Electronics

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Module No. # 07
Differential and Operational Amplifiers
Lecture No. # 09
Specification of Operational Amplifiers

We were discussing the specifications of Op Amps.

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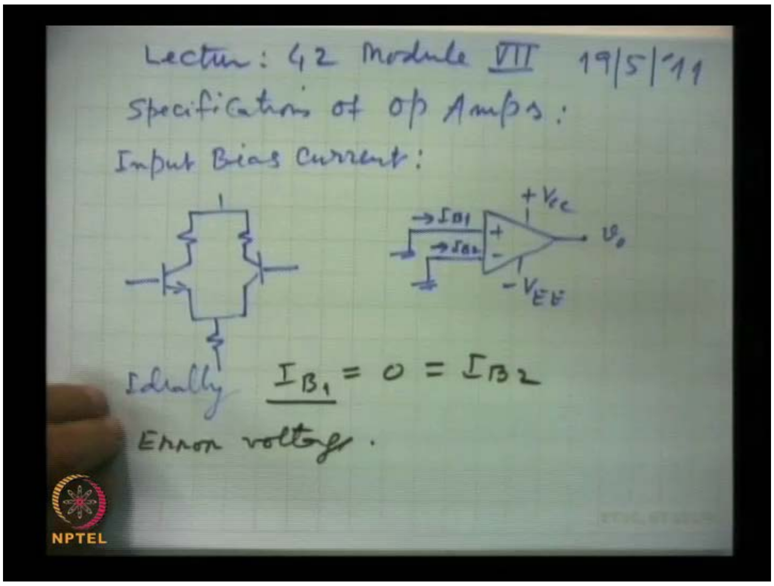

The specification of op amps, the first specification about which we talked that was actually input bias current input bias current, and this is (No audio from 01:05 to 01:17) when we do not attach any external voltage at the inputs, even then some output is observed in op amps.

And this is the base current I V 1 and I V 2, these in spite of the fact that the both these inputs have been grounded, some currents flow they go to the base region. You remember that first stage of the op amp is a differential amplifier. So, these are the two bases, so that is why it is called the base current.

This one is inverting input, other one is non inverting input, so some currents flow in these bases. Now ideally ideally I B 1 and also I B 2 both are supposed to be 0 but, normally some small currents flow. These currents do exist and I B 1 and I B 2 are not 0 then, these currents are amplified and they produce a output voltage, which is a error voltage. And smaller these currents I B 1 and I 2 I B 2 better it is, so and the manufacturers define this current.

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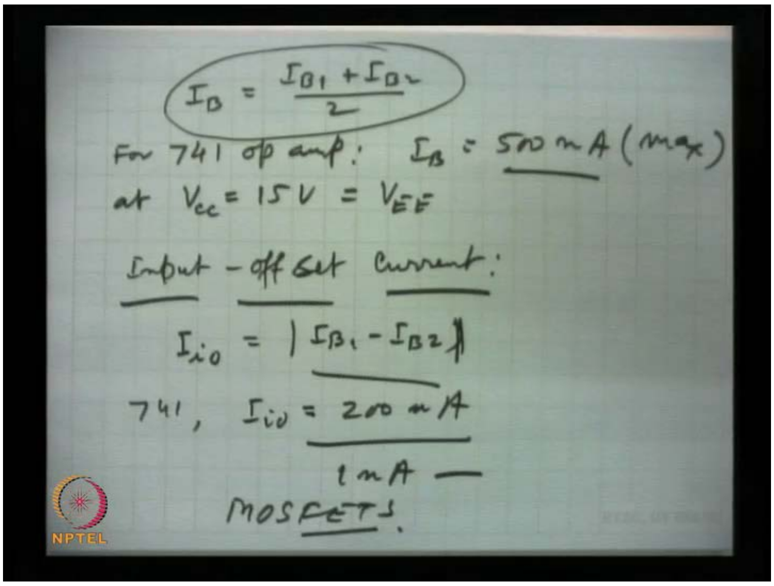

The input bias current by manufacturers is defined as the average current I B as I B 1 plus I B 2 by 2 and this is specified for various op amps. For example for 741 op amp I B is given as 500 nano amperes. This is the maximum current this is the maximum current at V c c equal to 15 volts same as also VEE when both the voltages are plus 15 and minus 15; then the maximum base input base current is 500 nano amperes.

And so, we will see that how corrective measures are taken regarding the errors which are created, because of the finite base current in the absence of any input signal. There is another specification input offset current input off set current, which is actually this is the average true current.

This input offset current is defined by the magnitude of the difference of two currents, so I input and o for offset, this is given by the magnitude I B 1 minus I B 2. And we have already talked, that what gives rise to currents, this is because the two transistors, which form the difference amplifier of the of the first stage.

They are not exactly 100 percent identical, they are not 100 percent perfectly matched, some differences in spite of the fact; that they are assembled on a chip by the processes, which are used in integration integrated circuits like the gas diffusion for making an N N p type and all that. In spite of that, some mismatches do occur and which give rise to this. And this current is normally very small and for 741, this input offset current this is 200 nano amperes and it is as small as 1 nano ampere in differential amplifiers, which are realized using MOSFETS.

