**Introduction:** In this lab, you will learn the interface and operation of a “bus-attached” peripheral; in other words, a controller IC that normally connects directly to the system buses. The controller you will learn about is the Hitachi HD44780 Liquid Crystal Display Controller (LCDC) as found on-board the LCD module used in this lab. You will become familiar with both the hardware interface and the software required to control and operate the display via the LCDC. Because the software for this device is somewhat more complex than previous labs, you will be given a collection of low-level control routines in the form of a software driver and you will learn how to use this driver from your application program. Of particular note in this lab is the fact that because the S12 MCU on board the Dragon12 EVB does not have external buses, you will see that all LCD interfacing is done via PORTK I/O lines.

**Objectives:**
- to provide the student an exposure to a complex peripheral controller IC as used for LCD applications and of its datasheet
- to demonstrate the interface and synchronization of a bus-attached peripheral controller
- to demonstrate the software control of a peripheral controller IC
- to demonstrate a single-point entry method of software driver implementation

**Materials needed:**
- DRAGON12 EVB
- LCD module (preinstalled)
- pushbutton switch
- Dragon12+ schematic
- Dragon12+ User’s Manual
- LCD-107 LCD module datasheet
- HD44780 LCDC datasheet

**Pre-Lab:**

1. Collect your own copies of the schematic, user manual and datasheets as listed in the *materials needed* section above. These documents should be available on the resources page of the course website.

2. Review the LCD module interface diagram shown in figure 1 below. Referring to the Dragon12+ schematic (pg. 4), add the LCD PORT (J12) pin numbers just outside its box in figure 1. Next, refer to the LCD module datasheet and add the LCD module pin numbers just outside its box in figure 1.

   Q1. Do you think this correlation was by design or just coincidence? __________

   Note: this is an informal but industry-standard interface.

![Fig. 1: LCD interface](image-url)
3. Review the HD44780 datasheet and answer the following questions.

Q2. The HD44780 is an example of LSI IC. What is LSI an acronym for? ________________
Review the HD44780 block diagram to see why this is so.

Q3. Review the table of pin functions. How many total pins does the HD44780 have? ______

Q4. How many characters are provided for by the internal character generator ROM? ______
Refer to table 4 and note the relationship between the character pattern codes and the ASCII table.

Q5. Review the section on the HD44780’s Functional Description.
   a. How many registers does the LCDC have? ____
   b. Name the ones that are directly programmer accessible? _________________________
   c. What is the purpose of the Busy Flag (BF)? ________________________________
   d. How many register locations in the memory map does the LCDC require? ______

Q6. Refer to the LCDC Instruction chart in table 6.
   a. How many different operations does the LCDC support? _____
   b. The function set instruction code for 8-bit transfers, 2 line display and 5x8 characters is: ___

4. Review the Dragon12+ User’s Manual, table 1-1 and section 4.5, and note how the LCD is interfaced to the S12’s port K lines. Note that in the absence of system buses, we will have to drive these pins programmatically to control the LCD.

5. Return to the HD44780 data sheet and review table 13 to learn how 8-bit operation for a 2-line display is conducted. Review figure 23 to become familiar with the required initialization sequence.

6. Go to Dincer’s LCD Simulator page (http://www.dinceraydin.com/djlcdsim/djlcdsim.html) and perform the appropriate steps to display your name on the simulated LCD. Don’t forget the required initialization sequence from figure 23 of the HD44780 data sheet! By accomplishing this, you will understand precisely what the processor must do to produce LCD output via the LCDC. Cool stuff, no?

7. Review the LCDdriver.asm listing as provided with this lab and answer the following questions.

Q7. This LCD driver as given has a single entry point subroutine named: __________.

Q8. How does the entry point routine determine what specific function the caller wants?
_________________________________________________________________________

Q9. How does this driver accept additional parameters from the caller?
_________________________________________________________________________

Q10. How does this driver synchronize output writes with the LCDC?
_________________________________________________________________________

At this point, you should be properly prepared for working with the actual LCD module in lab! Show your completed pre-lab to the instructor to proceed.

