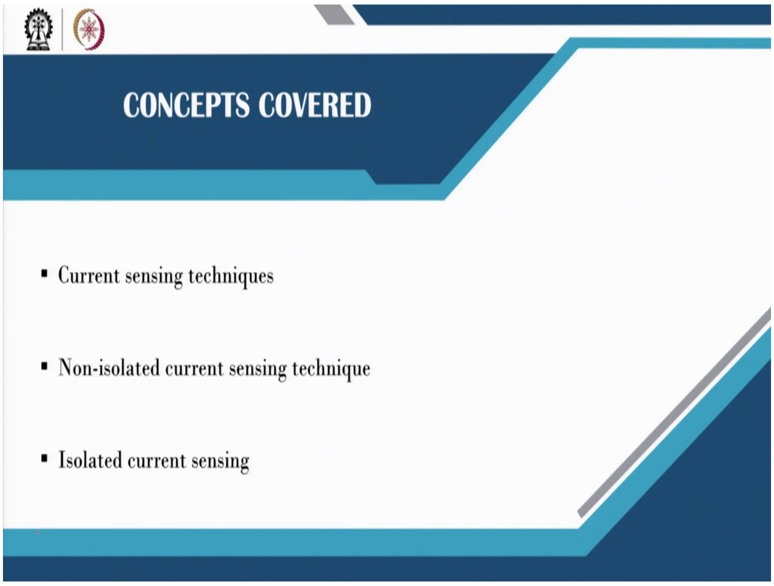
Digital Control in Switched Mode Power Converters and FPGA-based Prototyping

Prof. Santanu Kapat
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

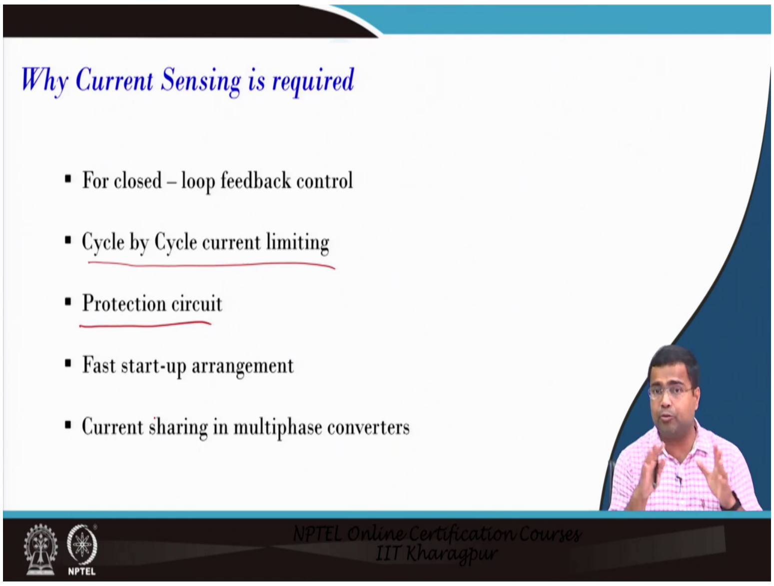
Module - 06
Digital Control Implementation and FPGA-based Prototyping
Lecture - 53
Current Sensing Techniques in Digitally Controlled High Power Converters

(Refer Slide Time: 00:31)



Welcome. In this lecture, we are going to talk about Current Sensing Technique in Digitally Controlled High Power Converter. This is the continuation of the previous lecture, here we will just want to touch upon the current sensing technique, what are the non-isolated current sensing technique, and the isolated current sensing technique and these are primarily used for the high power converters.

(Refer Slide Time: 00:45)



So, first of all, the current sensing is required you know for closed-loop feedback control because if you go for current mode control then current sensing is required and we know and depending upon whether we want to go for peak current mode control, valley current mode control or average current mode control. Then we may require a different type of current whether we need to sense high side current or low side current or we can we need to send the full current so, this all depends on your requirements of the control logic.

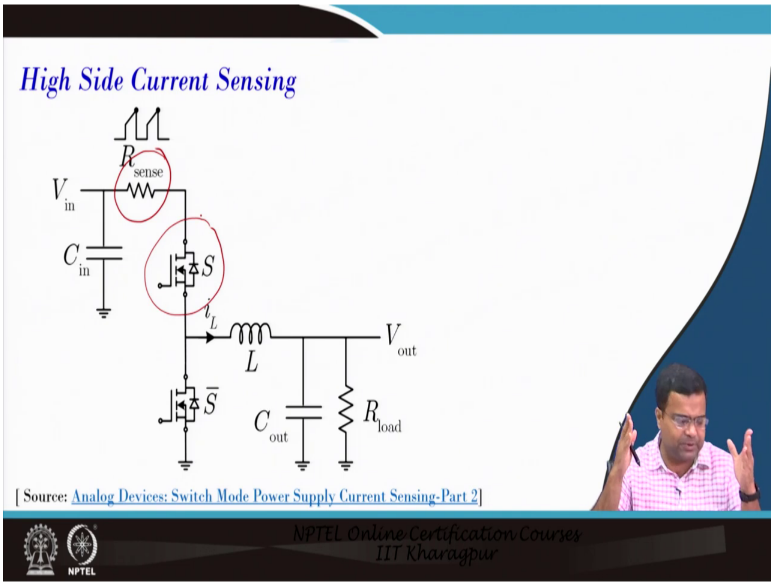
Sometimes the control logic is decided by the available current sensing I mean available sense current whether the high side currents are available. So, all these things we have to decide. Then the current in most of the cases product they use you know the current sensing for protection purpose; that means, this use high side current sensing for buck converter, you know they want to protect the circuit from the peak current protection.

