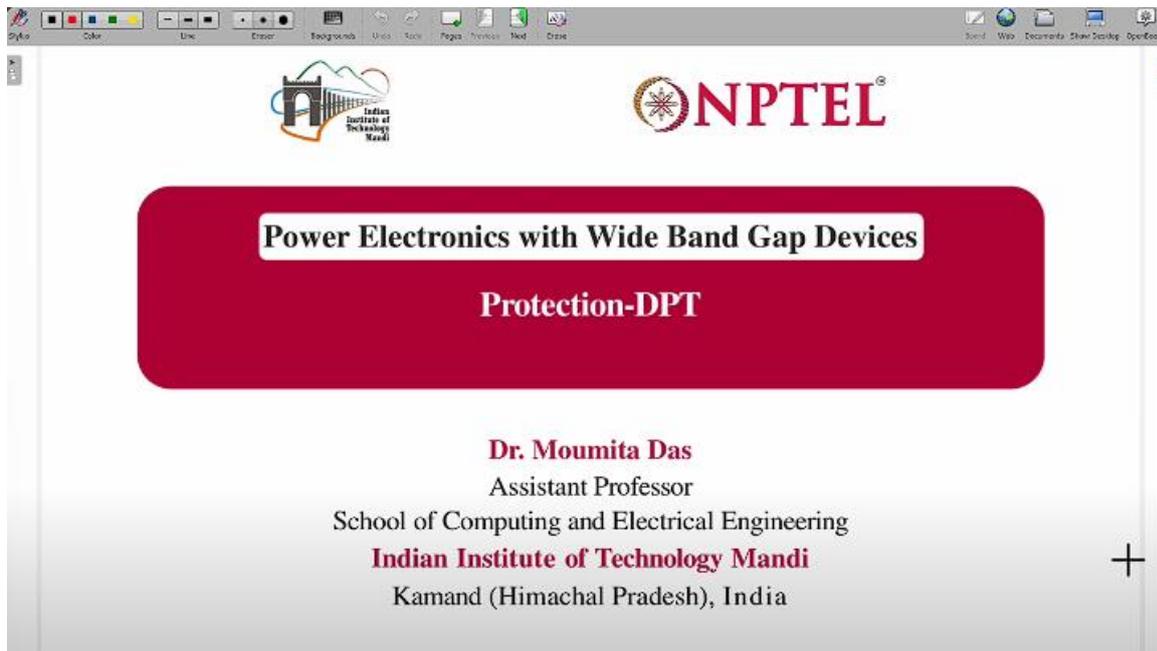


Power Electronics with Wide Bandgap Devices
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Lecture-12
PROTECTION-DPT

PROTECTION-DPT

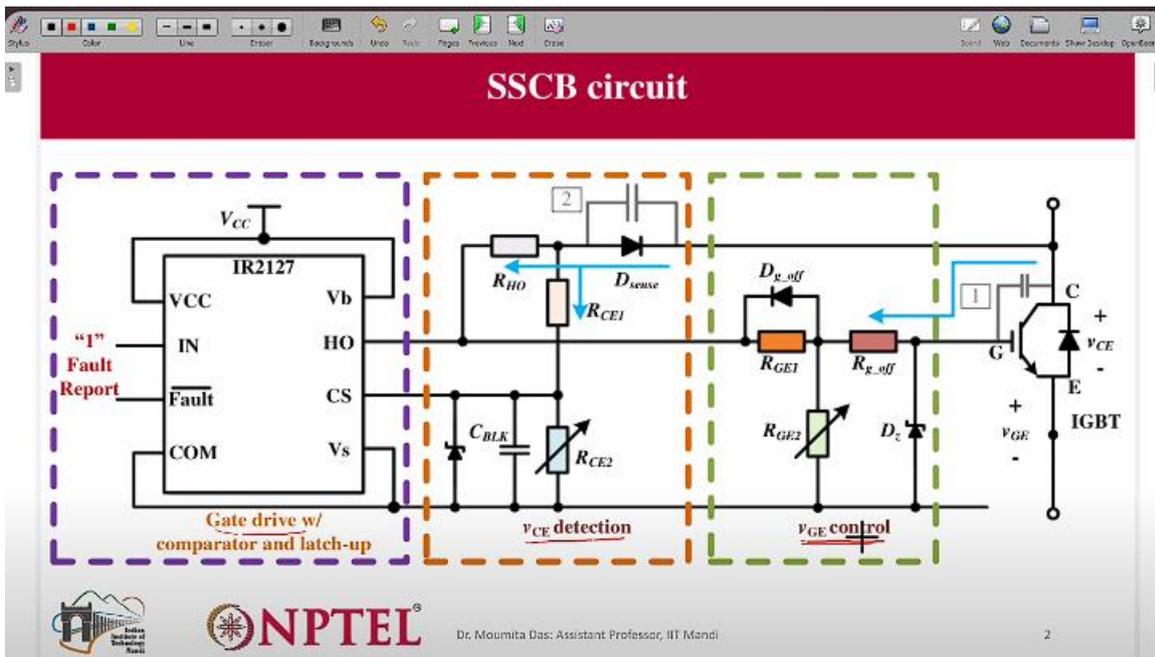
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The image shows a screenshot of a presentation slide. At the top, there are logos for the Indian Institute of Technology Mandi and NPTEL. The main title of the slide is "Power Electronics with Wide Band Gap Devices" and the subtitle is "Protection-DPT". Below the title, the presenter's name "Dr. Moumita Das" is listed, along with her title "Assistant Professor" and affiliation "School of Computing and Electrical Engineering, Indian Institute of Technology Mandi, Kamand (Himachal Pradesh), India". The slide is displayed within a software window with a standard toolbar at the top.