Pre-Lab Instructor Signoff: ______________
Lab Procedure:

8. You have noticed that the Dragon12+ EVB contains a backlit 16x2 LCD module preinstalled. Thus, no actual attachment of an LCD is required as we will be using this display. Note that the Dragon12’s J5 header does support an optional external LCD (you are welcome to try connecting a larger LCD such as the 2x40 modules we have in lab).

9. Although we could repeat step 6 on the Dragon12’s LCD, it would be unduly tedious because the LCD’s bus interface is connected to the S12’s general purpose I/O port K. Therefore, it’s now time for more neat software! Obtain a copy of the **LCDdriver.asm** file as shown in listing 1 to your work directory. Using the **template.asm** file as before, create an S12 program that will output a message of your choice to the LCD. At a minimum, your program should:
   a) invoke the `LINIT` function to initialize the LCD module
   b) invoke the `LWRSTR` function to output your message to the LCD
   c) use the “#include” assembler pseudo-op before your END directive as documented in the driver header

   You may proceed with the last part of this lab only after successfully completing this step.

(cont’d next page)
Lab 5 Project Assignment

Create and demonstrate to the instructor a digital stop watch using the EVB, the LCD module and software driver, and your ingenuity. At a minimum, your solution must track seconds and tenths of seconds. Specifications are as follows.

a) use a pushbutton "run" switch between an appropriate input port and ground
b) display a greeting and instructions to the user via the Terminal connection (not LCD)
c) display a project title on line 1 of the LCD (ex: “Ultimate Watch”)
d) call a subroutine that you create to display the current elapsed time (initially zero) on the far left of line 2 in an appropriate format (ex: 00.0)
   Note: the LCD driver includes a function for decimal output!
e) wait for the “run” switch to go active
f) implement the following loop:
   - delay 100 ms. (use the “millisecond delay” subroutine from previous labs)
   - increment the appropriate elapsed time counters (tenths, seconds, etc.)
   - output the updated elapsed time using your above subroutine†
   - repeat this loop if the “run” switch is still active
g) display an exit message to the user via the Terminal connection

†Your time output subroutine should first reposition the LCD cursor to the beginning of line 2.

Deliverables

Submit a laboratory packet including:

1. A cover page including:
   - course number & title
   - lab number & title
   - date submitted
   - lab team member names and signatures

2. A lab write-up including the Project Requirements and a Description of Solution. These sections should be clearly titled.

3. A section titled “Achievement of Course Outcomes” describing how this lab contributed to fulfillment of the given two program outcomes below (CET-Oc1 & Oc1 for CETs, EET-Oc1 & Oc10 for EETs). Each team member must complete this section individually according to your major - CET or EET. If you are other than a CET or EET major, you may choose either.

4. Documentation of software design development, i.e. flowcharts.

5. A properly commented, error-free assembly listing of your program per website instructions.

Total point value: 20

Selected program outcomes

By the time of graduation, Computer Engineering Technology students will demonstrate:

CET-Oc1: The knowledge, skills, techniques and applications of modern tools in the computer engineering technology discipline

CET-Oc3: Technical problem solving skills, including the ability to identify problems, use appropriate laboratory and test equipment, conduct experiments, gather data, analyze data and produce results

By the time of graduation, Electrical Engineering Technology graduates will demonstrate:

EET-Oc1: The knowledge, skills, techniques and application of modern tools in the electrical engineering technology discipline

EET-Oc10: The ability to analyze, design and implement analog and microprocessor systems through a blend of theoretical and practical methods
The following routines collectively form a driver to control a smart Liquid Crystal Display as interfaced to the DRAGON12+ EVB on port K. This driver is for any LCD module with an on-board Hitachi HD44780 LCD-II or equivalent controller. The 44780 requires two locations for its Instruction Register (IR) and Data Register (DR). All LCD functions are user callable via the single entry point "LCD" using a "function code" passed in accumulator A. Function parameters, when any, are passed in AccB and/or register X. This driver is code only, no memory-resident variables are required.

