Input/Output Devices

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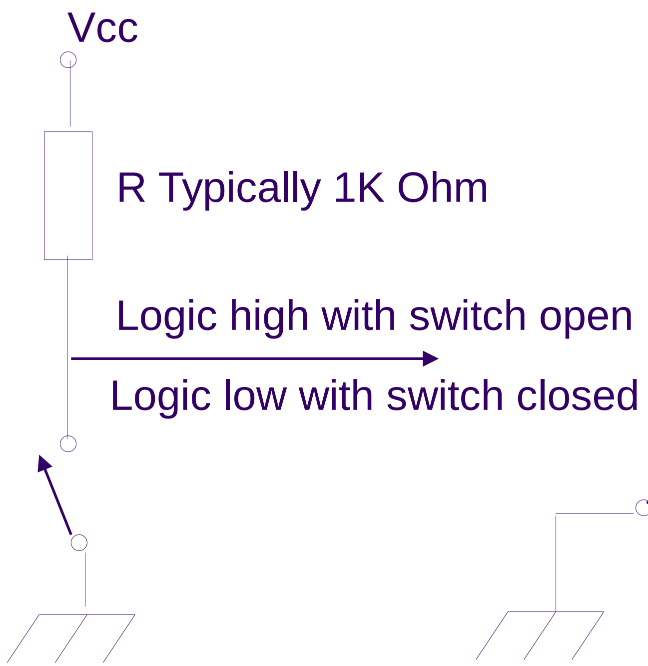
Lecture Overview

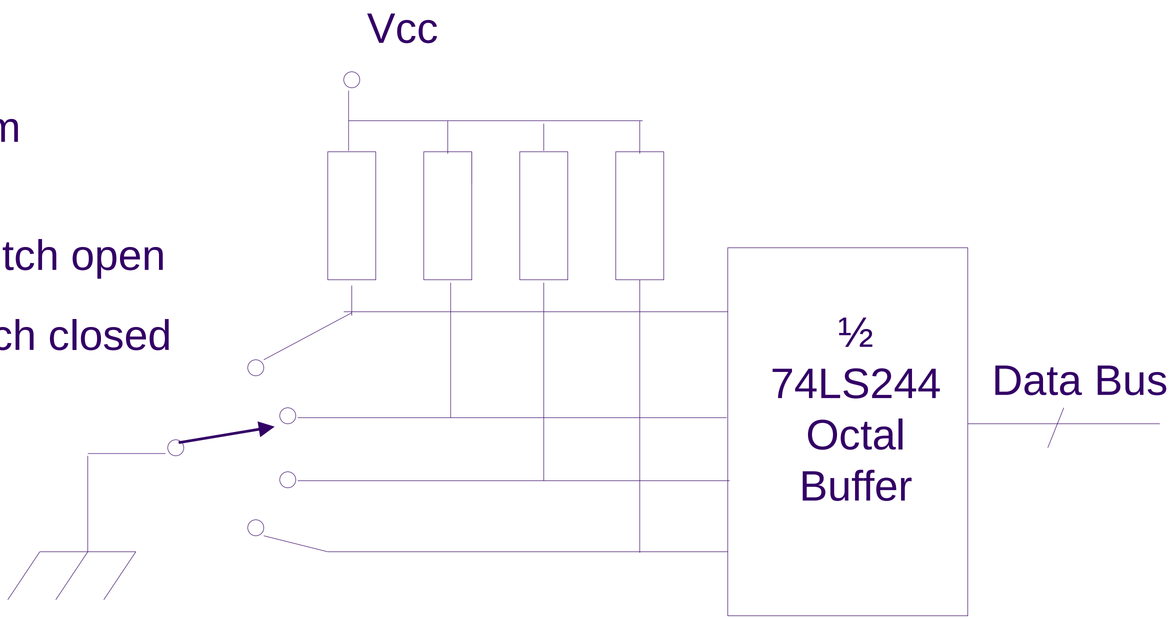
- Input devices
  - Input switches
    - Basics of switches
  - Keypads
- Output devices
  - LCD

Input Switches

- Most basic binary input devices
- The switch output is high or low, depending on the switch position.
- Pull-up resistors are necessary in each switch to provide a high logic level when the switch is open.
- Problem with switches:
  - Switch bounce.
    - When a switch makes contact, its mechanical springiness will cause the contact to bounce, or contact and break, for a few milliseconds (typically 5 to 10 ms).

Input Switches (cont.)

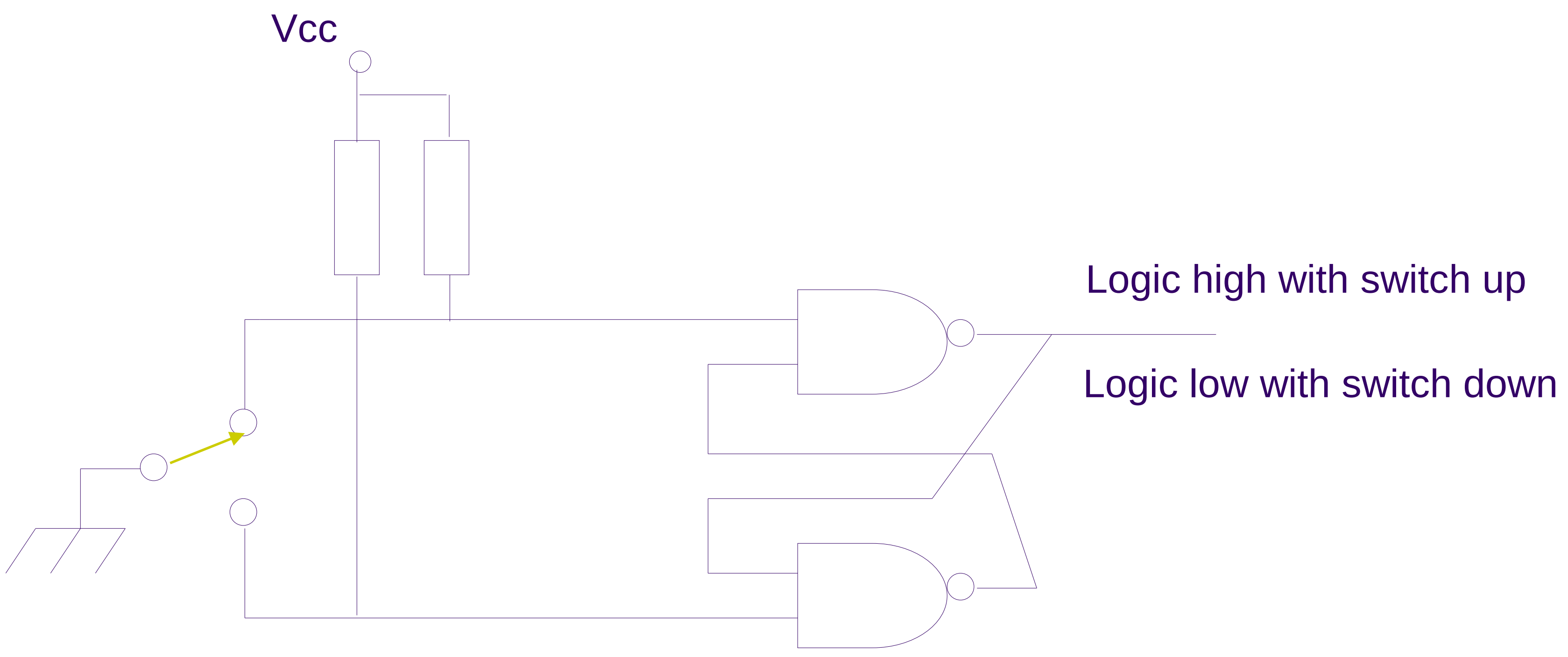




(a) Single-pole, single-throw (SPST) logic switch Data Bus

(b) Multiple pole switch.

