



**PicoBlaze™**

# Initial Design for Spartan-3E Starter Kit (LCD Display Control)

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Any problems or items felt of value in the continued improvement of KCPSM3 or this reference design would be gratefully received by the author.

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The author would also be pleased to hear from anyone using KCPSM3 or the UART macros with information about your application and how these macros have been useful.



# Design Overview

This design is provided on the Spartan-3E Starter Kit when it is dispatched from the factory. It confirms that the board is operational by scrolling a simple message across the LCD display and allowing the LED's to be controlled by the rotary knob, press buttons and slide switches.

The principle purpose of this document is to illustrate how PicoBlaze can be used to control the LCD display. It is hoped that the design may form the basis for future PicoBlaze designs as well as provide a general introduction to the board. Some exercises are suggested to encourage further self study.

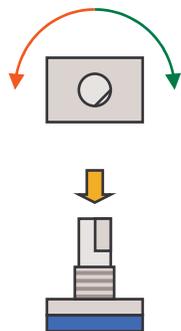
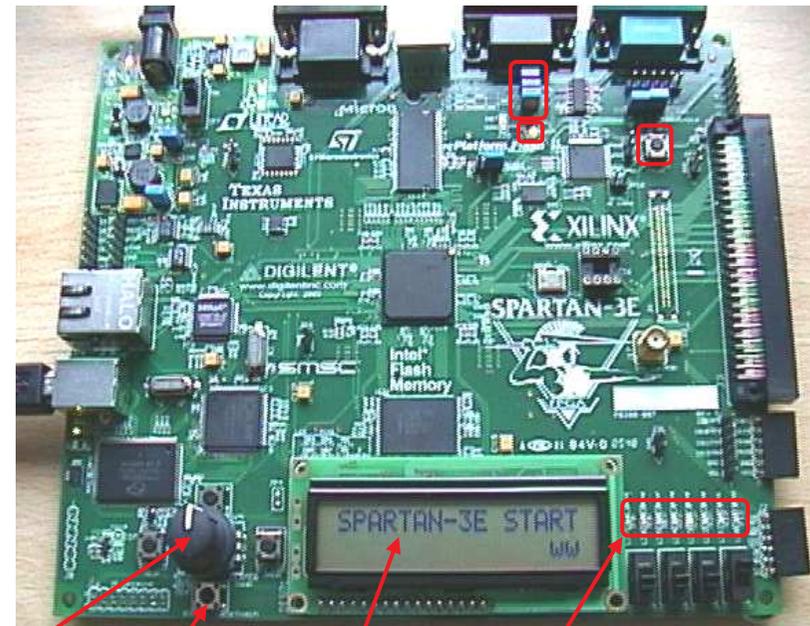
## Try it now – it only takes 30 seconds!

It is recommended that you try this to become familiar with what the design does before continuing to read. If your board is 'fresh out of the box', then simply connect the power supply, switch on and see the design come to life. If it doesn't work (XC-DONE LED remains unlit), check that all 3 jumpers are installed in J30 and press the PROG button again.

If your board has been reprogrammed since it arrived, you can still try the design quickly. As well as the source design files, a compiled configuration bit file is provided which you can immediately download into the Spartan XC3S500E device on your board. To make this task really easy the first time, unzip all the files provided into a directory and then....

**double click on 'install\_s3esk\_startup.bat'.**

Assuming you have the Xilinx software installed, your board connected with the USB cable and the board powered (don't forget the switch), then this should open a DOS window and run iMPACT in batch mode to configure the Spartan-3E with the design.



