Electronics

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Module No. # 07

Differential & Operational Amplifiers

Lecture No. # 02

Differential & Operational Amplifiers (Contd.)

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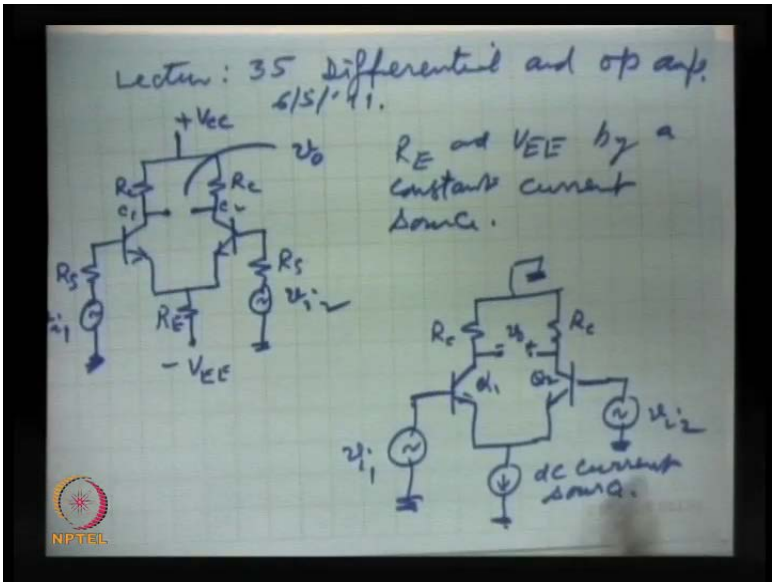

We continue our discussion on ac analysis of differential amplifier. And the basic circuit for the differential amplifier was this, containing two transistors, we are taking v j t and actually. And finally, we will see that this can be done even with the F E T and mosfets and the output is taken normally from that two collectors; this is one collector, this is another collector c 1 and c 2, this is R C, this is R C and this is R s, which is normally small this is the source resistance. This source which supplies the signal it has impedance and that source resistance; and this is v i1 and this is v i2, i for input impedance and here is v o the output. And we were discussing the in AC analysis of this basic differential amplifier; for that we said that the purpose of this register R E and this dc source V EE is to supply a constant emitter current.

Now, so for ac analysis, we can replace this arrangement R E and V EE by a constant current source. And for ac analysis, as we have discussed the several times that there are certain rules, and the rules are dc voltage sources have to be grounded, and dc current sources have to be opened. So, this source is to be grounded, so our ac circuit will become this; Q 1 and Q 2 and this we are replacing with a current source; this is dc current source, constant current source, and supply is the emitter current; and these resistance source resistance we are taking negligibly small, so that we neglect them, and here are these this is v i1, this is v 2 R C, R C and the output we take from two collectors here, plus minus this is v 0.

So, this is the equivalent circuit from the basic operational amplifier circuit which we are going to use for ac analysis. Now, I said that dc current sources sources have to be grounded. So, dc voltage sources have to be grounded and dc current sources are open for ac that means, they pose are very high resistance and ideally we take infinity that means no ac will pass through this path, this we have to remember. Now, from the analysis which we are going to have these are two sources. So, what we do? We will use super position theorem, we will take one input source as active and we will see and ground the other one we will see, what is the contribution in the output? Then we will ground this and we will activate the second input source, and what is the contribution and then we will the super position theorem says that the net output will be the algebraic sum of these outputs, which will be created by two fine input sources.

From this analysis, one very important point we are going to come out and that is, this two inputs of the differential amplifier, they are they are different in one way and that distinguishes them one will be the non inverting input the other will be the inverting input and they are always called like that inverting input and non inverting input. Because I have said it earlier that differential amplifier is the first stage in the multistage amplifier called operation amplifier, which we are going to study just after finishing the differential amplifier. And so this is very essential to know, what is the meaning of inverting input and non inverting input and and so on; so we pursue, we we continue the analysis, and here this is the circuit and as I said the second input source we will ground and we will see the output of the first one.

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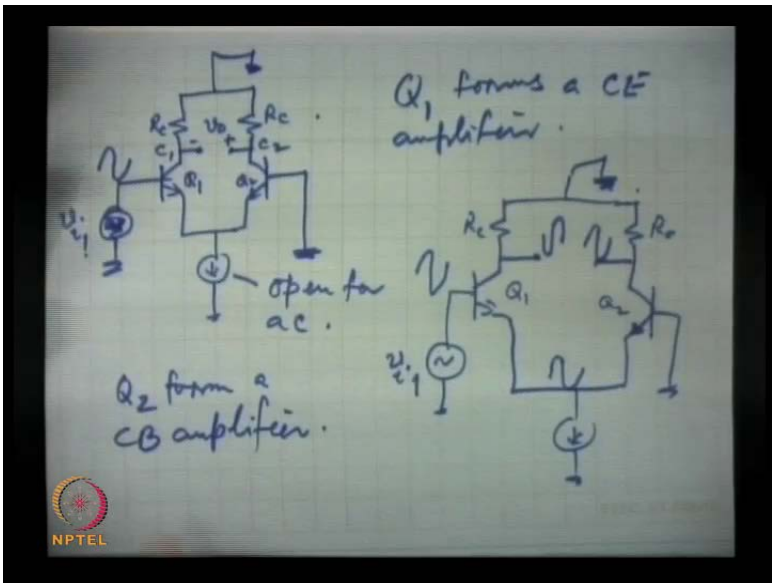

So, here it is this is grounded and here this is active, this is v i1 and this is grounded and here this is the dc source. So, open for ac now this is the output which is taken between these two collector c 1 and c 2 of transistor Q 1 and Q 2 and this is v 0. This is the situation when for one of the two input signals is activated is active. So, now see the signals that here we take the input signal is sinusoidal is like that now several very important point will come during this discussion. What is this Q 1? Q 1 this is we said earlier forms a common emitter CE amplifier and common amplifier common emitter amplifier shows the output inverted of the input. So, amplified output will appear at the collector and here this will be better out of this I make a bigger figure this is open.