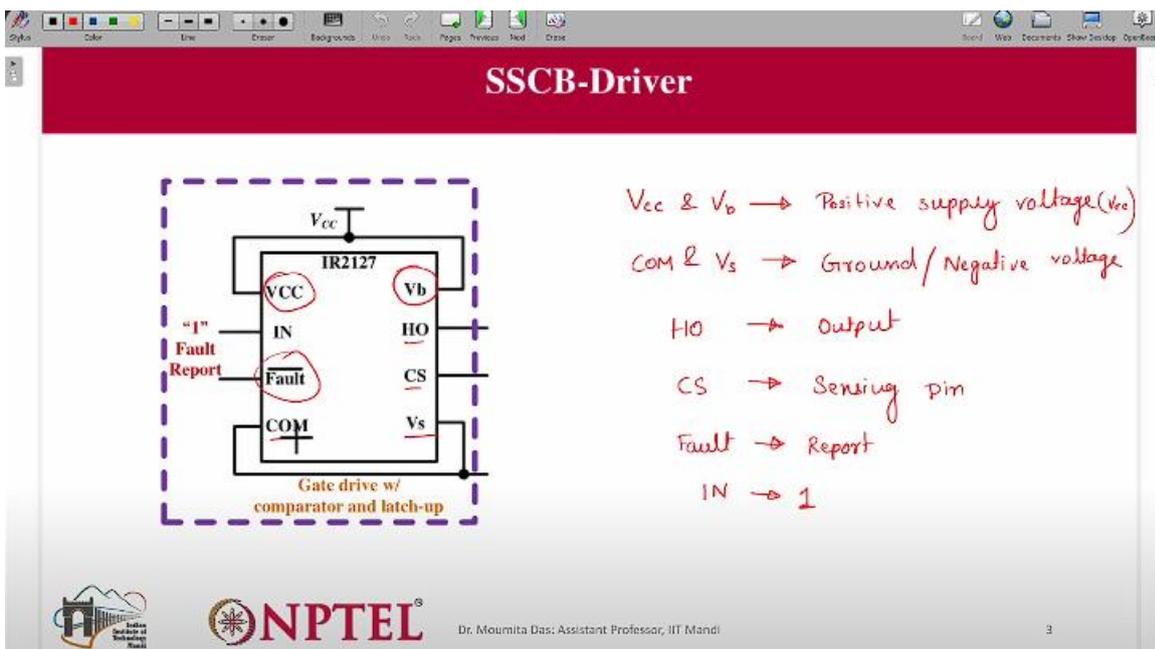
Welcome back to the course on Power Electronics with Wide Bandgap Devices. In the last lecture, I have discussed about different protection techniques which we can use for DPTs. Out of those techniques, most of them are suitable for the devices where the device parameters are known. But if the device is new and parameters are not known, so in that case, all the protection techniques are not suitable, because some of them require information about the devices. So, in that case we need a protection technique. So, where it can provide the protection for the device where the parameters are not known.

