**Power Electronics with Wide Bandgap Devices**
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**Lecture-24**
**Electromagnetic Interference (EMI - Active Filter)**

## Electromagnetic Interference (EMI - Active Filter)

Welcome to the course on power electronics with wide band gap devices. In the last lecture I have discussed about designing of passive filter for the reduction of EMI noises. Today I am going to discuss about design of the active filter for the reduction of EMI noises. So the main difference between the active and passive filter is that passive filter can provide noise suppression signal as per the design of the parameter. Means it is fixed for any system. But active filter it can actually change the noise suppression signal level as per the requirement.

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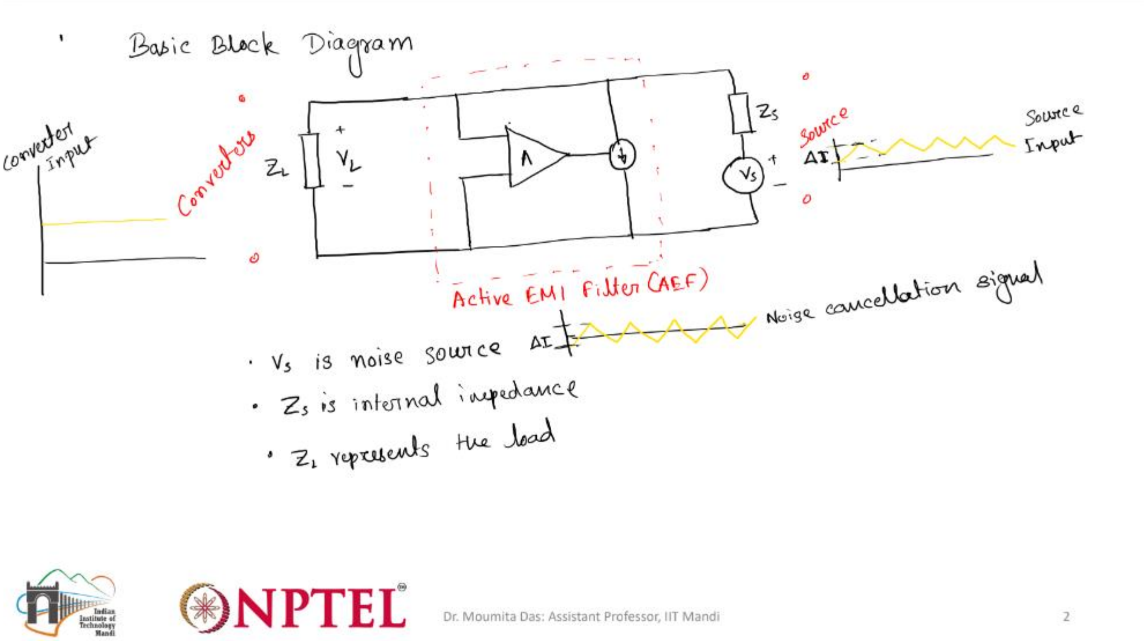


Let's see how that is possible. So as you know this EMI it is basically the inherent problem. in any power converter as we are going towards reducing size of the converter to operate the converter at higher frequency so the noise level in the system is also increasing so that is why we need to provide suitable filter right so now there are different filters i have discussed passive active are the two things i am discussing in details passive filter is fixed kind of filter which cannot change the signal level and if we want to achieve higher signal, signal means noise separation signal but active filter can modulate the noise separation signal level. So, the basic block diagram of the active filter.

So it is having load impedance ZL which is having voltage VL across it. Now this is connected to one op-amp. Now this op-amp we can actually provide we can represent the attenuation as provides the noise suppression signal in terms of current right now this is then connected to the impedance of noise source which is having a noise source as Vs. So, basically this is noise signal, signal voltage level, right. Now, the part where you can see the op-amp and it provides the current signal that we can highlight And this part is known as active EMI filter or in short we can say AEF.

right. So, this is the block diagram. Now, what are the components present in this particular block? So, you can see here different components ZL, VL, ZS, VS. So, here VS is noise source, which is actually generating the noise. Let us say this noise can be ripple kind of thing like this right now ZL is load means it can be the place where the converter will be connected means basically this point is where your system will be connected or the here since we are considering power electronics converters so the converters will be connected here and Zs or Vs it is the noise source basically this side it will be connected to the source as we have discussed earlier so this is the point where the source will be connected.

