Power Electronics with Wide Bandgap Devices
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Lecture-29
EMI Simulation with LTspice (Part 2)

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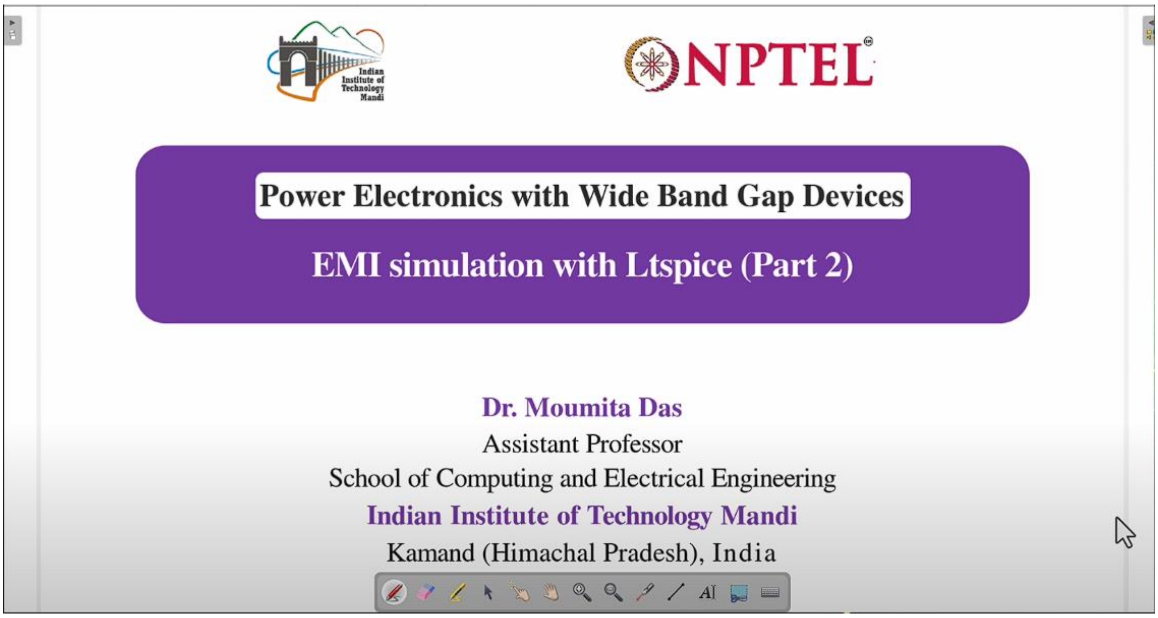

Welcome to the course on power electronics with wide bandgap of devices. In the last lecture I have discussed about EMI noises and how you can see these noises in LTSpice simulation. Okay? So today I am going to discuss about mitigation of these noises by using the filter.

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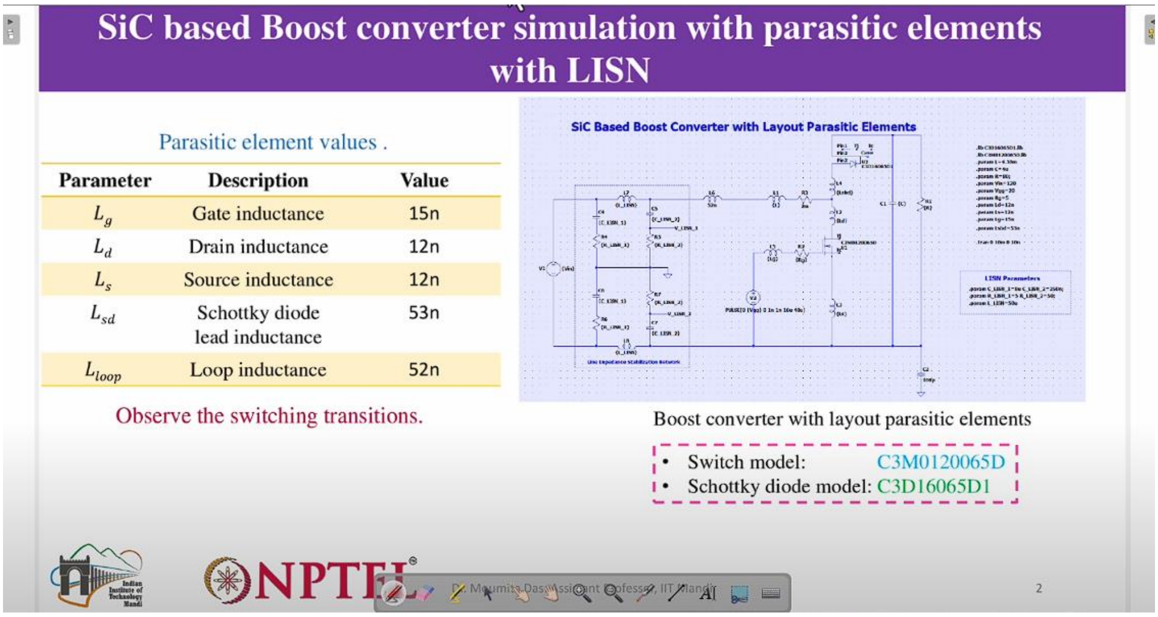

So let us see what I have discussed in the last lecture. In the last lecture, I have discussed about measurement of EMI noises and that is possible by using line impedance stabilized network. Already you know about this line impedance stabilized network which is added the front stage of the converter between supply and the converter. Once we connect this LISN, the values of the LISN are standard values which can be taken from any document. So, here it is listed this LISN values which you can directly use for your simulation. Only thing is that if your converter is different there you have to see what will be the parasitic parameter or you can just run the same converter to see whether you will be able to get this kind of noises in the simulation. Okay, so the devices and device, so both the devices, so basically switch and the diode, they are chosen like this. You can use the same device for use simulation.

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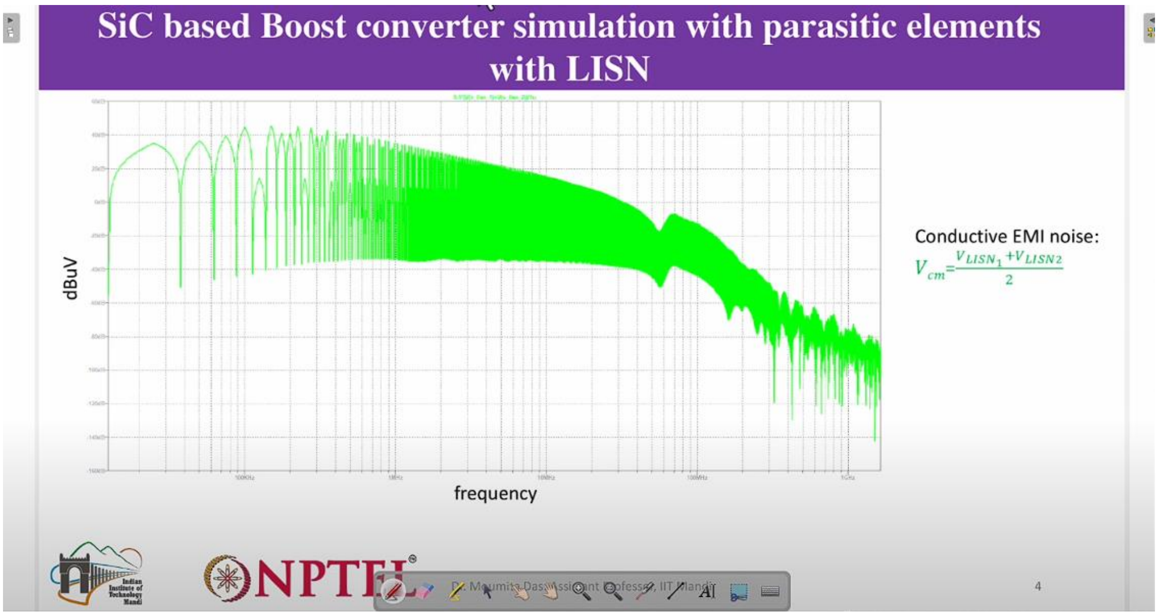

So now in this case, the noises which are achieved, they are two different noises. CM and DM. So, the CM, conductive noise can be seen in the simulation by considering two lines, adding two lines and you can see the resultant FFT.