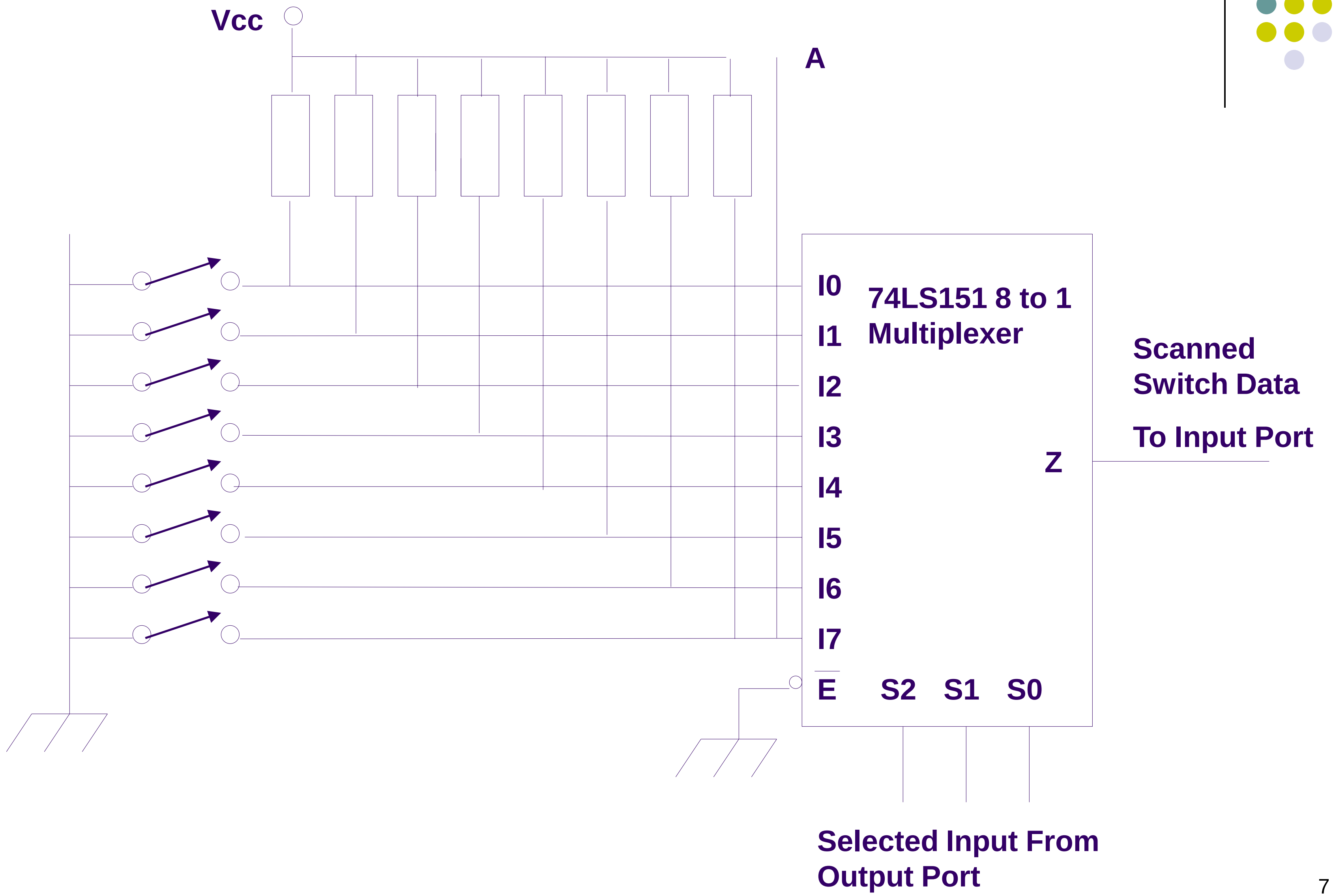
NAND Latch Debouncer



Software Debouncing

- Basic idea: wait until the switch is stable
- For example:
  - Wait and see:
    - If the software detects a low logic level, indicating that switch has closed, it simply waits for some time, say 20 to 100ms, and then test if the switch is still low.
  - Counter-based approach:
    - Initialize a counter to 10.
    - Poll the switch every millisecond until the counter is either 0 or 20. If the switch output is low, decrease the counter; otherwise, increment the counter.
    - If the counter is 0, we know that switch output has been low (closed) for at least 10 ms. If, on the other hand, the counter reaches 20, we know that the switch has been open for at least 10 ms.

