Analog Circuits
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Week -02
Module -01
Non Idealities in Op-Amp (Finite Gain, Finite Bandwidth and Slew Rate)

Welcome to week 2 of this course analog circuits, in the previous module we have covered the circuits of using ideal opamps, in this module we will be covering the circuits with real opamps where there will be certain non idealities present, so let us see some of the non idealities so the first type of non idealities that is there is.

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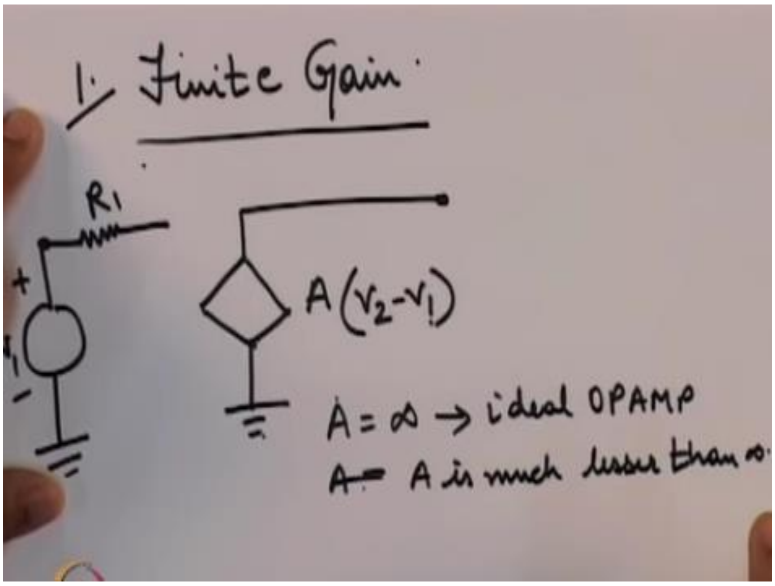

So finite gain means that the gain so the equivalent circuit of an opamp which we studied previously which is given by this expression, now for an ideal opamp A is ideal opamp for a real opamp A is much lesser than infinity, so if this is the case then let us see what is the impact on the total gain expression that we had derived.

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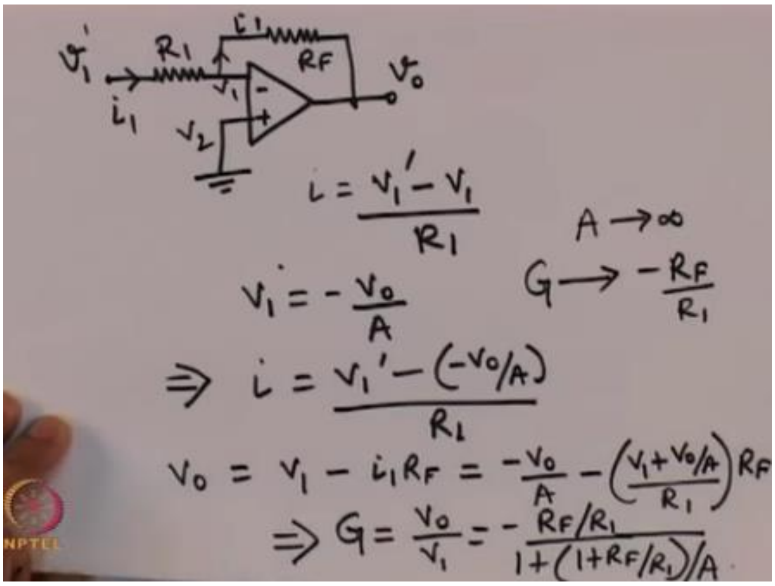

So the circuit of an inverting opamp is something like this okay, so we know that the current i1 flowing suppose this voltage is V1 and this is V2 and say the input voltage is V1 dash then i1 is = V1 dash - V1 upon R1 now this V1 dash V1 sorry is also given by this expression - V0 upon A.