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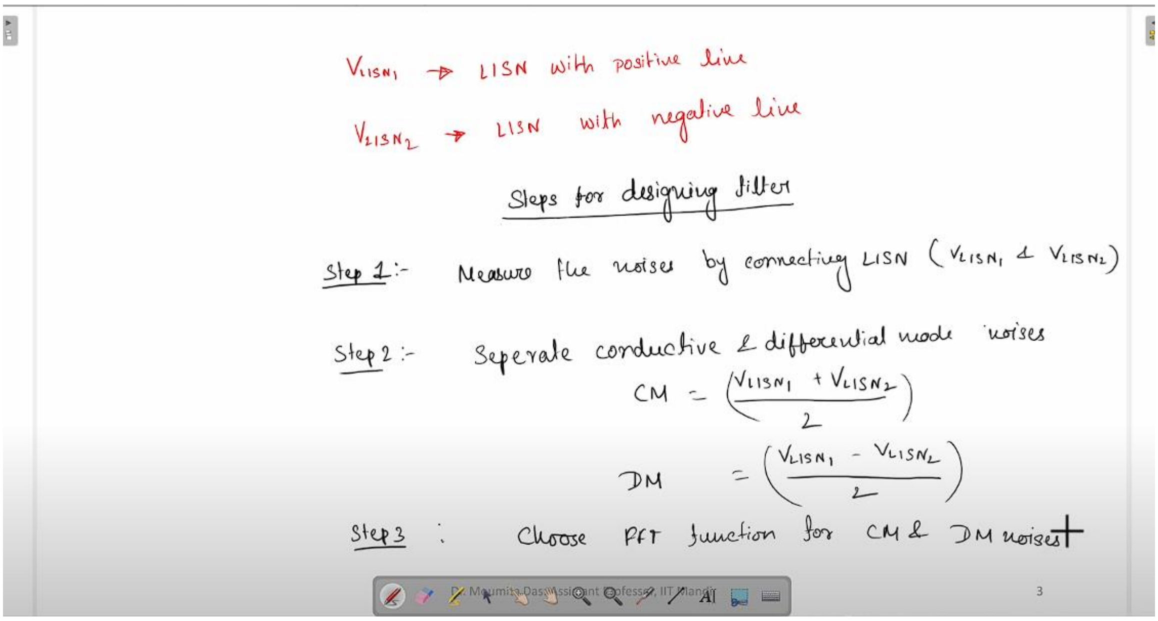

So, in LISN, these two lines VLISN1, it is with respect to the LISN connected with positive input and VLISN to positive, not exactly input, positive line. It is the positive line and LISN two, it is the LISN with negative line. So that's why we need two LISN or dual LISN. Single LISN will not be able to provide two different line related result. So, this two information you can directly get from the converter. You can measure the voltage. You can see the effect of this noises also, but you will not be able to see conductive and the differential mode of noises. So, ideally what we need to do, the first step of designing filter is that first we If you remember the lecture where I have discussed EMI noises, we have to measure. So, if I write the steps, steps for designing filter. Step 1 is that we need to measure the noises. By connecting LISN Step 2 We need to separate two different noises. Now we have noises but we don't have information of different noises. Separate conductive. Okay, so this is what is done by considering you know like this formula which is used VLISN1 plus VLISN2 divided by 2 for conductive and the differential VLISN1 minus VLISN2 divided by 2. So, this can be done. So, here we are measuring VLISN1 and VLISN2. Sn2. Conductive mode is VLISN1 plus VLISN2 divided by 2 and differential mode VLISN1 minus VLISN2 divided by 2. So, this is we are going. So, this we will use and then by choosing the FFT function we can get. So, step 3 choose FFT of function for CM and DM noises. Till this part you have seen in the last lecture. Now we have two different noises right.

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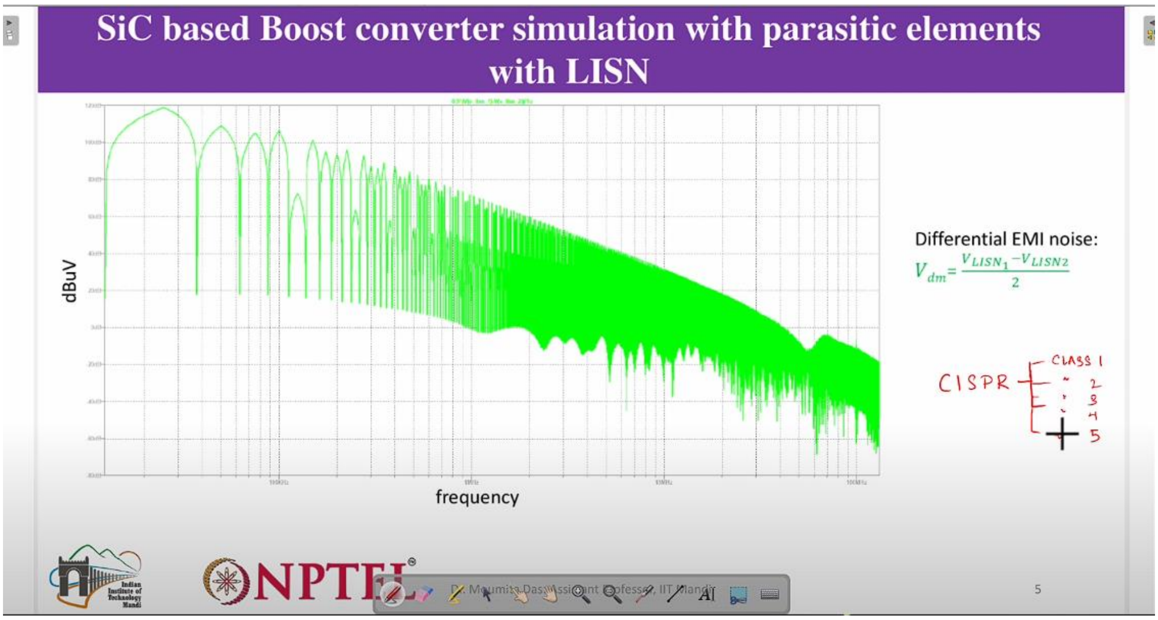

So these noises are this is the CM and this is the DM. Now we have to see whether filter is required or not. How that is possible? So filter requirement is required or not so that we can get from the standard limit. We need to compare these different noises with the standards given. So the standards are you already know the standard CISPR is the standard which we generally follow. There are other standards also. But generally we follow CISPR. So it is also having different like classes. Class 1, 2, 3, 4 and then 5. Class 1, class 2, class 3, class 4, class 5. What it tells? So class 1 means it is having magnitude which is much higher. Means standards is having the initial magnitude it is around 100 dB. And class 5 it is around 50 dB. Right. So generally the standards are like it is followed like this. So If it is like this so it goes to certain value and then it follows then it follows like this it goes on right.