So; that means, the current sensing is that protection purpose is one and the cycle by cycle current limit is also one, because during transient if the current overshoot is very large then you have to limit it because it may saturate the inductor. Then we also want to achieve fast data because if we go for voltage mode control-based start-up then we do not have the access current access or even if we have just protection current access.

Then in voltage mode control very slowly the output voltage is ramped up or V ref if there is a slew rate in the V ref that is very low. As a result, the voltage will rise very slowly but in most of the let us say if you are talking about mobile phones and others where we want to start the phone; that means, let us say it is in idle mode, but we want to start it up. So, for such cases, the starting up of certain sectors of power management requires a very fast startup and the current mode control can help.

The current sharing in multiphase is also very much useful we need some sort of current information for sharing the current among multiple phases.

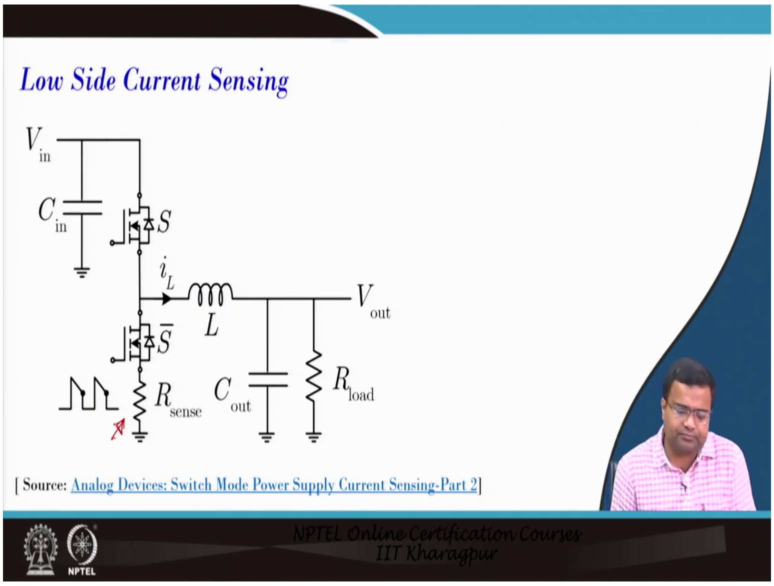
(Refer Slide Time: 02:56)



Now, if we talk about high currents and high side current sensing this we have discussed in the previous lecture. So, we are not going to spend time on that, but this is mainly for buck converter where we are sensing the either you know what is going inside the current. So, in most of the majority of the IC, they use the sensing circuit inside the silicon so; which means, they can use either the current mirror or sometimes they can use you know the RDS one of the MOSFET. So, there are multiple ways of sensing current.

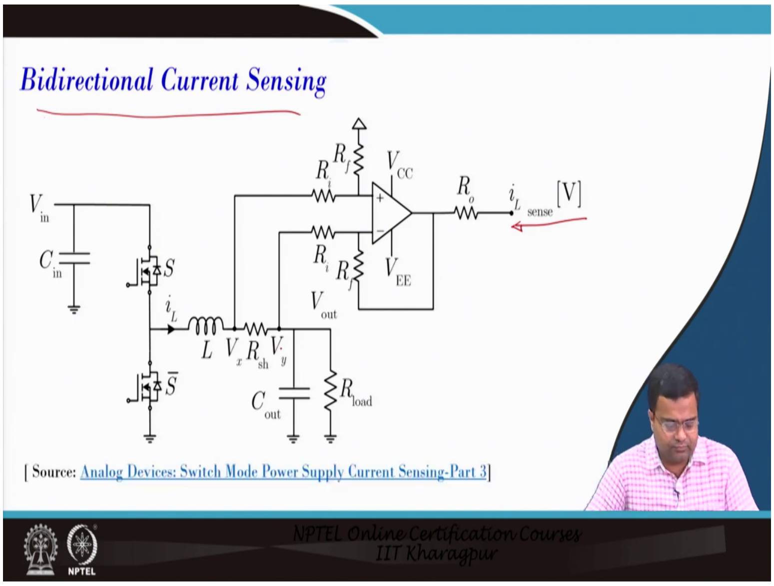
The low-side current sensing is easy you can put even a small resistance at the source of the in between the source of the low-side switch and the ground and then you can measure the current directly.

