Electronics

Prof. D .C. Dube
Department of Physics
Indian Institute of Technology, Delhi

Module No # 07
Differential & Operational Amplifiers
Lecture No # 01
Differential & Operational Amplifiers

We are going to have the next topic on differential and operational amplifiers we have done a small signal amplifiers either common emitter common base type or common source common drain in F E T and MOSFETS the knowledge which we gained out of these amplifiers that has been used for realization of more advanced amplifiers and differential and operational amplifiers are an example.

Now these operational and differential amplifiers they are available as integrated circuits they are design on a chip which is much more economical and convenient to use so these are complete circuits where externally only few capacitors and resistances may be required for the desired performance but, as such they have complete a circuit on the chip on.

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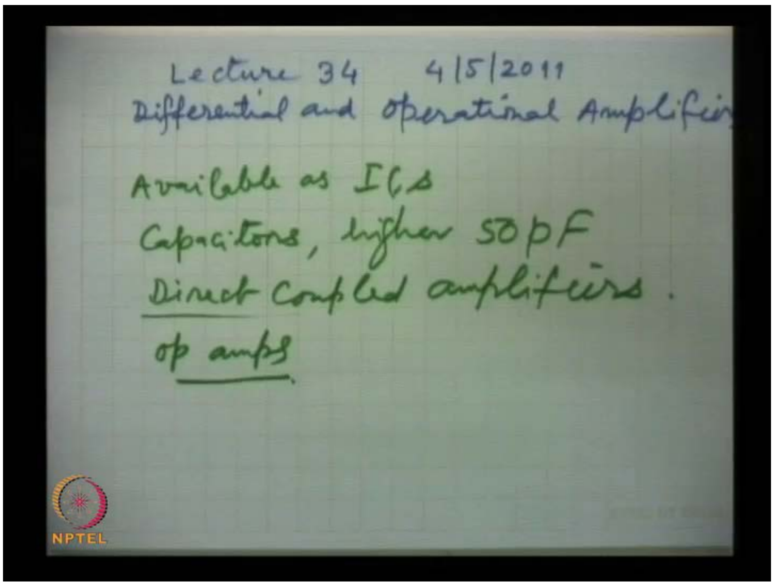

So they are available as available as IC's integrated circuits in integrated circuit large capacitances large value capacitances are difficult to fabricate so capacitors having values higher than say 50 pico farad they are avoided capacitors higher than 50 pico farad in value they are avoided on the chip bye pass capacitors and coupling capacitors are in micro farad range that means 100 times more than 50 p F so these circuits differential and operational amplifiers which we are going to use they are avoiding avoiding this direct this capacitor coupling.

These are direct coupled direct coupled amplifiers you remember when we talked about the coupling used in amplifiers there are three kinds of couplings which are used r c coupling very widely used direct coupling and transformer coupling here transformer coupling is having restricted applications because it is bulky and there are other features associated with them they cannot be integrated in that these transformers are not integrable at present.

So their use is a restricted and direct couple wear for coupling just direct conductant path connects the source for example, with the amplifier no need of coupling capacitor and hence frequency response obviously will be different there is no restriction on a smaller frequency these amplifiers will work at as lower frequency as 0 that means for dc also they will work equally well as for several kilohertz few 100 kilohertz and so on now so these are direct coupled amplifiers available on integrated circuits first we take differential amplifier and after finishing that we will take much more widely used amplifier circuit that is operational amplifier operational amplifiers in short and more popularly they are known as op amps op amps and why they are called operational amplifiers or op amps because these amplifiers can be used for summing subtraction multiplication and integration differentiation all kinds of mathematical operations can be realized using these amplifiers and that is why they are called operational amplifiers.