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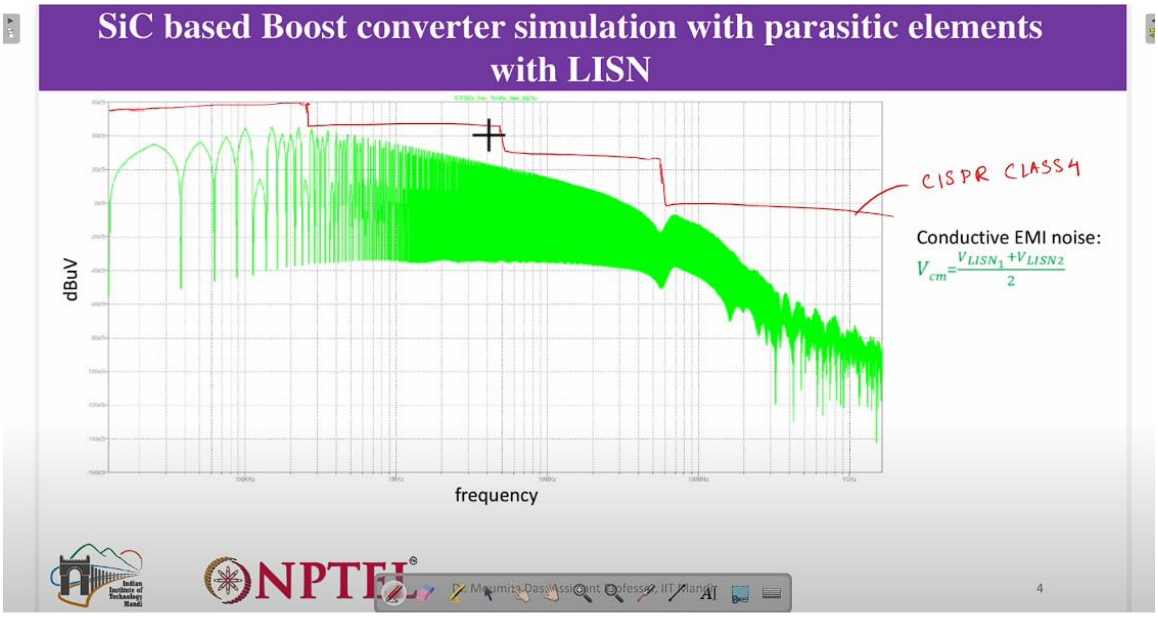

Now this standard so let's say class 4 or class 5 if we are selecting so if you see the previous one so generally what happens for let's say class 4 or 5 so generally what happens this is like standard it goes like this and this kind of pattern. You can see the exact values from the stand particular standard website ok. So now this looks more or less like this so for conductive mode noise if we choose this is let's say this is class 4 You need to compare this. So, the noise which is achieved in this particular converter that is well below with respect to the CISPR class 4. Now, if we choose class 1, then probably it will be much below than that. So, it is satisfying. It is even below in class 4. So, there is no requirement of filter for CM. So designing of the filter depends on whether there will be requirement or not. Now there will be requirement with respect to CM or DM. So that is why we need to separate out these noises first. And then accordingly we can decide exactly for what noise we have to design filter. Because you know for CM noise the filter requirement is different and DM noise it is different. For CM noise mostly choke kind of filter we need to use. So that is different kind of requirement and for DM we can use different type of filter. So that I will discuss. next. So, you can see here for this filter is not required. Now, if we are choosing this class 4, so for DM filter is required, and then requirement of attenuation you can see here from here so like what how much magnitude need to be attenuated so that you can calculate so if it is let's say 55 or 58 let's say it is 60 so then if it is maximum magnitude is 120 so 60 dB filter is required right so that is how we actually calculate. The attenuation required and what frequency this frequency level also you have to calculate at what frequency that magnitude because you know in all the frequency level the magnitude are not same so that is why this frequency part is very important okay now we got that for DM we have to design filter for CM we don't have to so then what we have to do we have to then step till step 3.

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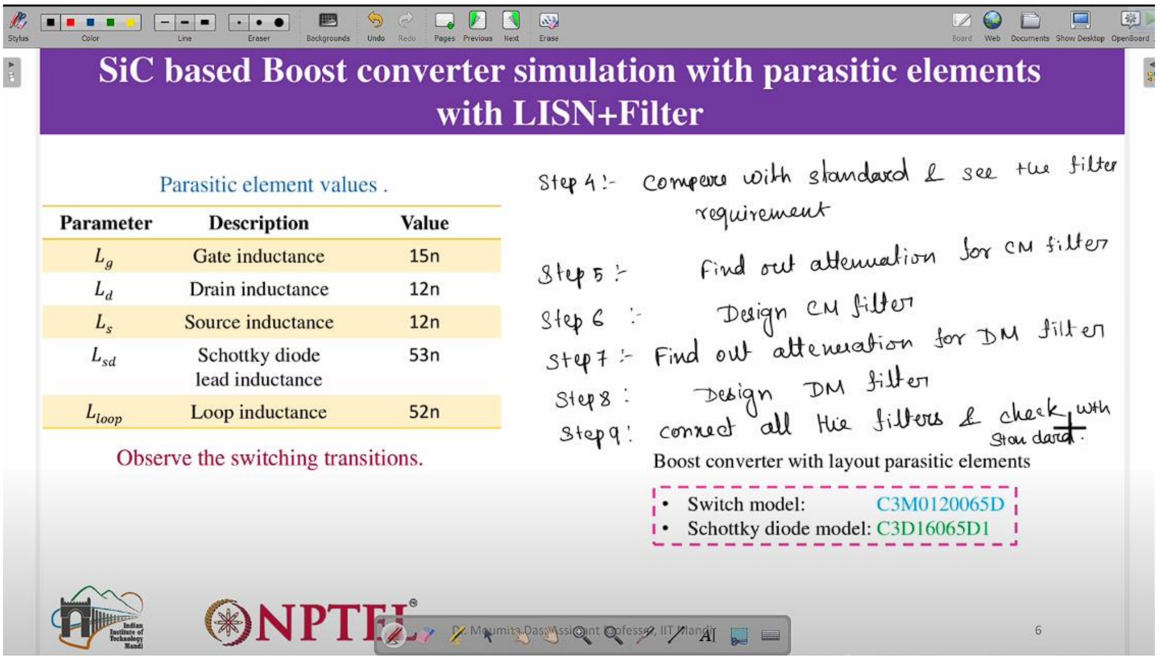

I have written here then step 4 so step 3 till step 3 you got the noises step 4, you have to find the filter requirement, compare with standard and see the filter step 5 if CM is required filter, if CM in this case it is not, for CM filter Step 5. Step 6. Design CM filter. Right. Now step 7. Find out attenuation for DM filter design DM filter. Step 9. Connect all the filters in the network and check with standard ok If it is matching then it is very good. You can use the filter and go ahead to use the circuit. If it is not then you have to follow the same procedure again and design filter basically attenuation level you have to select bit higher and then again design. Follow this procedure until it matches with the requirement. Okay. So in this case as you know this two part is not required as it is well below the standard limit. In this case we have to design the DM type of filter. Right, generally CM type of filter is like choke kind of filter and DM you can use different types of filters. So, generally what happens DM for DM filter there are actually different filter I have already discussed. What are different filter? Let us say pi type.