So, we need not to show it no this is the input signal this will appear here in the inverted form wide fully because, we are feeding to the base with respect to ground and we are collecting it at the collector and they are inverted. So, we will get a output here like that now this signal will move here as well and at the emitter when we take the output form then there is no face inversion. So, at the emitter the signal will be available like the original. Now, very important point c 1 forms ac amplifier but now look here this signal will propagate from here to this emitter. So, the that the signal is applied at the emitter and we are taking it at the collector this is Q 2 one see the form Q 2 forms a common base CB amplifier very important point. This is acting Q 2 is acting as a common base amplifier and in common base amplifier there is no inversion, but amplification we will just write the expression this is equal to this hence the signal will be amplified and will,

appear with this polarity and hence this will be here. So, that will be the met output, because of the first signal source input signal source v i1.

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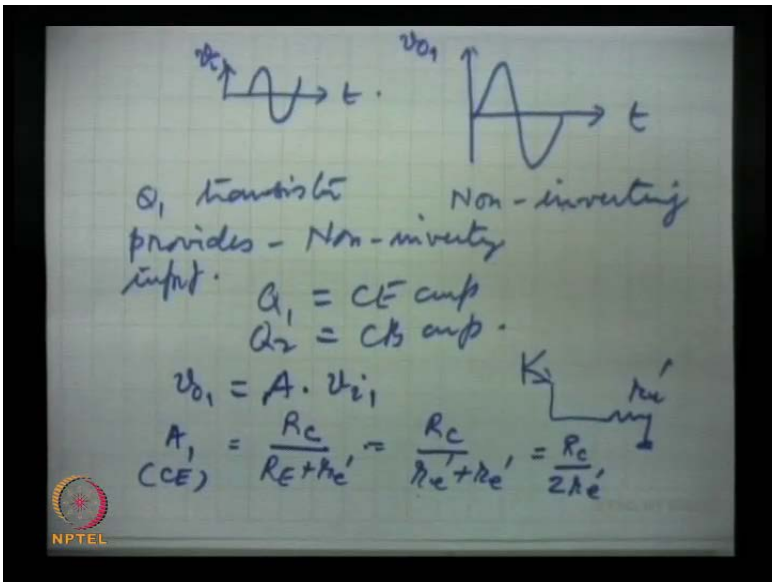

This is this this is time and this is v o 1 output net output because of first input. Now, look here this is the output you may say how the two will be combined now look here that at this point, if head it been safe with respect to ground, this will be the maximum and now instead of ground level which is more negative. So, this will be these two will be added this is like that we measure the height of this point from this table then say this is 20 centimeter, if we measure it from the ground, it will be say 1 meter and 20 centimeter. So, that is to be added and if it still from a deeper point, we measure this height that is to be added so the same thing, this is added up to that. So finally, this is the this is the output, and now see here this output appears for this input this was input v i1 with respect to t.

So, obviously this sin non inverting this is non inverting and this input is called non inverting input; non inverting and Q 1 is Q 1 transistor provides non inverting input it is called non inverting input. Now, we will see the other way we can find even the amplification actually, and as I said Q 1 forms CE amplifier Q 2 forms CB amplifier and the amplification will be the output v o1 is A is the gain into v I 1. If is the general expression for the voltage gain, where a is the voltage gain of the amplifier. Now, how much is that we can it is very simple because we have done it in the analysis of a small

signal b j t amplifiers. So, A 1 the gain because of CE amplifier this is R C by R E plus r e prime, where R E is the resistance with the emitter, where it is simply the I draw another figure to illustrate this point here.

So, the signal is going to the emitter and hence this will act as r e prime r e prime desire I R I I r e prime is the dynamic emitter resistance that is the emitter resistance of the junction dynamic a c resistance and here this will come for Q 2 but the two transistors are identical hence they are the same. So, this will be A 1 is equal to R C r e prime plus r e prime this is from the transistor, one is from Q 1, the other is from Q 2, and hence this is equal to R C by 2 r e prime and this is because of CE instead.

