Switched Mode Power Conversion
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Lecture - 26
Controller Structure

Good day to all of you, we shall continue where we left off in the last class with our objective of trying to design a controller for switch mode DC DC converter.

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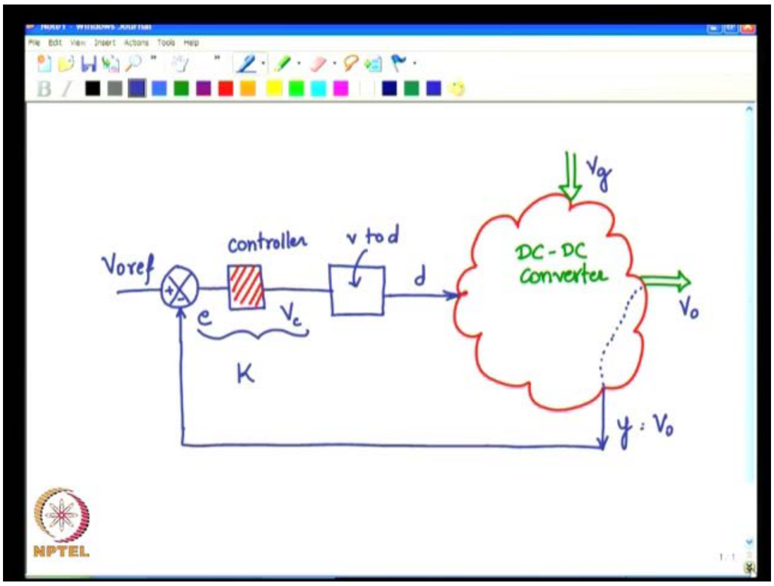

As you recall, we had spent considerable amount of time in modeling the DC DC converter and we have arrived at the state equation model. I am not going to write the state equation model, I am just going to indicate in the form of a picture the plant model we have the plant which is the DC DC converter, could be any DC DC converter. This converter is having a power input which is V g is having a power output where we have V naught. It has one control input the control input is d duty ratio it has an output to be controlled Y that we call which is sensed and taken from the power output V naught.

Here, on the signal control site we have a comparator which compares a reference desired value of V naught with the actual measured value of V naught. This compared value, the error is given to a controller this is the controller and the output the controller which is called the control voltage V c voltage to duty ratio converter V to d or V to time conversion block that is this and the duty ratio in the form of pulses would actually reach these switches over the converter.

We shall of course look in detail on the actual circuit diagram and how the duty ratio is effecting the switches by means of simulations later on, but for now today we are looking at how we are going to design this crucial block called the controller block. The last class, we also spend some time in discussing this relationship between the error and the control voltage V c and we call that as a controller gain k. Now, this control gain k we saw is needed to be very high a value which tends to infinity to a very high value.

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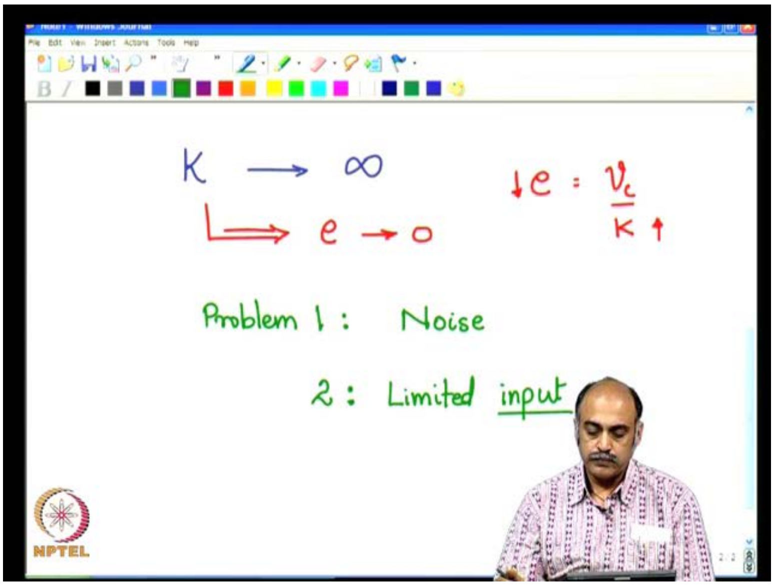

So if this is very high, the result of this the result of this is that the error tends to 0 because we saw that the error is nothing but V c by k. So, if k becomes high tends high e tends to a low value however we saw that we had two problems in the last class problem 1. Noise is an issue and especially if you have the controller gain k as a very high value then noise which is generated in every component in the electronic circuit will also get amplified by this infinite gain and it will swamp out all useful signal.

So, you will only have noise at the inputs in the outputs the second problem was that of limited input to the system there is a power supply which is given to the signal conditioning circuits of the switch mode converter DC DC converter is generally plus minus 12 volts or plus minus 15 volts, 0 to 5 volts, 0 to 3.3 volts and so on. These put a limit on the input absolute input voltage value and therefore, as consequence you cannot give any value to from the minus infinity to plus infinity an error.

If it swings beyond of particular value it will saturate the input it will go and struck to either plus 12 or minus 12 voltage limit and once it will get saturated there is no longer close loop action. As a result, the system will be open loop and primary objecting objective of closing the loop is not met. Therefore, these two are very important issues that needs to be addressed and that is what we would do in the remaining portion of this class therefore, we cannot.

