Design of Power Electronic Converter
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Module: Hardware Design
Lecture 61
Lecture: Sections of Power Converters

Welcome to the course on the Design of Power Electronic Converters. Till now, in the course, we have seen how to analyze a Power Electronic Converter from the perspective of design, how do you calculate the different inductors and capacitor values that are required in your converter? Then we also saw what are the different semiconductor devices? How do you select them? What are the specifications that you should look for in the datasheet.

Further we saw how to design snubbers? What are drivers? What are the different type of drivers circuits that you may choose to drive your power semiconductor devices? Then, we further saw how to do thermal design that means, how do you select the heat sinks, then we also saw how to do magnetic design that means inductors and transformers for your power electronic converters, how you can design them?

Further we saw the EMI, What is EMI? I gave you an introduction to electromagnetic interference problems and what could be the possible solutions from the perspective of power electronics engineer and I also briefly introduced to EMI filters. Now, having discussed all these things, now, let us look into how do you combine all these things and finally, design the hardware for the power electronic converter.

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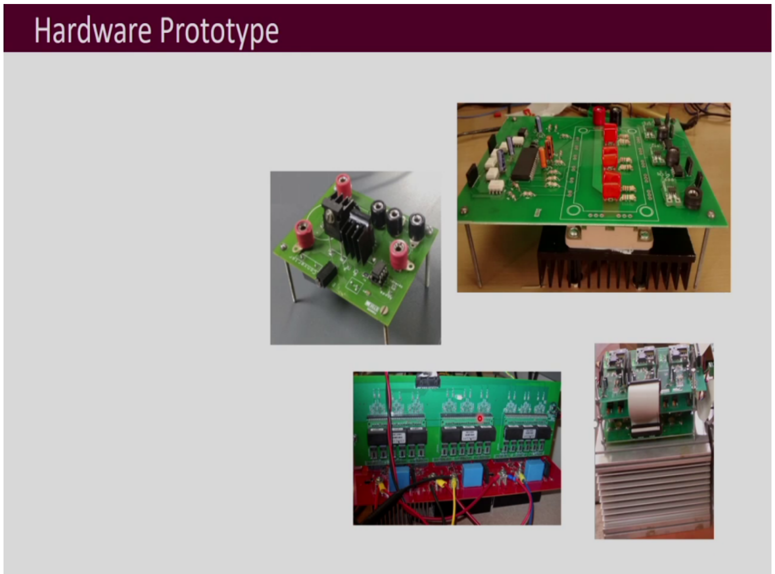

So, for that first let us look into different sections a power converter may be having. So, when you would like to design a power electronic converter. As a first time designer, you will be usually designing the prototype. So, it is a prototype which is designed first and then tested and then further based on the experimental performance, then usually another iteration of the prototype may be done.

So, it is like one or two iterations that may be doing and then finally, it may be translated into product also. So, this is a course, which has been designed from the perspective of a person who is a beginner in design of power electronic converters. So, at first, I you would like to design a prototype of the converters that you have studied before or which you will need for any particular application of yours.

So, you would be having targets of building prototypes something like this pictures which are shown here. So, this is a prototype of a three phase inverter, you can see here that it has been built just using one single module of IGBT then this is a very small prototype of a boost converter, then, these are prototypes of other converters, I will name them because we have not discussed this in those in the course.

So, but there are various different types of power electronic converters and whatever we have studied in this course, you can apply those theory for building up those power electronic converters, apart from the edge H and buck converter, which we have been using as an example to explain the design concepts.

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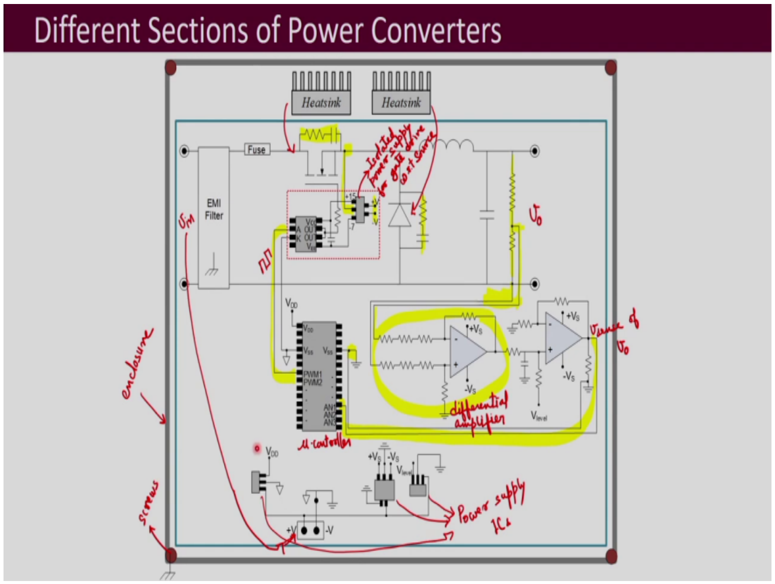

So, now, to know what are whether the usually the different sections in power converter. I am going to take an example a very, very simple example of a buck converter design. So, here I have shown one schematic. So, this schematic, let us see what all things that are there in it. So, first of all you can see here, this is the buck converter, the buck converter circuit, your L and C of the buck converter, this the diode and then this is the MOSFET.