Rotate knob to control position of the illuminated LED



Press and release knob to toggle between control modes



Operate buttons and switches to illuminate each LED

4 press buttons

Scrolling message

8 LEDs

4 slide switches

# PicoBlaze Design Size

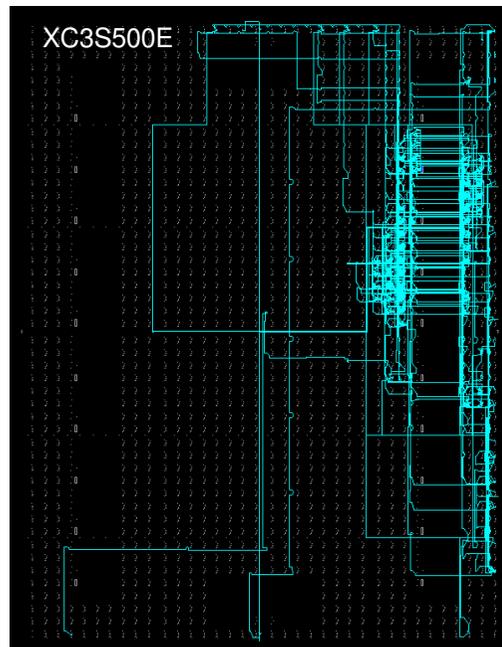
The images and statistics on this page show that the design occupies just 113 slices and 1 BRAM. This is only 2.5% of the slices and 5% of the BRAMs available in an XC3S500E device and would still be less than 12% of the slices in the smallest XC3S100E device.

## MAP report

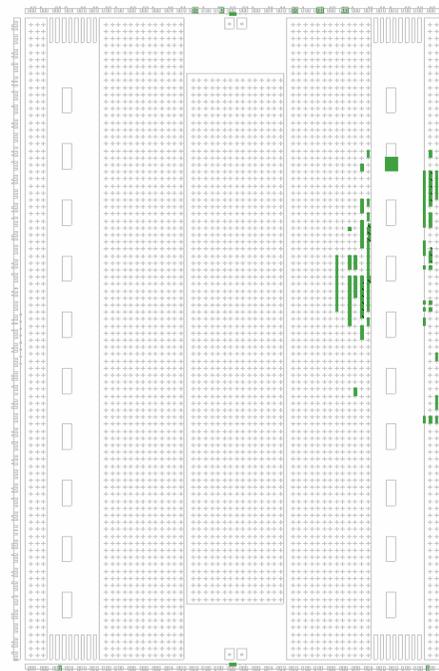
Number of occupied Slices:	113 out of	4,656	2%
Number of Block RAMs:	1 out of	20	5%
Total equivalent gate count for design: 75,945			

PicoBlaze makes extensive use of the distributed memory features of the Spartan-3E device leading to very high design efficiency. If this design was replicated to fill the XC3S500E device, it would represent the equivalent of over 1.5 million gates. Not bad for a device even marketing claims to be 500 thousand gates ☺

FPGA Editor view

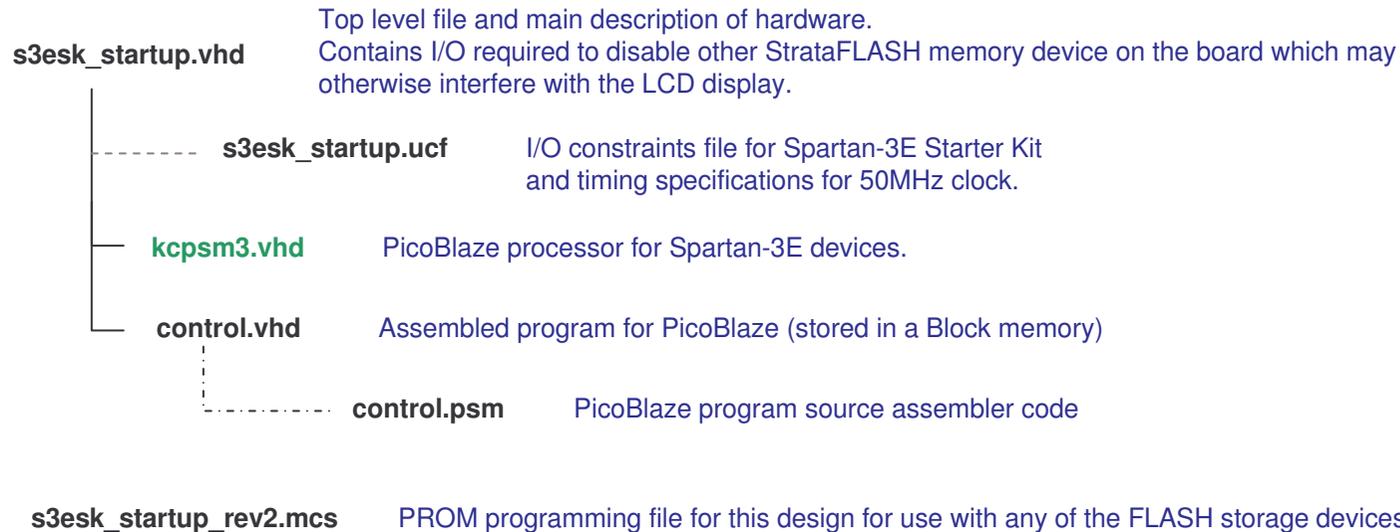


Floorplanner view



# Design Files

The source files provided for the reference design are.....