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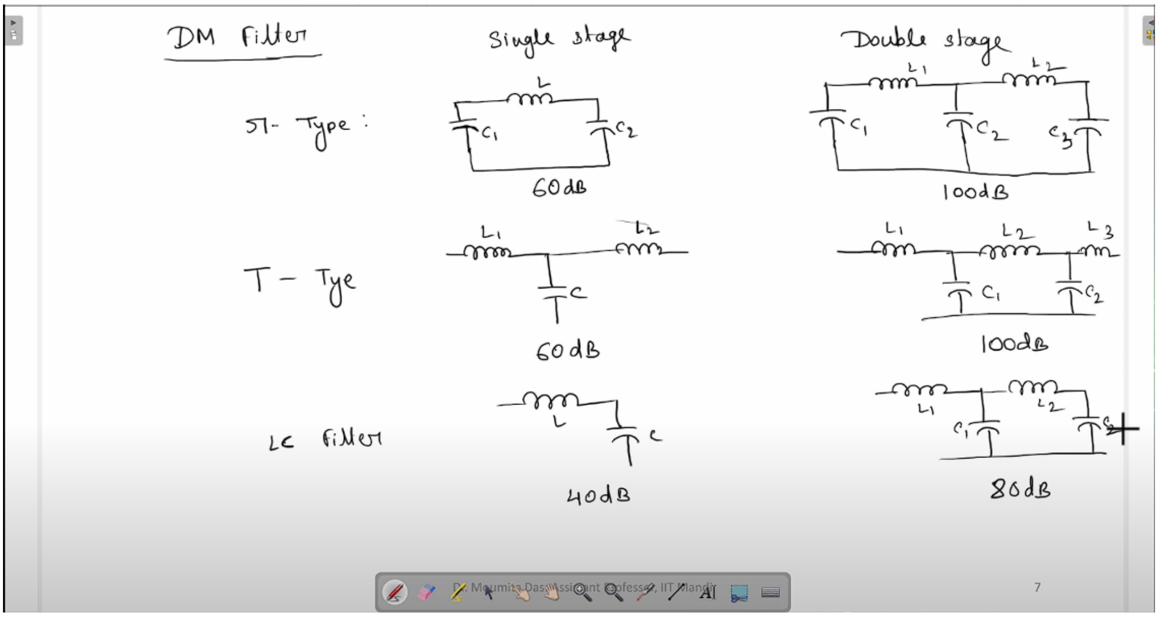

Okay. So, pi type means two capacitors along with one inductor will be presented. This is single stage. And this provide attenuation which is 60%. Values obviously you need to calculate based on the frequency where exactly this much attenuation is required. So, based on that C1, C2 and L value you need to calculate. Now, if it is having double stage, so then You need to connect means like it again like whether it will be single stage or double stage. So, that depends on the requirement of the attenuation level. It may happen the noise level is very high you know for high frequency operation. So, then it may happen that you have to use higher attenuation level. So, this provide attenuation of 100 dB. See obviously the values again you have to find out what will be the values of C1, C2, C3, L1, L2 right. Now this provides higher attenuation this lower. Similarly there are like filter like T type. So T type means there will be two inductor and one capacitor. So L1, L2. and C. It also provides attenuation of 60 dB for single stage. Now again like you can use the same thing for double stage. L1, L2, L3 C1, C2. So, here again the similar like the previous pi type it provides attenuation of 100 dB. So you can see here basically number of component in both the cases pi type and t type they are same for 60 dB or 100 dB attenuation only thing is that capacitor is replaced by inductor in some case like for t type a capacitor is replaced by inductor right in inductor is replaced by capacitor but number of component requirement is same so it is up to you which one you want to select for your application again there is like basic lc type of filter. So, it is like this right. So, it provides attenuation of 40 dB and then if you again use double stage. So, double stage it is it will be exactly double of the single stage the component. So, here again like it provides attenuation double 80 dB. So you see here so like different level of attenuations are given. So again like you can go for other types of filter also. So based on this you can choose the type of filter you want to use for your converter. Choose any type of the converter and then calculate the values of this L1, C1, L2, C2 and then use these values in the simulation to see whether it is working fine or not. So let's open the simulation with filter part. So without filter already you have seen.

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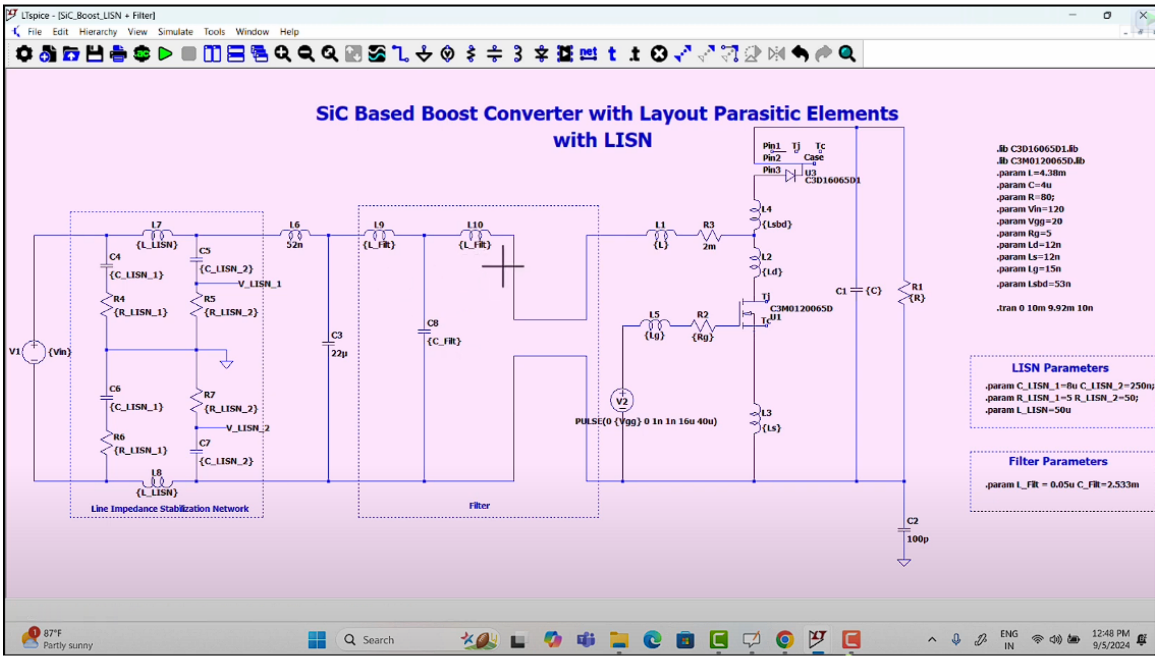

So this is without filter. So you can see this like this is having normal eliation and all the parasitic component which are required so that is presented here. So, now we will run this simulation and keep it so that we can compare with the filter part. Okay. So, the filter part we will just open now. And this is with filter. Okay. Let's So you can see here, here L, C, L type of filter is connected. So if I go back to the presentation, so you can check here. So here if you see, so around 60 dB attenuation is required. Right. So now that is possible by connecting this, you know, like T type of the filter as I said, single stage T type of the filter. So this is the one we can connect. So now just open this simulation to show you this. Simulation file. is with filter. So, this is this. So, you can see here this C L C sorry L C L this T type of filter is added as the filter part ok.

So, now these values are calculated based on the frequency that calculation you can do by yourself ok. Now, let us see without filter what are the Attenuation, you have already seen this VLISN1 you needed to select, again VLISN2 you needed to select, right. So, now you can get the common mode noise and the differential mode noise. This is the differential mode noise.