So, generally what happens? So, in between source and converter, so this EMI noise we measure by using LISN and then we provide the filter as per the requirement. So, this is why we are just representing the part which present between source and the in terms of noise and in terms of suppression using the filter right so vs is the noise source so this is how the noise will be will look like now zl or vl so here since we are considering the dc voltage source i have shown this vl as plus minus like dc voltage So, then the voltage what we expect in the converter input this will be having the structure looks like this. This is the DC, right. in this case like what is coming in between the active EMI filter so you can see in the converter part so so I can just represent the border in different lines so maybe then it will be much more clear This will be like this. This will be.

Right. Hopefully this is visible to you properly. Now what we want this active filter to do? We want this active filter to provide a signal which will look like so this is noise cancellation signal this is the input source this is the part where it is like you can say this is the input this is noise cancellation signal This will be in terms of current and this is the source input, converter input. Now this source input we expect it to be constant DC. But it is having noise associated with the DC. This noise can be because of the converter itself or maybe from the other sources or other equipment which is placed near to it due to their

EMI effect.

Anything is possible. So we just need to provide suitable filter to attenuate these noises. So, this is the thing. Now, Vs is the noise source. Zs is internal impedance.

ZL represent the load. Right. So, these are the different component of this system. So, this is active EMI filter. So, let us see in details how this is working.

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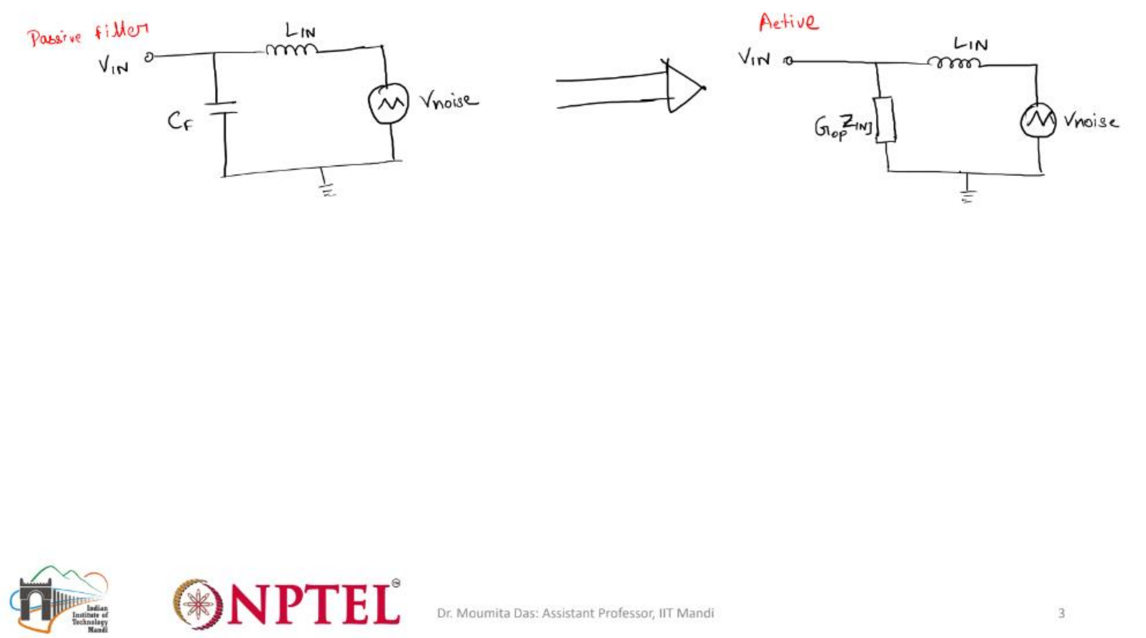


So whenever we try to represent any passive filter so then how it looks like so basically any passive filter generally will have passive components right. Let's say this is the capacitance of the passive filter and this is the inductor of the passive filter. And then this will be connected to the noise source. this v in means the input which is going to the converter right and v noise is the noise source which is like after the actual source then we connect this lc filter so so that these noises can be reduced this is with respect to the passive filter So, as per the like cutoff frequency we generally design this values of this LC filter. So, now in the last class I have discussed.

