Introduction to Embedded System Design
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Module 12
Lecture 40
Recap of Course Coverage and Project Demonstration from Concept to Final

Hello and welcome to this last session of this online course on introduction to embedded system design. I am your instructor Dhananjay Gadre. In this session, we are going to go through all the topics that we covered. And then terminate this session with a project description which will help you to visualize to plan and to implement a MSP430 or end for that matter any microcontroller based project. We have already seen some implementation issues, which will discuss shortly. So let us start. So let let us go through all the topics that we have covered from the first lecture as you know, we have covered more than 40 lectures.

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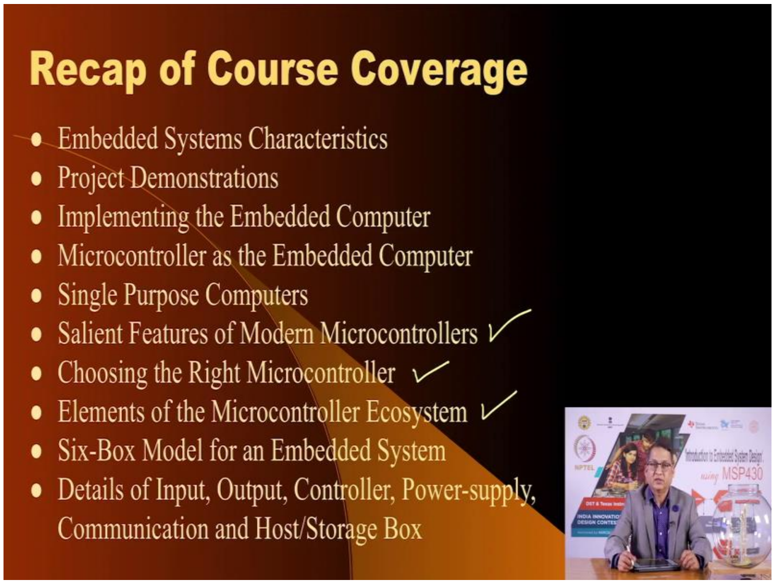

At the beginning we had a course on lecture on embedded system characteristics. We followed it up with a project demonstration. Then we saw how the embedded computer could be implemented many ways of implementing the embedded computers namely using a microprocessor or application specific controller and a single purpose computer. Then we saw how the microcontroller which is a very common and useful application specific device could be used for embedded system applications.

We also saw how we could implement embedded computer, embedded system using a single purpose computer here. Then we looked at the salient feature since our target was to use microcontrollers for implementing embedded systems. We started concentrating on various issues of microcontrollers.

We looked at the various salient features of modern microcontrollers. This was like a collection of all the good features of contemporary microcontrollers some or more may be available in the microcontroller that you may have chosen, then how do you choose the right controller for your application.

And we looked at not only the technical aspects but also other aspects which would impact the time to market and the economics of your project. After we did that, we looked at the ecosystem elements of a microcontroller. A micro controller requires four essential elements for survival for thriving in an embedded system application and they are power supply, reset, clock and the ability to download program from your development host into the memory of the microcontroller.

So, we looked at all those issues. Once we got done with this then we said, all right, let us now try to visualize an embedded system using a six box model in these six boxes we looked at the input boxes which has sensors and human input devices the controller box, then the output box with which the controller can interact with the outside world by controlling output devices such as motors and relays and LED’s and LCD’s and so on, then we looked at host and storage, what is meant by that for storing lot of data that you your application may be generating.

Then we looked at a box which allows you to which allows the embedded system to communicate with the outside world and last but not the least, we looked at the power supply block. Now, after having seen all these blocks.

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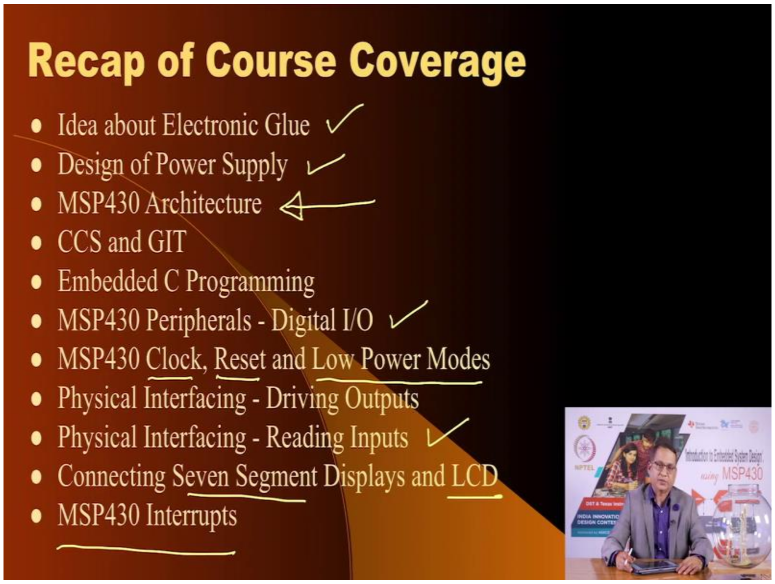

We also had some idea about what is this idea of electronic Glue, the electronic circuits which binds all these individual six boxes. We looked at those aspects briefly. Then we had a dedicated session on the design of a power supply. The design of power supply is very important. It is in my opinion a very neglected topic and I strongly recommend to you to focus more on understanding the design of power supplies. It will be a good skill to have. Once we were done with this, we started looking at the architecture of MSP430. We looked at the CPU, the register arrangement, the memory arrangement, the flash and so on and so forth.

After that, we had a session on how to install the code composer studio and the GIT software which allows you to maintain a repository of all the versions of programs that you would end up writing for a given application for a given project. And so having such a mechanism is very useful. After that, we had a session on embedded C programming, where we went through specifics of C programming language in the context of embedded applications.

Once we were done with that we started looking at the input output features of MSP430 microcontroller and we covered the digital input and output devices. We did some experiments to connect outside LED’s and switches and control those LEDs and switches. Then we looked at the specific aspects of the microcontroller ecosystem in the context of MSP430, namely the clocking mechanisms, what all the options of clocks you have on MSP430 and to recap here MSP430 as a very rich mechanism very rich source of clock sources, which could be manipulated and navigated to various CPU and other sub system blocks inside the MSP430 microcontroller.

There is the low frequency crystal oscillator. There is a very low frequency oscillator, which is RC based within the chip and then there is the DCO. And the three signals clock signals are namely A clock, the SM clock and the M clock. Then we looked at how many ways can be reset MSP430 microcontroller.

And the various low power modes that are available how you can enter those modes to conserve power and once having entered how do you exit those modes, so that you could resume the normal operation. When we were looking at the clock. We also saw how the clock frequency could be dynamically changed and this would allow an embedded application to conserve power in case you do not want to operate at a very high frequency because the current requirement at the time does not need you to you can reduce the clock frequency. So as to conserve power.

Then we started looking at some theoretical aspects as to how to drive output devices in the form of LED's and relays and motors and how to design the electronic circuit namely these are the aspects of electronic glue, how to design the drivers for for such devices? We also looked at various ways of reading inputs such as keypad or things like that switches. Then we saw specifically, how do we send information out from the microcontroller for human interaction namely through the seven segment displays and an LCD display.

And let me mention here that although we used character LCD, what is called as character in LCD, you can also try to experiment with graphics LCDs. There are many many graphics LCDs available. In fact, the graphics LCDs have the advantage that they conserve they consume much less power than the character LCD that the 16 cross 2 or 16 cross 4 character LCDs that are available in a market. These graphics LCDs also operate at 3 point 3 volts.

So that is a very natural, amalgamation or marriage between the MSP430 ecosystem and the LCD. Because you do not need to worry about having to get additional power supply and that is a very important could be an important consideration. Then we looked at the a very important aspect of embedded systems and microcontrollers. That is the interrupts.

We had several examples, how these interrupts could be utilized. So, as to perform the required tasks in a equitable fashion. When there are multiple things to be done. You cannot round robin and you cannot do polling and implement everything that you want. And so one of the methods of overcoming that obstacle is to use interrupts.

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Then we looked at another important feature of a microcontroller and embedded system, which is the mechanism to count time and count events. And for that we looked at the MSP430 timer in the compare and capture mode. Also how we could use the timer for PWM pulse width modulation. Although we also looked at the mechanism to generate pulse width modulation signal using a software code only without the requirement without the implication or without the intervention of a timer.

