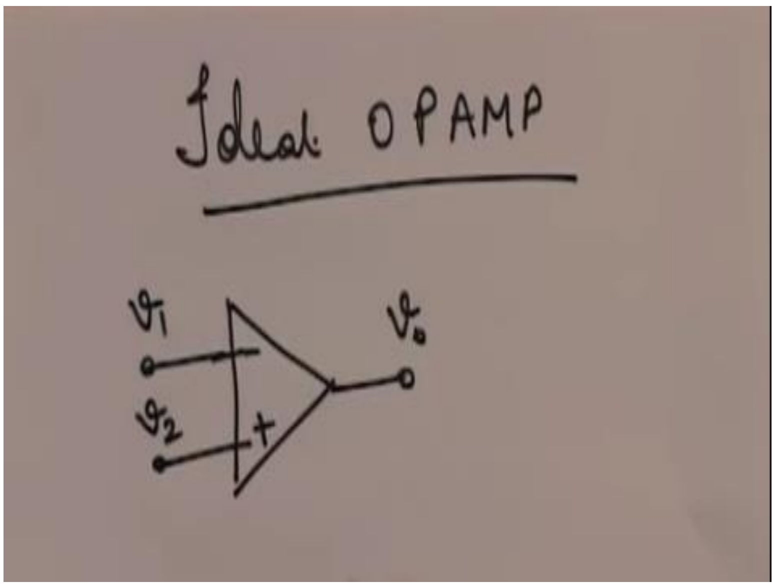
Analog Circuits
Prof. Jayanta Mukherjee
Department of Electrical Engineering
Indian Institute of Technology-Bombay

Week -01
Module -04
Applications of Op-Amps

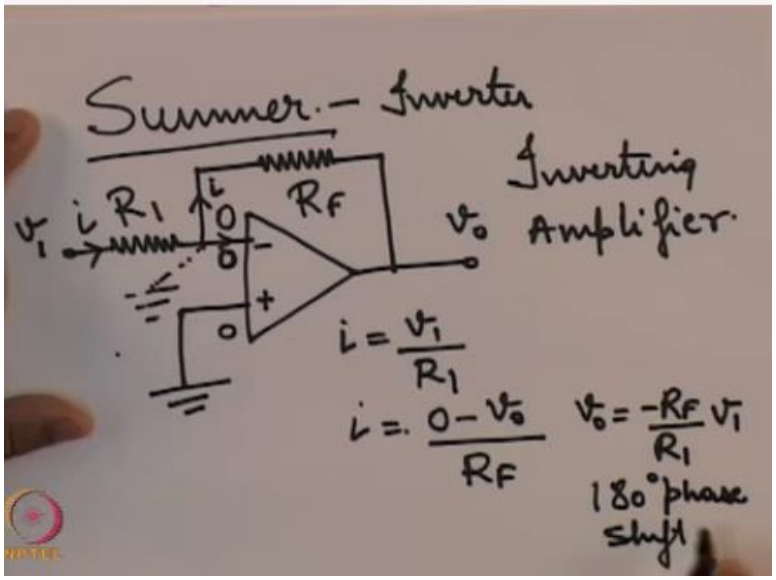
Hello, welcome to another module of this course analog circuits. In the last module, we had introduced you to the concept of an opamp, what is an opamp? What it is properties especially that of an ideal opamp. In this module we shall be seeing some applications of the ideal opamp.

(Refer Slide Time: 00:44)



So once again, if we draw the circuit of an ideal opamp so 3 port device vo, v1, v1 so this is the inverting this is the non inverting port.