So, this filter can be any type like LCL, CLC, T type, pi type any filter can be there and I have also discussed about different component of the filter right so here i am just showing the simple lc filter and how we can actually connect with this to active filter so where exactly the difference is coming so if you see here so this is the one which you know as the passive filter now if we have to represent active filter in terms of passive filter so when we are going in the active filter part so then what is happening the same diagram I can just modify so it will become easier for you to connect So same inductance will be there and here this V in which is going to the converter and this is connected to the noise source. Right. Here the difference is coming in place of Cf. So Cf again it will be C only but they are it will have some other parameters associated with it. So, that is why we can actually just represent this as Z injection.

So, whatever impedance is required to inject a required noise signal or the cancelling signal so that impedance we can put here. So, this impedance will be variable as per the requirement of the attenuation signal and this will be multiplied with a gain. output gain so these two will come in place of cm so z will be the equivalent impedance g will be the gain of the op-amp so that in the previous page i have shown the op-amp so if you see here so this so that will be gain of the op-amp so this is how we can represent this active filter so the ultimately it remains same so the noise here v noise it will be variable with respect to you know voltage current power level frequency level it will be variable so like in your system if like voltage is variable so let's say you are using for application where you need the voltage to be variable so that the noise level will also probably vary and in case the power is variable so generally it is not constant right so it will be variable so then the noise level will also vary for some applications we actually use the frequency control so then what happens frequency changes right so then the noise will also change so in that case this noise what we are showing here as V noise the amplitude of this V noise will change now the cancellation signal what we need to provide that should also change so you can see in the previous one so the noise cancellation signal so the magnitude of this noise cancellation signal will be as per the ripple given in the source input means here if you see this ripple Here if you see this ripple, this ripple will have some delta value, right, delta I. So, I am just showing it in terms of current because you know we are injecting here is the current. So, this delta I should be equal to this delta I which we will use to cancel out.

right. So, this delta I value is variable as per the frequency, voltage, power and all this level. So, as it is variable, so if we used in passive filter L in and Cf, it is fixed kind of component. So, sometime probably this component is output or the attenuation signal will be more or the more than sufficient for the required noise suppression signal. But sometime it may happen that may not be sufficient. So, if we have to provide the sufficient kind of noise cancelling signal probably we have to go for higher value of L and C and that is where the restriction comes.

you know like we are trying to reduce the system size again like by reducing the system size we are increasing the EMI noises and in order to suppress this noise again if we increase this filter sizes then the advantage of going for high frequency will not be there probably right but in this case if we use active filter so then this active filter can provide different level of noise cancelling signal as per the requirement so that is where the advantage of active filter comes right okay so let's see how this active filter implementation can be done.

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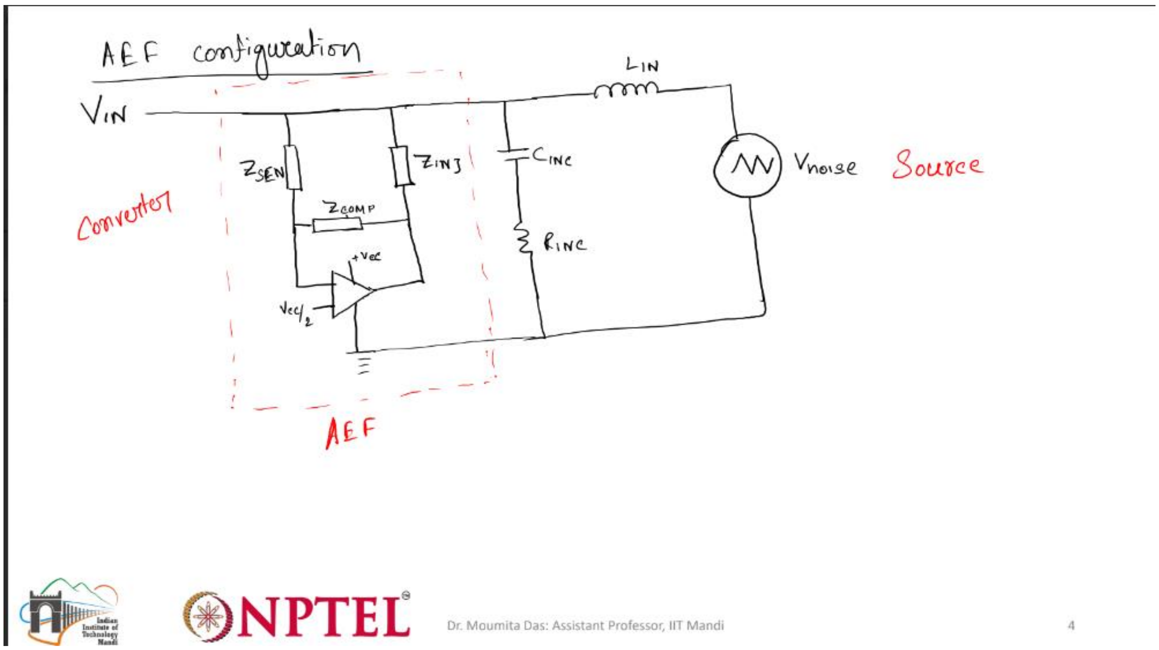