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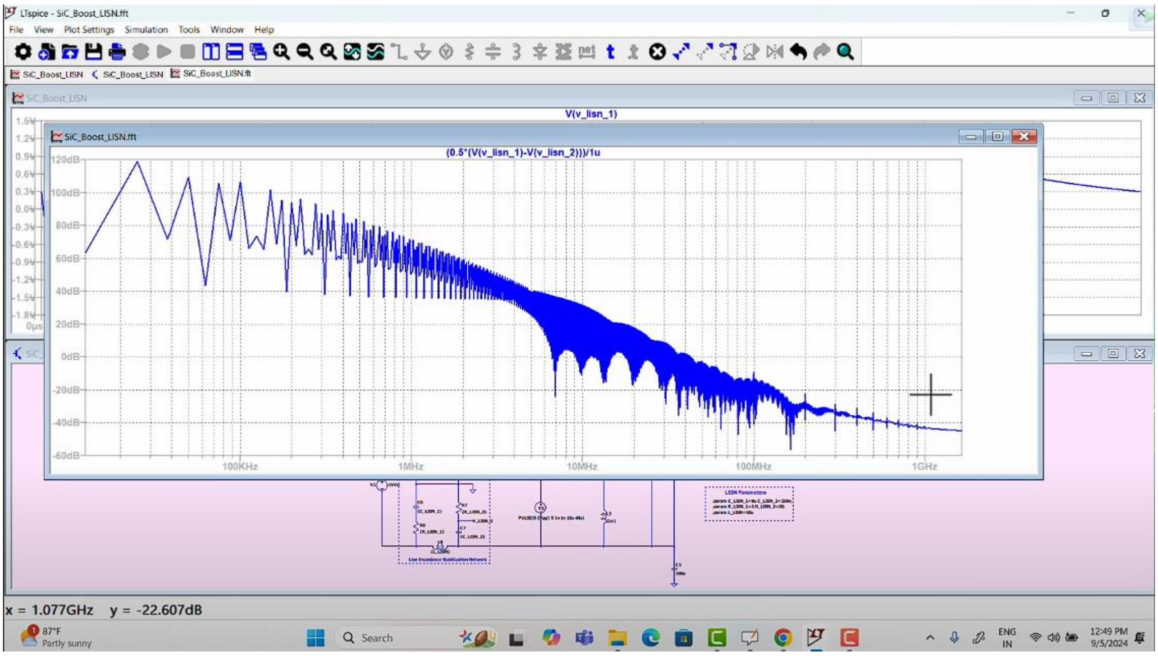

So, you see this is without connecting any filter the differential mode noise. Now, you can see the common mode also. So, same thing you just need to replace it with the positive sign.

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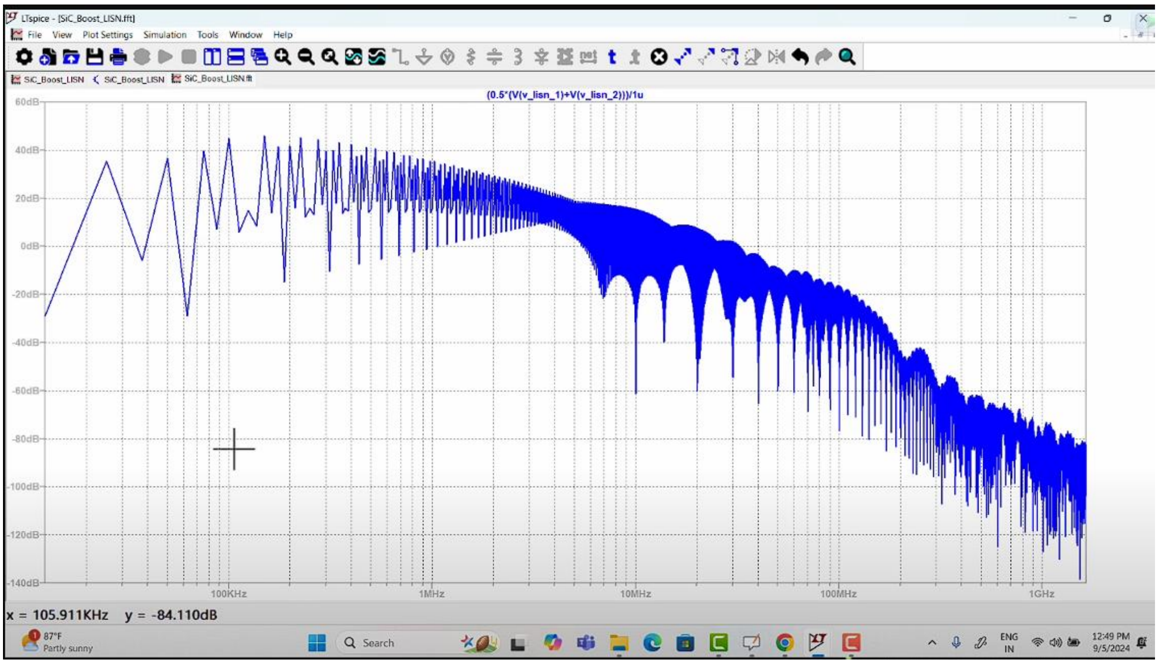

See, this is the common mode noise. It is like maximum time it is well below 40 dB. Some point it is like slightly higher than 40 dB. But maximum like till 100 kHz, see it is like well below 40 dB in high frequency. Then some part it is coming in that. Anyway like it is well below the standard which we are selecting. So, we don't have to bother about this. Now, let's see. After connecting the filter, what kind of noises we are getting? So, we can actually try to see in the same plot.

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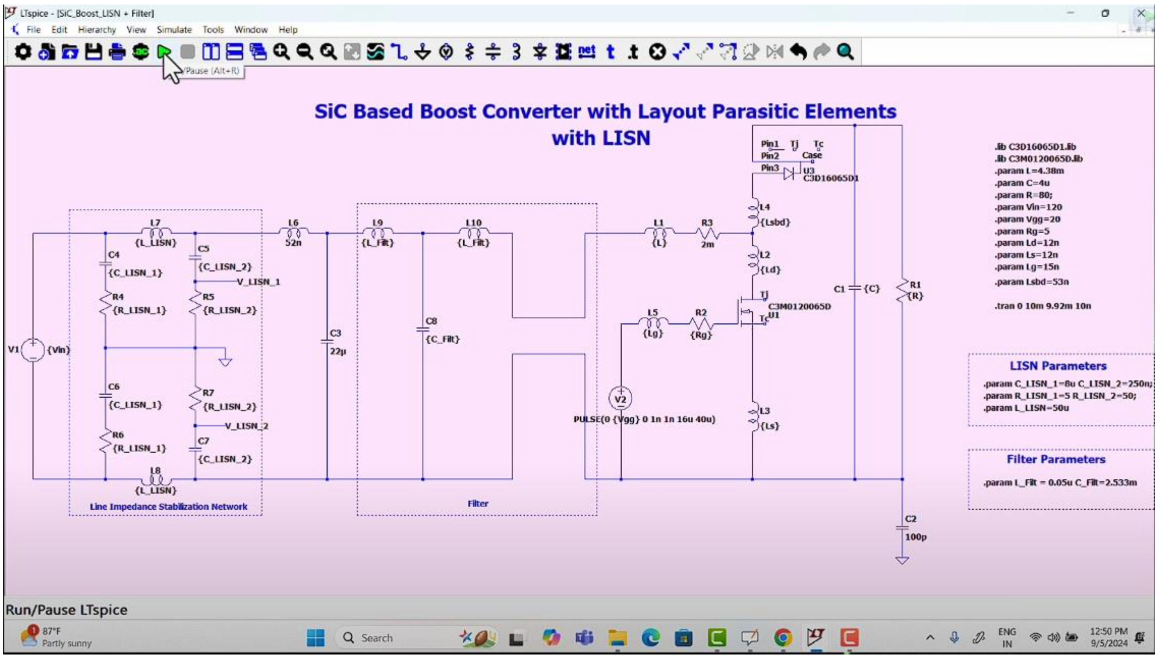

