Introduction to Embedded System Design
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Lecture 17
Physical Interfacing - 3

Hello, welcome back. We are going to continue our discussion on how to connect LEDs in various ways. LEDs and RGB LEDs and even 7 segment displays. So, let us begin.

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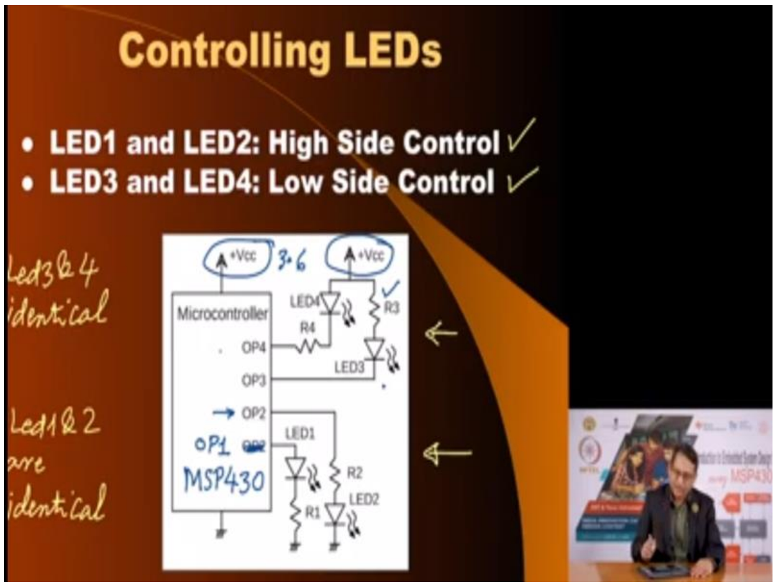

Now here if you look at this diagram that I have drawn. Here, my microcontroller is MSP430, for example, and I have shown that I have collected 4 LEDs in 4 different ways. This is to ensure that you understand that LEDs can be seen as binary devices. Binary output devices which means either the LED is on or off. There is another way to control LEDs where I would like to change the intensity of an LED, which will consider in a latter part but here, let us see how we can. So, if you see this is wrong, this is output OP1.

In the output 1, I have connected the LED with a resistor R1. At the output pin number 2, I have connected the resistor first and another LED. On output 3, I have now used a different configuration. I collected the LED first and then the resistor R3 and for output 4, I have connected the resistor 4 first the pin of the microcontroller and then the LED. Now, the question is how different. Are they all same or are they very different? Well, the answer is that LED1 and LED2 are identical.

These are LED1 and LED1 and 2 are identical in connection and LED3 and 4 are identical too and they are different from LED1 and 2. How? LED1 and 2 would light up when the output OP1 or OP2 is high. That is logic 1. On the other hand, LED3 and 4 would light up when the output of these pins that is OP3 and 4 is logic 0 and so these 2 LEDs will be called as active high meaning they are lighting up when the output is logic 1 and these 2 LEDs will be called active low outputs.

They are lighting when the output is 0. Also, we are controlling the high side of the voltage for LED1 & 2. That is why we have written high side control and for LED3, we are controlling the lower potential of these LEDs. So, we call it low side control and now let us see what should be the value of resistor R1 and R2 because R1 and R2 will be same value because the 2 configurations are same whereas R3 and R4 are also same but they might be different from R1 and R2.

How should you select the value of these resistors? That is an important point. So, first of all for that we have to consider what is the voltage drop across the LED. Now, most of the time when I asked this question to beginner students, they say the voltage drop across LED is 0.7 volts. For some reason, they think that the LED is also a normal silicon diode but that is not the case.

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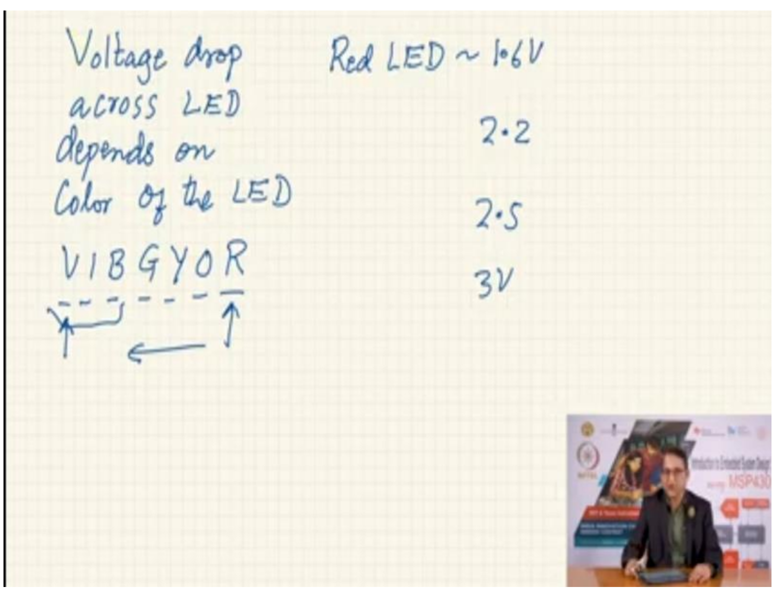

In fact, the voltage drop across LED, voltage drop across and here I mean in the forward region across LED depends on colour of the LED and we have the entire range of LEDs available which emit different colours and they might be VIBGYOR. Your you might have red coloured LED, you may have orange, yellow, green, blue, indigo and violet. So, it turns out that if you have a red LED, which has the smallest energy. This has the smallest voltage drop across it whereas the violet or blue in this range as you go to these colours, the voltage drop across the LED increases because the bandgap required to emit these colours is more and therefore the voltage drop is more.