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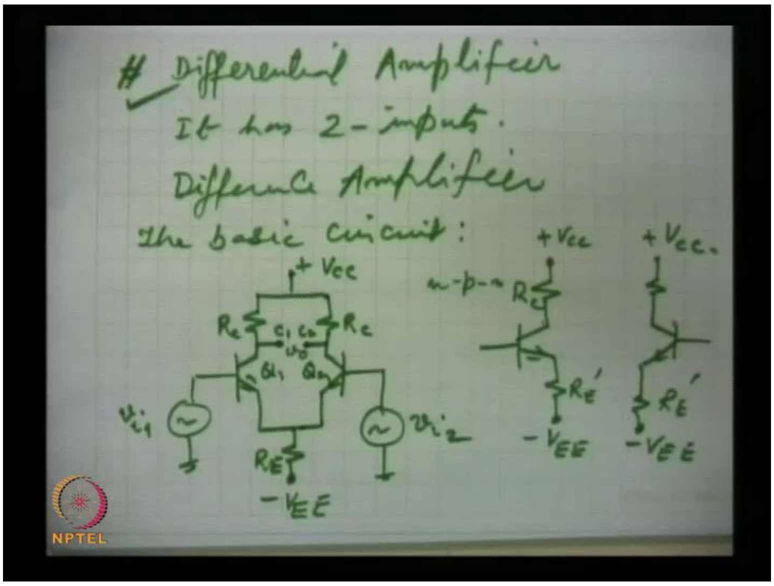

First we take a differential amplifier differential amplifier differential amplifier is very different from conventional a small signal amplifiers these are actually composite amplifiers and in differential amplifiers there are two inputs it has two inputs and we that means the two signals at the two different inputs can be applied simultaneously and then most important why it is called differential amplifier or sometimes difference amplifier but, most popularly it is called differential amplifier because when we applied two signals difference of the two signals is amplified and is available at the output of the amplifier I repeat differential amplifier has two inputs two signals input signals can be applied and this amplifier is capable of amplifying the difference of the two signals meaning any signal which is common to both inputs will be filtered out automatically only the difference will be amplified in real time situations.

There are many conditions where for example, noise generated by motors in a industrial area if you we use the conventional amplifier then actually those signals will be picked up and they will also be amplified unless precaution extra precaution is taken to reject them here that will be automatically we taken care of and noise will not be will not be amplified and will be filtered out by the difference only the difference of two signals will be amplified whatever is common to both that is not amplified now what is the basic circuit first let us talk about the basic circuit and what are why it is so important why we should give so much importance to differential amplifier those features we will bring out.

So the the circuit is the basic circuit for differential amplifier is basic circuit is this this is the basic circuit of differential amplifier there Q 1 and Q 2 these are two transistors two transistors and they have been connected such that they have a common emitter resistance r e and they are connected at the resistance r c also in fact these are the result of two amplifiers like this these are the two separate amplifiers which are coupled in this fashion you remember when we talked about biasing of transistors that the emitter bias which makes use of two power supplies one positive plus V cc with respect to ground and the other negative minus V EE with respect to ground this reverse bias is this is n p n transistor n p n.

So this reverse bias is the collector and this forward bias is the base emitter of the of the n p n transistor now this is forward bias this is reverse bias so this is amplifier where it will work in the active region of the I v characteristics and when we couple the two this is the shape which is the differential amplifier when we say that two adjacent emitter bias circuits have been coupled together to give differential amplifier this is the differential amplifier here the output is taken from two collectors while other possibilities exist we will talk little latter but, commonly this output is taken from two collectors between these two collectors whatever is the output that is taken so the output is here v 0 normally we take from collector with respect to ground here we take between the output is taken between two collectors symmetry of this amplifier is a essential part for proper performance it is symmetrical across its has a almost a mirror image of this Q 1 to as images Q 2 so the two transistors have been constructed as close to be identical as possible technically now this becomes very clear that when everything when when two signals you apply of identical magnitude say magnitude then this will be available at C 1 amplified in the amplified form and because the signal we are taking for as an example only identical to this the same voltage will appear so between the two collectors when we take output the output will be 0 as it is suppose to be because the signals that whole signal is common to both and hence output will be 0 so this is the way the differential amplifier works it has very wide applications and there are several other.

Associated reasons that why we should study a differential amplifier.

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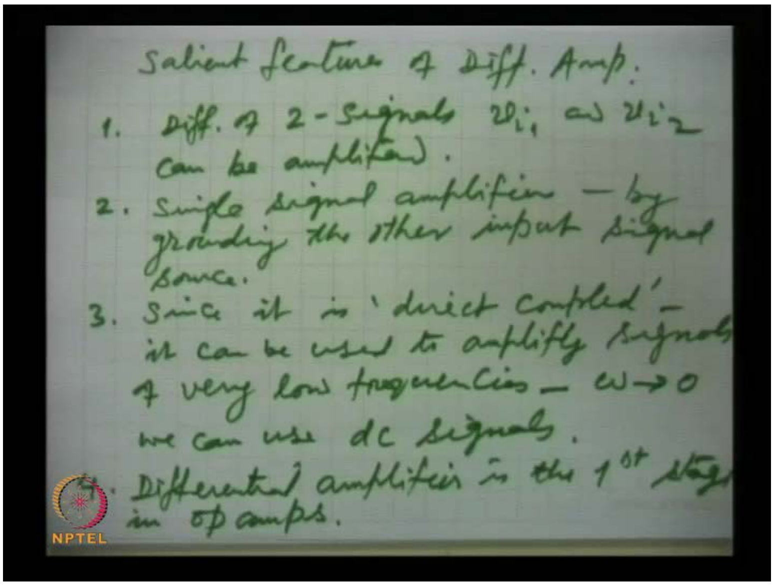