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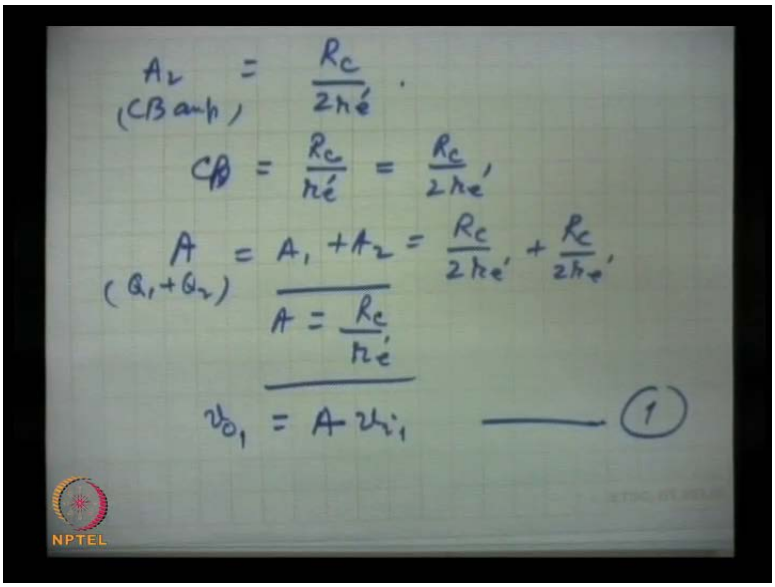

And similarly, it will be for the voltage gain in CE and CB are identical and hence this will be A 2 for CB amplifier this is at also this comes out to be 2 r e prime because, for CB CB the gain is R C by r e prime but there are 2 R C R C here R C here. So, they have we combine they are in parallel and hence this will also be R C by 2 r e prime therefore, A in this expression which gives the output A voltage gain due to Q 1 plus Q 2 this is simply A 1 plus A 2 and this is R C 2 r e prime plus R C 2 r e prime and A is equal to R C by r e prime this is the gain.

Differential gain and remember this is that v output because, of first input will be A v i1 this is equation one. Similarly, you will get the equation when the second input is a second input source is active we will get another output and then we will apply the super

position theorem. Always remember one very important point that we are always in the differential amplifier when we take output from the two collectors.

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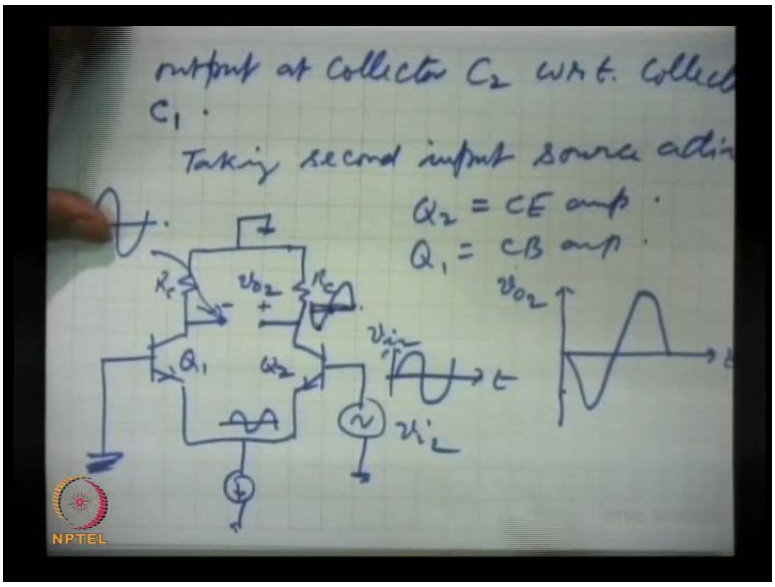

Then always we are taking at C 2 with respect to C 1, output at collector C 2 with respect to collector C 1 is very important that is why I said that at when this output was maximum when we measure with respect to this point this two will be added. Now, when second source taking second input source active and here the situation will be this this is active this is grounded here and this is R C, R C and this is minus plus at that instant when input has maximum like that the signal is like the t verses this v i2 this is v 02 when this input is active and this is grounded.

Now, the rows will reverse here feed in the signal at Q 2 at the base taking it at collector. So, Q 2 will be is CE amplifier and inverted output will appear here. So, here the out the output will be inverted that means like that CE amplifier this is the input just 5 phase will appear at the output. So, output will be like that and this signal this signal goes here and now Q 1 will be CB amplifier. So, without any inversion amplified signal will appear here so at this collector here at this collector it will be like that. So, when we sum up the two remember this is C 2 so this with respect to this therefore, the output v o2 as a function of time this will be as I have said up to earlier in the first case this will be like that when the two this is measure with respect to this then this is that and this now

compare these two this is the inverted output here for this input this is v i2 as a function of time this gives output like this v o2.

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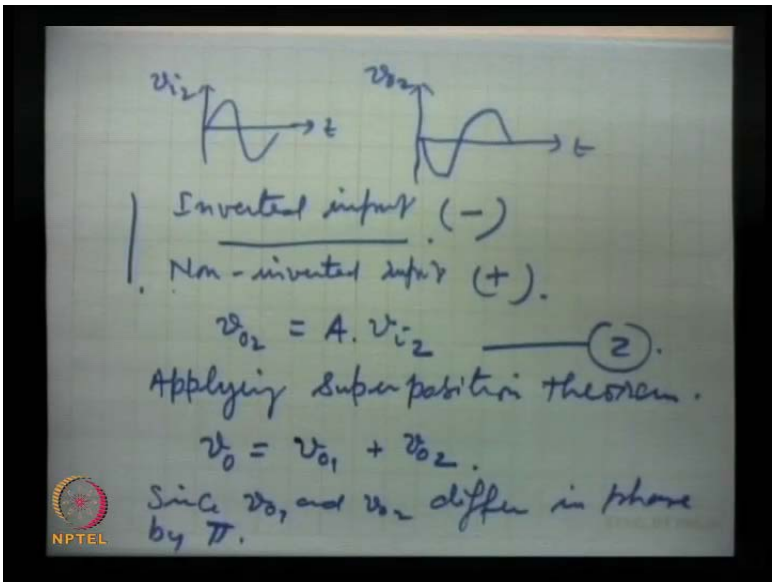