So, often either this or this (Refer Slide Time: 07:00) this is much smaller, then other currents so this is neglected but, smaller the input offset current the better it is. Now, we talk about another specification this is important and the remedy, which we will suggest for this, that single remedy is is is sufficient and it takes care for these currents and for this voltage.

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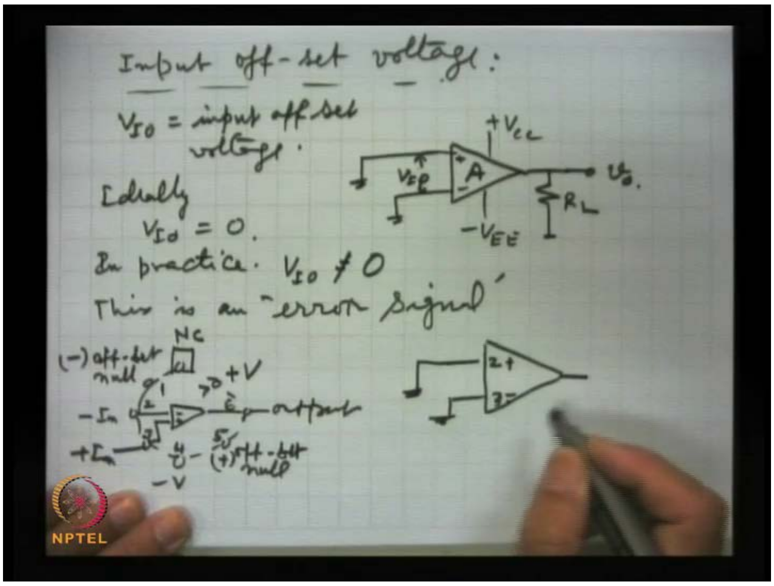

So this is input offset voltage, this is another important specification. Now, this input offset voltage is the differential input here (No audio from 07:55 to 08:22). This this input offset voltage is the differential input here, V I o offset, V I o is the input offset voltage and again this arises, because of the mismatches.

Actually or ideally, there should not be any input offset voltage, when we have not applied any signals, both these inputs are grounded but, still some voltage will exist. So, ideally V I o should be 0 in practice, this is not 0 this is a finite value and this is amplified after all open loop gain of the transit, of the op amp is very high, so this is amplified and then it gives a finite output voltage.

Now, so this is the error signal error signal and we have to take care of it, we have to correct it, because the output will exist in the absence of any input signal; and when input signal are applied they will be amplified and this will be in addition to the actual signals which we expect, so this error signal error voltage this is to be taken care off. Now to bring this output to 0 output voltage 0, we have to apply a signal voltage at the appropriate place equal in magnitude but, opposite in phase of the existing differential offset voltage.

And this is done with the help of the offset null pins, which were available with the operational amplifier. I remind you about the (No audio from 11:17 to 11:27), this was the pin diagram of the op amp, where this is pin number 2, this is pin number 6 this is output, pin number 2 is inverting input minus in and pin number 3 is this is 3 and this is the non inverting.

Pin number 4 is minus voltage that means V E E terminal and this is pin number 1, this we had mentioned that this is offset null offset null the negative terminal and this is the offset null positive voltage. So, between these two, 1 and this is terminal number 4, this is 5, this is 7, which is plus volts that means for plus V c c. And this is the extra terminal, which remains normally closed, N c, normally closed. So, a offset voltage equal in magnitude and opposite in phase of what is existing here is applied between these two and how we do that let us look here.

This is done almost with every op amp, whenever you want to use the op amp, we have to make corrective measures and this is invariably for all op amps it is very simple. This is the two inputs, 2 and 3 this is non inverting, this is inverting, this is inverting, this is non inverting and both are grounded and this is pin number 1 here, I will draw this figure again (No audio from 14:11 to 14:41).

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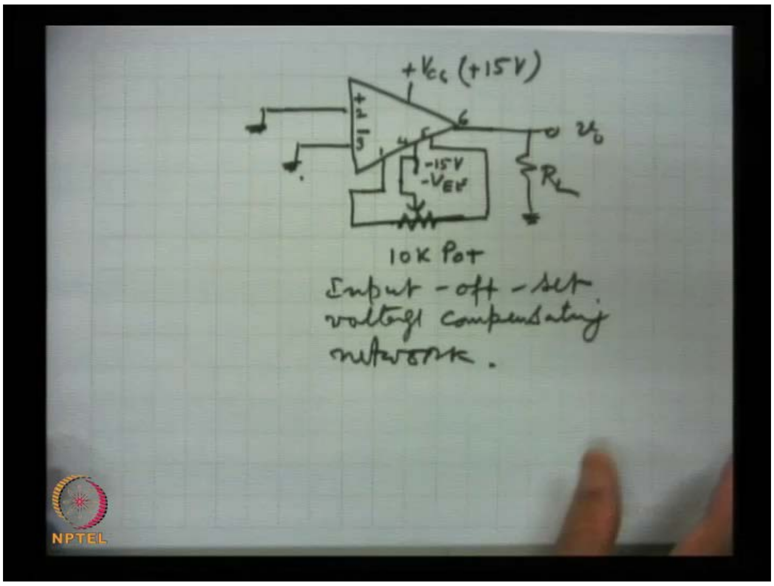