Now the salient features are salient features of differential amplifier are as I said the difference difference of two signals v i 1 and v i 2 can be amplified so as a we can use it as a difference amplifier amplifier second is by grounding one of the two inputs if one input is grounded to 0 then we can use it as an any other amplifier so this can be used as a single signal amplifier it can be used as a single signal amplifier by grounding by grounding we mean by making 0 the other signal source other input signal source and since it is direct coupled since it is direct coupled it can be used it can be used to amplify amplify signals of very low frequency we can amplify signals of very low frequencies including 0 frequency and when omega is 0 we talk we can use we can use dc signals also and very important is the operational amplifier.

Which has almost revolutionized the system design today and hardly there are circuits which do not make use of op amps wither digital or analog circuits where op amps have not used in all circuits op amps are very widely used so differential amplifier is the first stage of operational amplifier differential amplifier is the first stage operational amplifiers are multi stage amplifiers we will go in great details how does it work and all that but, the first stage is a differential amplifiers.

So differential amplifier is the first stage in op amps operational amplifiers and then there are other features also for example, as we will see that input impedance of differential amplifiers is very high it is several 100 kilo ohms or even may ohms inspite of the fact that we lconstruct them by using bipolar transistors so these are the salient features that make differential amplifiers very popular and we should study them in greater detail now basic circuit we have talked actual circuits are not very different from the circuit and that we will be drawing now for any amplifier.

There are two ways two types of analysis which we are suppose to carry one is the dc analysis other is the ac analysis dc analysis is done to a certain I C Q that means collector current at the operating point and V CQ what is the drop across the register between the collector and the emitter that is to be studied and from there we can take out the design processes that how to choose the value of R C or R E very simple so this comes under dc analysis then we will carry on ac analysis of a differential amplifier in which we will find out what is the amplification factor what parameters the amplification of the differential amplifier defends there we will see that how does it act as a differential amplifier and from the ac analysis we will come to a very important point that these two inputs input one and input two they are also not identical they are distinguishable and we will see that one is called inverting input the other is called non inverting input and why we call them a reasons will become clear when we go for the ac analysis.

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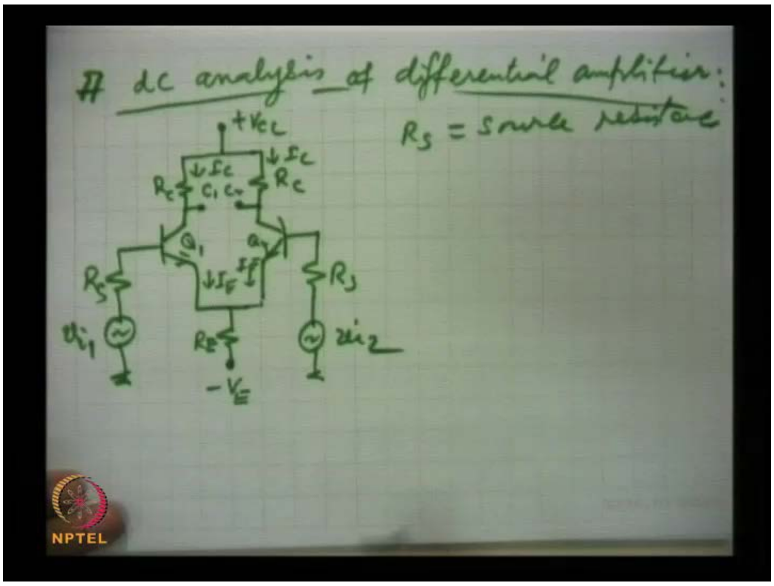

So first we take dc analysis of differential amplifier dc analysis of differential amplifier in the differential amplifier and the dc analysis the ac sources have to be grounded so the actual this is the situation this is the first source v i 1 v i 2 and this is the source resistance R s R s is source resistance resistance of this signal source which is normally small this can be your or it can be for example, mike or some other device and every device has a impedance and that is called source resistance and normally these are small for dc analysis which currently we are carrying out a c sources they have to be grounded we are we are not going to consider them so then what will be the circuit which remains that is this here these are all both are grounded.