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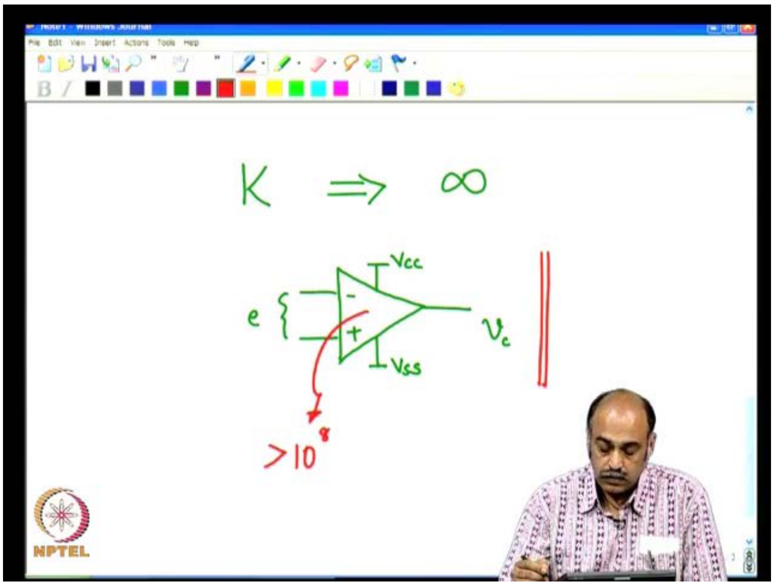

Even though practically it is possible to set k even though it is possibly it is possible to set k to a very high value see we have OP amp comparators the one OP amp comparators with a power supply given as V c c, V s s again limited plus minus 12 volts. This is the output of the o p amp and let say we set it is V c and we have the error e. Now, this OP amp gains of the order of 10 to the power of 8 and axis of that, so you can go to really high gains. So, component why is technology why is we do have possibility capability to give very high gains a hand position them in the system as controller. However because of the previous two problems that we mentioned noise and limited import we cannot do that.

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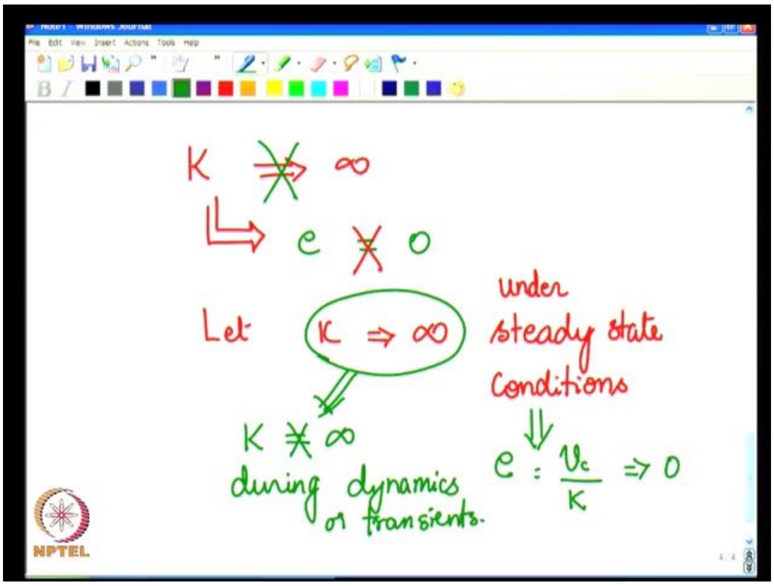

So therefore, k setting to infinity is not allow, now this would mean this would imply that e cannot be equal to 0. So, this as a consequence of this decision, so if we cannot have k set to infinity e cannot be 0 under all conditions. Therefore, we need to make a compromise let k be said to infinity under some conditions and that is under steady state conditions.

So, under steady state conditions can we set k to infinity which means that under steady state conditions if we are able to set k to infinity e which is equal to any control voltage by k will get set to 0. So, steady state accuracy is achieved however during dynamics we relax this condition k is not equal to an infinite value during dynamics or transients.

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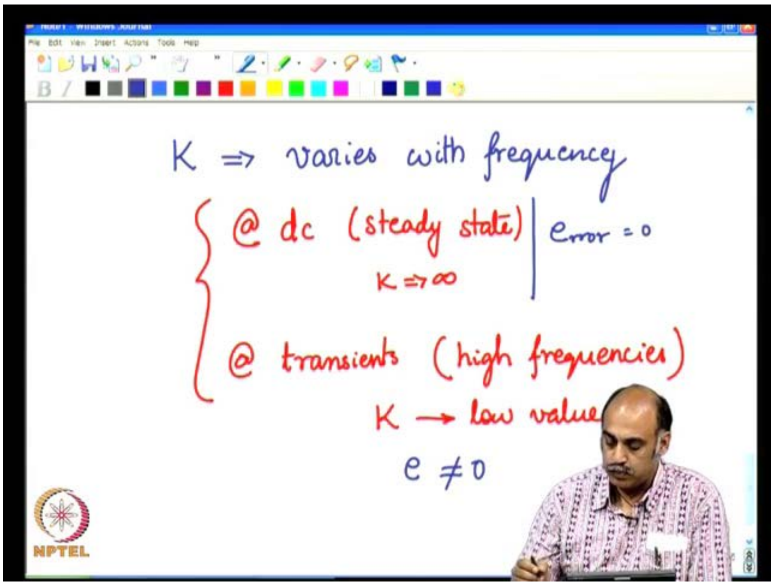

So, let us do a k with varies with varies with frequency in such a way that at DC or steady state at DC or steady state k will be set to infinity during at transients or high frequencies k will tend towards a low value. So, let us shape the k in such a manner make it variable k such that it follows these kind of constraints. So, under such a condition you can say during steady state error will be 0 and during transients error is not equal to 0. This in fact is what will try to solve the two problems that we mentioned that is the noise problem and the issue of limited input.

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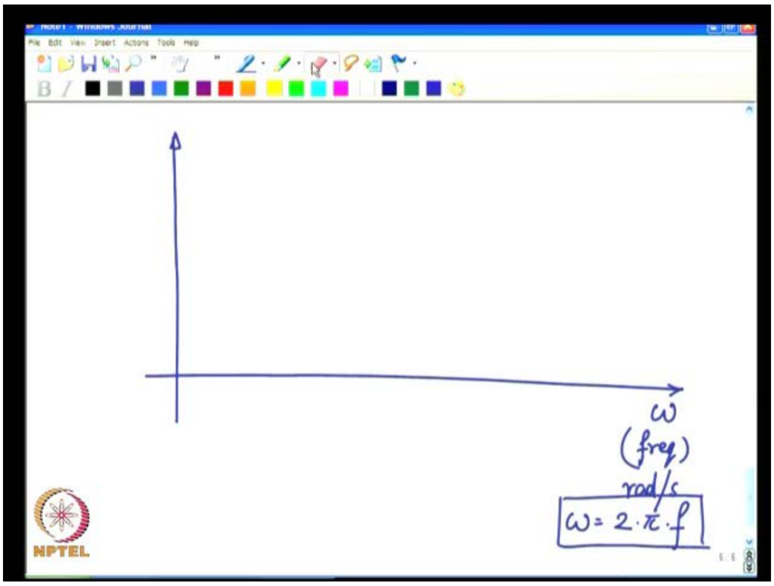

So, let us just look the look at a graph get a picture of what would happen if we look with respect to omega which is the frequency in radians per second. So, if you have frequency in hertz omega would be 2 pi f radians per second, so on the x axis, let us how omega frequency and on the y axis let us have two components one is of course the gain.