So from here we can straight away write that i is = V1 dash -, - of V0 upon A upon R1 and then this Vo on the output voltage can also be given in terms of V1 as V1 - I Rf from which we get this is = V0 upon A - of V1 + V0 of A upon r1 times Rf from where we can get the value of gain is = V0 upon V1 which is = - Rf upon R1 upon 1 + 1 + Rf upon R1 upon A gain.

Now we see that this is the expression A is finite of course when A tends to infinity the value of gain will tend to - Rf upon R1 so this also validates that this formula is correct so just like the previous case with ideal opamps here also we had at our solution that we get for this gain is consistent with this value of G is consistent with the values that we got in the previous case.

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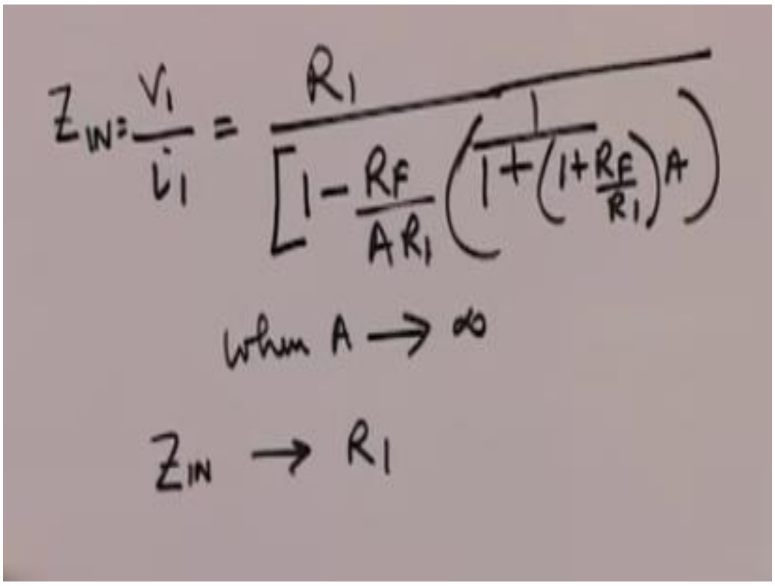

So now coming to the next part about the input impedance the input impedance that is V1 upon i1 will be given by this formula, I will leave it as an exercise for you to verify this ok and just like the previous case when A tends to infinity the Zin which is given by this value when A tends to infinity Zin will tend to R1, the next type of non linearity that we come across or the non ideality that we come across is what we called finite bandwidth.

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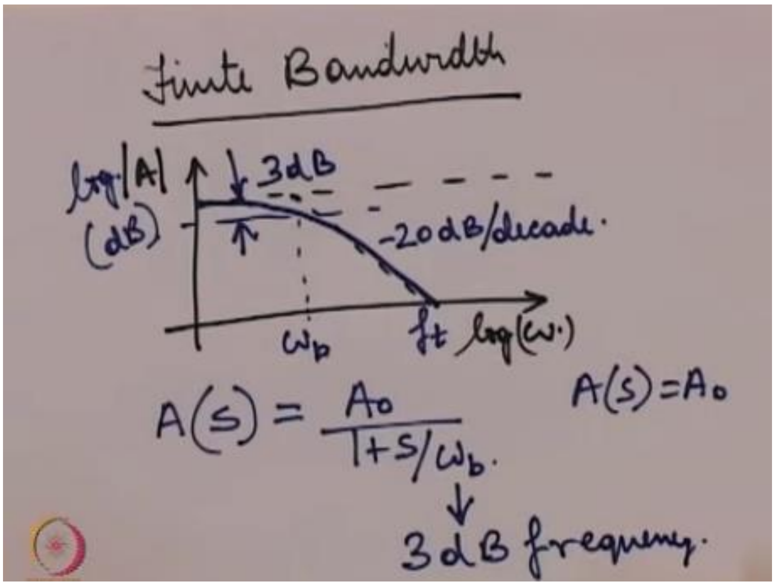

Now what is this finite bandwidth? In fact what is bandwidth? So for any active device not just in opamp I had mention that the property one of the ideal properties of an opamp that we will be considering is that bandwidth is infinite, so if suppose we plot the gain A versus omega for an ideal opamp it should be like this for a real opamp what happens is this is on a log scale of course the plot that we get is something like this.