So, this is inverted inverted the input one is non inverted input out of that two input this input is non inverted input this is inverted input this you remember and there are mod actually the inverted input with a minus sign and a circuit diagram it is shown and the logic circuit diagram also on the device it is minus and non inverted input with a plus sign. So, these are the two input now we return back that these are the contributions v o1 and v o2 these are the contributions from individual sources when the first v i1 was activated we got the output here. Now, v o2 is a as the same because the same thing is been repeated Q 2 forms the CE amplifier Q 1forms the CB amplifier so we get the same gain and this is v i2 this is equation two now we apply super position. So, applying super position theorem v o the when both are both inputs are active that means when both signals are present then the output will be algebraic sum of the two and they differ in phase by pi since v o1 and v o2 differ in phase by pi.

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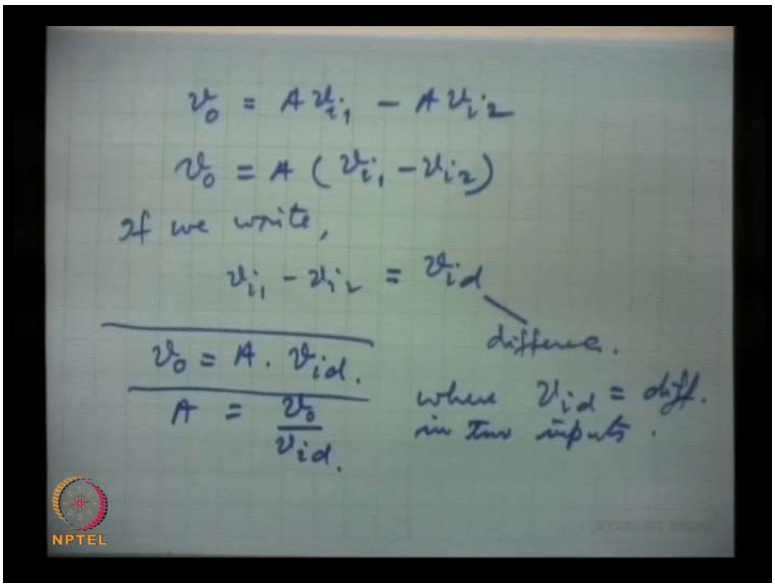

Therefore, v 0 will be equal to a v i1 minus A v i2 or v o is A is common v i1 v i2. If this difference, if we write if we write the difference v i1 minus v i2 as v id d for difference d for difference then v 0 is A into v id or A is v 0 by v id. That means this is what earlier we said as a statement now mathematically by the ac analysis this is coming true that in differential amplifier differential amplifier amplifies the difference of the two signals. So, we can write like this the output where v id is a difference in two inputs. So, this is very important analysis and this has brought out several important features of the differential amplifier that this acts as a differential amplifier plus the two inputs one is the inverting and other is non inverting input. Then we take another parameter from this is analysis and that is input impedance for every amplifier input impedance is very important parameter.

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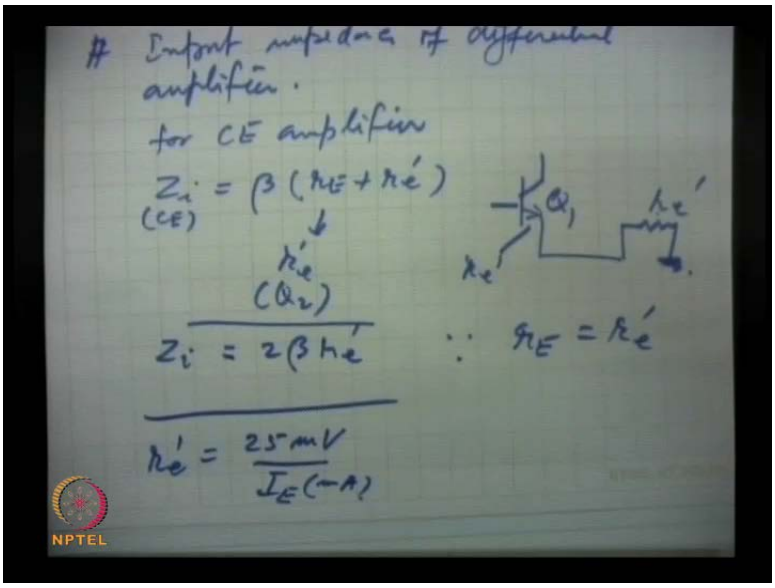

So, input impedance of differential amplifier the differential amplifier is always symmetric is symmetric. So, whether we take we input at the Q 1 or we take at the output which comes out to the same and when we measure it here say at Q 1. This is the C amplifier and for ac amplifier for CE amplifier common emitter amplifier the input impedance for CE amplifier from the analysis the small signal analysis of bi polo transistors we have said that this is beta in the current game into r E effective resistance as seen by the emitter plus r e prime. And this r E is also r e prime was just I take this figure again here this is from Q 2 r e prime. So, this will we seen and this itself has a resistance r e prime this r e prime appearing, because of the dynamic emitter resistance of Q 1 but this is seen because the other will also connected and this is this current source constant current source is open.