Now, further what all other things that we see here, this one is a driver, this is a driver IC. So, this is an opto coupler based gate driver, which is put here and as you can see here, this one is connected to this gate resistor through the gate of this MOSFET and one terminal over here is going to be connected to the source of the MOSFET.

Further what we see here is that this is a power supply IC. Now, this DC to DC converter IC provides the power supply for this gate drive. So, this gives a +15 and -7 with respect to this source point. So, over here this is the source. So, this point is the source which is connected to reference of this DC to DC converter.

So, this one is the isolated power supply for gate drive and this is with respect to the source. Then, further what we see here is that the input the that means PWM pulses, those PWM pulses, they are coming from this IC, this is a microcontroller IC which is going to generate the PWM pulses. Now, here the reference is with respect to the ground or the reference of this microcontroller IC.

And here on this side, the reference is the source of the MOSFET, then further what we see here, these ones are the snubbers. So, simple RC snubbers are chosen here. Also for the diode that RC snubber is chosen then, what we see here are your heat sinks. One heat sink is for this MOSFET So, this one is for the MOSFET and this heat sink is for this diode.

Then further what we see here is an EMI filter, which is going to be connected at the input of this buck converter that means, whatever is the EMI and that is generated by this buck converter to stop that going to the source here an EMI filter is put. Then further here we have a fuse for protection. And now this is a potential divider arrangement that is done here. That means the resistances are put in then there is a potential divider that is created out of it and then what we see here these two points are brought out and here what you see is a differential amplifier.

So, this is a differential amplifier, now here in this differential amplifier, what it is doing is that it is sensing these this voltage that is the output voltage. So, here this is your output voltage V_O. So, to sense that part of the voltage using the potential divider is given to this differential amplifier which uses this OPAMP then the output of it is level shifted. So, this is a level shifter circuit that you observe here which has also been created using OPAMPS and resistors.

Again between you also see a simple RC filter for some noise filtering that is being done here a low pass filter and this output of it that means this is your sensed voltage. So this is your V_{sense} or of the output of V_O. So, that output and then from here so, that output from here goes to one of the analog inputs of this microcontroller. And this is also with reference to the common of the microcontroller.

Now, here this microcontroller what it does is this that it forms a closed loop control that means, it senses this voltage, it reads this voltage through this analog input and it has got inbuilt ADC, that is your Analog to Digital Converter. And then you can program what is the output reference that you need, and then you can have different types of controllers programmed inside the microcontroller and then it can do the comparison of with the reference and it can generate the PWM.

So, that is the PWM output that is going to come through it and then it has to go through the gate driver circuit and then it drives this MOSFET and further what we see here on this side, these are your power supply ICs. So, all these three that you see here, this one and also this one, these are your power supply ICs and, these give the supply to this OPAMPS and also to the microcontroller. So, it is a supply for all these ICs which are either doing, either performing some digital control or they are doing some sensing or level shifting or any other miscellaneous component that may be there which require some supply.

So, for that different power supply ICs can be put and that is what those three are shown here. So, this gives your V_{dd}. So, this V_{dd} goes here to the microcontroller this power supply IC then this power supply ICs gives the output as + Vs and -Vs which goes to these to OPAMPS then this power supply ICs gives the voltage level of V_{level}. So, that is what is the V_{level} is given to this level shifter circuit.

Now, all these three ICs they also require their own power supply that means, there is some voltage input voltage has to be given to them. So, that is that input which is shown here V+ and V- and that V+, V- acts as a input to all these 3 power supply ICs. Further this V+ and V- this is also the input of this power isolated power supply IC which is used here to supply the opto coupler-based gate driver.

So, that is what can be there in this PCB. Now, this can be inside one single PCB or multiple PCBs. Now, this is a very simple circuit. So, all these things can be inside one printed circuit board, but, if you have a big converter, big power electronic converter and the rating is high, then multiple PCBs also can be used for making different, different parts of the circuit in different, different PCBs.

Now, further that this V+ and V- which is giving supply to different, different power supply ICS this V+,V-this voltage source can be obtained from this input voltage itself this input V_{in} itself can be step down and then that can be given to this V+ and V-. Else we can also have some other source single phase source from which you can have some adapter and then also you can obtain V+, V- so, that there can be different ways of obtaining this V+ and V- that is shown here.

Now, then further this entire all these heat sinks filters and all these things then has to be put inside an enclosure. Now, here just for the sake of representation I shown an enclosure with this gray colored box. So, this represents the enclosure, enclosure means the box inside which you are going to put everything and then finally that that is what your converter that is going to be and then you can also have different screws that may be fixed to the enclosure via which your PCBs are all other your inductors and heat sink different components in your converter may be fixed to the enclosure.

So, those are represented here by this circle, this brown colored circle that you see here. Now, this is this schematic I have shown you is to explain you the different sections that are there in a power converter. Let us look into one by one what are the different sections which we can divide this schematic and based on accordingly for any power electronic converter that you have to design what could be the different sections because if you have to design the converter and if you think in terms of different, different sections, then it becomes the simpler you will have ease in thinking and understanding what are the different components or circuits that you require for your full converter.