So you see that it is not going on with the same value through out for all frequencies, if like this A is actually the logarithm or db scale as we called now how to module this the usual way to module this is to consider the open loop transfer function of an opamp something like this now this A0 is the DC gain for an ideal opamp this As will be simply = A0 for a real opamp it is like this.

So as you can see as the frequency increases the magnitude of A of S keeps on decreasing and at this frequencies omega b the magnitude of the gain decreases by 3 db hence this omega b is also known as the 3 db frequency so with this in mind how should the characteristics of a closed loop or one of the inverting or non inverting opamps look like the frequency response characteristics.

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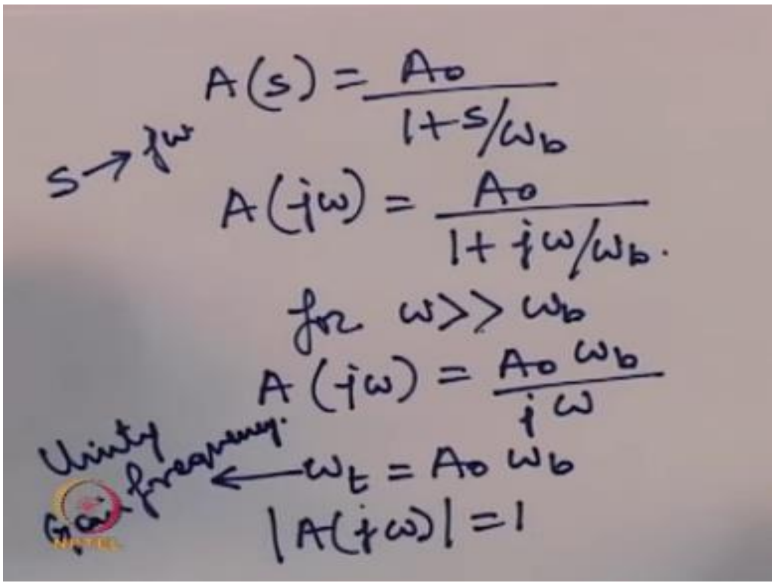

So we have this A of S is = A of 0 upon 1 + S upon omega b, now taking making this substitution S to j omega we have A of j omega given by A0 upon 1 + j omega upon omega b now for omega much larger than omega b we have A of j omega is = A0 omega b upon omega j omega now here you see this at a certain frequency omega t given by A0 omega b this modulus A of j omega will be = 1 and this frequency omega t is therefore called a unity gain frequency.

It is that frequency where the gain of opamp becomes unity that is it no longer able to give any further gain, now let us see what happens to the same thing in a inverting opamp, so for an inverting opamp we have already derived the express for gain with finite gain.

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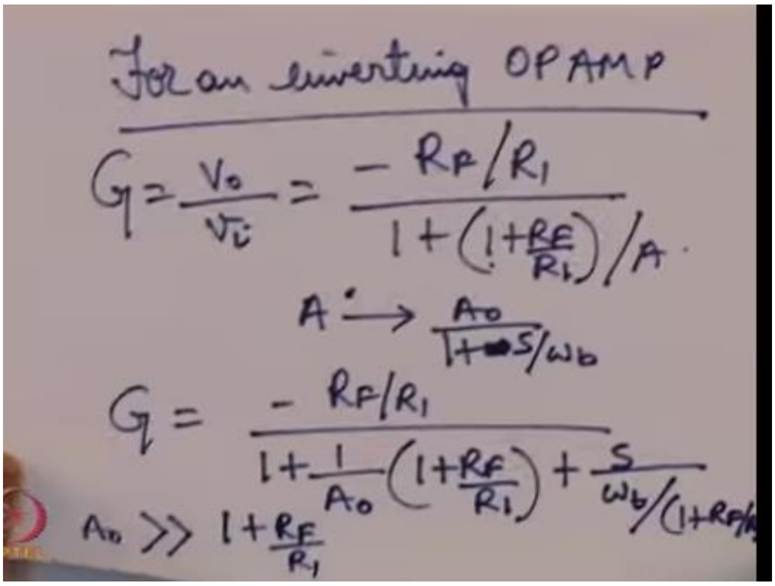