(Refer Slide Time: 03:28)



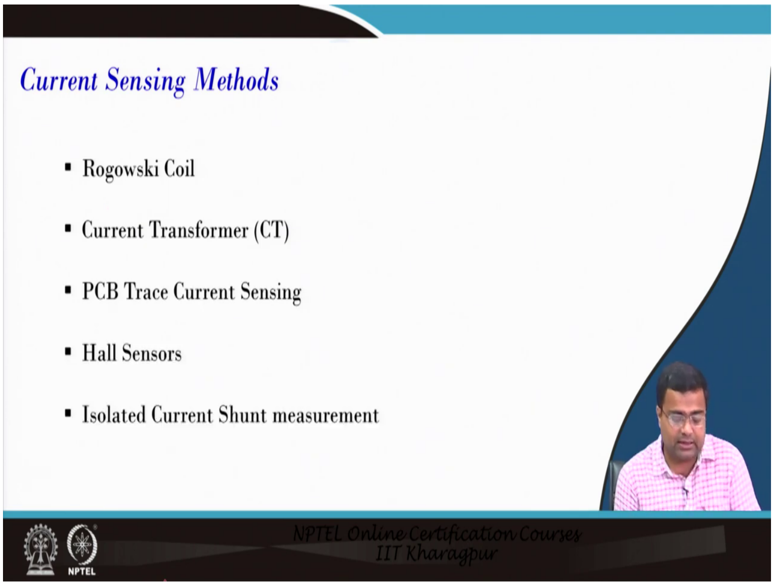
But, in many applications the low side current sensing let us say in buck converter, you can implement analog low site current sensing you can implement valley current mode control. But in digital even by sensing low side current, you can implement peak current mode control by using fully digital current mode control where the rising slope can be emulated inside the digital controller. So, many possibilities exist.

(Refer Slide Time: 04:06)



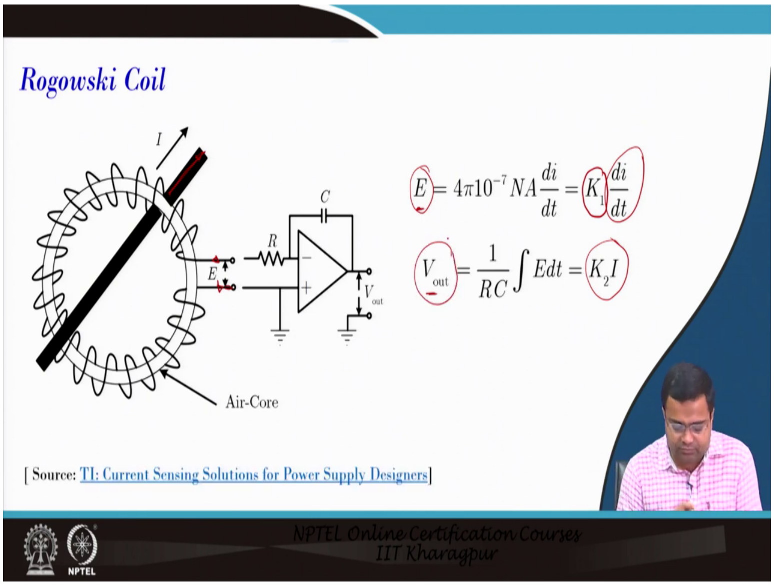
Now, the bidirectional current sensing: So, this is something like a full current sensing in this case; that means, we are putting a shunt; that means, the resistance in series is the inductor and in that way, we can sense the full current. So, this is a differential current sensor arrangement where we are sensing the current across the resistance and then this differential amplifier used to convert into differential current into you know comma like a single-ended voltage and the voltage is equivalent voltage is getting which is reflecting the sense current.

(Refer Slide Time: 04:46)



Now, in the current sensing method in high power, we will use a Rogowski coil, current transformer, PCB trace current sensing, hall sensor, and an isolated current shunt measurement.

(Refer Slide Time: 04:58)

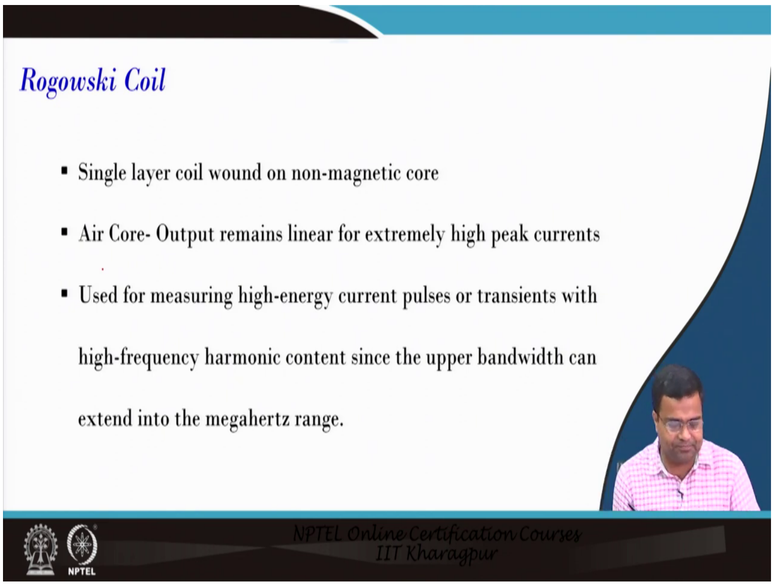


So, first, we will talk about the Rogowski coil, in this coil what does it do? So, the beautiful thing about this coil is that this coil has this one terminal here then wrap around then another terminal coming out. So, when the current flows through this and it is you know just it is kept just in wrap around the coil where I mean the wire which is carrying current whenever the current flows and, but the requirement here is that this current should be a change in current because; that means if there is a current flowing through this.

