LCD: liquid crystal displays

- Many kinds
  - Passive: multiplexed, simpler, slow refresh
  - Active: each pixel has its own transistor
- Related technologies
  - LED - light emitting diode, higher power
  - OLED - organic LED, bright, low power

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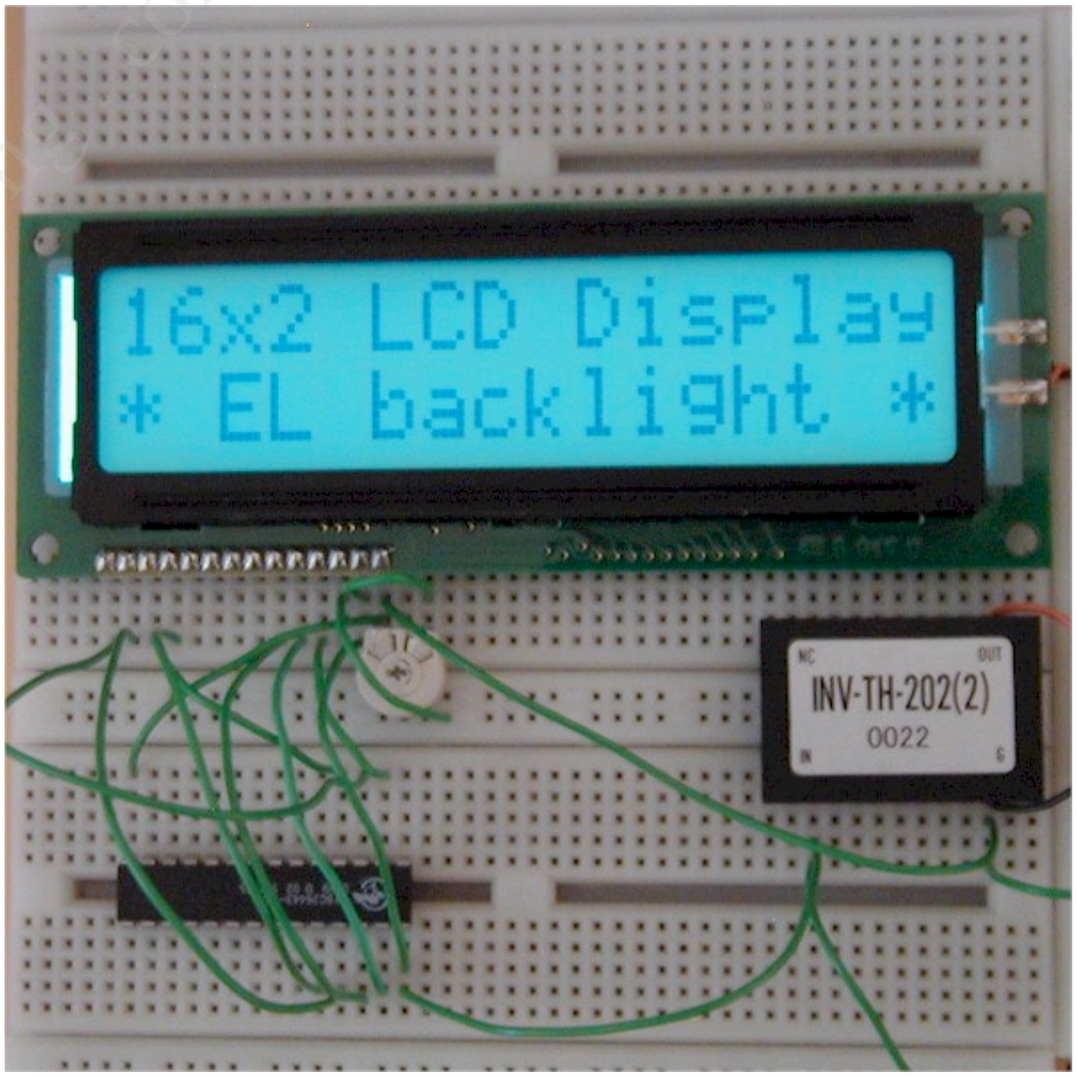
LCD used in this book
16 x 2 alphanumeric

- bitmapped font
- display character
- has a cursor
- diff. scolling effects
- blinking possible



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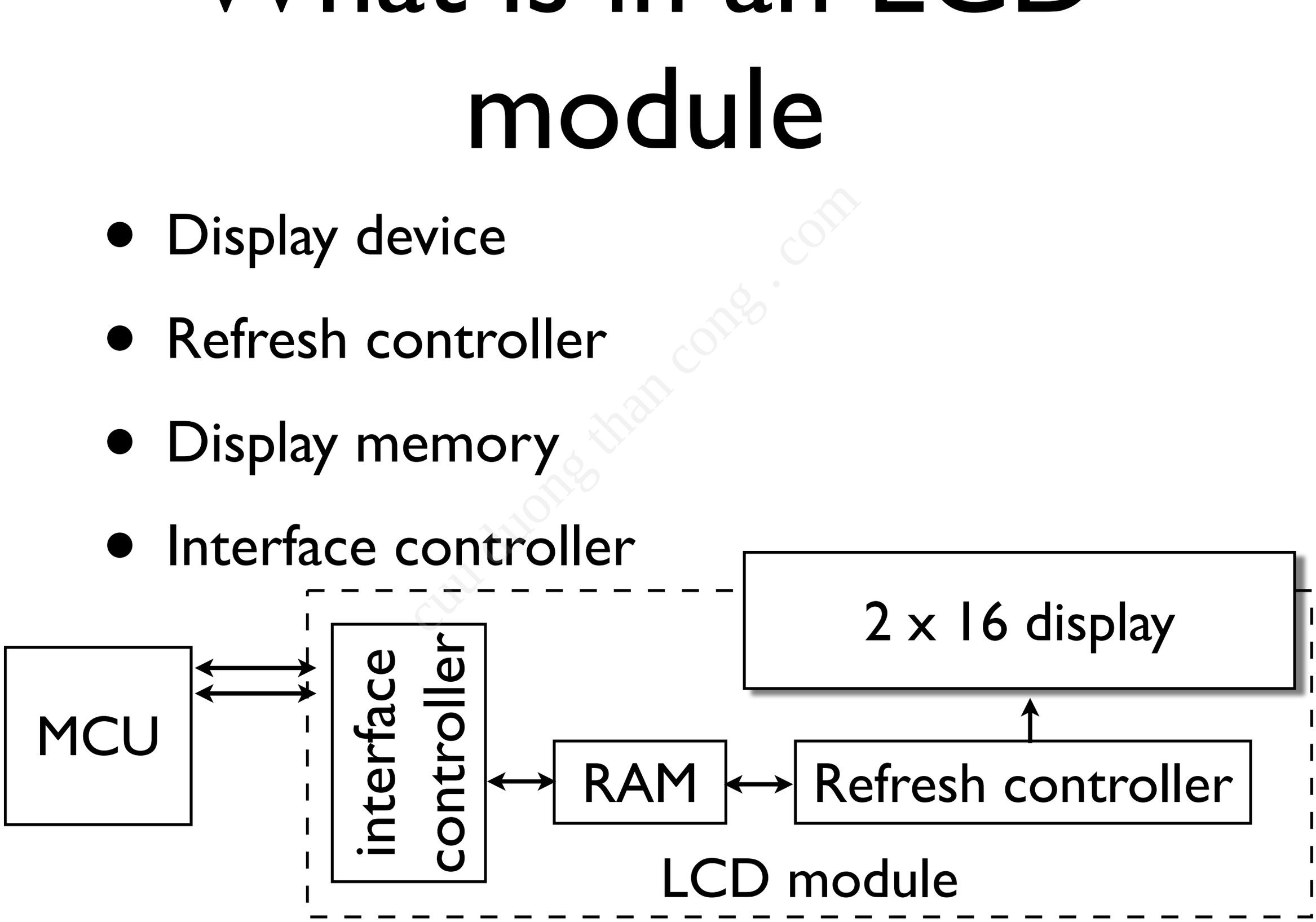
What is in an LCD module