Typically, a red LED has a, red LED requires about 1.6 volts and as you go towards blue, the voltage goes from 1.6 to maybe 2.2 for orange and yellow maybe for green about 2.5 volts and for blue roughly 3 volts and so you must consider this when you are designing a system to control these LEDs. Let us go back.

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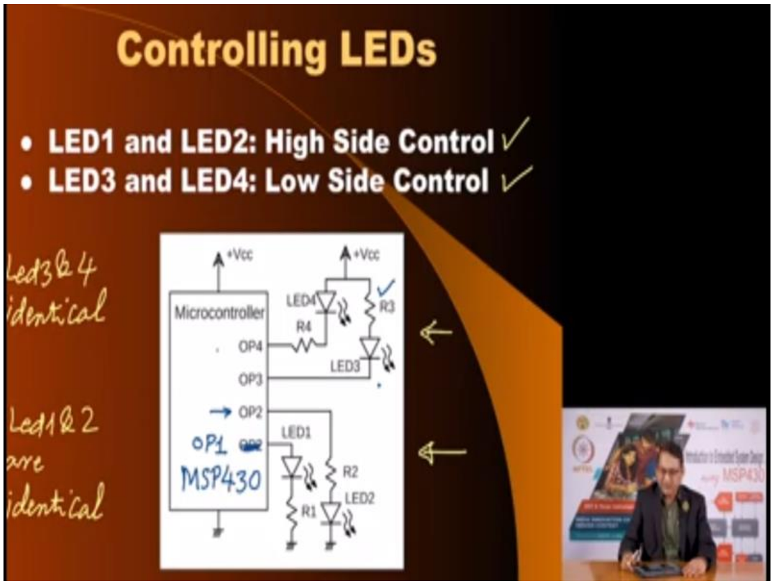

Now, here we see we have the VCC here. Now, if the VCC itself is 3 volts then it may be difficult to control a blue LED but MSP430 can, the supply voltage can go up to 3.6 volts. So, we can power this with say 3.6 volts and we will be able to connect blue LEDs also. However, in the calculations we must use a forward voltage drop across an LED appropriately so that we can estimate the value of the resistors.

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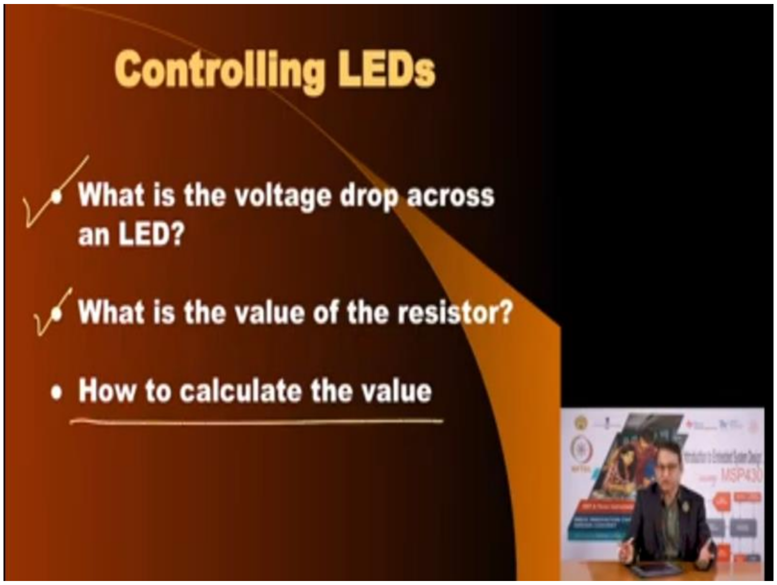

So, what all we need to know? We need to know what is the voltage drop across the LED. Secondly, to control these LEDs we need how much what should be the value of the resistors and now the question is how to calculate. Now the 2 calculations for the 2 setups are different and let us go through those calculations.

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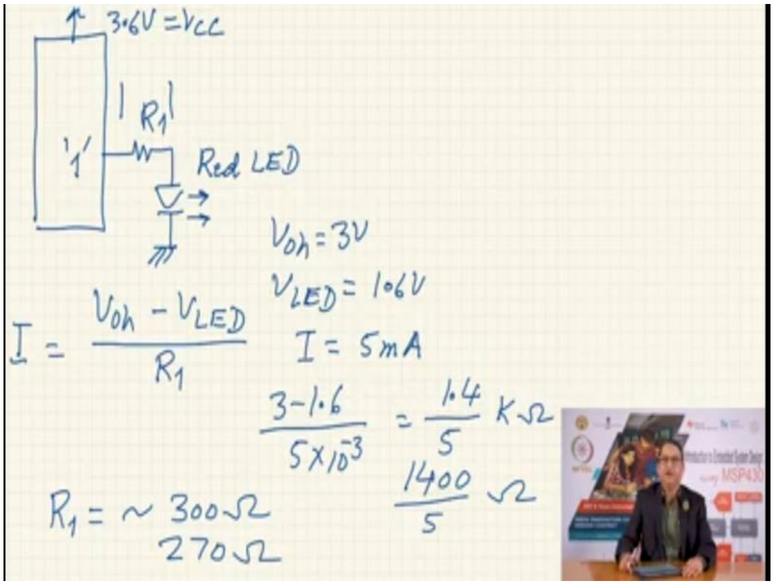

In the case of a high side control meaning I have the LED set up so that they will light up when the output voltage is high here in this case. So, let us say this is R1 and let us say this is some LED. Let us say this is R red LED and I do not have to use exact values. I will use symbolic values here. So, when I turn the pin to logic 1, the voltage of this will be V OH. The voltage across the LED will be V LED. You can find out from the data sheet that what is the voltage drop across a red LED. This difference is the voltage across R1 and therefore the current through this will be I is equal to Voh minus V LED divided by R1.