Then we looked at MSP430 ADC, how we could use the ADC for so many applications not only reading external analogy sensors, but also using it as a seed to feed into our lfsr based random number generators. We looked at various ADC interfacing issues, how to connect them to sensors. We looked at how to generate random numbers. And then how do we convert analogy voltages from the microcontroller. Although one of the methods is using PWM, but we looked at how additional mechanisms such as R2R ladder networks could be used for generating analogy voltages.

Then we looked we had a lecture on MSP430 serial communication. We looked at UART in great detail. We also brief briefly covered I square C and SPI. And then once we had done this

this basically covered a lot of physical issues of the modules that are available the functional blocks that are available inside a microcontroller.

Now, was the time was improve our C programming skills and we looked at we looked at mechanism to interface four digit seven segment display in a multiplex fashion how that would improve the performance of that display would be improved. If you went from sequential mechanism to refresh the display to an interrupt based display.

And then we had a lecture on how to plan for a project and here there was no specific dimension that the project has to be necessarily microcontroller based. It was a general discussion that you start with the visualization and then start with the objectives. Then you have a visualization and then you plan for the electronic parts and then the enclosures and how the wiring and have to has to be in place and documentation.

This was very general topic. It could be non-microcontroller based project also and then we looked at various methods of prototyping circuits. This would be very useful. If you are going to play with microcontrollers or any other circuit in future. And now once we have covered all these topics now is a time to sort of pull build all of them bring all of them together in one last, like they say the topping on the cake to integrate all these issues and illustrate it with the sample project based on MSP430.

That has been specifically implemented for this course. In the beginning, I showed you so many projects that has been that have been implemented in my lab. But this specific project that is here with me right next to me was implemented during the course of the recording of these videos by one of my students. And I am going to go through the entire process from visualization to from the objectives to visualization and how it was implemented in this lecture.

So instead of saying we want to implement a project and that project could be any project. We are saying we want to implement a MSP430 based project. This course has been about implementing an embedded system specifically using micro controllers and even more specifically using the MSP430 microcontroller. So, it makes a lot of sense to actually illustrate how you can plan test and implement a MSP430 microcontroller project. And so this rest of this lecture is about that.

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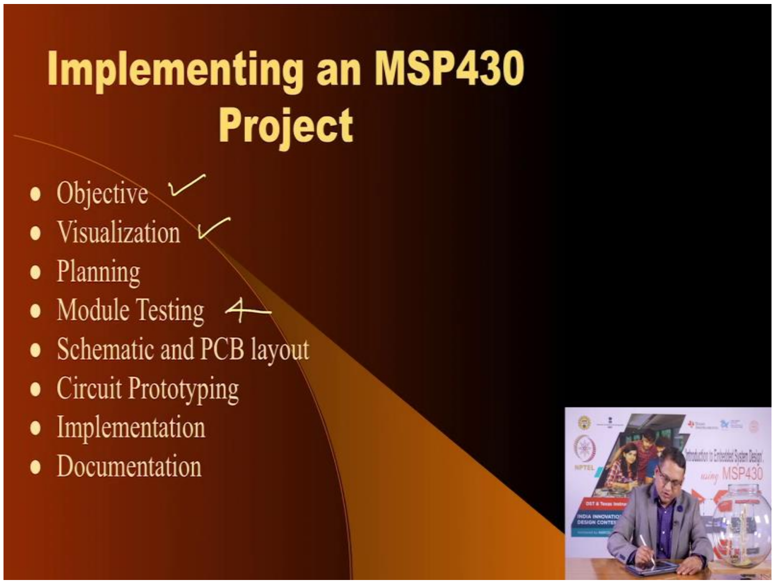

So, as as we discussed earlier in any in any such activity, you must start with an object. What do you want to implement unless you know specifically what do you want to implement, what can, how can you plan for it? And so objective setting down the objective in black and white is very important. Just discussing that you want to do this is not good enough.

Because when you actually come to implementing it you may forget what you actually wanted to implement or new ideas may creep in and that would make the implementation near impossible. And so not only thinking about the objective, but also to put it in black and white on a piece of paper is very important.

Once you have done that then you start visualizing that, all right, I want to implement this. What would it look like or what would I want it to look like that is very important. Then you start planning based on that visualization and obviously instead of implementing the project from scratch. You like to test some parts of it. So that you can ascertain the the feasibility of your project.

Because if at this point of time you find that some of the aspects that you visualized about or you put in in the objectives, if they are, you are not able to achieve then there is no point in proceeding with the project. Then you better resolve that issue. So, testing if you have access to certain modules, or you can test it in some way some aspects of your implementation. It is a good idea.

Once you are once you have done that testing which will give you a good confidence that till now the progress that you have made will lead to success. Then you can start planning on creating this schematic from the schematic to create a printed circuit board layout. If if you have the necessary ecosystem support to actually fabricate it. And in this case, we have actually done that, then you start prototyping. Meaning you put put all the components together, circuit fabrication and then you start implementing it, maybe download the code and test parts of it and then eventually once everything is done you document it.

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So I am going to show you that. So what happened was a couple of years ago. I was coming to my institute and I saw a roadside vendor selling these very nice glass fish fish tanks, fish bowls, and I was intrigued they look very interesting although the reason why they looked interesting is because he put coloured water in some of these bowls.

Anyway, I like them enough to take a picture. And so I wanted to see could I use this fishbowl to implement some project. I like to implement use electronics to create artistic projects. And so this sort of caught my imagination. And so I said, maybe I would put a circuit inside the fishbowl and see if I can power that circuit in some way which does not require me to drill hole into a glass bowl, which is very difficult.

But then, how do I provide power to the circuit inside the glass ball? One solution could be that I put a battery. But the moment I put a battery the problem is that once the battery is discharged, I had to replace it. If it is a chargeable battery then again, I had to take it out and charge it. But that is when an idea came to my mind.

Especially because in these in this age, we are talking about mobile phones, which have a wireless charging mechanism that you get certain mobile phones with a charging mat and you simply put your mobile phone on that mat and it gets charged. So I thought why not use such a mechanism into our system.

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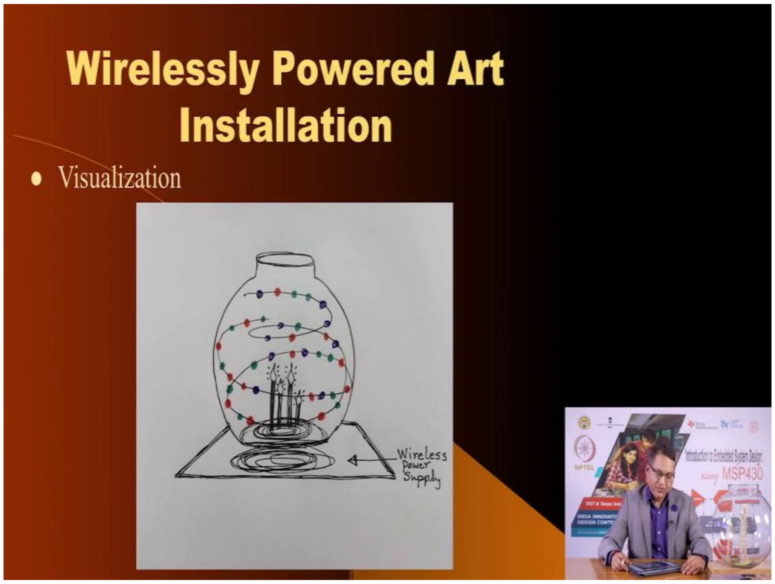

So this was the, so once I started thinking about it, I created a sketch. Which helped me visualize this project and if you see this sketch here and you see the implementation. I hope you agree that this is more or less than a hundred percent reproduction of the visualization. The actual implementation is almost hundred percent same as visualize. So what do we have here, that we a few candles inside and we have these string of LED’s. And the reason why I thought of this string of LED’s was also, because you may have seen in the in these last couple of years on traffic junctions, these kids sell balloons, which have beautiful LED strings strung on those balloons.

And in fact, I had bought some of them and I found that these the LED string was unique. It was unlike I had other LEDs strings that I had seen and in fact we the the LED string that is in used here is exactly from that source is actually two very thin wires and the LED is contained in some glue.

And these two wires are actually turning those LEDs on and off. And these are not addressable LEDs meaning I cannot individually turn each LED on or off or I can control it individually I can control all of them together. And so if I apply a voltage to the two wires, the LEDs will glow I can apply less and more voltage and then it will its intensity will change. So, that is how these LED balloons that I saw last year and the year before last. So I thought I should integrate that in the in this project. So this was the visualization and then we started with the implementation.

