

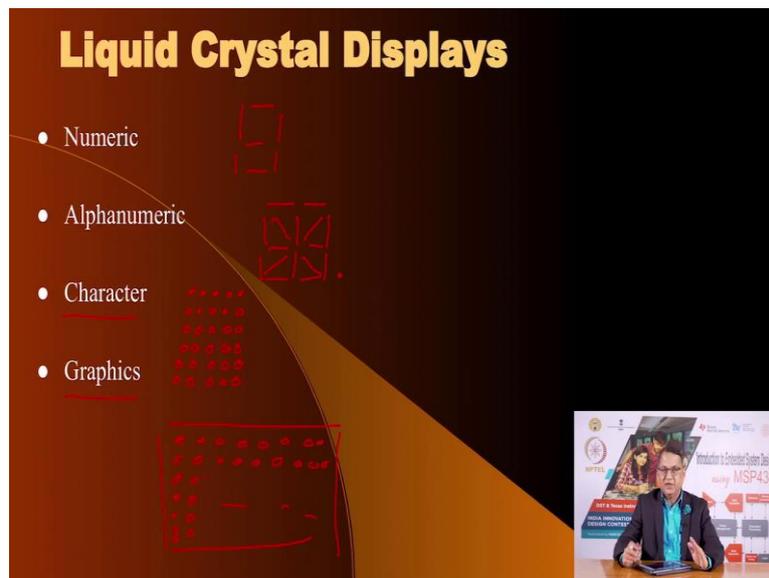
Introduction to Embedded System Design
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Lecture 28

Interfacing Liquid Crystal Displays (LCD)

Hello and welcome to a new session for this ongoing online course on introduction to embedded system design. I am your instructor Dhananjay Gadre and in this session I will be talking about how to connect additional output devices for human interaction namely the liquid crystal display.

So, liquid crystal displays are commonly called as LCD outputs and we are going to talk about how to connect them to our favourite MSP430 micro-controller. Now, you would have seen LCD displays commonly around you in many of the gadgets that you use on a regular basis. For example, on your calculator, on your specially the AC remote and so on. And these are common output devices because they allow very low power operation.

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These liquid crystal displays come in various types. The simplest one are called numeric displays and these are the ones which are used in calculators. The numeric displays will allow you to display information in seven segment format like you have seen for seven segment displays which use LEDs but you have same format for LCD also. So, you would have seen this on calculators.

Similarly, the seven segment display is not able to display a variety of information and so you have another type of output configuration which is called alphanumeric display which is similar to the numeric display except it has additional segments and typical alphanumeric display will look like this. Something like this.

This allows you to display alphabetical characters with little more clarity than is possible with a numeric displays. Then the third type of liquid crystal displays which are common are called character LCD displays in which you can display ASCII characters in the form of a 5 by 7 or 5 by 8 matrix of LCD elements, liquid crystal elements. Something like this.

Now, on such a matrix you can display almost a large number of alphabets, numbers, special characters and so on and so forth and that is why these are called character displays. And the most common of the liquid crystal display is what is called as graphics. In which row and column full of pixels are available that you can use to create whatever graphical or numeric or alphabetical information that you would like to display. So, these are the common LCD displays that are available.

We will now investigate how are LCD displays different from LED displays and the basic difference is in a LED display emits light. So, it has a source of light namely the light emitting diode. In the case of LCD we do not have the mechanism to generate light in a way that a LED does. But LCD allows you to manipulate light.

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Liquid Crystal Displays

- Liquid crystal display technology works by manipulating light.
- Uses two polarizers - horizontal and vertical placed on top of each other, with a source of light at the bottom.
- Liquid crystal between the two polarizers
- Liquid Crystals, when potential is applied, have the ability to 'twist' the light.

The slide includes a diagram illustrating the light manipulation process. It shows light rays entering from the left, passing through a horizontal polarizer, then a liquid crystal layer that twists the light's polarization to vertical, and finally a vertical polarizer that allows the light to pass through. A small inset image in the bottom right corner shows a man in a suit sitting at a desk with a presentation board behind him. The board contains logos for MPTET, IIT Bombay, and other institutions, along with text including 'Introduction to Embedded System Design using MSP430' and 'MCA UNIVERSITY'. The man is holding a tablet and looking towards the camera.

So, LCD liquid crystal display works by manipulating light. What does it consist of? It consists of several layers of structures. Initially a source of light, the source of light can be ambient light as well as light from a LED source, followed by a polarizer in which it polarizes the incoming light let us say in the horizontal direction.

Then you have the liquid crystal in between and then you have another polarizer where the polarization happens in a vertical direction and then of course here is the human eye which is able to see what is reaching the human eye. Now, how does it work? If the 2 polarizers, polarize a light in such a way that one is polarizing it in horizontal direction and the other offers polarization in the vertical direction no light from the source would reach the human eye.

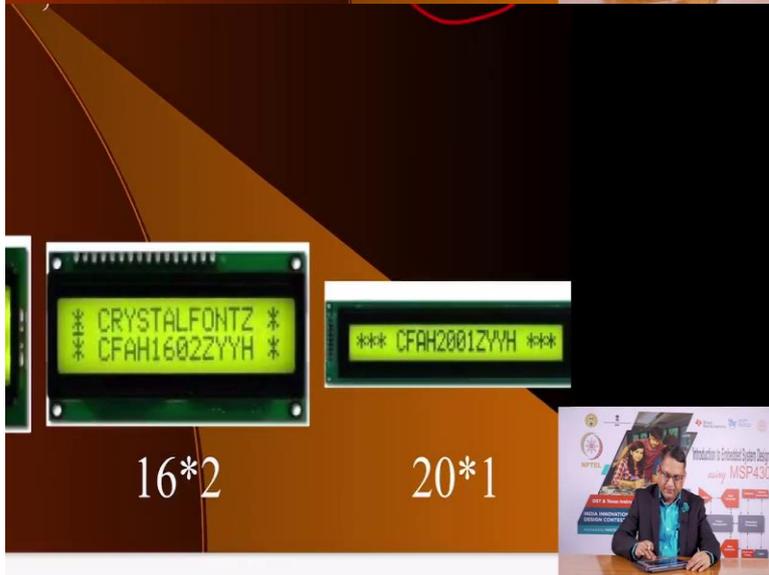
But the intervening liquid crystal has a great ability that once you apply potential to it, it has the ability to twist the light meaning it has the ability to change direction of the light which reaches this the crystal and change its direction and if it is aligned to the vertical direction then the light will come out and you can see it, the human eye can see it.

And so LCD is very different from LED. In LED you generate light, whereas in LCD you manipulate existing light. So, this is the basic difference. Because it is not generating any light, it is able to operate at much low power levels as compared to LED display and that is the reason why LCDs are so common in everyday gadgets for sharing information for human interaction.

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Liquid Crystal Display Types

- Character LCD Type: $8*1$, $8*2$, $12*2$, $16*1$, $16*2$, $16*4$, $20*1$, $20*2$, $20*4$, $40*1$



Liquid Crystal Displays

- Numeric
- Alphanumeric
- Character
- Graphics



These liquid crystal displays specially the so called character LCD displays, we are not going to talk about numeric and alphanumeric because numeric displays and alphanumeric displays do not have the ability to share too much variety of information.

We are going to concentrate on character LCD displays in this lecture and I will mention what all graphic displays, LCD displays you can have. In liquid crystal display of the character type you get it in the form of what is called as 8 cross 1 or 8 cross 2 and these refer to the number of characters in the first instance and the second information is the how many lines you have.

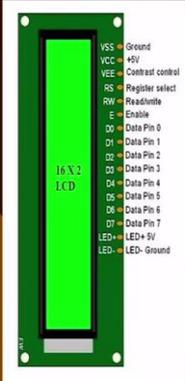
So, when I say that I have a 8 cross 1 LCD character display, it means I have 1 line and this line has 8 characters. Each character can be any ASCII value, any ASCII character you can display. Similarly, 8 cross 2 would be 2 lines of 8 characters. 16 cross 1, 16 cross 2 these are the most in fact 16 cross 2 is the most common LCD display that you can find and in this exercise we are going to use a 16 cross 2 display.