(Refer Slide Time: 1:14)



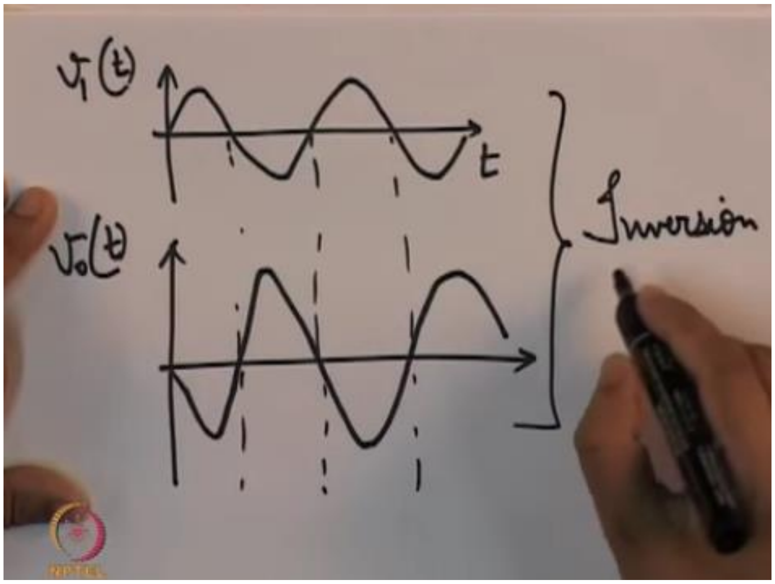
Now let us see one first application which is the summer, this is the basic circuit of a summer or more precisely what we call a summer inverter also known as an inverting amplifier, why it is called an inverting amplifier? It will become clear if we see the equations now, see that the non inverting terminal is grounded but the inverting terminal is not grounded, now since this is an ideal opamp there is a virtual short present between the inverting and non inverting terminal.

Therefore the voltage here is 0, the voltage here is also 0, if this is 0 voltage then that means there is a material called a virtual short and virtual short means that whatever be the input voltage this point will keep on acting like a short, it is not really connected to the ground but it is for all practical purposes it acts like a short, because this voltage will always be the same as this voltage which is 0.

So now if we write the current i that will be given by v1 over R1 and also we know that the input impedance of an opamp is infinity so the current flowing inside opamp is 0 therefore all the current coming flowing through R1 will be diverted to this path and hence the current along this path is also i.

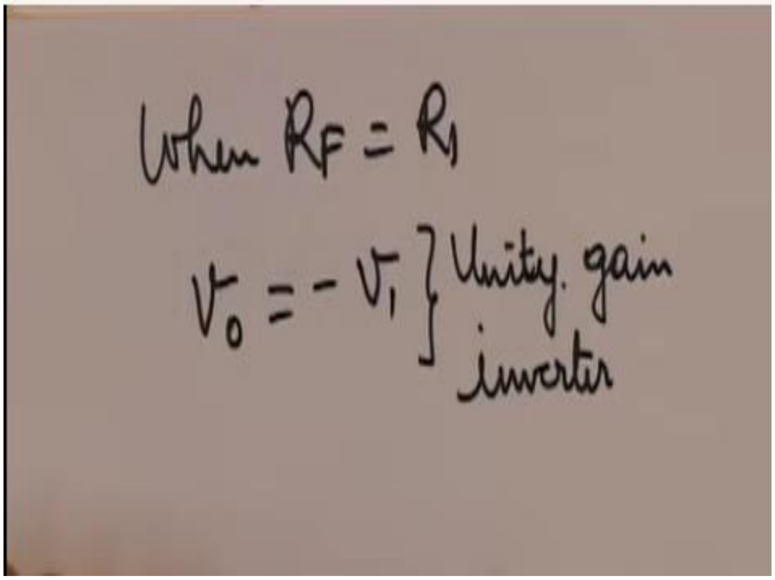
So, we can say that now what is the current flowing through this resistance Rf, it is the same as this current but what is the value in terms of Rf can we write that i is equal to this voltage - this voltage upon the resistance so then i equal to 0-vo upon Rf now equating the 2 we get vo is equal to -Rf upon R1 v1 that is it now it is called an inverting amplifier because the output is the negative of the input negative of the input also means invert like 180 degree phase shift.