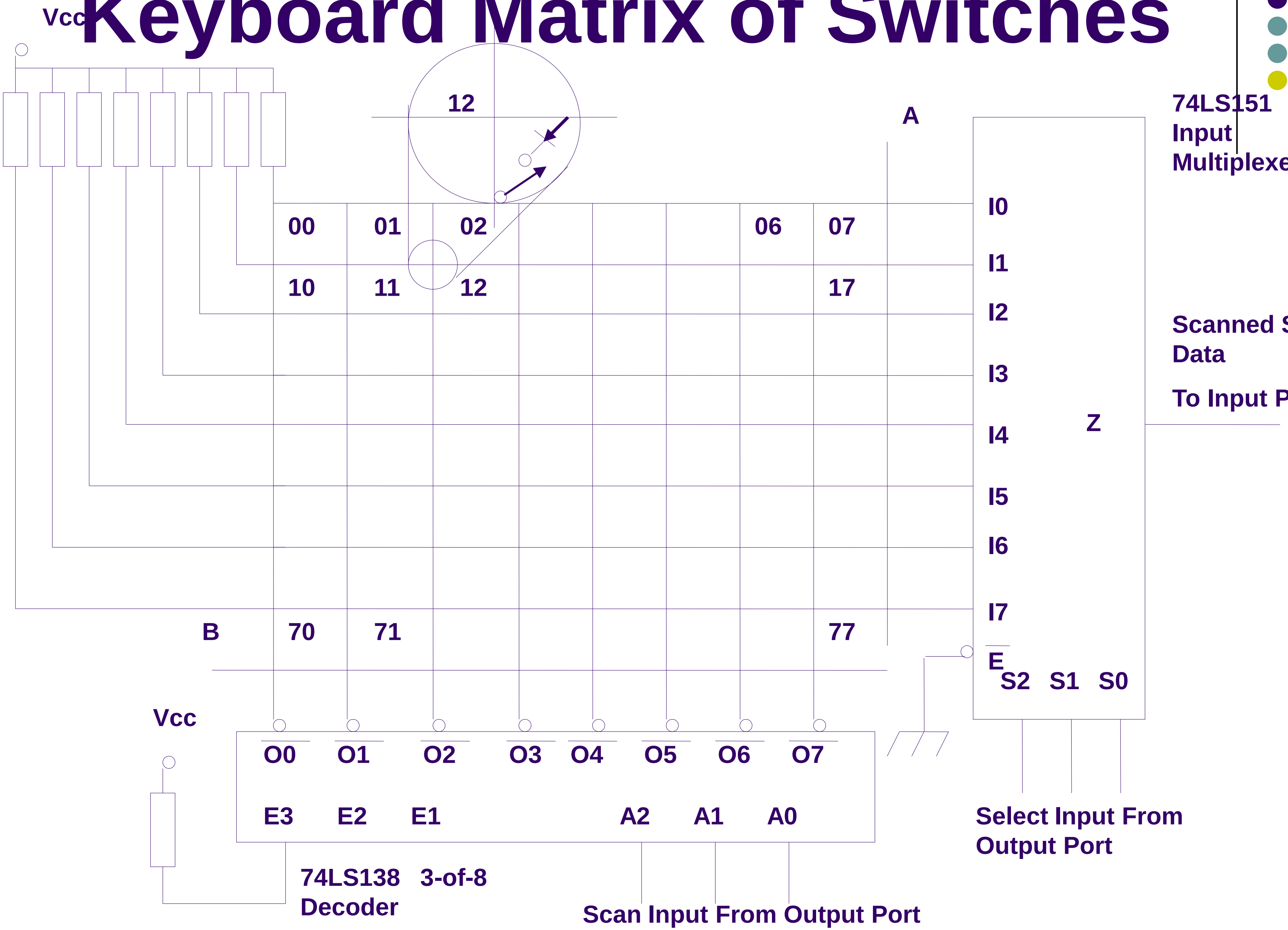
One-Dimensional Array of Switches



One-Dimensional Array of Switches

- Switch bouncing problem must be solved
  - Either using software or hardware
- The array of switches must be scanned to find out which switches are closed or open.
  - Software is required to scan the array. As the software outputs a 3-bit sequence from 000 to 111, the multiplexer selects each of the switch inputs.
  - The output of switch array could be interfaced directly to an eight-bit port at point A.

Keyboard Matrix of Switches



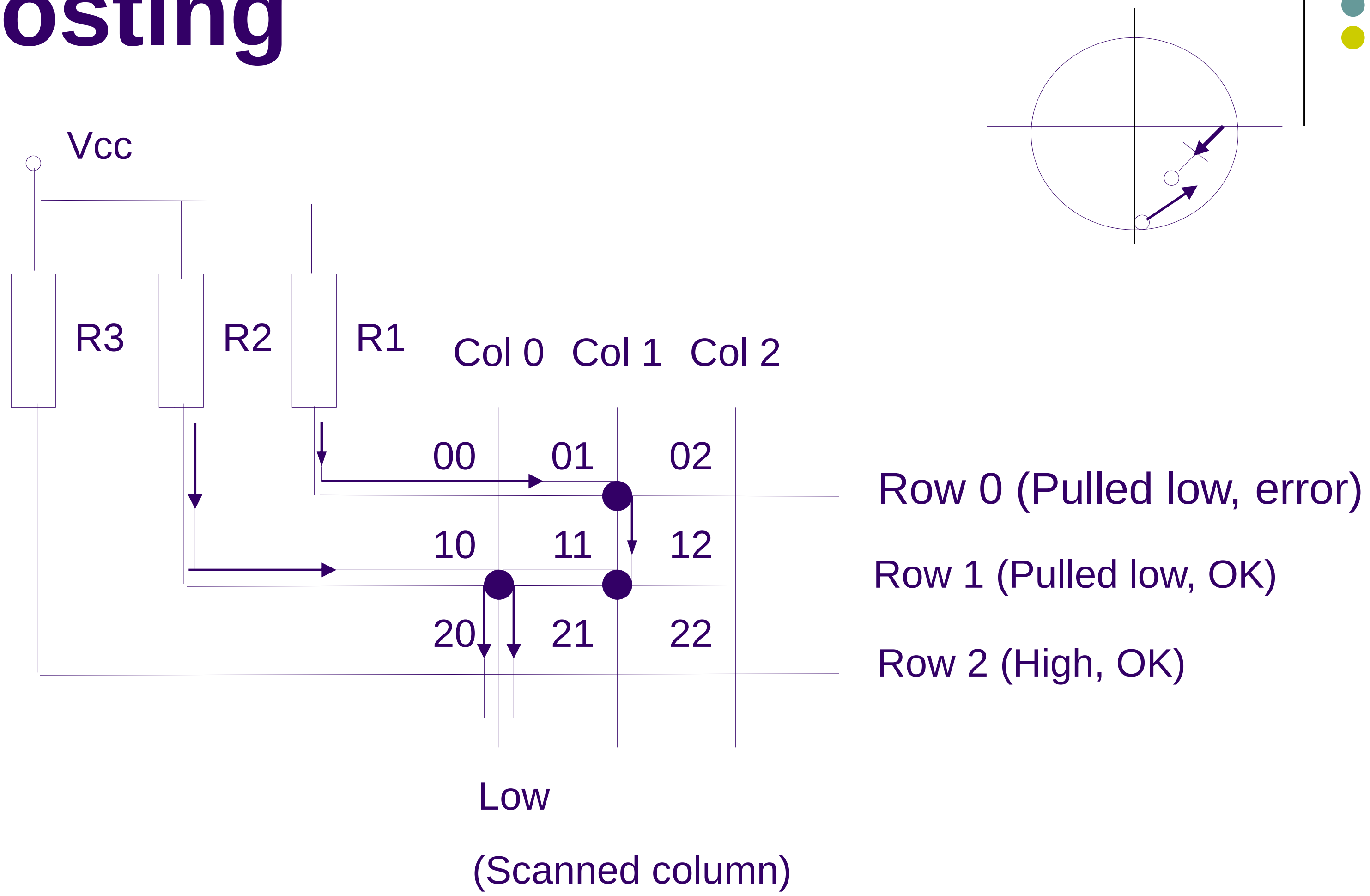
Keyboard Matrix of Switches (cont.)

- A keyboard is an array of switches arranged in a two-dimensional matrix.
- A switch is connected at each intersection of vertical and horizontal lines.
- Closing the switch connects the horizontal line to the vertical line.
- 8*8 keyboard can be interfaced directly into 8-bit output and input ports at point A and B.

Keyboard Matrix of Switches (cont.)