Now, suppose you want 5 milli amperes of current. Let us take some numbers. Let us say V oh is 3 volt. If your VCC is say 3.6 volts, this is equal to VCC and let us say V oh is V oh is equal to 3 volt. The exact value you should find out from the data sheet. Let us also assume that V LED for a red LED is say 1.6 volts and let us say we want the current to be equal to 5 milli ampere and therefore this becomes 3 minus 1.6 upon 5 into 10 to the power minus 3 amperes. This is 1.4 divided by 5 kilo ohm.

So, this is 1400 divided by 5 ohm and this is roughly R1 will be equal to roughly 300 ohm and you can safely use a standard value of 270 ohms in this case to allow about 5 milli amperes of current through the LED.

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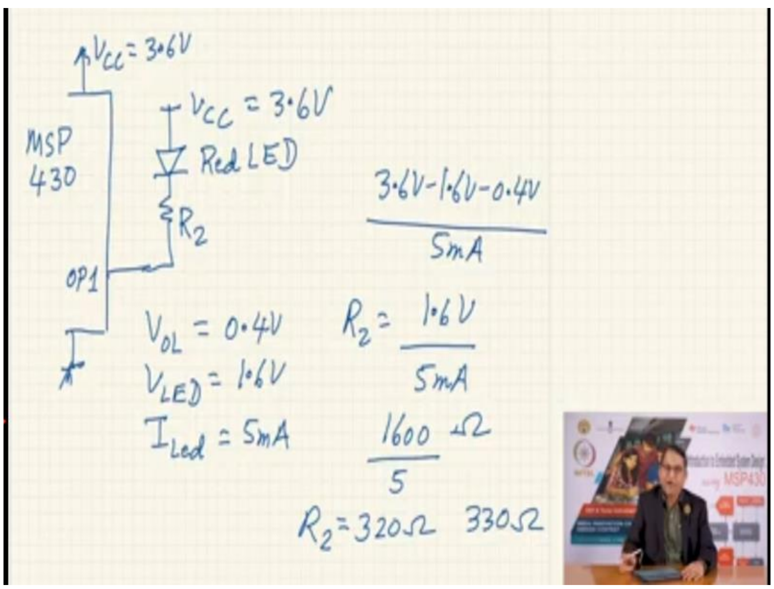

On the other hand, if you want to control the LED in the low side control method, then your configuration will change and it will be here is my microcontroller MSP430. My VCC is set to 3.6 volts. Here is my ground and here is my output pin say output 1 and I have connected the LED in the low side control. Here is my VCC and this is now say R2 and this is still red LED.

As I mentioned earlier the LED will be turned on when the output 1 is set to logic 0 but when the output is set to logic 0 the output voltage is not 0 volts. In fact, the maximum value of voltage that you will get will be VOL and we can go to the data sheet to find out the value but let us assume that VOL, this is 0.4 volts. We will still assume that V LED for this red LED is equal to 1.6 volts. My VCC is here 3.6 volts. The V LED 1.6 volts. The VCC is 3.6 volts and we want to estimate the value of R2 from the current that we desire through the LED.

Let us say the current we want through the LED is also 5 milli ampere. Now, the calculation will be 3.6 volts minus V LED, which is 1.6 volt minus the V OL output which in this case is 0.4 volts divided by 5 milli ampere. Therefore, the resistor R2 is equal to 1.6 volt because this is 2 minus 0.4 1.6 divided by 5 milliampere and now this is about 1600 ohm divided by 5.

So, this would be roughly 320 ohm and so you can R2 is 320, ohms and you can use a standard value of 330 ohms for allowing about 5 milli amperes of current through this configuration. Now, what if you wanted to increase the current through the LED through either of these configurations whether low side or high side. Let us see that but before that let us see other than the LEDs, individual LEDs what all can be controlled.

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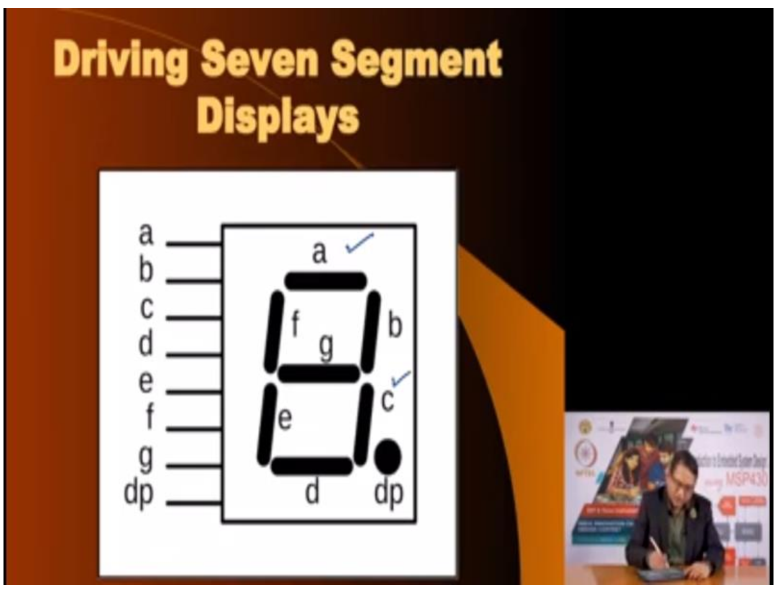

And in this case, here is an example of a 7-segment display. A 7-segment display is actually a misnomer because there are 8 segments as you see here. You have a b c d e f g and a decimal point. So, really there are 8 LEDs in a 7-segment display. Now, these 7 segments displays come in 2 varieties.