So, this is non existence for ac so this is the part and so this r E is also r e prime because of transistor Q 2 and this revolt we are not driving this we have done you just look back to the analysis of a b j t small signal amplifier. So, Z i is equal to 2 beta r e prime because r E is r e prime two. So, this becomes r e prime r e prime 2 r e prime so this is the input impedance in normal is not signal amplifiers like having one input like CB CE. So, the CE amplifier this r e prime was 25 volts but when we multiply with beta that comes out to be it is high voltage of 1 or 2 chromes. In this case, because this depends r e prime if you remember the dynamic emitter resistance of the transistor by definition is 25 mille volts by I E in mille amperes then it depends on current and in differential amplifiers this

current is very small and hence r e prime is a very high r E if it is 1 kilo ohms for example, r E is 1 kilo ohms then this will be depending on the value of beta several 100 chromes are or even 1000 kilo ohms. So, very high input impedance differential amplifiers have so this was about the input impedance.

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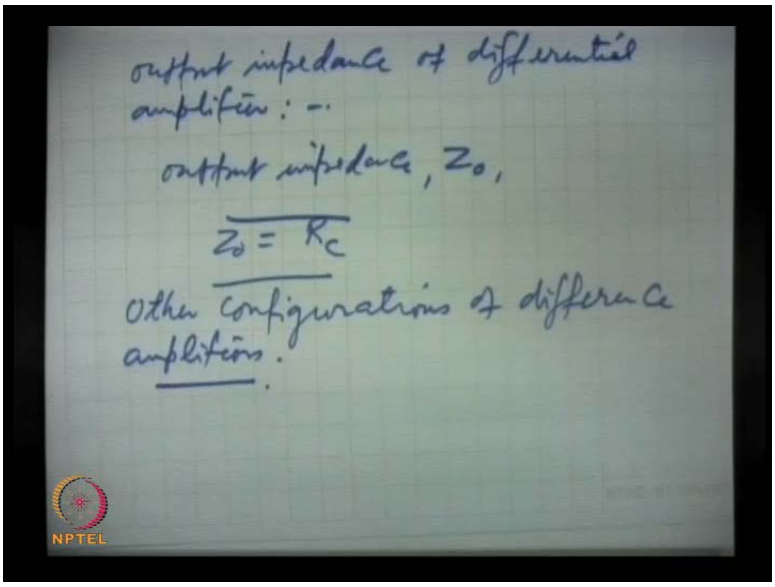

Then the output impedance output impedance of differential amplifiers. The output impedance if we look at the diagram and this is grounded then between this an ground what is the impedance which we will be either we measure here or we measure here we are going to get R C. I repeat between the collector and the ground the impedance which we are going to have output impedance will be equal to R C whether we measure for Q 1 or Q 2 therefore, output impedance Z o this is equal to R C R C R C. Whatever if it is 500 ohms or 1 kilo ohm whatever it is that will be the output impedance. So, the three most important parameters of ac analysis for any amplifier the gain and the input impedance and output impedance that completes the ac analysis of the differential amplifier. This was the general analysis and by general we mean for the differential amplifier when we take output from the two collectors that means for balanced output differential amplifiers dual input balanced output that is the most widely used configuration of the differential amplifier and for that we presented the analysis.

That dc analysis is same for all other possibilities also ac will slightly differ because from whether we are taking output from two collectors or from collector c 2 with respect

to ground that will change the gain and so where that that the part is slightly different. So, having done the analysis for the dual input and balanced output differential amplifier we can briefly take other configuration some are not used actually but for the sack of argument and for the sack of logic they are there but others are used. So, what are these and how we can infer the results because input impedance will be the same whatever is the configuration whether single ended output or double ended output input impedance does not depend on that. So, input impedance will not be effective only output impedance will effect will be effective.

Now, the other configurations we take other configurations of differential amplifiers. The next one we take is this dual inputs un balanced output that means, single ended output we take output from c 2 with respect to ground this is sometimes used on some special conditions situations are there we are this configuration proves useful and is used.

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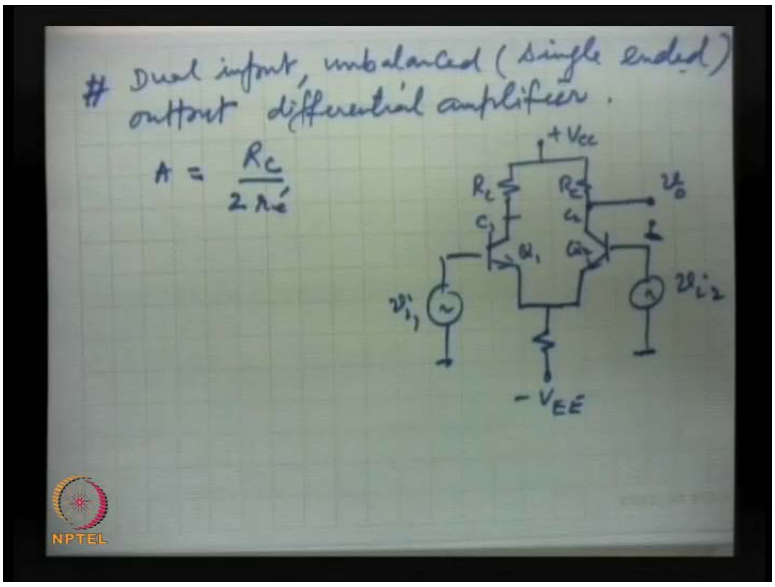

So, this is dual input and unbalanced unbalanced that is single ended output differential amplifier. This is dual input unbalanced that is single ended output differential amplifier what we are saying is this we are taking output here this is v out with respect to ground we are applying two inputs and we are taking in the previous case balanced output we are taking output at the two collectors C 1 and C 2. Now, only single ended single ended unbalanced so from collector C 2 with respect to ground in this case only one point is to be remember that let as look at the signal the signal will be amplified it will be

amplification factor will be half of the previous case because here for example, this case was amplified here also and it goes it is amplified here also and similarly, the other one but here this gain a will be equal to R C by 2 r e prime because the signals will be amplified what we have now using is only half the capability of the differential amplifier.

