP R7, #0X0A
BNE NT
ADD R7, 0X06
NX:
LSR R6, #4 (if left shift then see logic as per that)
MOV R5, R6
CMP R5, #0 OR IMPLEMENT COUNTER
BNE LP
LDR R8, #BCDSUM
STR R8, [R7]
STOP B STOP

NUM DCD 0X123456789

AREA data, DATA, READWRITE
BCDSUM DCD 0
```

END

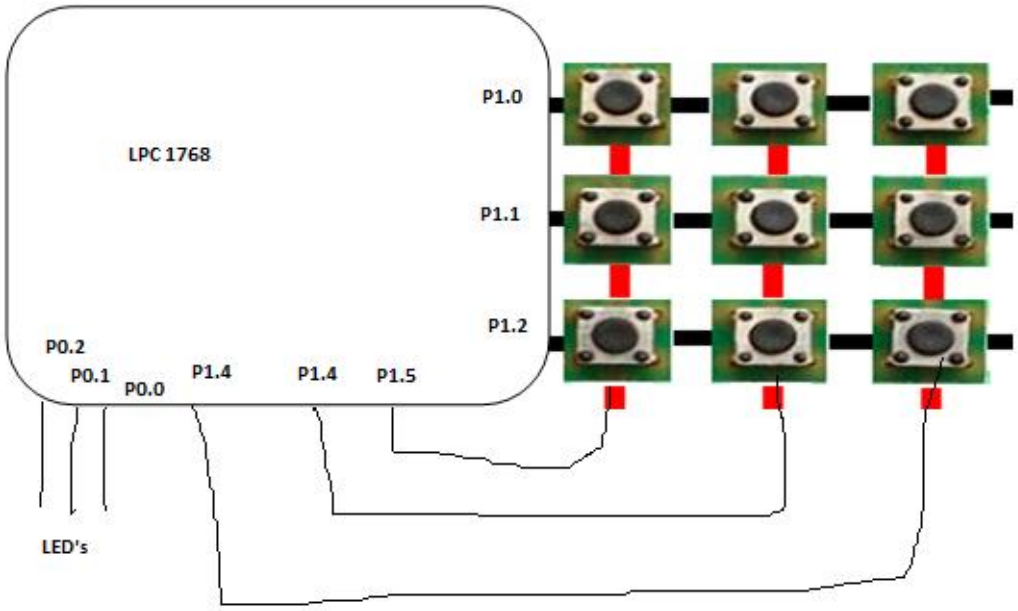
5. Assume that output of a square wave generator is connected to P2.12 input. Write an embedded C program using GPIO interrupt to generate a square waveform at P0.4 whose frequency is 0.125 times the frequency of the input square waveform at P2.12. **4**

```
#include<LPC17xx.h>
unsigned int x;
void EINT3_IRQHandler (void)
{
}
x ++
if (x==4) // for frequency 1/8
{
x=0;
LPC_GPIO0->FIOPIN = ~ (LPC_GPIO0->FIOPIN & 1<<4);
}
LPC_GPIOINT->IO2IntClr = 1<<12;
}
void main(void)
{
LPC_GPIO0 ->FIODIR = 1<<4;
LPC_GPIOINT->IO2IntEnR=1<<12; // P2.12 raising edge
NVIC_EnableIRQ(EINT3_IRQn);
while(1);
}
```

Functions – 2each

6. With a neat diagram, explain how a 3x3 matrix keyboard can be interfaced to microcontroller. Write an embedded C program to display the keycode of the key pressed on the LEDs connected to P0.2-P0.0 **4**

Interfacing Diagram: 1 Mark
LPC Pin configuration : 0.5 Mark
Polling the key pressed with identification : 1+1.5 Mark




```
  Main(void)
{
Initialization for P1.0 to P1.5 (Key Pad:GPIO);
Initialization for P0.0 to P0.2 (LED's GPIO);

Setting Direction Port1 : Input (Key Pad);
Setting Direction Port0 : output (LED);

Int flag, row;

While(1)
{
 For row = 0; row<3; row++)
{
Making each row high one after other;
Flag = 0 ;
Scan();
If(flag = 1)
Break;
}

