Design of Power Electronic Converters
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Module Snubber Design
Lecture: 34
RC Snubber Design - I

Welcome back to the course on Design of Power Electronic Converters, we were discussing snubbers and we had done the derivation for under damped, over damped and critically damped cases for RC snubbers. Now, let us summarize all those results and let us look into it that how we can use those results for snubber design.

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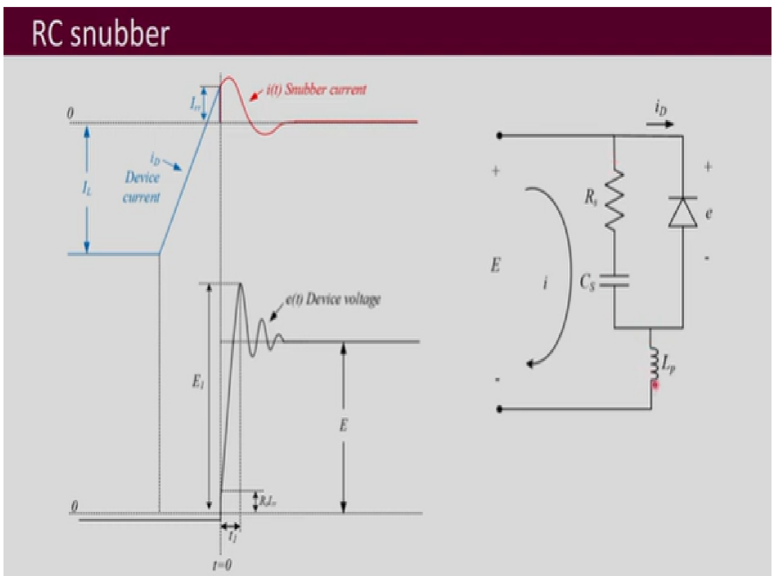

So, to recall back this was the circuit that we were using this is your RC snubber and this is the parasitic inductance and these were the basic waveforms using which we had done the derivation.

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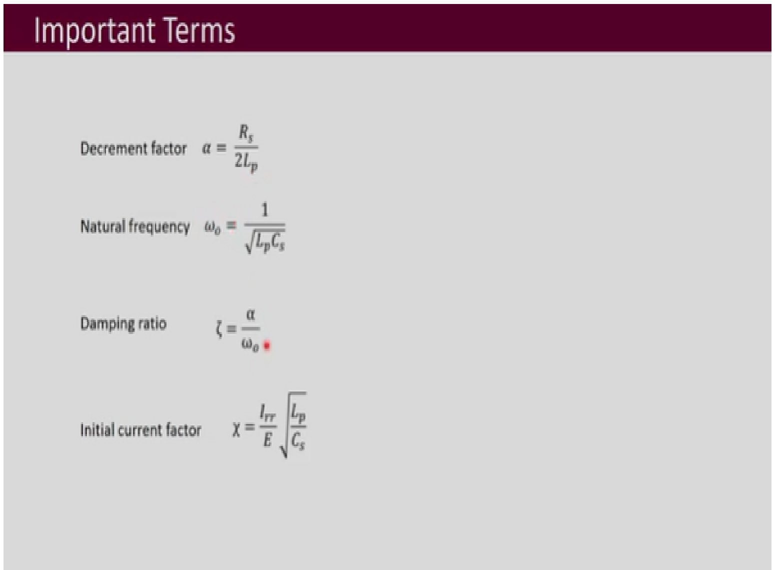

And these were the important terms your alpha which is

Then omega 0 is the natural frequency damping ratio zeta, which is alpha by omega 0 and your initial current factor which is the ratio of your square root of inductors initial energy by your capacitors final energy.