- Display device
- Refresh controller
- Display memory
- Interface controller



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LCD pins

- V_{CC}: supply power (+5V)
- V_{SS}: ground
- V_{EE}: LCD contrast control (analog)
- RS: Register select (in)
- R/W: Read, ~write (1: read, 0: write) (in)
- E: Enable (in)
- D0-D7: data (in/out)

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Concept: Bus Transaction

- An "atomic" sequence of signal changes
  - Control signals, Data transfer
- Purpose
  - Writing Command into the LCD module
  - Writing Data to be displayed
- Representation: Timing Diagram

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Command transaction

- Sequence
  - RS = 0 (for command)
  - R/W = 1 for reading, = 0 for writing
  - Pulse the E signal (like a clock pulse)
  - Read or write D port on falling edge of E
- Timing -- very important!

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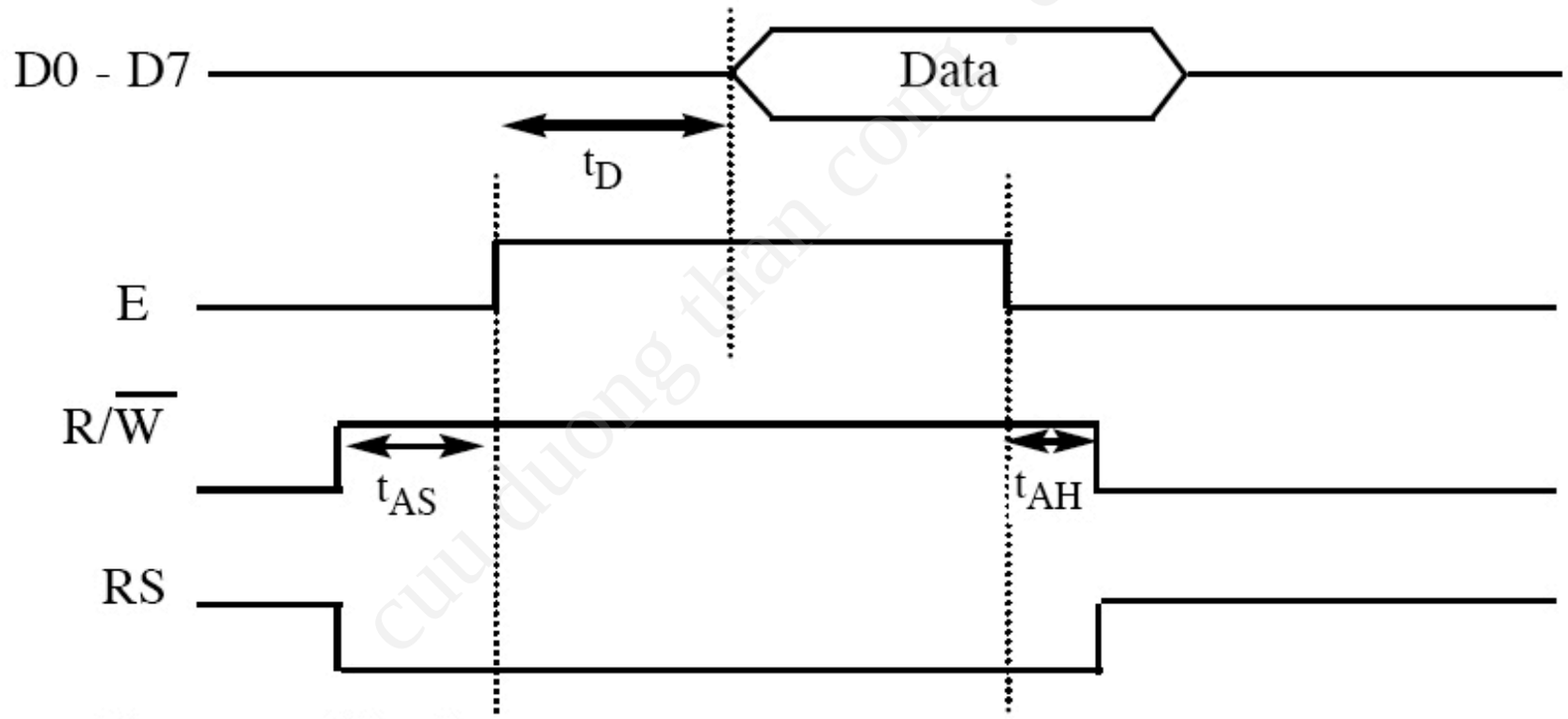
Command-Read Transaction



t_D = Data output delay time

t_{AS} = Setup time prior to E (going high) for both RS and R/W = 140 ns (minimum)

t_{AH} = Hold time after E has come down for both RS and R/W = 10 ns (minimum)

Note: Read requires an L-to-H pulse for the E pin.