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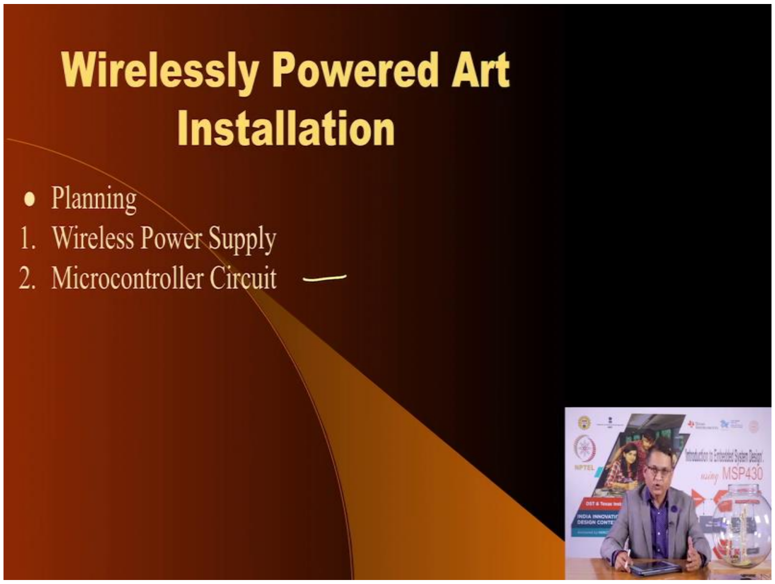

So the first part was since we, so the objective is now to create a wirelessly powered art installation. This could very well I could put it in my office here or I could take it home and set it out in my drawing room and it would be a great piece of art sort of a conversation starter if he guest come come home and so on and so forth.

So, question is there are two important parts in this one is how do I supply power to this micro controller circuit and then the micro controller circuit itself. What all do I want to do it. As you see in this visualization, there are four candles looking candle like structures. They are not candles they are implemented out of LEDs, but they behave like candles. So they need to flicker.

So, the part was that part was about this microcontroller circuit. So the first aspect was spent on the first activity was spent on getting the wireless power supply working. And for that what we did was we read through the available literature and then it turns out that the mechanism of wireless power transfer is the transmission of energy without wires. As is very obvious from the from the the term. And what it involves is that you apply a time varying electromagnetic field and launched it in some way over space and then on the other side, you must have some mechanism to receive this power to extract this from the space.

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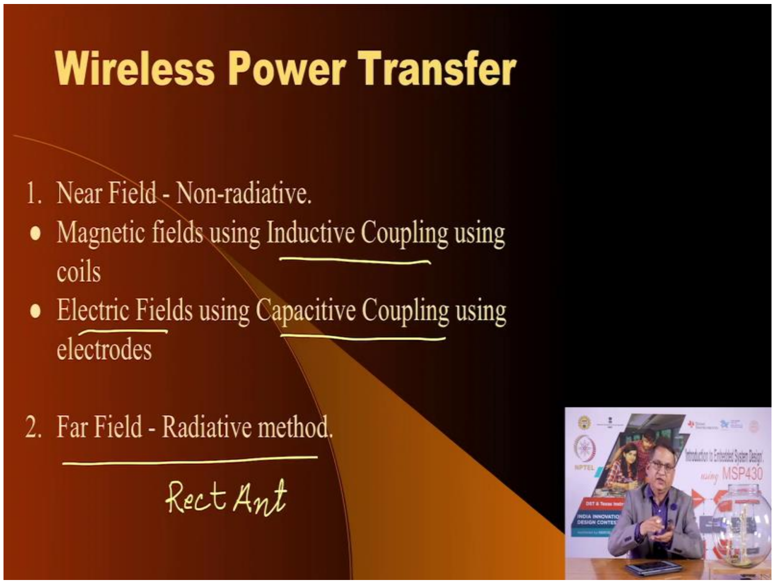

It turns out that wireless power transfers are largely of two categories one is called near field non-radiative. And the second is far field in the near field non radiative method again there are two sub methods one is one uses magnetic field and uses inductive coupling using coils. And the second one is uses electric fields and uses capacitive coupling and for capacity coupling it uses plate's electrodes.

The second method is far field the technique here uses microwave radiation. And in fact people have done projects that normal transmissions of telephone towers, you could actually receive energy from these if you put a create a receiving antenna, in fact that method is called Rect Ant meaning a receiving rectifying antenna. Please search for this term and you would get to know what I mean here. So that method is far field using a radiative method. The more common ones are near field which means you put the transmitter of the power and the receiver close to each other.

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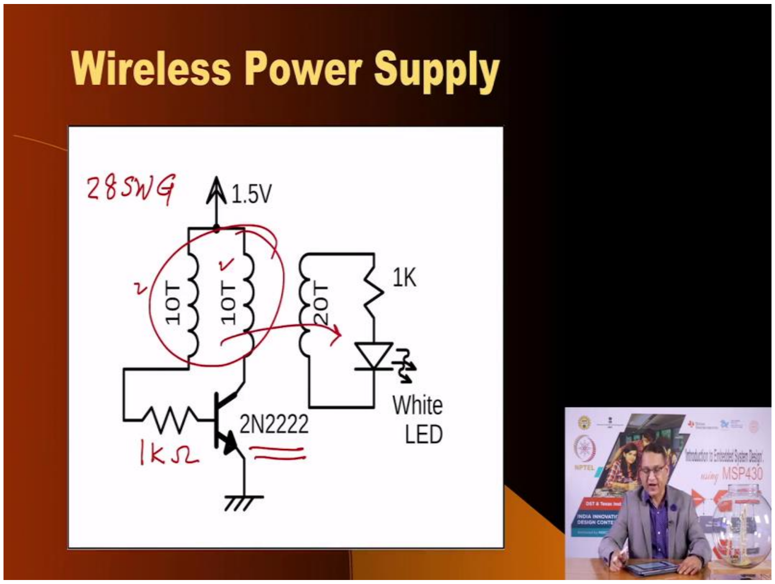

And sure enough you can actually create such a mechanism very very easily. In fact, we have these in our lab for demonstration for school kids and it requires just a handful of components if you see this is nothing but a couple of a feet or so of wire of certain gauge. We in this case we use 28 SWG to create a 10 tons, 10 tons of coil.

We simple lab NPN transistor like 2N2222 and 1 kilo ohm resistor here in series at the base. And you can use a simple 1.5 volt, alkaline battery to power this. And on the other side you just double the number of turns from 10, you make a single coil of 20 turns and you put a resistor if you want or if you like you do not need to put a resistor either. And when you bring the second coil, which is powering the LED close to the the first coil here, you would you would find that the because of inductive coupling you are basically able to turn the white LED on.

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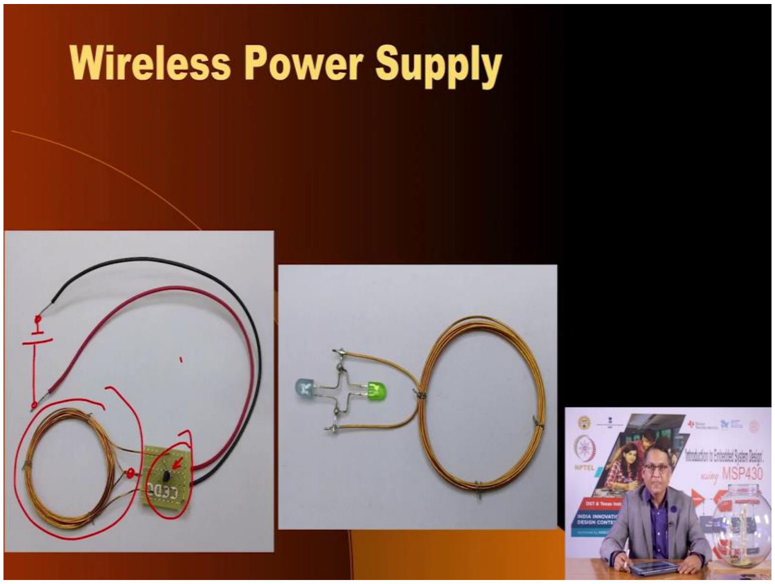

Here is a simple implementation that we have in the lab. This is this is the transmitter as you see this is the NPN transistor. This is the coil in two parts. That is the centre tap which connects to the VCC. This you can apply here 1.5, 1.5 volt cell here like this here. Once you do that then this fellow, this call will start radiating. And if you put the second coil now this has double the number of turns or rather the sum total of these terms the sum total of these turns are also here and I just put two LED's back to back and if you put one this coil on top of the the transmitting coil, you will see that these LED's light up.

And so this is basically wireless power transfer. The only issue is the amount of power being transmitted from here to here is very very small. It hardly it just turn these LEDs on quite brightly though, but not enough to power several LEDs and the micro controller circuit to. And so the way to go about it was to scale the power being handled at the transmitter.