(Refer Slide Time: 05:03)



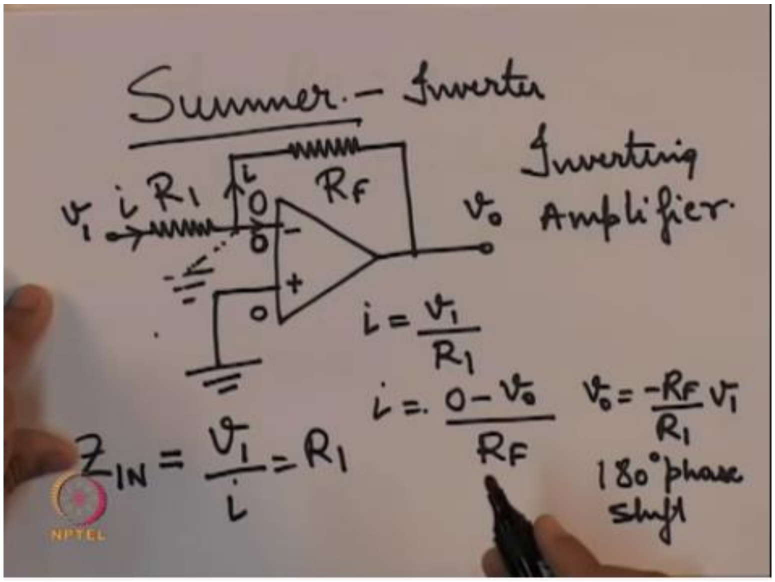
So if suppose our v1 is a sinusoidal signal then it will look something like this, we plot the input that is v1 as a function of time like this then the output which is usually amplified will be the inverse of this, so where it is positive it will become negative and where it is negative it will become positive and so on so because of this inversion or this 180 degree phase shift we call amplifier as inverting amplifier.

(Refer Slide Time: 05:59)



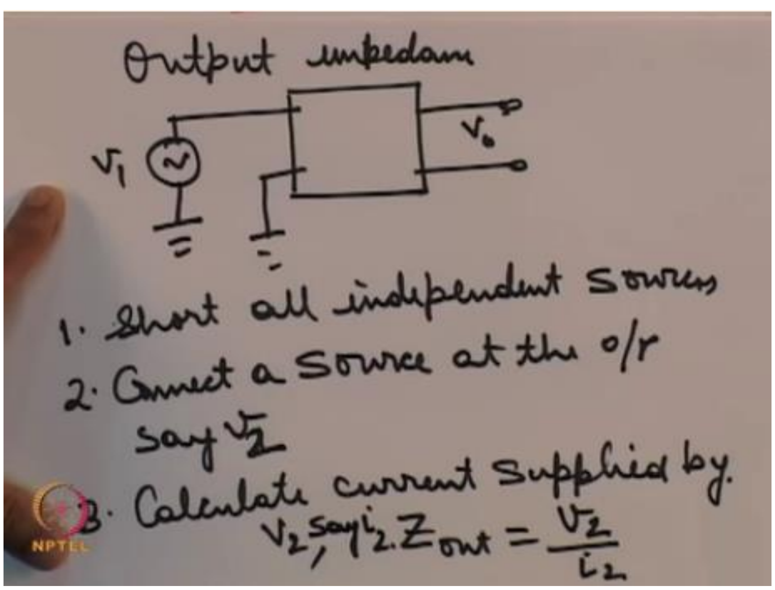
A special case arises when Rf is equal to R1 then vo will simply be the negative of v1 and such a configuration is called unity gain inverter so all this inverter does is change the sign or introduce a phase shift.