Then this current will cause an induced actual change in flux because we know Faraday's law and this change in flux will create an induced voltage. So, as long as there is a change in flux then only induced voltage will be developed otherwise it cannot. So, this is mainly used for AC circuits where the current is changing, because if you take the expression of the induced voltage it is some gain factor into di it; that means, the rate of change of current. So, if the current is constant then this circuit this technique cannot be used.

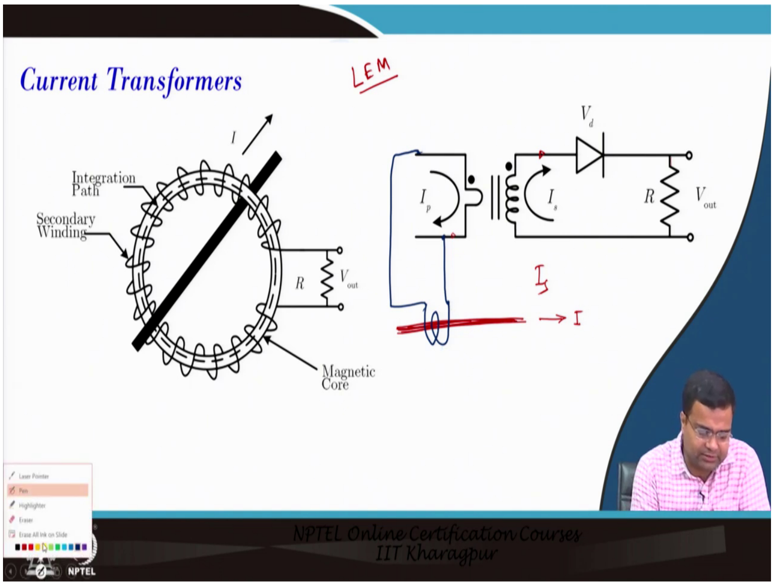
Now, since this technique uses the derivative of the current, we need to do integration; that means, if we integrate this then you will get the actual V out if we integrate then it will give rise to the actual current; that means, the actual current is obtained by integrating the output of this Rogowski coil and this overall voltage is actually analogous or the linearly proportional to the current.

(Refer Slide Time: 06:40)



Now, so, this Rogowski coil is a single-layer coil owned on non-magnetic core and air core - output I mean this flux; that means, the air core output remains linear for extremely high peak current. And this is useful for fast transient current even the pulse current.

(Refer Slide Time: 06:58)



Next, going to the current transformer: So, the current transformer again the current transformer means you have a primary side and the secondary side. So, the primary side coil actually is used and actually, if you take the primary side coil then you have to insert the wire which is carrying current through the primary side coil; that means, if you take this you have to insert this actually three dimensional.

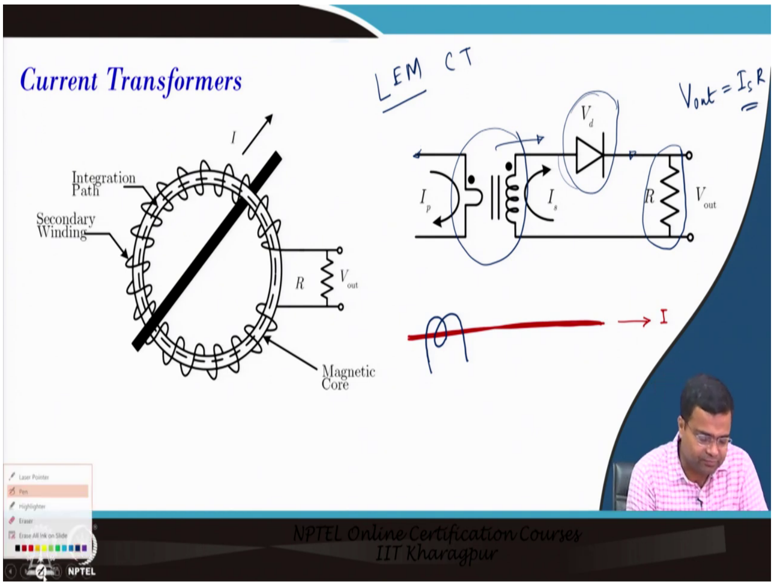
So, this is the let us say current is carrying and whenever current so, is (Refer Time: 07:42). So, now, we are talking about the current transformer ok CT and you know you know about LEM current sensor which uses a current transformer, it has a primary and the secondary side. Typically, the turns ratio is very high, so that whatever current is going through it that should be attenuated in the secondary side, because this current transformer should not be left open. So, there used to be one resistance here and typically this resistance is high.

So, the current should be stepping down; that means, the primary to secondary current should be reduced attenuated by this factor if you know about how the turns issue and the current ratios are related. So, here typically on the primary side either it can be one turn or two turns, and this turn is made suppose we are carrying we are trying to measure the current through this a wire.