So I'll just show you in details like how this diagram looks like. Active EMI filter configuration. Right. so if i draw this so gently what happens if i try to expand that capacitor basically the Gout multiplied by Zinj is shown then it looks like it will be having one sensing impedance so I can just represent Zsen sensing impedance which will be connected to here it will be having Zinj impedance this impedance is with respect to the injection of the noise signal so this is what I have also shown Now, this will be connected to one compensating impedance, jet compensating. And this is connected to the op-amp.

So, you can see here, this is the VCC positive. Then here, this signal will be VCC by 2. this will be connected to the negative terminal of the input or I can just show it to ground right and this point will be connected to here which provide so this op-amp will provide the gain Gop which I have shown and this Z injection it will be multiplied with that and this different impedance Z compensator and Z sensing is required. Z sensing is for the sensing the signal and Z compensator to provide the compensation and then this will be connected to the input capacitor which will be having one register input register Cinc Rinc and this will be connected to the inductor so that inductor i have shown so this is the Lin so in the previous one so here this l okay this l in it should be this is the one this inductor now it will be connected to noise source This noise which we generally get in the converter input. And this is the one which is going to the input of the converter.

So this side is the source side, this is the converter side. And this entire thing means not entire the part where the op-amp is connected. So, which basically provide this gain G multiplied by Z. So, this is the part for AEF.

Okay. Okay. So, this is the part for AEF. So, this is with respect to the impedance terms. So now if I expand it further in terms of resistance and capacitances then the diagram looks like .

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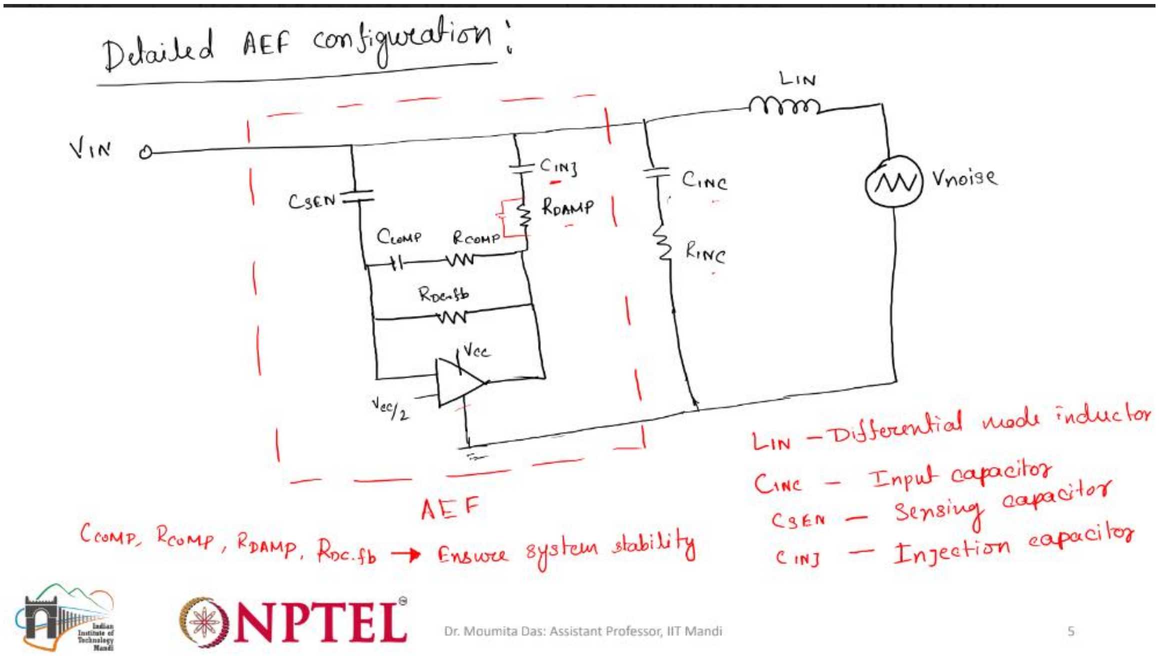