(Refer Slide Time: 06:33)



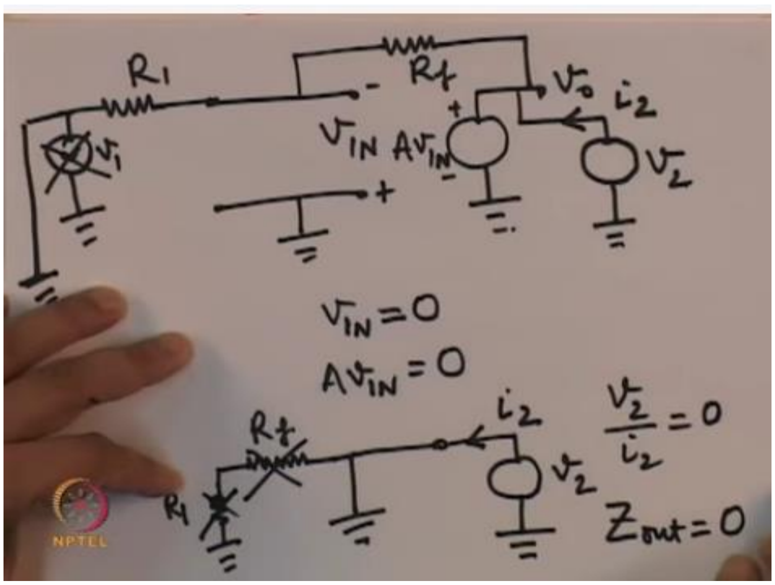
Now if I ask you to find out the input impedance of this configuration, so let us go back to our circuit, so to find out input impedance what you do is you calculate the input voltage over the input current so Zin is equal to v1 over i and that is simply equal to R1, we can also try to calculate the output impedance output impedance of any amplifier.

(Refer Slide Time: 07:08)



Suppose this is a general rule to calculate the output impedance, what we do is suppose you have a source or many sources feeding this amplifier and you are taking output between certain points then the way to find out the output impedance is to short all independent sources number 1, number 2 connect a source at the output say v1 or let us say v2 calculate current supplied by v2 then your output impedance is equal to v2 by i2 say that current i call it as i2.

(Refer Slide Time: 08:49)



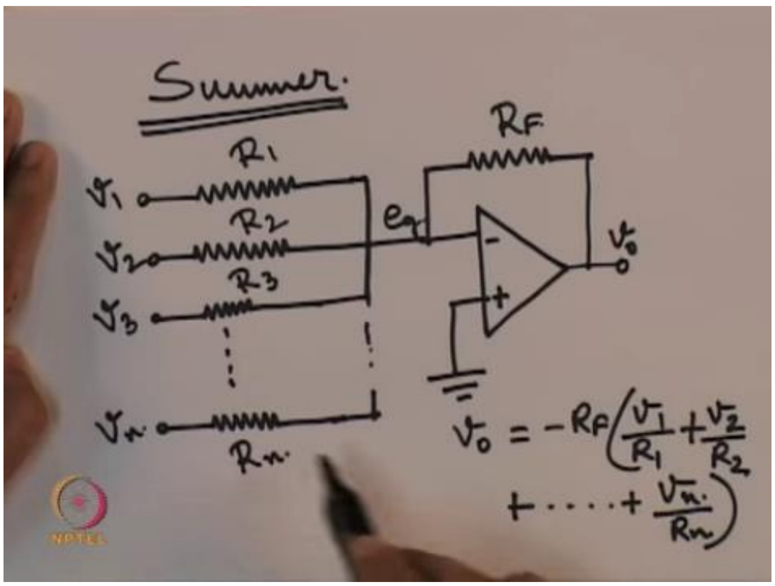
Ok, so in the case of an opamp what is let us go back to the equivalent circuit that we discussed in the previous class, so the equivalent circuit of an opamp is given like this okay now here or it is v now here we have connected a resistance R1, ok this terminal this is the non-inverting terminal which is grounded and between these 2 terminals.