Let us say this is a wire and this wire is carrying current this carrying current then what we do typically, we typically put this kind of maybe two winding. So, this is your primary side winding I am talking about these two terminals, maybe this is connected here and this is connected let us say here this secondary side or if I just reverse this diagram this would be better. So, what I will do? I will just make on the other side that means.

So, let us say this is connected here, and let us say this is connected here. So, this is a primary side instead of one turn it can be two turns right and then actually this. So, (Refer Time: 09:43) just I think I made a mistake.

(Refer Slide Time: 09:57)



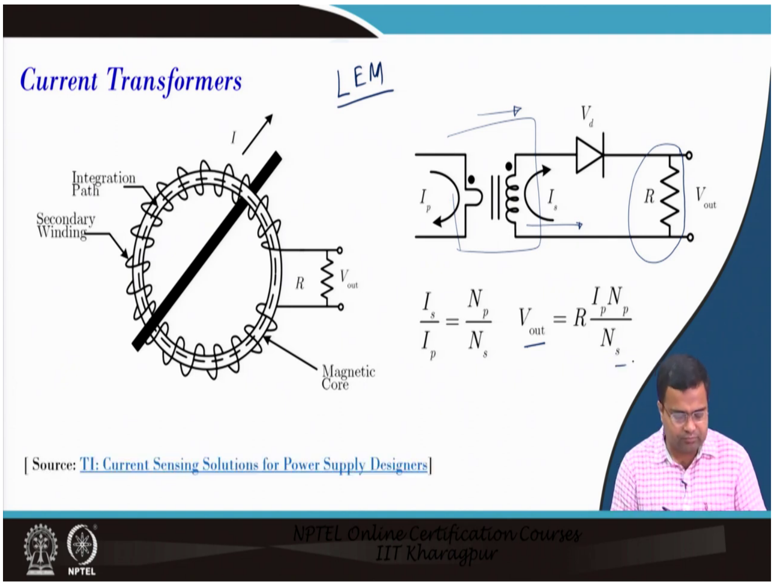
So, now coming to the current transformer so, what does current transformer do? So, let us consider a wire-carrying current. So, this is a wire this is a thick wire and it is carrying current I, now what do you have to do?

We need to put a primary coil, this is a primary so; means, the coil and this coil this is a primary turn ok; that means, then the secondary side; that means, if there is a current flowing through it then this current reflected in the secondary side and then the secondary side there is a diode here and the secondary side the turns ratio is taken in such a way you know if you go to LEM sensor current transformer CT.

So, this current is reduced substantially and this current transformer of the secondary side should not be left open so; that means, we put a resistance here. So, whatever current is going the secondary side into R that will be your V out is your I s into R. So, this R is typically you know 1-kilo ohm or maybe 100s of ohm and you need to accordingly decide. So, this I s and I p will be related by this turns ratio, and then it will you will get the actual.

So, this current is going through it, and this is converted into the secondary side. Now, in this current transformer we need to put a diode, why do we put a diode? Because when the current you know because if you go to the transformer is required if you disconnect this path suppose the current is negative then what will happen if the current goes negative for positive current this is fine negative current this flux has to be reset, that is why the diode is there ok once more.

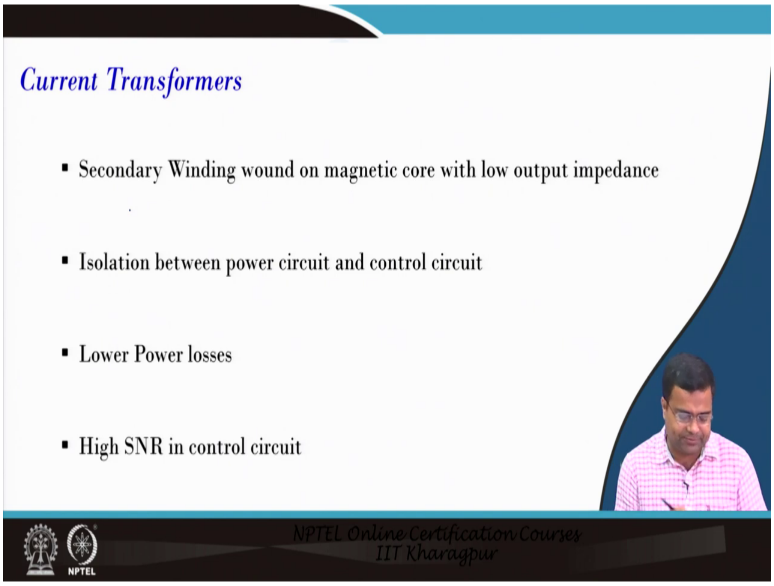
(Refer Slide Time: 12:09)



So, this is a current transformer, in the current transformer one of example is the LEM current sensor which is the current transformer. So, the primary side coil actually whatever current is passing through that goes to the secondary side coil. And the secondary side there is a diode and now how it works; that means, it is using a current transformer principle and the step-down ratio is quite small the current.