If(flag = 1)
{
Keypress = 3*row + col;
LEDdisplay(Keypress);
}}}

Voidscan()
{
X = LPC_GPIO1→ FIOPIN;
X = x&07;
If(x!=0)
{
Flag=1;
```

Using switch case finding the column;
}

Void LEDdisplay(Keypress)
{
Based on keypressvalues

Using if statement or switch and LPC_GPIO→FIOSET enable the LED's

}

MANIPAL INSTITUTE OF TECHNOLOGY
MANIPAL
(A constituent unit of MAHE, Manipal)

V SEMESTER B.TECH (IT) INTERNAL EXAMINATIONS NOV 2021

In-Semester (Online)

SUBJECT: EMBEDDED SYSTEMS [ICT 3158]

Date of Exam: **18/11/2021** Time of Exam: **4.00 PM - 5.20 PM** Max. Marks: **20**

Instructions to Candidates:

- Answer ALL the questions
- All the questions are pertaining to LPC1768 microcontroller.
- Upload the single PDF file of your answer booklet

1. Explain the following instructions with an example for each:
(a) SMLAL (b) BGE (c) CMN

a. SMLAL:
Instruction Description :
Signed Long Multiply
SMLAL{cond}{S} RdLo, RdHi, Rm, Rs
Signed multiply and accumulate long
0.5 Mark

Example:

SMLAL R1,R0,R2,R3
(R0:R1) = (R0:R1) + R*R3
0.5 Mark **3**

b. BGE:
Instruction Description :
Greater than or Equal; Singed Integer comparison gave greater or equal
0.5 Mark
Example: 0.5 Mark

c. CMN:
Instruction Description :
Compare Negative
CMN{cond} Rn, Operand2; (Description of Entities)
0.5 Mark
Example: CMN R0, #12 0.5 Mark

2. Write an embedded C program using timer interrupt to generate a square waveform of frequency 1 kHz and duty cycle 67% on P2.6 using TIMER-1 (PCLK = 6 MHz)

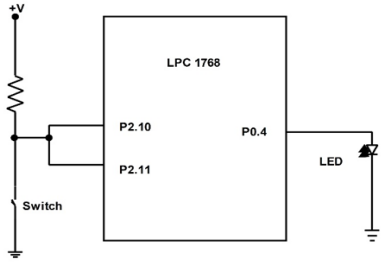
```
#include<stdio.h>
#include<LPC17xx.h>
unsigned char flag=1;
void TIMER1_IRQHandler(void)
{
```
3

```
    if(flag)
    {
        flag=0;
        LPC_TIM1->TCR = 0x00000002;     // Timer1 Reset
        LPC_GPIO2->FIOCLR=1<<6;
        LPC_TIM1->MR0 = 1980;
        LPC_TIM1->TCR = 0x00000001;     // Timer1 Enable
```

```
        }
        else
                {
                flag=1;
                LPC_TIM1->TCR = 0x00000002;     // Timer1 Reset
                LPC_GPIO2->FIOSET=1<<6;
                LPC_TIM1->MR0 = 4020;
                LPC_TIM1->TCR = 0x00000001;     // Timer1 Enable
        }
                LPC_TIM1->IR = 1;
        }
void init_timer1(void)
{

        LPC_TIM1->TCR = 0x00000002;     // Timer1 Reset
        LPC_TIM1->CTCR =0x00;
        LPC_TIM1->MR0 = 4020;
        LPC_TIM1->EMR = 0X30;
        LPC_TIM1->PR = 0;
        LPC_TIM1->MCR = 0x00000005;
        LPC_TIM1->TCR = 0x00000001;     // Timer1 Enable
        LPC_GPIO2->FIOSET=1<<6;
        return;
        }


int main(void)
{
        LPC_GPIO2->FIODIR=1<<6;
        init_timer1();
        NVIC_EnableIRQ(TIMER1_IRQn);
        while(1);}
```

Main-0.5, Timer init 1.5, ISS - 1

3. For the connections shown below, write an embedded C program using GPIO interrupt to turn ON the LED after pressing and releasing the Switch FOUR times.



3

```
#include<LPC17xx.h>
unsigned int x, count1, count2, y;
void EINT3_IRQHandler (void)
{
}
x = (LPC_GPIOINT->IO2IntStatR)>>10;
y = (LPC_GPIOINT->IO2IntStatF)>>10;
if (x== 0x01)
count1++;
```

```
if (y== 0x02)
count2++;
if (count1==4 && count2 ==4)
LPC_GPIO0->SET = 0x04;