And one way to scale that was to increase the voltage. But when you increase the voltage, it turns out that this transistor should be capable of handling there large power dissipation. And if you experiment with such a small transistor will find that soon enough as you start increasing the voltage the transfer will simply not be able to handle the increase power dissipation and will simply burn off.

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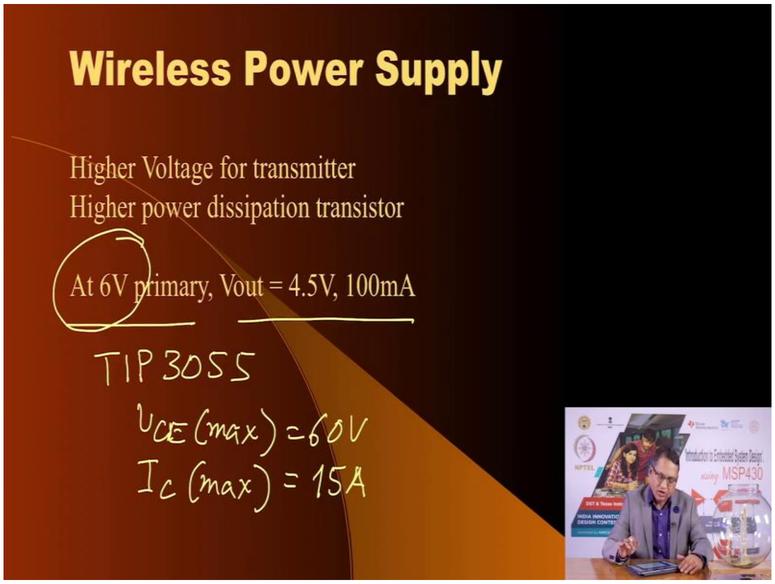

And so we replace this transistor with the more powerful transistor and the more powerful transistor in our case what we did was we used a TIP3055. This is a very hefty power transistor, which has a VCE max of I think about 60 volts, but that is not as much important as that the IC the collector current maximum that you can have on this is 15 amperes.

And that is the important 15 amperes. So that is the important part the part necessary for our requirement. And so this transistor was chosen at the as we start increasing the supply voltage the transistor becomes extremely hot and the only way to handle that is to attach it to a heat sink. Heat sink does nothing but increases the power dissipation capability of the transistor, it increases the metal surface through which the transistor can dissipate that heat.

And so we did that and we did some testing and we found that if we applied 6 volt at the primary that means 6 volt in the energy the the transmitter part on the secondary side, you could easily get 4.5 volts and you could get up to a 100 milliamperes of current of course at that time the source was consuming much more.

It was consuming about 1 and the half 2 amperes of current. So, the efficiency of the system is extremely poor and that it is not normally the case because the your wireless phone chargers and increasingly, vehicles are being charged using this method. It does use near field non radiative technique, but there is a further specialization in that it uses resonance.

So, it uses a resonant circuit where the efficiency is very high. And so but the complexity of such a circuit increases we have chosen to keep it simply because the idea was to illustrate this process from visualization to implementation. And therefore we have kept a non-resonant mechanism, which of course consumes waste more power, but it serves our purpose. Now, once we have once we were able we are confident about the power supply part.

The second part was to concentrate on the micro controller circuit and for doing that instead of creating a custom circuit our lunch box comes into picture and we use that to connect several LED's on the pins and wrote program to be the linear feedback shift register to generate random numbers and for making one candle one candle one candle, we you be used 2 LED's.

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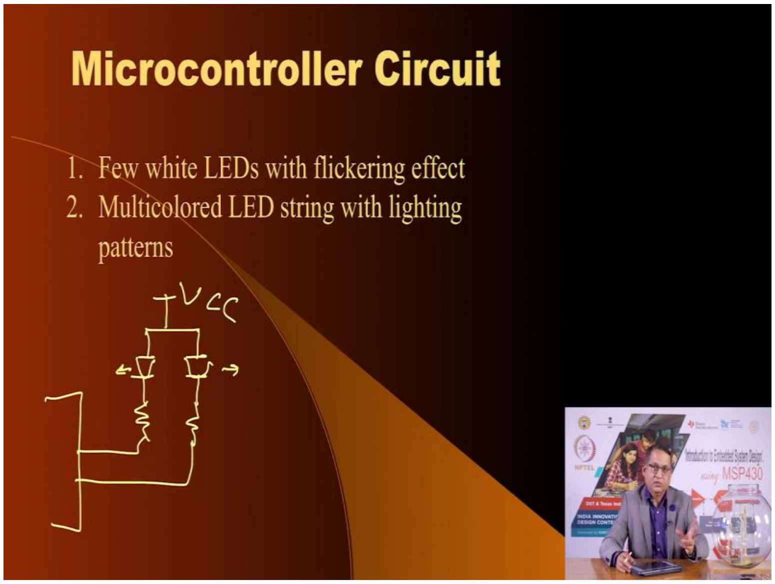

So, it could be something like this one LED here one more LED and then limiting resistor. This is your VCC and this goes to 2 pins of the microcontroller and they were control together with random bits being thrown at both these LEDs. And so what you end up getting is a flickering effect, and once we tested that we were confident that we would be able to control these candles.

And then since the the LED string we wanted to blink the LED is on that string. We wanted to increase and decrease the intensity. So, we connected it to an appropriate pin of the microcontroller which had a PWM output. So, that we could ramp up the LED intensity make it go down and so on so forth. So, this was tested using the lunch box. And once that was there then we started creating the schematic and from the schematic the board layout.

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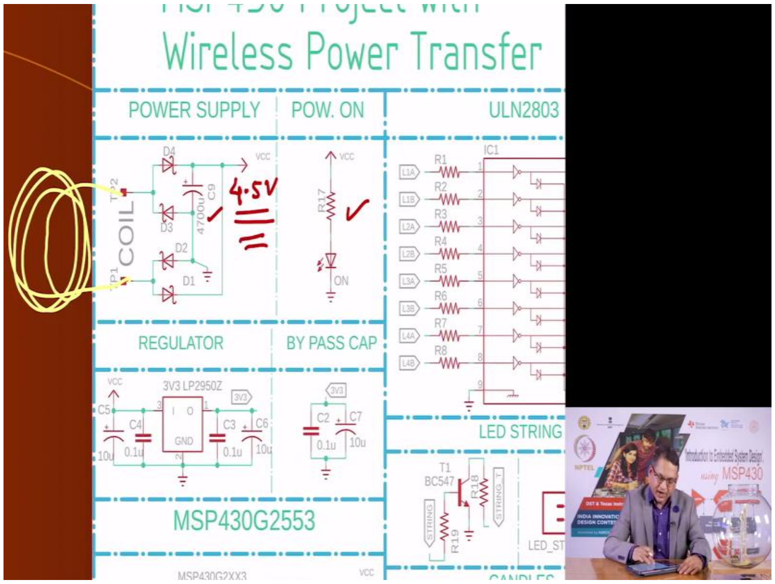

And so let me show you the schematic. So, this is the schematic diagram for this MSP430 based wireless power transfer project. Let us go through all the parts of this schematic. This is the power supply part. So, on this on these two terminals you would be able to collect a coil. Like this here, and then this would generate AC. It would receive the voltage in AC form. And so you are going to have rectifiers. This is the bridge rectifier.

These you see if you notice these are not normal rectifier diodes. They are short key diodes and the reason by short key diodes where used is that the short key diode voltage drop is much less than the drop that you would get with a silicon diode. And because we want to extract as much power from the system as possible. We did not want to waste the voltage over a silicon diode, so short key diodes were used.

And then it was filtered out using this 4700 4700 micro microfarad capacitor as you see here. So, this was the part of the power supply. Now this would this as I mentioned in our test this would provide us about 4 point 5 volts. Now, of course MSP430, now when you start designing the system you would put the requirements for the microcontroller and as I mentioned you have to look at four aspects, how do I provide the power supply for the microcontroller.

When you decide that you want to implement it with MSP430, you have to worry about providing about 3.3 volts. You can go maximum up to 3.6 volts. You can look up the data sheet. It can go down to 1.8 volts. But of course at 1.8 volts the LED’s is will not light up all the LEDs all the coloured LEDs. And so you have to up if we choose the supply voltage to be 3.3 volts. You have to worry about getting 3.3 volts from this 4.5 volt raw voltage. So, we come to that briefly. Then once we have the power supply available. Every project must indicate that the circuit is working. The system is working and though so we had we have provided a power all LED.