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So, there comes one protection technique. So, that is known as solid state circuit breaker or SSCB. So, the circuit diagram of SSCB is shown here. So, today I will be discussing about details of this SSCB circuit and the operating principle. So, you can see here. So, different parts of SSCB is shown in different blocks. So, here the first one is gate driver, so you can see this is the gate drive block which is shown in the purple dotted block and then in the orange one is the VCE detection. Now this VCE detection it is for IGBT. Now if it is MOSFET then you can consider it is VGS sorry VDS detection now after that VGE control. So this VGE control. It is for IGBT and for MOSFET you can consider VGS control. Okay, so now I will be discussing details of each network.

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So you can see here this is the driver network. So you know the gate driver, so the working principle of the gate drive remains same. So it amplify the voltage level. But in this particular case since we have included protection, so the protection part is also included in the driver component. So either you can use the protection separately or there can be inbuilt driver pin which can provide protection or that can get the information from the device and provide the gate signal based on the information. If the device is operating in normal condition, then it will keep on sending the regular gate signal. If there is any fault condition then it will detect and then immediately send turn off signal to the device in order to protect the device. So that is why this particular driver IC it is shown here. Here you can see the fault pin is included. Means it is considering the protection part. So here there are actually different pins of these devices. So you can see here VCC and VB, it is shorted. So you can see here these two pins VCC and VB, These two pins are shorted. And it is connected to the positive supply voltage VCC. Positive voltage here it is shown here as VCC. So this VCC can be any voltage depending upon the device requirement. For silicon and silicon carbide it can be 15 volts. For GaN it can be 5 volts. So it will take according to the device voltage rating. Now the common and VS pin, so you can see this common and Vs these two pins are also shorted together and it is connected either to the ground terminal for only one polarity voltage and if it is having negative voltage during the turn off, then this will be connected to the negative voltage. Okay. Now other than these four pins there are other four pins. So among other four pins you can see here. So this HO it provides output of the gate driver. Output means this signal, the signal whatever gate driver is generating, so that it will go to gate terminal of the device by this output terminal. So, this output terminal will be connected to the gate terminal of the device. Now, there is one point here below this HO, this is CS. So, CS it is actually getting the input from the device. So, sensing input. Sensing pin, so this gather the information from the device, so whatever component or whatever parameter we are using for the protection, it can be let's say the voltage across the device, that is VCE or VDS or maybe if we are considering di/dt kind of protection, so that kind of information it can gather from the device and then it provide to the sensing pin. Now sensing pin once it is sensing then it will compare with the threshold voltage or threshold protection parameter. Then it will decide whether there is a normal operation or faulty operation. If there is a faulty operation then this fault pin is given here. So it provides fault report. If it is normal operation it will say that okay fine. Otherwise it will give the fault signal. So it will provide the fault report. It will provide the report if there is fault condition. If it is normal condition then it will operate in normal condition. Now, once this fault report is provided, so then get signal will be modified according to that. Means even if there is like signal which is coming from the microcontroller, it is giving some signal but this fault pin it is providing report that there is a fault condition in the circuit, so then what will happen immediately the gate drive will decide to turn off the device by providing the turn off signal through this HO pin. Okay. This IN pin here it will remain 1 condition or the 1 condition, it can in all all the time so, it can also be connected to the positive supply voltage so that it will be ensured to have 1 signal or the like this there can be either zero or 1. So one means like it is ON. So this pin is always on to ensure that it can also be connected to the positive supply voltage point. Okay, so these are the different pins of this gate drive. So now this HO output will be connected to the gate drive, sorry not gate drive, to basically the gate of the device. Now before that, there will be sensing input. So this sensing input will sense the voltage across

the device. Here the voltage will be VCE. So the next slide discusses this VCE detection. So this VCE detection once it is sensing. So this particular pin you can see here so this particular, I will just write down then it will be easier for you to understand. So this particular pin is the CS pin of the gate drive and this is the common or the VS, so you can see here, So this common or the VS pin. So that is basically ground pin so that is connected here. So this is VS pin.