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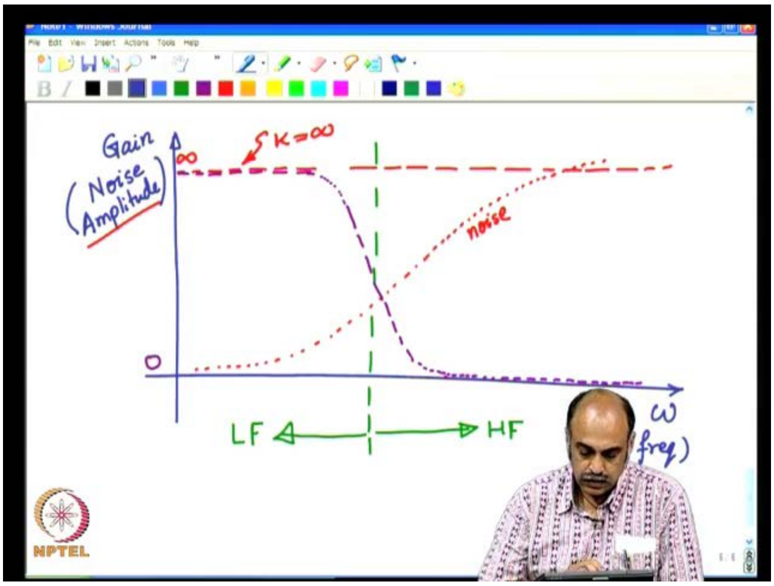

Another thing would be the noise sensitivity or the noise amplitude where is just put it plain in simple noise amplitude. So, this noise is not so significant in the low frequency so it is low at the low frequency gradually starts to increase towards the high frequency portions of the system. So, if you demark it, so this region is the l f or the low frequency region and this region towards right is the h f or the high frequency region. So, in most of the systems and especially in the DC DC converters which are switched you will see that the noise is more predominant in the high frequency zone this is the high frequency zone.

It becomes very significant here and not so much in the low frequency zone it is more, it can be tolerated much better and therefore, you need to address this portion of the this portion of the gain that is seen by the system. Now, if you look at the gain, so let us say that that gain here is an infinite value you imagine that this scale is pretty large vertical as an infinite value to their, now let us say our initial proposal was to have the gain value k constant at a very large value.

So, this is k set to a very large value infinite value, now what would happen k not only amplifies the signal. It also amplifies the noise sprat which is inherent in the circuits being generated within the components. These noise components noise parts a various frequency get amplified by infinity and swamp out any meaningful signal. Therefore, what is required is that we need the gain let us say this 0, we need the gain to take a turn somewhere.

Here, let the gain take turn somewhere here start falling down and may be even going to 0 even going to 0 at high frequencies. So, this is what we need our new gain to look like it is high it is having a value in the low frequency region low frequency region high gain at these especially it is a high gain and as it starts as the frequency starts increasing. We want the gain value to fall such that it in fact at 10 units the noise at the high frequency so that is the basically principle.

We want to shape the gain curve in this manner this being the noise and we want to attain the noise which are predominant in the high frequency region. So, the next step is to make an implementable gain, a gain that has large value at DC and a very low value as omega becomes higher and higher, so let us slightly change the notations.

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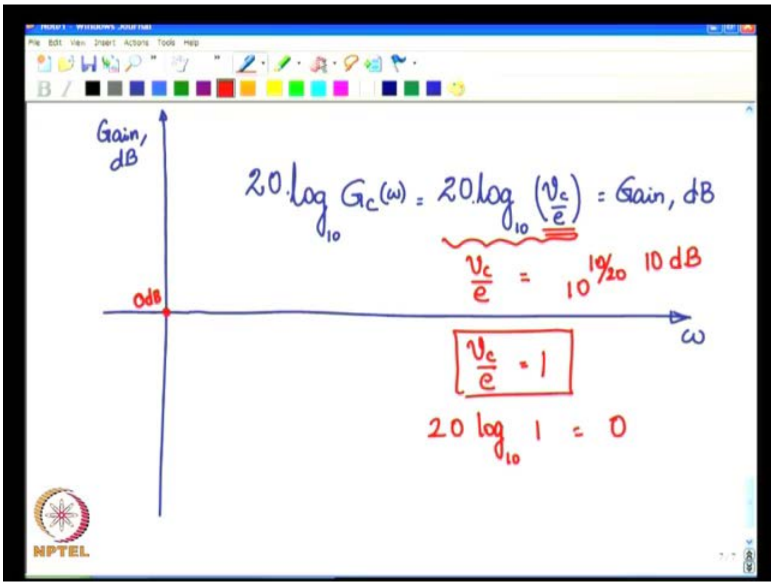

So, let us draw this kind of a curve, now let method write here V c by e, now this is the gain k, now let us say this gain k we are going to replace it this simple assemble, we will replace it because k is normally represented for a constant. This is being replaced by G c gain of the controller, so the G c means gain of the controller which can vary with frequency now this is a function of omega this is no longer constant function of omega.

Now, we talking of infinite gain to zero value of gain in, so you will see to the vertical axis pretty expanded elongated. So, let us compress the vertical axis, so I have good means of compression would be to take the logarithm log 2, let say 10 and let me push this log to this 10 we have V c. So, this will compress the log the vertical axis gain and if you want to express it in dB 20 times as log is at dB value. So, we have sat 20 log 20 in to log, now this means that the gain this is called a gain which is expressed in dB decibels so this is the one in order to compress the vertical scale so that you can put it in a reasonable frame work within a page.