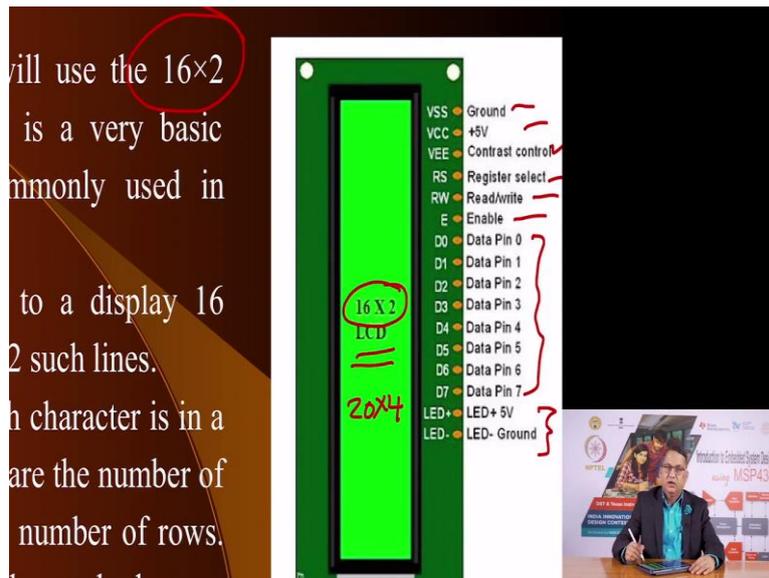
Here is an example of a variety of this. This is a 8 cross 2, next to it is a 12 cross 2, then you have a 16 cross 2 and you have a 20 cross 1. You may have seen this at various locations and we are going to use this in our experiment.

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Hitachi HD44780 LCD Controller

- In this course, we will use the 16×2 LCD display, which is a very basic module (16-pin) commonly used in DIYs circuits.
- The 16×2 translates to a display 16 characters per line in 2 such lines.
- In LCD displays, each character is in a 5×8 matrix. Where 5 are the number of columns and 8 is the number of rows. This knowledge will be used when we have to print custom text or letters.



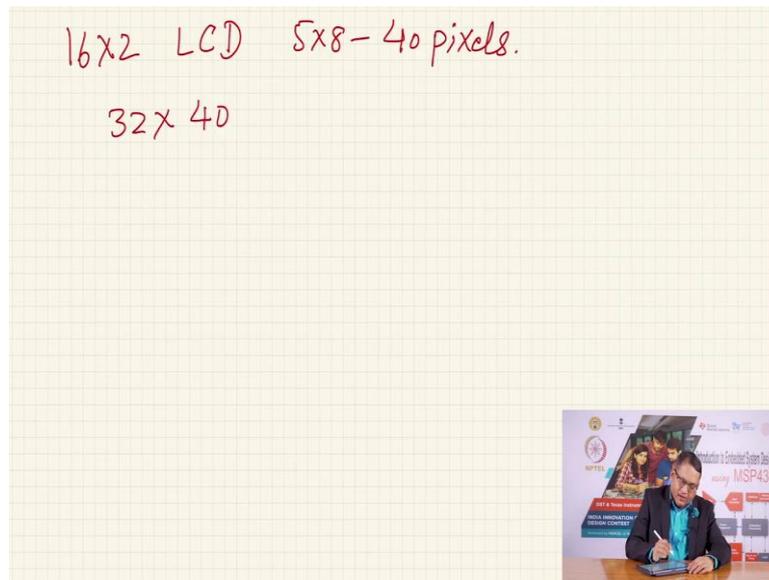


Now, one could create a mechanism for connecting such a display to a micro-controller and the most common interface for connecting such a display to a micro-controller is what is called as Hitachi HD44780 LCD Controller. This has become a defector standard for character LCD displays which spans the entire range from 8 cross 1 to 20 cross 4.

It has a common interface as we see here. This is the interface that it requires certain pins for sending information and reading information from the display for providing power supply to this display, for providing power supply for the backlight. The source of light which we are able to stop or allow to come out of the LCD that is the light we were talking of initially and this has been available for a very long time. In this display the one we are going to use in our experiment, we are going to use a 16 cross 2 LCD display.

This is the most common display that is available and therefore the cheapest that you can find. The 16 cross 2 translates to 2 lines and each of the line allows you to display 16 characters. Each character can be displayed in a 5 by 8 matrix which means that a 16 cross 2 LCD, how many pixel it has? Let us calculate that.

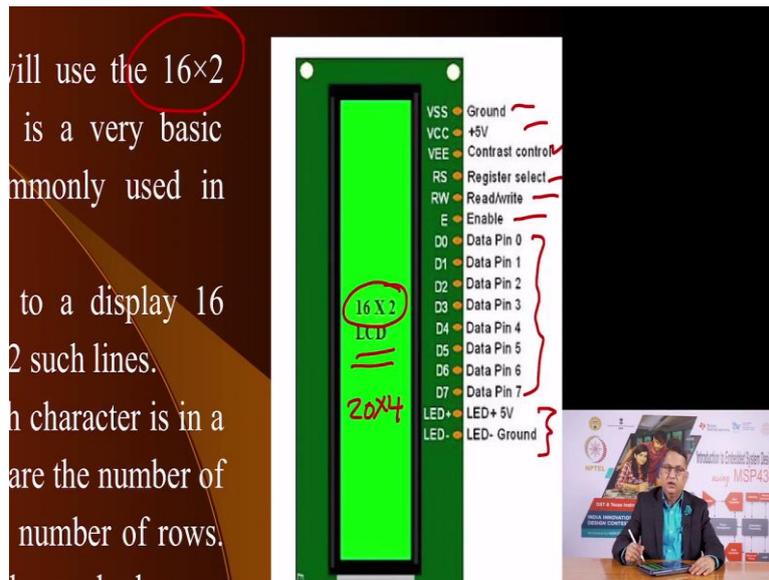
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A 16 cross 2 LCD where each of the displays, each of the character is 5 cross 8, that means 40 pixels. Therefore, the total number of pixels on a 16 cross 2 LCD is 32 into 40 and that is a large number of pixels that you have. Now, obviously to be able to turn control each of these pixels is equal to controlling so many LEDs that we have seen in a previous lecture and the only way to achieve this is by way of multiplexing except the responsibility of multiplexing is not on the micro-controller.

The LCD has resident micro-controller or a single purpose computer which is doing that job on our behalf. All we have to do is send information to the controller that what do you want to display and this information, this interface that we are talking about basically allows an external controller such as MSP430 to communicate with the resident single purpose computer on the LCD display, convey information to it so that controller is able to multiplex all these LCD pixels to display whatever information that the user may want to provide.

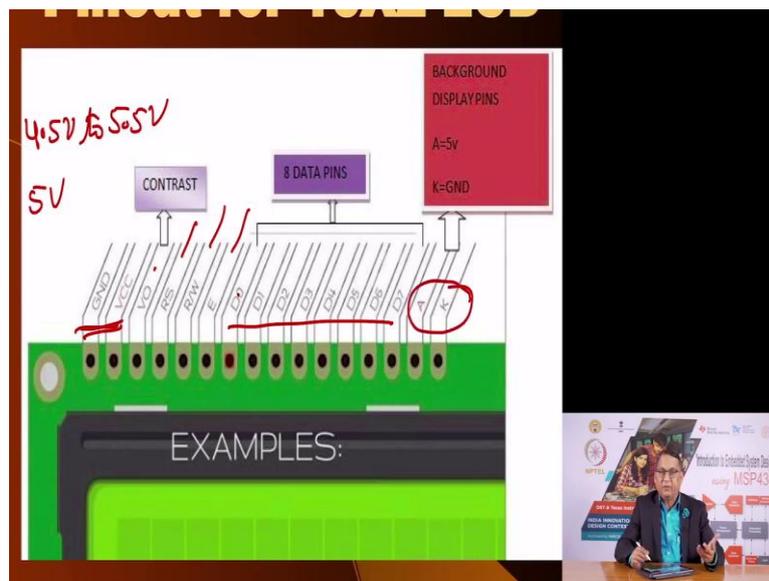
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And the Hitachi controller HD44780 offers a unique and uniform interface which has these 8 data lines, some control lines like this and this and a power supply here, a power supply for the backlight and a contrast control. Using a 16 pin interface any micro-controller such as MSP430 or any other micro-controller can display information in a uniform fashion and it does not matter that you have a 16 cross 2 LCD, you can also have a 20 cross 4 LCD.

Even then the interface to the LCD will remain the same. That is the beauty of this Hitachi HD44780 LCD controller. Let us go through the pin out of this LCD controller. The most important part is what is the power supply required.

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The power supply that you require is here ground and VCC and this is the commonly available LCDs required 5 volt. Of course, 5 volt does not mean 5 volt. Usually it is 5 volt plus minus 10 percent which means you can have a supply voltage from 4.5 volts to 5.5 volts. Apart from that you need to set the contrast and I will share the circuit that you have to connect to be able to adjust the contrast of the LCD. Apart from that you have data pins D0 to D7 as you see here and control signals which is read write enable and register select.