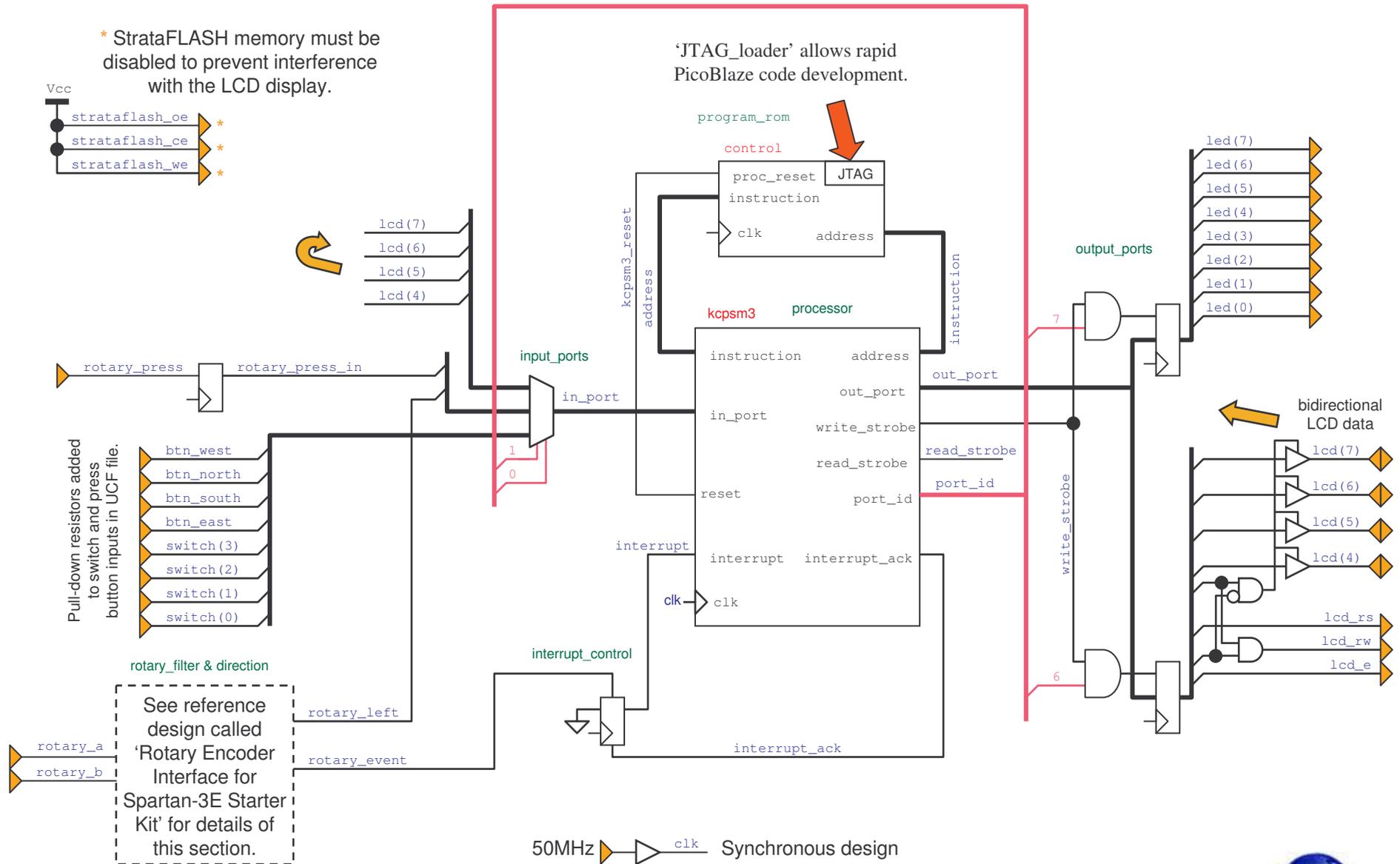
Note: The file shown in **green** is not included with the reference design as it is provided with PicoBlaze download. Please visit the PicoBlaze Web site for your free copy of PicoBlaze, assembler, JTAG\_loader and documentation.