So, this is being expressed as dB, so always remember that it is nothing but 20 log base 10, so just to give an idea if the gain let us say let us say you have again of 10 sorry, let me write it here. Let us say we have 10 dB, now here this 10 dB is actually coming as 20 log base 10 V c by V e what is this ratio what is this ratio so V c by e is nothing but 10 by 20.5 10 to the power of 10 by 20. So, this is nothing but root of 10, so if V c by e is equal to one the absolute gain the actual gain is 1, then in dB y it is 20 log base 10 one which is 0 dB. So, this is zero dB graph so when you say zero dB it implies unity gain absolute y is unity gain. So, keep that in mind, so let us say so let us say that we have an integrator just too given idea.

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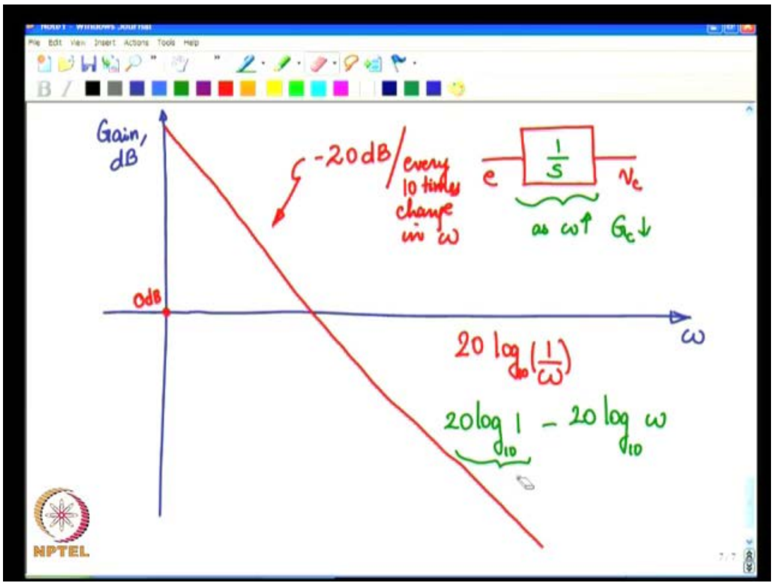

Let us say we have an integrator, integrator has an input and an output, so in the lap lose domain this integrator is written as 1 by s. Now, s is the real fact is zero s is a omega is actually 1 by omega, so as omega increases this gain keep decreasing as omega increases G c decreases. So, DC even omega is equal to 0 the gain is a very high value infinite value and it very large frequencies very high frequencies.

The denominator G omega, omega is very large and therefore, the gain seen by the gain presented by the controller is very low. So, essentially you will see if you take it is log logarithmic scale you will see a straight line which starts going down like this and it starts going down at the rate of 20 minus 20 dB for every 10 times change in omega. Now, the gain as 1 by omega log to base 10, 20 is the gain in dB which is nothing but minus 20 wipe on this which is nothing but 20 log base 10 1 minus 20 log base 10 omega, now this portion is 0. So, you can remove that, so you are left with only this sole said this results in some dB, so what is absolute value of omega would be dB by 20 minus 10 to the power, now let us look at this itself.

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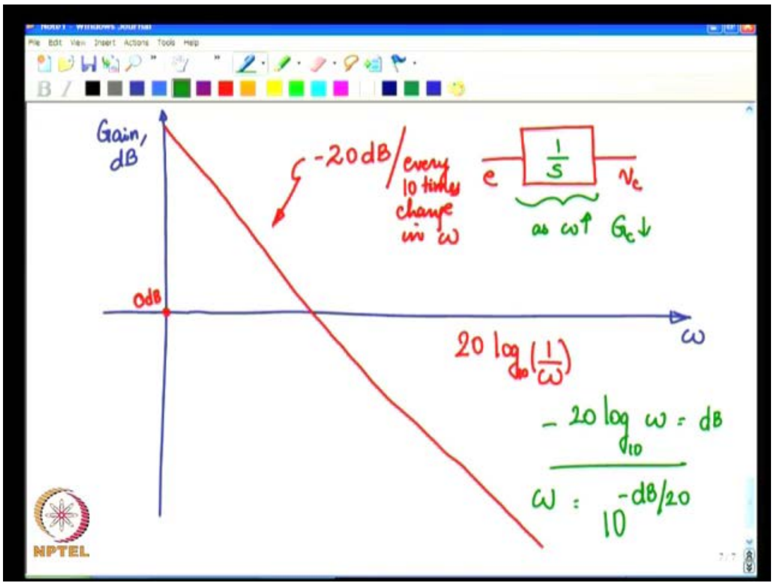

Let us look at this 20 log base 20 omega which is the dB gain as omega is equal to 1.

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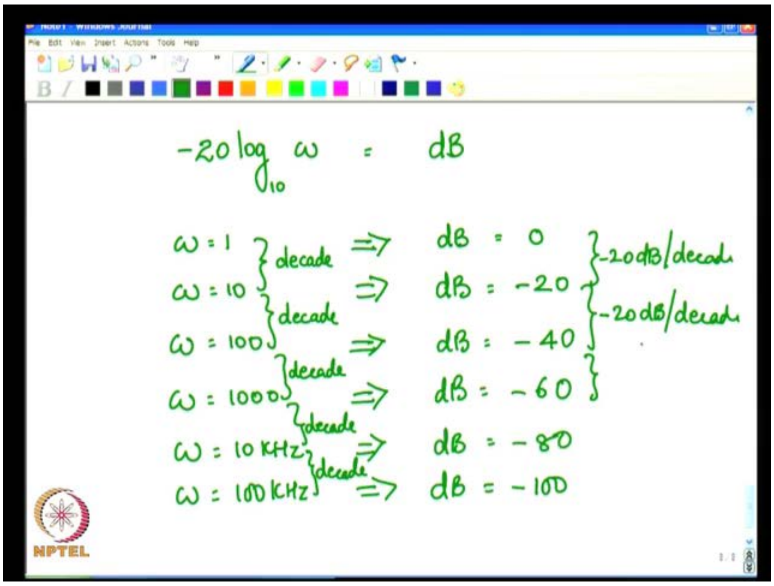

Then, the dB gain is equal to 0, omega is equal to 10, then log base 10 is 1, so then the dB gain is minus 20 minus 20 omega is equal to 100 long based in 100 is 2 to into 20 40 minus 40 dB. So, the dB game becomes minus 40 omega is equal to 1,000 long to based in thousand is 3 into 20 minus 60. So, dB gain is equal to minus 60 and so on 10 kilo herds you see the dB gain is equal to minus at omega is equal to 100 kilo herds dB gain is equal to minus 100 dB so on.