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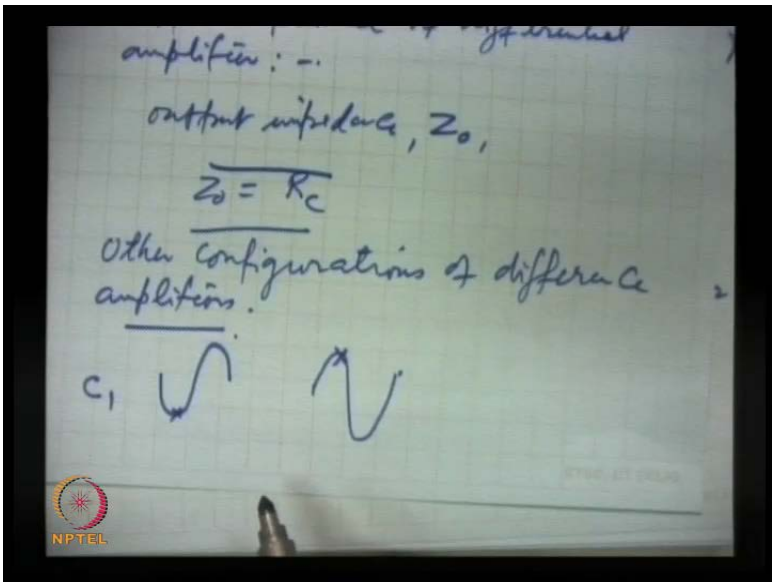

I just make this point clear for example, when both signals were there the output at the Q 1 collector was like this was from the collector C 1 and the collector of C 2 that was that that was like this now if we measure this with respect to ground this will be the gain this two are identical as far as the magnitude is concern, but when this point will be measured this is doubled we explain this that this will come double.

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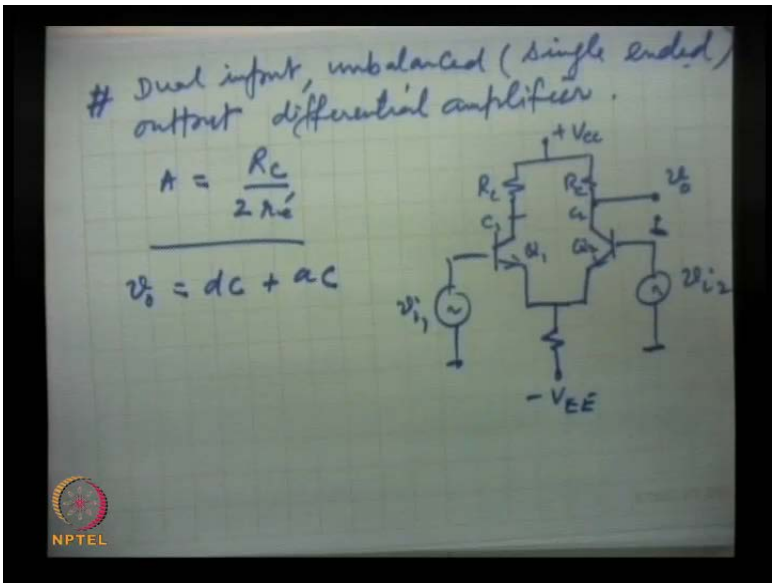

So, in this case when we are taking output with respect to ground that gain will be half. Another important point that because, of the symmetry of the differential amplifier that dc parts were absent because they were equivalent they were they will be cancelled in the output when we take output from two collectors that means, in the case of balanced output the dc parts was absent. Now, the dc part was absent now this dc will also with here so output will contain dc plus ac signal dc voltage will also begin. So, if this configuration is to be used then at some stage you will have to take care because this will change the dc level of the signal so there are circuits which take care of dc level and amplifiers so that is to be used. And as I said input impedance of this amplifier will be the same as in the previous case because input impedance does not depend how we take the output.

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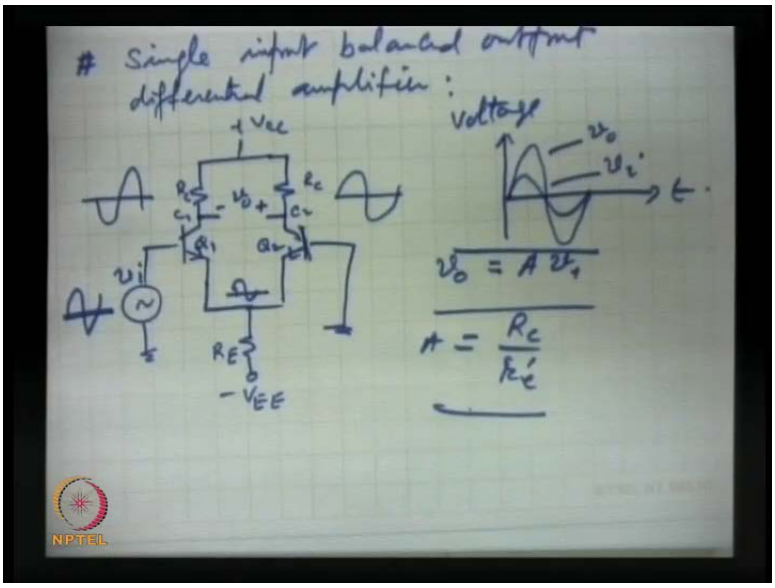