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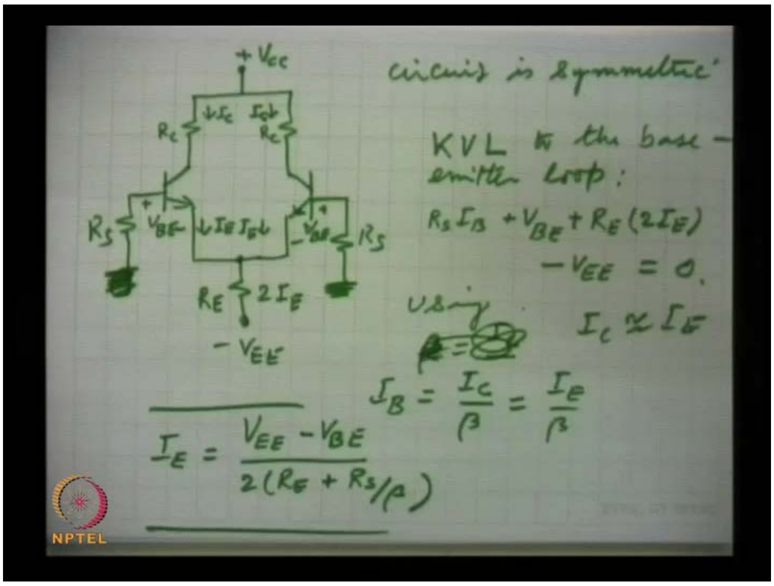

And then the circuit will be when we ground them we leave the R s in the circuit which we we may drop at some stage because they are normally very small resistances and here I C and since we are saying circuit this is very important circuit is symmetric so here this is also I C and then from Q 1 I E will flow and from here also from this emitter I E will flow so this I E and this I E that means from this tail two I E will be the connector I E from here I E from here and both will go through this resistance emitter resistance I R E and hence two I E current will flow here now let us analyze the circuit and V this voltage BE as usual this also is plus minus V BE we apply K V L ko kirchoff's voltage law to the base emitter loop base emitter loop and we apply we get this R s base current here base current and plus.

V BE plus R E and into 2I E minus V BEE this is equal to 0 we sum up all the voltages here for symmetric reasons only this one is sufficient to do instead of rather doing the same process twice only this is sufficient the analysis for one transistor currently is sufficient to be carried out and then we apply in this equation using beta the current gain these are common emitter amplifiers as usual so beta is I C by I I B actually sorry I B is equal to I C by beta which is equal to because I C is same as I E so this is I E by beta so I B we replace with I E by beta and one I E is already here so then from this equation what we come I is equal to V EE minus V BE by twice R E plus R s by beta this is the expression for as I said in the beginning that the objective the objective of dc analysis was to find out I CQ.

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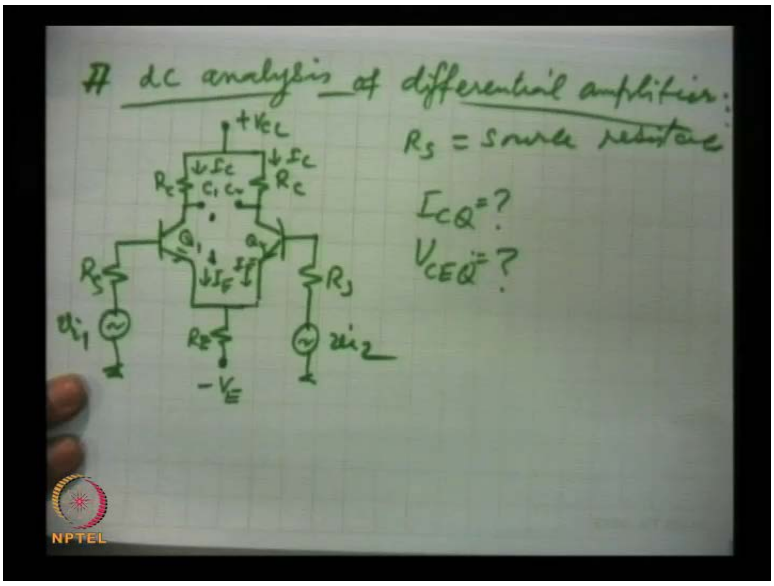

And V CEQ what are the value V CQ that is the voltage drop between this and ground here this voltage so these have to be find and for the symmetry region we are doing it only for one transistor this we have said so this is the I C now here the R s is small as I said in the beginning the source resistance is small and R s by beta will obviously be very small.