These are the 3 control pins that you require for communicating with the common LCD display and then you have 2 LEDs, 2 pins of LED, anode and cathode which provide the backlight to this LCD. These LCDs are available in many colours like green colour with black segments or any other colour and you can choose whatever is available for you.

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16X2 LCD Pin Description:		
PIN		Description
<ul style="list-style-type: none">Ground Pin (GND) andSupply Pin (4.7V - 5.3V)	GND VCC	Grounded pin and Vcc is given on the respective pin.
<ul style="list-style-type: none">Read/Write andAn Enable pin (-ve Edge triggered for Write and +ve edge triggered for Read)	R/W* E	<ol style="list-style-type: none">Low to write to the register. High to read from the registerAn edge triggered signal used to writing or reading data to/from LCD
<ul style="list-style-type: none">Contrast adjustment. <p>A variable resistor (mostly a preset) is generally attached on this pin.</p>	VO/VEE	Output of the potentiometer is connected to this pin. Rotate the potentiometer knob forward and backwards to adjust the LCD contrast.
<ul style="list-style-type: none">8 Data pins	D0-D7	8 data pins for data transfer.
<ul style="list-style-type: none">Register Select: (A 16X2 LCD has two registers, namely, command and data.)	RS	The register select is used to switch from one register to other. RS=0 for command register, whereas RS=1 for data register.
<ul style="list-style-type: none">Backlit Supply (5V)	LED+	
<ul style="list-style-type: none">Backlit Ground (GND)	LED-	



Now, these are the description of the pins. You have read write pin. If the read write pin is 1 that means you want to read internal register. If you set this pin to 0 that means you want to write into that register. You also have a enable pin which is like a chip select.

You have to keep this signal low to be able to a negative edge on this signal which indicates to the LCD controller that you are writing something. Then you have a contrast adjustment on one of the pins. You have 8 data pins D0 to D7 and you have a register select.

You have 2 registers. One is for command and the other is for data. So, if this value is 0 that means you are sending information to the command register. If this value is 1 that means you are sending information to the data register and apart from that you have 2 pins which are the anode and cathode of the backlight LED.

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Command Codes for LCD					
S.no	Hex Code	Command to LCD Instruction Register	11.	0F	Display On, Cursor Blinking
1.	01	Clear Display Screen	12.	10	Shift Cursor to Left
2.	02	Return Home	13.	14	Shift Cursor to Right
3.	04	Decrement Cursor(shift to left)	14.	18	Shift Entire display to the Left
4.	06	Increment Cursor	15.	1C	Shift Entire display to the Right
5.	05	Shift Display Right	16.	80	Force Cursor to Beginning (1st line)
6.	07	Shift Display Left	17.	C0	Force Cursor to Beginning (2nd line)
7.	08	Display Off, Cursor Off	18.	38	2 line and 5X7 Matrix
8.	0A	Display Off, Cursor On	19.	28	2 line 5X7 matrix in 4bit mode
9.	0C	Display On, Cursor Off	20.	32	Send for 4bit initialisation of LCD
10.	0E	Display Off, Cursor On	21.	33	Send for 4bit initialisation of LCD



Now, to create a uniform interface the Hitachi LCD controller offers a set of commands and any controller can send these commands and the Hitachi controller will react appropriately. At this point I would like you to take this LCD that you have in your hand and flip it around and see what is behind that LCD.

You will find 2 black dots and those black dots are what are called as chip on boards. Underneath those black dots are ICs which are the controllers and the memory for this LCD controller. So, these are the commands. What commands you send. You can send a command to clear the display. You can send a command to return the home. Home means the initial position of the cursor. You can increment or decrement the cursor. You can go forward or you can go backward and so on.

There are about 20-25 commands. Here as you see 21 commands which allow you to interact with the LCD controller. Some of these commands we will see when we do an exercise. Let us go towards that.

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16*2 LCD Working Modes

- 16*2 character display can be operated in two modes -
 - 8 Bit mode - This is the default mode in which all the data pins (D0 - D7) are used.
 - 4 Bit mode - Only four data pins (D4 - D7) are used.



Now, one of the problems with the LCD 16 cross 2 or any other character LCD is that it works at 5 volts.

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+5V Power Supply Options

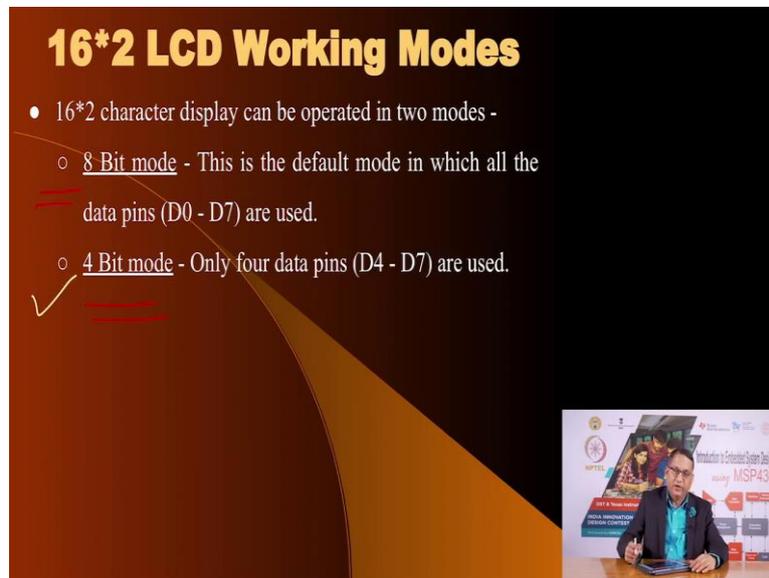
1. Modified USB cable
2. Breadboard Power Supply
3. Lab Bench Power Supply



Here, it works at 5 volts and so we have this issue that our MSP430 lunch box operates at 3.3 volts but the LCD works at 5 volts. Now, how do you provide 5 volts? So, in this lecture we have offered you several ways of creating 5 volts supply so that you can power your LCD and the first method is to use a modified USB cable that you may have or if you search the internet you can get access to what is called as a breadboard power supply, small module that will fit into the power supply pins, the

side pins of a breadboard easily or if you have access to a lab power supply, you can set it to 5 volts and you can use it to power your LCD also. I come to that in a brief moment but let us go back to the interface of the LCD.

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 - 8 Bit mode - This is the default mode in which all the data pins (D0 - D7) are used.
 - 4 Bit mode - Only four data pins (D4 - D7) are used.

The slide features a dark background with a curved orange and brown gradient on the left side. A small inset video in the bottom right corner shows a man in a blue shirt and glasses sitting at a desk with a laptop, presenting a slide that includes the text 'Introduction to Embedded System Design using MSP430'.

Now, because you have 8 pins for interaction the LCD, the controller inside the LCD expects you to send commands over these 8 pins. But often times we do not have 8 pins. The Hitachi interface is very benevolent in that sense that it will adjust to send you information on 4 bits also. Instead of 8 bits you can communicate with LCD controller on 4 of the 8 pins and that is called the 4 bit mode. The default mode is 8 bit mode but if you like, if you do not have pins select the 4 bit mode.

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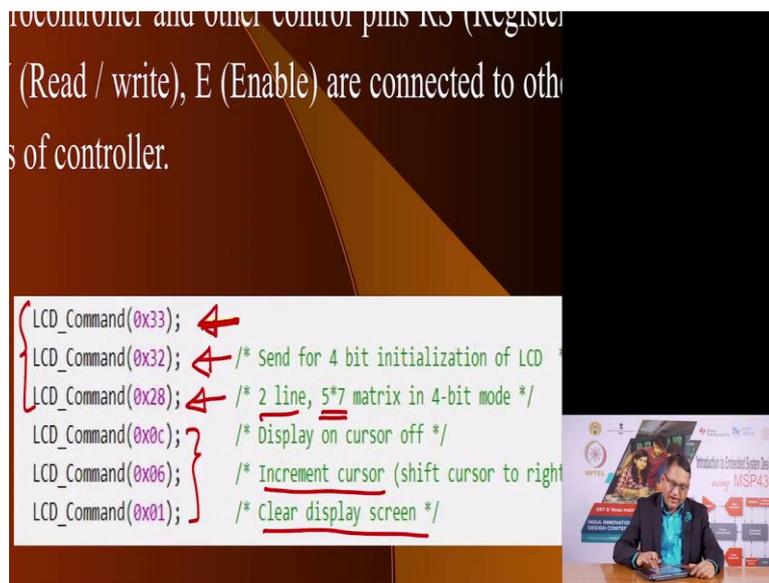
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In fact one of the commands as you see here, these 2 commands allow you to tell the, communicate to the LCD, that no we do not have 8 pins to communicate to you and we are going to send information on 4 bits also. So, you have to send these commands and we will see briefly how you send these commands.