LPC_GPIOINT->IO2IntClr = 0x03<<10;
}
void main(void)
{
LPC_PINCON -> PINSEL4 = (1<<20) | (1<<22) ;
LPC_GPIO0 ->FIODIR = 0x10;
LPC_GPIOINT->IO2IntEnR=0x01<<10; // P2.10 raising edge
LPC_GPIOINT->IO2IntEnF=0x01<<11; // P2.11 falling edge
NVIC_EnableIRQ(EINT3_IRQn);
while(1);
}
```

Functions – 1.5 each

4. Write an assembly language program to find the sum of all the bits of a 8-digit BCD number available in the code memory and store the BCD result in the data memory.

Loading the data into register from code memory and find the sum of all the bits of a 8-digit BCD number – 2 Mark (0.5 + 1.5)

Storing the BCD result in the data memory – 1 Mark

```
AREA    RESET, DATA, READONLY
   EXPORT  __Vectors
```

3

```
__Vectors
        DCD  0x100000FF     ; stack pointer value when stack is empty
   DCD  Reset_Handler  ; reset vector

   ALIGN

        AREA mycode, CODE, READONLY
        EXPORT Reset_Handler
        ENTRY
Reset_Handler
        LDR R3, = NUM
        LDR R1, [R3]
MOV R5, R1
MOV R4, #0x20 ; count 32-bit
MOV R7, #0 ; STORE SUM
LP:
AND R5, #0X01
ADD R7,R5
```

```
CMP R7, #0X0A
BNE NT
ADD R7, 0X06
NT:
LSR R6, #1 (if left shift then see logic as per that)
MOV R5, R6
SUB R4, #0x01
CMP R4, #00
BNE LP
LDR R8, #BCDbitSUM
STR R8, [R7]
STOP B STOP

NUM DCD 0X123456789

AREA data, DATA, READWRITE
BCDbitSUM DCD 0

        END
```

5. Assume that output of a square wave generator with 50% duty cycle is connected to P2.12 (EINT2, Function-1). Write an embedded C program using external hardware interrupt to generate a square waveform on P0.4 with frequency one eighth of the frequency of the input square waveform at P2.12 and duty cycle 75%.

```
#include<LPC17xx.h>
unsigned int count =0;
void EINT2_IRQHandler(void)
{
count++;
if (count==6)
LPC_GPIO0->FIOCLR = 1<<4;
if(count==8)
{
LPC_GPIO0->FIOSET = 1<<4;
count=0;
}
LPC_SC ->EXTINT = 0x04;
}
int  main(void)
{
LPC_GPIO0->FIODIR = 1<<4;
LPC_PINCON -> PINSEL4 = (1<<24);
LPC_SC ->EXTMODE =0x04;
LPC_SC ->EXTPOLAR = 0x04;
NVIC_EnableIRQ(EINT2_IRQn);
LPC_GPIO0->FIOSET = 1<<4;
while(1);
        }
```

4

EINT ISS -2, Main-2

6. With a neat diagram, explain how a 16x2 LCD can be interfaced to the microcontroller. Write an embedded C program to display the message “Best Wishes” **4**

on the LCD.

Interfacing Diagram:1 Mark

LPC Pin configuration with LCD configuration (Control and Data Register) : 1.5 Mark

Port Write Function and Delay : 1+0.5 Mark

```
#include <lpc17xx.h>
#define RS  27 //P0.27
#define EN  28  //P0.28
#define DT  23  //P0.23 to P0.26 data lines

 unsigned long int temp1=0, temp2=0,i,j ;
 unsigned char flag1 =0, flag2 =0;
 unsigned char msg[] = {" Best Wishes "}; //As message is written in codes they are stored in ASCII values

void lcd_write(void);
void port_write(void);
void delay_lcd(unsigned int);
unsigned long int init_command[] = {0x30,0x30,0x30,0x20,0x28,0x0c,0x06,0x01,0x80};
int main(void)
 {
          SystemInit();
          SystemCoreClockUpdate();
             LPC_GPIO0->FIODIR  =  1<<RS|1<<EN|0XF<<DT;   //used  to  make  all  pins output
              flag1 =0;      // flag1 = 0 all are command and flag1 = 1 all are data
           for (i=0; i<9;i++)
               {
             temp1 = init_command[i];
             lcd_write();
               }
              flag1 =1;
          i =0;
          while (msg[i] != '\0')
                {
                 temp1 = msg[i]; // char by char
                 lcd_write();
                         i+= 1;

if(i==16)  //check for 1 charactres in first line
                                                                                {

           flag1=0;  //if yes

           temp1=0xc0; //configure second line in command register

           lcd_write();

           flag1=1;
                                                                                }
                }
          while(1);
```