This is 15 volts normally and this is minus 15 volts, this is V E E and here between pin 1 and 5 pin 1 and 5 (Refer Slide Time: 14:59), which are meant for offset null connection. A potentiometer is connected this is a pot potentiometer and this is the battery and this is the wiper; this is say 10 k pot pot is tens for potentiometer, it is a very tiny hardly few millimeters and dia in few centimeter, long it is a cylinder and it is a that is a pot having 2 connections and 3 connections.

So, the extreme two are connected to the pins 1 and 5 and the movable one which can be moved through a screw driver that is connected to the battery. So, here we make measurement of the output be 0, we measure across the loop of few kilo ohms and these both inputs, the non inverting and inverting both are grounded.

So, what we do we take a 10 kilo ohm potentiometer a pot and that is connected to these null offset pins and both inputs are grounded and the output is measured. And we change this wiper, that means this the movable part a screw is provided, so by a screw a small screw driver, we can rotate till we get a 0 voltage at the output, we stop there and we leave the potentiometer in that position.

So, that takes care the, this is called input offset input offset voltage compensating network it compensates; so we rotate till we get the output 0 and that is it. So, at that point this takes care it produces a voltage here a magnitude opposite in phase as the input voltage; so, this is how we take the corrective measures. And as I said this is required for accurate results almost invariably in all the operational amplifiers, now we take very important characteristic.

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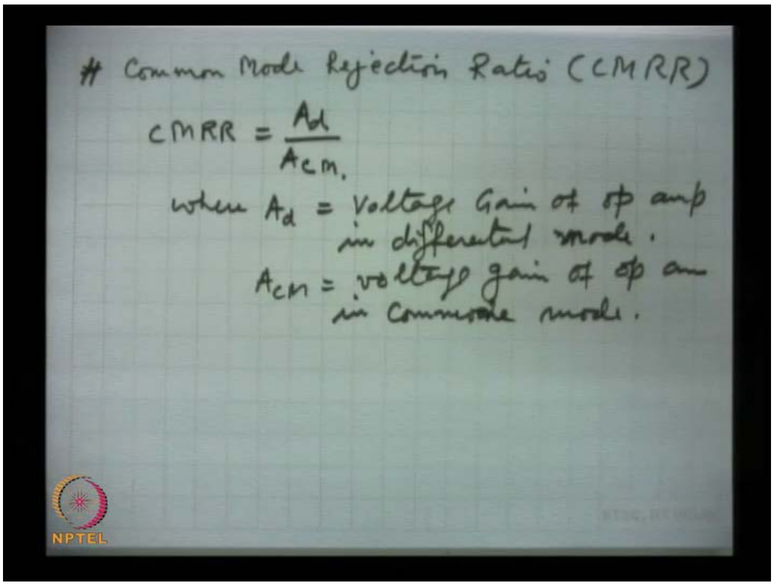

For operational amplifiers two characteristics are quite important, one was the Common Mode Rejection Ratio CMRR, this we have talked when we talked the differential amplifier that, this is CMRR is defined as the differential mode and ratio of differential, gain in differential mode and gain in common mode. Where A d is voltage gain of op amp in in differential mode differential mode, we apply some difference voltage at the inputs and we apply and we measure the output ratio of the two will give the differential gain we have talked about all this.

And A c n is the voltage gain of op amp in common mode in common mode here, a common signal is applied to both inputs and output is measured ideally this is supposed to be 0 giving this common mode rejection ratio is infinitely high but, in practice that voltage will not be 0 and but, still it is very small.

And this common mode rejection ratio is measured in decibels and normally 70 to 80 even higher CMRR CMRR common mode rejection ratio are there for there for op amps as I said several types of op amps are available.

So, if common mode rejection ratio is a very important parameter for the performance then, we choose the op amp with very high values of common mode rejection ratio, so this we have already talked; now we are going talk about a another parameter which is which we mentioned earlier slew rate.

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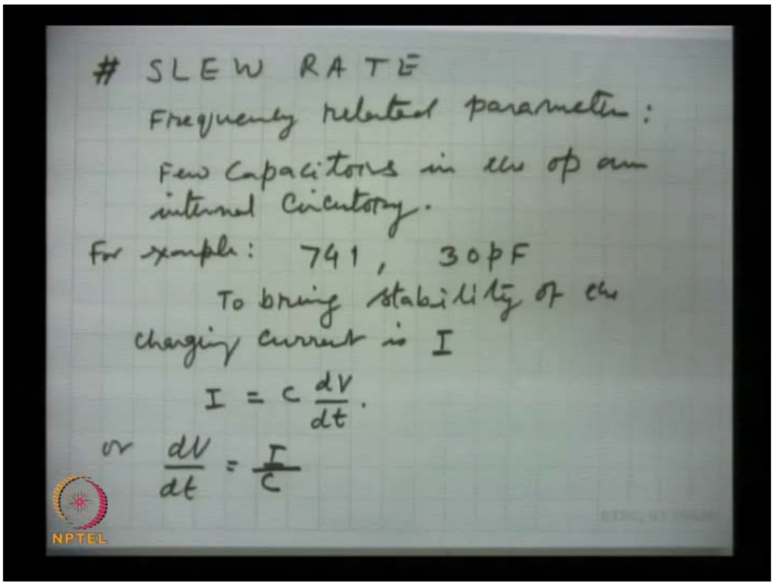