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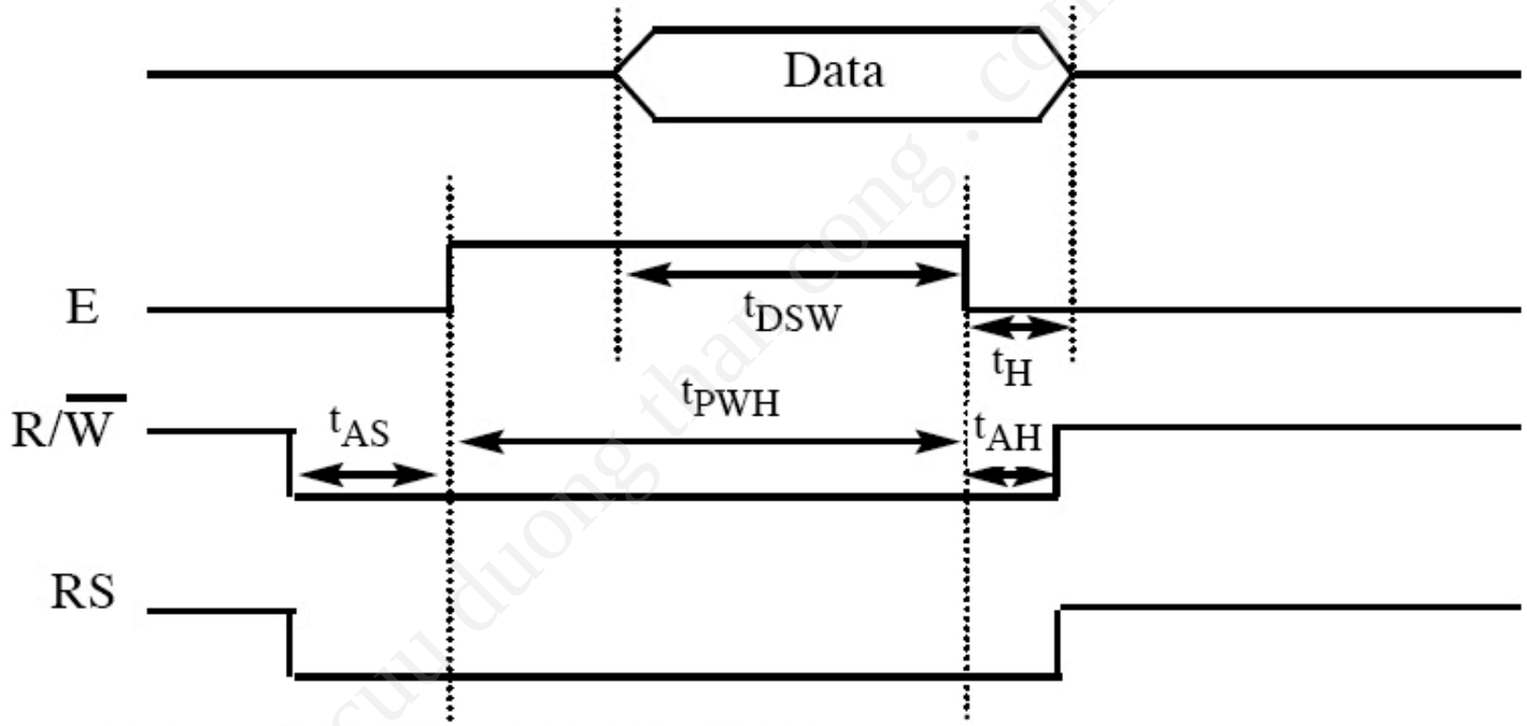
Command-Write Transaction



t_{PWH} = Enable pulse width = 450 ns (minimum)

t_{DSW} = Data setup time = 195 ns (minimum)

t_H = Data hold time = 10 ns (minimum)

t_{AS} = Setup time prior to E (going high) for both RS and R/W = 140 ns (minimum)

t_{AH} = Hold time after E has come down for both RS and R/W = 10 ns (minimum)

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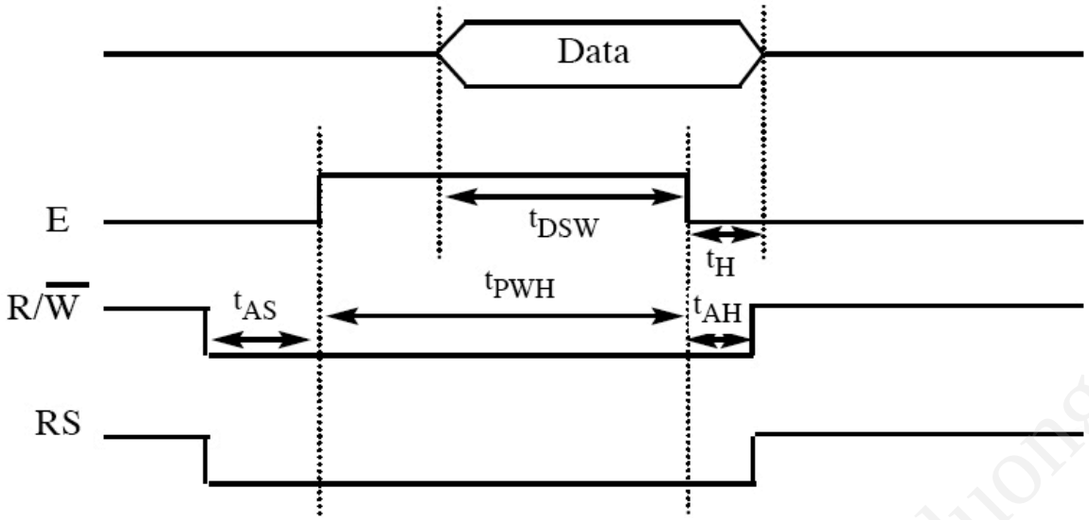
Command List (subset)



These are Write transactions

Code (Hex)	Command to LCD Instruction Register
1	Clear display screen
2	Return home
4	Decrement cursor (shift cursor to left)
6	Increment cursor (shift cursor to right)
5	Shift display right
7	Shift display left
8	Display off, cursor off
A	Display off, cursor on
C	Display on, cursor off
E	Display on, cursor blinking
F	Display on, cursor blinking
10	Shift cursor position to left
14	Shift cursor position to right
18	Shift the entire display to the left
1C	Shift the entire display to the right
80	Force cursor to beginning of 1st line
C0	Force cursor to beginning of 2nd line
38	2 lines and 5x7 matrix

Note: This table is extracted from Table 12-4.