So the expression will be so for an inverting opamp we saw that our gain which is = V0 upon Vi is given by - Rf upon R1 upon 1 + upon 1 + Rf 1 + 1 + Rf upon R1 upon A now substituting A = the expression you know this in place of A of A just say A to A0 upon 1 + omega sorry 1 + S upon omega b.

If you make this substitution this gain expression turns to something like this Rf upon R1 upon 1 + 1 upon A0 1 + Rf upon R1 + S upon omega t upon 1 + Rf upon R1 okay you know usually this A0 the DC gain or the gain when I say = 0 is much larger as compared to 1 + Rf upon R1.

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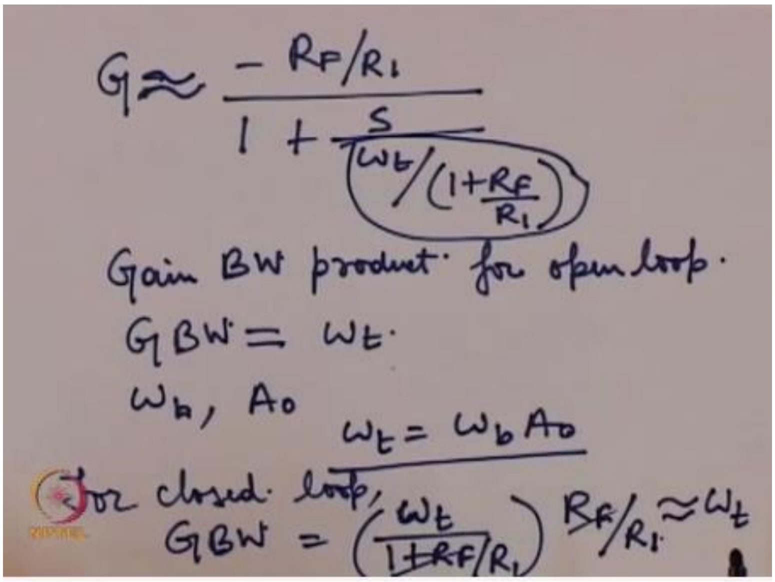

Therefore this expression reduces to, gain is = - RF upon R1 upon 1 I should give the nearly equal sign 1 + S upon omega t upon 1 + RF upon R1 okay there is a concept of this gain bandwidth product so this is in the previous case our we saw that our gain bandwidth product was = for open loop or without any feedback was simply = omega t isn't it, because this bandwidth in the previous case was omega b and gain was A0.

So omega t which is = omega b times A0 this was the gain bandwidth product for closed loop this with an inverting configuration this gain bandwidth or we can say GBW is = the new 3 db frequency this is the new 3 db frequency which is omega t upon 1 + Rf upon R1 now this multiplied by the new DC gain which is Rf upon R1, so this almost = this they cancel each other so this is nearly = omega t which is the same as previous case for a non-inverting opamp also we can derive a function for the gain bandwidth product.