So, let me just start from the converter side. So, this is Vin which is connected to the converter. Now, let me just explain in terms of capacitance, resistance, inductance, right.

So, this is the C sensing. which I have represented in terms of Z sensing, it will be connected to compensator, C compensator and R compensator, right. And this will be having one feedback kind of network connected RDC and this will be connected to C injection and then Then this will have The same opamp Connected here. This is VCC This will be having CINC, RINC as previous. So, this will be also connected to ground, same ground. Actually, it will be connected together only.

So, we will just remove the ground part here. And now comes our inductor Lin Then this is the noise which we are talking about, the noise. Right, this part is our active filter part

EMI filter now if I have to discuss the details of this different component then this can be given as you know this is so probably I can just write down here  So, you can see here there are different components. Let me just write down in different color.

Lin,  I start from L in. L in is the differential mode inductor. Right. Cin  input capacitors Csense sensing capacitor  is shown here Cin the input capacitor shown here and  Cinj here so that is injection capacitor so basically the noise cancelling signal that we will be providing so for that this capacitor is connected. Now we have other components. What are those components? Ccomp, Rcomp and then we have damping is there, Rdamp.

and RDC. So these are basically ensure system stability this component. So, these are the different components of the active EMI filter. So, now we have different component and we know about the block diagram of how this active EMI filter looks like and what kind of signal we are trying to attenuate or provide the attenuation signal. So, that also we know.

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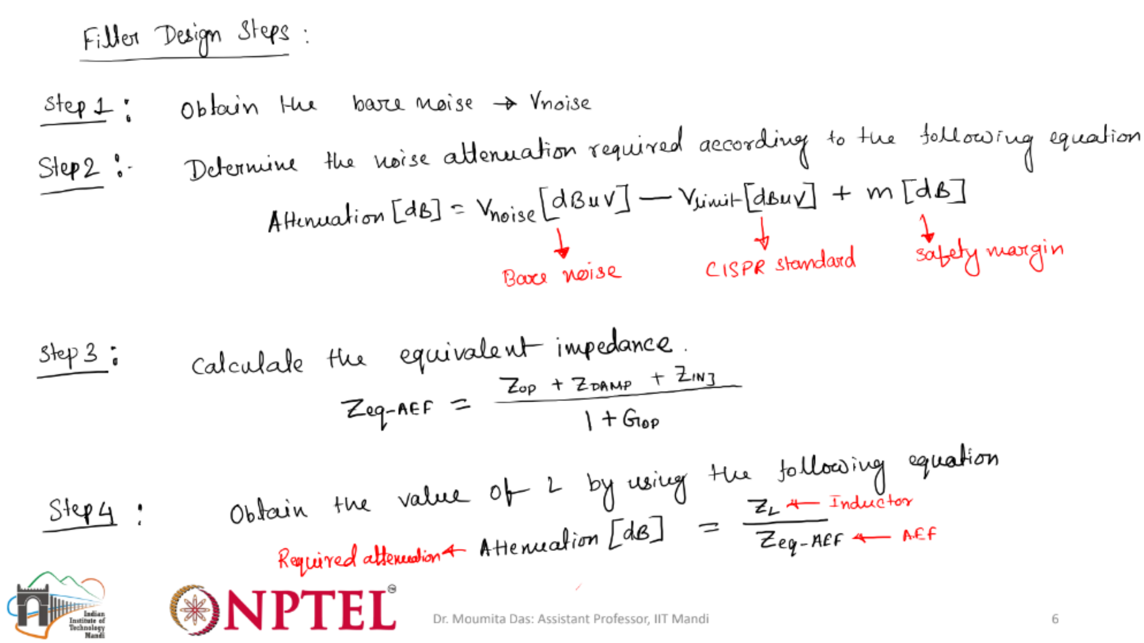


Now, let us see how to design this kind of  filter means if we have to design any active EMI filter in place of passive filter so what should be the procedure we know the structure now we need to find out different parameters for that what we need to do right so first step is that Step 1.