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SSCB-Fault Detection

- ① Diode D_{sense}
- ② R_HO → charging resistor
- ③ V_{CE} → R_{CE1} & R_{CE2} for voltage divider
- ④ C_{BLK} → Blanking capacitor

So in this particular slide I will be discussing about this CS and VS pin. So basically the input will be going to CS and VS. So, basically the CS pin will sense the signal and that signal how it is coming? So, that will be coming from the output. So, now you can see let me go to the previous diagram. So, you can see here this particular pin. So, we are talking about this particular block. So, this particular pin it is connected to the common terminal or basically you collector, sorry collector terminal of the IGBT. This particular pin it is connected to the emitter terminal of IGBT. So, CE this is coming across this particular block. So, let me just write down that then it will be easier for you to understand. So, this particular block, it is actually it is connected to VC and VE so I can just write down here the voltage whatever it will be getting, so that is VCE. So this will be the voltage across this particular points. Okay, so now VCE is coming across it and it is generating VCS signal. Now, once this VCE is coming across it, so this is coming from the device, then what will happen? So, this will cause voltage to be generated across VCS pin. How this voltage is generated? You can see here. So, basically it will have different component you can see here. So, one is the, so, let me just write down 1 is the diode D_{sense} what is given and here R_{HO} is given here, it is charging resistor, now VCE related resistor it is R_{CE1} and R_{CE2} . It is working as voltage divider. Now you can see here this R_{CE2} it is variable. The resistance R_{CE2} , it is shown here as variable because it will provide the required voltage to the gate drive input. Now this required voltage may vary means if there is very high current, very high current it can come from the upper device or the another device through this miller capacitance, so the miller capacitance is shown here, so this through

this miller capacitance if there is very high current is coming So then it will give very high voltage across these resistances. So if the resistances are fixed then what will happen it will not be able to provide the suitable voltage to the gate drive input. That is why in that particular condition any of the two resistances either VCE1 and VCE2 we can keep variable and we can actually modulate the value so that it can provide the required voltage or the safe voltage. So, that is why it is shown as variable. Now, 4 is the blanking capacitor C blank. Why we have this capacitor? In order to reduce the noise in the input signal. So, these are the different parameters of this particular VCE. Now, I will be discussing details about this VCE operation in the in the next slide. So, first I will discuss about this gate control path and after that I will be discussing about that particular path. So now, so these are the different components involved and how it is working that i will be discussing, um at the end. So now you can see here this is the control input.

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SSCB-Control Input

① R_{GE1} & R_{GE2}

$$V_{GE} = \frac{R_{GE2}}{R_{GE1} + R_{GE2}} \times V_{CC}$$

② D_{g-off} , R_{g-off}

③ D_z - zener diode

So control input where it is exactly connected, so this is connected to the HO pin. And this is connected again to the VS pin. So let me go back to the previous slide so that you can connect this particular point. So you can see here this HO pin is connected to this Dg_off and RG1. And then this VS pin is connected to this negative pin. So these two pins we are talking about here. And then output it is connected to gate and emitter terminal of the IGBT. So, let me just write down that. So this is VGE. Okay. So the output whatever going is going from the gate terminal. So that is going through this VGE1 and then so you can see here two different resistances are given VGE1 sorry, RGE1 and then RGE2. So RGE2 is variable resistance again and then there is another resistance which is RGOFF. So let me just write down different components here. So you can see here so different components here are first is the RGE1 and RGE2. Two different resistances are given. So, what is the function of these two different resistances? Again it will give required voltage to the gate drive. So, VGE it will be related to

these two resistances by this equations. RGE2 divided by RGE1 plus RGE2 multiplied by VCC,

$$V_{GE} = \frac{R_{GE2}}{R_{GE1} + R_{GE2}} \times V_{CC}$$

because this voltage, here so you can see here so this gate drive voltage will be VCC input it will be getting VCC. So based on this resistance or the voltage divider this VGE will be generated. Again we can actually vary this RGE2 and based on that this VGE can be also be changed Okay, now there are other components also.

You can see here there are actually component which is having name with respect to OFF. So, Dg_off and Rg_off it is given. So, Rg_off is considered to be resistance for the turn OFF condition. So, basically the DG of it is bypassing the resistance RGE1. So what happens, whenever we are providing or we want to turn OFF the device, so then if we as i have discussed earlier if we use the same resistance, so then what will happen the response or the operation may not be optimum, so that is why during turn ON and turn OFF condition. We can use two different resistances the same principle we are using here only case is that during the turn ON condition this Rg_off it is coming in series. And during the turn OFF condition this diode DGOF it is bypassing this resistance RGE1. So only one resistance is coming. So then if this resistance is having small value. So then it will turn OFF the device faster. So in case of protection, so we want to turn off the device as soon as possible. So there will be some time given. So like from the detection to the device turn OFF, so that time it is actually different from the different for the different devices for silicon that time is bit higher for wide band gap device that time is very small so that is why if we try to keep this resistance small. So then we can turn off the device in like very short time. Now again we cannot keep this resistance very small. So then what will happen? Then the problem is that so this resistance can cause any like if the device turn off like in super fast condition, so then that may destroy the gate drive part. So, then what will happen if this Rg_off if we try to keep zero. So in no time the device will turn OFF. If the Rg of is zero then very high current can flow through the device or the driver part. So here I am referring the driver as the device, so here the Rg_off that is why we try to keep in optimum condition for turn ON condition. Okay? Now third part is the Zener diode, Dz. Right, so these are the different components of the VGE control.