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Checking LCD's Busy Flag

- Use a transaction with RS=0, RW=1
  - The only type of command-read
  - Result: DB7 (data pin 7) is the busy flag
    - 1: busy
    - 0: ready to accept new command
- Should check Busy Flag before all other transactions! Else do it at your own risk

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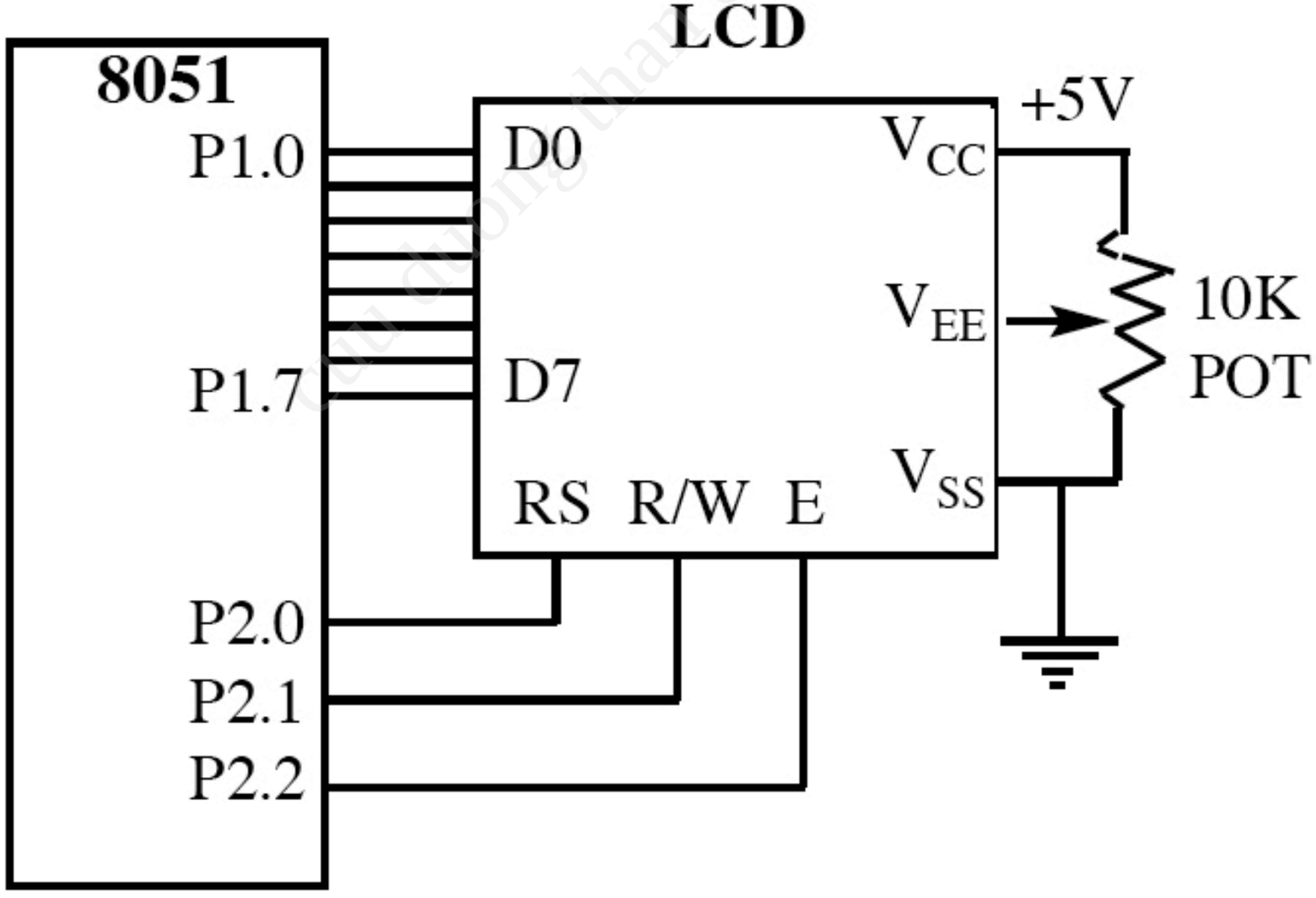
Hardware connection

- D7-D0: an 8-bit I/O port
- RS, R/W, E: a single-bit port



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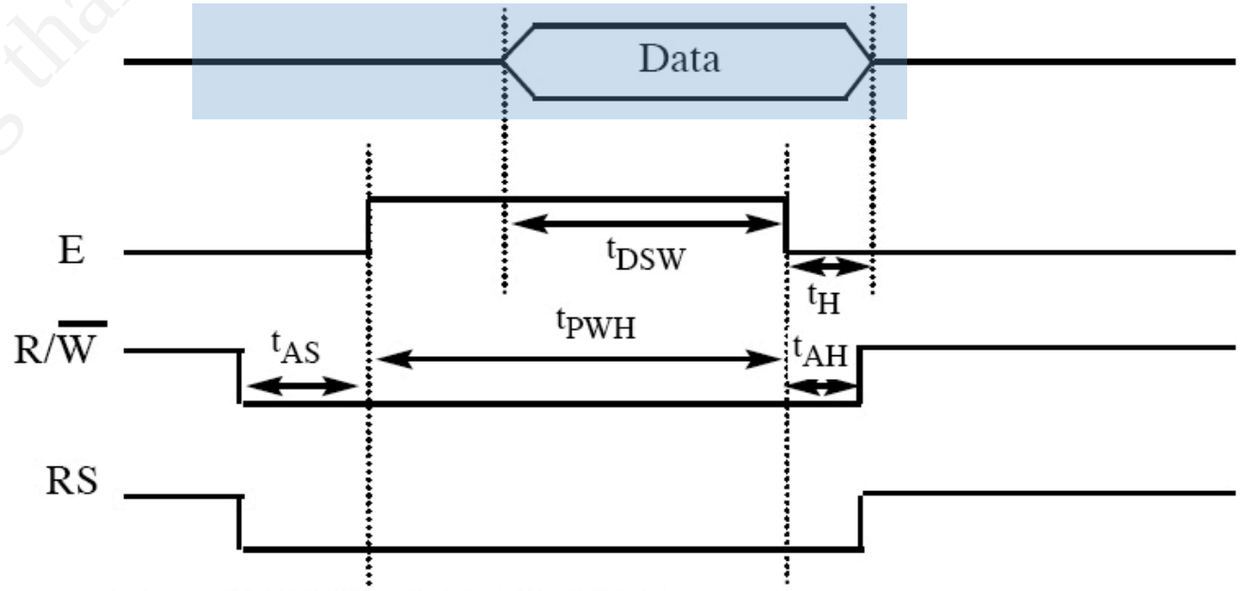
Subroutine for cmd-write transaction