Right. Step 1 is the we have to find out the noise signal. Obtain the bare noise which is Vnoise. Right. First we have to measure this signal without connecting any filter.

This is the same as passive filter. First we need to have information of the noises. Then only we can design the filter. So this noise we can measure. Then what we can do? Step 2 will be determine  the noise attenuation required according to the following equation. So we have bear noise we know the standard then we can find out what is the attenuation required.

So that we can actually represent as attenuation which will be in dB which will be equal to the difference so V bare noise  You know like this where V noise I can just represent it. You know I have shown there noise. So it will be easier to connect V noise in dB micro volt. This is without connecting the filter.

$$A_{atten}[dB] = v_{bare}[dB\mu V] - v_{limit}[dB\mu V] + m[dB]$$

Now the standard. What is the limit? is provided as per the standard, you know CISPR class 1, class 2, class 3, class 4, class 5, these standards I have discussed. Use any of the standard which you want to consider for your design, you can take class 1 or class 5, right. So, then this will also be in dB microvolt. Now we should get this attenuation but this is not the only thing.

We have to also add some safety margin. We can probably get exact same attenuation level but it is always better to have some safety margin. So that is why this M is added. So, these different things are actually this is actually you can say bare noise which we measured in step 1. This is from standard  And this term is providing safety margin.

Right. So these are the different component of measurement of attenuation signal. Now in step 2 we measured the signal. Now step 3. what we need to do we have the signal so then calculate the equivalent impedance when we have the attenuation signal  this we know that ok fine this is the one which we need to find out. Now we have to find out the equivalent impedance which is required.

Now this equivalent impedance will come from the different impedance component  of active filter or maybe impedance component of passive filter. So, here we are considering different components in active filter. So, that will come all together. So, then what we can write down is that. So, this will be Z equivalent with respect to active EMI filter can be written down as

$$Z_{eq\_AEF} = \frac{Z_{op} + Z_{damp} + Z_{C\_inj}}{1 + G_{op\_amp}}$$

Right, so Z output, Z damp, Z injection and G op-amp that already you know. So, injection part you know will come from this C injection. Damp part will come from R-damp. So, if it is Z-damp, so if it is required to connect one capacitor, so that will be connected in parallel with this R-damp. So, if it is required then one parallel capacitor can be connected for damping.

And this comes, so basically output is already there. So, output you can say this output Z is with respect to this C and R components are there. Now comes the gain of the op-amp. So, that comes from the op-amp part itself, right. So, all this component, all this resistance capacitance, all this component will give you the equivalent impedance of the active EMI filter.

Now, you have the equivalent impedance, right? So, you got the equivalent impedance. Now, what you have to do? Next step is that, okay, sorry, step 4. You have to find out the value of the inductor, right? You have the Z equivalent gain of the op-amp U Now you have to find out the value of the inductor. So, that will be we got this attenuation in dB right. So, that will be equal to this attenuation in dB will be equal to the ZL,

$$A_{atten} = \frac{Z_{L\_inductor}}{Z_{eq\_AEF}}$$

So this part gives the inductor component and this part comes from the active EMI filter. And this is the required attenuation. So, we know the value of the required innovation. So, from there we can actually find out inductor and AEF. So, then we can provide the required filter by using the active EMI filter.