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SSCB-Control Input

NPTEL
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Now you can see here so again if the SSCB control input is shown here, so here the miller capacitance is shown here, so if there is like if this R_{g_off} we try to keep very small, so there will be very high current can flow, so so basically the voltage drop across the device will be very high, so that can actually destroy the device. So you can see here so during the turn OFF of the upper device the current which can flow through this resistance it can be very high so then i with respect to this miller capacitance can destroy the device so that is why we I have discussed earlier how we can provide miller clamp or maybe the path for this current, but that is like already we have discussed, so I am not discussing that part again here now. Let's go back to the discussion of this VCE detection.

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Vce detection

$$i_{CHG} = i_{RD} + i_{DSAT}$$

$$i_{RD} = \frac{V_{RD}}{R_{CE1} + R_{CE2}} = \frac{V_{DSAT} + V_{CE}}{R_{CE1} + R_{CE2}}$$

$$i_{DSAT} = \frac{V_{CC} - V_{DSAT} - V_{CE}}{R_{HO}} - \frac{V_{DSAT} + V_{CE}}{R_{CE1} + R_{CE2}}$$

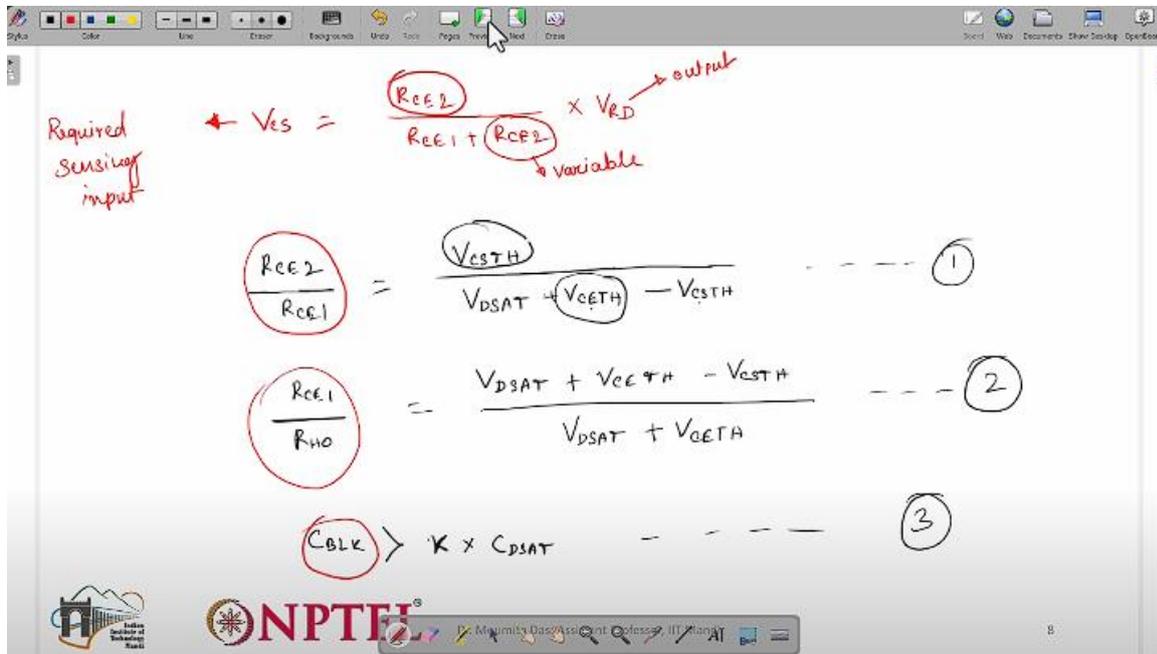
$$i_{DSAT(max)} = \frac{V_{CC} - V_{DSAT} - V_{CE(min)}}{R_{HO}} - \frac{V_{DSAT} + V_{CE}}{R_{CE1} + R_{CE2}}$$