[www.xilinx.com/picoblaze](http://www.xilinx.com/picoblaze)

Hint - If you only want to write new programs for PicoBlaze using the existing hardware design, then simply use the JTAG\_Loader utility supplied with PicoBlaze. The design supplied is already equipped with the JTAG loading circuit (see schematic on next page).

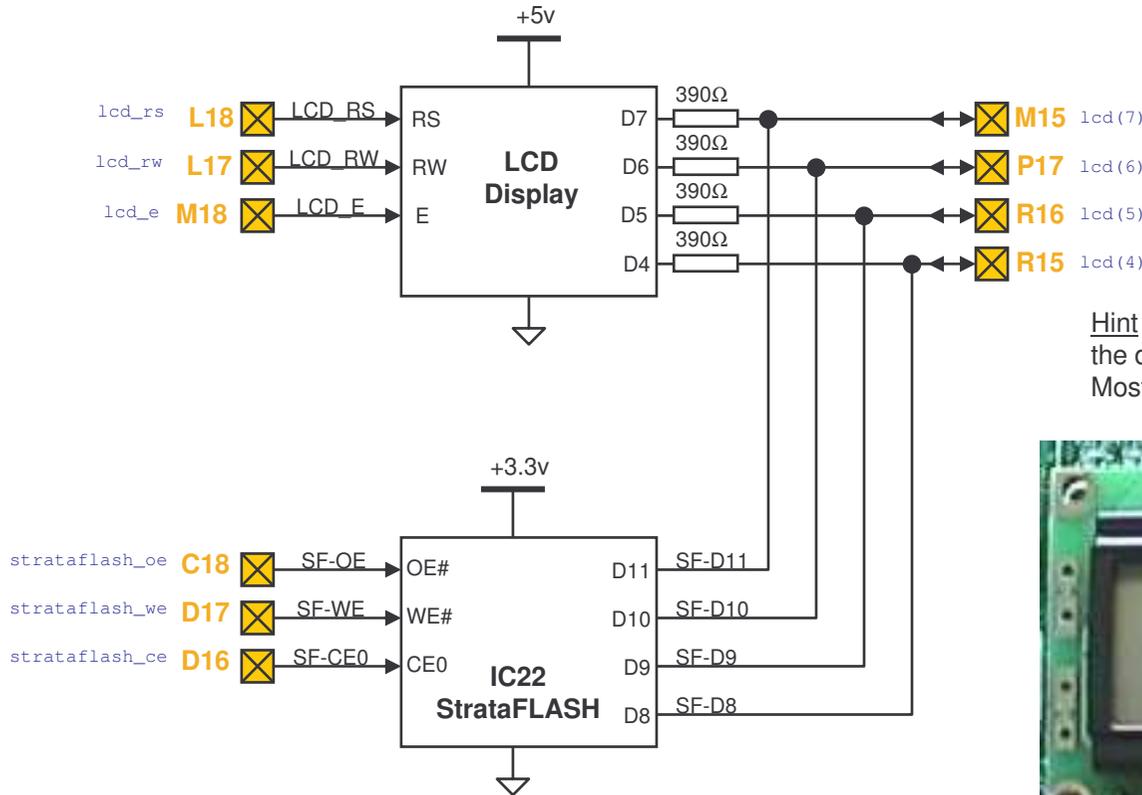


# PicoBlaze Circuit Diagram



# LCD Display Connections

The board is set up to use the 4-wire data interface to the LCD character module. The data connections are shared with the StrataFLASH memory which must be disabled to prevent interference. This diagram shows the pin connections to the Spartan-3E device.



The LCD display is powered by a +5v supply. This means that if the display is read it will potentially drive the data signal lines above the maximum level ( $V_{CC0}+0.5v$ ) allowed for the Spartan-3E and StrataFLASH pins which are both powered by 3.3v. Therefore the display data pins have been connected via 390Ω series resistors to limit the current and voltage during read operations.

Hint – This design provides all the mechanisms to enable the display to be read but does not actually need to use it. Most applications only require write operations.

Holding all three controls High ensures that the StrataFLASH memory does not interfere with the LCD display and also prevents inadvertent modifications to the memory contents.



GND +5v RS RW E D4 D5 D6 D7

Hint - The signals can be easily monitored at the edge of the display if desired.