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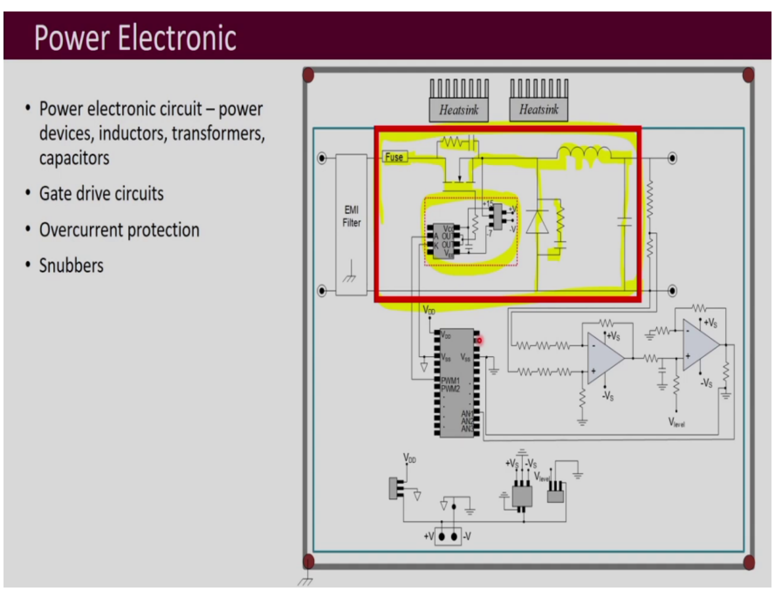

So, first of all is the power electronics section. So, power electronics section means that is your, this, this box that I have drawn here, that one that contains your power electronic circuits. A power electronic circuit here is this thing, this one, this buck converter familiar circuit, that is your electronic circuit, that is part of the electronic section plus this driver section your gate drivers that is a part of the power electronics section because you have to drive the devices.

Now, you may think of the driver as a separate section also if you have a big converter, you have several devices to which you have to drive let us say you have six devices to which you need to drive or nine devices or eighteen devices or more than that, then you can also think of driver as a different section. So, a driver could also be taken as a part of the power electronics section plus these snubbers that are shown here that is a part of the power electronic circuit itself.

So, those also you can categorize as the part of the power electronics section and plus the over current protection which is your fuse or some other protection circuit which you may be attaching or adding to the power electronic circuit. So, those will be part of your power electronics section. So, inductors, transformers, whatever magnetics you have designing or these large capacitors DC base capacitors or big AC filter capacitors, those are going to be part of your power electronic section means power electronic section means more or less there is the power electronic circuit be your basic protection circuits and the driver circuit that also if you wish to add in the power electronics section that forms the power electronics section of the power converter.

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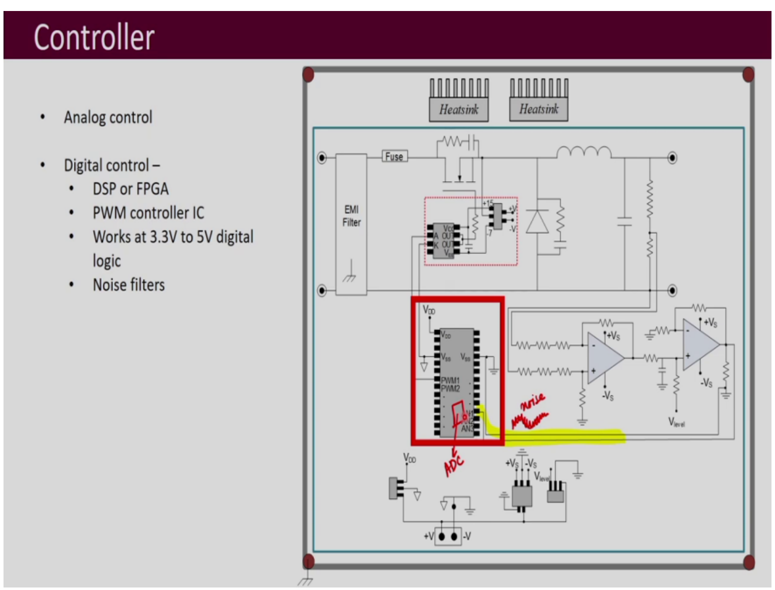

Then next important section is the controller. So, whatever power electronic circuit you have, you have to drive it you have to provide the gate pulses to the power electronic device. So, those gate pulses have to be generated and there are two ways by which they can be generated either you could use an analog control or you can use a digital control. So, analog control means you will be using OPAMPS or different analog circuits or which within you will be comparing that either the reference I mean a DC reference with the triangular carrier or a sawtooth carrier.

All right we will be comparing visually a sinusoidal reference with your triangular or sawtooth carrier. So, this entire thing can be implemented using analog ICs, analog electronic ICs that can be implemented or we can use digital ICs, digital method that means you can use microcontrollers or DSPs that is your digital signal processors or FPGAs also.