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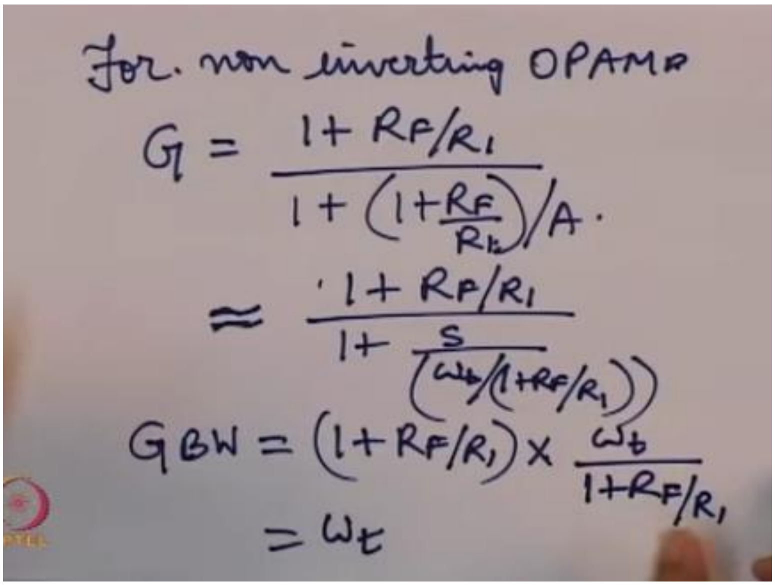

Just like for the inverting case we will finite gain and finite bandwidth the expression for the gain for non-inverting opamp will be something like this and then substituting the expression for A we will approximately get the expression like this okay so here also we see that the gain bandwidth product is = 1 + RF upon R1 this is the DC gain this is the DC gain times the new 3 db bandwidth which is omega t upon so this is this a new 3 db bandwidth upon R1 which is = omega t.

So the gain bandwidth product as we are seeing is remaining constant even with feedback now we are seeing that the bandwidth has increased now what is exactly happening from a graphical point of view.

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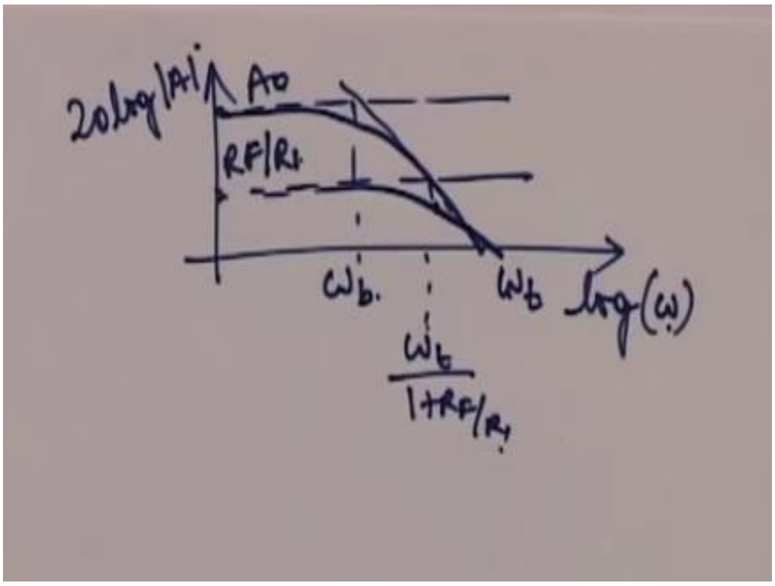

So if we once again plot our 20 log of A and this is log of omega in the previous case what was happening is we were getting a curve like this in with feedback is not that our characteristics has changed just this curve I shifted, so this was previously A0 now this is Rf upon r1 and my new characteristics is something like this.

So this is my new you know omega t upon 1 + RF upon R1 whereas in this case it was omega b and this is omega t you see that it is not that the device has changed and that is a reason this gain bandwidth product of the unity gain bandwidth remains the same it is just that we have shifted our characteristics from this part to this part and because now the DC gain itself is lower that is why it appears as a bandwidth is larger but the device itself has not changed.