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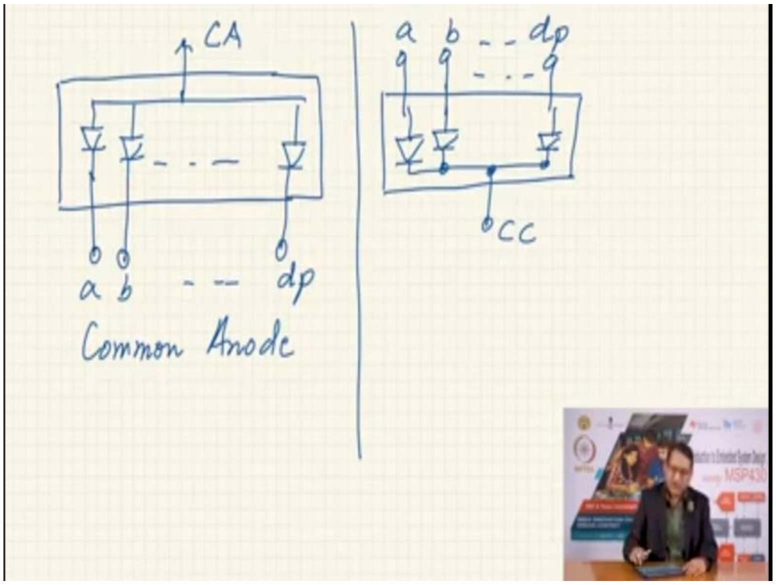

One is called common anode which means this display internally will have 8 LEDs and the anodes will be connected together. So, you would have 8 LEDs. This is the so this terminal will be called common anode and you would have a b so on and so forth up to the dp and the other so this is common anode.

The other type of LEDs, 7 segment displays are called common cathode where what do you have is that the cathodes of the LEDs are all connected together like this and this terminal will be called CC that is Common Cathode and here are the actual inputs. So, this is your a, this is your b and so on and this is your dp that is decimal point. Now, how can we connect these 7 segments displays to microcontrollers. Let us look at this game.

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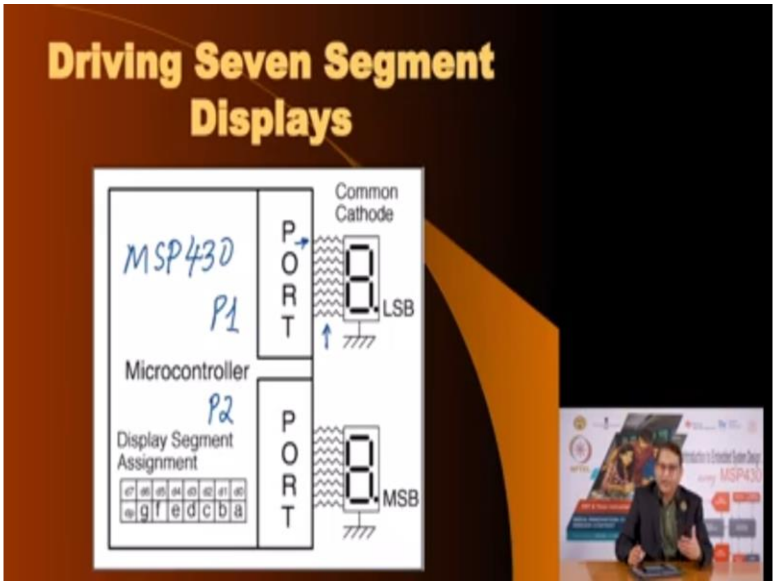

So, I have shown here that a microcontroller in this case, let us say we are talking of MSP430 that we have 2 ports. This is port 1 and this is port 2. Each port has 8 outputs and we have used common cathode LED here and we have used 8 resistors and how to calculate the value of the resistors here because here common cathode, the common point is grounded. That means what sort of control will you be exercising. This will be high side control that is when an individual port pin here is set to 1, it will turn that led on. If you want to turn a LED off, a segment off, that port pins will have to be set to 0. The value of the resistor will be calculated in the same way as this calculation.