So, this is the with filter. So, the simulation is running now. So, you can see the LISN part is there. So, in between LISN, so this is like one LC filter is added with the input. So, then this part is added and this is the converter with the parasitic element. You can also refer to the lecture where I have discussed these different filter stages. So I have discussed in the details like which part will be with respect to this conductive type of EMI, which one will be for differential mode EMI. So, this different part is discussed in detail. So, you can just refer back that again and then you can come back to this simulation and then accordingly you can add the filter. You may also select the GaN switch, right, where probably you will be seeing if you operate at higher frequency, maybe there is a requirement of common mode field. Then you can consider this choke in the system here we haven't connected common mode filter this for conductive noises this like kind of filter so conductive noise deleted filter because you know it is not required anyway this simulation is complete now so now you can see this is with respect to the output we can see in output whether there will be simulation sorry there will be noise or not you can see here.

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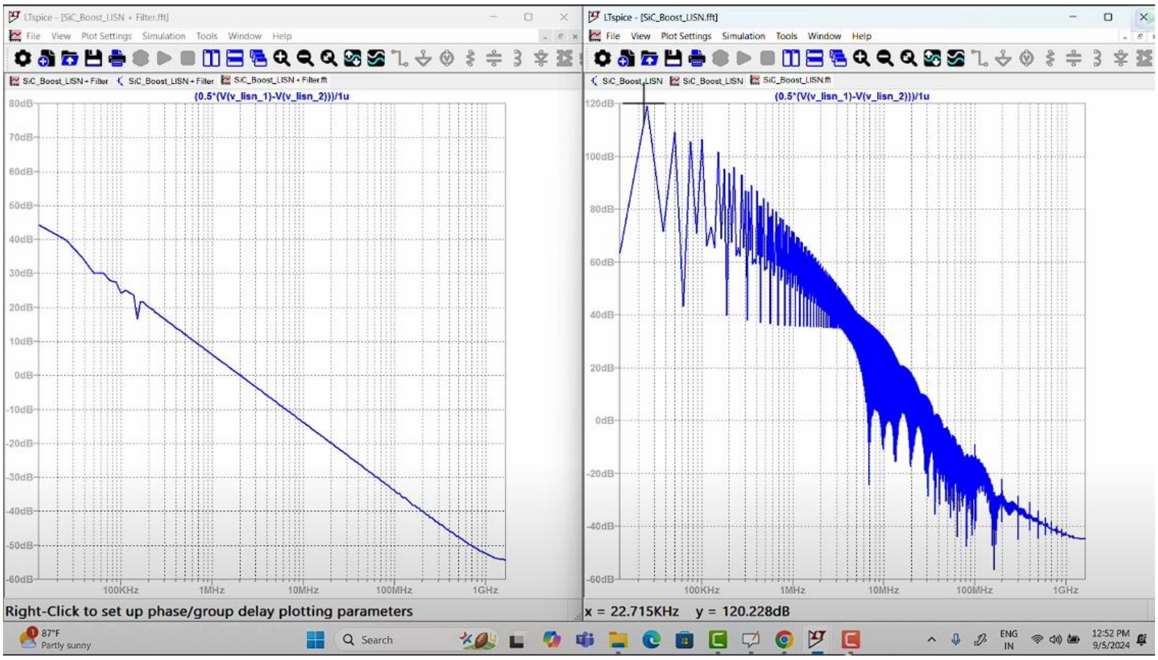

So this is after connecting the filter part this is coming so basically previously so can i'll just show you with the previous plot so you can see it together how it is so this is with respect to the common mode this is not different so let me just need to change this to differential mode right so you can see here the magnitude here initially so it was like starting from this point and then it is going to 120 dB so in here it is like well below 50 dB in the left hand side by connecting the filter okay so now this values also like again like you need to check what values you need for your system so accordingly you can see whether it is well below or not once you have this result This left side see with filter you can compare it with the standard given or standard you are following. So you see the standard with respect to standard it is generally starting from here and going down and down is like this. So then it is if you see compare this result then you will see the entire thing is well below the standard provided. So we can actually consider that okay fine this is working fine. So yeah. So this is so then I mean like your system then is with filter it is working perfectly fine. Okay. Now we can close this window. In case if it doesn't work. Right. It may happen. It is not working. Then you can choose instead of T you can choose Y type of filter. Or you can change the values of this C, L1, L2 and check whether it is matching or not. And even if that is not working you can choose LC type of filter. And then like if attenuation requirement is high then you can go for the double stage instead of the single stage type of the filter. Okay.

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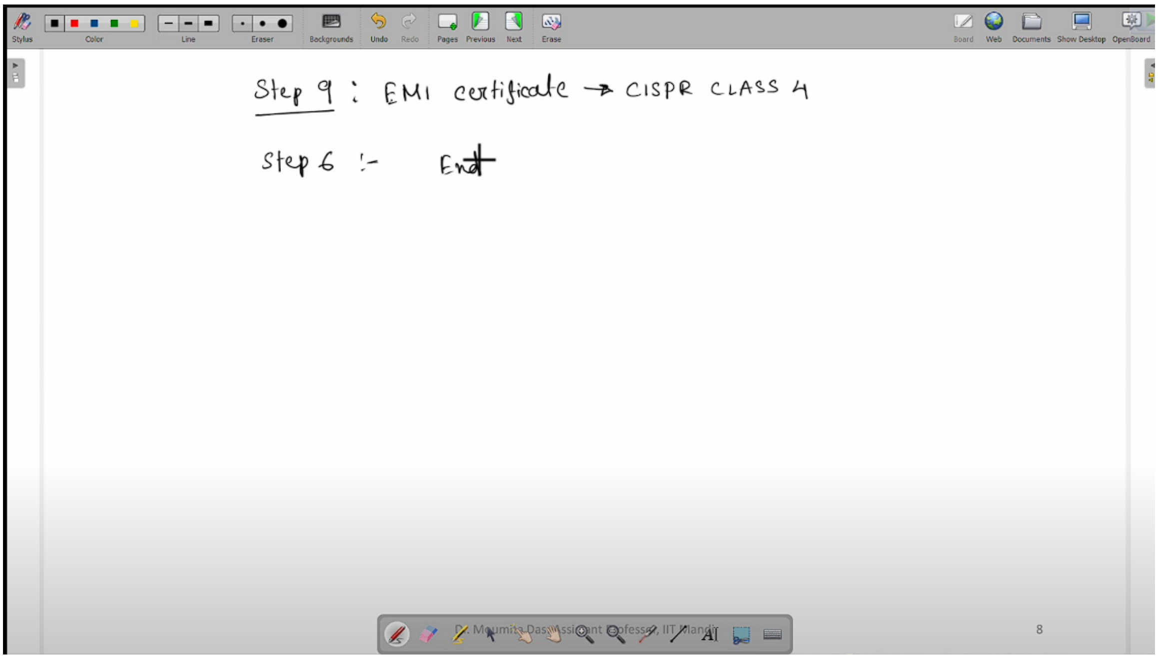