Slew rate slew rate is a frequency related parameter it is a frequency related parameter, when input inputs change the outputs never change instantaneously. I repeat when inputs change the change in the output of the op amp is never instantaneous, it takes some finite time. And this finite time, why it is I will just talk but, let me say, that this finite time how fast the output will rise that is given by slew rate; and why it is not instantaneous? Because there are there are 1 or 2 small value capacitors, few capacitors in the op amp internal circuitory.

For example for example, in 741 there is one 30 pico farad capacitor, which has been used for bringing stability to bring stability of the working of the operational amplifier this 30 p f capacitor was not there in the earlier version; the first version which was brought out in 1965 by fair child USA, it was not there; so, the outputs will oscillate there will be less there was some problems and this capacitor takes care for those problems, so this is there.

Now, there is a finite required for the charging this capacitor, now if charging current charging current is I, then the capacitor c, will have a rate of change of voltage I which is is equal to c d v by d t; this is from the basic theory of the capacitors that is if I is the charging current then the rate of change of the voltage across the capacitor is given by this and there or d v by d t is I by c I by c.

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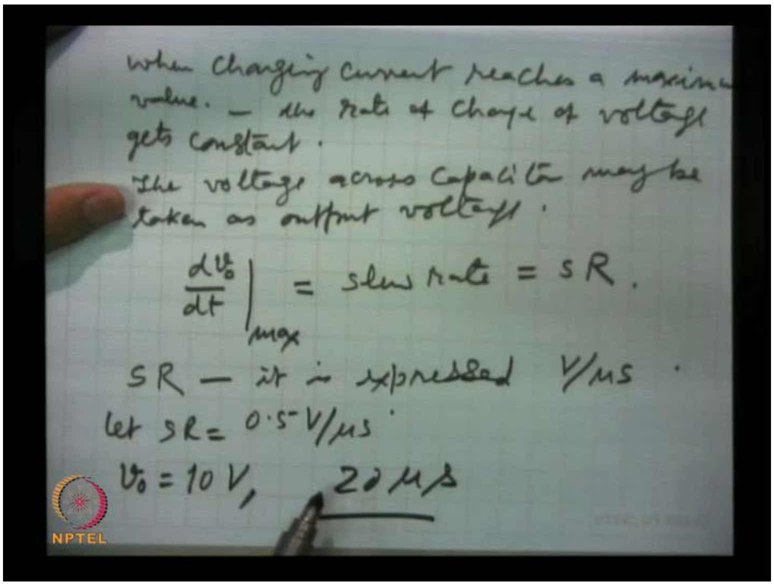

Now, when the charging current reaches a maximum when charging current reaches a maximum value, the rate of change of voltage gets constant (No audio from 26:08 to 26:22) gets constant. And taking the voltage across the capacitor as output voltage, the voltage across capacitor may be taken as output voltage, then the maximum rate at which reaches (Refer Slide Time: 27:15). And this by the maximum current this maximum current will come from the input signal, so this is called the charging current puts this rate a maximum and this is known as slew rate; and this is written as SR. Now, this slew rate is expressed SR slew rate it is expressed in the units of volts per micro second.

So, if the slew rate is for example, 0.5 let SR be 0.5 volt per micro second and if the output goes as high as say 10 volts, then slew rate puts the restriction and it says that it will take 20 micro seconds, when the output will rise to 10 volts. And so this is the meaning of the slew rate, it cannot be faster than this; and again there op amps with different slew rates, in some applications will require very fast slew rates and those op amps will are manufactured differently.

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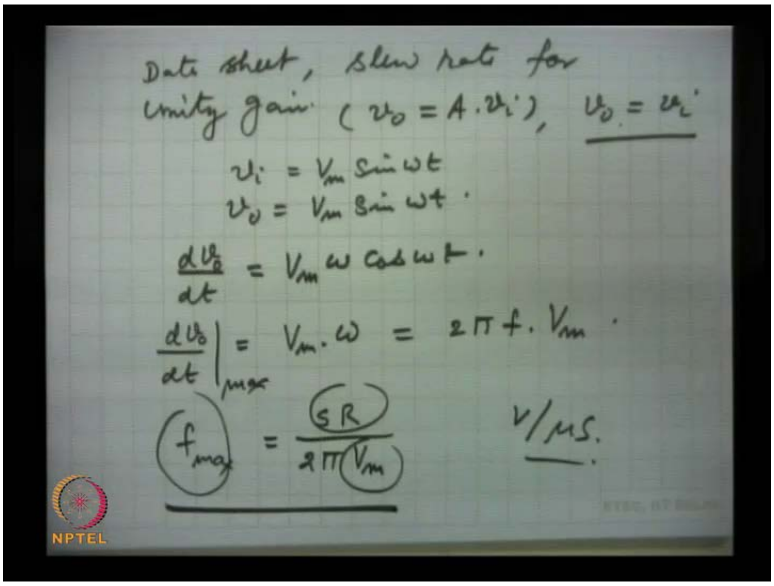