- Software can scan the key board by outputting a three-bit code to the decoder and then scanning the multiplexer to find the closed switch or switches.
  - The combination of the two 3-bit scan codes (A2A1A0 and S2S1S0) identifies which switch is closed. For example, the code 000000 scan switch 00 in the upper left-hand corner.
- The diode prevents a problem called ghosting.

Ghosting



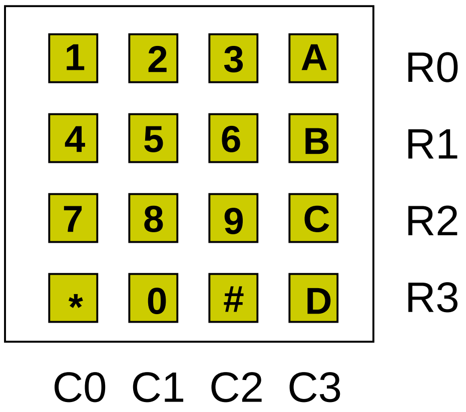
Vcc
R3
R2
R1
Col 0
Col 1
Col 2
00
01
02
10
11
12
20
21
22
Row 0 (Pulled low, error)
Row 1 (Pulled low, OK)
Row 2 (High, OK)
Low
(Scanned column)

Ghosting (cont.)

- Ghosting occurs when several keys are pushed at once.
- Consider the case shown in the figure where three switches 01, 10 and 11 are all closed. Column 0 is selected with a logic low and assume that the circuit does not contain the diodes. As the rows are scanned, a low is sensed on Row 1, which is acceptable because switch 10 is closed. In addition, Row 0 is seen to be low, indicating switch 00 is closed, which is NOT true. The diodes in the switches eliminate this problem by preventing current flow from R1 through switches 01 and 11. Thus Row 0 will not be low when it is scanned.

Example

- Get the input from 4*4 keypad



Example (solution)

- Algorithm

```
Scan columns from left to right
        for each column, scan rows from top to bottom
                for each key being scanned
                        if it is pressed
                                display
                                wait
                        endif
                endfor
        endfor
Repeat the scan process
```

  - A column is selected, its related Cx value is set to 0.
  - A mask is used to read one row at a time.

Code Implementation

```
; The program gets input from keypad and displays its ascii value on the
; LED bar

.include "m2560def.inc"

.def row = r16                  ; current row number
.def col = r17                  ; current column number
.def rmask = r18                ; mask for current row during scan
.def cmask = r19                ; mask for current column during scan
.def temp1 = r20
.def temp2 = r21

.equ PORTADIR = 0xF0            ; PD7-4: output, PD3-0, input
.equ INITCOLMASK = 0xEF         ; scan from the rightmost column,
.equ INITROWMASK = 0x01         ; scan from the top row
.equ ROWMASK = 0x0F             ; for obtaining input from Port D
```

Code Implementation

```
RESET:
        ldi     temp1, low(RAMEND)     ; initialize the stack
        out     SPL, temp1
        ldi     temp1, high(RAMEND)
        out     SPH, temp1

        ldi     temp1, PORTADIR        ; PA7:4/PA3:0, out/in
        out     DDRA, temp1
        ser     temp1                  ; PORTC is output
        out     DDRC, temp1
        out     PORTC, temp1

main:
        ldi     cmask, INITCOLMASK     ; initial column mask
        clr     col                    ; initial column
```

Code Implementation

```
colloop:
        cpi     col, 4
        breq    main                    ; If all keys are scanned, repeat.
        out     PORTA, cmask            ; Otherwise, scan a column.

        ldi     temp1, 0xFF             ; Slow down the scan operation.
delay:  dec     temp1
        brne    delay

        in      temp1, PINA             ; Read PORTA
        andi    temp1, ROWMASK          ; Get the keypad output value
        cpi     temp1, 0xF              ; Check if any row is low
        breq    nextcol
                                        ; If yes, find which row is low
        ldi     rmask, INITROWMASK      ; Initialize for row check
        clr     row                     ;
```

Code Implementation

```
rowloop:
        cpi     row, 4
        breq    nextcol                     ; the row scan is over.
        mov     temp2, temp1
        and     temp2, rmask                ; check un-masked bit
        breq    convert                     ; if bit is clear, the key is pressed
        inc     row                         ; else move to the next row
        lsl     rmask
        jmp     rowloop

nextcol:                                    ; if row scan is over
        lsl cmask
        inc col                             ; increase column value
        jmp colloop                         ; go to the next column
```

Code Implementation

```
convert:
       cpi     col, 3          ; If the pressed key is in col.3
       breq    letters         ; we have a letter

                               ; If the key is not in col.3 and

       cpi     row, 3          ; If the key is in row3,
       breq    symbols         ; we have a symbol or 0

       mov     temp1, row      ; Otherwise we have a number in 1-9
       lsl     temp1
       add     temp1, row
       add     temp1, col      ; temp1 = row*3 + col
       subi    temp1, -'1'     ; Add the value of character ‘1’
       jmp     convert_end
```

Code Implementation

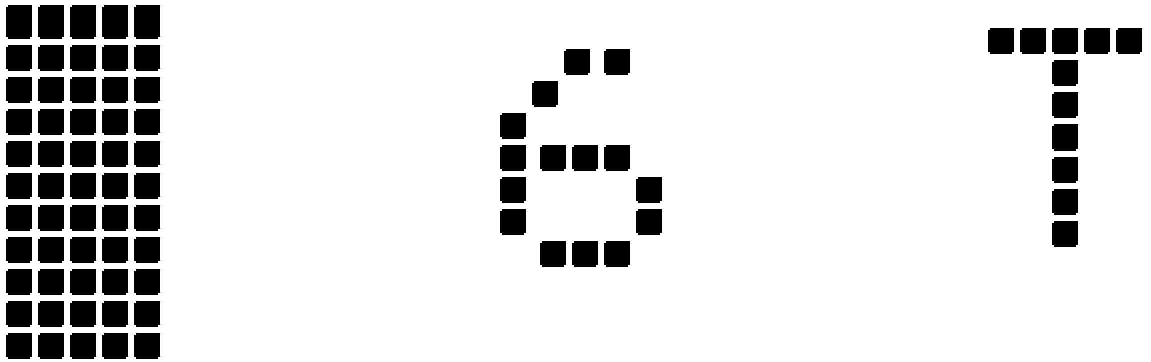
```
letters:
        ldi temp1, 'A'
        add temp1, row              ; Get the ASCII value for the key
        jmp convert_end

symbols:
        cpi col, 0                  ; Check if we have a star
        breq star
        cpi col, 1                  ; or if we have zero
        breq zero
        ldi temp1, '#'              ; if not we have hash
        jmp convert_end
star:
        ldi temp1, '*'              ; Set to star
        jmp convert_end
zero:
        ldi temp1, '0'              ; Set to zero

convert_end:
        out PORTC, temp1            ; Write value to PORTC
        jmp main                    ; Restart main loop
```

LCD

- Liquid Crystal Display
- Programmable output device

Dot Matrix LCD

- Characters are displayed using a dot matrix.
  - 5x7, 5x8, and 5x11
- A controller is used for communication between the LCD and other devices,e.g. MPU
- The controller has an internal character generator ROM. All display functions are controllable by instructions.