So, you have a 8 bit mode and a 4 bit mode. Now, in the 4 bit mode the actual information is being send, you want to send 8 bit of information, but because the communication connection only has 4 pins, you have to send information on those pins twice so that you can send entire 8 bit of information. So, you have to tell the controller that we are going to send 4 bits and then another 4 bits, the lower level and the higher level and the way to do that, here is the sequence of instructions.

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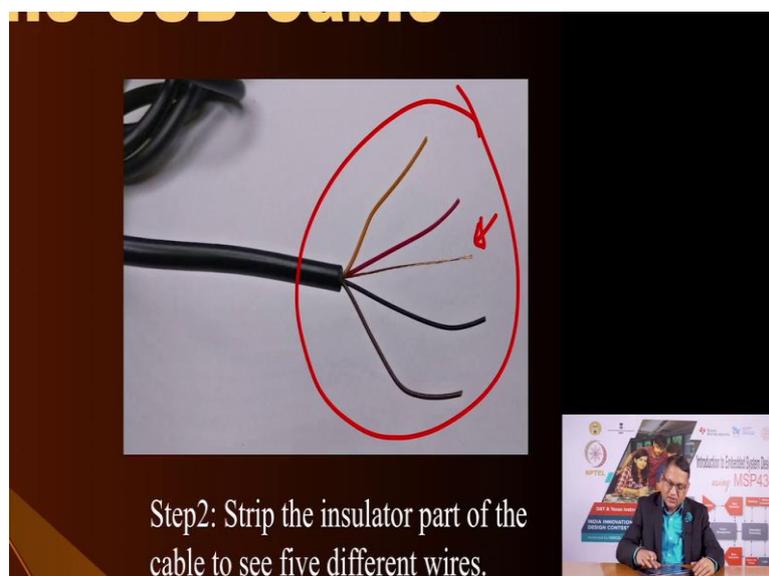
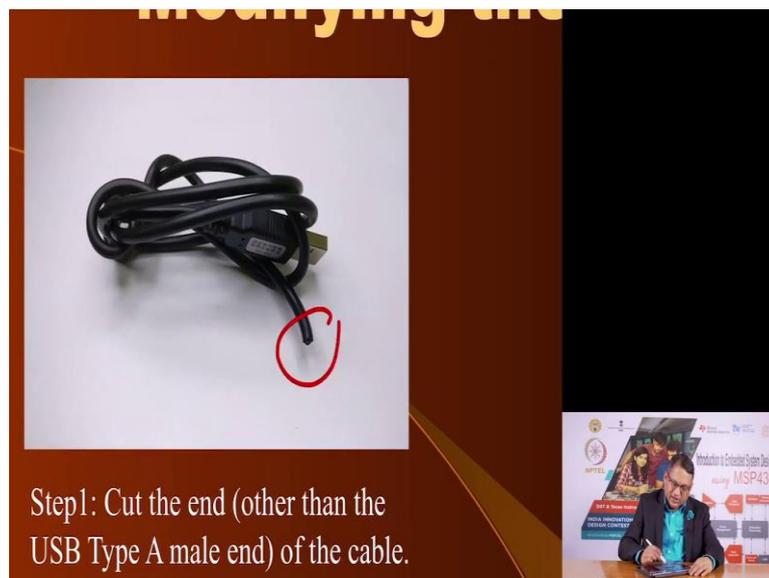
You send a information like this and say you send a value called 33. 33 is in hexadecimal. Then you send 32 and then you send 28. When you send these 3 bytes it conveys to the LCD controller that you want to communicate with the LCD controller in a 4 bit mode and you want to have 2 lines and each of the line will have character which are defined as 5 by 7 matrix.

And then these are additional commands where you are turning the cursor off and you want the increment cursor automatically and you want to clear the display screen that any previous information is cleared off. But the most important is that you want to send these 3 bytes of information to the controller but you do not have 8 bits to send, 8 wires to send. You are sending it in chunks of 4 bits each. So, we will see when we look at the code for doing this how we achieve that.

Since our MSP430 lunch box does not have 5 volt available easily, we have to find a mechanism to provide 5 volts.

One option is that you take any USB cable whether it is a micro-USB or a mini-USB output, plug it into your power bank or onto your laptop and on the other side you can cut it and select appropriate wires to provide 5 volts and in this PPT we are going to show you how we can do that.

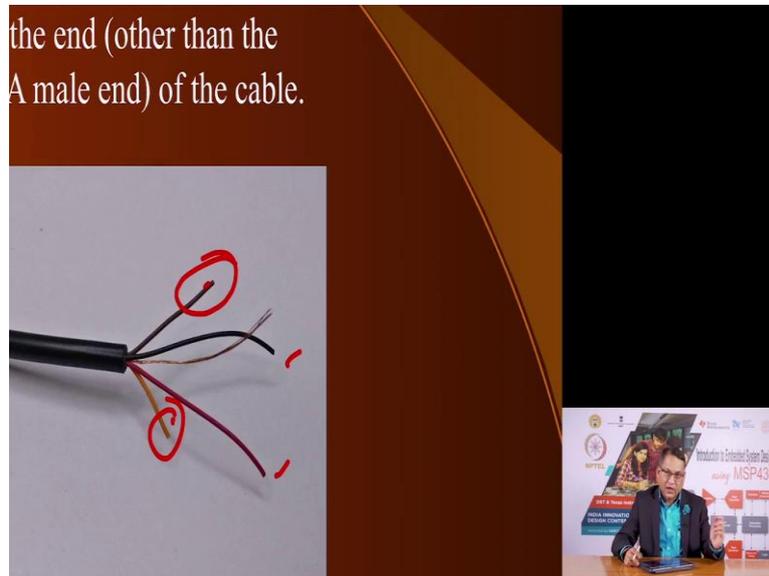
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So here is the, you take a USB cable like this. Cut one side off. This is the cut side. Then you strip it of and you will find the insulator side there are 4 wires. The 2 of the wires are yellow and black, red and black and that is the power supply plus 5 and

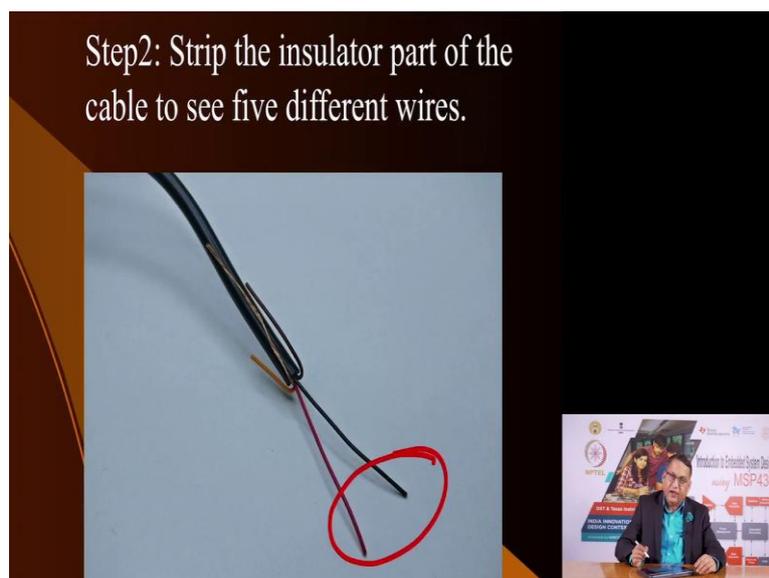
ground and then you have a copper wire which is like the shield and then you have 2 more wires. Those are for communicate data plus and data minus. We do not need them in our application so we are going to cut them off.

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Then you cut them off at different length. The black and red wire you keep of the maximum length and the other 2 wire this one and this one you cut at different lengths because you do not want to short them because that may give false information to the cable where you are connected it.

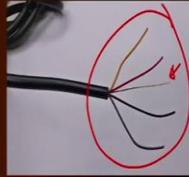
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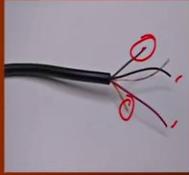
Modifying the USB Cable



Step1: Cut the end (other than the USB Type A male end) of the cable.