Now, manufacturers they define the data sheet the data sheet of the op amp by the manufacturer, they give slew rate for unit gain for unity gain; by unity gain is v 0 is gain in to V I and if gain is unity, then V 0 is V I; for this the data sheets give slew rates. So, let us take a sinusoidal signal v I at the input value and the peak value of v m sin omega t and same as output V m sin omega t then d v 0 d t will be V m omega cos omega t.

We said slew rate we define (Refer Slide Time: 30:30), when d V 0 by d t the rate of change of output voltage is maximum; so this is maximum when cos omega t is 1, so d V 0 by d t maximum and this is V m in to omega and omega is 2 pi f and this is 2 pi f into V. And from here we get a relationship between the peak voltage and the maximum frequency, so f max comes out to be slew rate, this is the slew rate defined, slew rate by 2 pi V m S R is the slew rate.

So, for example, if we have the highest frequency at a certain value, when peak value is say a 10 volts and this maximum frequency depending on of course, slew rate suppose this comes out to be 5 kilo hertz or 20 kilo; hertz 20 kilo hertz when V m is 5, when V m is high magnitude a higher magnitude signal is used frequency will fall.

Frequency the maximum usable frequency that means, maximum frequency, which will give undistorted output is fixed, so it is related to two things all these parameters are related; depending on the slew rate the maximum frequency for the peak value is fixed.

And if peak value increases the frequency will go down; if this falls, then this maximum frequency will increase.

If we exceed that frequency, then for example, a sinusoidal signal will appear as triangular at the output a distorted signal will appear. So, this is the slew rate which is measured in volts per meter second and already expressed that finite time output takes to rise to come to the maximum level and that is given by slew rate.

So, that cover the basic of the specifications of characteristics of operational amplifiers; in fact we have finished this module and this course as such is over. I will first summarize what we have done in this module, then I will write the references which are good enough for the whole course and then if time permits, which I hope will permit quickly I will take some problems from this module. To summarize what we have done, we started with a differential amplifier, the differential amplifier has two inputs it is very different from conventional amplifiers and one input is called inverting; inverting in the sense that the input signal will appear with a inversed phase at the output.

And the other terminal is non inverting, where it will appear as such will appear in the same phase at output, if the and these signals for operational amplifiers they can be d c as well as a c, because direct coupled direct coupled amplifier it is and hence this is signals can also be used. Now the differential amplifier can be used in four different modes which we said, normally the outputs we take from the two collectors and when there is a perfect symmetry of the two transistors, their characteristics are 100 percent identical then output will be 0 for the same or no inputs.

But, there are departures as we have seen because of lack of perfection, lack of 100 percent symmetry of the two transistors and that give rise to certain currents and voltages; which with a pot we can correct. So, anyway, so the differential amplifier it can be normally we take from the two collectors the output, and then, this is called dual input and balanced output balance, balanced output this is one configuration, which is most widely used for differential amplifier.

There are the next usable which is the which is quite widely used is a dual input and unbalanced output that means, the output is taken from the collector of q 2 with respect to ground. So, these two configurations are out of the foue are most widely used then, we talked about the importance of the differential amplifier, that differential amplifier is the first stage of the multi stage direct coupled very high gain amplifier, which we call operational amplifier op amp op amp.

So, we gave the block diagram of various stages of the op amp and what was the purpose of each stage that was briefly explained. And then we gave the why it is called the operational amplifier, because it can be used for mathematical operations, we have taken several applications like sign changer, summing amplifier and subtraction can also be done by a differential amplifier for with gain unity; then it will just be the difference of two input signals at the output.

And integrator and differentiator that also we took and these were the mathematical applications, which we have taken and some other amplifiers were discussed like log amplifier, where output will be log of the input; and so these were mathematical applications applications for mathematical operations, which are used in analog computation and these circuits are there. And then we have covered basic three amplifier modes in which op amps are used; one is the inverting amplifier, in inverting amplifier the one basic thing was that the input inverting input is virtual ground that is at ground potential and it is called virtual, because actual ground can absorb infinite current but, these are small power devices.

So, hardly maximum few 100 mille ampere current they can tolerate, that is why it is called the virtual ground but, the concept of virtual ground is very important and it simplifies all the analysis, which we have done. Whether it is a integrator, differentiator or is summing amplifier or whatever it is, it simplifies the analysis significantly; and so that is why we used a inverting mode for these applications though it can be used realized using non inverting configuration also.