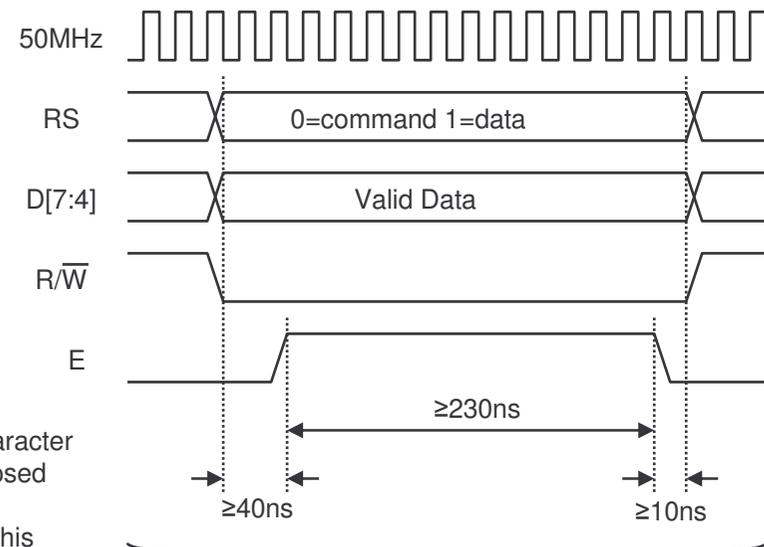
# LCD Display Timing

Once mastered, the LCD display is a practical way to display a variety of information using standard ASCII characters and even allows you to create some of your own. However, these displays are not fast. This design scrolls the display at  $\frac{1}{2}$  second intervals and that really is the practical limit for clarity. This low performance rate also relates to the signals used for communication. Compared with a Spartan-3E operating at 50MHz, the display can appear extremely slow. This is where PicoBlaze can be used to efficiently implement timing delays as well as control the actual content of the display.

## 4-bit Write Operation

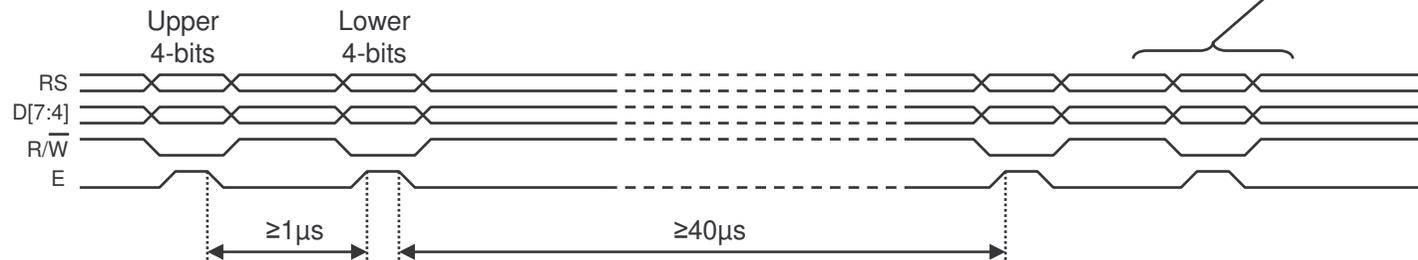
This timing diagram shows a single write operation being performed. The diagram is approximately to scale showing the minimum times allowed for setup, hold and enable pulse length relative to a 50MHz clock (20ns period). The data D[7:4], Register Select (RS) and write control (RW) must be set up at least 40ns before the enable E goes High. Enable must be High for at least 230ns which is almost 12 clock cycles at 50MHz.

Hint – In a write only system, the R/W signal can be tied Low permanently.



## 8-bit Write Operation

After initial display communication is established, all data transfers are 8-bit ASCII character codes, data bytes or 8-bit addresses. Each 8-bit transfer obviously has to be decomposed into two 4-bit transfers which must be spaced by at least  $1\mu\text{s}$ . Following an 8-bit write operation, there must be an interval of at least  $40\mu\text{s}$  before the next communication. This delay must be increased to  $1.64\text{ms}$  following a clear display command.



Exercise – Implement a hardware based state machine which obeys the timing requirements for an 8-bit write of data including the  $40\mu\text{s}$  delay. Modify the PicoBlaze interface and code to use your hardware circuit to write to the display. Under what circumstances would this approach be useful?