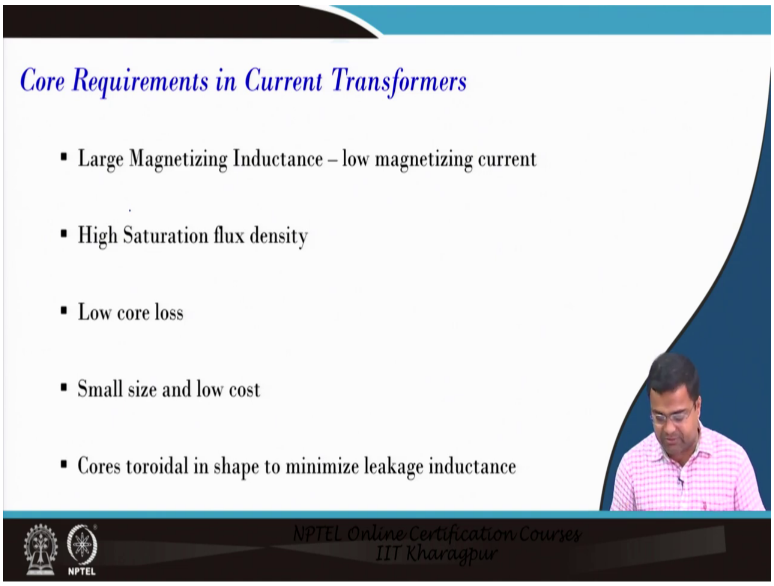
So, the secondary side's current is low and the secondary side should not be left open so, you need to put a resistance. So, the secondary current into resistance will give you the equivalent analogous current which is flowing in the primary side ok. And this is a turns ratio. So, V out equal to I p N p by N s where I p is the primary side current and N p is the primary side winding turns ratio and the secondary side transition.

(Refer Slide Time: 13:02)



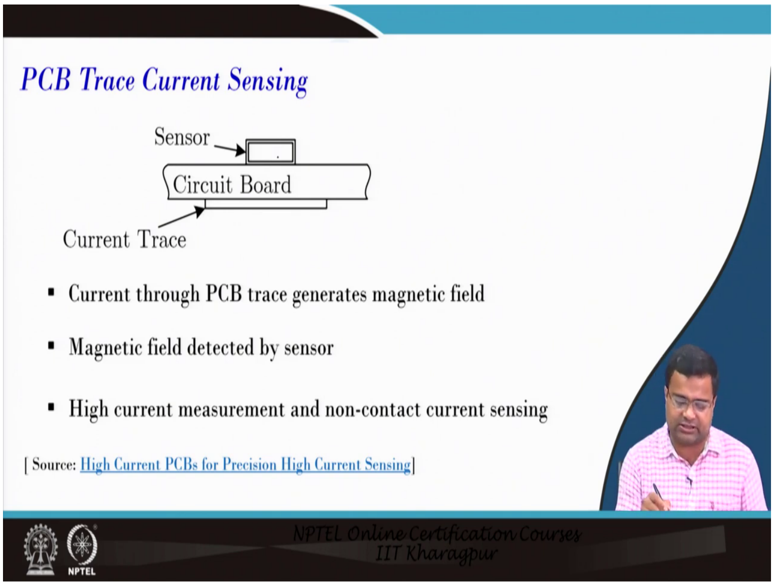
So, the current transform on the secondary side is one so, it has it should have a low output impedance and it gives you isolation between the power circuit and the control circuit. And the power loss can be reduced in this case the transformers should have a very low power loss and this kind of sensor also gives you a high signal-to-noise ratio.

(Refer Slide Time: 13:30)



And the requirement of the current transformer, the current transformer should have a very high magnetic inductance so that the low current magnetizing current should be very very low. And the saturation flux should be high so that it can swing you now to large extent. The core loss should be reduced and also size and the cost should be reduced. And then it is if you take a toroidal kind of shape then you can also reduce or minimize the leakage inductance.

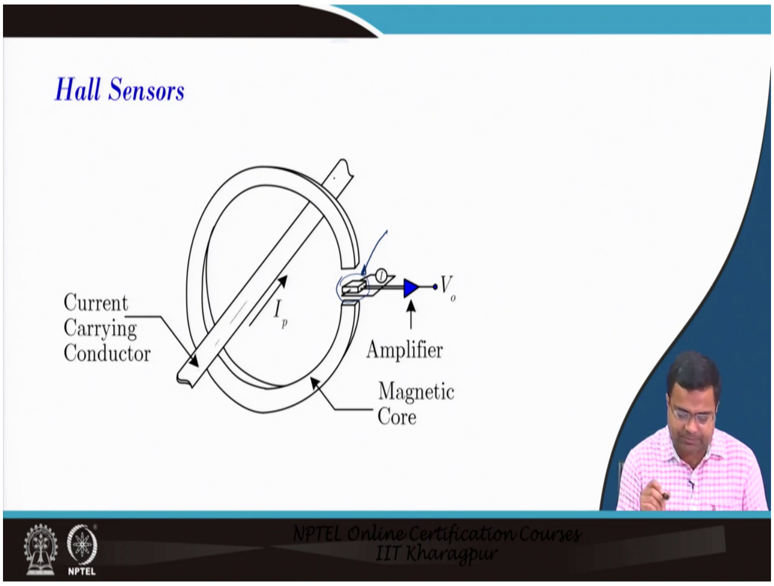
(Refer Slide Time: 13:57)



Now, if you are going for PCB trace current sensing typically what we do in through a PCB you know trace current. So, it generates a magnetic field in the PCB trace because whenever the current flows through the trace any current flowing through a trace it will create a magnetic field. The magnetic field detects by a sensor.