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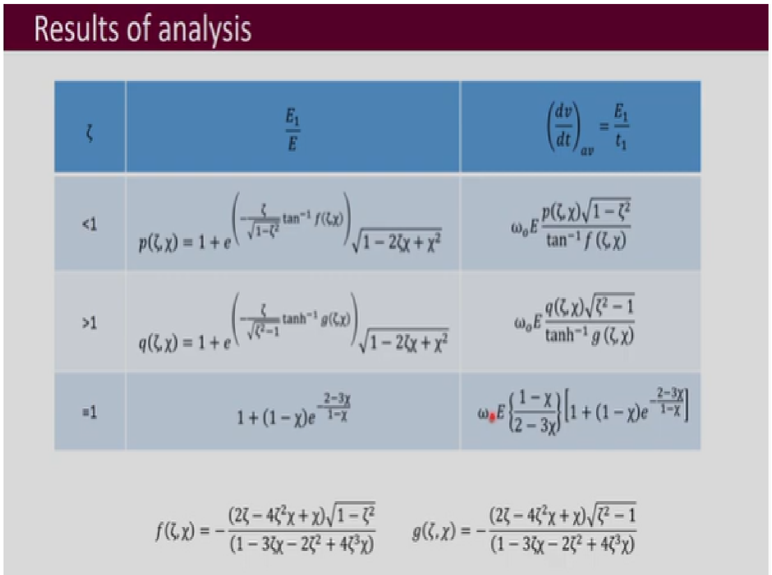

Results of analysis

ζ	$\frac{E_1}{E}$	$\left(\frac{dv}{dt}\right)_{av} = \frac{E_1}{t_1}$
<1	$p(\zeta,\chi) = 1 + e^{\left(-\frac{\zeta}{\sqrt{1-\zeta^2}}\tan^{-1} f(\zeta,\chi)\right)}\sqrt{1-2\zeta\chi+\chi^2}$	$\omega_0 E \frac{p(\zeta,\chi)\sqrt{1-\zeta^2}}{\tan^{-1} f(\zeta,\chi)}$
>1	$q(\zeta,\chi) = 1 + e^{\left(-\frac{\zeta}{\sqrt{\zeta^2-1}}\tanh^{-1} g(\zeta,\chi)\right)}\sqrt{1-2\zeta\chi+\chi^2}$	$\omega_0 E \frac{q(\zeta,\chi)\sqrt{\zeta^2-1}}{\tanh^{-1} g(\zeta,\chi)}$
=1	$1 + (1-\chi)e^{-\frac{2-3\chi}{1-\chi}}$	$\omega_0 E \left\{\frac{1-\chi}{2-3\chi}\right\}\left[1 + (1-\chi)e^{-\frac{2-3\chi}{1-\chi}}\right]$

$$f(\zeta,\chi) = -\frac{(2\zeta - 4\zeta^2\chi + \chi)\sqrt{1-\zeta^2}}{(1 - 3\zeta\chi - 2\zeta^2 + 4\zeta^3\chi)} \qquad g(\zeta,\chi) = -\frac{(2\zeta - 4\zeta^2\chi + \chi)\sqrt{\zeta^2-1}}{(1 - 3\zeta\chi - 2\zeta^2 + 4\zeta^3\chi)}$$

So, this is the result that we have obtained by doing the derivation(see the above screenshot). So, for zeta it is less than 1 so, that means, this is your under damped case. Under damped case, this is the normalized your peak voltage expression that we had obtained.

So, this has this function f and this is a little complicated function, which in terms of zeta and chi is given as this

and then further you multiply this by root over of 1 minus 2 zeta chi plus chi square and here we have gotten in exponential term, so this is denoted as the function p of zeta and chi.

And then we had obtained that this dv by dt average which is equal to

the rate of rise to this peak voltage E1 because this E1 is attained at the time t1. So, dv by dt average can be written as this for underdamped case.

Then, we have obtained this for over damped condition that is zeta greater than 1 so, that E1 by E is denoted as the function of as a function q

and we see that it is similar only thing is now here tan is replaced by tan h and this f is replaced by g, where g is

and this f and g are basically same only difference is that in f it is 1 minus zeta square. Here it is zeta square minus 1 and this dv by dt average which is your equal to E1 by t1

this is also similar for the case of under damped condition, only difference here is this, this is again here is zeta square minus 1 instead of 1 minus zeta square and this is tan h instead of tan and f is replaced by g and f and g we saw that it is actually similar and P and q are also actually similar only thing is this is your tan h and this is g.