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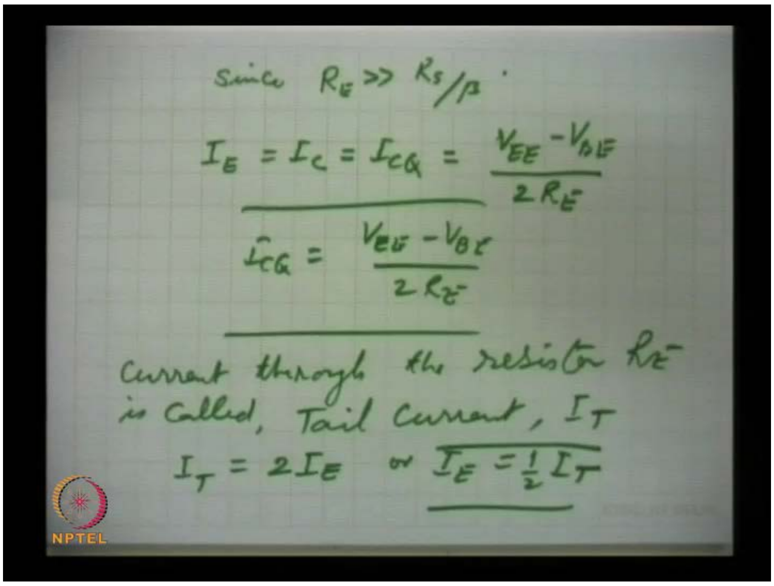

And since since R E is very large compared to R s by beta so R s beta we can drop and the expression I E which is seen as I C and at in the absence of any signal this is I CQ and that is V EE minus V E this is point seven volts for silicon device and divided by 2R E this is the current I CQ is V EE and many times this V BE is dropped in comparison to this and this does not incur much here but, anyway this is this is the quotient current and if we chose the current we can find out what value of R E is required that will give that much current or if R E is fixed then what will the I CQ that is that can be known in the circuit and then this R E this actually is like a tail so current through R R E current

Through the resistor R E is called tail current is called tail current and often written as I T I T for tail and how much is the current tail current 2I E why 2I E because I E will go from transistor Q 1 and I will go from transistor Q 2 so the tail current and the I T the tail current is equal to 2 I E or I E the emitter current in each transistor will be half of tail current I T this is another useful relation and then we have to find out what is the voltage drop here which is V CEQ that we have to find out and for that we can apply again the kirchoff's voltage law K V L.

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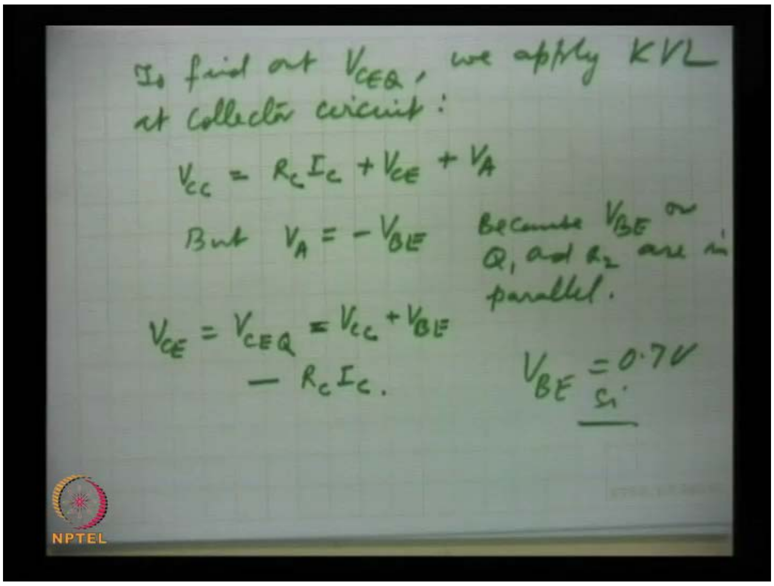

To find out V CEQ we apply kirchoff's voltage law summation of voltages at the collector circuit when we do that we get V cc V cc is equal to R C I C plus V CE plus V A where V A is the voltage at this point A what is the voltage so we have taken this but, we know this important what is the voltage here at this point A what is the voltage this is plus minus V BE this is also plus minus V BE so what is the voltage here these the voltages V BE they are in parallel.