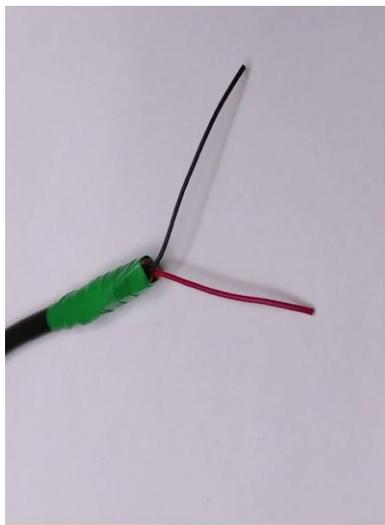
Step2: Strip the insulator part of the cable to see five different wires.



Step3: The Red and Black ones are used for the Power supply. Cut the three other wires at different lengths.



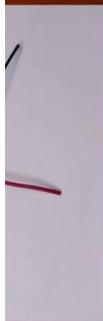
Step4: Now, bend the three wires.



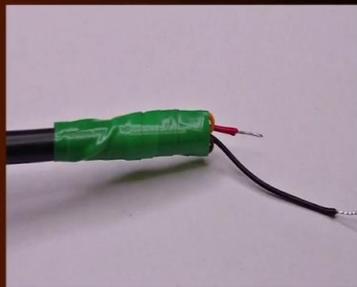
5: Tape the three ends with the help



Modifying the USB Cable

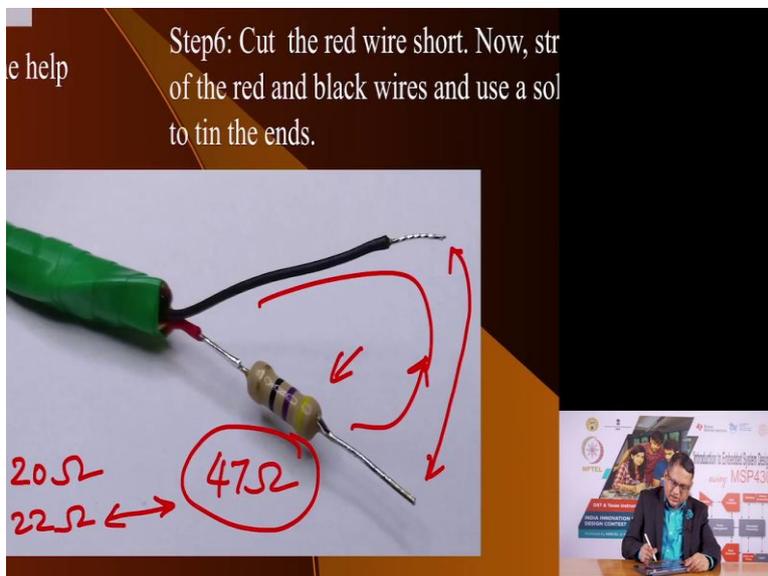
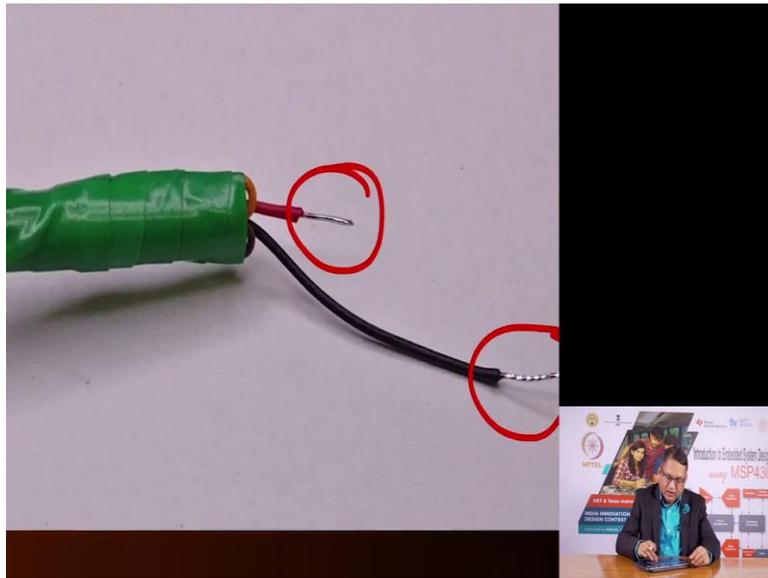


ends with the help



Step6: Cut the red wire short. Now, strip the end of the red and black wires and use a soldering iron to tin the ends.





Then leaving the black and red cable you bend the rest of the 3 cables and then you tape them off like we see here. Use an insulating tape. Tape it off. Now, these wires can be cut at different lengths. Why? Because we will see, we do not want them to be of equal length. They may short with each other and they may create problems where the USB interface.

So, you cut them at different levels. Those cut wires you tilt using solder wire. You apply solder onto it so that the breads of the wire are all joined together. Then I suggest you use a resistor on the positive wire.

In this case this is the 47 ohm resistor. You can choose any resistor up to 20 ohms. The reason is if inadvertently you short these 2 pins the resistor will limit the amount

of current that can flow in this circuit and the safe limit for USB normal USBs 500 milli amperes. Till 500 milli amperes it will not damage the USB port. So, we have put a 47 ohm resistor that means we are allowing up to 100 milli amperes of current and this is suitable and sufficient for our LCD.

If you have a lesser value resistor up to 20 ohm that is suitable. So, you can choose a 22 standard ohm up to 47 ohm resistor like this and this once you solder on the 2 wires it provides you 5 volts that you can use safely to power your LCD. Now, here we are looking at the hello LCD code. This is the code we are going to write on our code composer studio. We are going to build and compile it and we are going to download it in our lunch box and we will see here which connections we have made to the LCD.

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The image shows a screenshot of C code for an MSP430 microcontroller. The code defines pins for LCD control and data. Handwritten red annotations include a bracket grouping LCD_OUT (P1OUT), LCD_DIR (P1DIR), and data bits (D4-D7) as 'CNT', and another bracket for RS and EN as 'RW'. A circuit diagram shows a resistor connected between a +5V supply and the CNT pin, with the RW pin connected to ground. A video thumbnail in the bottom right shows a presenter at a desk with a presentation slide titled 'Introduction to Embedded System Design using MSP430'.

```

1 #include <msp430.h>
2 #include <inttypes.h>
3
4 #define CMD      0
5 #define DATA    1
6
7 #define LCD_OUT  P1OUT
8 #define LCD_DIR  P1DIR
9 #define D4       BIT4
10 #define D5       BIT5
11 #define D6       BIT6
12 #define D7       BIT7
13 #define RS       BIT2
14 #define EN       BIT3
15
16 //
17 /**
18  *@brief Delay function for producing delay in 0.1 ms increments
19  *@param t milliseconds to be delayed
20  *@return void
21  */

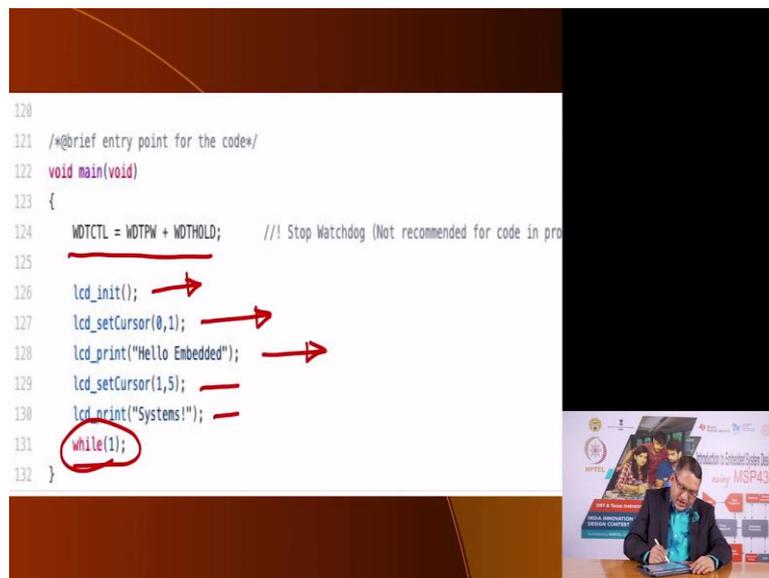
```

Let us go through those connections. So, these are the pin outs. The LCD output we are going to take out of P1. So, we are taking it P1. The direction is set here that they will all be output and these are the 4 bits of data. As I mentioned we are going to interface the LCD in the 4 bit mode.

So, we have 4 bits - bit 7, 6, 5 and 4 and the resistor select and enable pin are going to be derived from P1.2 and P1.3. Now, we are going to come back here later. Let us go back to our main program. So basically, what you need to do is using this pin out, you need to connect your MSP430 micro-controller to the connections of the LCD that we have seen earlier.