So when we say that bandwidth increases with feed back or with the inverting configuration it is not that anything fundamentally has changed in the device it is just that we are operating at a different region of the characteristics of the device then one more non ideality that is frequently counted while discussing opamps is what we called the slew rate. So what is the slew rate?

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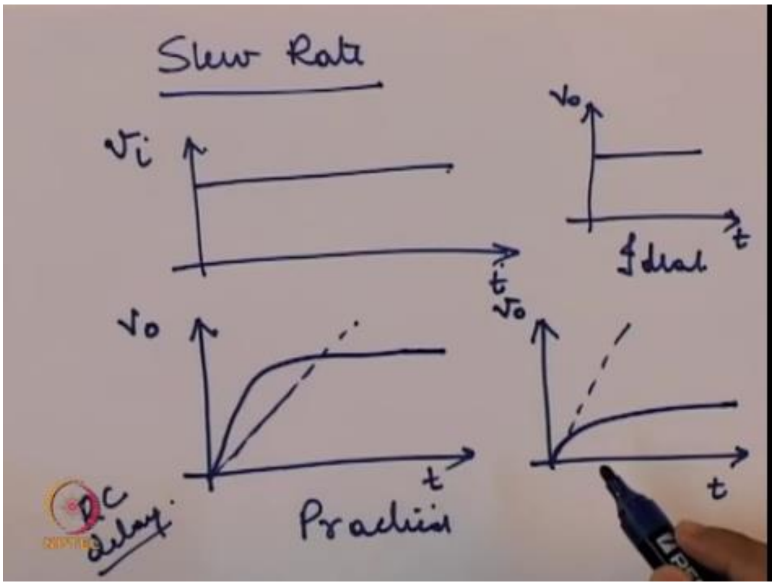

Now for an ideal opamp what happens is if my if my input changes like this then my output should change like this also but in reality what happens is the output so this is ideal practically in practical opamps what happens instead of the output shifting instantaneously with the input there is a slight delay or distortion whatever you called that and that is known as this slew rate.

Now 2 cases can be indentified you know depending on the magnitude of the output voltage in the first case you see that the output goes up slowly and this is because what we called RC delay or the delay (()) (19:17) in the output due to parasitic capacitances in the second case when the output voltage is less then there is a limitation on the output due to something else other than the parasitic.

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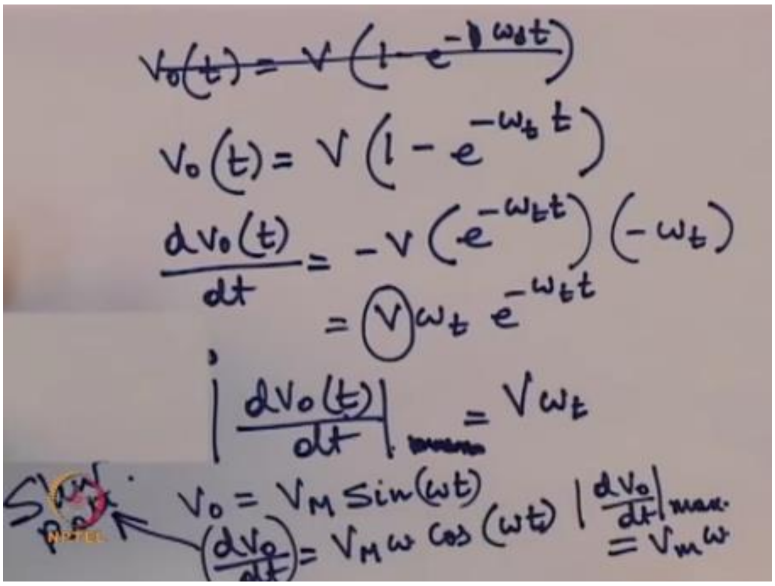

Now let us try to mathematically formulate this problem so you have the output V0 given by something like this okay, let me rewrite this the rate of change of output voltage is given like this now you see that the rate of change of output voltage depends both on the frequency that is the that is this coefficient of the exponent and also and this coefficient of the exponent is dependent on the output R and C values it is also dependent on the magnitude of the final magnitude of the output voltage, now so the maximum value of this rate of change or if I try to find out the magnitude of this change okay.