So, here, what I have shown here in this example is a PWM controller IC. So, that is a digital control IC that is shown, digital control method which is shown here. Now, also know that that these ones these digital controllers, they will be mostly working at either 3.3 Vor 5 V or sometimes even below them that below 3.3 V also. So, that voltage then has to be provided to those ICs and that is why it is important of importance of these power supply ICs which I just told you a while ago.

And further in this digital control means when you were programming it you can also program filters in it because whatever inputs that are going to the controller that may be having some noise in it as you would like to filter out the noise. So, for example, here if you see this one a whatever this sensed signal is coming which is going to this microcontroller.

Now, further we can have an ADC inside it analog to digital converter. So, after that, if this signal let us say the signal was supposed to be like this the sensed signal and it has some noise in it. So, that noise, this noise you would like to filter out. Now, one way of filtering it is, is that you put some filtering analog filtering circuits here or that means some hardware filtering you can do.

Inside this program that you will be writing in the microcontroller you can program a filter, so, that will also filter out the noise. So, noise filters can also be programmed inside the digital controllers apart from the main control program that you will have to write. So, controller is another section of the power converter.

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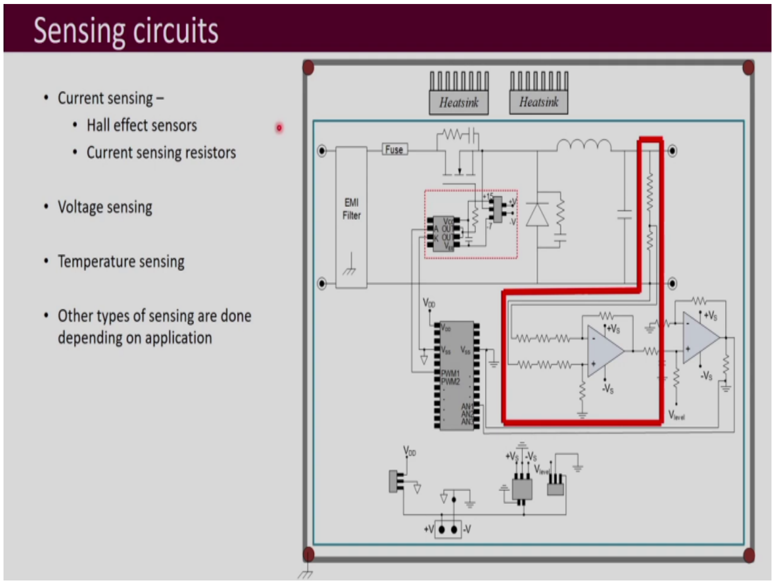

Further we will have sensing circuit so that means sensing is another section of a power converter. So, what do we see here, this is the potential divider which is created to sense the voltage and then differential amplifier which is used. So this is the sensing circuit. So this is the voltage sensing circuit. So, that is the section which is your sensing circuit section, which is shown over here. Apart from that when you have a converter then you may like to also sense the current. Now, current sensing can be done using Hall effect sensors. And also many times they are done using current sensing resistors.

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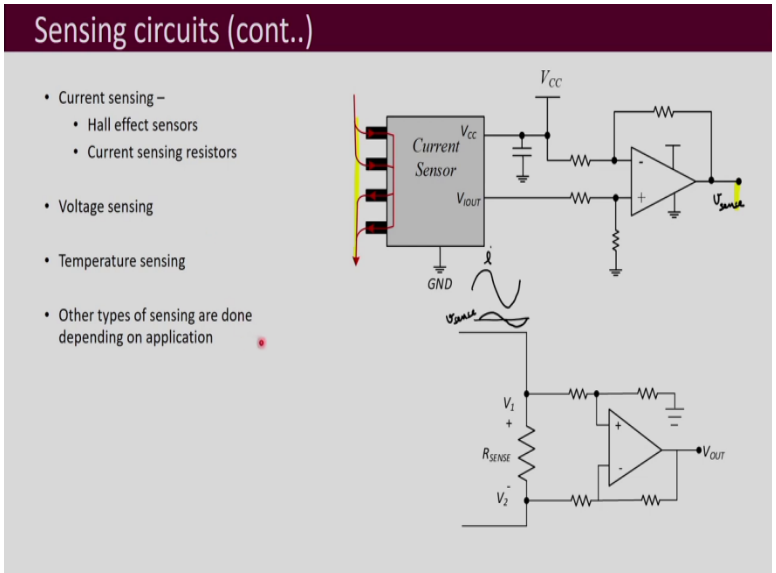

So, if we have these kind of current sensors, which is which are also called as your LEM sensors and so, then what happens is that here what the current the main current power circuit current that flows through it, and based on it the sensor gives a voltage and output voltage with respect to its reference and this is basically the reference of the control circuit or the sensing circuit and you also have to give some supply voltage to this current sensor. In this current sensor what should be the supply voltage that will be given in the datasheet of that current sensor.

And then further whatever is this voltage coming that may be very small or more which mean which you might have to again scale up or scale down or amplify or reduce based on your your controller. So, that is what you may be having some OPAMP circuit after the current sensor, this circuit that output voltage it gives. Or another method of sensing the current is current sensing resistor. So, wherever you want to sense the current in series with that you can put a small resistor. Now, this resistor will be of a very, very small value so that it is it does not become (())(24:53). It is not going to affect the efficiency of the converted much.