So, you see here for every ten times this is a decade 1 to 10 your multiplying by 10 is decade. This is another decade another multiplication by 10 for every multiplication by ten you have decade will call it as a decade for every decade increase in omega there is a 20 dB decrease minus 20 dB. So, you say this is 20 dB per decade this is another minus 20 dB per decade so on. So, you will see that you will have linear curved like this what we see at minus 20 dB for every 10 times change in frequency or 20 dB per decade, so that is the character of the integrator this is nothing but the integrator.

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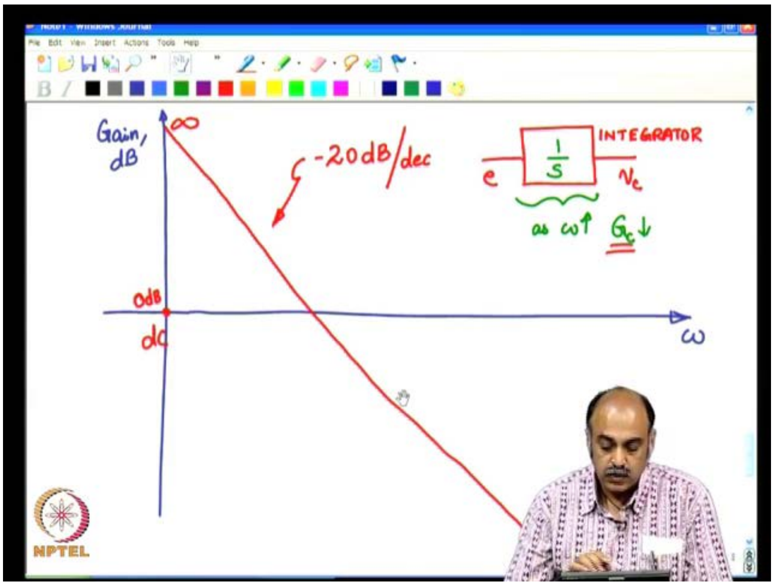

This is nothing but in integrator this is nothing but an integrator, the integrator seems to give something like this, if G c is the gain curve of the integrator. So, this is how the gain curve look like this is a straight line imagine this is the straight line even though I have not drawn it strictly. It forms at minus 20 dB for every decade every 10 times change and omega, so this is a very nice block this is a very nice component that you can use which has an natural gain pattern like this very high infinite gain at DC this is DC towards DC. A very low gain towards higher frequencies as the frequency is increasing the gain starts falling down, so this pattern this component will be our basic building block in the control.

We will use it extensively to design controller is because of this natural following gain pattern which actually is very close to the desirable thing where we have where we want the gain to the infinite. In the low frequency regain and start going low towards a high frequency the regain, it may not following exactly the same kind of pattern as we have shown here, but non the less you have a infinite gain the low frequency regain. Here, you have low gains at the high frequency regain and you should observe that this is this 0.01 dB is absolute terms wise is unity gain.

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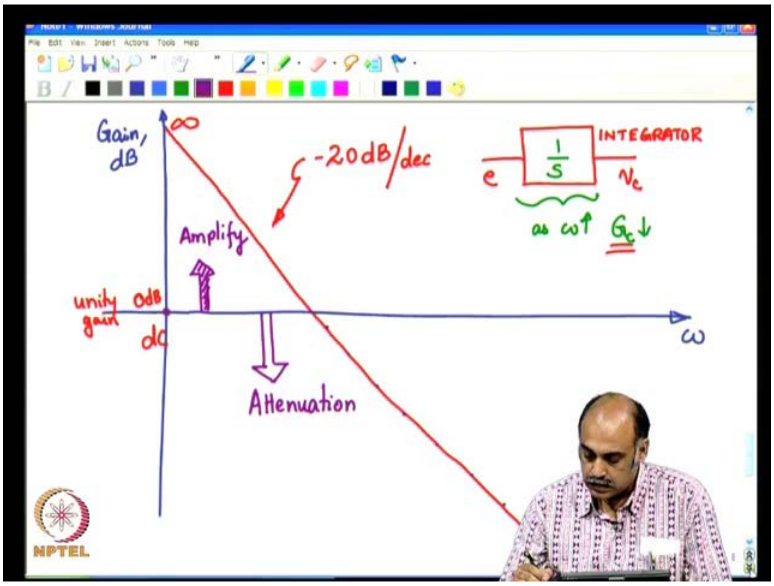

So, the zero line is not nothing but unity gain above that is amplification and below that would be at envision. So, minus dB minus 1 dB 2 dB 3 dB you would imply attenuation, so any point that any of this point gain points would imply that the output is going to attenuated with respect to the input. So, proceeding from here this is one component, let us take another component and see how it looks like with respect to omega.

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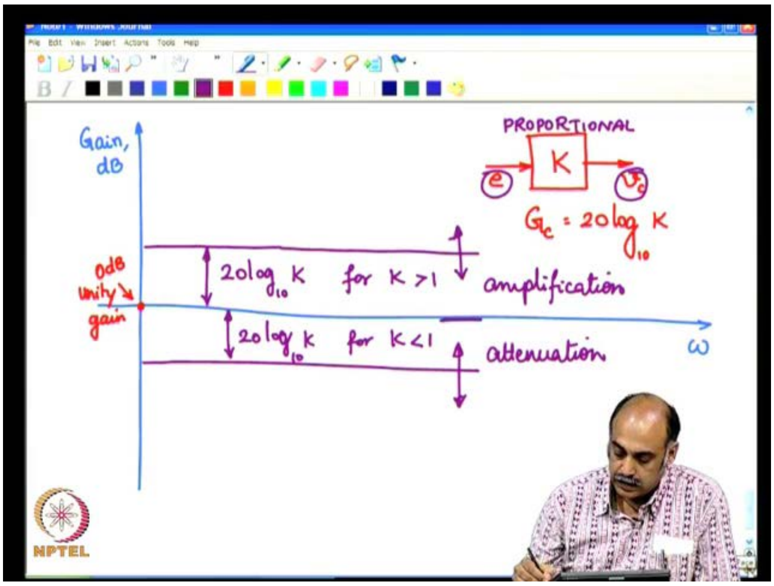