# PicoBlaze Timing

In this design, PicoBlaze is used to implement the LCD communication 100% in software. The fact that a processor is sequential in nature means that the required delays can be formed simply by executing the appropriate number of instructions. PicoBlaze simplifies the task of writing code because all instructions execute in two clock cycles under all conditions.

```
                CONSTANT delay_1us_constant, 0B
delay_1us: LOAD s0, delay_1us_constant
wait_1us:  SUB s0, 01
           JUMP NZ, wait_1us
           RETURN
```

```
delay_40us: LOAD s1, 28
wait_40us:  CALL delay_1us
           SUB s1, 01
           JUMP NZ, wait_40us
           RETURN
```

```
LCD_pulse_E: XOR s4, LCD_E
              OUTPUT s4, LCD_output_port
              CALL delay_1us
              XOR s4, LCD_E
              OUTPUT s4, LCD_output_port
              RETURN
```

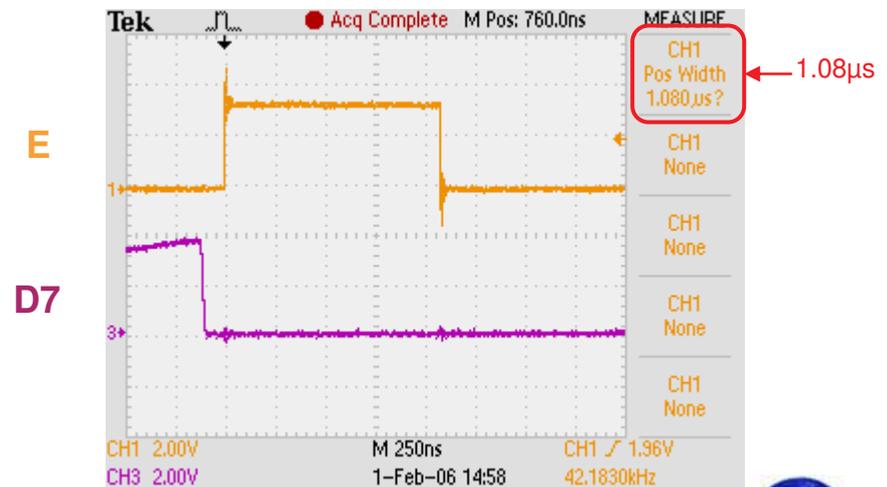
The enable E pulse is formed by setting the E signal High on the output port, waiting for 1 $\mu$ s and then driving E Low again. This oscilloscope screen shot shows a single enable pulse observed at the LCD display pin. Data bit D7 is also shown (see code on next page for more details).

Exercise – 1 $\mu$ s is greater than the 230ns minimum requirement for the enable pulse width. Modify the code to generate an enable pulse which is 250ns.

The PicoBlaze program supplied implements a 1 $\mu$ s delay in software which it then uses as the base for all operations. This subroutine is invoked with a 'CALL delay\_1us' which then LOADs register s0 with 11 (0B hex). This in turn causes the SUB and JUMPNZ instructions to execute 11 times before RETURN completes the routine. This means that a delay of exactly 1 $\mu$ s is formed by the 25 instructions each taking two clock cycles at 50MHz.

Creating other delays such as the 40 $\mu$ s required between 8-bit transfers is then a simple case of calling the 'delay\_1us' the appropriate number of times. In this case 40 (28 hex) times results in slightly more than 40 $\mu$ s due to the executions of instructions within the routine itself.

Exercise – Calculate the exact number of instructions, clock cycles and delay provided by the 'delay\_40us' subroutine. Prove your result either by simulation or preferably by running a test design on the Starter Kit and making measurements.