Now VCE detection already you have seen, so you can see here the components which are involved in this, VCE detection, so they are three different resistances, one diode and one capacitor. So, let me just write down. Let me just actually discuss it here only. So during the operation of this VCE, so then what will happen? So basically the current which flows from this particular pin, so this pin is connected to HO pin. So this pin is connected, you can see here this HO pin. So now during the normal operation, so the current from HO pin, it will go to RHO and some part will go to this voltage divider path, some part will go to the output. So now out of this so if I represent this current in terms of let's say this is charging current. Okay, this is going here and then the current it is divided in this two, I can represent this as i_{RD} and then the output current I can represent it as $i_{DSAT(max)}$. Okay, so the current, now I can write down here as there are three different current component, so I charging current which is coming from the input, it is having two different component then one component is going to the voltage divider part and then another component is going through the diode. Ok? i_{CHG} is equal to i_{RD} plus i_{DSAT} .

Now, these two out of these two current, this current i_{RD} will depending upon the voltage V_{RD} divided by two different resistances R_{CE1} plus R_{CE2} , right. These two different resistances are present. This V_{RD} , we can actually represent as the voltage drop across the diode $V_{D(sat)}$ plus output voltage V_{CE} divided by R_{CE1} plus R_{CE2} . Right? Now the current which is going to the output that we can represent as V_{CC} minus $V_{D(sat)}$ minus V_{CE} divided by R_{HO} which is shown here or R charging capacitors R_{CE} . okay? so here in this diagram I have shown R_{HO} , so I am just writing so you can see here. So, this R_{HO} is shown here. So, that is what I am writing now. Okay. So, now this can be subtracted from the current i_{RD} . So, that is $V_{D(sat)}$ plus V_{CE} divided by R_{CE1} plus R_{CE2} . So, this particular component is with respect to I charging and this particular component is with respect to i_{RD} . So, this is the current which is going to the output. Now, we can get the condition when this i_{DSAT} will become maximum. The i_{DSAT} will become maximum in condition when V_{CC} minus $V_{D(sat)}$, this V_{CE} sorry V_{CE} will be having minimum

value or the knee value divided by obviously RHO and then the same equation remains. $i_{DSAT(max)}$ equal to $V_{CC} - V_{DSAT} - V_{CE(Knee)}$ divided by RHO minus V_{DSAT} plus V_{CE} divided by R_{CE1} plus R_{CE2} . Okay. So, we get the maximum current. So, we need the current for the maximum condition.

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Now, once we have this current and the voltages, so how much current is going, then the next parameter we need is VCS. So, this will be R_{CE2} divided by R_{CE1} plus R_{CE2} into V_{RD} . So, this much voltage will be coming across the sensing pin. Now, this V_{RD} , you already know. So, this how much voltage will be there. So, in the previous slide which I have already shown here. So, this will come from the output. So, V_{RD} , it is basically coming across the device, so or the driver input as like V_{CE} input plus desaturation, so whatever voltage, so let's say V_{CE} input if it is having 1.5 volts and V_{D} saturation, so that saturation voltage if it is 0.7 volts, so based on that V_{RD} will come and based on this V_{RD} so how much voltage we can provide to the sensing input that we can decide based on this resistance value so if the if we vary this resistance value, based on that the required voltage across the sensing input, we can provide, so this is the formula for this. So basically, this is coming from the output. This is variable so this based on this output, the variable input will change to provide required sensing input. Okay, now so there are other component of this R. So, once we have this value, so now we can provide this R_{CE2} by R_{CE1} , we can write down as so, this ratio we can write down based on this sensing threshold voltage. R_{CE1} divided by R_{CE1} equal to V_{CETH} divided by V_{DSAT} plus V_{CETH} minus V_{CSTH} . So, V_{CS} sensing. So, this voltage defines V_{CSTH} is sensing threshold voltage and V_{CETH} is the voltage across the device that minimum voltage whatever We can consider. So, these two this all these voltages we can actually consider to get the ratio of these resistances. Once we have the ratio of the resistances, so then what we can do we can assume any of the resistance. So, let us say we can assume V_{CE1} based on this ratio or the requirement, we can actually decide whatever will be the resistance of the V_{CE2} . This ratio will come from