- Parameter
  - A: command number to send to LCD

```
CMDWRT:
        MOV     P1,A      ;; D
        CLR     P2.0      ;; RS
        CLR     P2.1      ;; RW
        SETB    P2.2      ;; E
        ACALL   DELAY
        CLR     P2.2      ;; E
        RET
```



t_{PWH} = Enable pulse width = 450 ns (minimum)
t_{DSW} = Data setup time = 195 ns (minimum)
t_H = Data hold time = 10 ns (minimum)
t_{AS} = Setup time prior to E (going high) for both RS and R/W = 140 ns (minimum)
t_{AH} = Hold time after E has come down for both RS and R/W = 10 ns (minimum)

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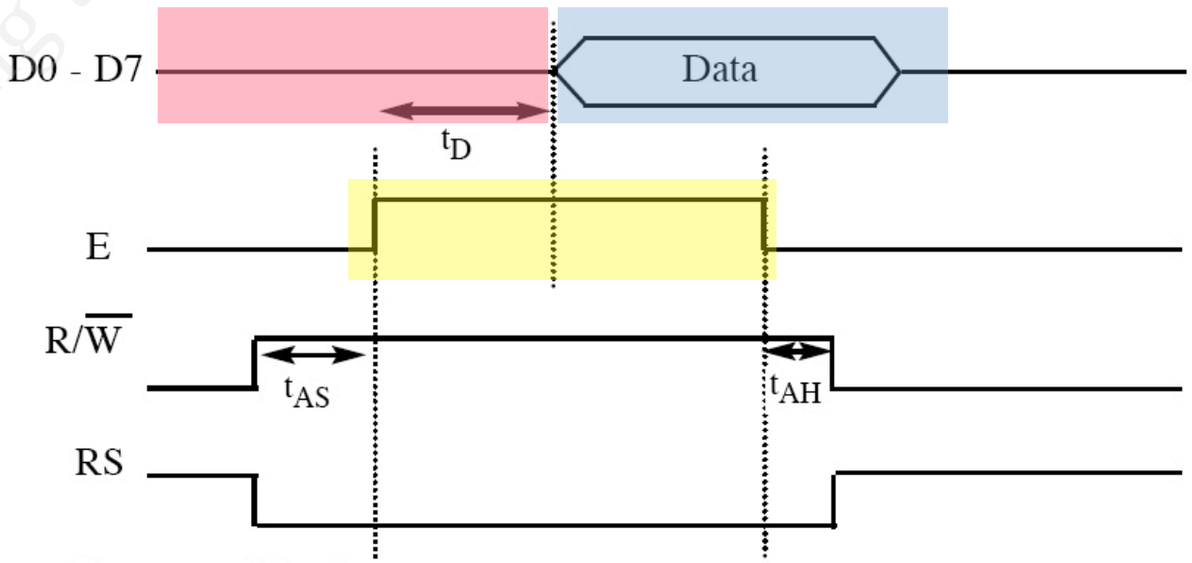
Subroutine for cmd-read transaction

- The only use: check busy flag
- Done as a polling loop

```
CHKBUSY:
        SETB    P1.7        ;; inp
        CLR     P2.0        ;; RS
        SETB    P2.1        ;; RW
BACK:   SETB    P2.2        ;; E
        ACALL   DELAY
        CLR     P2.2        ;; E
        JB      1.7, BACK
        RET
```



t_D = Data output delay time
t_{AS} = Setup time prior to E (going high) for both RS and R/W = 140 ns (minimum)
t_{AH} = Hold time after E has come down for both RS and R/W = 10 ns (minimum)

Note: Read requires an L-to-H pulse for the E pin.

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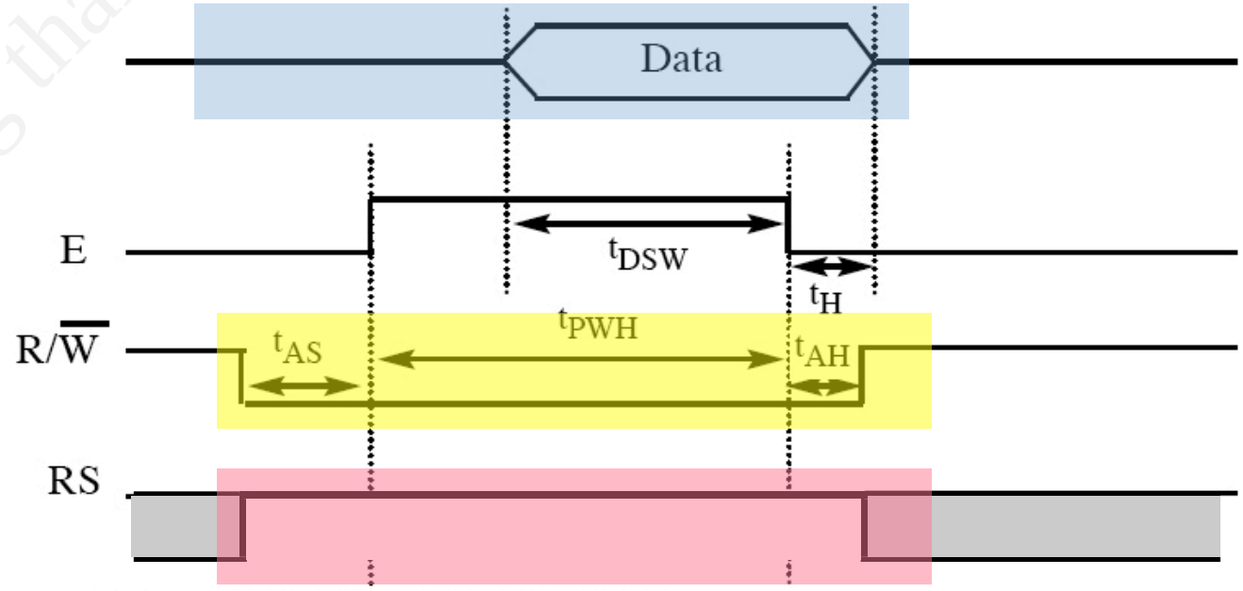
Subroutine for data-write transaction