You need to also connect the 5 volt and ground. You need to connect the potentiometer between VCC that is plus 5 volt and ground and the centre of the potentiometer or the pre-set you need to connect to the contrast pin of your LCD. Apart from that these 4 data pins, the register select and enable pin you need to connect to the port 1 pins and the other pin that we mentioned, RW pin you need to connect to ground. Once you make those connections on your LCD which you can insert in your breadboard, you are ready to go. Let us see the main program.

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```
120
121 /*@brief entry point for the code*/
122 void main(void)
123 {
124     WDTCTL = WDTPW + WDTHOLD;    ///Stop Watchdog (Not recommended for code in prod
125
126     lcd_init();
127     lcd_setCursor(0,1);
128     lcd_print("Hello Embedded");
129     lcd_setCursor(1,5);
130     lcd_print("Systems!");
131     while(1);
132 }
```

So, the main program starts here. The main program is actually very simple but that is because most of the functionality has been outsourced to in the form of functions. The first thing that we do the moment we enter into the program is that we disable the watchdog timer. We do not want the watchdog timer on our MSP430 to interrupt us.

Then we call a subroutine to initialize the LCD and then we set the cursor to the home position that is 0, 1 which is the top left pixel is our home position and then we want the LCD to print Hello Embedded on the first line and on the second line we want to print Systems and then we are going to wait here in this, doing nothing. That is the main code. Now, let us go through each of the functions and see what it does. Let us see what LCD in it does.

(Refer Slide Time: 27:39)

```
90 /*
91  *@brief Initialize LCD
92  */
93 void lcd_init()
94 {
95     LCD_DIR |= (D4+D5+D6+D7+RS+EN);
96     LCD_OUT 6= ~(D4+D5+D6+D7+RS+EN);
97
98     delay(150); // Wait for power up ( 15ms )
99     lcd_write(0x33, CMD); // Initialization Sequence 1
100    delay(50); // Wait ( 4.1 ms )
101    lcd_write(0x32, CMD); // Initialization Sequence 2
102    delay(1); // Wait ( 100 us )
103
104    // All subsequent commands take 40 us to execute, except clear & cursor return (1.64 ms)
105
106    lcd_write(0x28, CMD); // 4 bit mode, 2 line
107    delay(1);
108
109    lcd_write(0x0C, CMD); // Display ON, Cursor OFF, Blink OFF
110    delay(1);
111
112    lcd_write(0x01, CMD); // Clear screen
113    delay(20);
114
115    lcd_write(0x06, CMD); // Auto Increment Cursor
116
117
118
119 }
120
```



So, LCD in it what it does is, it initializes the port 1 pins to be output and it sets the direction as output and it defines them as output. This is what it does and it makes all the pins equal to 0. The register select is 0. The enable is 0 and all the data pins D4 to D7 are set to 0. Then it calls a delay of certain amount which we will see what it does and then it writes a value called LCD write here. Let me erase this. It calls a function called LCD write and in that LCD write there are 2 variables, 2 parameters.

One is number called 33 and then it says this number should be treated as command. Now, you remember the LCD is able to accept either command or data using the register select function RS. If we are sending a command, that value has to be 1, if you are sending a data that value has to be 0, you are basically conveying to the LCD

write function that this value, this number 033 0x33x should be sent as a command. Then you are delaying for some more time and you are sending another command with a value 32. Then you are delaying for a lesser period of time.

Now, you are sending these 4 commands basically as you can correlate with the commands that you can send to the LCD. This is allowing you to initialize the LCD in 4 bit mode, the 2 lines. You want the cursor display to be on, you want the cursor to be off and you want the cursor not to blink and then you clear the screen using this command.

After some delay you are setting the cursor for auto increment meaning when you write one character, you want the cursor to go to the next character and initially you want to set the cursor to 0,0. This means in your display, this is 1 line, this is your second line, you want it to go here.

This is the initial location. Once you have initialized the LCD you are executing the second command where you are saying set the LCD cursor to 0, 1.

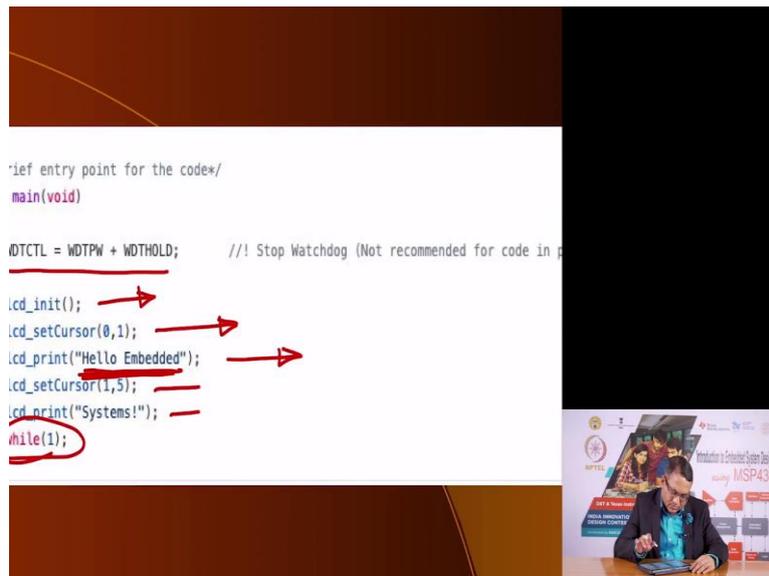
(Refer Slide Time: 29:54)

```
    {
        lcd_write(*s, DATA);
        s++;
    }

/**
 * @brief Function to move cursor to desired position on LCD
 * @param row Row Cursor of the LCD
 * @param col Column Cursor of the LCD
 * @return void
 */
void lcd_setCursor(uint8_t row, uint8_t col)

const uint8_t row_offsets[] = { 0x00, 0x40};
lcd_write(0x80 | (col + row_offsets[row]), CMD);
delay(1);
```





So, let us see what that command is LCD cursor. Here you are sending some information which uses the same LCD write. You are sending this information and you are sending the offset of the values to the LCD and then you are delaying it for some time.

Let us go back to the program. Then you are saying Hello Embedded. You want to print this information. You want to print this characters on to this LCD. Let us go back to the LCD print. What it does?

(Refer Slide Time: 30:29)

```
52
53 /**
54  *@brief Function to print a string on LCD
55  *@param *s pointer to the character to be written.
56  *@return void
57  */
58 void lcd_print(char *s)
59 {
60     while(*s)
61     {
62         lcd_write(*s, DATA);
63         s++;
64     }
65 }
66
67 /**
68  *@brief Function to move cursor to desired position on LCD
69  *@param row Row Cursor of the LCD
70  *@param col Column Cursor of the LCD
71  *@return void
72  */
73 void lcd_setCursor(uint8_t row, uint8_t col)
74 ..
```

The image shows a code editor window with C code for an MSP430 LCD application. Red annotations highlight the lcd_print function definition and the lcd_setCursor function definition. A red arrow points to the lcd_setCursor function definition. To the right, a small inset shows a person at a presentation desk with a slide titled 'Introduction to Embedded System Design using MSP430'.



```

f entry point for the code*/
in(void)

CTL = WDTPW + WDTHOLD;    ///< Stop Watchdog (Not recom

_init();
_setCursor(0,1);
_print("Hello Embedded");
_setCursor(1,5);
_print("Systems!");
le(1);

```



Now you are passing an array to the LCD print and you are passing its pointer. So, till the pointer does not give you a null because when the pointer ends, the value is null. Till the null point, null value is received, you are sending information and you are saying that this information should be treated as data. What does it consist of?

This consists of the characters under the apostrophes Hello Embedded. So, you are sending one byte at a time to the LCD write function here.

(Refer Slide Time: 31:12)

```

62
63 /**
64  *@brief Function to print a string on LCD
65  *@param *s pointer to the character to be written.
66  *@return void
67  */
68 void lcd_print(char *s)
69 {
70     while(*s)
71     {
72         lcd_write(*s, DATA);
73     }
74 }
75
76
77 /**
78  *@brief Function to move cursor to desired position on LCD
79  *@param row Row Cursor of the LCD
80  *@param col Column Cursor of the LCD
81  *@return void
82  */
83 void lcd_setCursor(uint8_t row, uint8_t col)
84 {

```



So, let us go and evaluate the LCD write function. Here is the LCD write function here.

(Refer Slide Time: 32:04)