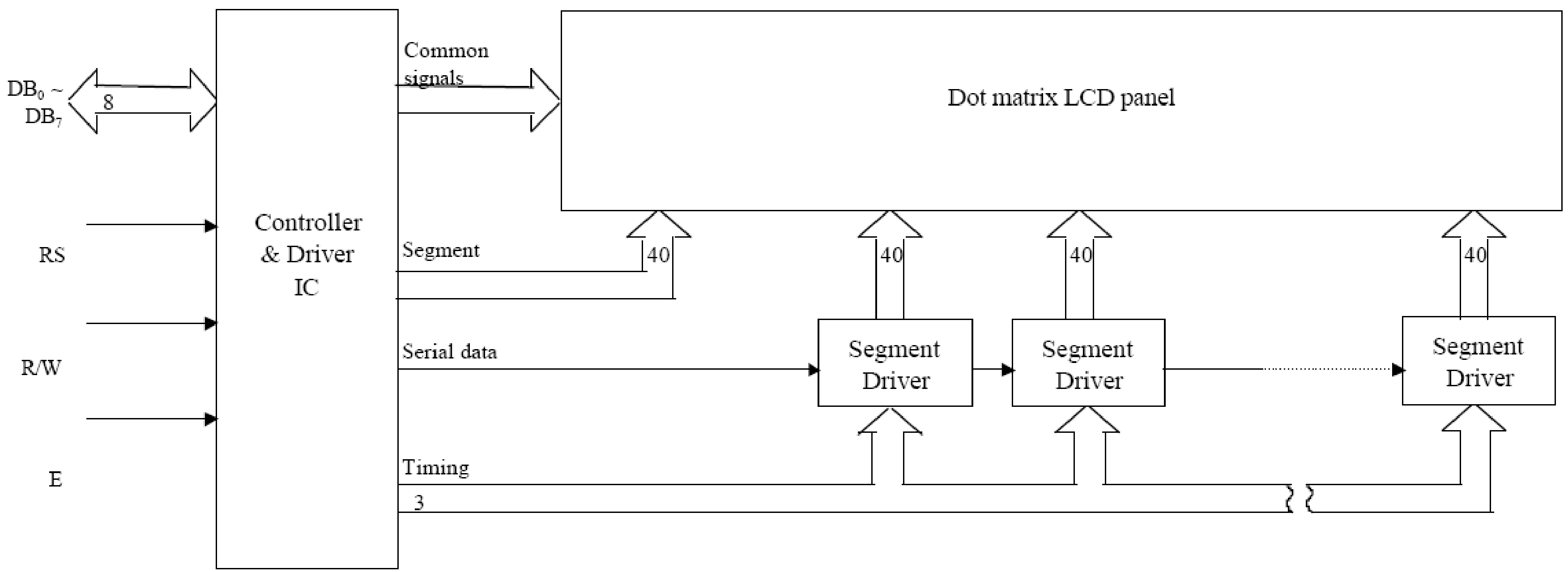
Pin Assignments

Pin Number	Symbol
1	V_{ss}
2	V_{cc}
3	V_{ee}
4	RS
5	R/W
6	E
7	DB0
8	DB1
9	DB2
10	DB3
11	DB4
12	DB5
13	DB6
14	DB7

Pin Descriptions

Signal name	No. of Lines	Input/Output	Connected to	Function
DB4 ~ DB7	4	Input/Output	MPU	4 lines of high order data bus. Bi-directional transfer of data between MPU and module is done through these lines. Also DB_7 can be used as a busy flag. These lines are used as data in 4 bit operation.
DB0 ~ DB3	4	Input/Output	MPU	4 lines of low order data bus. Bi-directional transfer of data between MPU and module is done through these lines. In 4 bit operation, these are not used and should be grounded.
E	1	Input	MPU	Enable - Operation start signal for data read/write.
R/W	1	Input	MPU	Signal to select Read or Write "0": Write "1": Read
RS	1	Input	MPU	Register Select "0": Instruction register (Write) : Busy flag; Address counter (Read) "1": Data register (Write, Read)
Vee	1		Power Supply	Terminal for LCD drive power source.
Vcc	1		Power Supply	+5V
Vss	1		Power Supply	0V (GND)

Dot Matrix LCD Diagram



Operations

- MPU communicates with LCD through two registers
  - Instruction Register (IR)
    - To store instruction codes like Display clear or Cursor Shift as well as addresses for the Display Data RAM (DD RAM) or the Character Generator RAM (CG RAM)
  - Data Register (DR)
    - To temporarily store data to be read/written to/from the DD RAM of the display controller.

Operations (cont.)

- The register select (RS) signal determines which of these two register is selected.

RS	R/W	Operation
0	0	IR write, internal operation (Display Clear etc.)
0	1	Busy flag (DB_7) and Address Counter ($DB_0 \sim DB_6$) read
1	0	DR Write, Internal Operation (DR ~ DD RAM or CG RAM)
1	1	DR Read, Internal Operation (DD RAM or CG RAM)

Operations (cont.)

- When the busy flag is high or ‘1’, the LCD module is busy with internal operation.
- The next instruction must not be written until the busy flag is low or ‘0’.
- For details, refer to the LCD USER’S MANUAL.

LCD Instructions

- A list of binary instructions are available for LCD operations
- Some typical ones are explained in the next slides.

Instructions

- Clear Display

	RS	R/W	DB7	DB6	DB5	BD4	DB3	DB2	DB1	DB0
Code	0	0	0	0	0	0	0	0	0	1

- The display clears and the cursor or blink moves to the upper left edge of the display.
- The execution of clear display instruction sets entry mode to increment mode.

Instructions

- Return Home

	RS	R/W	DB7	DB6	DB5	BD4	DB3	DB2	DB1	DB0
Code	0	0	0	0	0	0	0	0	1	x

- The cursor or the blink moves to the upper left edge of the display. Text on the display remains unchanged.

Instructions

- Entry Mode Set

	RS	R/W	DB7	DB6	DB5	BD4	DB3	DB2	DB1	DB0
Code	0	0	0	0	0	0	0	1	I/D	S

- Sets the Increment/Decrement and Shift modes to the desired settings.
  - I/D: Increments (I/D = 1) or decrements (ID = 0) the DD RAM address by 1 when a character code is written into or read from the DD RAM.
  - The cursor or blink moves to the right when incremented by +1.
  - The same applies to writing and reading the CG RAM.
  - S: Shifts the entire display either to the right or to the left when S = 1; shift to the left when I/D = 1 and to the right when I/D = 0.