So voltage will remain just single V BE and with minus sign so but, V A is equal to minus V BE because V BE of Q 1 and Q 2 are in parallel so in parallel the voltages are not summed up only in series they are summed up so this is the voltage so then we substitute here and we get V CE which is same as V CEQ and this is equal to V cc plus V BE minus R C I C this I C is the same as I CQ so this is known several paralel parameters in this will be known how much battery now normally it can be 5 volts or 9 volts or 12 volts so we know this we know this this is known 0.7 volts for silicon most of the because integrated circuits are mostly on silicon some very high devices are one gallium arsenide not a single I C is formed with germanium so V BE is equal to 0.7 volts for silicon devices so this is known and hence the value of R C keeping how much voltage we want so out of the two if one is known the other can be calculated now this is the dc analysis and this dc analysis is applicable for this particular this differential amplifier and this is important and all its variations which are possible this can be used in more than one way this differential amplifier so this analysis is applicable to all the variants of differential amplifier now what are the variations within these differential amplifier what are the variations possible the variations come from the fact from where we are taking the output when we take output from two collectors this is called balanced output.

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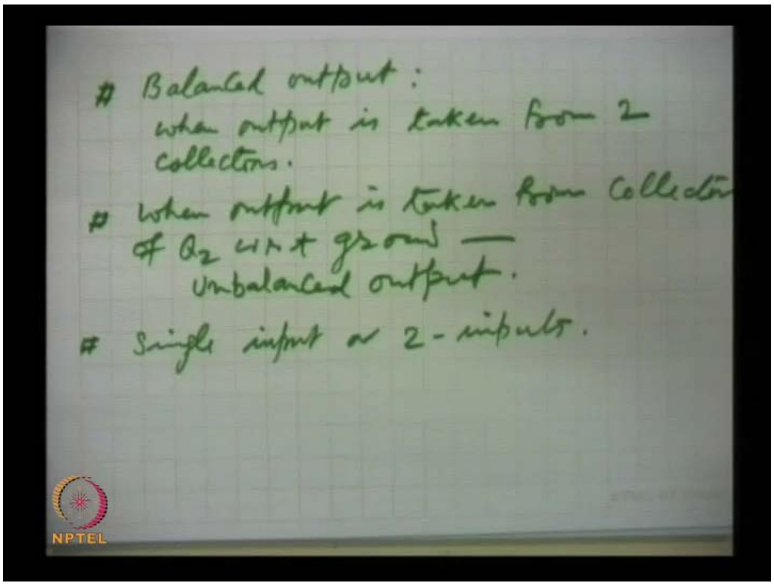

So what is balanced balanced output balanced output that means when output is taken from two collectors this is balanced output and in fact output can be taken from one collector c 2 with respect to ground this is one possibility other possibility is when output is taken from one collector normally c 2 c 2 collector collector of this Q 2 from here we take the output from collector of Q 2 with respect to ground we call it unbalanced output.

Unbalanced output similarly, there are we use two input signals so we can get a balance output or unbalanced output depending on the application besides that we can have single input or two inputs there is no restriction that essentially we will have to use two inputs we can ground one and the other we can use as an amplifier so this gives rise to different variants.

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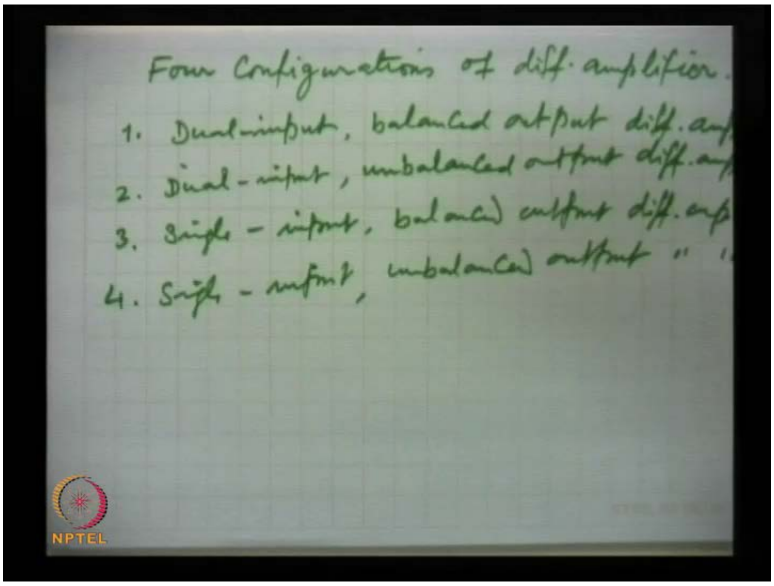

