Electronics

Prof. D .C. Dube

Department of Physics

Indian Institute of Technology, Delhi

Module No. # 07

Differential and Operational Amplifiers

Lecture No. # 03

Differential and Operational Amplifiers (Contd.)

For differential amplifier, the constant current supply for the emitter is a fundamental to the appropriate working of the differential amplifier. The simple arrangement, which we exhibited in the basic circuit consisting of the resistance R E, and the battery, the dc source V EE, they does not form a very good constant current source; for the simple reason that nortance equivalent of that is having the source resistance R E. And the current source should have a very high impedance, R E cannot be very high, because that reduce the emitter current drastically.

So, we can replace a better arrangement is if we replace the arrangement of R E and V EE with the transistor. Now transistor collector as we know is reverse bias, and that has much higher resistance than simple R E would exhibit; and therefore, that forms a better current source.

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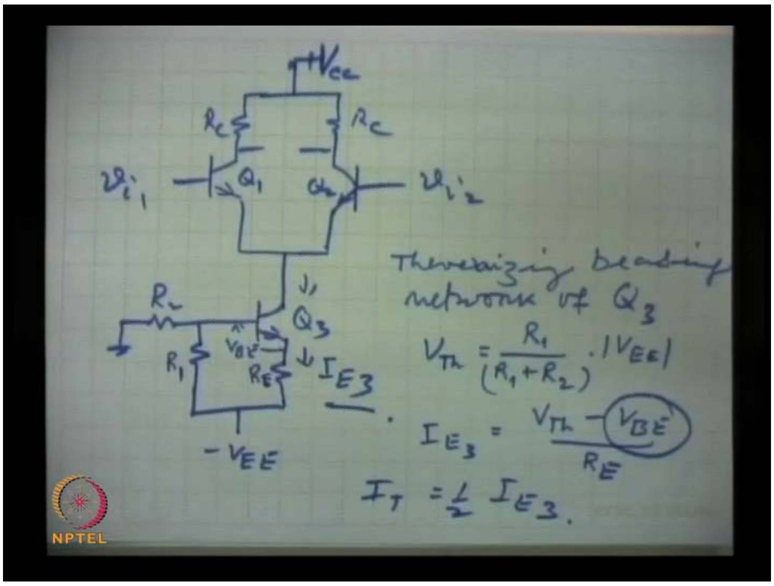

So, the circuit under discussion was this. That resistance R E and battery V EE, it has been replaced by this transistor circuit. Now, here this there are two resistance is R 1 and R 2, a voltage divided bios is we used, and here we can thieveries this circuit and thievenizing biasing network for Q 3 thievenizing biasing network for Q 3 that is the transistor Q 3, you know simple rules of the Theveniaz theorem. The Theveraized voltage is whatever is the voltage is across this. So the current will be V EE by R 1 plus R 2, and that current when passes through R 1 gives the voltage that is thevenaized voltage, this is that.

And the emitter current as we have done several times when we were talking about bi polor transistor, the emitter current I E is V Th that is this voltage, which we calculate minus V BE by resistance R E, this resistance R E. So, this is the emitter current and this will be much more constant than the earlier one just the current which will be flowing by the resistance R 3 with R R E with battery V EE and so the tail current I T is half of this, this is I E 3 that is this current and this current, I C 3 is equal to I E 3, because in bi polar transistor emitter current in and collector are very close to each other. So, this is half of I E 3.

Now in this arrangement, which is quite very widely used. We have taken care for one factor, and that is of the current source this current source will have much higher and impedance sources resistance, when comparison to the previous arrangement but is still there can be some variations because of current, this voltage V BE, this voltage V BE, this is temperature dependent. 2.5 mille volt per degree it falls, so this variation will cause if this input voltage V BE varies, and that will vary the I V of this transistor and hence I E will depend, because of temperature variations; and so one of the better than this arrangement is if we replace this resistance R 1 with two diodes.

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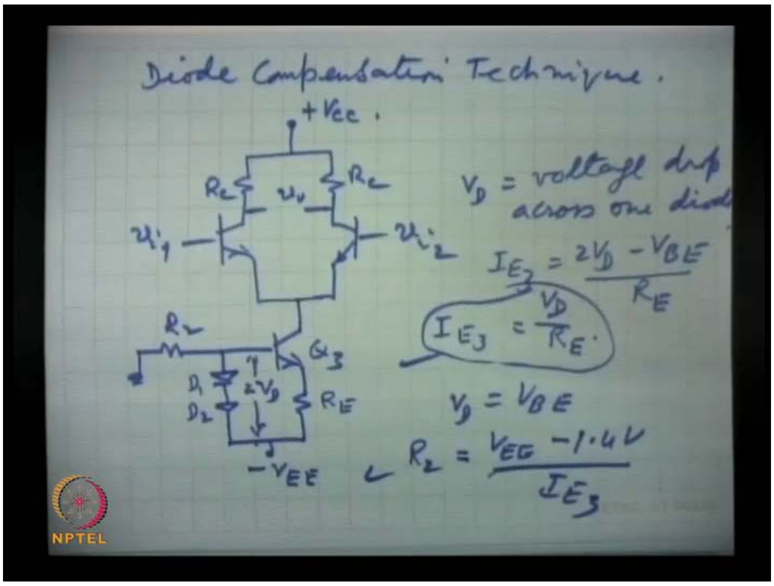