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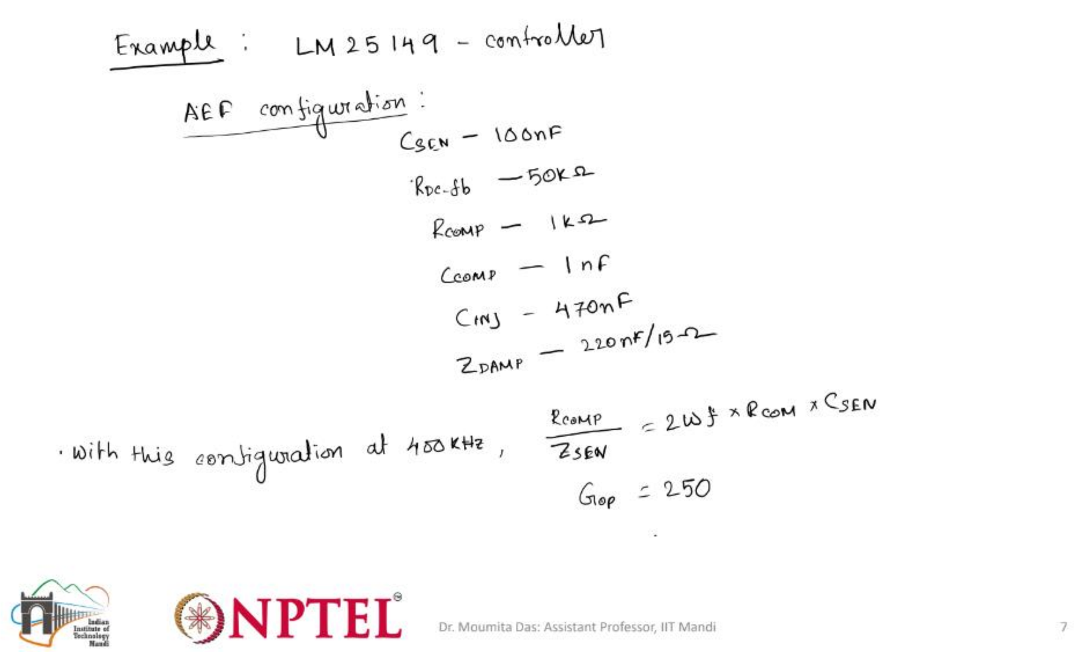


So, just to give you an example. So let's consider example of LM25149 controller. So the AEF or the active EMI filter configurations will be it will be of you know so Csense in this case will be hundred nanofarad see so I'm just taking one example just to give you idea about how this will be . This is I have taken from one document which is given in the reference. R compensator 1 kilo ohm pin C compensator 1 nano farad. so this is with respect to this particular controller LM25149 so these different components which are required Cinjection 470 nano farad right now with this configuration at 400 kilohertz ,400 kilohertz the Open gain if we try to find out 400 kilohertz basically the cutoff frequency if we find out R compensator divided by Z sense will be 2 omega F into R compensator into C sense.

So, this will give op-amp gain equals to 250. So, this is the design problem, design actually example which I have taken from the reference. So, this is how the different component will look like. now this you can actually use for the designing of this controller so this different component and you can use this gain and then here they have configured for this configuration they have used the cutoff frequency at 400 kilohertz now you can use different component and you can select different cutoff frequency once you have this jg output and everything so you can find out the equivalent impedance and from there you can also find out the equivalent inductance or the input inductance required so generally in the so this is like different component which you have seen in active EMI filter hopefully at least now you understand about like how this system works.

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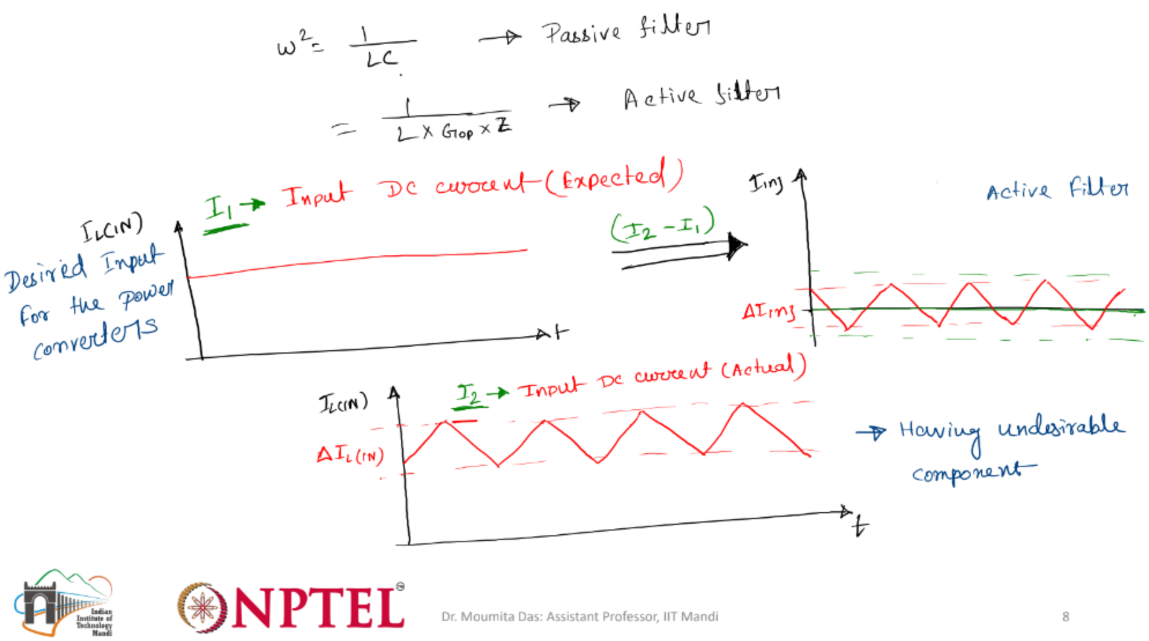