Instructions

- Display ON/OFF Control

	RS	R/W	DB7	DB6	DB5	BD4	DB3	DB2	DB1	DB0
Code	0	0	0	0	0	0	1	D	C	B

  - Controls the display ON/OFF status, Cursor ON/OFF and Cursor Blink function.
    - D: The display is ON when D = 1 and OFF when D = 0.
    - C: The cursor displays when C = 1 and does not display when C = 0.
    - B: The character indicated by the cursor blinks when B = 1.

Instructions

- Cursor or Display Shift

	RS	R/W	DB7	DB6	DB5	BD4	DB3	DB2	DB1	DB0
Code	0	0	0	0	0	1	S/C	R/L	x	x

  - Shifts the cursor position or display to the right or left without writing or reading display data.

S/C	R/L	
0	0	Shifts cursor position to the left (AC is decremented by one)
0	1	Shifts cursor position to the right (AC is incremented by one)
1	0	Shifts the entire display to the left. The cursor follows the display shift.
1	1	Shifts the entire display to the right. The cursor follows the display shift.

Instructions

- Function Set

	RS	R/W	DB7	DB6	DB5	BD4	DB3	DB2	DB1	DB0
Code	0	0	0	0	1	DL	N	F	x	x

  - Sets the interface data length, the number of lines, and character font.
    - DL = 1, 8 –bits; otherwise 4 bits
    - N: Sets the number of lines
      - N = 0 : 1 line display
      - N = 1 : 2 line display
    - F: Sets character font.
      - F = 1 : 5 x 10 dots
      - F = 0 : 5 x 7 dots

Instructions

- Read Busy Flag and Address

	RS	R/W	DB7	DB6	DB5	BD4	DB3	DB2	DB1	DB0
Code	0	1	BF	A	A	A	A	A	A	A

  - Reads the busy flag (BF) and value of the address counter (AC). BF = 1 indicates that on internal operation is in progress and the next instruction will not be accepted until BF is set to ‘0’. If the display is written while BF = 1, abnormal operation will occur.

Instructions

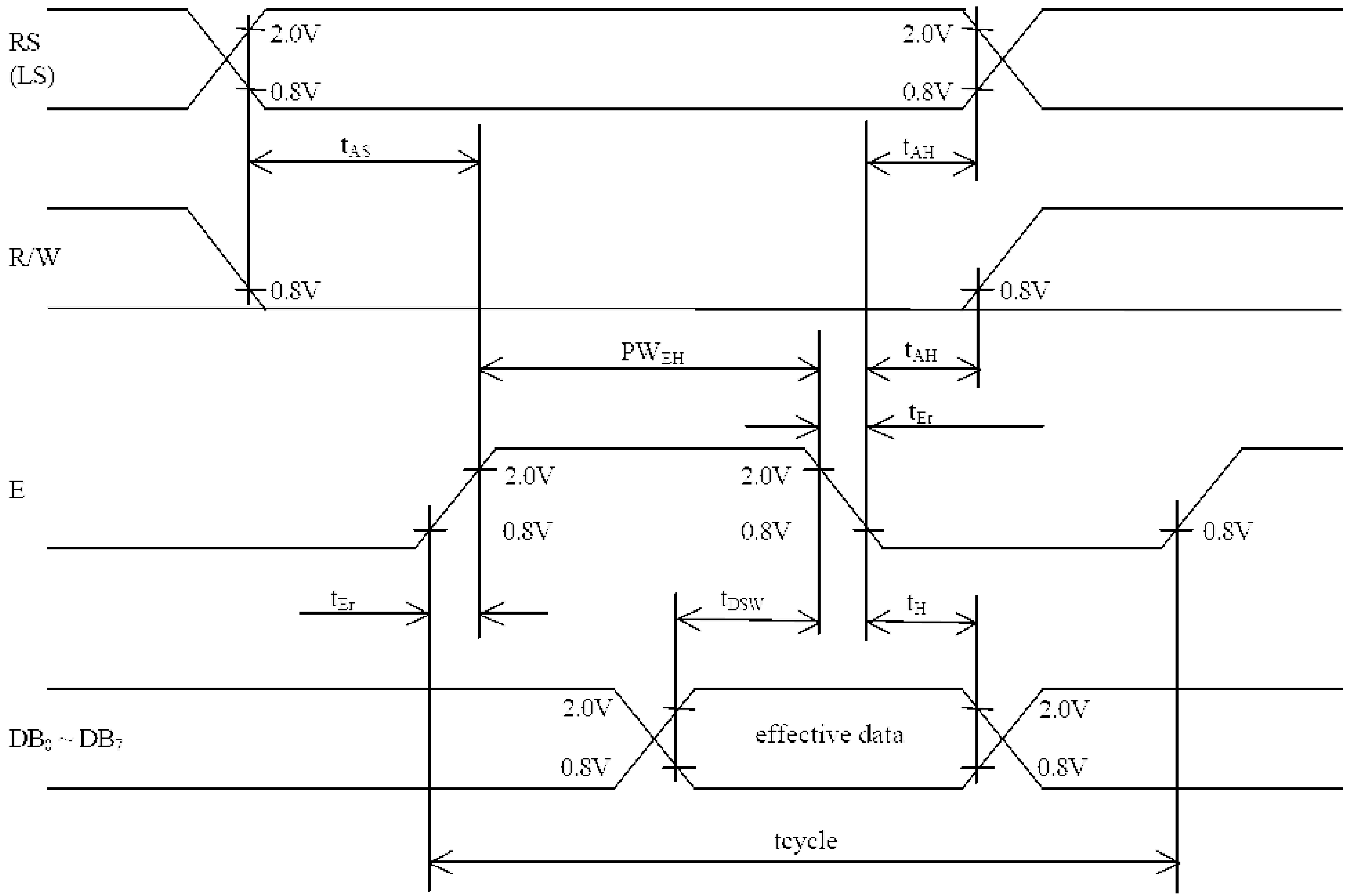
- Write Data to CG or DD RAM

	RS	R/W	DB7	DB6	DB5	BD4	DB3	DB2	DB1	DB0
Code	1	0	D	D	D	D	D	D	D	D

  - Writes binary 8-bit data DDDDDDDD to the CG or DD RAM.
  - The previous designation determines whether the CG or DD RAM is to be written (CG RAM address set or DD RAM address set). After a write the entry mode will automatically increase or decrease the address by 1. Display shift will also follow the entry mode.