Then, we will try to integrator is various components to form one integrator controller, so let us look at the gain and dB we have at this point 0 dB or unity gain. Now, let us consider a block which is a constant just a simple constant k you have the input and the output. We will say the input is e output is we see because in this case input is a error and output is control voltage. Now, if this for the case the gain G c is equal to k sorry is equal to 20 log based 20 k gain, now if k was constant when k is independent of frequency. So, 20 log based 10 k is a constant value, so you will see that it will take on a curve which is something like this 20 log based 10 k.

If this was amplification or if you are having k which is less than 1 for k greater than 1, so it can very any where here or it could be here 20 log is 10 k for k less than 1. You will have a variations from here to here, so this is attenuation and this is amplification and a K is constant 20 log based 10 k will be constant and it will be air constant value through.

So, here you say that the output control output controller output is proportional to the error input. So, this is a proportional component this is proportional component, we saw earlier one by s nothing but n integral the integrator component. Here, just take constant k is proportional component are the proportional component gives a variation of the gain with respect for frequency which is like this and this is nothing but constant as k is independent of frequency unlike the integrator which gave a k. This was following with respective frequency, now let us focus that one more important component which we were in.

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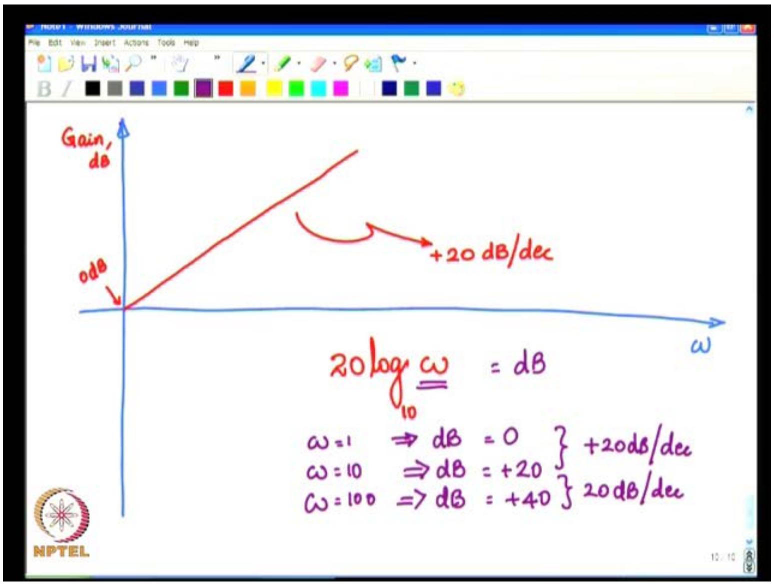

Looking same example back gain in dB and this point is 0 dB, so let us say that we have gain pattern going live back 0 dB and at some point here the start taking a turn like this. Now, this is this interesting in the since that up to this point you do not have an either attenuation of or amplification is this is the unity gain and from here on your having amplification.

Now, let us say can be obtain and amplification at the rate of plus 20 dB or d k just like we are minus 20 dB per d k for the integrator, so how do you get plus 20 dB per d k let us. Reframe this problem in the following manner, let us make it simple simpler by saying that like the integrator like this also start going like this from 0 and from 0. It is going at plus 20 dB per decade, so you see that it keeps on going towards infinity is such thing possible now to get this, it would mean you need to have 20 log base 10 omega, so here the omega is equal to 1.

Then, give the gain will be 0 omega equals 10 dB gain will be 120 plus 20 dB omega is equal to 100 dB gain will be plus 40 so on. So, you see that for every decade you have plus 20 dB per decade 20 dB per decade, so to get 20 dB per decade kind of a iteration you need to have a gain controller gain which is like this.

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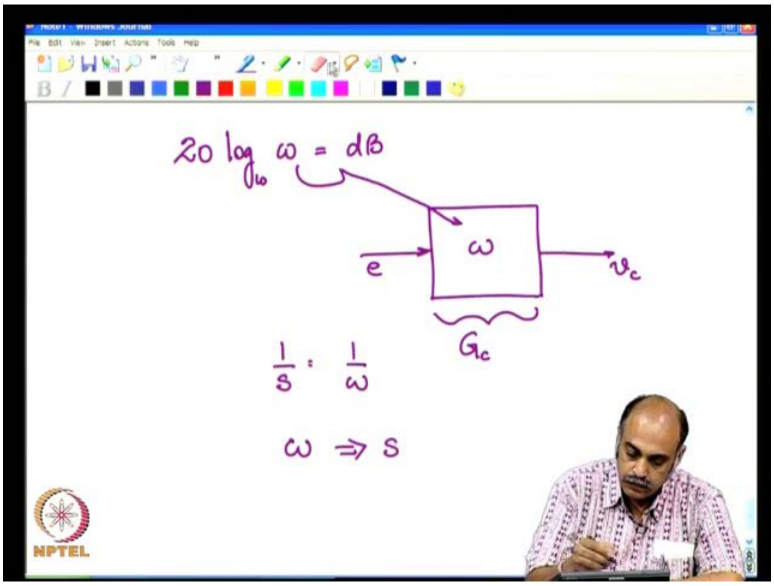

This just omega multiplied by omega which component will give you such thing as a gain which component this implies that the component omega should be your controller gain. So, just like we had one by s which is nothing but 1 by omega because the real part of the integrator is 0. You have in the s plane the integrator poor locator at this point, so the movement along the j omega axis like wise to get omega which would imply s or at derivative.