Then, we obtained for critically damped condition the expression so, this is what we had found out that E1/E turns out to be equal to

this dv by dt average which is equal to E1 by t1 this also we had obtained

and what we see is here this is actually a repeat of this so, if you want to write it again as call it as something and then want to show it in a compact form, you can write that and this multiplied by actually inverse of this which is one minus chi by 2 minus of 3 chi multiplied by this omega 0E. So, this is the summary of the results that we had obtained.

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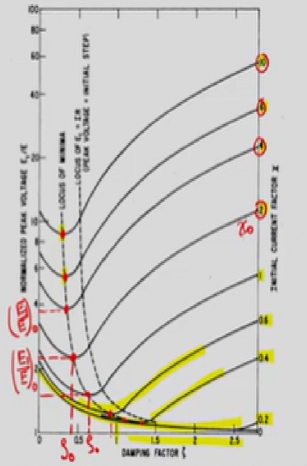
Design for limiting spikes



Peak voltage as function of damping and initial current *

* Source: W. McMurray, "Optimum Snubbers for Power Semiconductors," in IEEE Transactions on Industry Applications, vol. IA-8, no. 5, pp. 593-600, Sept. 1972.

Results of analysis

ζ	$\frac{E_1}{E}$	$\left(\frac{dv}{dt}\right)_{av} = \frac{E_1}{t_1}$
<1	$p(\zeta,\chi) = 1 + e^{\left(-\frac{\zeta}{\sqrt{1-\zeta^2}}\tan^{-1} f(\zeta,\chi)\right)}\sqrt{1-2\zeta\chi+\chi^2}$	$\omega_0 E\frac{p(\zeta,\chi)\sqrt{1-\zeta^2}}{\tan^{-1} f(\zeta,\chi)}$
>1	$q(\zeta,\chi) = 1 + e^{\left(-\frac{\zeta}{\sqrt{\zeta^2-1}}\tanh^{-1} g(\zeta,\chi)\right)}\sqrt{1-2\zeta\chi+\chi^2}$	$\omega_0 E\frac{q(\zeta,\chi)\sqrt{\zeta^2-1}}{\tanh^{-1} g(\zeta,\chi)}$
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$$f(\zeta,\chi) = -\frac{(2\zeta-4\zeta^2\chi+\chi)\sqrt{1-\zeta^2}}{(1-3\zeta\chi-2\zeta^2+4\zeta^3\chi)} \qquad g(\zeta,\chi) = -\frac{(2\zeta-4\zeta^2\chi+\chi)\sqrt{\zeta^2-1}}{(1-3\zeta\chi-2\zeta^2+4\zeta^3\chi)}$$

Now, we can do Snubber design in two ways. One is that we can have the objective of limiting this spike voltage, even the peak voltage. So, we can first do the design by using these equations. So, for that what was done was that these were plotted these functions were plotted with respect to this damping factor zeta with chi as the parameter.

So, what we are doing is that you substitute you put for zeta you keep on varying zeta and you select one value of chi and then you find out what is the corresponding value of this function P for zeta less than 1 and we keep on varying it and we can keep on plotting it then when zeta becomes equal to 1 we use this function to obtain the value then when zeta becomes greater than 1 at that time we use this function to obtain the values in plot.

After that what we do is we change the value of chi, we take another value because chi is being used as a parameter change the value of chi redo it start varying zeta from 0 then up till 1 then at 1 we use this equation and then greater than 1 we use this equation to obtain the values and we keep on plotting it.

So, when you do that, these are the curves that you will be obtaining these are the nature of the curves that you will be obtaining. So, this is for your up till here zeta less than 1 then this is at zeta equal to 1 and over here this is zeta greater than 1. So, we use all those three functions to do the plotting and this is for different-different values of chi, this is for chi equal to 0.2, 0.41 and then this is chi equal to 2, 4, 6 and 10, so, like that we plot it. So, once we have plotted it what we observe here is that, that at a certain point these curves have got a minima, so here over here these are becoming minimum.

So, we see that these are the points where your for this particular value of your chi's, your E 1 by E this normalized peak voltage is becoming minimum. And so, we can also note down the corresponding values of E1 by E and let us denote these points is E1 by E0 and correspondingly this we can call it as I0 and whatever is the value of zeta that we are obtaining, let us call this as zeta 0. So, like this also we will be obtaining another set of values of zeta 0 and E1 by E0.