```
39 }
40
41 /**
42  *@brief Function to write data/command to LCD
43  *@param value Value to be written to LED
44  *@param mode Mode -> Command or Data
45  *@return void
46  */
47 void lcd_write(uint8_t value, uint8_t mode)
48 {
49     if(mode == CMD)
50         LCD_OUT &= ~RS; // Set RS -> LOW for Command mode
51     else
52         LCD_OUT |= RS; // Set RS -> HIGH for Data mode
53
54     LCD_OUT = ((LCD_OUT & 0x0F) | (value & 0xF0)); // Write high nibble
55     pulseEN();
56     delay(1);
57 }
```

We know any character will be less than (0-255) 2^8 value in its ASCII notation.



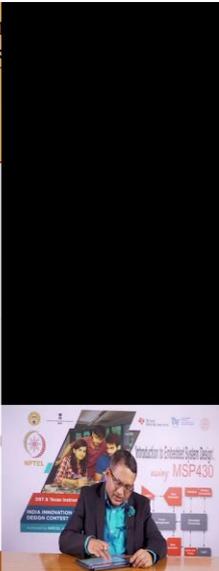
```
43  *@param value Value to be written to LED
44  *@param mode Mode -> Command or Data
45  *@return void
46  */
47 void lcd_write(uint8_t value, uint8_t mode)
48 {
49     if(mode == CMD)
50         LCD_OUT &= ~RS; // Set RS -> LOW for Command mode
51     else
52         LCD_OUT |= RS; // Set RS -> HIGH for Data mode
53
54     LCD_OUT = ((LCD_OUT & 0x0F) | (value & 0xF0)); // Write high nibble
55     pulseEN();
56     delay(1);
57
58     LCD_OUT = ((LCD_OUT & 0x0F) | ((value << 4) & 0xF0)); // Write low nibble
59     pulseEN();
60     delay(1);
61 }
```

We know any character will be less than (0-255) 2^8 value in its ASCII notation.



```
44  *@param mode Mode -> Command or Data
45  *@return void
46  */
47 void lcd_write(uint8_t value, uint8_t mode)
48 {
49     if(mode == CMD)
50         LCD_OUT &= ~RS; // Set RS -> LOW for Command mode
51     else
52         LCD_OUT |= RS; // Set RS -> HIGH for Data mode
53
54     LCD_OUT = ((LCD_OUT & 0x0F) | (value & 0xF0)); // Write high nibble
55     pulseEN();
56     delay(1);
57
58     LCD_OUT = ((LCD_OUT & 0x0F) | ((value << 4) & 0xF0)); // Write low nibble
59     pulseEN();
60     delay(1);
61 }
```

We know any character will be less than (0-255) 2^8 value in its ASCII notation.

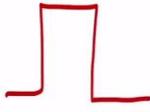


```

/**
 * @brief Function to pulse EN pin after data is written
 * @return void
 */
void pulseEN(void)
{
    LCD_OUT |= EN;
    delay(1);
    LCD_OUT &= ~EN;
    delay(1);
}

/**
 * @brief Function to write data/command to LCD
 * @param value Value to be written to LED
 * @param mode Mode -> Command or Data
 * @return void
 */

```




So, LCD write requires 2 values. One is the value and the other is what is the mode meaning in what mode should these values be sent to the LCD. So, this mode can be either command or it can be data and whatever value is there it will be set. But this value will be 8 bits. But as we know we are not able to send 8 bits of data from the controller to the LCD. We are sending 4 bits at a time.

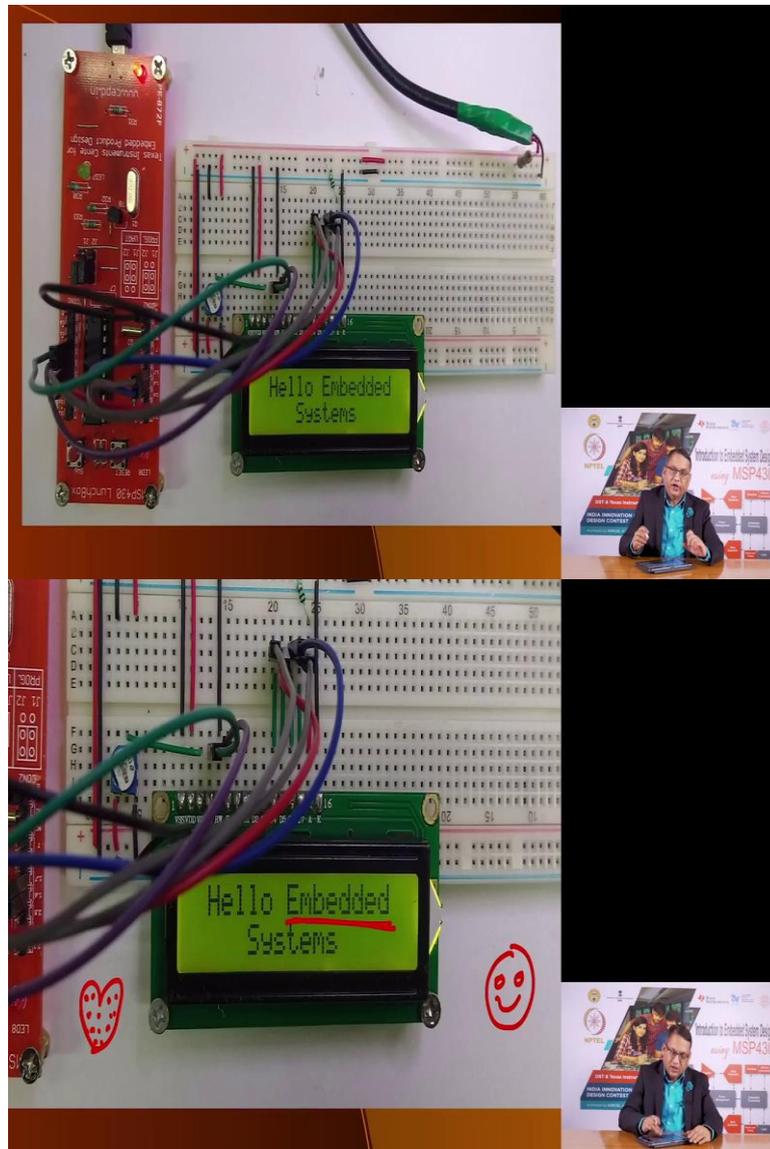
So, this LCD write function will actually split the 8 bits of data that you get here and split it into nibbles and send one at a time. Let us see how it does that. So, first of all it says that it going to generate a low command on RS for command mode. So, it is going to generate a pulse like this, making this using this command. It makes RS 0 and using this makes RS 1.

Then it is going to output the 2 values which is there in the value here. You are going to take the upper nibble by ending it with F0 and the original LCD out value you are retaining the lower values but the upper values you have made 0 by ending it with 0F and that value is being odd with this information. And then you provide this value onto the port 1 pins that is LCD out. Then you pulse the EN pin which makes the LCD controller receive this information. Then you delay for some time.

Now, you are still left with sending the lower nibble. The value in the lower nibble is shifted to the upper nibbles and with F0 so that the other bits are 0 and same function you operate here and create a value to be send to port 1 and once you send it to the port 1, you pulse the signal on EN and then you delay and you go back and what does pulse EN does? It does nothing but it creates EN equal to 1 and then it makes 0.

So, these are the sequences of operations that LCD needs to, the controller needs to perform so as to send information to the LCD. So, I recommend that you download this code, build and compile and download it into your MSP430 lunch box.

(Refer Slide Time: 34:45)



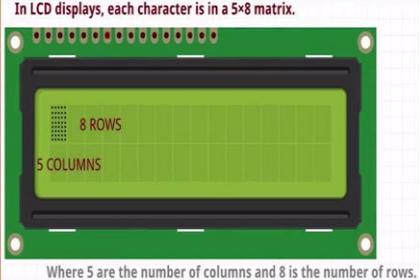
Make the connections to the LCD as discussed and this is what it would appear that you have made appropriate connections to the LCD and when you run the program you will see that the LCD prints this message. So, this is one part. Now the LCD is capable of creating custom characters also. These are all built in ASCII characters that it is able to print. But what if you wanted to print a smiley?

Something like this or a heart. Something like this. It is possible to print the heart like this by creating a pixel character and store this information in the RAM that the LCD has and then invoke them so that you can print these characters.

(Refer Slide Time: 35:32)

Custom Display on the LCD

In LCD displays, each character is in a 5x8 matrix.



Where 5 are the number of columns and 8 is the number of rows.

CG-RAM is the main component in making custom characters. It stores the custom characters once declared in the code.



So, the second part of this code we are going to show, how we can create custom characters, store them in the memory of the LCD and then invoke them and tell the LCD controller to display them.

(Refer Slide Time: 35:57)

- CG-RAM size is 64 byte providing the option of creating eight characters at a time. Each character is eight byte in size.
- CG-RAM address starts from 0x40 (Hexadecimal) or 64 in decimal.
- We can generate custom characters at these addresses.
- Once we generate our characters at these addresses, now we can print them on the LCD at any time by just sending simple commands to the LCD as shown on the right.



The information can be stored in a RAM that is available on the LCD that is called custom graphics RAM and that information that size is you are getting 64 bytes for each character you are getting 8 bytes.

(Refer Slide Time: 36:07)

CG-RAM Characters	CG-RAM Address (Hexadecimal)	Commands to display Generated Characters
1 st Character	0x40	0
2 nd Character	0x48	1
3 rd Character	0x56	2
4 th Character	0x64	3
5 th Character	0x72	4
6 th Character	0x80	5
7 th Character	0x88	6
8 th Character	0x96	7

As shown above, you can see starting addresses for each character and their corresponding printing commands.




CG-RAM Characters	CG-RAM Address (Hexadecimal)	Commands to display Generated Characters
1 st Character	0x40	0
2 nd Character	0x48	1
3 rd Character	0x56	2
4 th Character	0x64	3
5 th Character	0x72	4
6 th Character	0x80	5
7 th Character	0x88	6
8 th Character	0x96	7

In the table above, you can see starting addresses for each character with their printing commands.

The first character is generated at address 0x40 to 0x47 and is printed on LCD by just sending simple command 0 to the LCD. The second character is generated at address 0x48 to 0x55 and is printed by sending 1 to LCD.




Out of these 8 bytes as you see here you can have 8 characters. Each character requires 8 bytes. Out of these 8 bytes you are ignoring 3 bits because your character is 5 columns and 8 rows. So, you can specify into this 5 by 8 or you can think of it as a 8 by 8 RAM which of the bits have to be 1 and once you write that information you can then invoke them later on and the first character is stored at address 40 and its address is 0. The second character is stored in these are RAM addresses. 40, 48 as you see they are all 8 bytes apart.

So, you can write information into these RAM locations and once you have written you can invoke them by sending information to the LCD that you want to display the characters stored at address 0 or 1 or 2 and so on.

(Refer Slide Time: 37:07)

Display letter 'b' on the LCD

Starting Address of CG-RAM

01000000

4 0

Decimal = 64

Byte Address	C1	C2	C3	C4	C5	Pattern For 'b' is:
0 0 0 0	1	0	0	0	0	Row1 0x10
0 0 0 1	1	0	0	0	0	Row2 0x10
0 0 1 0	1	0	1	1	0	Row3 0x16
0 0 1 1	1	1	0	0	1	Row4 0x19
0 1 0 0	1	0	0	0	1	Row5 0x11
0 1 0 1	1	0	0	0	1	Row6 0x11
0 1 1 0	1	1	1	1	0	Row7 0x1E
0 1 1 1	0	0	0	0	0	Row8 <-Cursor Position

Here, in the 8 bit data,

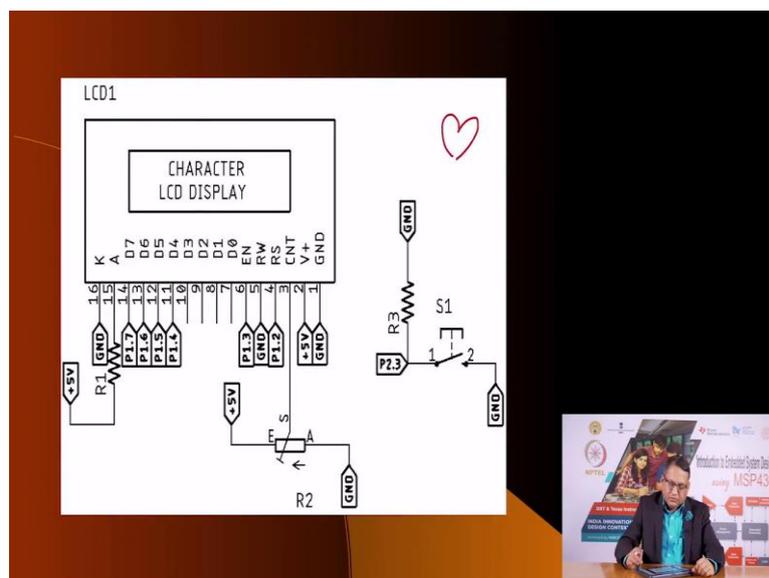
- First 3 bits are treated as Don't cares.
- Rest 5 bits are loaded at the address

- Send address where you want to create character. Now create your character at this address.
- Send the 'b' character array values defined above one by one to the data register of LCD.
- To print the generated character at 0x40.
- Send command 0 to command register of LCD.



So, I strongly recommend that you go through this code. It is not very different from what we have discussed earlier.

(Refer Slide Time: 37:11)



The only addition is that we have stored custom characters. In fact, we have stored a heart. We have stored a heart like this in the CG RAM and you can invoke it and display this into your display.

(Refer Slide Time: 37:31)

The 'Hello LCD With Custom Character' Code