And then after that, whatever this voltage that comes here that you we can let it go through a differential amplifier and then whatever is the output voltage then that can be given to the controller. So, these two are common methods of sensing current and voltage sensing I showed you, you can have a potential divider and then you can use a differential amplifier and there are also a special voltage sensors which are which gives you electrical isolation as well. So, those type of sensors voltage sensors are also there and you can also use that.

And when you have the sensing circuits know that the sensing sensors have got their own delays. So, here in this case whatever is the input signal here the current that is coming and what you obtain the output here the output voltage which is corresponding to this input current there may be a delay in it. So, let us say if this is the current I that you wish to sense and the voltage that you may be sensing may be slightly delayed from there.

So, that will be your this if we call it as V_{sense}. So, this V_{sense} is going to be delayed with respect to the current that you are going to sense. So, this delay is part of any quantity which you are going to sense. So, you should keep in mind the whatever sensors that you choosing, that should be giving you as less delay as possible or at least a delay which is affordable by a controller. Then temperature sensing that you can use thermocouplers or thermistors for temperature sensing and there could be other types of sensings also present in a power converter depending on the application. So, in short, the sensing is another section of a power converter.

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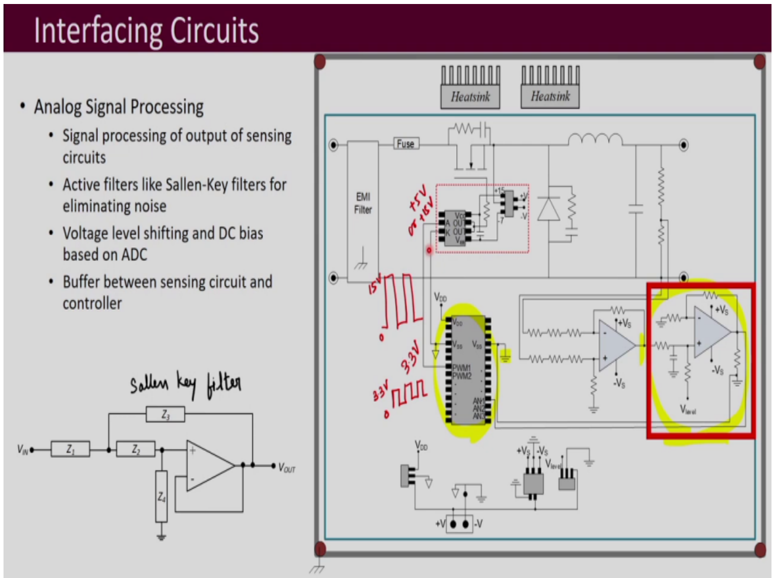

Then your interfacing circuit. Now, what is an interfacing circuit? Interfacing means you have to interface between two different sections and usually sensed output and the controller and you have to interface between the two that means you have to match the voltages in between them. Means your output of the sensor is let us say giving with respect to your 15 V and your controller accepts voltages of the range of 3.3 V.

So, you have to scale down then. So, that is the interfacing that you have to do you have to do some signal processing that you might also have to filter out some noise. So, that is the signal processing and interfacing that is required at that site. Further interfacing is required whatever the controller the output, it is giving the PWM gate pulses that it is providing and when you have to give it to the driver, those voltages also have to be matching. So, there also further interfacing is needed. So, here let us understand what is the interfacing that is being shown here in this example.

So, here what you see is this is here what where you get the output of the sensor the voltage sensor, voltage sensing circuit and now this is going to give you both plus and minus voltages whereas this PWM controller this microcontroller this only accepts voltages which are positive with respect to its common or the reference. So, we have to do level shifting. So that is why this is the level shifting circuit that is used here this level shifter so this X is an interface between this voltage sensing circuit and this digital controller or the PWM controller the microcontroller.

And now, here this is very simple thing that is shown. Apart from that in the interfacing we can have other signal processing also like we can put filters as I said, they can be hardware filter, analog filters, or what you call us active filters it is like one which is shown here. So, this is the diagram of your Sallen key filter which you may be familiar with, if you are not you may read it on your own also.

So, this is OPAMP based filter and how you can have different RCs put in these places of Z1, Z2, Z3, and Z4. So to filter out the noise that may be present in the sensed voltages. So, signal processing of output of sensing circuits and active filters like Sallen Key Filters for eliminating noise, and I also told you about the voltage level shifting and the DC bias that my might have to be given based on the output of the sensed voltage and what the controller accepts the level of the voltages that the controller accepts.

And further your buffer between sensing circuit and controller, sometimes we want to give a buffer as well. Now, what is this buffer that we are talking about here? So, these controllers now here, this is the digital controller that is shown here, you might have analog control also. So, most of the time, when you have these kinds of controllers, so their current capacity may be very small, we have to ensure that we are not drawing any current to the pin to which it is connected.

So, they so we want to ensure that I mean, the impedances should be such that we are not drawing current from the controller.

So, there we want to keep the impedances high. So, for that also buffer many times put between the sensing circuit and the controller and similarly, we want to have buffers over here as well. So, a one is your interfacing over here between sensor in controller and second I told you, it is a buffer between your level shifting and buffer that is required between the output of the controller these digital controller and your gate driving. Now, here, this is directly connected to the opto coupler based gate driver, but many times it may happen that this voltage over here this can be in the range of + 5 V or + 15 V is what these gate driver circuits may demand.