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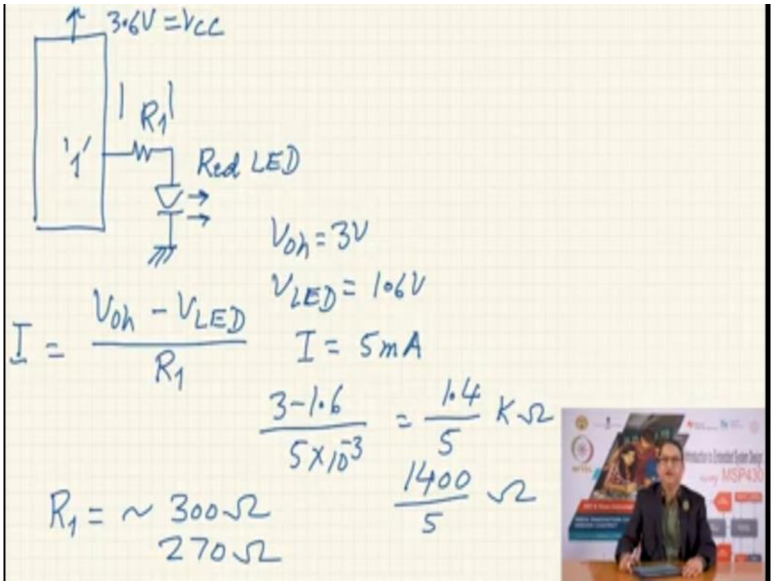

This calculation why because the cathodes are of each of these LEDs are grounded. So, I do not have to repeat that discussion here. Another method to connect these LEDs instead of common cathode LEDs you can have well here is another variation to that. Now, you may wonder that instead of connecting using 8 resistors can you connect use a single resistor like this.

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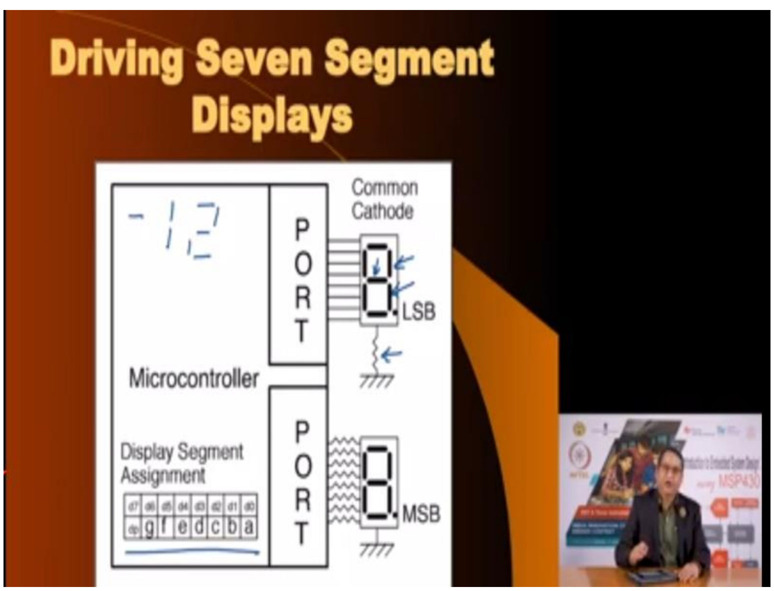

And this way you can save 7 resistors. Well, this may seem like a good deal but this will give you unequal intensity of the LEDs. Now, imagine that you want to turn only 1 LED out of these. Maybe you want to just display a bar. So, this particular LED you want to turn on. So, the corresponding pin will be set to 1. The rest of the pins output pins will be 0 which means this resistor, the current that can flow through this configuration is going to all that current is going to flow through 1 LED.

So, it will grow bright. Now, imagine that you want to display 1 which means you want to turn this and this led on. Now, this same current will be shared by 2 LEDs. So, the LED intensity will become half. Similarly, if you display dash, you will get certain intensity. When you display 1, you will find that the intensity has become half. If you display 2 which will look like this. How many LEDs have you turned on? 1 2 3 4 5 LEDs.

That means the current through each LED becomes 0.2 times the maximum current so each LED will be roughly lighting up with one fifth the intensity and so although this appears to be economical method because it uses only one resistor. What you will end up having is that as you change the display numbers the intensity of that display would vary and therefore it is not very recommended to use this configuration and so one should use a resistor on all the pins as mentioned yet.

Also, important to know is you have to know which segment is connected to which pin of the port because in the software this will be used so that you can display numbers or any other symbols on this display and we will cover that when we do an exercise to control 7 segment displays using MSP430. Right now, we are only looking at the electrical aspects, the circuit aspects of controlling 7 segment displays.

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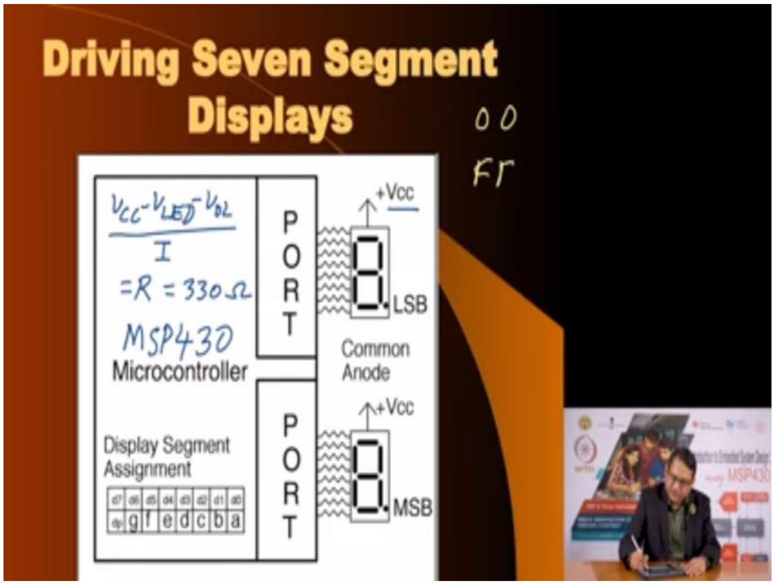

The second method would be to use common anode LEDs. Now, here the anodes are common. Therefore, it is connected to VCC and the cathodes are the segments which is a b up to dp. They are connected to port pins. This is your MSP430 microcontroller and here the calculations will be same as we saw. This is low side control and so the calculations would be what we did is equal to the resistor value will be to VCC minus VLED minus VOL divided by the current that you require.