Then the other configuration is single input balanced output single input balanced output differential amplifier this is I draw the figure only one input source is their this is grounded and this is active and output is taken from two collectors C 1 of Q 1 and C 2 of Q 2. So, here this is output now if this signal we take then we remember that this will appear here as inverted but here, it will appear as like this and here. So, when we take the balanced output the voltage is input and output this is in phase with this input. So, this is the voltage time and this is for v i this v i and output is in phase with it this is v out. So, we will get the output and input like that and v 0 will be equal to A v 1 here A is R C by r e prime as in the first case we studied.

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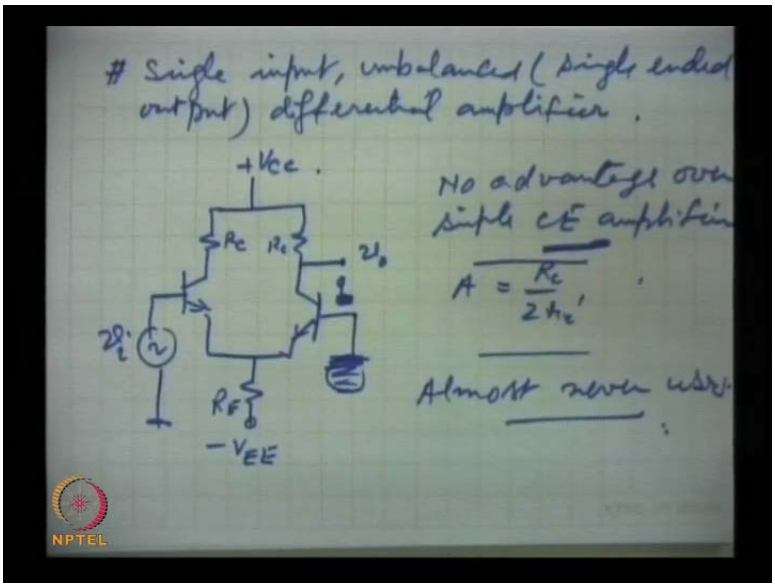

And the last one which is not used actually that is single input unbalanced output single input unbalanced that is single ended output, differential amplifier differential amplifier and this is the configuration which show we are talking this is the input signal and output this is grounded and output is taken from here v out with respect to ground this is the single ended unbalanced output. So, here the game will be half of the first case plus important feature is that this does not offer any advantage over simple no advantage over simple CE amplifier but a disadvantage is this makes use of much more components large number of components has compare to simple CE amplifier. So this is almost never used there is no advantages in using this the so this is not used here gain will be half of the previous case when we take unbalanced.

So, A will be R C by half r e prime so almost never used, so this were the different configuration which we had said earlier that four possibilities exist and these are the four different differential amplifiers. Now, all through this analysis we have taken b j t differential amplifiers but instead of a b j t we can use a FET JFET or MOSFET and we can found a differential amplifier.

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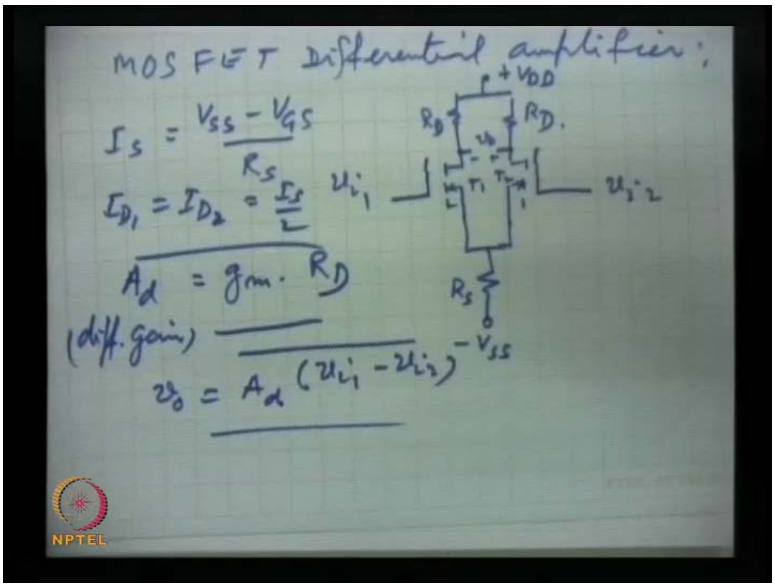

For example, the MOSFET differential amplifier the analysis which we have done they are with slight modification for example, gain will depend on not on beta, but you remember that trans conductance that those terms have to use otherwise this same. So, very briefly I take this here this is the source resistance and these are the two MOSFETS. This is one input this is the another input and we connect this is V DD this is R D drain resistance and the output can be taken from two drains this is v 0. So, these are the two MOSFETS T 1 and T 2 and they can also form a differential amplifier this is one transistor MOSFET this is another MOSFET and it can be shown actually that the source current R s is V SS this battery minus V GS by R s and drain current in one as the same as drain current in two and this will be half of I s.