We have our Rf so this the vo terminal okay now when I say so the first step is to short this if I short this then this gets cancelled and we have this terminal directly connected to ground, so if this terminal is connected to ground and this terminal is connected to ground and here at the output we connect the source let us say that is v2 and suppose the current supplied by v2 is i2 then if we can compute what is the value of i2 we shall be able to calculate the value of the output impedance.

Now first thing note that because this source voltage is now 0, so we can say that Vin that is the voltage actually appearing at the input and the non inverting terminal is 0 Vin is 0 then this AVin is also equal to 0, so in that case the equivalent circuit becomes something like this now this Rf and R1 which are in series is shunt to this short this terminal is shorted directly here so then the effect of these resistance go away and therefore v2 upon i2 becomes equal to 0, since this is a short so the output impedance is therefore equal to zero for an inverting amplifier.

Now the next application of this is in the same way now this particular configuration that we discussed this was with a single source present but you may have a number of inverting sources or sources present which have to be uh amplified so the circuit for that is or what we called as summer.

(Refer Slide Time: 12:36)



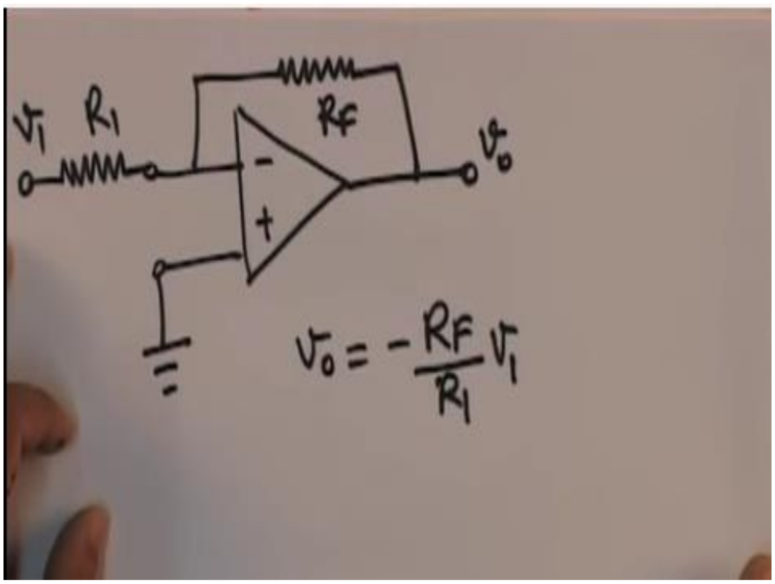
In the previous case we just talked about an inverting amplifier, but what if we have a number of such signals then we get a circuit what is called the summer which was the original topic that we are discussing now. So in the circuit for that is this is the circle now here what we have is this all voltage sources v1 till vn connected in shunt and then the shunt at the point where they are all joint is fed to the inverting input of an opamp.

Now the first thing is that the vo is very simply can be written as -Rf upon v1 by R1+ v2 upon R2+ till vn upon Rn, how did we obtain this result so here we apply the principles of superposition, superposition means since this is a linear system the effect of all the sources will be the sum of the effects of individual sources acting at a time.

So assume at the beginning we have only v1 connected and all the sources are not connected other sources are not connected then what it means is that these R2, R3 till Rn they are simply floating and therefore they do not contribute anything to the output, in that case the output will be if only v1 is connected with simply be -Rf upon R1 times v1 similar will be the result for the other sources.