Example usage:
```
lda #LCLEAR ;A=clear display function code
jsr LCD ;clear display
lda #LWRDEC ;A=decimal output function code
ldab #123 ;decimal number to output
jsr LCD ;output decimal number
```

Note that the "LINIT" function must be invoked to initialize the LCD before any other function will work. This should part of your one-time initialization code. To add this driver to your main program, insert the following line before your END statement:
```
#include "LCDdriver.asm"
```

Interfacing details:
- PK7 = LCD R/W' (Read/Write, not used)
- PK5 = LCD DB7
- PK4 = LCD DB6
- PK3 = LCD DB5
- PK2 = LCD DB4
- PK1 = LCD EN (Enable)
- PK0 = LCD RS (Register Select: 0=control, 1=data)

Revision history:
- 10-Feb-1990 jss initial writing
- 02-Dec-2003 jss revised for Axiom CME11 board
- 11-Oct-2008 jss additional documentation added
- 20-Oct-2011 jss revised for DRAGON12 EVB

LCDPORT EQU $0032 ;PORTK
LCDDDR EQU $0033 ;DDRK
RSBIT EQU 1 ;bit mask for RS
ENBIT EQU 2 ;for Enable pulse
RWBIT EQU $80 ;for Read/Write line

***************************************************************************
*
* LCD DRIVER ROUTINE FUNCTION CODES
*
***************************************************************************

The following definitions define symbolic names for LCD functions available in this driver. The desired function code is loaded into AccA before a JSR to LCD is executed. Some functions additionally require other parameters in AccB and/or X.

LINIT EQU 0 ;initialize display function
LCLEAR EQU 1 ;clear display function
LHOME EQU 2 ;home cursor function
LGOTO EQU 3 ;move cursor to row (Xhi), column (Xlo)
LWRCMD EQU 4 ;write LCD command (in B)
LWRCHR EQU 5 ;write character (in B)
LWRSTR EQU 6 ;write null terminated string (X points to)
LWRDEC EQU 7 ;write byte (in B) as decimal
LWRHEX2 EQU 8 ;write byte (in B) as 2 hex digits
LWRHEX4 EQU 9 ;write word (in X) as 4 hex digits

***************************************************************************
*
* LCD DRIVER ROUTINE MAIN ENTRY
*
On entry to LCD via JSR, AccA contains the desired function number and is used (after doubling) as an offset into a vector table to call the corresponding routine. This works much like a computed GOSUB so that only a single entry point for all LCD functions is needed.

All registers (except CC) are preserved for the caller.

```assembly
; ORG $1100 ;or where ever you want (optional)
LCD pshy ;save caller's registers
pshx
pshd
asla ;double function number
cmpa #$LCDTBLLEN ;is function number invalid?
bhs LCDEX ;return immediately if not
ldy #$LCDJMPTBL ;point Y to jump table
exg A, B ;swap A & B
ldy B, Y ;get address of routine
jsr 0, Y ;call function handler
LCDEX puld ;restore caller's registers
pulx
puly
rts ;and return to caller

*** Jump Table - contains 2 byte address for each function handler ***

LCDJMPTBL FDB LCDINIT ;0 = initialize display
FDB LCDCLEAR ;1 = clear display
FDB LCDHOMECU ;2 = home cursor
FDB LCDGOTORC ;3 = goto row, column
FDB LCDWRCMD ;4 = write LCD instruction
FDB LCDWRCHR ;5 = write LCD data character
FDB LCDWRSTR ;6 = write character string
FDB LCDWRDEC ;7 = write byte as decimal
FDB LCDWRHEX2 ;8 = write byte as 2 hex digits
FDB LCDWRHEX4 ;9 = write word as 4 hex digits

LCDTBLLEN EQU *-LCDJMPTBL ;length of jump table in bytes

LCDITBL FCB 6 ;number of table entries
FCB $33 ;1st reset code, must delay 4.1ms after sending
; all following 10 nibbles must be delay 40us min each after sending
FCB $32 ;3rd/4th reset code,
FCB $28 ;4 bit mode, 2 line, 5X7 dot
FCB $06 ;cursor INCrement, disable display shift
FCB $01 ;clear display memory, set cursor to home pos

*** INITLCD: initialize display ***

LCDINIT clr LCDPORT ;initial outputs all low
movb #$FF, LCDDDR ;make LCD port all outputs
ldx #$LCDITBL ;point X to LCD initialization table
ldab 1, X+ ;get length of table
LCDILOOP ldaa 1, X+ ;get init code from table
psha
rora ;move top nibble into position
rora
lbar LCDWRNIB ;send 4-bit nibble to LCD
lbar Delay5ms ;5ms delay between all table values
pula
rola ;move bottom nibble into position
rola
lbar LCDWRNIB ;send 4-bit nibble to LCD
lbar Delay5ms ;5ms delay between all table values
dbne B, LCDILOOP
rts

*** LCDCLEAR: clear display to blanks and home cursor ***

LCDCLEAR ldaa #1 ;clear display instruction
bsr LCDWRCMD

*** LCDHOMECU: return cursor to home position ***

LCDHOMECU ldaa #2 ;return home instruction
bsr LCDWRCMD
lbar Delay5ms
```
rts