Whereas this digital controller that may be giving output, also have the level of 3.3 Volt. So, then you will have to do a level shifting the same PWM pulse. So, here whatever PWM pulse if it was coming in the range of 0 to 3.3 V, you have to do the level shifting and you have to make it from 0 to 15 V or 5 V whatever as it is required by this gate driver. So, that level shifting has to be done.

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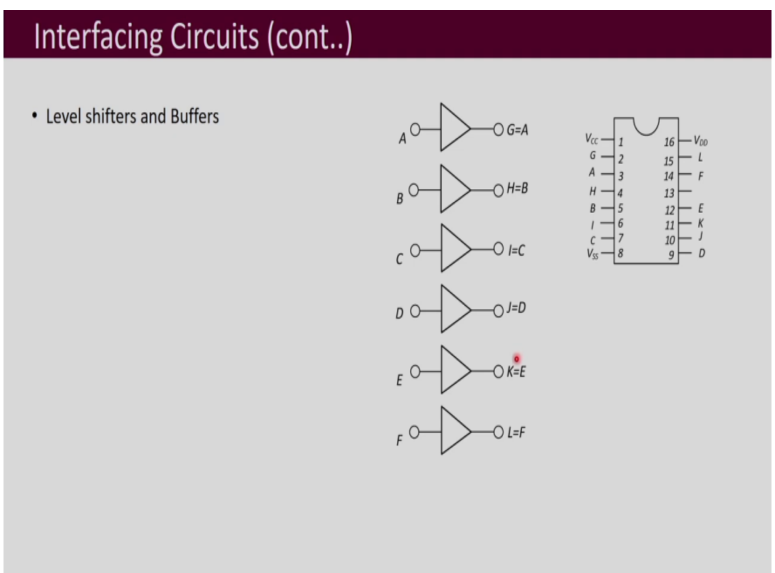

So, for that level shifting these kinds of ICs are used. So, these are your level shifter ICs or Buffer ICs this can be inverting or non-inverting. So, here you can see that this is a non inverting level shifter that is shown here. So, they provide both level shifting as well as buffer that means they give high impedance provide so that we are not overloading the, the microcontroller.

And apart from that in the interfacing we might have some logic gates also AND gates, NOT gates, whatever different types of such simple digital logic circuits might also be present in the interfacing circuit. So, interfacing circuit contains many miscellaneous circuits that you require usually between your driver and the controller, controller means here the microcontroller or the DSP or the FPGA or the between the sensed output and your controller. So, various miscellaneous circuits that are required that between these two parts is what are your interfacing circuits I can tell that as the interfacing section.

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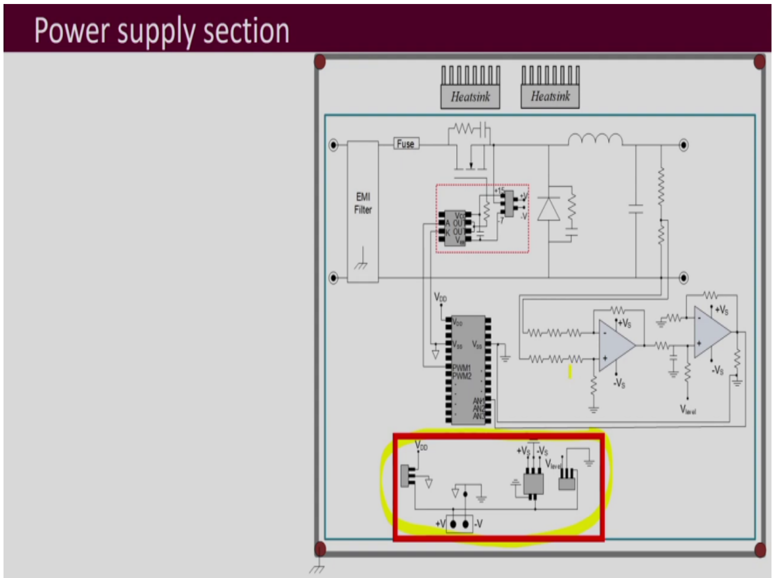

Then whatever all these different ICs that we may be using in your converter, they all have their own voltage requirement, they all may be working in different, different voltage levels. So, as I showed, I have shown you here this an opamp which works and let us say + V_s, - V_s. So, this can be + 15 /-15, + 12/-12 whatever it could be, depending on the opamps that you are using and plus here also this level shifter OPAMP that its voltage requirement and this V_{level} requirement and the V_{DD} requirement of this microcontroller.

So, all that we have to obtain using different ICs so, that consist of the power supply section. So, this is that power supplies section that is shown here. So, here this is a simple schematic so, it contains only few power supply ICs. Now, in large converter, there may be many miscellaneous circuits in the interfacing section and like you may be having logic gates or different level shifters and buffers and they all have their own voltage requirements all that has to be those voltage levels has to be created or generated by the power supply section.