This is the value of the resistor and you would have all these 8 resistors equal to this value as we estimated in the last calculations for 5 milli amperes of current and read display 7 segment, display the value of resistor. Each one of these will be, I think we got a value of let me go back and check. This was 330 ohms.

So, in this case, you can connect all these 330 ohm resistors, 8 of them like this and here I have shown that we have connected 2 digits so we can have we can just use this to display numbers from 00 to 99 or if you want to display hexadecimal numbers, you will be able to display from 00 all the way up to FF which means you can display a total of 256 values on these 2 sets of displays.

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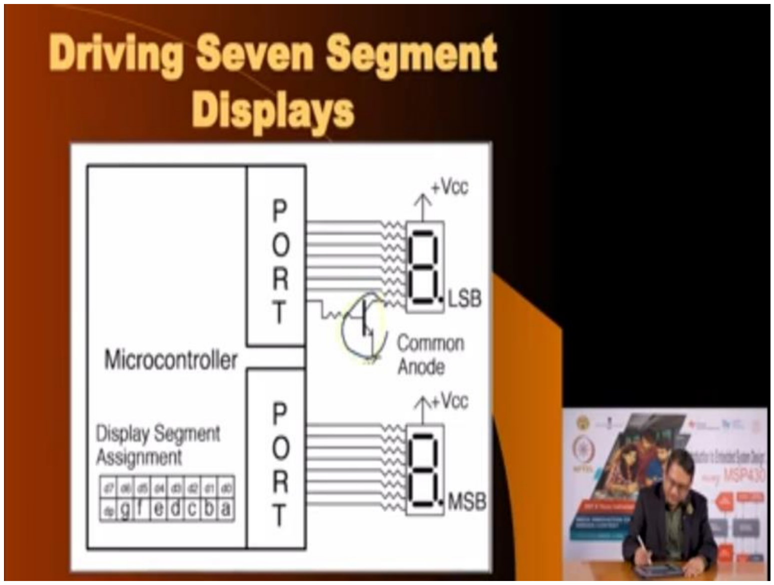

Let us see how what else we can do. Now, imagine that we want to increase the current through each of the these LEDs that is you want to turn these you want to drive these LEDs more brightly. Then you would require a transistor here as I have shown and we are going to take this discussion forward in the next few slides.

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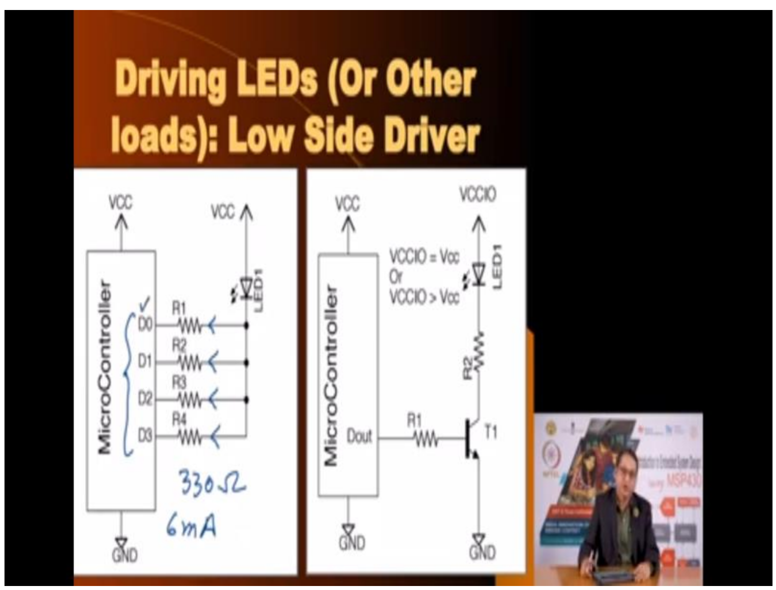

Now, here is what I meant when I mentioned that what if you wanted to increase the intensity of the LED. Now, each of the port pins of the microcontroller has only a limited amount of capability. As we have seen for MSP430, the maximum current that each of the pins can provide you is about 6 milli ampere and so what if you wanted to drive the LED with say 20 milli amperes of current. There are 2 ways. This is the first method. If you have multiple pins available, spare pins, then you can connect 4 resistors to drive a single LED and if you want 20 milli amperes, you can share it each of these to be 5 milli amperes and so together you can drive 20 milli amperes through LED1.

Of course, it requires 4 resistors and the value of the resistor will be calculated assuming that you want 5 milli ampere and so I think this is if we go back here we can see the calculation here. Well no, this the configuration is this one and so here we have 330 ohm. So, if you want the low side control of the LEDs and more current through the LED of say 20 milli amperes, you allow 5 milli amperes each and the resistors. All resistor will be 330 ohm. Now, with this you can turn the LED on by making all these bits set to 0 and you want to turn the LED off then all these bits will be set to 1.