- Parameter
  - A: data to send to LCD

```
DATAWRT:
        MOV     P1,A      ;; D
        SETB    P2.0      ;; RS
        CLR     P2.1      ;; RW
        SETB    P2.2      ;; E
        ACALL   DELAY
        CLR     P2.2      ;; E
        RET
```



t_{PWH} = Enable pulse width = 450 ns (minimum)
t_{DSW} = Data setup time = 195 ns (minimum)
t_H = Data hold time = 10 ns (minimum)
t_{AS} = Setup time prior to E (going high) for both RS and R/W = 140 ns (minimum)
t_{AH} = Hold time after E has come down for both RS and R/W = 10 ns (minimum)

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Example use of LCD

```
MOV   A, #01H     ;; clear disp. screen
ACALL CMDWRT      ;; execute
```

```
MOV   A, #06H     ;; clear disp. screen
ACALL CMDWRT      ;; execute
```

```
MOV   A, #0EH     ;; disp. on, cursor blink
ACALL CMDWRT      ;; execute
```

```
MOV   A, #38H     ;; config 2 line 5x7
ACALL CMDWRT      ;; execute
```

Code (Hex)	Command to LCD Instruction Register
1	Clear display screen
2	Return home
4	Decrement cursor (shift cursor to left)
6	Increment cursor (shift cursor to right)
5	Shift display right
7	Shift display left
8	Display off, cursor off
A	Display off, cursor on
C	Display on, cursor off
E	Display on, cursor blinking
F	Display on, cursor blinking
10	Shift cursor position to left
14	Shift cursor position to right
18	Shift the entire display to the left
1C	Shift the entire display to the right
80	Force cursor to beginning of 1st line
C0	Force cursor to beginning of 2nd line
38	2 lines and 5x7 matrix

Note: This table is extracted from Table 12-4.

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More Example use of LCD

```
MOV     A, #84H         ;; cursor to line 1 col 4
ACALL   CMDWRT          ;; execute
```

```
MOV     A, #18H         ;; shift screen to left
ACALL   CMDWRT          ;; execute
```

```
MOV     A, #'Z'         ;; write character 'Z'
ACALL   DATAWRT         ;; execute
```

```
ACALL   CHKBSY          ;; check busy flag
```

Code (Hex)	Command to LCD Instruction Register
1	Clear display screen
2	Return home
4	Decrement cursor (shift cursor to left)
6	Increment cursor (shift cursor to right)
5	Shift display right
7	Shift display left
8	Display off, cursor off
A	Display off, cursor on
C	Display on, cursor off
E	Display on, cursor blinking
F	Display on, cursor blinking
10	Shift cursor position to left
14	Shift cursor position to right
18	Shift the entire display to the left
1C	Shift the entire display to the right
80	Force cursor to beginning of 1st line
C0	Force cursor to beginning of 2nd line
38	2 lines and 5x7 matrix

Note: This table is extracted from Table 12-4.

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Command list

Instruction	RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0	Description	Execution Time (Max)
Clear Display	0	0	0	0	0	0	0	0	0	1	Clears entire display and sets DD RAM address 0 in address counter	1.64 ms
Return Home	0	0	0	0	0	0	0	0	1	-	Sets DD RAM address 0 as address counter. Also returns display being shifted to original position. DD RAM contents remain unchanged.	1.64 ms
Entry Mode Set	0	0	0	0	0	0	0	1	I/D	S	Sets cursor move direction and specifies shift of display. These operations are performed during data write and read.	40 µs
Display On/ Off Control	0	0	0	0	0	0	1	D	C	B	Sets On/Off of entire display (D), cursor On/Off (C), and blink of cursor position character (B).	40 µs
Cursor or Display Shift	0	0	0	0	0	1	S/C	R/L	-	-	Moves cursor and shifts display without changing DD RAM contents.	40 µs
Function Set	0	0	0	0	1	DL	N	F	-	-	Sets interface data length (DL), number of display lines (L), and character font (F).	40 µs
Set CG RAM Address	0	0	0	1	AGC						Sets CG RAM address. CG RAM data is sent and received after this setting.	40 µs
Set DD RAM Address	0	0	1	ADD							Sets DD RAM address. DD RAM data is sent and received after this setting.	40 µs
Read Busy Flag & Address	0	1	BF	AC							Reads Busy flag (BF) indicating internal operation is being performed and reads address counter contents.	40 µs
Write Data CG or DD RAM	1	0	Write Data								Writes data into DD or CG RAM.	40 µs
Read Data CG or DD RAM	1	1	Read Data								Reads data from DD or CG RAM.	40 µs

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More details about the LCD

- Data sheet:
  http://www.optrex.com/pdf/Dmcman_full.pdf
- Handling precautions (page 7)
  - connect unused pins to Vcc or GND
  - avoid applying input signal w/out power
  - avoid electrostatic discharge
  - avoid direct sunlight, pressure, ...

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LCD Timing

- LCD is a slow device!
  - Clearing screen, Return home => 1.64ms
    - @12MHz, that is 1640 instr. cycles!
    - Avg 40µs, still long => 40 instr. cycles
- Two ways to ensure not too fast
  - Delay sufficiently long
  - Check busy flag

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Registers in the LCD controller

- IR (instruction register)
  - write-only, for command code
  - Also for display data or char gen address
- DR (data register)
  - read/write, for Data read/written to RAM

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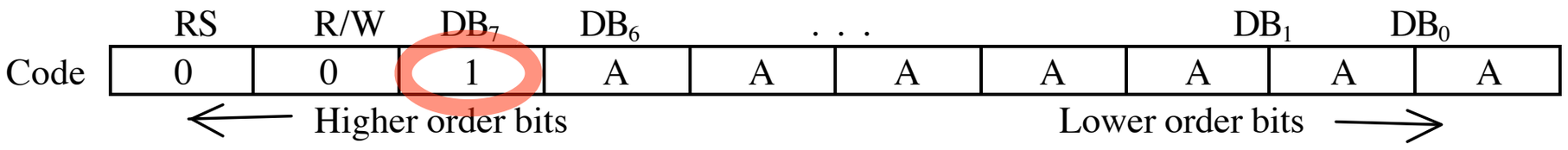
Display Data RAM (DD RAM)

- stores the 8-bit character code
  - up to 40 chars per line
  - Addresses of the characters
    - set using a cmd-write transaction

00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F
40	41	42	43	44	45	46	47	48	49	4A	4B	4C	4D	4E	4F

- However, as a transaction to set address,



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Char Gen. RAM, ROM

- Stores bitmap of font
- ROM: built-in
  RAM: user defined

High order bit / Low order bit	0000	0010	0011	0100	0101	0110	0111	1010	1011	1100	1101	1110	1111
X X X X0000	CG RAM (1)												
X X X X0001	(2)												
X X X X0010	(3)												
X X X X0011	(4)												
X X X X0100	(5)												
X X X X0101	(6)												
X X X X0110	(7)												
X X X X0111	(8)												
X X X X1000	(1)												
X X X X1001	(2)												
X X X X1010	(3)												
X X X X1011	(4)												
X X X X1100	(5)												
	(6)												
	(7)												
	(8)												

Note: Character of high order bit 1110 and 1111 may be inadequate.