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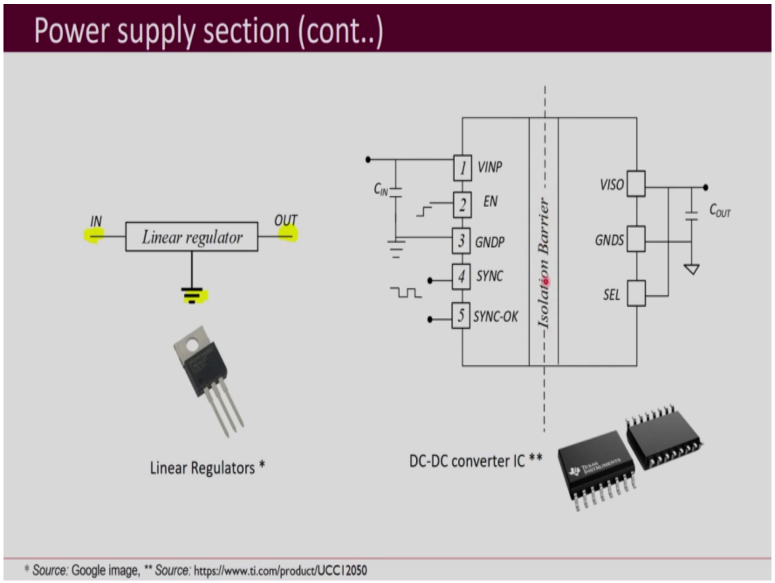

Now, what are the different types of ICs that are used? One is a very common one of which you may be familiar that is your linear regulator. So, that is basically a transistor which is operated in active regions it acts like a variable resistor in. We have to explain in very simple words, so, you have a input voltage here and then you have got an output regulated voltage depending on whatever the output voltage that you require like 5 V, 3.3 V ,15 V, 8 V whatever it is the voltage requirements that may be there and with respect to the reference of the controller usually, so, this is the reference that is shown here.

So, that is the linear regulator and this is a picture of a linear regulator that is shown over here. Apart from that, these days, we get DC to DC converter ICs also that means in one IC we can see an entire DC to DC converter that is present. So, you can have sometimes buck converter boost other converters as well simple very this DC to DC converters for small power ratings, which you can use to obtain the different voltage levels that you require.

And some of those converters are also providing isolation that means, those are isolated DC to DC converter inside one integrated circuit that means one IC you can buy that can be an isolated DC to DC converter. So, those can be then also be used for your gate drive circuits. So, that is what is one diagram which is shown here for this IC by Texas Instruments.

So, here you see here this the input voltage that is provided here that is a different level that is going to be then what is the output that you would like to get and then some clock pulses can also be provided in enable pulses can also be given with the help of the DSP or the microcontroller and it is an isolated DC to DC converter that is inside this IC isolated non-isolated both types of DC to DC converter ICs are available these days. So, you can also use those inside your power supply section to obtain different, different voltage levels that are required by those various types of circuits in your different sections.

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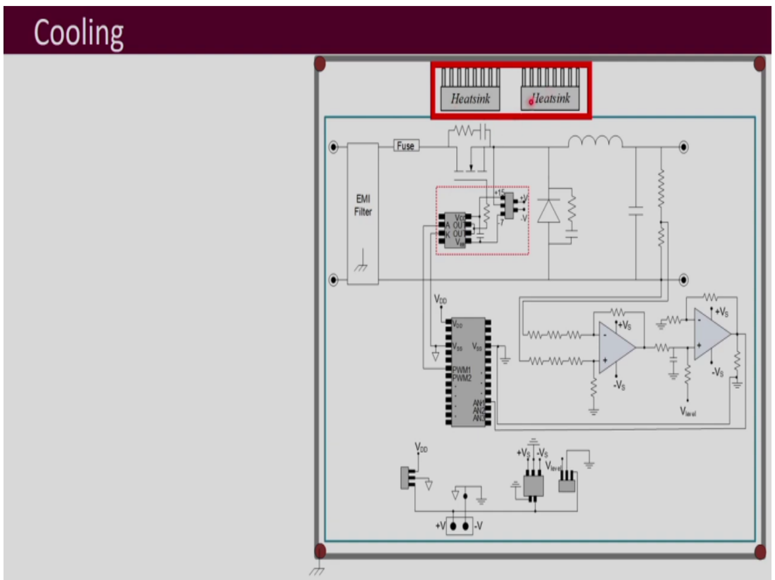

Then further, what is there is your cooling section that comprises of your heat sinks fans or if you have liquid cooling the cold plates and whatever the cooling arrangement further the accessories that are required for the cooling, so, that is your cooling section that will be there new converter.