*** LCDGOTORC: move cursor to row, column
* Stacked Xhi is target row (0..1), Xlo is column (0..39)
* For a 2-line LCD, RAM addresses $80..$BF are for line 0
* while $C0..$FF are for line 1.

LCDGOTORC ldaa 4, S ;pick row from stack
ldaa #01000000 ;B=2^6
mul ;calculate row address
ldab #%01000000 ;B=2^6
aba ;row*64 to col
ora #10000000 ;make "set RAM addr" command
bra LCDWRCMD ;go write it & return

*** LCDWRDEC: write byte in AccA as unsigned decimal number

LCDWRDEC ldaa 0, X ;pick up a chr from string
beq LCDWRSEX ;exit if end-of-string
bra LCDWRCHRS ;else output it

LCDWRSEX rts

*** WRCHR: write a data byte to LCD ***

LCDWRCHR bset LCDPORT, RSBIT ;set RS bit to LCD high
bra LCDWRBYTE
*** WRCMD: write an instruction to LCD ***

LCDWRCMD  bclr      LCDPORT,RSBIT       ;set RS bit to LCD low
;  & fall thru to LCDWRBYTE
*
*** lowest-level LCD output routines using I/O port ***
*
; LCDWRBYTE: output AccA value to LCD in 4-bit mode

LCDWRBYTE psha                          ;save original value
       rora                          ;move top nibble into position
       rora
       bsr       LCDWRNIB            ;send it
       pula                          ;recall original value
       rola                          ;move low nibble into position
       rola
       bsr       LCDWRNIB            ;send it
       bsr       Delay50us           ;minimal output delay
       rts
;
; LCDWRNIB: output middle 4 bits of AccA to LCD

LCDWRNIB  anda      #$3C                ;extract middle 4 bits to write
       psha                          ;save on stack
       ldaa      LCDPORT             ;read current output pattern
       anda      #$C3                ;clear middle 4 bits
       oraa      1,SP+               ;turn on needed bits
       staa      LCDPORT             ;send to LCD
;
; LCDENPLS: send Enable pulse to LCD

LCDENPLS  psha                          ;preserve A
       bset      LCDPORT,ENBIT       ;drive enable line high
       ldaa      #$8                  ;count for 1us delay
       dbne      A,*                 ;hold it a while
       bclr      LCDPORT,ENBIT       ;return to low
       pula
       rts

* Delay5ms: delay 5 millisecond via software,
*    assumes F=24 MHz (and no interrupts)
*    all registers preserved for caller

Delay5ms  pshx                ;2~  preserve registers used here
       ldx       #39996              ;2~  iterations for 5ms.
       dbne      X,*                 ;3~  39996 loops * 3-/loop = 119988~
       pulx                 ;3~  recover used registers
       rts                 ;5~  119988 + 12 = 120000~ = 5ms.

Delay50us:  pshx                ;2~  preserve registers used here
       ldx       #396                ;2~  iterations for 50us.
       dbne      X,*                 ;3~  396 loops * 3-/loop = 1188~
       pulx                 ;3~  recover used registers
       rts                 ;5~  1188 + 12 = 1200~ = 50us.

***************************************************************************
*                            End of LCD Driver                            *
***************************************************************************