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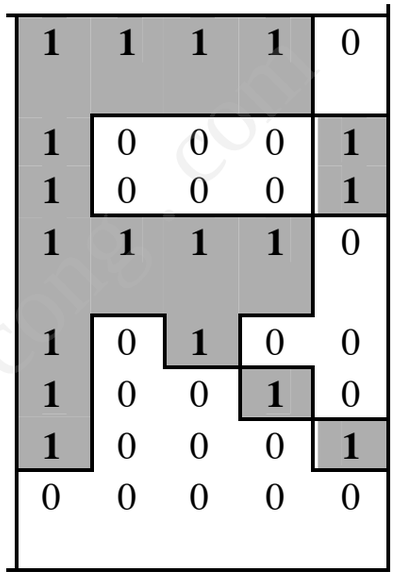
Character Generation RAM (CG RAM)

- 64 bytes RAM
  - Either eight 5x7 or four 5x10 bitmaps
- User defined chars have code 00H..07H
  - actually, 08H..0FH also select the same



char code	CG RAM address	
00	00	07
01	08	0F
02	10	17
03	18	1F
04	20	27
05	28	2F
06	30	37
07	38	3F

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Address counter

- Address counter is auto-incremented on data-write or data-read
  - I/D=1: increment; =0: decrement
  - S=1: display shift

Entry Mode Set	0	0	0	0	0	0	0	1	I/D	S	Sets cursor move direction and specifies shift or display. These operations are performed during data write and read.

- The same AC for both DD and CG RAM!
  - Depending on what bit was set

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Setting address counter

- To set DD address 00..0F => DB=80..8F
  To set DD address 40..4F => DB=C0..CF
  To set CG address 00..3F => DB= 40..7F

3.1.7 Set CG RAM Address

	RS	R/W	DB_7	DB_6	. . .	DB_1	DB_0
Code	0	0	0	1	A A A A A A		

← Higher order bits — Lower order bits →

Sets the address counter to the CG RAM address AAAAAAA. Data is then written/read to from the CG RAM.

3.1.8 Set DD RAM Address

	RS	R/W	DB_7	DB_6	. . .	DB_1	DB_0
Code	0	0	1	A	A A A A A A		

← Higher order bits — Lower order bits →

Sets the address counter to the DD RAM address AAAAAAA. Data is then written/read to from the DD RAM.

For a 1-line display module AAAAAAA is “00” ~ “4F” (hexadecimal). For 2-line display module AAAAAAA is “00” ~ “27” (hexadecimal) for the first line and “40” ~ “67” (hexa decimal) for the second line. (See section 1.7.6 “DD RAM addressing”)

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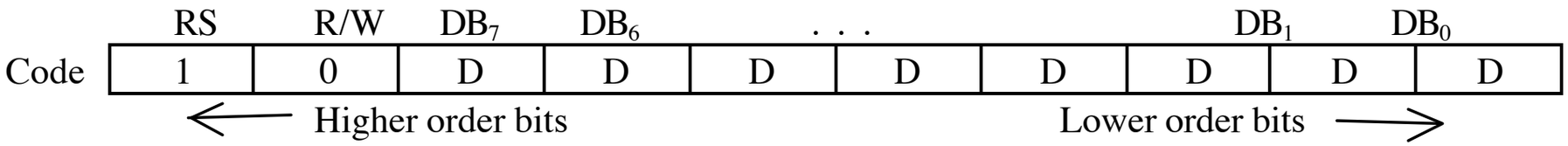
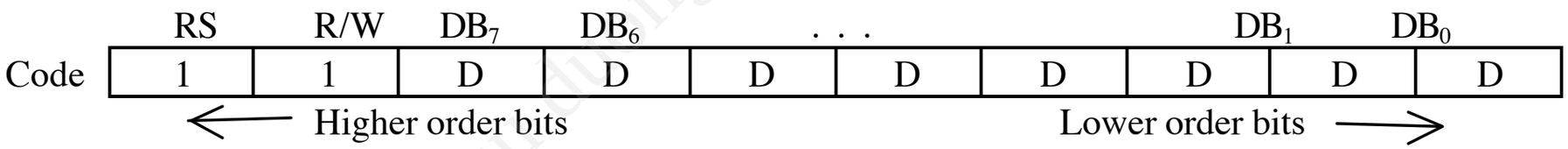
3.1.10 Write Data to CG or DD RAM



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.

3.1.11 Read Data from CG or DD RAM



Reads binary 8-bit data DDDDDDDD from the CG RAM or DD RAM.

The previous designation determines whether the CG or DD RAM is to be read.

Before entering the read instruction, you must execute either the CG RAM or DD RAM address set instruction.

If you don't, the first read data will be invalidated. When serially executing the "read" instruction the next address data is normally read from the second read.

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Busy flag revisited

3.1.9 Read Busy Flag and Address

	RS	R/W	DB_7	DB_6	. . .			DB_1	DB_0
Code	0	1	BF	A	A	A	A	A	A	A

← Higher order bits Lower order bits →

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.

The BF status should be checked before each write operation.

At the same time the value of the address counter expressed in binary AAAAAAA is read out. The address counter is used by both CG and DD RAM and its value is determined by the previous instruction. Address contents are the same as in sections 3.1.7 and 3.1.8.

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Example Instructions

3.1.1 Clear Display

	RS	R/W	DB_7	DB_6	. . .	DB_1	DB_0
Code	0	0	0	0	0	0	1

Writes the space code “20” (hexadecimal) into all addresses of DD RAM. Returns display to its original position if it was shifted. In other words 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.

3.1.2 Return Home

	RS	R/W	DB_7	DB_6	. . .	DB_1	DB_0
Code	0	0	0	0	0	1	x

Note: x = Don’t Care

Sets the DD RAM address “0” in address counter. Return display to its original position if it was shifted. DD RAM contents do not change.

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

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Example Instructions

3.1.3 Entry mode set

	RS	S/W	DB_7	DB_6	. . .	DB_1	DB_0
Code	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. Thus it looks as if the cursor stands still and only the display seems to move.

The display does not shift when reading from DD RAM nor when S = 0.