# PicoBlaze Timing

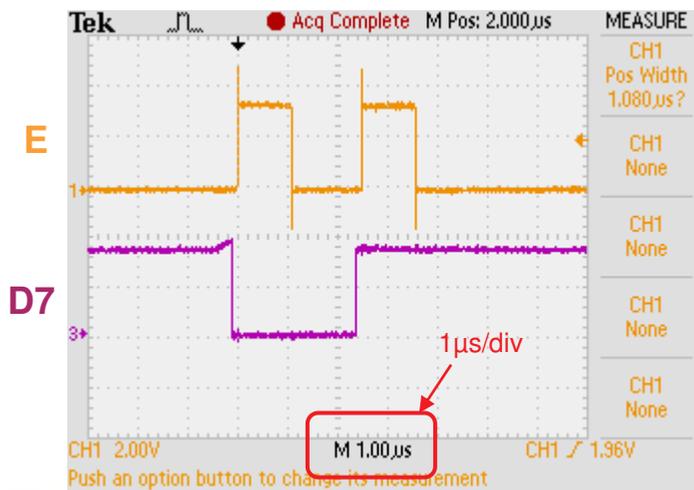
```

LCD_write_data: LOAD s4, s5
                AND s4, F0                ;Enable=0 RS=0 Instruction, RW=0 Write, E=0
                OR s4, 0C                 ;Enable=1 RS=1 Data, RW=0 Write, E=0
                OUTPUT s4, LCD_output_port ;set up RS and RW >40ns before enable pulse
                CALL LCD_pulse_E          ;write upper nibble
                CALL delay_1us            ;wait >1us
                LOAD s4, s5               ;select lower nibble with
                SL1 s4                     ;Enable=1
                SL1 s4                     ;RS=1 Data
                SL0 s4                     ;RW=0 Write
                SL0 s4                     ;E=0
                OUTPUT s4, LCD_output_port ;set up RS and RW >40ns before enable pulse
                CALL LCD_pulse_E          ;write lower nibble
                CALL delay_40us           ;wait >40us
                LOAD s4, F0               ;Enable=0 RS=0 Instruction, RW=0 Write, E=0
                OUTPUT s4, LCD_output_port ;Release master enable
                RETURN
    
```

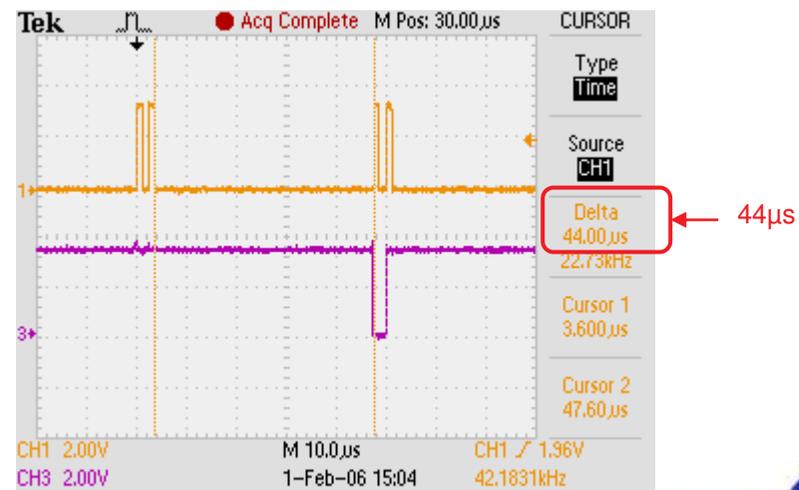
The writing of 8-bit data is achieved using the delays and enable pulse routines together with appropriate setting the D[7:4] data bits, RW=0 and RS=1.

Writing command instructions to the display is very similar but requires that RS=0.

>1 $\mu$ s between E pulses writing upper and then lower nibbles



8-bit writes. >1 $\mu$ s between E pulses

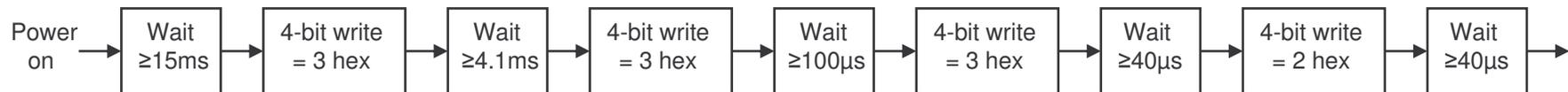


# Display Setup

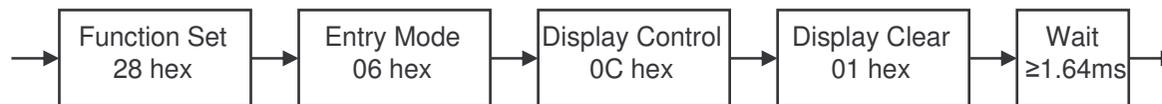
Before the display can be used for the first time, there is an initialisation sequence which must be followed to allow communication to take place. These sequences are ideally suited to an 8-bit processor such as PicoBlaze. Besides the relative complexity of the sequence, the process is only executed once and then the processor is available to perform other tasks including the control on the display itself.