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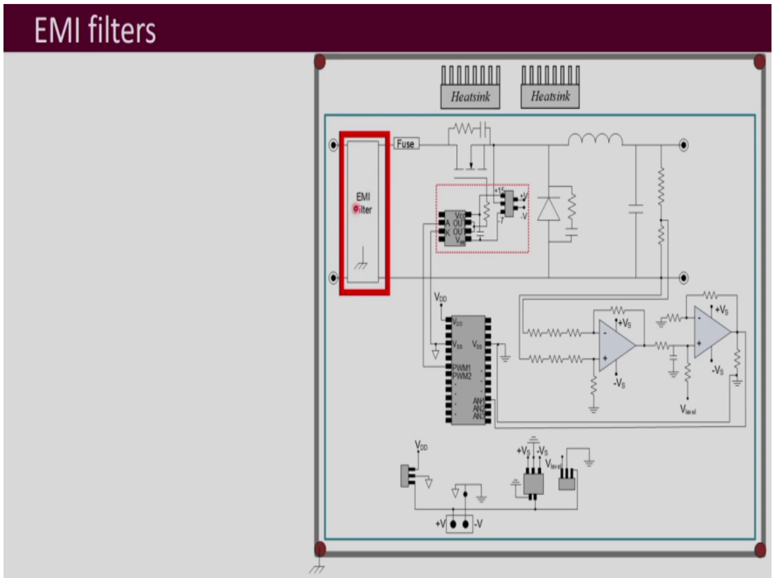

And plus you will be having the EMI filter section for reducing your conducted EMI.

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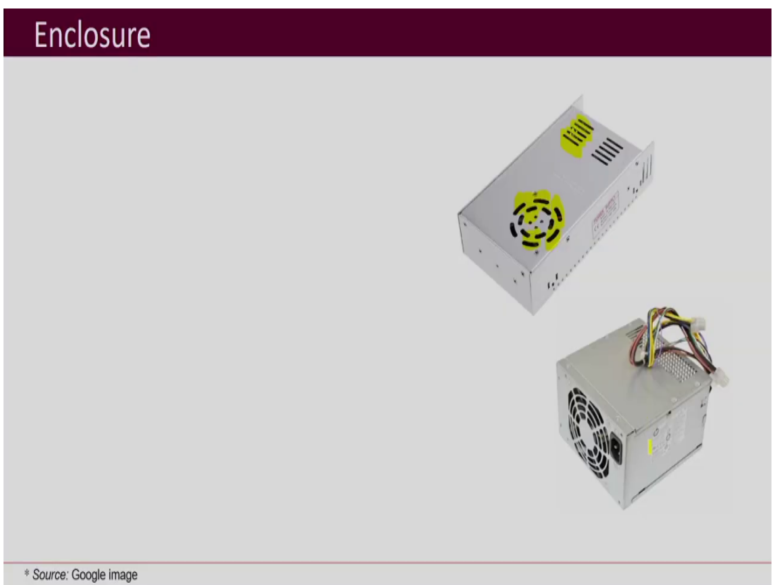

Apart from that, we should you should also keep in mind of the enclosure. Now, this I have noted it down as a separate section because enclosure design also one has to think of enclosure affects a lot your thermal performance as well as your EMI performance of your converter. These vents that you see here over here they are they not only help in cooling, they also change the radiated EMI performance. So, in this course, we are not discussing enclosure design, but know that that also affects the overall performance of the converter and you should have it in your mind while designing the converter. So, different types of enclosures may be designed for a particular power converter.

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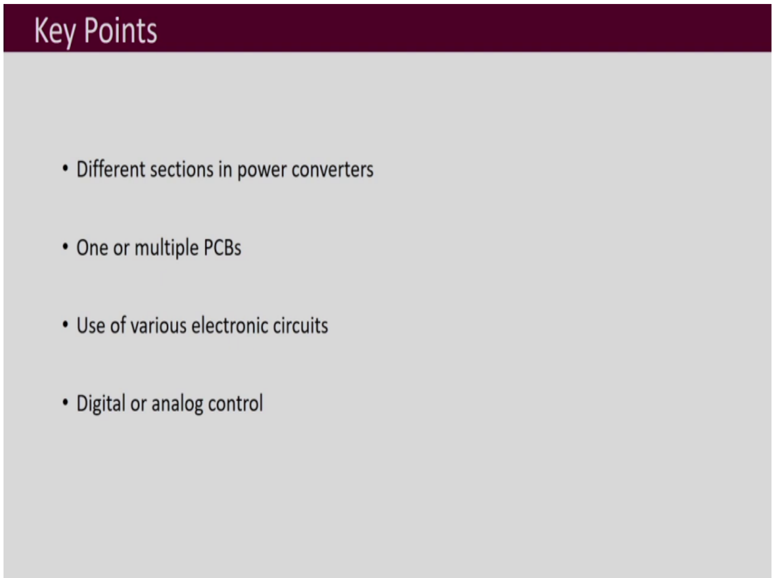

So, the key points of this lecture are in the different sections in power converters and you can have all these say all of these different sections in one PCB or you can have it in multiple PCBs it depends on the complexity of your power electronic circuit and how big or small your converter is going to be. And various electronic circuits are used it is not just the power electronic circuit its power electronic circuit is the heart of it the main heart of the power converter.

Apart from that you have sensors you have controllers and various interfacing circuit. As you may have different logic circuits, so, many miscellaneous circuits may be present. So, you should also have knowledge of simple analog electronics and digital logic circuits for designing your converter. So, and you can also choose to have digital control or analog control.

Analog control is used when we have very high switching frequencies and the application is less is simpler, where the control is not too complex where control is complex you have many things to control and the switching frequencies are relatively lesser there we go for digital control. Thank you.