Please remember that whenever you make any project provide for a power on LED. Otherwise if the system is not working you would wonder why did not working. It could be that the power supply itself is not available or if the power supply is available, then you know, the power supply is not an issue. You should look at other aspects. So, providing a power on LED is very important. That is what this second box does for you.

Now as I mentioned we wanted 3.3 volts our source was 4.5 volts. So, we could use a regulator. And again, we have seen various regulatory options. We could use a switching regulator. But again the there no need because we are getting 4.5 volt raw voltage and we could choose LDO low dropout voltage regulator.

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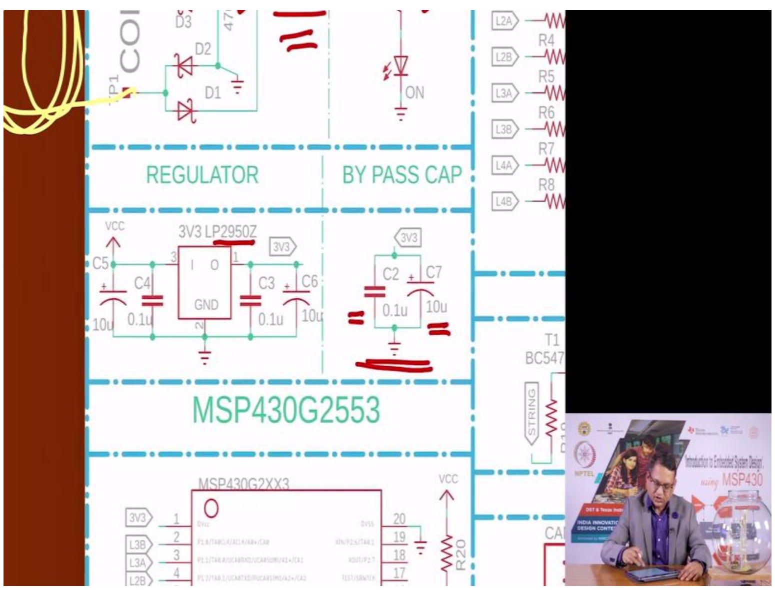

And so we use this three point LP2950 with 3 point 3 volt output. It works very well with the differential voltage here. In this case up to 1.2 volts it this regulator works very well. And so this was chosen to power the MSP430. The expected current for the MSP430 itself. If you are going to use the internal DCO clock the default clock or 1 point 1.1 megahertz, you know that the current is of the less than a milleampere.

And so this this regulator is quite happy to provide that current. And all circuits require decoupling capacitors. And usually we should do 10 microfarad electrolytic and point 1 micro farad ceramic and connect it to the output of the supply voltage near to the nearer the pins of the microcontroller. So, this was the bypass capacitors.

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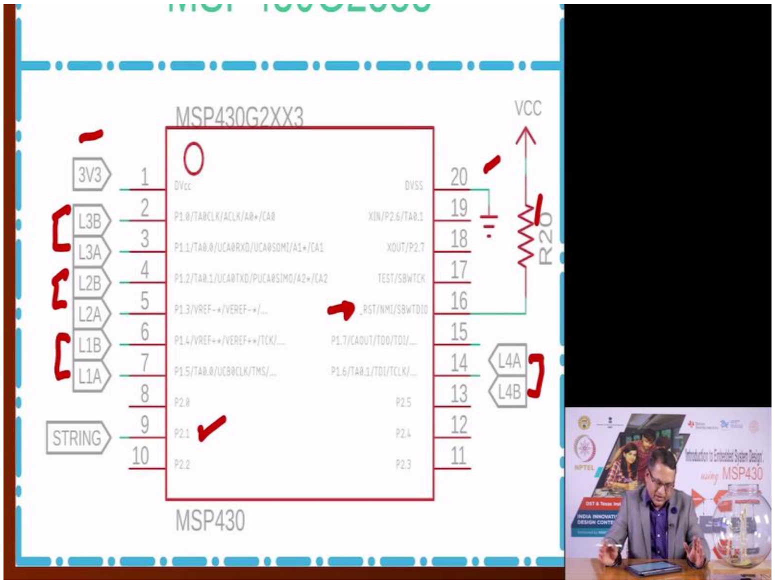

Here is the MSP430 circuit here as you see. This pin is the reset since we are not doing anything. We are not resetting it manually we have pulled it up with this resistor. So, that the only way to reset the system is to turn the power off and turn it on again. And then all the rest of the pins here is the supply voltage connected here. Here is the ground and these are so these these two these two these two and these two they are driving two LEDs in the output low mode meaning when these outputs are low, the LEDs will be on.

And then this P2 point 1 was chosen to drive the string because on P 2 point 1 you can have a PWM output. And rest of the pins since they were not being used. They have been left unconnected.

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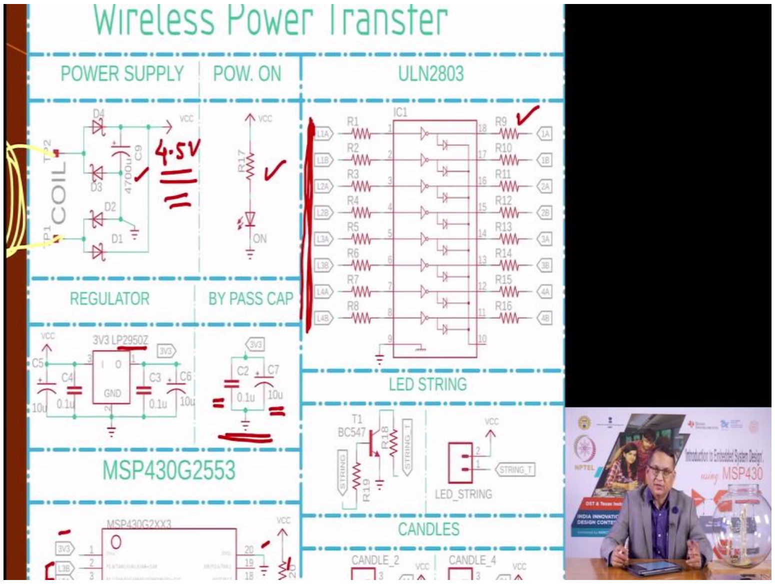

Let us go here. Now, I have 4.5 volts available. I am going to use white LEDs. In fact, I would choose what is called as a warm white shade. Because warm white would mimic a candle much better than, cool white would do. So, warm white but a warm white LED requires more than 3.5 volts for operation. I supply voltage of the MSP430 power supplies only 3.3. So, instead of directly driving what we choose to do was as follows.

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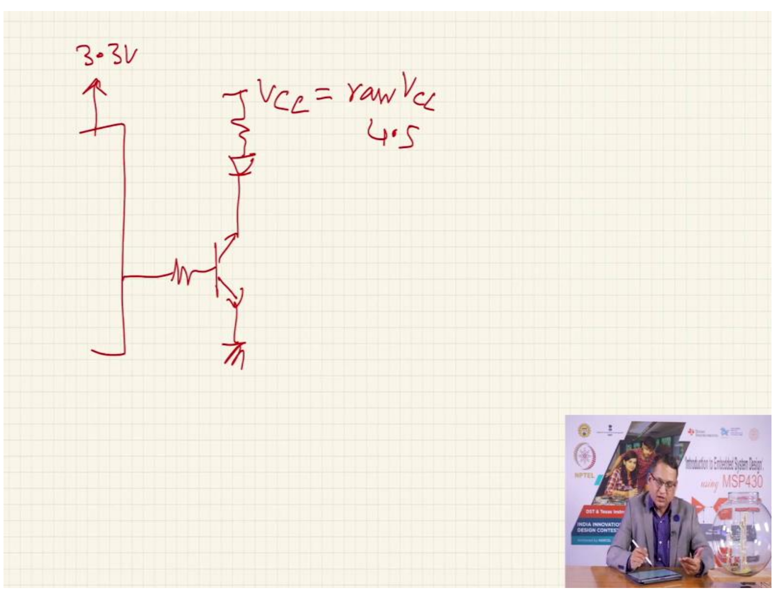

We took the MSP output here and we could have a low side driver as we have already, understand that term and then we could have a LED like this. So, this is the raw voltage raw

VCC of 4.5 volts and this is the 3.3 volts MSP430 power supply. And if you wanted to drive the LEDs with 4.5 volts, the only way to do that would be to isolate the supply voltage using this NPN transistor as a switch that is a low side switch.

And so in we would need 8 of these switches 8 of these transistors instead of using individual 8 transistor what we choose to do was use this NPN driver called ULN2803. It has 8 NPN type of low side drivers. And then so this was connected to the output these inputs of the driver were connected to the MSP430 pins. And these outputs were connected to LED’s. These are the current limiting resistors.