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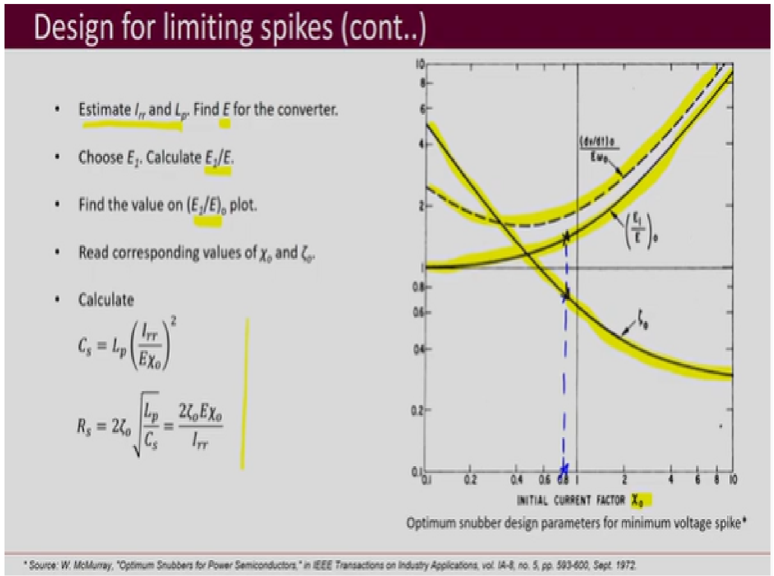

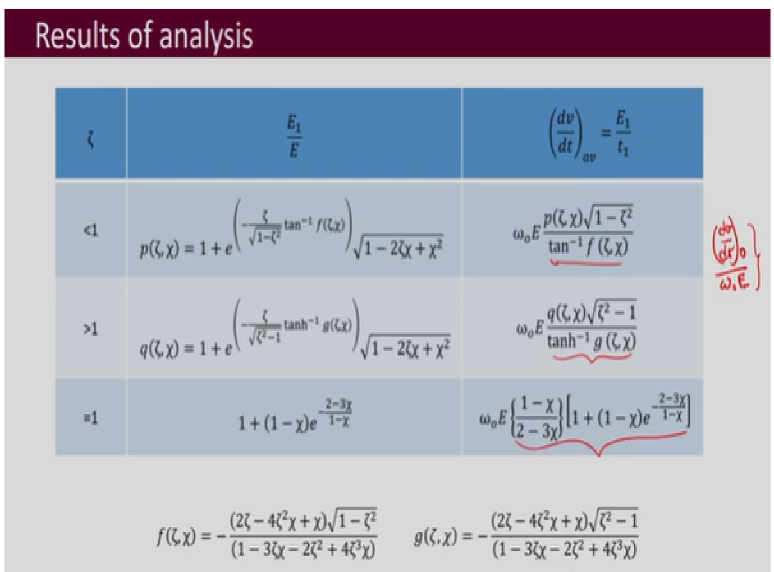

So, we note down all these points and we can make another plot and that plot what we do is that we plotted with respect to this initial current factor chi 0. So, that n whatever values of zeta 0 we noted down for the minima point, this is what the nature of the plot we get, and we also plot for those corresponding E1 by E0 terms and this is the plot that we are going to get.

Now, these same two zeta 0 and chi 0 that we had obtained at the minima point, what we can do is, we can substitute those in these expressions and obtain the corresponding values of dv by dt average and that we can call it as dv by dt 0. And since we want everything to be normalized, so, if you normalize it then we have to divide dv by dt at 0 by omega 0 E $\left(\dfrac{\left.\dfrac{dv}{dt}\right|_0}{\omega_0 E}\right)$

So, then we use these expressions

underdamped overdamped

whatever is this part, that much part can be used to obtain the normalized plot of this one dv by dt 0 by omega 0 E.

So, that is this plot that is obtained. So, now this is the plot then that is used to do this optimum snubber design for minimum voltage spike because these are the chi 0 and zeta 0 points at which your minimum spike voltages obtained. So, then for that what we do is first you estimate your Irr and LP you should have an idea of it, I already said in the derivation It was assumed to be known.