So, is by 2 and differential gain differential gain in this case this will be g m into R D this also for a MOSFET we have derive this relation so this the voltage gain. And v 0 will be a d into v i 1 minus v i 2 as usual so this is the differential amplifier. So, differential amplifiers are common and MOSFETS also when very high impedance input impedance input impedance in are required are rather is still higher then MOSFETS are used and this may be the requirement in several instrument and instrument fabrication so these differential amplifiers are used.

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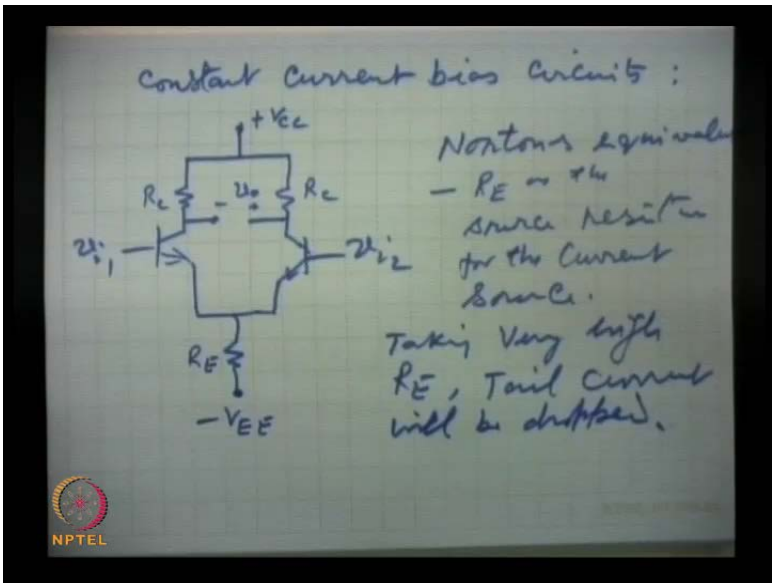

Now, we will talk about the constant current source constant current bias circuits constant current bias circuits. In the conventional design which we have been taken as the basics basic differential amplifier this constant current source this resistance R E and this voltage this forms the constant current. And remember we have said we have made a statement several times v i 1 v i 2 we made a statement and in the hole ac analysis we have taken this as a constant current source. Now, if we draw the Norton's equivalent Norton's equivalent of this circuit then R E then for that current source Norton's equivalent will have R E as the source resistance source resistance for the current source. For a current source the source resistance must be very high ideally infinite.

You know this was a voltage source a voltage source constant voltage source should have a low resistance, while a current source should have the and we have neglect that this R s sets at several places but a current source should have very high resistance but in this case R E cannot be very high because, if R E is very high that will reduce the tail current taking very high value of R E the tail current will be dropped drastically. So, we cannot use very high value of R E so but a good current source constant current source should have a higher resistance. So, better circuits at this are replaced by a transistor and a constant current source can be fabricated by using a transistor a b j t.

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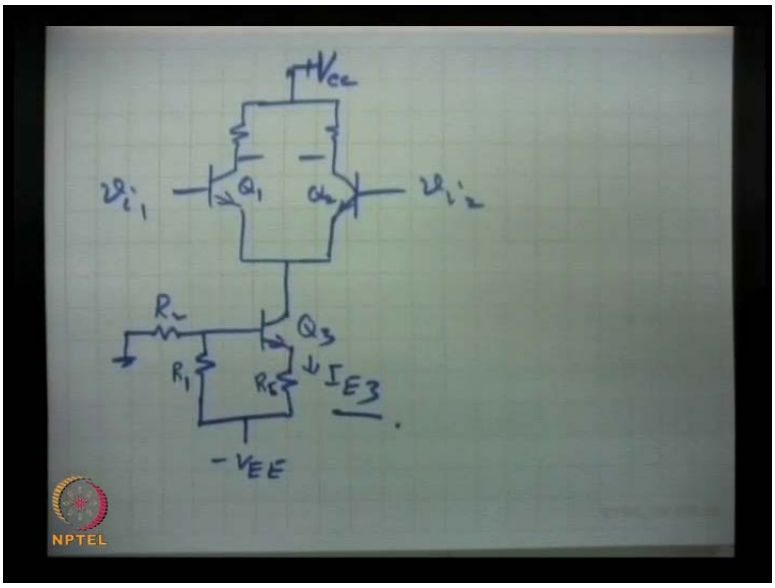

So, what will be the circuit that is this; because the reverse bias collector has a much higher resistance than simple resistance R E, so this acts as a transistor Q 3, Q 3, this is Q 1, Q 2, this is v i 1, v i 2 rest is same as we have discussed. This circuit is taken, R E and the current I E 3 flows through it. What we have done? We have replaced the simple arrangement of that resistance R R E, and this battery, because this does not fall a high quality constant current source. So, this we have replaced by a transistor. The transistor collector, which is reverse bias and that that exhibits in much higher impedance as compared to simple R E. So this x has the better constant current source, very widely used, because this is essential, this point was essential that the constant current source is a providing a constant current to the differential amplifier. And this can be analyzed in a simple manner; we will be talking about that. And this can further be improved; this resistance R 1 can be replaced with two diodes have an identical characteristics as this emitter base junction. So, these are the points, which we will be discussing, and then we will move further.