different voltages. So suppose any device is given and the device VCE threshold is given some voltage in the datasheet. So now once we have this voltage, so then based on the sensing input threshold voltage, then we can decide whatever will be the required resistances in the voltage divider circuit. And based on that we can select the resistances for this VCE detection. Okay. So in VCE detection this resistance is the main parameter. So how to select that that is very important. So let me write down this as. Now we can actually consider, R_{CE1} divided by R_{HO} equal to V_{DSAT} plus V_{CETH} minus $V_{DSAT} + V_{CETH}$. Now the resistance R_{CE1} and R_{HO} , this we can represent in terms of this particular equation. So now here also we have all the information. So once we have this ratio, we can again choose the value of resistances. So there are three different resistances in the VCE detection circuit two are for voltage divider and one is coming in series so that is R_{HO} that is charging resistance. Now these three resistances will depend upon different voltage level of the device and the driver. So the device and driver voltage level we if we have then we can select these resistances for the detection circuit. Okay now if we have this resistance values, the another parameter which is present in this particular network that is c blank. So C blank we can choose a value, so that should be more than, so we have to take some factor, so some factor will come from So, that we can consider as constant. So, that will depend upon us like how much noise we want to reduce. C_{BLK} greater than K multiplied by C_{DSAT} . So, this K factor will be there that will be multiplied with the capacitance of the desaturation. So, basically C of D. So, this capacitance, so you can see here so this capacitance which is actually shown across this particular diode, so this capacitance value we can actually get from the datasheet of the diode and this is parasitic capacitance of the diode. So this capacitance whatever it will be so based on that we can actually select the capacitance required for this blanking. So, now we have all the parameters. So, we have these resistances R_{CE2} , R_{CE1} , then also the resistance R_{HO} . and then c blanking. So all the passive components present in the network that we can get from this equation. Now what are the other components present that is d. So d is saturation so basically that will depend upon the device rating. So that will come from the device part. So we have all the parameters which is required for the VCE detection. Now if we try to see a case study, basically if we try to select any device so any wide bandgap device, let's say we are we want to protect that particular device, then we can select any IGBT which will work as SSCB or solid state circuit breaker so the IGBT.

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Case study :-

WBG — 450V
50A

SSCB — IGBT (1200V/200A)

Step 1 :- Infineon IR2127

Step 2 :-

Step 3 :-

$$V_{GE} = 9V$$

$$V_{CE} = 5V$$

$$V_{CE\text{ knee}} = 0.5V$$

$$V_{GE} = \frac{R_{GE2}}{R_{GE1} + R_{GE2}} \times V_{CE}$$

$$\frac{R_{GE2}}{R_{GE1} + R_{GE2}} = \frac{9}{15}$$

$R_{GE1} = 300\Omega$ (Assume)
 $R_{GE2} = 3.12K\Omega$

Step 4 :-

Step 5 :- Zener diode DZ

Step 6 :- $V_{DSAT} = 0.5$ $C_{DSAT} = 20pF$

Step 7 :- $C_{G1K} > 7.5 \times 20pF$

Step 8 :- R_{HO}, R_{CE1}, R_{CE2}

$R_{HO} = 1.65K\Omega$
 $R_{CE1} = 681\Omega$
 $R_{CE2} = 324\Omega$

Graph: V_{GE} vs V_{CE} at $I_C = 50A$. The curve shows V_{GE} increasing from 0 to 9V as V_{CE} increases from 0 to 5V. At $V_{CE} = 5V$, $V_{GE} = 9V$. The knee voltage is marked at $V_{CE} = 0.5V$.

So let's say we are considering a situation or any device wide bandgap device. Considering a wide band gap device which is having voltage rating of 450 volts or we want to test the DPT at 450 volts and let's say 50 amperes. Now, if this is the rating of the device then we can select one switch for SSCB. So let's say for SSCB we are selecting one IGBT which is having part number So, you can select any part number. So, I am just giving you the voltage and current level. So, which is having voltage level of 1200 volts and 200 ampere. So, the important thing here to notice is that if you want to protect any device, so then the rating of the SSCB should be much higher than that. So, if there is any condition where the voltage and current which can come to the SSCB will be much higher, then it should be able to take that. So that is why the voltage rating is 1200 volts which is much higher than the WBG device and the current rating is 200 ampere which is much higher than that of the WBG device. Now what we have to do? We have to select the characteristic of this SSCB. So basically these characteristics you can get from the datasheet. So generally the characteristics of IGBT it will be like this. So now we can select a point in the characteristics, so if this is the current of the IGBT, it is 50 ampere 50 ampere corresponding characteristics because we are testing the device for 50 amperes. So, then IGBT characteristics although it can take 200 ampere. So, we will take the characteristic with respect to the 50 ampere. So, with respect to 50 ampere, we have to get the VGE. So, let's say the VGE with respect to this equals to 9 volts. And then this is let's say equals to 5 volts. And this is 0.5 volts. This is VCE. So, this is VCE of IGBT, VGE of IGBT with respect to corresponding to 50 amperes and then we can get the knee voltage which is equals to 0.5 volts. So, with respect to this particular characteristic, the step 1 is to find out different component of this IGBT with respect to the particular device rating. So, particular device rating is 50 ampere. So, with respect corresponding to 50 amperes we will get whatever component of this solid state circuit breaker is. So, components related to this protections are so, we can say this VGE that is the first component because you know this is the voltage will be appearing across the gate of the IGBT. So, that will be equal to 9 volts at 50 ampere. VCE equals to 5 volts and VCE knee, so in one equation I have already shown this VCE knee that is equals to 0.5 volts.