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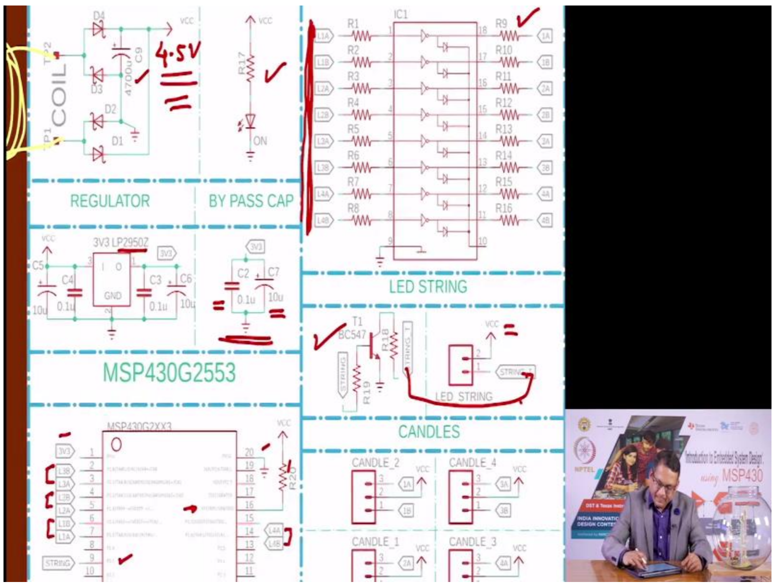

Now we are left with only the mechanism to drive the string of LED’s and for that we took another transistor and connected the string here. So, this is the raw supply VCC here is raw supply voltage and the string was connected between this point and this point like this. And a connector has been provided so that you can remove it if you like.

And then these are the 4 connectors for 4 candles. Each of them would have two LEDs like this and this and this is the supply voltage. So, as I discussed it will be in the low side switch mode that is the anode will be connected to VCC and the cathodes will be connected will be controlled by the microcontroller. So, this completes the schematic of the project. Here is the board layout.

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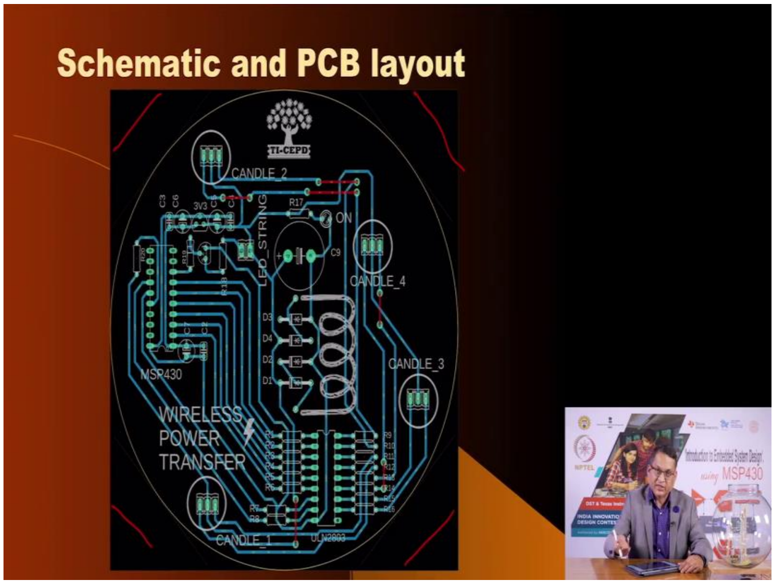

This was implemented like on a single sided PCB. The blue wires indicate tracks and the red bars indicate jumpers. Because the signals have to cross so you bring them up on jumper wires and then put them bring them back in. So, as you see it only uses about 1, 2, 3, 4, 5, 6 jumpers.

And now cutting a circular PCB is a challenge, although in my lab, I do have a CNC machine and I can cut a PCB in any shape. I wanted it to be cut in a way that anybody with access to basic tools could do it. So, we decided not to although the, you see a circle here. We did not implement a circle. What we did was we cut a square which could inscribe this circle and then we cut out these parts of the square here. So, ended up making a octagon. So, let us see how is this was implemented.

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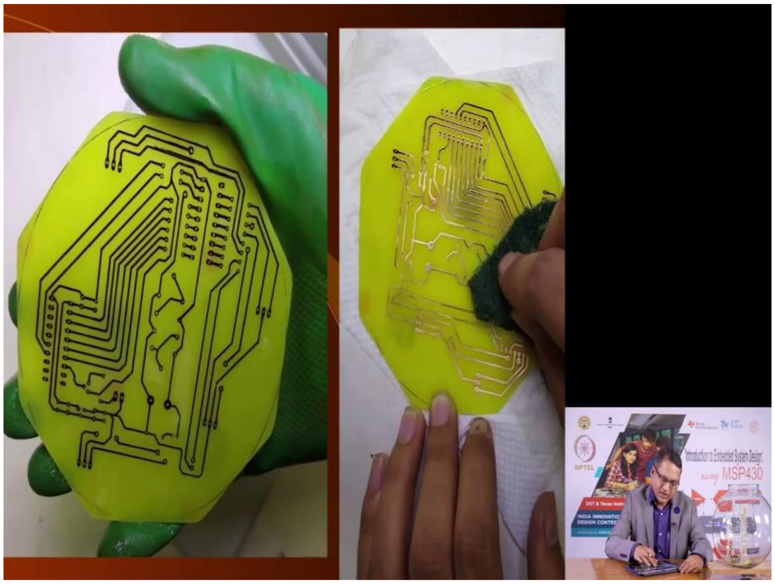

So, the PCB was cut as you see there is a circle, marking inside, but it was actually cut like a square and then the corners were cut off using a hacksaw. So, all this whole this whole stuff was done using a normal hacksaw. And the, we have already seen the PCB fabrication method all that was done the layout was stuck here. And then the board was put in ferric chloride. The raw PCB board was put in ferric chloride etched and then once that etching was complete the ink from the laser printer was removed using this scrubber. And then it was drilled and sprayed with that acrylic spray. And then we started soldering.

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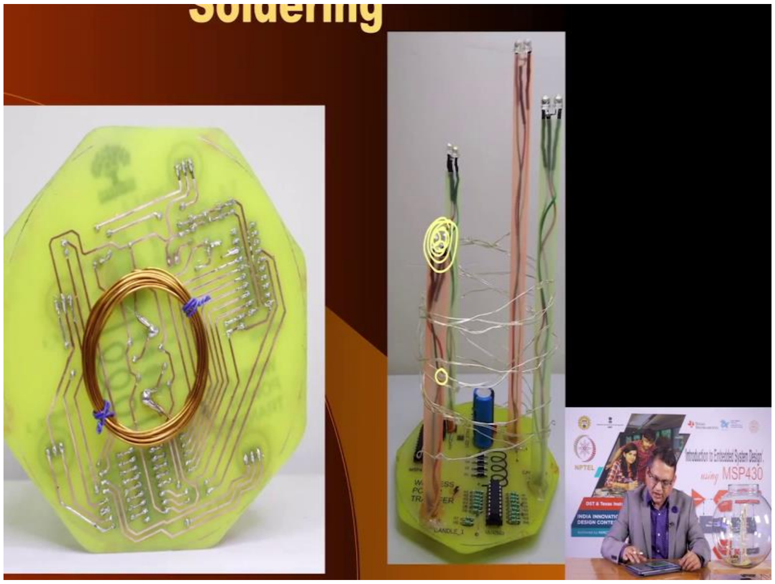

Here is the coil at the bottom. And on the top you would see here is the, this is the top side as you see the top side has been printed with the what what is called as identification layer. So, this PCB actually went through two processes of transferring the layout. The bottom layer was the tracks and the top layer was the the identification layer. So, that we know where each of these components are going to be put and this can be easily done.

And then once all the things where solder, drilled and all. These components where solder and these plastic things are nothing but thick strands and they were glued on the base with hot glue and inside you see these two white LEDs and in this the current implementation, I have covered these these LEDs with the hot glue. So that it can diffuse that light even better. And as you see this is the string of LEDs you see this is the string of LED’s and this bubble that you see here little drop here droplet that contains a LED of various colours. So, this was all soldered together.