```
}

 void lcd_write(void)
            {
                flag2 =  (flag1 == 1) ? 0 :((temp1 == 0x30) || (temp1 == 0x20)) ? 1 : 0;
            temp2 = temp1 & 0xf0;//move data (26-8+1) times : 26 - HN place, 4 - Bits to extract MSB and then LSB as nedd to send 4 bit at a time
                                                                    temp2=temp2>>4;
          temp2 = temp2 << DT;//data lines from 23 to 26
          port_write();
              if (!flag2)
                {
            temp2 = temp1 & 0x0f; //26-4+1
            temp2 = temp2 << DT;
            port_write();
              }
             }


void port_write(void)
{
          LPC_GPIO0->FIOPIN = 0;
          LPC_GPIO0->FIOPIN = temp2;
        if (flag1 == 0)
              LPC_GPIO0->FIOCLR = 1<<RS;
        else
                    LPC_GPIO0->FIOSET = 1<<RS;

          LPC_GPIO0->FIOSET = 1<<EN;          //this and below 3 lines are used  give pulse for enable and wait for some time interval
          delay_lcd(25);
          LPC_GPIO0->FIOCLR = 1<<EN;
              delay_lcd(30000);                                  // 3 ms  highest delay

 }

void delay_lcd(unsigned int r1)
{
          unsigned int r;
          for(r=0;r<r1;r++);