So now this kind of filter you can just use and then if it is working fine the last step so basically step 9 I guess step 9 so then this EMI certificate can be provided for the particular product because when we are using the system for any application then this EMI certificate is required so this EMI certificate it will be written like what kind of standard is followed for designing the filter.The particular class will be written. You know like as you have seen like as you go towards class 5 the filter is like filter requirement is much higher as the attenuation is much higher. So then the system will have much less noise. If it is in 1 noise will be much higher. If you go towards 5 then noise will be much less. Then CMI certificate will be provided and step 6 you can use the product or maybe end of the filter designing or you can use the system as product if it is like used for any particular application.
Now your work will be use the same simulation for GaN application or maybe for silicon carbide you can go for higher much higher frequency right. So here can see so can you show me this okay fine so this switching frequency we have given okay we can actually see the simulation the switching frequency how much it is selected so we can go in the simulation again the switching pulse we can just see so you can check from here so see this is with respect to 25 kilo hertz this frequency is used now since we are talking about wide band gap devices you should go for higher frequency now from 25 you go for 100 kilo hertz so can we okay fine let me just show you in 100 so if we go without filter 1 the simulation part close this window it's okay if we increase the simulation to 100 kilohertz then this way you can change and now if you see the simulation results then you can see that noise level you can check the noise level I just wanted to show you for wide band cup devices how this is going to be different so now this we have selected 100 kilohertz now you can go for 1 megahertz also you can select GaN device and import the model of GaN here and then choose the switching frequency as 1 MHz actually vary the switching frequency from let's say 25 kHz to 1 MHz or may be 100 kHz to 1 MHz to check the noise level variation and see whether the design filter will be suitable for all the level or not. For if the noise level is high you will be needing higher value of the filter.

Attenuation level will be higher.
But that will also work at lower frequency. So you can design the filter at maximum frequency. Anyway it will work at lower frequency. You know like lower frequency the attenuation level will be much less. This noise level will be much less.
That you already know why this noise level will be less. So accordingly you can actually design the filter. So, run this simulation for higher frequency and see the noise level. So, let us see how much noise we get here at 100 kilohertz.

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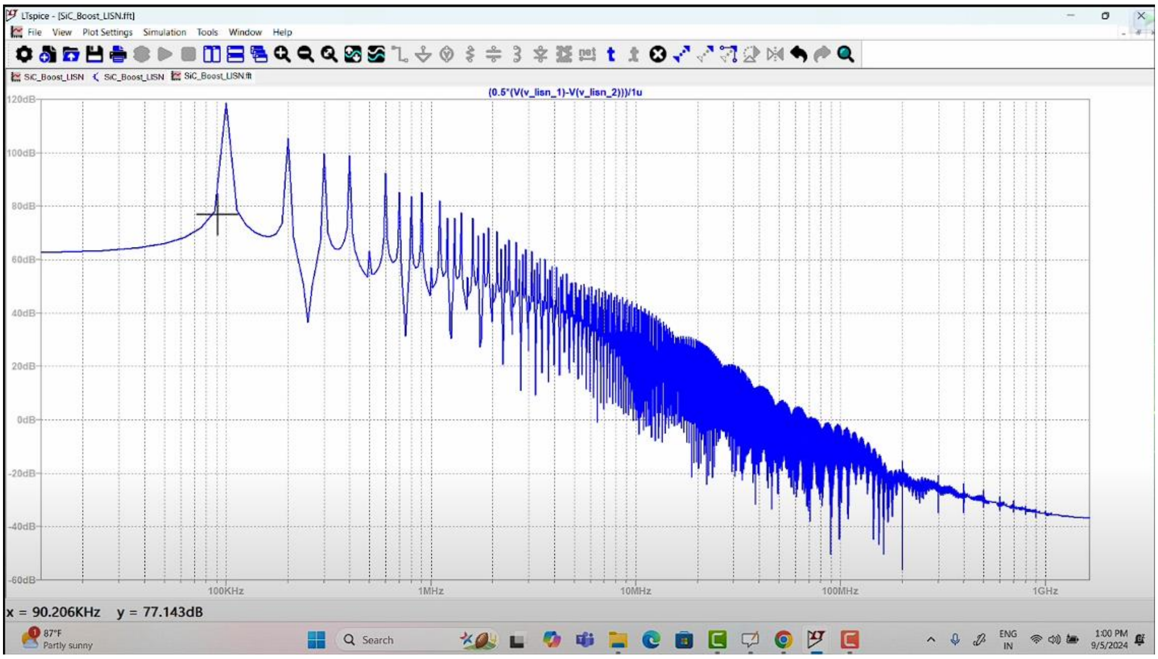

Now, it is done so let's just see see this is with respect to DM noise so initially you can see this till this point it is much less as it is going towards higher frequency this frequency it is actually shifting the noise path so this is with respect to the differential mode let's just check whether this common mode noises is getting affected or not.

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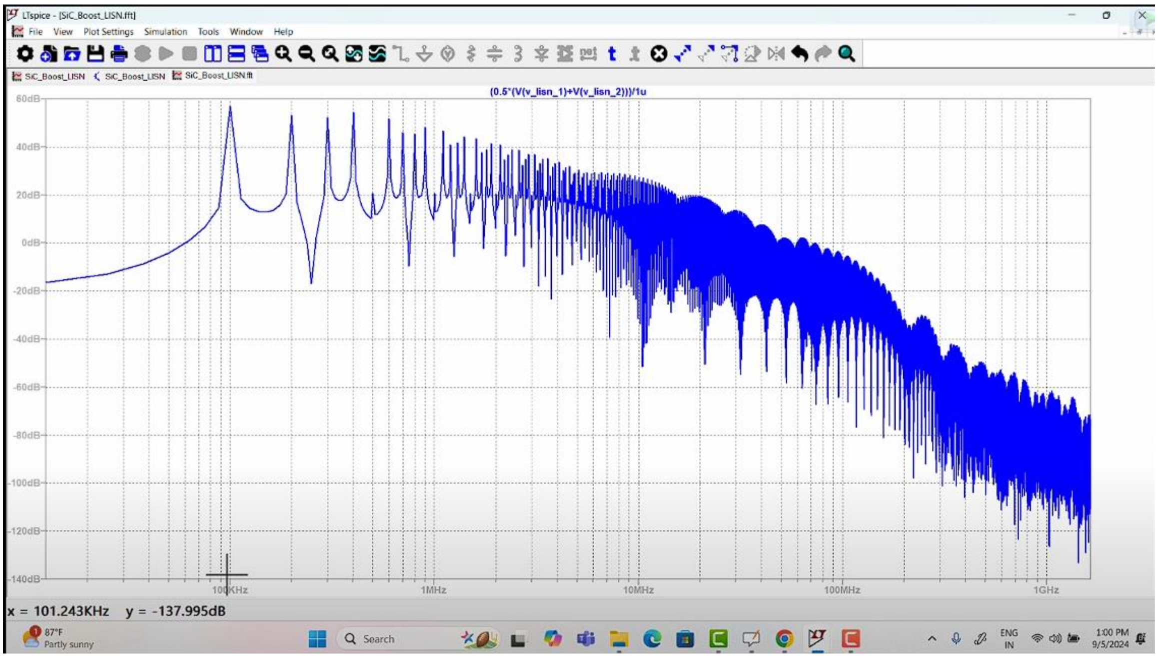

See here so it is actually going bit higher in like 100 kilohertz initially it is starting like you can see here like till before 100 kilohertz so the level is much less but as it goes higher frequency this level is increasing so now so like initially like for lower frequency this initial part was well below the standard limit here probably you have to design the same filter so kind of filter for the conductive noise so let's see with filter if we keep the same frequency then it will it will whether it will satisfy or not so let's check the width filter part with and simulate uh so the boost converter with filter part so we can just check same like it is 10 uh 4 micro and then this is 10 okay we let's just run the simulation then we can get so the thing is that now without filter you have seen that initially it is below the standard but after sometime it is increasing so if I go back here so if I tell you while the simulation is running let me just tell you this part so see here so this is for the common mode noise right so initially till let's say some point this is this filter like the magnitude is higher means this particular part if you see this particular part basically initial part the magnitude is higher as the frequency is increasing so after some point so the exact frequency point you can get from the standard itself because there the exact frequency point is given here I am just giving you idea that how it looks like exactly.