So and then, the amplifier how simple it is to construct a amplifier using op amp, just to choose two resistors, one the feedback resistance R F and one the input resistance R 1 and in the inverting amplifier the gain will be the ratio of two resistances R F by R 1. Very simple nothing could be simpler than this, where R I will give you the input impedance of the amplifier feedback amplifier also; and then we took the non inverting amplifier and we have shown that, non inverting amplifier comes closest to an ideal voltage amplifier.

Ideal voltage amplifier in which we can use the feedback concepts and the term 1 plus A B, A is the open loop gain and this is the gain of the feedback network. So, this term is used to get the modified parameter for the non inverting amplifier.

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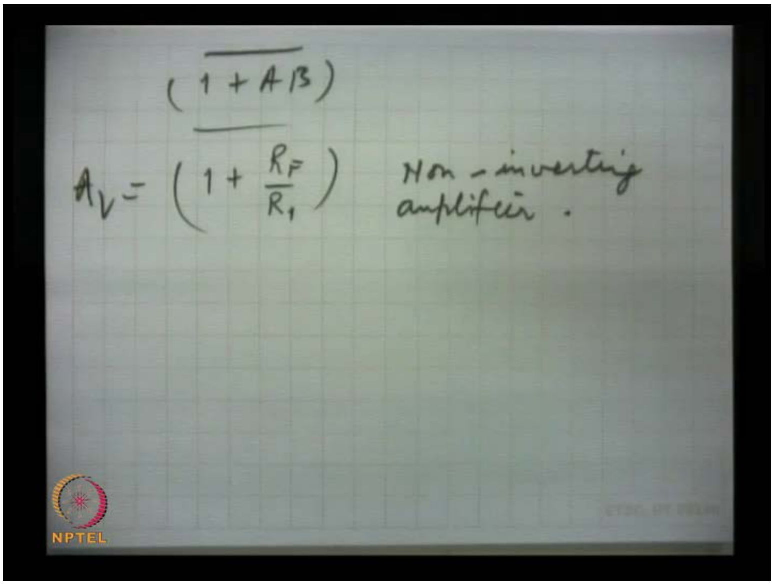

For example the the input impedance it will be changed it will be enhanced it will be enhanced, by how much amount this much; the input impedance without feedback into this term that will be the input impedance for the feedback non inverting amplifier. Similarly for the changing bandwidth, that has to the bandwidth also increases and that change is given by this. So, there are several parameters and the gain is also very simple to remember 1 plus R F by R 1 this is the voltage gain for the non inverting amplifier; so that we have taken and then we covered applications of op amps in designing filter circuits.

Filter circuits are very widely used in electronic systems to select or to reject frequencies, from a wide spectrum we select certain frequencies for our purpose, then a band select filter is to be used; if we just want up to this you can see, they should be available, they should pass through our network and remaining work should be rejected and rejected one is the stop band and this is the pass band. So, this is a low pass filter and similarly, high pass filter and so on; this we have covered in a almost quite reasonable well, the circuit design and the analysis.

In analysis just the important thing was, how to choose the components for the cut off frequency and for pass band gain, gain of the pass band frequencies, so these were done. So, what is a ideal op amp, we also discussed and a practical op amp is a direct coupled very high gain and very high input impedance amplifier, it is very useful. Hardly now actually the design of the systems using discrete components has gone drastically, it it has been cut down.

Most designers take the help of various kinds of op amps, because op amp is available on a chip and because they are produced in bulk in millions and billions, so the cost per unit is very low. And hence all operations can be obtained by using a operational amplifiers, in the system last one or two stages may be high power (()) they may be taken from high power transistors so they are discrete components and this is how the op amps are used.

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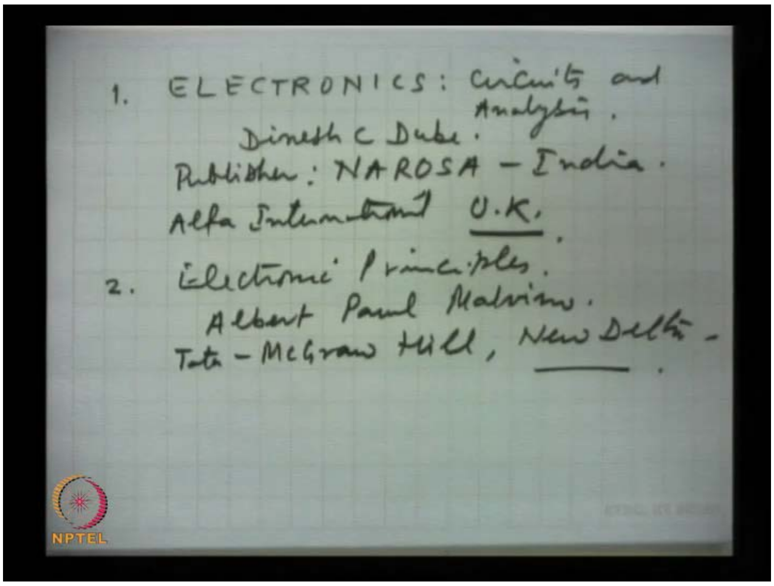

So, this is about this unit and now I give the text books for this course, there are two text books, which will be sufficient for almost everything, what we have covered, one is electronics ELECTRONICS circuits and analysis, I have authored this book, this is by Dinesh c Dube for India and neighboring countries the publisher is NAROSA narosa India they have branches in Delhi, Chennai, Calcutta and Mumbai all the cosmopolitan have their branch. And for Europe, United States and Canada this has been published by Alfa international U K this is you can see on the internet by giving these details electronics circuits and analysis by Dinesh c Dube.