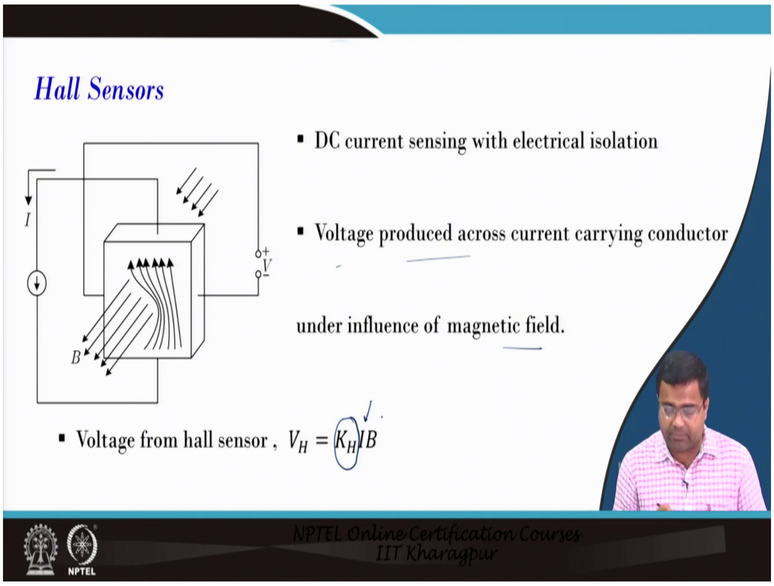
So, you will place a sensor here and then the high current measurement and the non-contacting current sensing this technique because you are not physically cutting the path you are just putting on top of the current path; that means, and then, but this sensor you have to be you know non-invasive sensor; that means, you are not breaking the loop you are just touching on the path where the current is flowing through.

(Refer Slide Time: 14:50)



The hall sensor is another you know kind of very important sensor, where is the hall sensor principle? So, the hall sensor works in the principle that it has its voltage this is a sensor hall sensor, and if you keep this sensor close to the magnetic field, because if the current is flowing through this path and then it will create a magnetic field.

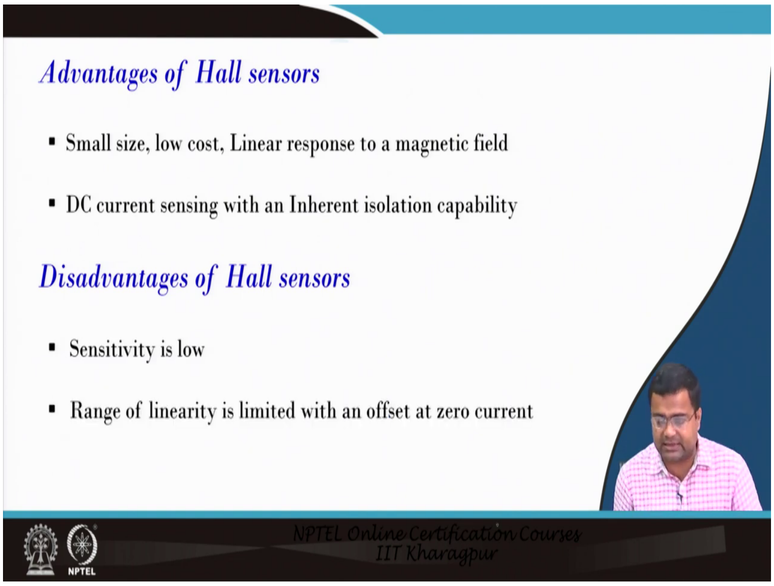
(Refer Slide Time: 15:19)



And this magnetic field will influence the voltage produced across this sensor. This voltage produced across the sensor will be influenced by the magnetic field; that means if the magnetic field changes the voltage will change and that will capture the current flowing through this conductor.