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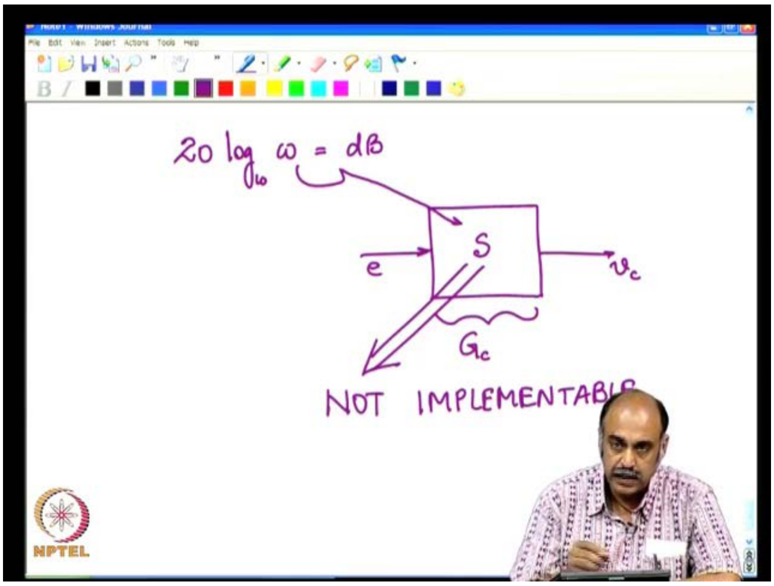

So, the transfer function here to would mean it is just s but, remember you cannot have a pure derivative. This form is not implementable a pure derivative cannot be implemented because we cannot know the future it is friction what set mean derivative is nothing but the slow.

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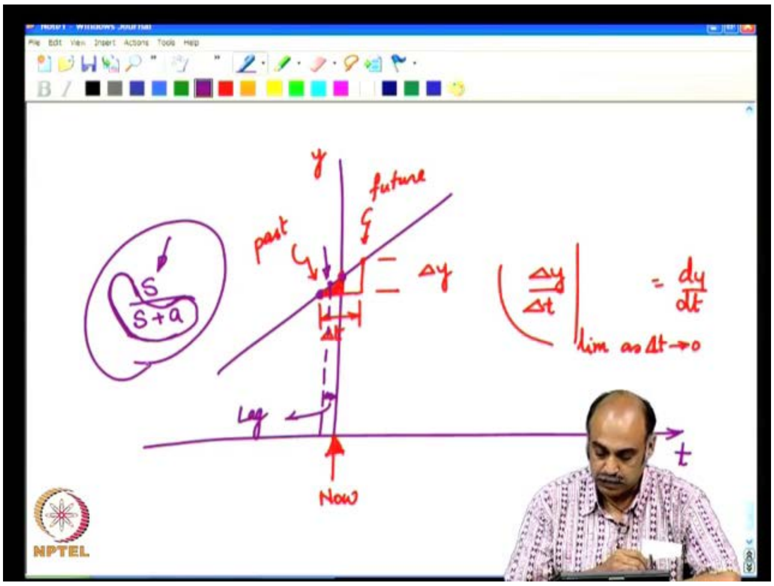

So, let us say you have a particular a revolution of particular signal and you are seeing things with respect to fine and let us say at the this point. This is now so what do we say that the derivative at know nothing but you take a small deviation from that operating point another small deviation from that operating point. You will say that now this is let us say y this is t that said delta y and this is delta t there is in this case it is t s that why x axis variable so the derivative is delta y by delta t in the limit as delta t tends to 0.

Now, this is point and this point is the future point and this point is the past point, so you can always get the past point you can measure it you can get points up to. Now, beyond that future you cannot give a get it is not only a guess, so you can never always get any of the points after therefore you can never truly get dy by dt. You can at most scarred try angle, but this would the derivative of this at point with is just before, now so it is actually the derivative of the past or delivered derivative. So, you cannot get s you can always get delayed as and that is the delays nothing but a low past filter.

So, this is low past filter this is the derivative at now, but derivative now you can get because you cannot measure points greater than this later than this, so you have this two points and therefore the derivative which will represent that. The point which mean and this is actually in the past already, so it is lagging by sometime and that lag is represented by this low past filter or the lag effect, so always an implemented derivative is of this nature s by s plus a.

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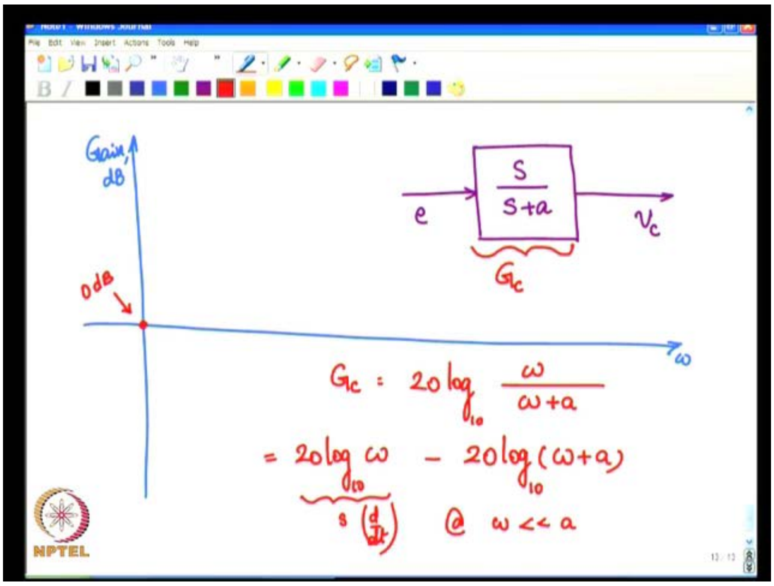

Therefore, what is implementable is something like this, so let us seen how the gain looks like for this so this is the gain in dB and this is with respect to the frequency. This point is the 0 dB point, so this is g this is a function of omega. Now, let us replace s s by omega, so let us say G c this 20 log to base 10 omega by omega plus a, so this food turn out this would be equal to 20 log base 10 omega minus 20 log base 10 omega plus. So, look at this is like your pure derivative like the s term the e by the theta d by dt, now this is another term which is the lag effect which is bringing in the lag effect, so let us same at omega much lesser than a this portion is a constant.