The other book electronic principles electronic principles this is by Albert Paul Melvino and this is published by Tata McGraw hill, new Delhi. These two books should be sufficient for op amps, those who want to go in greater detail about op amps, there is a book by Rama Kanth Gaikwad.

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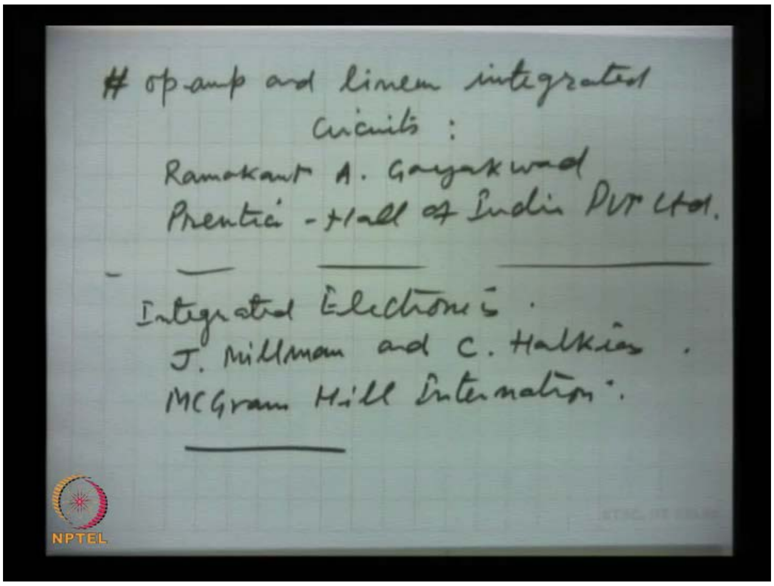

Op amps and linear integrated circuits this is the title op amps and linear integrated circuits, this is by Ramakanth A. Gayakwad and this is published by Prentice Hall of India private limited very good book whole book is on op amps and integrated circuits; besides in this in general you can have a reference book and that is integrated electronics by j Millman and c halkias this McGraw hill publication McGraw hill international. So, as a reference book for any details you want to consult this can be a nice book; now there is time for few examples, which I can take.

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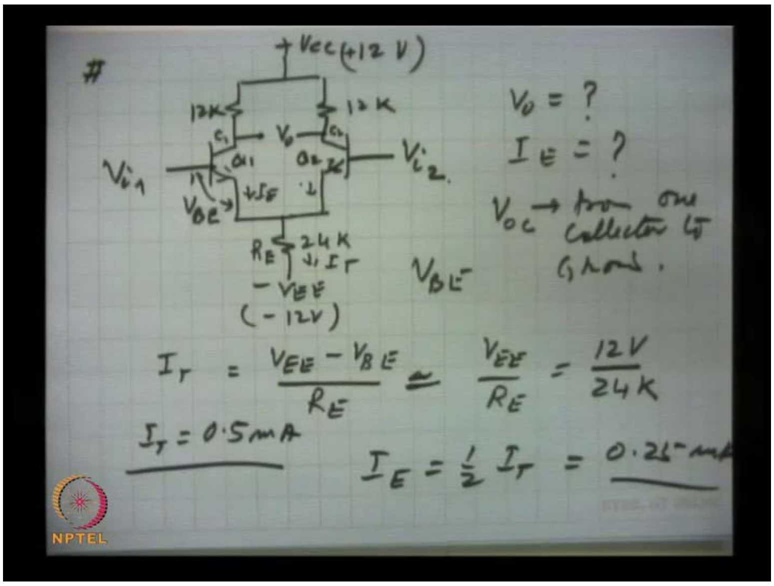

For example there is a, this is a problem that for this circuit, which I am drawing I will write briefly what is required, this is a differential amplifier this is plus V c c which is 12 volts plus 12 volts and this is minus V E E which is minus 12 volts and this is R E which is a 24 kilo ohms and these resistances are 12 k, 12 kilo ohms and here we take V 0 and this is V i 1 and V i 2. So, in this question how much is V out, this is between two collectors c 1 and c 2, how much is the current I E, this this is I E this is also I E, I E how much is I E in each transistor Q 1 and Q 2.

So and this voltage, we can find how much is the voltage V out between with collector from one collector to ground; now for this solution is simple first, we have to find out the tail current, this is tail current I T, in I T is if you simply this is a potential V E, V B E is this voltage but, and and this is at V E E.