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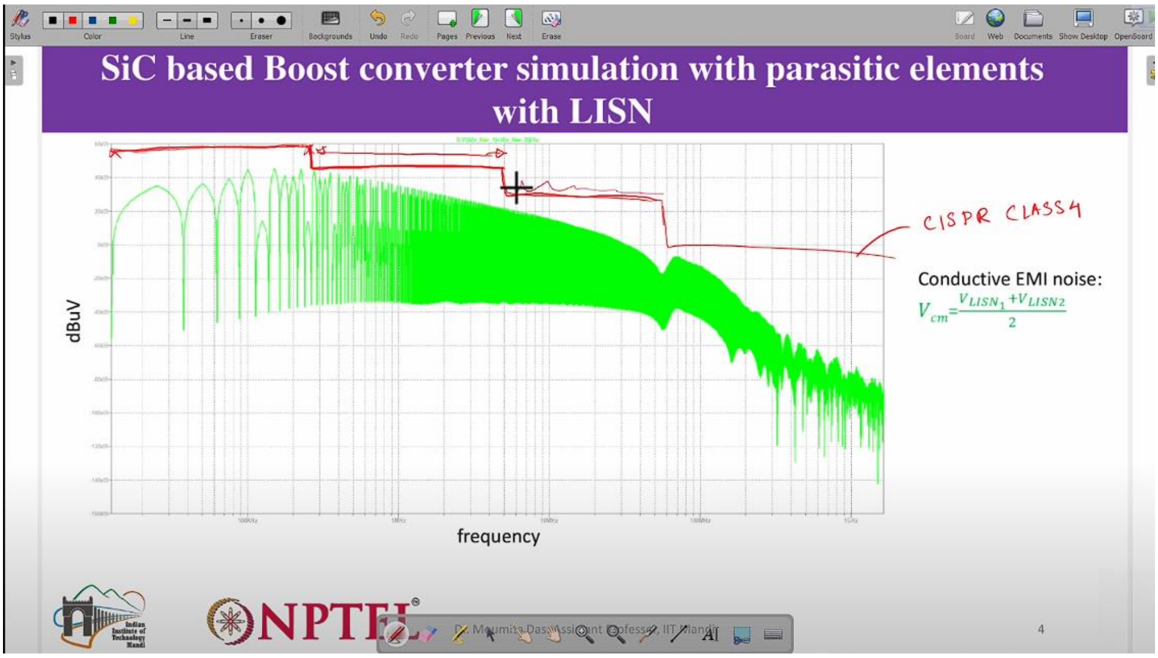

So, then after some point this magnitude decreases. But in the simulation as we are increasing the frequency. So, initially from this point to this point it is below the magnitude which is provided in the standard. After some time this magnitude is increasing. So, in this particular part the magnitude is higher. So, then what you need? You need to design filter in this particular part considering the frequency. Then in this particular part the frequency is higher. right frequency is much higher so then what will happen your filter size may be lower but you will need filter for this particular region it may happen that you will need filter also in this particular part but again like higher frequency it is so the filter if you design for this particular part it may satisfy the filter requirement of this particular part as well Okay. So this is the difference. So like for lower frequency you needed filter in this particular part. Right. Then it moves to the second part. It may happen if you choose the further higher frequency it may move towards the third part. So like this like as you are going for higher frequency the filter requirement with respect to that also will increase at higher side frequency. Then the requirement of the filter will be probably at high frequency so size will be less. But requirement will be there. Okay. So that you need to see. So let's just see whether the simulation is complete or not. So this is done now. So let's just see this. like with filter whether it is satisfying because you know we have designed it for lower frequency right so initially like at 25 kilohertz now we will be seeing this filter with respect to the high frequency see it is like now in this frequency also you are getting this result right so this filter is satisfying Because see you have already designed the filter for low frequency.

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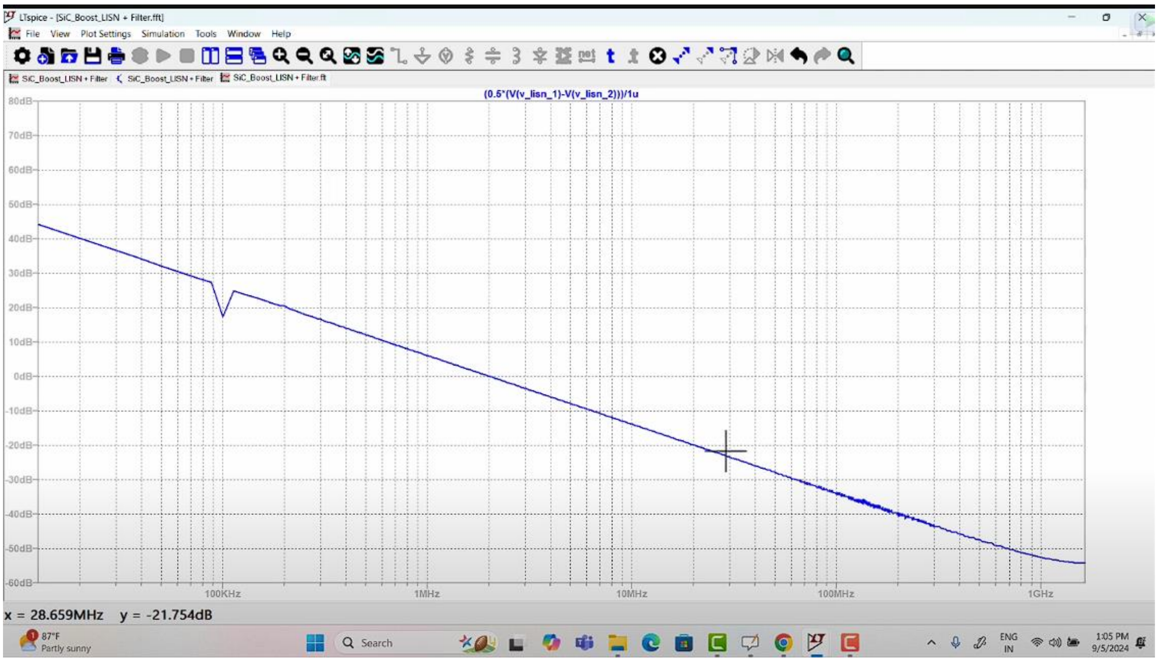

Anyway it is capable of attenuating signal which attenuation at higher frequency. Right. It is see this particular point it is well below the standard limit. So it is satisfying. So there is no problem. But if you sometime it will happen that if you design the filter for high frequency it may not satisfy the requirement of low frequency attenuation.
So that you have to check based on your application. Again like some application the variation like in control frequency variation is there. But for some application frequency variation is not there. So if frequency variation is there then you have to choose like different stages in frequency to design the filter. If frequency is constant then you have to choose only single frequency to design the filter.
So then you can get the actual value. Okay, so this you can actually design. So, you use any of the device and design the filter for EMI requirement. Okay, that is all for today. Thank you.