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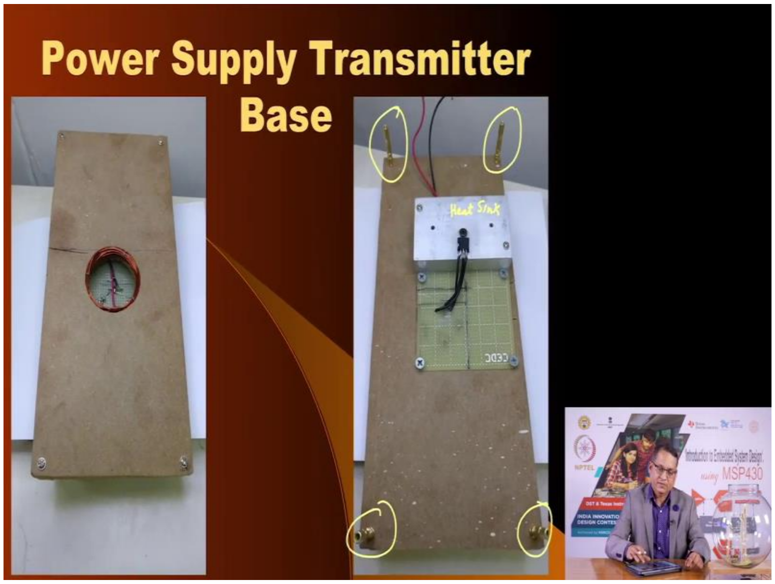

And then the power supply part. So, a wooden base was taken at the centre of it, hole was drilled large enough for this coil the transmitting coil to be installed and then on the bottom side, this is the Hefty transistor that I mentioned and this is the heat sink. This is the heat sink. And the transistor was mounted.

You may see some white paste kind of thing that is not paste that is what is called as heat sink compound. It removes any air gaps between the metal surface of the transistor and the heat sink and provides better conductivity for the heat. This is this was done on the general purpose PCB.

And because when we put it other way around it, this would not allow the base to be horizontal. So, 4 mounting screws were installed on the wooden base and this is the close up of the the transistor.

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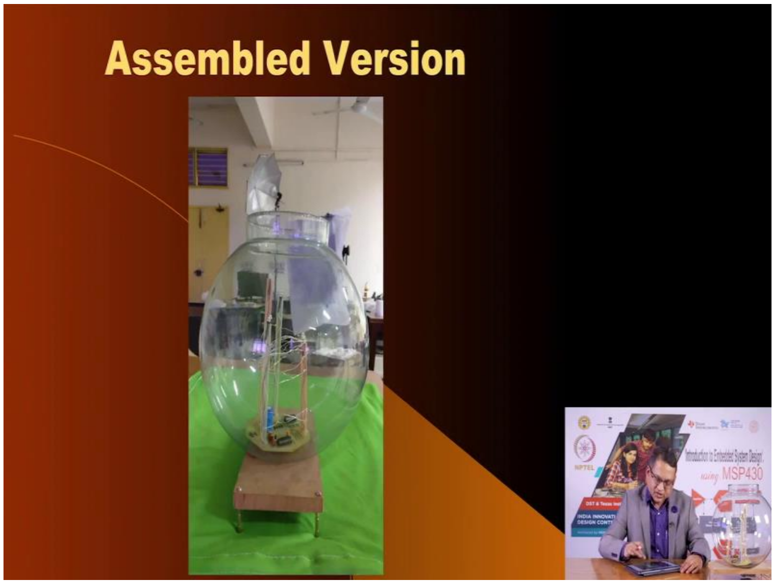

Anyway, this is the final implementation as you see here the fish bowl containing the the the art installation and at the bottom. This is the power supply part.

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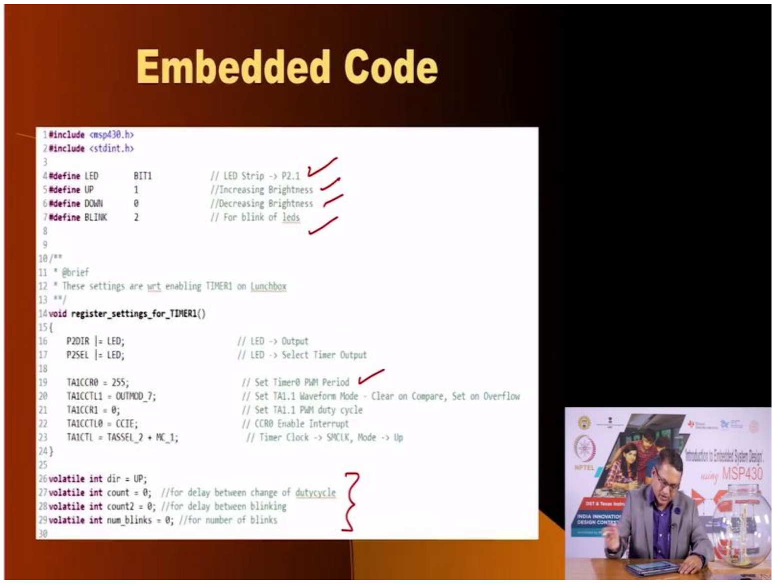

And I have this whole thing here, but let let us go through the code first and then I will demonstrate this project to you. The code is very simple. You have the LED strip on P 2 point 1.

This is our PWM output. Then there are some constants to find for increasing and decreasing the brightness and for blinking LEDs, this is the register setting for timer one, the timer one has been programmed for the PWM output here. Then these are variables declared here. These are all declared as volatile because some interrupt is happening.

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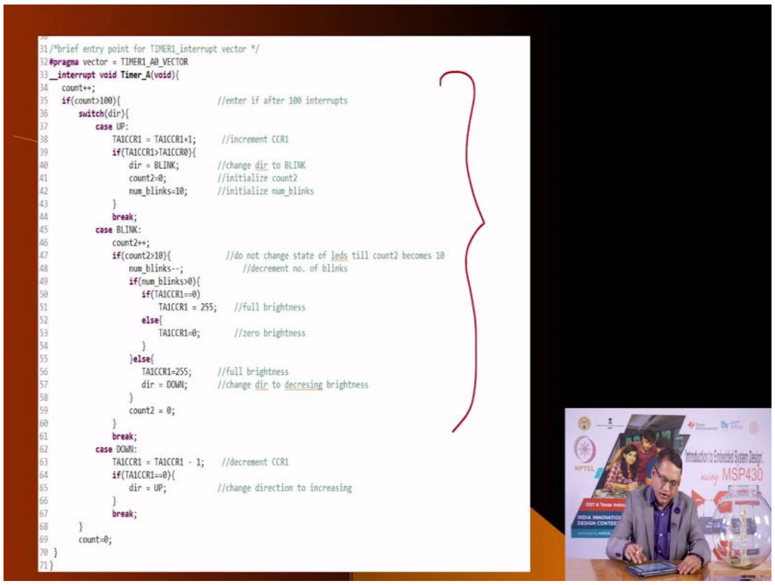

This is the whenever the timer interrupt happens. It goes into it. And in this at some point, it will blink the LED and at some point after sometime it will do PWM on on those LEDs. So, this is the timer code which control that string of LEDs.

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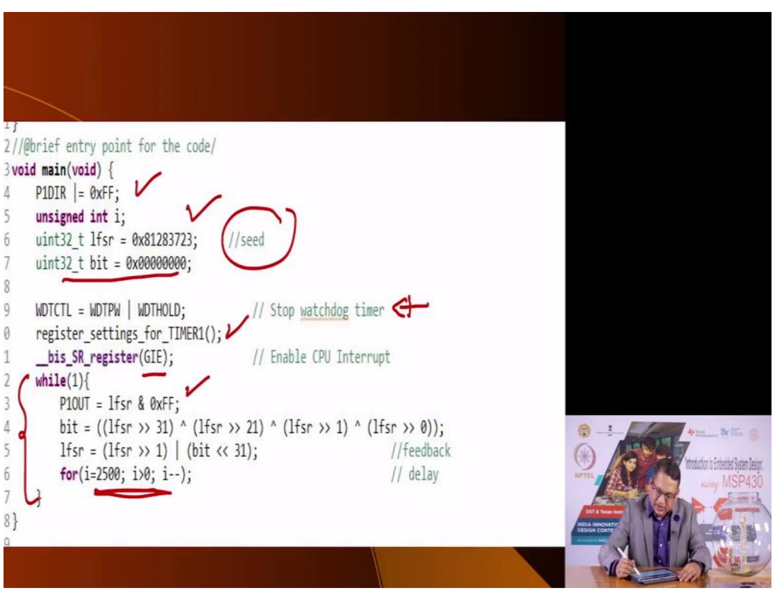

And this is the simple mean code where we have defined the P1 port 1 as all outputs. This is the seed for lfsr a 32 bit lfsr was chosen and this are seed for that lfsr, although it means that every time you turn the system off and on it will always start with the same pattern and one way to overcome that would be as we have discussed we could use ADC a spare ADC channel without connecting it to any source just read it and you will get a random number and use that to feed into the linear feedback shift register for subsequent random numbers.