So, you should have an estimate of it for your circuit, then you have to find out E which is usually very well known in for the converter, then you have to choose an E 1 you decide what is the spike voltage to which you want to limit it depending on your device and you calculate this normalized ratio E1 by E and you find out that value on this plot and the corresponding values of zeta 0 and chi 0 is what you are supposed to obtain. So, let us say this is the value that you have chosen and so, corresponding to it this is the value of zeta 0 that you get and corresponding to that, this is the value of chi 0 that you obtain.

So, these two values then you use to do this snubber design. So, what you do is that you then while you have obtained these two zeta 0 and chi 0, you use these two expressions

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So, these are the two equations which you can use to obtain the values for Rs and Cs for your snubber design, when you want to do it for the minimum voltage spike.

Now, we did this design based on limiting this ratio E1 by E. We can also do this design with the perspective of limiting this dv by dt average which is your E1 by T1 because when we discussed your devices, we saw that several devices have got limits on the rate of change of voltage across them. And so, by this number design, we would like to limit this rate of change. So, we can also do the design with the objective we want to limit this dv by dt. So, then we follow the similar procedure, but we use the equations for your what we had obtained for your dv by dt average and we will be using this normalized your expressions which is dv by dt by omega 0 E. $\left(\frac{\left.\frac{dv}{dt}\right|_0}{\omega_0 E} \right)$

So, same procedure we take chi as a parameter and zeta we keep on varying and we keep substituting and depending on the range of zeta we use the corresponding function for zeta less than 1 we use

for zeta greater than 1 we use

and when zeta equal to 1 when we use this function.

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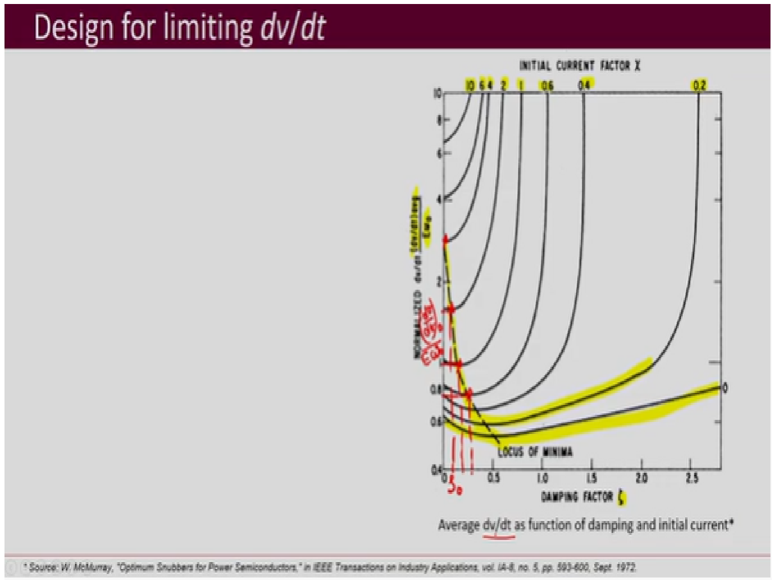

So, like that, we can obtain these plots this is your dv by dt average by E omega 0 this normalize dv by dt plot with your chi, this chi as a parameter and plotted with respect to damping factor your zeta. So, these are the nature of the plots that you are going to get. Now, again here also we see the same thing that at certain points these curves are becoming minimum and we can note down the corresponding points.

So, we can note down these points and whatever is the corresponding values of your zeta 0, that can be denoted zeta 0 and this can be denoted as dv by dt 0 by E omega 0. So, like that you will be having several of these and you can note down all those corresponding values. So, by noting down all that, then we get another set of values where your this average dv by dt function is minimum.