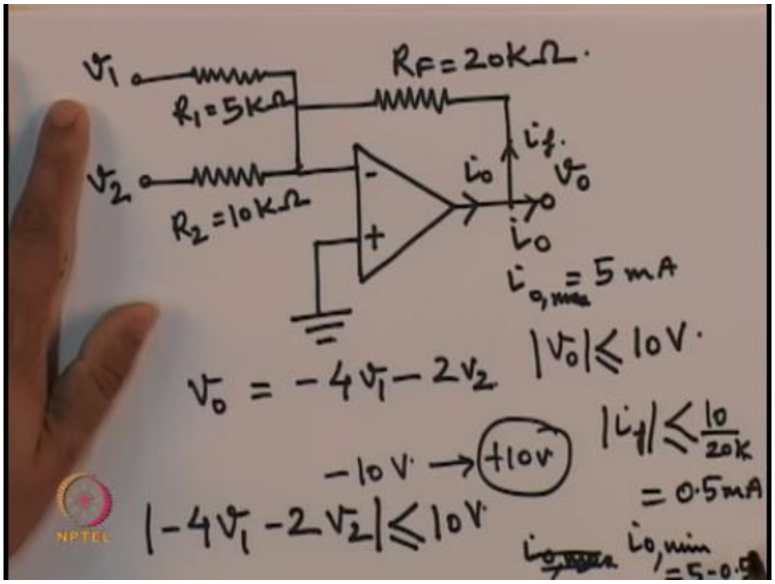
For example, when only v2 is connected the output will be -Rf upon R2 v2 and so on and finally so the overall impact on vo will be the sum of the impacts produced by these individual sources and that is how we get this sum.

(Refer Slide Time: 16:13)



One thing that we are not so far considered is the current that is being sourced at the output of the open what I mean is suppose we have an opamp in an inverting configuration the relationship between vo and v1 is like this so from this it appears as if the only the ration of Rf and R1 that is what matters individual values of Rf and R1 do not matter, but is it so?

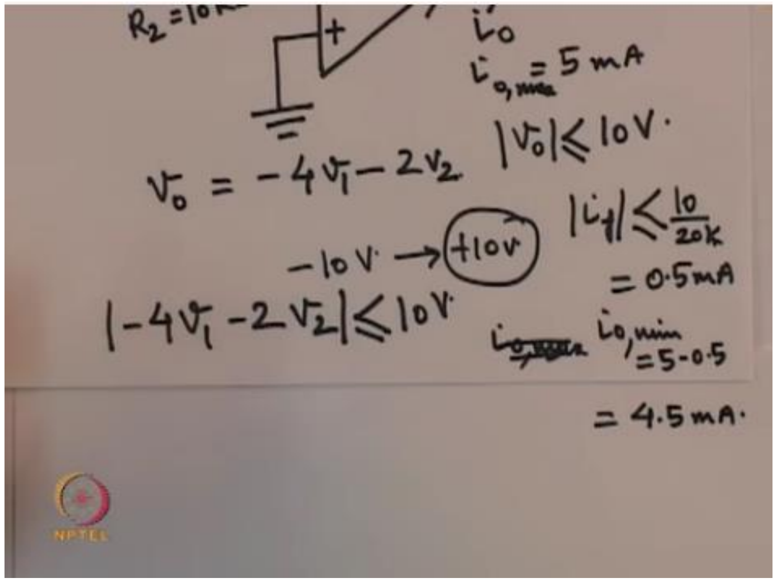
(Refer Slide Time: 17:06)



Let us see with an example suppose we have summer in this configuration, now as we can see Vo will be given by -4v1-2v2 now suppose the maximum current that can be sourced say the maximum current that can be provided at the output of this opamp is say 5 m 5 milli ampere so iomax is say equal to 5mA milli ampere and say the maximum output voltage that can be provided at the output is equal to 10 volts now this maximum output voltage this concept comes from the saturation voltage of the device used.

For example in any this is after all a practical circuit so this might have been built with some BJT's or MOSFET's, by BJT I mean bipolar junction transistor and MOSFET I mean a metal oxide semiconductor field effect transistor whichever device we use they have a certain maximum output voltage and a minimum of it usually the maximum output voltage that can be supplied by a device is the upper rail or the upper value of the power supply.

(Refer Slide Time: 19:35)



For example, if your power supply is between -10 volts to +10 volts then this +10 voltage will be the upper rail of the power supply and this is the maximum output voltage that can be provided and similarly this -10 volt is the lower rail of the output voltage and this is the minimum voltage that can be provided in this case this is the way it is, so vo magnitude is lesser than 10 volts so we have the rail to rail output voltage will be between -10 volts to +10 volts.