so generally what happens whenever we try to use the passive filter so then what happens omega we represent as the like the frequency, cutoff frequency. So, what we do? So, omega we try to find out it is equals to 1 by root under LC or omega square equals to 1 by LC, right.

This is the term what we try to use in case of passive filter. So now in active filter what happens in place of C the gain term will come into picture. So that is where the difference is coming. So op-amp output gain will come into picture. Now this gain of the op-amp will make the difference in passive and active filter.

So this is where the modulation will come into picture. So as I have shown in the first slide also not slide so like first page. So here basically what we are trying to do so the input DC current what we are trying to provide it has to be constant DC right we want it to be ripple free if it is constant if it doesn't have any signal noise anything it will not affect the load due to the problem in the source right but what happens there will be the noise associated with the source signal so this is the expected now what we expect that is not the one which we are getting at the input what we are getting at the input we are getting here the input DC current input DC current only I am talking about right here also I just write down so then here we are getting IL this D. So, you get the idea. So, this will be the ripple current of the inductor. this is the ripple current in the input inductor IL in right now if you are getting this ripple current at the input so this is the input actual input put DC current actual right this is the one expected and this is actual what we are getting then what we have to do we have to substrate this actual the expected one to get the required attenuation so this is the one this let's say this is the expected so this is let's say this is I want just let me use the different color I1 this is the definition of I1 and this is I2 this is the definition of I2 now what we want is that we want something where we can have the noise cancellation signal will be I2 minus I1.

This is the one we want to get rid of. Then how it will look like? It will look like this same. This is the one is coming from the C injection. I injection. Right. This T and this average ripple current has to be zero right so it will cancel out with this now this will give us the current which will be something like this basically it will cancel out with this So this whenever we add with the actual DC current so then it will give us expected one by cancelling out the noise part.

So this is the one will be the amplitude will be here. So, this will be t or not that I do not know. So, just writing because you know this will be the subtraction. So, this can be anything.

So, just do not write t here. So, this is what we want. So, this will be equal to again I mean this is the same thing will be equal to delta iLin minus delta Iinj. So, this will give us that delta Iinjection. So, we are getting this signal.

This is I injection getting this. So, you can see here. So, basically I1, I2, I2 minus I1. These three components we are actually dealing with. I2 is the undesirable part, so this is having undesirable part, so I2 is having, it is having undesirable component. right using passive or active filter to get rid of the undesirable part here we are getting desired input for the power converters.

So, these three things we are actually focusing here. Now, this delta iLin it is variable. It is not constant. So, that is why to vary. So, sometime it may be like this. Sometime it this this line which you see here so this may not be the this is not zero actually this is just giving you the this this value we can get from like subtraction only so this will be how much it will be it will get from the subtraction part only so it has to be something so sometime it may be here sometime this may shift let's say a little bit down or little bit up.

So, this will come with the operation. Accordingly, the active filter will be able to provide this variation. So, that is why the filter component here it will be active filter. Okay. I hope you understood to do the active filter, but you can take example of this active filter similarly to the passive filter to get different parameter values ok.

And you can actually follow this references active filter. to reduce size and cost of the EMI filter this particular difference. So, this second one in order to understand this discussion. That is all for today. Thank you.