And then we stopped the watchdog timer here. We call the function to program the timer 1 and then we set the bits in the SR register to enable the interrupts and then enter a infinite loop where we are simply outputting the lfsr bits on all the 8 pins of port 1 that is what we are doing with some delay. This delay was experimentally a certain for this value.

So that it gives you flickering effect. If it is too slow. You will not see, if it is too fast again you will not see. So, this was inferred experimentally and once this code is compiled. Now the problem is how do you put the microcontroller, till now we have been downloading our code into the lunch box. So that is last aspect that I want to discuss. You can do your experiments on lunch box.

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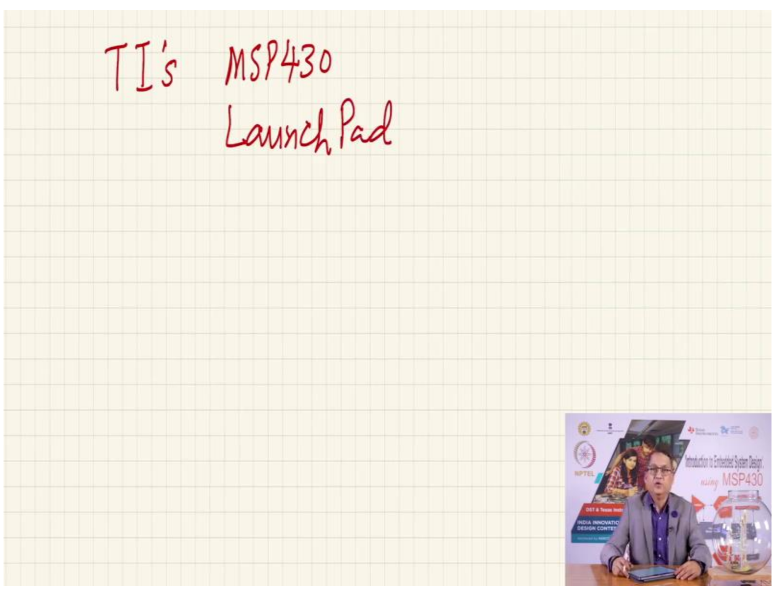

And there are similar evaluation kits available such as Texas Instruments very own TI's, what is called as MSP430 launch pad. This is a very very worthy evaluation kit. It allows you to debug the code also and it has a mechanism that the pins which are used for programming the target microcontroller. There are jumpers, you could remove the jumper and connect it to your target board. But for this present case what we decided to do was we tested everything on the lunchbox, program the IC in the lunch box and then simply took it out and insert it into the PCB of the system here.

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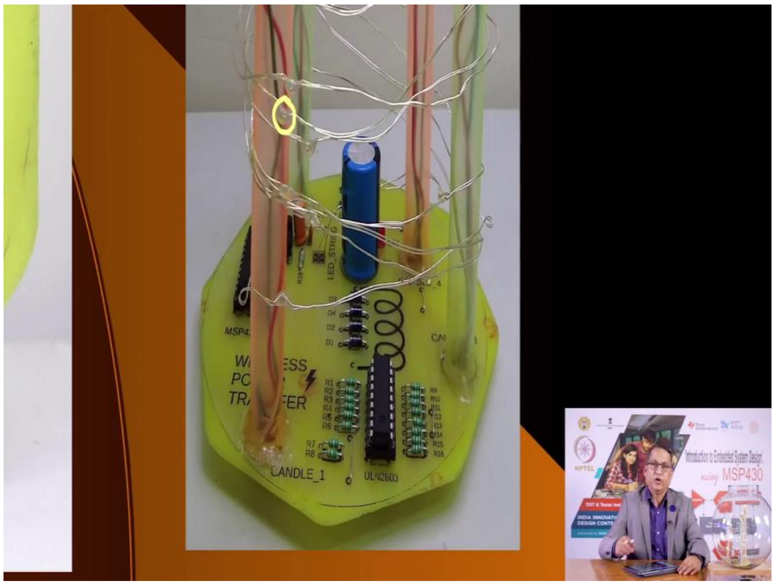

And you may need to do some iterations. If it does not work the way you want it to work. You can always put it back reprogramming and put it in there are some dangers that the pins of the microcontroller will get bent and so on so forth, but for a simple project, that should not be a worry.

So, but when you are developing your own projects, you have to be aware of the need for appropriate programmer so that you can download the code from the desktop into the memory of the microcontroller and in this present case we use the MSP430 lunch box. I hope that you would continue using the lunch box.

You can get more MSP430 microcontroller from the open market or you could even send request mails to TIME, they are happy to offer free IC’s provided you make that request from your official student email address you could request them and then you could use those IC’s in your projects. And if these IC’s are MSp430G2553 you could continue to use the existing lunch box that you have.

So, this is this is all for this project. I hope we were able to illustrate how all the skills that we have acquired over the course of this lectures series of lectures that all of these could be integrated at the end to implement a MSP430 base project. Let me show how it works. So as you see this is blinking here.

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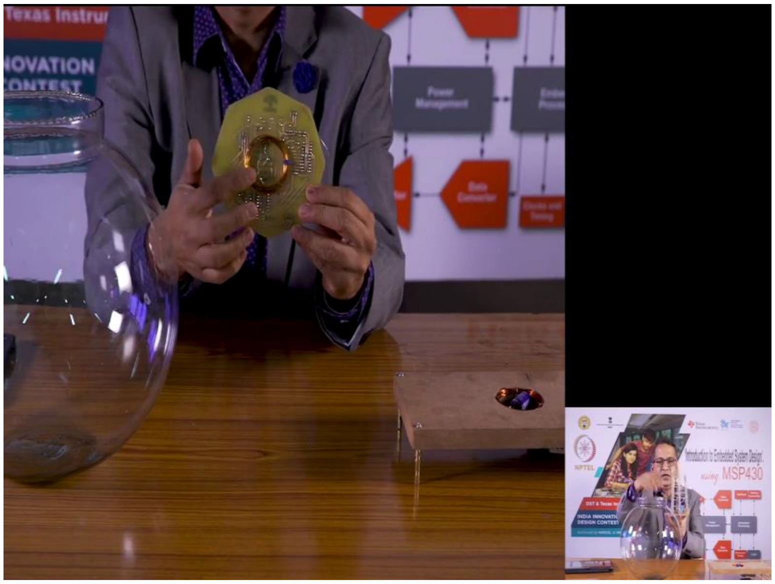

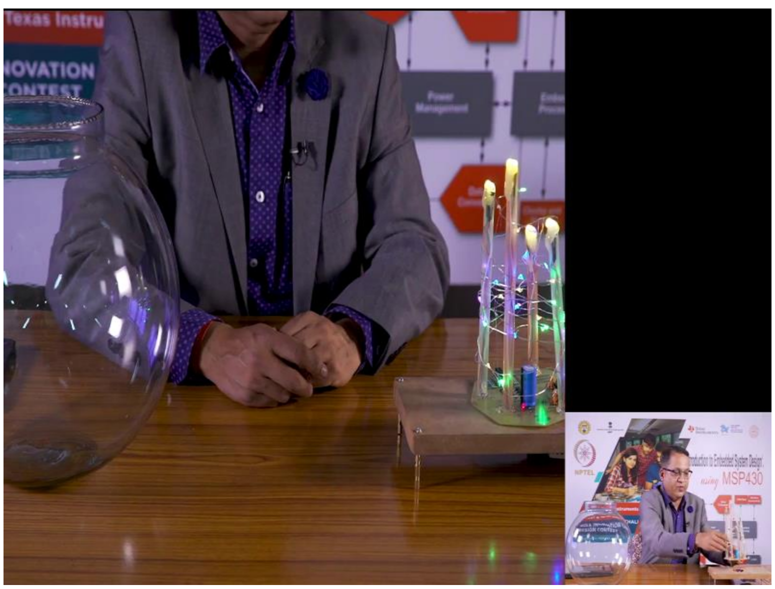

I can remove it and it stops working by because there is no source of power. Let me also take it out of the fishbone to show you the circuit here. Now, I could put it back on top of it and it starts working again why because here is the the receiving coil and in this there is the transmitting coil, I put it on top of it it starts working.

And I can remove it put it back into my fish bowl. And then transfer it over here and you see it starts working again. So, this is how it works. I hope you enjoyed this course. I hope it enthused you to fall in love with electronics in general and microcontroller circuits in particular. I hope that you will continue to build more and more projects not only in your student life, but when you enter the professional life, and I would be very happy to hear from you. Should you want to share your success stories with me. Thank you very much. See you soon.