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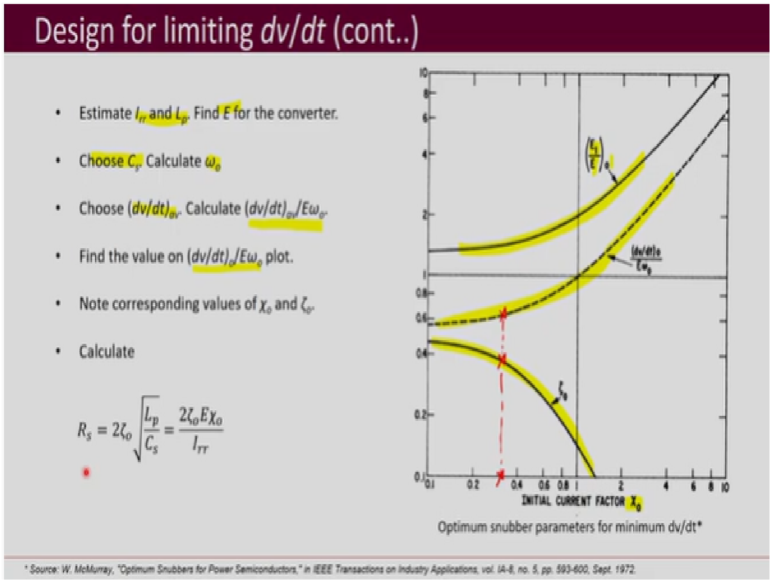

And we do this plot as before with initial current factor chi 0 but for that corresponding values of zeta 0 that we had obtained from the previous set of plots, we do this plotting and then dv by dt 0 by E omega 0. And then using this values of zeta 0 and chi 0 you solve, you also substitute in the expressions for E1 by E and you obtain that graph of E1 by E 0. So, now we can also use these set of plots to do this number design. And here the procedure that you are supposed to follow is again you estimate these Irr and LP you find out E for your converter and you choose C s you choose the capacitance that is going to be suitable.

Now, when we do a design, then many times we may have a limit on how much Cs we can use there, okay the capacitor that we can use. So, you may choose the value of Cs that you want to put and you calculate the corresponding value of omega 0 because that is the natural frequency and you already have an estimate of your LP then you choose the dv by dt average or rather what is the allowed rate of change that you can put there and you normalize it.

So, you calculate this and then further what you do is that, that you find this value on the plot whatever you have calculated, you find the corresponding value and you read the corresponding values of chi 0 and zeta 0. So, let us say for example, you found out this value you calculate this value and then you find out the corresponding values of zeta 0 and chi 0. Once you have obtained this, then you use this expression to obtain your value of Rs. So, that is how you do the snubber design for limiting your dv by dt.

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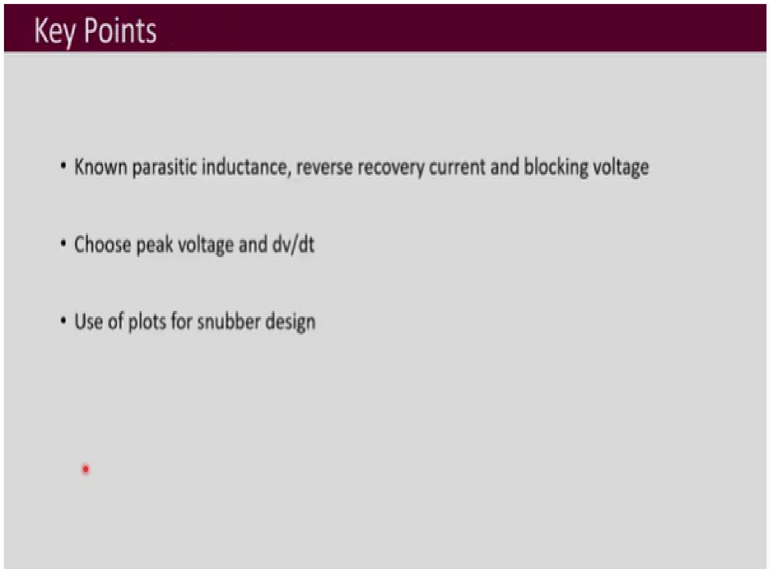

So, the key points of this lecture are that we assume that the parasitic inductance is known, reverse recovery current is known and the blocking voltage is known for this number design. Then we use this set of plots that I have shown you here to do this number design and you can do the design as to try to limit this spike voltage or you can also do it with the objective of limiting dv by dt the rate of change of voltage across the device. Thank you.