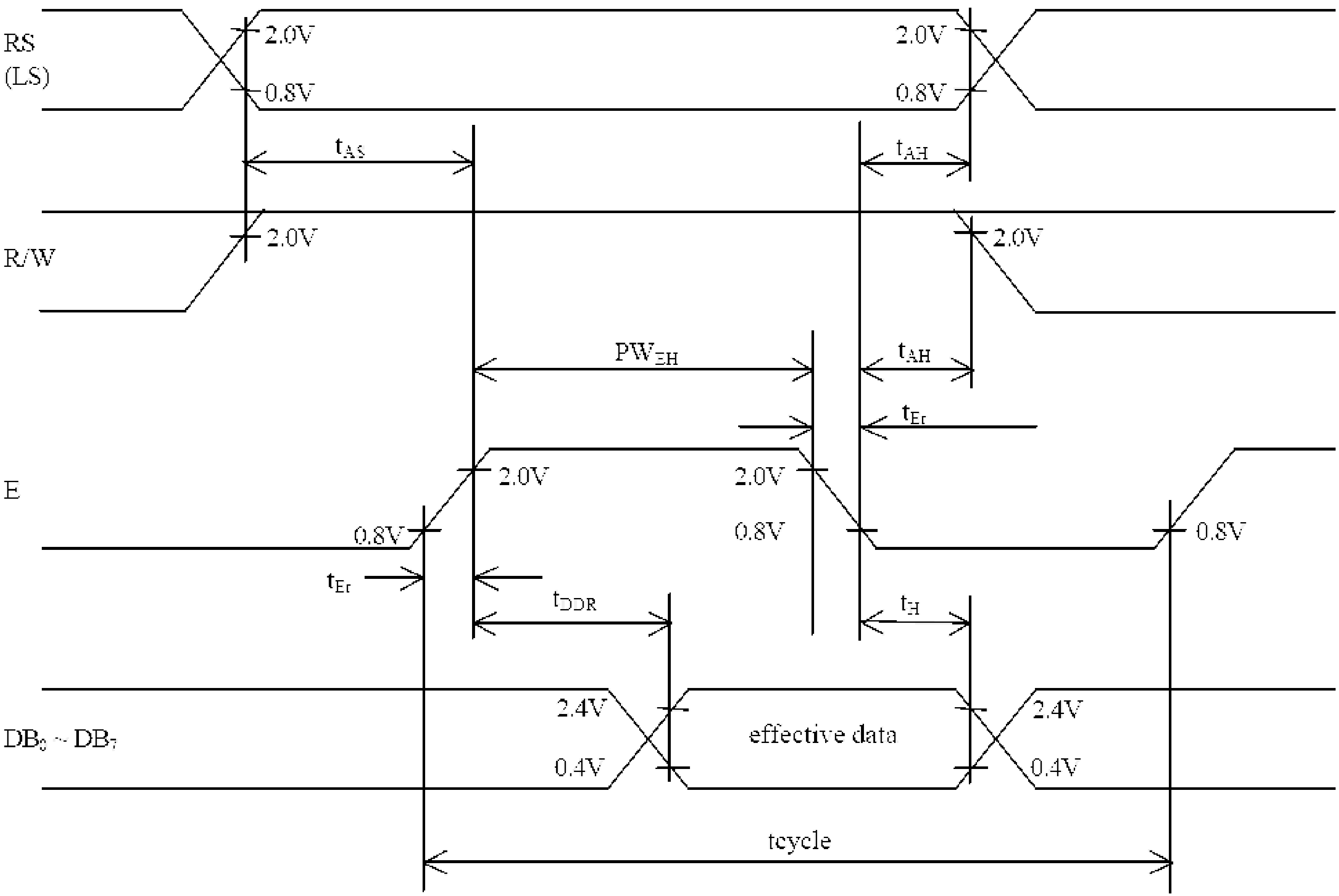
Timing Characteristics

- For write operation



Timing Characteristics

- For read operation



Examples

- Send a command to LCD

```
; Register data stores value to be written to the LCD
; Port D is output and connects to LCD; Port A controls the LCD.
; Assume all other labels are pre-defined.

.macro lcd_write_com
        out PORTD, data         ; set the data port's value up
        clr temp
        out PORTA, temp         ; RS = 0, RW = 0 for a command write
        nop                     ; delay to meet timing (Set up time)
        sbi PORTA, LCD_E        ; turn on the enable pin
        nop                     ; delay to meet timing (Enable pulse width)
        nop
        nop
        cbi PORTA, LCD_E        ; turn off the enable pin
        nop                     ; delay to meet timing (Enable cycle time)
        nop
        nop
.endmacro
```

Examples

- Send data to display

```
; comments are same as in previous slide.

.macro lcd_write_data
        out PORTD, data              ; set the data port's value up
        ldi temp, 1 << LCD_RS
        out PORTA, temp              ; RS = 1, RW = 0 for a data write
        nop                          ; delay to meet timing (Set up time)
        sbi PORTA, LCD_E             ; turn on the enable pin
        nop                          ; delay to meet timing (Enable pulse width)
        nop
        nop
        cbi PORTA, LCD_E             ; turn off the enable pin
        nop                          ; delay to meet timing (Enable cycle time)
        nop
        nop
.endmacro
```

Examples

- Check LCD and wait until LCD is not busy

```
; comments are same as in the previous slide
.macro lcd_wait_busy
        clr temp
        out DDRD, temp                ; Make PORTD be an input port for now
        out PORTD, temp
        ldi temp, 1 << LCD_RW
        out PORTA, temp               ; RS = 0, RW = 1 for a command port read
busy_loop:
        nop                           ; delay to meet set-up time)
        sbi PORTA, LCD_E              ; turn on the enable pin
        nop                           ; delay to meet timing (Data delay time)
        nop
        nop
        in temp, PIND                 ; read value from LCD
        cbi PORTA, LCD_E              ; turn off the enable pin
        sbrc temp, LCD_BF             ; if the busy flag is set
        rjmp busy_loop                ; repeat command read
        clr temp                      ; else
        out PORTA, temp               ; turn off read mode,
        ser temp                      ;
        out DDRD, temp                ; make PORTD an output port again
.endmacro
```

LCD Initialization

- LCD should be initialized before use
- Internal Reset Circuit can be used, but it is related to power supply loading, may not work properly.
- Therefore, software initialization is recommended.

Software Initialization

8 - Bit Initialization:

Power ON

Wait more than 15ms after Vcc = 4.5V

No data should be transferred to or from the display during this time.

RS	R/W	DB_7	DB_6	DB_5	DB_4	DB_3	DB_2	DB_1	DB_0
0	0	0	0	1	1	x	x	x	x

Function Set Command: (8-Bit interface)
BF cannot be checked before this command.

Wait more than 4.1ms

No data should be transferred to or from the display during this time.

RS	R/W	DB_7	DB_6	DB_5	DB_4	DB_3	DB_2	DB_1	DB_0
0	0	0	0	1	1	x	x	x	x

Function Set Command: (8-Bit interface)
BF cannot be checked before this command.

Wait more than 100µs

No data should be transferred to or from the display during this time.

Software Initialization

Wait more than 100μs

No data should be transferred to or from the display during this time.

RS	R/W	DB_7	DB_6	DB_5	DB_4	DB_3	DB_2	DB_1	DB_0
0	0	0	0	1	1	x	x	x	x

Function Set Command: (8-Bit interface)
After this command is written, BF can be checked.