So, the potential difference across this resistance is this divided by R E this is tail current, this voltage this voltage is very small in comparison to this, so this approximately equal to V E E by R E and this is 12 volts and 24 k. So, I T becomes 0.5 mille ampere if we take resistance in kilo the current will be in mille amperes, this is will go 10 to power minus 3 here, it will come, so this is the tail current. And the answer I E is equal to half of I T, so 0.25 mille ampere is the current in each transistor; and this much current.

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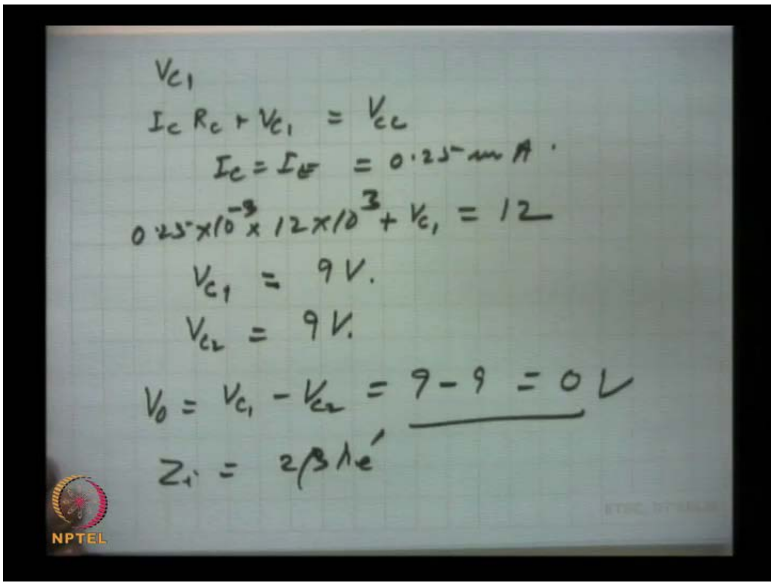

Now, to find out the potential difference between the two collectors, we apply, we find V c 1 the collector of first one is at what voltage, we apply the summation of voltages for this circuit and that gives I c R c plus V c 1 equal to V c c. I c in all B j t's I c is equal to I E, so I c equal to I E, which is equal to 0.25 mille ampere. So, this current we substitute here 0.25 into 10 to the power minus 3 in to R c, R c is 12 k, so 12 k and plus V c 1 equal to 12.

And from here we get V c 1, this is at 9 volts V c 2 will also come to be at 9 volts, so this is the potential with respect to ground and between the two V out is V c 1 minus V c 2 and this is 9 volts, 9 volts both are 0. So, we expect that for no signal or same signal the out put will be 0, so we can find out the input impedance Z i is 2 beta r e prime; and this is beta if we take 100 R E prime we calculate, once we know I E; so we can find out the value of this impedance. There is time for one more problem and that is construct, suppose this is the problem construct a inverting amplifier.

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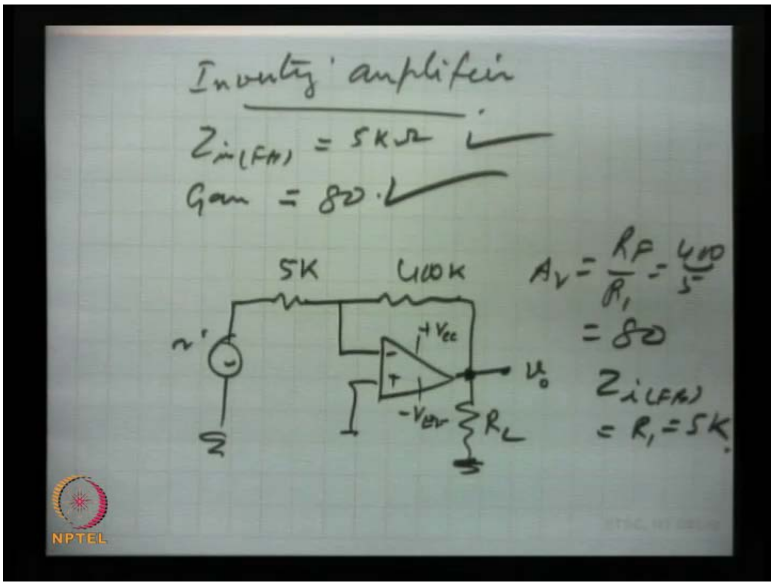

Inverting amplifier such that input impedance with feedback is 5 kilo ohms and gain is 80 it is simple, this is we have to choose these 2 values rightly, this is V out, this is R L this is V c c, this is V E E this, we choose 5 k and this we choose as 400 k and apply the signal here.

Then gain is R F by R 1 which is 400 by 5, which is 80 as desired and input impedance Z i F B is equal to R 1, which is 5 k so that is it. So, this is very simple and similarly, the non inverting amplifiers are simple and construction of the filter circuits is very simple only one or two expressions are to be used. The gain is R F by R 1 and cut off frequency is 1 by 2 pi R c, R and c values connected with the filter circuit; so I hope we have done justice to this course and you all have enjoyed, thanks.