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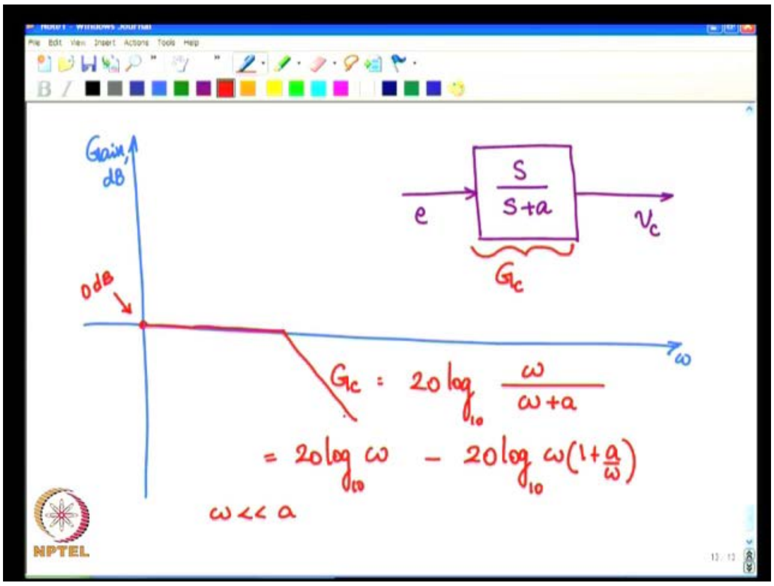

If you say we have same omega can be taken out and we will rewrite it in this form omega 1 plus a by omega, so case one when omega is small when omega is small this value is higher. This this particular expression would leave to something like this, so let us same it goes and this manner there is no space let us take a fresh page. Let me quick for this verses omega take first just 1 by omega plus a, so 1 by omega plus a would give, so it will be at omega equal to 0, it will just be going along just be 1 by a not along 0.

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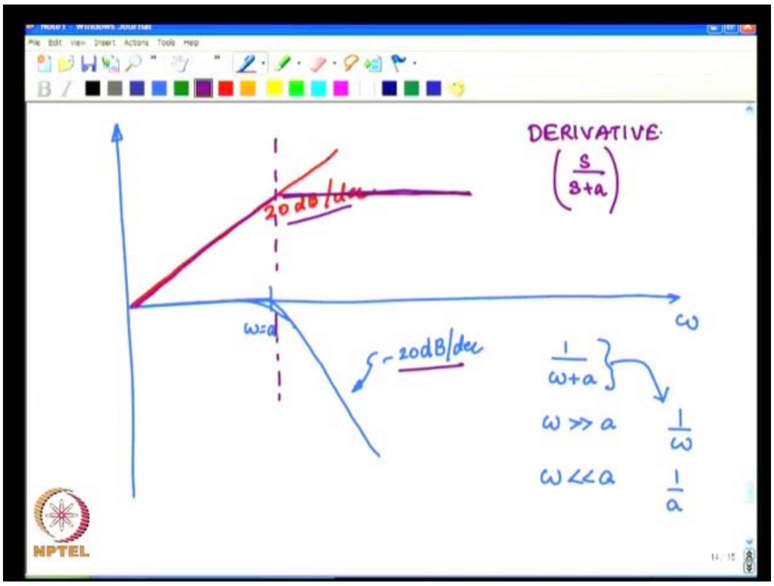

Again, we take up to some omega equal to a and then further on goes like this this is minus 20 dB per decade that is at omega much greater than a. The lack portion becomes one by omega a is neglected at omega much lesser than a you can just write it as by a. So, it could be an attenuation or gain depending upon the way depending upon the value of a omega can be neglected is constant. So, you have a constant and then you start having a drop minus 20 d per decade of course it would in actual practice it would be a smooth curve like that.

Now, the derivative portion the derivative portion starts giving a value starts giving a value which is increasing at plus 20 per dB per decade. So, that portion gives you an increasing curve at plus 20 dB per decade 20 dB per decade and this lack portion gives a minus 20 dB per decade at high omegas. Therefore, we land up with you will see that at this point there is cancellation a plus 20 dB per decade minus 20 dB per decade beyond air.

There is cancellation up to a there is build up, so which would mean that it starts building up like this then beyond that plus 20 dB per decade minus 20 dB per decade cancels and there is no further increase it gives going like this. So, this would be the nature of the derivative that can be built up that is s by s plus a kind of a block, so this is called the derivative block derivative block. So, you have an integrator block where in the gain in dB starts following like that you have our proportional block.

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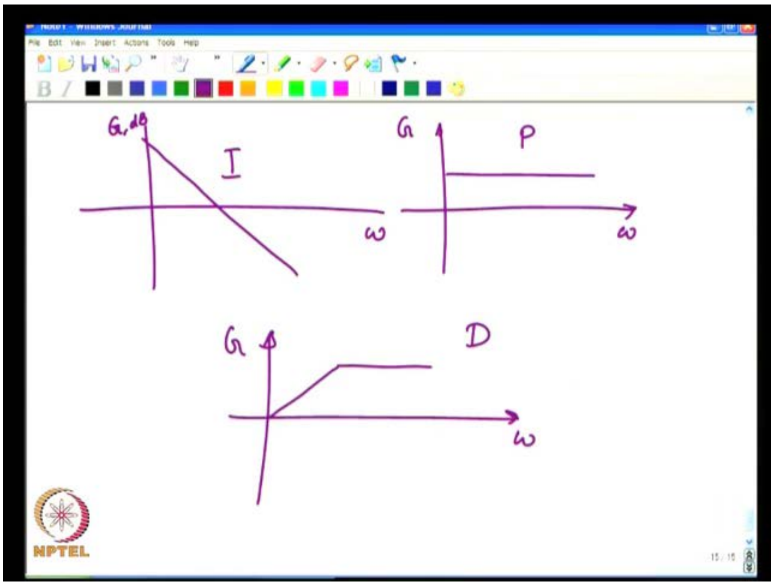

Here, it is constant with respective frequency and you have at derivative block where it in increases and then stress flat with the respective frequency. So, this is the I block, this is the proportional block, this is the derivative block, now this three blocks we will try to combined them the next class and build and integrated controller.

Thank you.