**Hint** - The PicoBlaze code provided includes a subroutine called 'LCD\_reset' which performs this initialisation sequence.

The first part of this sequence is to establish that the 4-wire data interface is being used. Note that some of these delays are in milliseconds.



The 4-wire interface is now established which means that all subsequent communication is formed of the 8-bit writes described previously. Note that these writes are all commands and therefore RS must be Low. The next part of the sequence is used to establish how the display should operate.



Function Set = 28 hex : This code describes the display type as being 2 lines, 5×7 dots per character and using 4-wire communication (again).

Entry Mode = 06 hex



- Do not shift display left or right when writing a character
- Increment cursor position when writing a character

Display Control = 0C hex



- Cursor blinking off (character flashes)
- Cursor (line under character) is off
- Display is ON

**Exercise** – Implement a hardware state machine which can perform the LCD initialisation sequence. Compare the size of your implementation with the 96 slices required to implement a PicoBlaze processor. Does the claim of the first paragraph hold true?

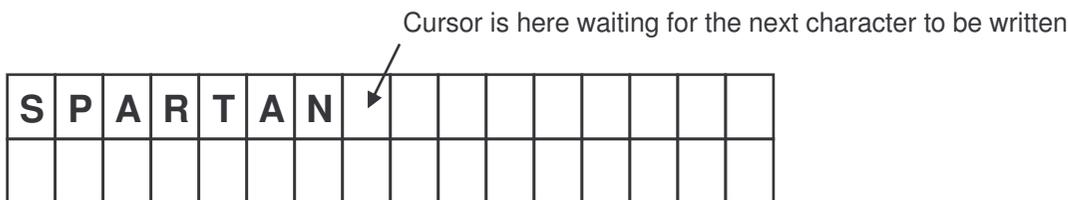


# Display Control

The most common operation is simply to write ASCII characters to be displayed. These are considered to be data and hence RS will be High. With the display set up as described previously, writing a series of characters will automatically result in their display on the top line of the display.

```
LOAD s5, character_S
CALL LCD_write_data
LOAD s5, character_P
CALL LCD_write_data
LOAD s5, character_A
CALL LCD_write_data
LOAD s5, character_R
CALL LCD_write_data
LOAD s5, character_T
CALL LCD_write_data
LOAD s5, character_A
CALL LCD_write_data
LOAD s5, character_N
```

Following the execution of this code, the display will look like this.



If you continue to write characters, they will eventually fall off the end of the first line but they will not automatically appear on the second line. This is because the memory map of this display is not consecutive from line to line. The diagram below shows the memory address of each character location.

To set the cursor in the position required for subsequent characters to be displayed, the 8-bit memory address of that position must be written to the display as a command (RS=0). Note that this can not be confused with any of the other commands since the MSB is always '1' in these addresses.

The ability to move to any particular location and write a few characters is ideal for the display of various information as it becomes available such as time, date, measurements and short status messages.

1	80	81	82	83	84	85	86	87	88	89	8A	8B	8C	8D	8E	8F
2	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	CA	CB	CC	CD	CE	CF
	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F

**Hint** - The PicoBlaze code provided includes a subroutine called 'LCD\_cursor'. Load register 's5' with the desired position. The upper nibble (value 1 or 2) will define the line and the lower nibble the character position on the line (0 to F). E.g. s5 = 2B will position the cursor at the 12<sup>th</sup> position on line 2.

**Exercise** – Although this design does make use of the scrolling display feature, it really is not recommended other than for simple messages as used in this example. Analyse the supplied PicoBlaze code and LCD display controller data sheets to determine how scrolling is achieved. Implement a design in which the message is greater than 40 characters per line (Hint – The memory map is actually 40 locations per line. Addresses 80-A7 and C0-E7).



Subroutines are used for delays and LCD display

# Complete PicoBlaze Program

This information is intended to give a guide to the way in which the PicoBlaze assembler code is organised. It is not intended to be a lesson in how to write assembler code or explain how PicoBlaze works. Please refer to the documentation for PicoBlaze (KCPSM3).

There are comments contained in the 'control.psm' file which should help explain the finer points.