So four configurations of differential amplifier are are there and these four variations are four configurations four configurations of differential amplifier the four the one is dual input that means we are using two input sources dual input balanced output balanced output differential amplifier dual input balanced output that means that we are taking output balanced output from two collectors and the two sources we are using so dual input balanced output differential amplifier then we have dual input unbalanced unbalanced output differential amplifier here the output we take from this collector with respect to ground and we are using two input signals so dual input unbalanced output differential amplifier and similarly, we can use a single input single input balanced output differential amplifier so here we are using only one input source and we are we will be taking output from the two collectors and finally, single input single input unbalanced output differential amplifier in this single source will is to be use the other input source will be grounded and output is taking from collector of Q 2 with respect to ground so these are the four configurations some of them are widely used others not that we will be taking now we take the general analysis ac analysis of differential amplifier and then from that general general analysis we will take important parameters for these amplifiers also, general analysis means dual input balanced output differential amplifier so this we are going to do.

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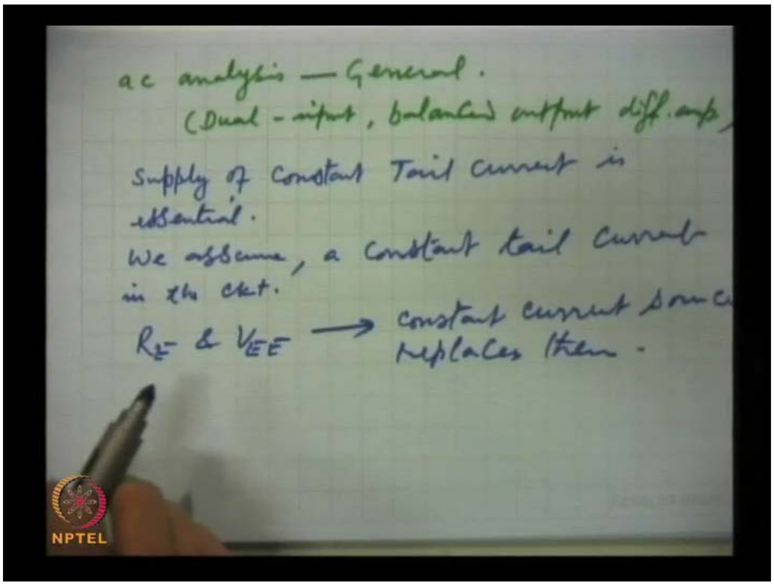

So ac analysis ac analysis general that means the first case dual inputs balanced output for satisfactory performance gradually as we learn more and more about differential amplifiers their salient features will also emerge and we will come to know many things about the differential amplifier now for satisfactory performance of differential amplifier the tail current has to be constant the supply of constant supply of constant tail current is essential for the of the differential amplifier constant tail current is required how we provide.

So we will elaborate in better designs this resistance and this battery we can elaborate by some other arrangements which will be providing a constant tail current so this is essential we assume that a constant tail current we assume a constant tail current in the circuit so this R E and R E and V EE arrangement can be replaced by a constant constant current source constant current source replaces them.