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3.1.4 Display ON/OFF Control

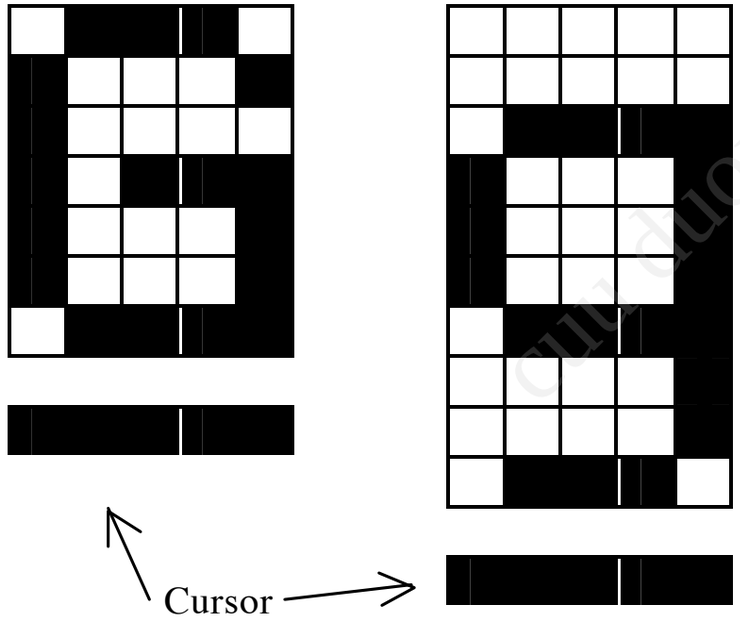
	RS	R/W	DB_7	DB_6	. . .			DB_1	DB_0
Code	0	0	0	0	0	0	1	D	C	B

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. When OFF due to D = 0, display data remains in the DD RAM. It can be displayed immediately by setting D = 1.

C: The cursor displays when C = 1 and does not display when C = 0. The cursor is displayed on the 8^{th} line when 5 x 7 dot character font has been selected.

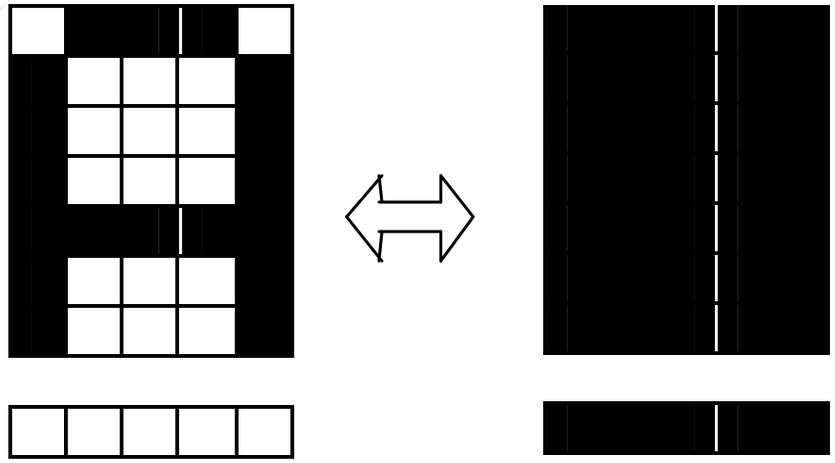
B: The character indicated by the cursor blinks when B = 1. The blink is displayed by switching between all blank dots and display characters at 0.4 sec intervals.
The cursor and the blink can be set to display simultaneously.



5 x 7 dots character font

5 x 10 dots character font

(a) Cursor display example
C = 1 ; B = 0



Alternating display

(b) Blink display example
C = 1 ; B = 1

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Example Complete Sequence

No.	Instruction	Display	Operation
1	Power supply ON (Initialized by Internal reset circuit) RS | R/W | DB_7 ~ DB_0 / | / |		Module is initialized.
2	Function set RS | R/W | DB_7 ~ DB_0 0 | 0 | 0 0 1 1 1 0 * *		Sets the interface data length to 8 bits and selects 2-line display and 5 x 7-dot character font.
3	Display ON/OFF Control RS | R/W | DB_7 ~ DB_0 0 | 0 | 0 0 0 0 1 1 1 0	_	Turns on display and cursor.
4	Entry mode set RS | R/W | DB_7 ~ DB_0 0 | 0 | 0 0 0 0 0 1 1 0	_	Sets mode to increment address by one and to shift the cursor to the right at the time of write to internal RAM

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Example Complete Sequence

5	Write data to CG/DD RAM RS: 1 | R/W: 0 | DB_7 ~ DB_0: 0 1 0 0 1 1 0 0	L_	Writes “L”. Cursor is incremented by one and shifts to the right.
6	Write data to CG/DD RAM RS: 1 | R/W: 0 | DB_7 ~ DB_0: 0 1 0 0 0 0 1 1	LC_	Writes “C”
7	⋮	⋮	
8	Write data to CG/DD RAM RS: 1 | R/W: 0 | DB_7 ~ DB_0: 0 0 1 1 0 1 1 0	LCD MODULE DMC16	Writes “6”

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Example Complete Sequence

No.	Instruction	Display	Operation
9	Set DD RAM address. RS: 0 | R/W: 0 | DB_7 ~ DB_0: 1 1 0 0 0 0 0 0	LCD MODULE DMC16 _	Sets RAM address so that the cursor is positioned at the head of the 2nd line.
10	Write data to CG/DD RAM RS: 1 | R/W: 0 | DB_7 ~ DB_0: 0 0 1 1 0 0 1 1	LCD MODULE DMC16 1_	Write “1”
11	Write data to CG/DD RAM RS: 1 | R/W: 0 | DB_7 ~ DB_0: 0 0 1 1 0 0 1 0	LCD MODULE DMC16 16_	Writes “6”
12	⋮	⋮	

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Example Complete Sequence

13	Write data to CG/DD RAM address RS: 1 | R/W: 0 | DB_7 ~ DB_0: 0 0 1 0 1 0 1 0	LCD MODULE DMC16 16 DIGITS, 2 LINES_	Writes "S"
14	Set DD/RAM address RS: 0 | R/W: 0 | DB_7 ~ DB_0: 1 0 0 0 0 0 0 0	LCD MODULE DMC16 16 DIGITS, 2 LINES	Moves cursor to original position
15	Clear display RS: 0 | R/W: 0 | DB_7 ~ DB_0: 0 0 0 0 0 0 0 1	_	Return both display and cursor to the original position
16	⋮	⋮	

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