Now if this is the case then what it means is since vo is given by this relationship it means that -4v1-2v2 modulus will be lesser or equal to 10 volts now in the worst case we will have an i f or the current flowing from this to this resistance that is if the output voltage is at its maximum then i f the current that is flowing through Rf the maximum value that will be reached is 10 divided by 20K which is equal to 0.5 milliampere, so i f max the maximum value of this is 0.5 mA and i f will be magnitude of i f will be lesser than this value

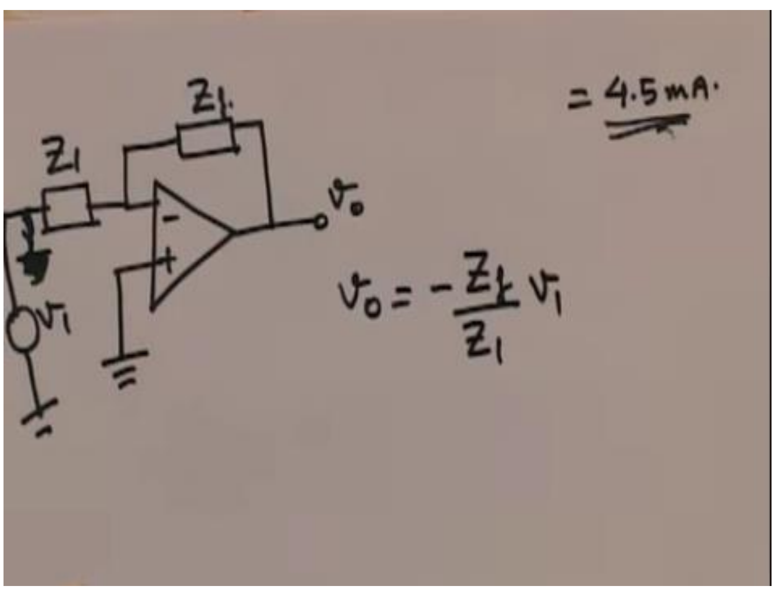
So if that is the case then suppose we are assuming the maximum current is being fed to do this RF which is 0.5 mA and the maximum current that can be supplied by this opamp is 5 milliampere, then what is the maximum current that can be supplied to the next stage that is I so then iomax or I should say it is the minimum sorry because i f will be lesser then 0.5 will be equal to 5 - 0.5 which is equal to 4.5, so this is the maximum or the minimum current that will always be present.

Of course, if no current is flowing through this Rf then in that case the current the maximum the current that can be supplied to the output will be the full value of Io which is 5 milli ampere, so this is the minimum current that can always be ensure at the output this example shows that if the current sourcing ability of the opamp is also an important parameter.

So our RF values for example, say in this case if our requirement was indeed so suppose our requirement at the output of the opamp is there such that we have to keep on supplying 4.5 m milli amperes of current always, then in that case this RF value cannot be lower than 20 kilo ohms if it is lower than 20 kilo ohms then the current supplied through RF will increase and it will make the current that can be sourced to the next stage lesser than 4.5 mA.

So, this is where the value of RF comes into play and there will be other such restrictions on the performance of opamp due to which Rf and R1 will have to be adjusted properly, so it is not just the ratio of Rf to our one that matters it is also the individual values that matters.

(Refer Slide Time: 23:37)



Taking forward this concept, if we have a general impedance Z1 and a general impedance Zf connected like this will be this will not be like this will be connected to v1 so then for any in the previous case we had derived the relationship between Vo and v1 for resistance is only but in place of resistances if we have general impedances Z1 and Zf then vo will be given by Zf upon

Z1 v1 so using this formula we can derive some special circuits like integrators which we shall be discussing in the next module, thank you.