Now the step 2 what we have to do to design this SSCB, so we have to select particular gate driver. So we have all this component now we have to select a suitable gate driver which can be used. So here in this particular case they have selected a Infineon gate driver, which is IR2127. So, the properties of this is suitable or for this gate driver connection. Now, step 3, here I will write down. So, step 3, what you have to do? So, you have all these voltages. Now, what you have to do? You have to find out different resistances and the capacitance which you need. Now, what you have to do is the, you have all these component. Now, you have to get this VGE with respect to this voltage ratio $R_{GE2} + R_{GE1}$ plus R_{GE2} multiplied by VCC. This equation already you have seen. So, from this you have VCC equals to 15 volts and VGE already you got here is 9 volts. Then you will get the ratio. Then once you get the ratio, you will get the ratio of R_{GE2} divided by $R_{GE1} + R_{GE2}$ equals to 9 by 15. You can select any of the two resistances. So let's consider R_{GE1} , assume it is equals to 300 ohm. This if you assume so then you will get R_{GE2} . So that will be equals to here from this equation, you can get this R_{GE2} equals to 3.17 kilo-ohm. Now, step 4, what you have to do? You have to select the turn OFF resistance and the turn OFF diode. So this turn OFF resistance and turn off diode you have already seen here in the main diagram, I will just show to you. So you can see here this this you got R_{GE1} and sorry this you already got R_{GE1} and R_{GE2} . Now you need to get R_{g_off} and D_{g_off} . Okay. Now step four if you have to select R_{g_off} and D_{g_off} , so then what you have to do? This you have to get from the datasheet or if it if you don't have the resistance in the datasheet you can connect the resistance and then test multiple times to get the optimum value that we i have already discussed how to decide what will be the turn OFF resistance. Okay now step five you have to select the zener diode. So that will come from the device rating. Okay. So now step 6 what you have to do you have to select this. Now VD saturation that will come from this VCE knee point. So that will be 0.5 volts for this D saturation and then CD saturation you can actually get from this data sheet or you can select or from this data sheet you can select as 20 pico farad here and then step 7, you can now select C blanking capacitor. Now K factor it is generally is taken 75 times. So C blanking capacitor will be greater than 75 multiplied by 20 picofarad. So it will be more than 1500 picofarad. Okay. Now you have this blanking resistance C blank and now what you need to do? You have to find out RHO, RCE1 and RCE2. So, this you can find out from the equation which I have discussed previously. So, you can see here. So, this equation you have and all the voltages you will have. So, then you can find out these different resistances. Now, it is coming RHO is coming is equal to. So, I do not have space here. So, let me just write down here. RHO is coming equal to 1.65 kilo-ohm RCE1 equals to 681 ohm and RCE2 equals to 334 ohm. So now you have all the values and you can connect all these different resistances, capacitance and diode in the network. So the previous network which I have shown here. So you can connect all the parameters here and then to design protection for particular device. Okay.

Refer slide (47:29)

The image shows a presentation slide with a red header bar containing the word "References" in white. Below the header, there is a single reference entry: "➤ Jones, E. A. (n.d.). *Characterization of Wide Bandgap Power Semiconductor Devices* Fei (Fred) Wang, Zheyu Zhang." The slide is displayed in a software window with a standard toolbar at the top and a footer at the bottom. The footer includes logos for "AP" (Assam University) and "NPTEL" (National Programme on Technology Enhanced Learning), along with the name "Dr. Manmika Das" and the title "Assistant Professor, IIT Kharagpur". The slide number "10" is visible in the bottom right corner.

So this is all. So you can go through the reference. This particular reference to understand this in details. Thank you.