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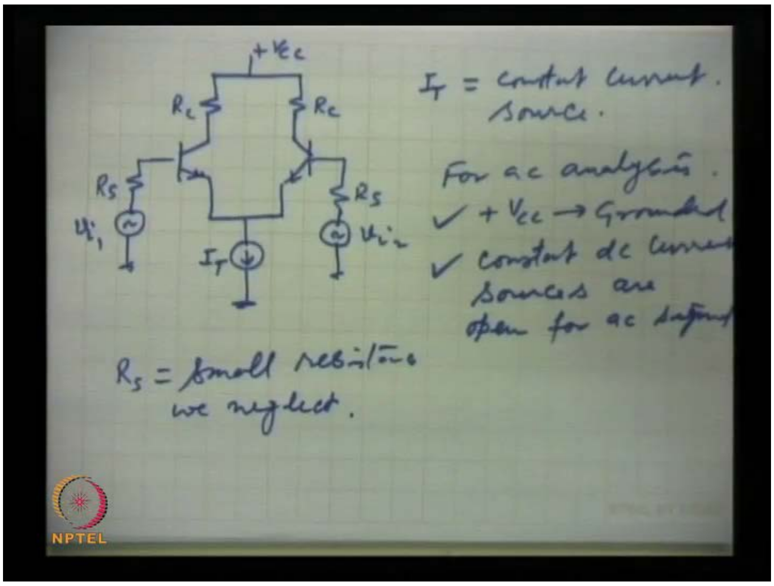

So what will be the circuit the circuit will be this is the this is the we replaced that R E V E by the constant current and that is I T I T is constant current and this is constant current source which applies constant current now we perform ac analysis and we apply the rules as we have been talking all through that for ac analysis the dc voltage sources have to be grounded and ac current sources have to be open or the sorry dc now voltage sources have to be grounded and dc current sources have to be open I write here for ac analysis ac analysis the rules are which we have talked many time that V cc the dc voltage sources have to be grounded and because constant current source we are using for the first time so we should write that constant dc current source sources are open that means they form infinite resistance open for ac signal this is grounded and this is open open means that no a c will propagate through this path so when we ground this

And we open it and this resistance is R s they are small a small resistance so we can neglect it in this analysis to make the analysis bit simple so we neglect we neglect then what is the circuit.

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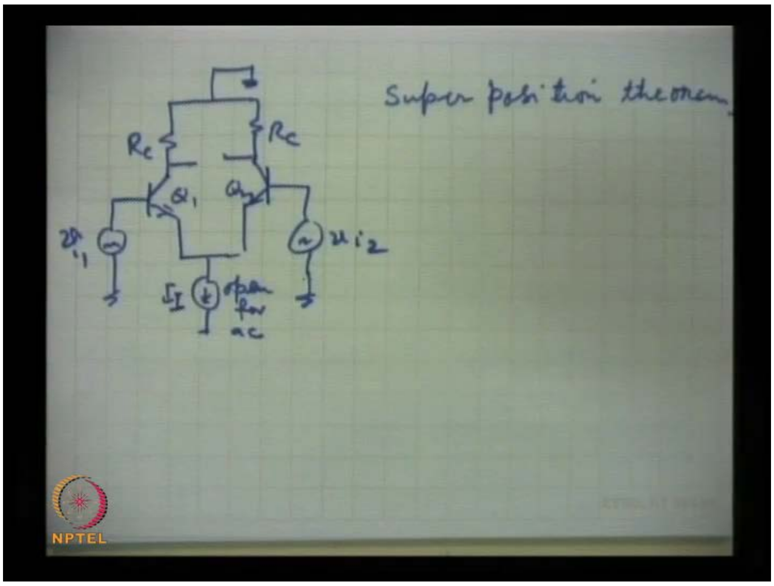

The circuit becomes this open for ac actually we need not to show it but, still as a this is customary to leave them like that what remembering that they are open these are the sources v i 1 v this is R C this is R C and this is Q1 Q 2 now to have because now we have more than one input source so to study the effect of two sources on on this on this circuit we apply the super position theorem super position theorem and what is super position theorem that first we apply only one source for example, v i 1 the other source is grounded and we will study the circuit we will study we are interested in gain.

So what will be the gain and what will be the output because of only one source that we will study and then this we will super impose on taking this as grounded and v i 2 will be taking as active I repeat to study this differential amplifier in which dc source have been grounded and this constant current source is open for ac that means no ac will propagate here to study this we apply the super position theorem and super position theorem is that we take one input signal as active initially.

And we study what will be the output what will be the gain then we keep that result and then we take the first one the ground and we take the other input source as active and so we study that then we apply the super position theorem which says that that the net output from these two sources will be the algebraic sum of individual contributions that is this that is the way this analysis is to be done so we will apply the super position theorem and from here we will come to very significant point that one of the inputs is a inverting that means the output will appear out of a with the input signal and the other will be non inverting that there when the signal is applied that will appear without any face chain so all these these details will come out of this analysis ac analysis of this amplifier.