   return;
}
```

1. Given the contents of registers:
   R2=0x12345678
   R5=0x3498765B
   R8=0xFFBBCC19
   What is the content of stack pointer after the execution of the following block of code?
   LDR R13, =0x1000002C
   STMDB R13!, {R2, R5, R8}
   LDM R13!, {R3, R6, R7}

   *
   (0.5/0.5 Points)

   - 0x10000038
   - 0x10000020
   - 0x1000002C ✓
   - 0x10000000

2. Assume that the content of R1 is 2 and the content of N flag is 0. After the execution of the instruction RSB R1, #0, the N flag will be set to 1. The statement is *
   (0/0.5 Points)

   - True
   - False ✓

3. Given the contents of registers:
R4=0x12345678
R5=0x3498765B
R6=0xFFBBCC19
What is the content of stack pointer after the execution of the following block of code?
LDR R13, =0x10000020
STM R13!, {R4-R6}

*
(0/0.5 Points)

- 0x10000020
- 0x10000014
- 0x10000032
- 0x1000002C ✓

4. Which of the following statements will send logic ZERO to P0.7 and P0.6 without affecting the values on the remaining pins of the Port-0? *
(0/0.5 Points)

- LPC_GPIO0->FIOCLR0 = 0x3F
- LPC_GPIO0->FIOPIN = 0xFFFFFF3F
- LPC_GPIO0->FIOPIN = 0x000000C0
- LPC_GPIO0->FIOCLR0 = 0xC0 ✓

5. Assume that content of R1 register is 6. What is the content of R1 after the execution of:
MLA R1, R1, R1, R1
LSR R1, #2 *
(0.5/0.5 Points)

- 0x15
- 0x05
- 0x0A ✓
- 0x21

6. Given the contents of registers:
R4=0x12345678
R5=0x3498765B
R6=0xFFBBCC19
What is the content of stack pointer after the execution of the following block of code?
LDR R13, =0x10000010
STMDB R13, {R4-R6}
*
(0/0.5 Points)

- 0x10000004
- 0x10000010 ✓
- 0x1000001C
- 0x10000012

7. Which of the following flag is not tested by BGT instruction? *
(0.5/0.5 Points)

- Sign Flag
- Overflow Flag
- Zero Flag
- Carry Flag ✓

8. Assume that
R1 = 0x10000020, R2 = 0x12345678
Value at the address 0x1000001C is 0x3976ABCD`
Value at the address 0x10000020 is 0xF45EC98A
What is the content of the register R2 after the execution of the following instruction?
LDR R2, [R1], #-4 *
(0.5/0.5 Points)

- 0xF45EC98A ✓
- 0x12345678
- 0x3976ABCD
- 0x1000000C

9. Given the contents of registers:
R2=0x12345678
R5=0x3498765B
R8=0xFFBBCC19
What is the content of R3 after the execution of the following block of code?
LDR R13, =0x1000002C
STMDB R13!, {R2, R5, R8}
LDM R13!, {R3, R6, R7}

*
(0/0.5 Points)

- 0x12345678 ✓
- 0x3498765B
- 0xFFBBCC19
- 0x10000020

10. What are the contents of Z and C flags after the execution of the following statements?
LDR R1, =0xE3D469FF
MSR xPSR, R1
LDR R4,=0x398F4CDE
RSB R1, R4 *
(0/0.5 Points)

- Z = 1, C=1 ✓
- Z=1, C=0
- Z=0, C=0
- Z=0, C=1

11. Complete the following instruction by filling the blank, to configure P2.28 with Function-02.
LPC_PINCON->PINSEL3 = _____; *
(0.5/0.5 Points)

- 2<<8
- 2<<12
- 2<<24 ✓
- 2<<56

12. Assume that
R1 = 0x1000000C
What is the content of the register R1 after the execution of the following block of code?
LDR R4, [R1], #4
LDR R4,[R1, #4]
LDR R3, [R1,#8]! *
(0/0.5 Points)

- 0x10000016
- 0x1000001C
- 0x10000018 ✓
- 0x10000014

13. Assume that content of R13 is 0x10000020 and the content of R14 is 0x10000040. What is the content of Stack Pointer after the execution of the instruction PUSH {R2, R6, R7} ? *
(0.5/0.5 Points)

- 0x10000003
- 0x10000014 ✓
- 0x1000002C
- 0x10000030

14. Assume that
R1=0xFFFFFFFE
R2=0xFFFFFFFF
R3=5
R4=-7
What is the content of R1 after the execution of instruction
SMLAL R1,R2,R3,R4? *
(0/0.5 Points)

- 0xFFFFFFFB
- 0xFFFFFFFF
- 0xFFFFFFDB ✓
- 0xFFFFFFFC

15. Assume that
R1=0x10000030
R2=0x12A96B3C
R3=0xFECD49EA
What is the byte stored in the address 0x1000002E after the execution of the following instructions?
STR R2, [R1, #-4]!
STR R3, [R1], #4
*
(0.5/0.5 Points)

- 0x6B
- 0xCD ✓
- 0xA9
- 0x49

16. Assume that the content of R4 register is 0x12345678. What is its content after rotating it right by 240 bits? *
(0.5/0.5 Points)

- 0x81234567
- 0x12345678
- 0x56781234 ✓

17. Which of the following instructions is invalid in LPC 1768? *
(0/0.5 Points)

- ADCLS R1, R2, #4
- ROL R3, #4 ✓
- RRX R3, R4
- CMN R2, #-4

18. Assume that value at the address 0x10000020 is 0x3456789A, value at 0x10000024 is 0xF34A6987, value at 0x10000028 is 0xFFEEAABB, and value at 0x1000002C is 0xABCDEF01. Given the content of Stack Pointer as 0x10000028: What is the content of register R4 after the execution of the instruction POP {R3, R4, R1, R5} ? *