RS	R/W	DB_7	DB_6	DB_5	DB_4	DB_3	DB_2	DB_1	DB_0	
0	0	0	0	1	1	N	F	x	x	Function Set (Interface = 8 bits, Set No. of lines and display font)
0	0	0	0	0	0	1	0	0	0	Display OFF
0	0	0	0	0	0	0	0	0	1	Clear Display
0	0	0	0	0	0	0	1	I/D	S	Entry Mode Set:
0	0	0	0	0	0	1	1	C	B	Display ON (Set C and B for cursor/Blink options.)

Initialization Complete,
Display Ready.

Note: BF should be checked before each of the instructions starting with Display OFF.

Example of Initialization Code

```
.include "m2560def.inc"

; The del_hi:del_lo register pair store the loop counts
; each loop generates about 1 us delay
.macro delay
loop:  subi del_lo, 1
       sbci del_hi, 0
       nop
       nop
       nop
       nop
       brne loop    ; taken branch takes two cycles.
                    ; one loop time is 8 cycles = ~1.08us
.endmacro

                                        ; continued
```

Example of Initialization Code

```
ldi del_lo, low(15000)                ; delay (>15ms)
ldi del_hi, high(15000)
delay

; Function set command with N = 1 and F = 0
; for 2 line display and 5*7 font. The 1st command
ldi data, LCD_FUNC_SET | (1 << LCD_N)
lcd_write_com

ldi del_lo, low(4100)                 ; delay (>4.1 ms)
ldi del_hi, high(4100)
delay

lcd_write_com       ; 2nd Function set command

                    ; continued
```

Example of Initialization Code

```
ldi del_lo, low(100)                ; delay (>100 ns)
ldi del_hi, high(100)
delay

lcd_write_com                       ; 3rd Function set command
lcd_write_com                       ; Final Function set command

lcd_wait_busy                       ; Wait until the LCD is ready
ldi data, LCD_DISP_OFF
lcd_write_com                       ; Turn Display off

lcd_wait_busy                       ; Wait until the LCD is ready
ldi data, LCD_DISP_CLR
lcd_write_com                       ; Clear Display

                                    ; continued
```

Example of Initialization Code

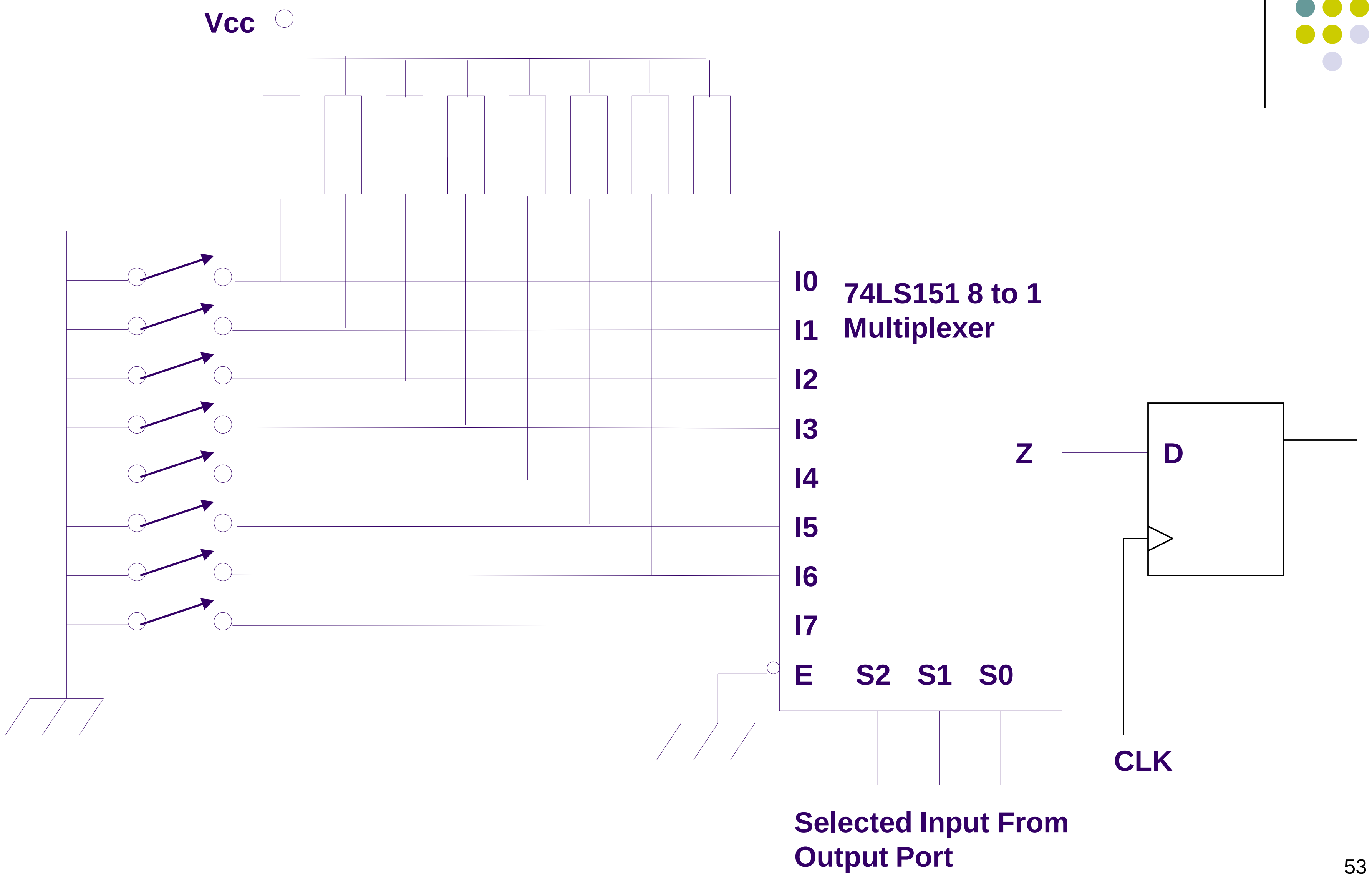
```
lcd_wait_busy                 ; Wait until the LCD is ready
; Entry set command with I/D = 1 and S = 0
; Set Entry mode: Increment = yes and Shift = no
ldi data, LCD_ENTRY_SET | (1 << LCD_ID)
lcd_write_com

lcd_wait_busy                 ; Wait until the LCD is ready
; Display On command with C = 1 and B = 0
ldi data, LCD_DISP_ON | (1 << LCD_C)
lcd_write_com
```

Reading Material

- Chapter 7: Computer Buses and Parallel Input and Output. Microcontrollers and Microcomputers by Fredrick M. Cady.
  - Simple I/O Devices
- DOT Matrix LCD User's Manual
  - Available on the course website.

Homework

1. The circuit shown in the next slide is a switch array input circuit. Is there any switch bounce issue with this circuit? Can the CLK frequency have any impact on this problem? How to solve it in hardware?


Vcc
I0
I1
I2
I3
I4
I5
I6
I7
74LS151 8 to 1
Multiplexer
Z
E
S2
S1
S0
D
CLK
Selected Input From
Output Port

Homework

2. Write an assembly program to initialize LCD panel to display characters in one line with 5x7 font.