Now, this configuration also has an interesting side effect that instead of all the output pins turned to logic 1 or logic 0 will turn the LED completely on or completely off. What if you turned only D0 equal to 0 and D1 and D 2 and D 3 are set to logic 1, you will see that the intensity of LED will go from minimum to maximum and you can actually control the intensity also not just in a binary way 0 and 1, LED on or LED off. You can have various levels of intensity in the LED. The other method of increasing the current through the LED is list shown in the right side of this diagram. Here we have used the npn transistor. Here to control the current through the LED why because since the microcontroller pin cannot provide say 20 milli amperes of current we will choose an external transistor and we have to select the transistor appropriately.

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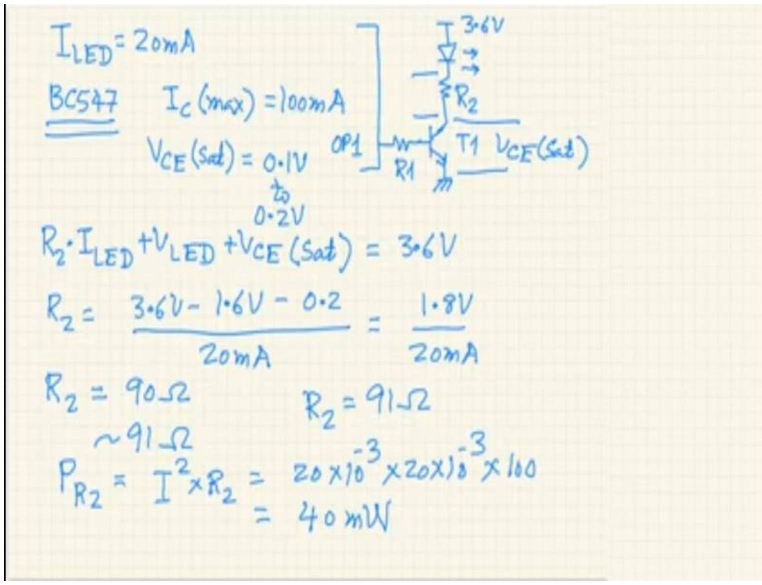

So, let us continue with this firm example. Our requirement is that the LED current ILED is to be 20 milli amperes. Our microcontroller cannot provide 20 milli amperes of current. So, we have to connect an external circuit which we saw in the previous slide. Let me redraw it here for easy reference. Here is our microcontroller. Here is the output pin. Let us call it OP1. It is connected to a resistor which we label as R1. Here is the npn transistor. We have to choose a low side switch and so we choose a transistor as we discussed earlier. The supply voltage is 3.6 volts. Here is our red LED.

The choice of LED is important because knowing what led we are going to drive will allow us to know what is the voltage drop across the LED and here is our current limiting resistor through the LED. We call it R2 and this transistor is T1. Now, we can choose any transistor npn transistor that will offer maximum collector current which is much more than the load current. The load current in this case is the current through the LED which we have decided to be 20 milli amperes. So, as long as the transistor is able to handle much more than 20 milli amperes, any transistor should be fine.

Now, how much is much more? Let us say we use commonly available transistor, which we use in our undergraduate electronics laboratories BC 547. Then we know from the data sheet, of course that the maximum collector current IC max for a BC 547 is 100 milli amperes and so such a transistor would be quite suitable.

You could of course choose another transistor which has collector current more than this. Apart from the maximum collector current that the transistor offers, we also have to look at the data sheet of the transistor to find out what is the saturation voltage the collector emitter saturation voltage VCE because that is going to come in this loop in the calculations for calculating the value of R2 and subsequently for the calculation of value of R1.

For BC 547, the saturation voltage is typically in the range of 0.1 volts to 0.2 volts. So, now we have to calculate the value of R2. So, R2 into the collector current that is ILED that is this volts plus VLED, the voltage drop across the LED plus VCE SAT as we see here. Here is the VCE SAT, VCE saturation. All the sum of these 3 elements will be equal to the supply voltage, which is 3.6 volts. Now, what is the voltage drop across LED? That of course depends on the colour of the LED and if we choose red LED, typically the voltage is 1.6 volts.

So, we are going to use that as a reference of course for particular LED that you use you must find out the value of the forward voltage drop across the LED for the given current. What is that voltage, you must plug it into this equation. So, let us solve this equation for the value of R2. So, R2 is equal to 3.6 volts minus 1.6 volts for the voltage drop across the LED minus VCE SAT and let us choose this 0.2 volts as the saturation voltage for PC 547 divided by 20 milli amperes because that is our load current and so this becomes 1.8 volts divided by 20 milli ampere and this returns a value of R2 to be equal to 90 ohms.

Of course, 90 ohms may not be a standard resistor value. So, you must choose the nearest resistor value to 90 and I can tell you that the nearest value is 91 ohms, which is very close to what we actually need and so R2, the value of resistor R2 turns out to be 91 ohms. Now, having a value of resistor is important but also selecting an appropriate resistor which can dissipate the power is also important. In this case, we must find out what is the power dissipated by R2 so that we can choose resistor which can dissipate more power than that so that it operates in a safe region.

Now, here we can use the PR2 that is the power dissipated by R2. We can calculate using I square into R which in this case is 20 into 10 raised to power minus 3 milli amperes into 20 into 10 raised to power minus 3 into for sake of ease of calculation, let us plug the value of R2 to be 100 ohms and so this gives me a value of 40 milli watt. If you go through this calculation, this is what you would get, 40 milli watts of power and a typical 5 percent quarter watt resistor. Quarter watt resistor means 250 milli watts. That would be quite suitable to be used in this configuration.