Now when this V0 is a say as sinusoidal voltage given like this then this rate of change is given by the maximum value again is given by so we see that when the output for a very small instant of time after the input is applied this rate of change of the output voltage directly proportional to the magnitude of the final value sinusoidal output voltage as I was discussing the maximum value of this rate of change of output voltage is given by Vm omega and the maximum rate of change allowed at the output this V dvo upon dt is called as slew rate.

Now this is a phenomenon which is slightly different from the parasitic effect due to parasitic as I said parasitic are the delay does not depend on magnitude of voltage but slew rate does depend on the magnitude of the output voltage for example you have been given a maximum frequency and you want to find out what is the for a given slew rate what is the maximum output voltage allowed then we can derive an expression for bandwidth like this.

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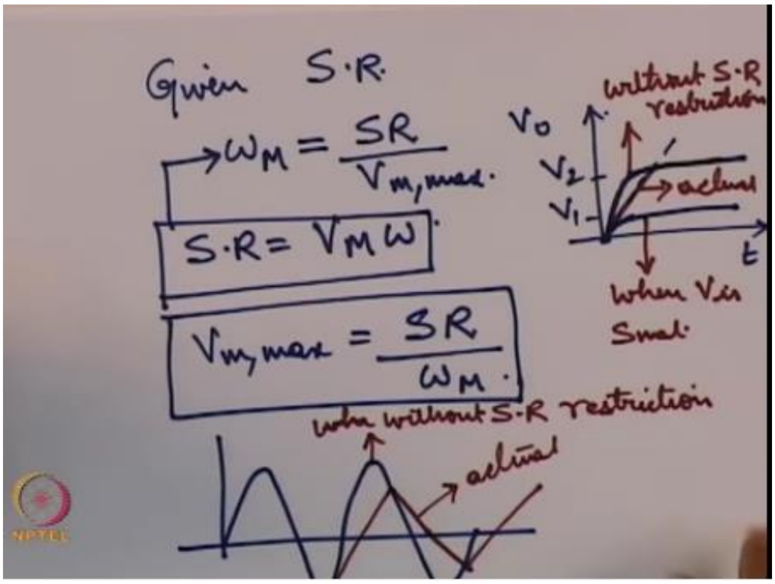

So say given a certain slew rate then the maximum frequency allowed for a sinusoidal output voltage is given by SR upon the maximum output voltage and this comes because slew rate is given as the maximum value of the output change rate of change of output voltage and that comes to Vm omega.

So from this expression we can derive this expression or say if omega the maximum frequency present at the in at the output voltage is fixed then the maximum value of the output voltage is given by SR upon omega M this is a important criteria it has to be taken in to an account and as I said like keep on repeating the slew rate is dependent on both the output parasitic as well as the maximum output voltage.

For example say you know if your output voltage is not that high then that might not be a problem for example say this is the curve representing the slew rate ok and if your output voltage final output voltage is not that high then it does not matter the slew rate you will get as it was predicted without any affect of the output voltage but suppose your final output voltage at the output is quite high then you will get a curve like this, this is when your output is where in exponentially so this is what you should this solid line what you should have got but you actually get is something like this okay.

So this is actual and this is without slew rate restriction this is when V is small ok then if you have a sinusoidal output then let us see what happens so you should have say got an ideal output like this but what you actually get is something like this because of the slew rate restrictions so it is distort so in this module we covered about slew rates about finite bandwidth and finite gain of an opamp, in the next module we shall be continuing with our discussions on the non-idealities of an opamp, thank you.