(0/0.5 Points)

- 0x3456789A
- 0xF34A6987 ✓
- 0xFFEEAABB
- 0xABCDEF01

19. Assume that the following block of code is executed:
LDR R1, = 0x10000000
LDR R2, =0xABCDEF12
LDR R3, =0x39BC139F
STR R2, [R1], #4
STR R3, [R1]
What is the value of a byte stored in the address 0x10000005? *
(0.5/0.5 Points)

- 0xAB
- 0x13 ✓
- 0xBC
- 0x00

20. Given the contents of registers:
R4=0x12345678
R5=0x3498765B
R6=0xFFBBCC19
What is the content of memory location 0x10000027 after the execution of the following block of code?
LDR R13, =0x10000020
STM R13!, {R4-R6}

*
(0/0.5 Points)

- 0x12
- 0x34 ✓
- 0x5B
- 0x19

1. Assume that TCR is loaded with 0x03; PR is loaded with 0x01 ; CTCR is loaded with 0; Which of the following statement is TRUE?
(0/1 Point)

- The TC counts at each positive edge of PCLK
- The TC counts at each positive edge of CAP input
- The TC counts for every 2 positive edges of PCLK
- The TC is cleared and the Timer will not count ✓

2. Given PCLK = 12 MHz and the PR is loaded with 1999. The value to be loaded to MR register to get 500 milliseconds delay ----------
(0/1 Point)

- 1999
- 2999 ✓
- 5999
- 8999

1. The EM2 bit of Timer-1 can be pinned out on ----------
(1/1 Point)

- MAT 1.1
- MAT 1.2 ✓
- MAT 2.1
- MAT 2.2

2. Type- 5 interrupt vector is stored at an offset of ---------- in the Interrupt Vector Table.
(0/1 Point)

- 0x08
- 0x10
- 0x14 ✓
- 0x20

1. How many SFR's are there in Input/output interrupts (Port0, Port2)
(0/1 Point)

- 6
- 10 ✓
- 11
- 12

2. To have a level one external interrupt values to be loaded into the EXTPOLARx and EXTMODEx are
(0/1 Point)

- 0, 0
- 0, 1
- 1, 0 ✓
- 1, 1

1. To have a Falling Edge Interrupt, values to be loaded into the EXTPOLARx and EXTMODEx SFR's are *
(1/1 Point)

- 1, 1
- 0, 1 ✓
- 1, 0
- 0, 0

2. _____ is the interrupt handler for IO Interrupt *
(1/1 Point)

- External Interrupt handler 0
- External Interrupt handler 2
- External Interrupt handler 3 ✓
- External Interrupt handler 1

3. Io Interrupt Supports both +ve and -ve Edge, level Triggering *
(1/1 Point)

- YES
- NO ✓

4. Port 0 and Port 2 pins support External Interrupts *
(1/1 Point)

- YES
- NO ✓

1. What is the input analog voltage required to produce the digital output of 0x064 in LPC 1768?
(1/1 Point)

- 5.152 mV
- 51.52 mV
- 8.05 mV
- 80.5 mV ✓

2. How many analog channels could be simultaneously converted into digital in LPC 1768?
(1/1 Point)

- 4
- 8 ✓
- 12
- 16

1. In software controlled mode of ADC, only one of the SEL bits to be 1 in the ADCR register so that the selected channel gets converted into digital. TRUE/FALSE
(1/1 Point)

- TRUE ✓
- FALSE

2. How many data registers are there in LPC 1768 ADC module?
(0/1 Point)

- 6
- 8
- 9 ✓
- 12

1. Resolution of DAC in LPC1768 *
(1/1 Point)

- 8
- 12
- 14
- 10 ✓

2. DAC Register used to hold the digital value to convert into Analog *
(1/1 Point)

- DACAR
- DACCTRL
- DACCNTVAL
- DACR ✓

1. LPC 1768 PWM module supports up to ---------- double edge PWM lines
(1/1 Point)

- 2
- 3
- 5 ✓
- 6

2. To generate the double edge PWM output waveform on PWM4 line, following Match Registers are to be used.
(1/1 Point)

- MR0, MR4
- MR0, MR3, MR4 ✓
- MR0, MR3
- MR0, MR4, MR5

1. SFR's associated with DAC in LPC1768 *
(1/1 Point)

- [x] DACR ✓
- [x] DACCTRL ✓
- [ ] DACCNTAL
- [ ] All of the Above

2. Name the SFR used to enable double buffering option *
(1/1 Point)

- ( ) DACR
- (•) DACCTRL ✓
- ( ) Both DACR and DACCTRL
- ( ) None of the above

1. Value to be loaded on to LCR to configure UART for 8-bit word length, parity disable, enable divisor latch *
(1/1 Point)

- ( ) 0x00000081
- ( ) 0x00000082
- (•) 0x00000083 ✓
- ( ) 0x00000084

2. Value to be loaded into FCR register to enable both Tx and Rx FIFO buffer *
(1/1 Point)

- ( ) 0x00000008
- (•) 0x00000007 ✓
- ( ) 0x00000006
- ( ) 0x00000004

1. When a PWM Match 0 event occurs, the contents of match register will be transferred to the ----- if the corresponding bit in the ---------- has been ----------.
(1/1 Point)

- latch enable register, shadow register, set
- shandow register, latch enable register , set ✓
- latch enable register, shadow register, reset
- shandow register, latch enable register , reset

2. Given MR0 =200, MR2 =40, MR3 = 130.
The width of the double edge PWM pulse on PWM1.3 is ---------
(1/1 Point)

- 40
- 70
- 90 ✓
- 160