```
#include <msp430.h>
#include <inttypes.h>
1
2
3 #define CMD 0
4 #define DATA 1
5
6 #define LCD_OUT P1OUT
7 #define LCD_DIR P1DIR
8 #define D4 BIT4
9 #define D5 BIT5
10 #define D6 BIT6
11 #define D7 BIT7
12 #define RS BIT2
13 #define DN BIT3
14
15
16 #define SW BIT3
17
18 #define LCD_SETGRAMADDR 0x40
19
20 //Heart character
21 uint8_t heart[8] = {
22     0x00,
23     0x04,
24     0x0F,
25     0x1F,
26     0x1F,
27     0x0F,
28     0x04,
29     0x00
30 };
31
```

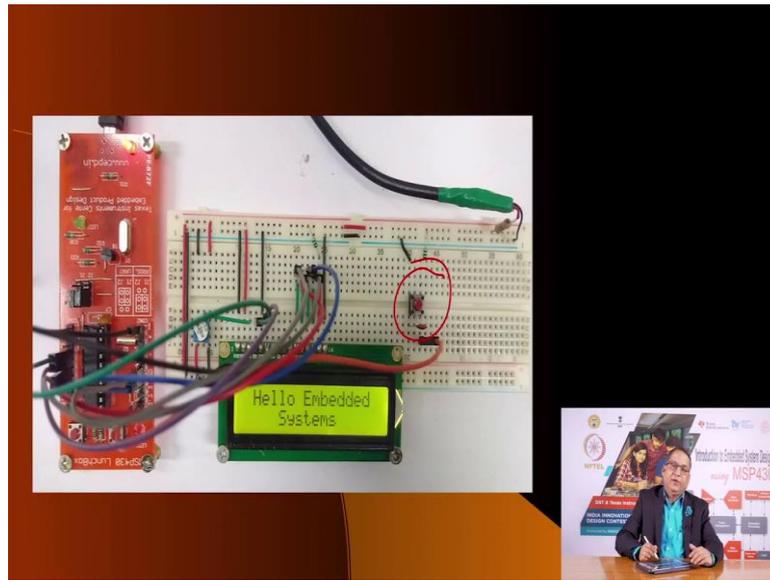


```
30 //
31 /**
32  *Brief Delay function for producing delay in 0.1 ms increments
33  *@param t milliseconds to be delayed
34  *@return void
35  **/
36 void delay(uint16_t t)
37 {
38     uint16_t i;
39     for(i=t; i > 0; i--)
40         __delay_cycles(100);
41 }
42
43 /**
44  *Brief Function to pulse EN pin after data is written
45  *@return void
46  **/
47 void pulseEN(void)
48 {
49     LCD_OUT |= EN;
50     delay(1);
51     LCD_OUT &= ~EN;
52     delay(1);
53 }
54
```



So, I strongly recommend that you go through this. The codes are very well documented. Reading it will tell you what we are doing.

(Refer Slide Time: 37:43)



And once you connect the connections are not very different. Other than the LCD you only need to connect a switch here. So when you press the switch, when you download the code you will see the same hello embedded systems, when you press the switch you will see that 2 hearts appear around before and after the systems. When you press the switch again they will disappear and so on and so forth.

So, I strongly recommend that you go through that code. That code is not very difficult. That code is not very different from the earlier code. The only addition is to add custom characters and the code is quite readable. I recommend that you go through it and use that template for creating your own custom characters and use it whenever your application demands so. So, with this we are at the end of this lecture where we have illustrated how we can connect character LCDs to your projects using MSP430 and we will see how we use it in our future projects. Thank you. See you.