So, we have seen that what equation to use to be able to calculate the value of the current limiting resistor with the LED. Now, if you want to change the value of the current from 20 milli amperes to say 100 milli amperes, you would still use the same approach but find out a suitable transistor to replace BC 547 which will be able to give you what you need. Which will be able to handle 100 milli amperes.

So, if you want to conduct 100 milli amperes through the LED, you must choose a transistor which is say, 200 or 500 milli amperes of maximum collector current and you can repeat go through these equations again, plug the values appropriately and estimate the value of R2. Now, that we have the value of R2, we must also estimate the value of the base resistor. What is the value of the base register here labelled as R1.

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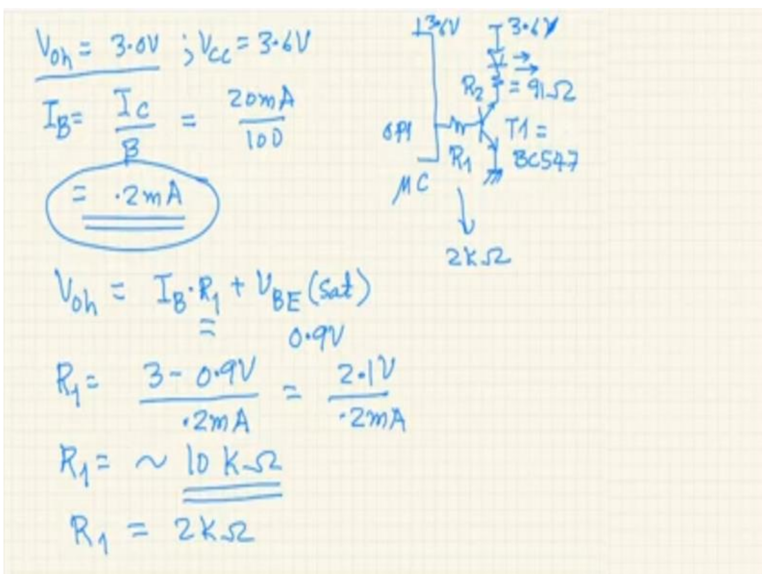

Let me take you through that equation and for ease of reference, let me redraw the circuit here. We have value of R1, our transistor T1 which in our case we have decided to be BC547. We have the supply voltage of 3.6 volts. Here is our red LED, which is going to be driven with 20 milli amperes and our value of R2, which we have estimated to be 91 ohm. Now, we are left to calculate the value of R1. Here is our microcontroller. Now, a microcontroller will turn the LED on when the output is logic 1. So OP1, when OP1 is 1, it will turn the LED on. Now when the output of a micro controller is set to 1, it means it necessarily is logic 1, but it does not mean that it will have the same voltage as 3.6 volt.

If it is also driven with a supply voltage of 3.6 volts, it is not necessary. So, what we have to find out from the data sheet of the microcontroller that what is VOH that is the output voltage. When the output is high, what is the VOH for that given microcontroller and in this case from the datasheet, let us assume that it is 3 volts. 3.0 volts for VCC equal to 3.6 volts. Now, we have to our collector current is 20 milli amperes. We must saturate the transistor in nominal base current that will be required to maintain 20 milli amperes of current. The value will be IB is equal to IC by beta that is the current gane of this transistor.

BC547 is available in many varieties and the simplest value that the simplest version of this transistor has a beta of about 100 and so our base current that we require will be 20 milli ampere divided by 100 which turns out to be 0.2 milli ampere. Now, to ensure that the transistor is driven strongly into the saturation region, we must provide base current which is much more than this value.

Now, how much is it how much more is much more? Well value of 2 or 3 times or even 5 times more than this current would be suitable. So, let us first estimate the value of the resistor R1 for current of 0.2 milli amperes and then we will reduce it by a factor say factor of 2 or 5 so that we are sure that transistor T1 is driven deep into the saturation.

So, for this VOH, that is the output high voltage is equal to the voltage drop across R1 which is IB into R1 plus VBE saturation because we are driving the transistor in saturation. For typically, the turn on voltage for a npn transistor, the base emitter voltage is 0.6 0.7 volts, but when you drive the transistor in saturation, this voltage is slightly higher and let us we can refer to the data sheet and it will tell you that the saturation base emitter saturation voltage is 0.9 volts.

So, we have to find out the value of R1. Therefore, R1 is equal to VOH which we have estimated to be 3 volts 3 minus 0.9 volts divided by base current which in this case is 0.2 milli ampere. So, the value of resistor, this calculation shows 2.1 volt divided by 0.2 milli ampere here and therefore the value of resistor turns out to be approximately 10 kilo ohm.

Now, this is the minimum current that you would require for the base current but to ensure that the transistor is driven strongly into saturation, we must provide a base current which is 2 or 3 times or even 5 times more than this base current and so it will reduce the value of this resistor by that much factor.

So, let us say that we want 5 times more base current so it will reduce the value of R1 by a factor of 5 and so R1 should actually be 10 kilo ohms divided by 5 2 kilo ohms. So, now we have the values of all the components that are required. R1 is 2 kilo ohm, R2 we have already estimated to be 91 ohms. Our transistor is BC 547 and we have chosen the red LED and, in this configuration, the micro controller will be able to drive 20 milli amperes of current through the LED and this is the process. This is the steps. These are the steps that you must take to be able to design all the components to arrive at the values of the components for a low side switch as we have illustrated. We will resume this discussion in the next lecture. Thank you.