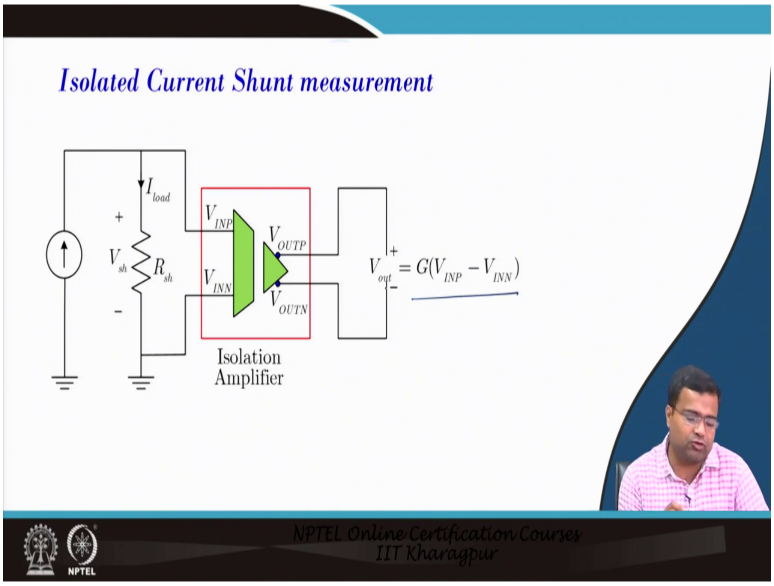
So; that means, the DC sensing with electrical isolation there is no physical connection, and the voltage is produced across the current wire-carrying conductor under the know influence of the magnetic field. So, that will be the voltage and this voltage of the whole sensor is nothing but is a constant I into B where I is the current flowing through this and B is the magnetic flux density.

(Refer Slide Time: 16:02)



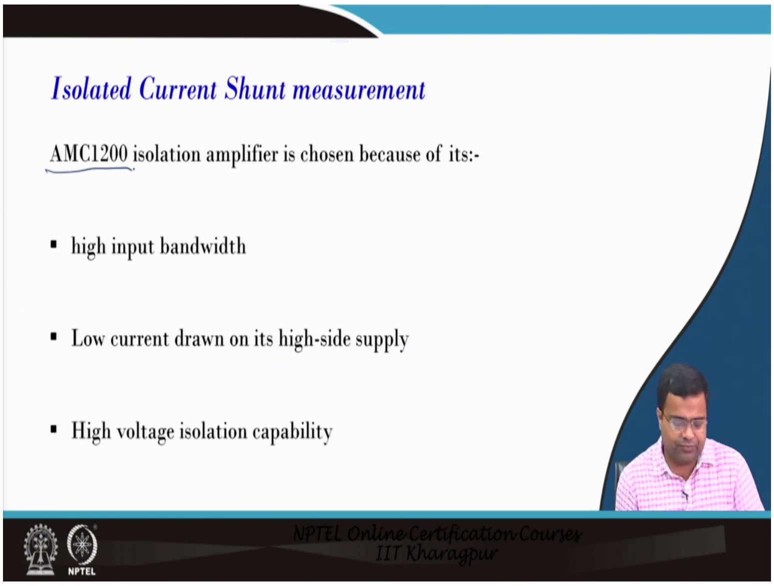
So, the advantage of the hall sensor; is the hall sensor can be small in size, low cost, linear response to a magnetic field, and DC sensing with an inherent isolation capacity. Disadvantage; it has a low sensitivity and the range of linearity is limited.

(Refer Slide Time: 16:18)



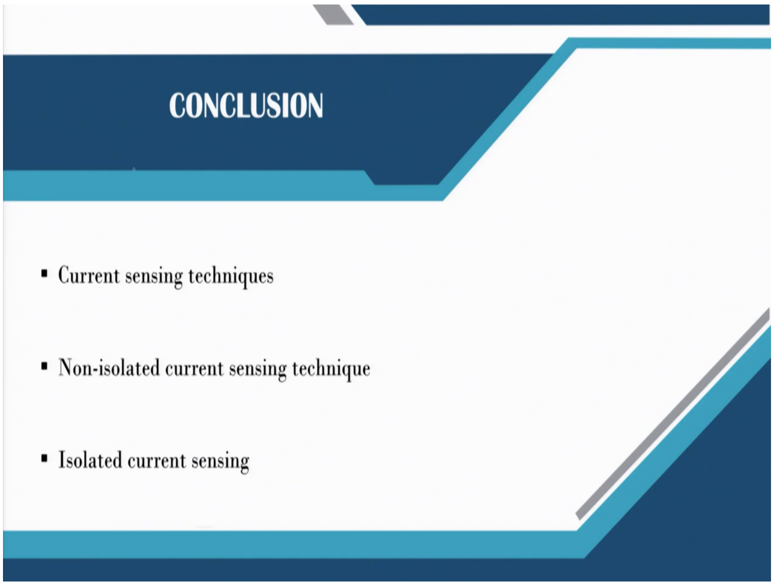
Another current sensor is the isolated current shunt measurement where if you are sensing using a shunt you know current; that means, the current is flowing through the shunt and we also need isolation. Then we can use an isolation amplifier and this amplifier output is in the differential form then we have to take the have we may have to use another stage of differential to single-ended conversion. So, in that way, you will get the voltage corresponding to the current flowing through that high current path.

(Refer Slide Time: 16:54)



So, typically AMC 1200 is one example of an isolation amplifier it has high input impedance, low current drawn, and then high voltage isolation capability.

(Refer Slide Time: 17:07)



So, in summary, we have discussed various current sensing techniques, we have discussed non-isolated current sensing techniques and we also discussed some isolated current sensing techniques. So, with this, we will go into more of the hardware implementation and will present what current sensing we have used in our PCB for this teaching kit and which will be used in this particular lecture that is it for today.

Thank you very much.