So, this is the diode compensation technique and the circuit is these are the two diodes D 1 and D 2, so the voltage here is will be 2V D, where V D is voltage drop across one diode; and this resistance here resistance R 1 is replaced by two diodes. Important thing is that the characteristics of emitter base junction of the transistor Q 3 have they have the same characteristic as this diode; diodes, we have chosen not any diode, but the diodes which have similar characteristics, identical characteristics as the emitter base junction of the transistor. So, any variation which will occur here that will be compensated, because this voltage across this V D will also be temperature dependent.

And they will change to compensate the changes, and hence here it can be shown, this circuit can be analyze that I E3 is equal to V D by R E, this is R 2; this is grounded here; the voltage drop is V BE, so this is this and, because this has been derived from 2V D minus V E for example, I could have written another expression earlier than this has 2V D minus V BE, this voltage minus this voltage by R E, but because they have identical characteristics the base emitter junction diode and this diodes. So, V D is equal to V BE and when we use that then, we get this expression and further it can shown that how to choose value of R 2; for this is V EE minus the voltage which is normally 1.4 volts by I E 3, I E 3 is here; this is this resistance can be calculated and this normally comes in the range of 100, 200 ohms. So this way; this is one of the best constant current source which takes care of two parameters.

The source resistance this constant current source resistance has very high source resistance in this circuit, and it also takes care for that temperature variation of this voltage here V BE, and so this is one of the best. So, this was the content current source and what are the various options we should we have. Now, we define another very important characteristic by which we differentiate between this is one of the characteristic between among different differential amplifier, and this is the parameter is common mode rejection ratio common mode rejection ratio CMRR.

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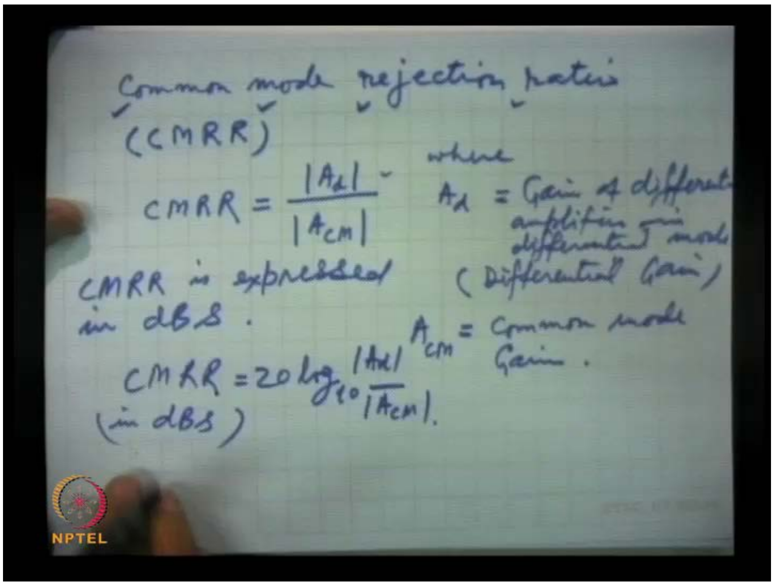

This is also called CMRR. CMRR ratio common mode rejection ratio. In the beginning we have said that, any voltage which will be common to both inputs that will be totally rejected totally 100 percent rejected at the output; any circuit we take either this circuit here also any in the differential mode when we take the output here from two collectors when whatever signal is common to both, we said it is totally rejected; it is absent in the output.

So, whether this circuit or this circuit that does not make a difference. Now, this is the ideal situation; this assumes that two halves Q 1 and Q 2, these are 100 percent identical. This is true that is I made a statement in the beginning that normally differential amplifiers are fabricated as I C on a single chip, and the process of fabrication is the gas diffusion for introducing n and p impurities to made this transistors and resisters and all that. So, the process is very systematic and computer control in spite of all that some differences may occur. And they do between the two transistors characteristics and this compensation is not 100 percent that means, any signal which is common to both, is a 100 percent absent is the ideal situation; it is not the practical thing.

Practically yes, well designed differential amplifiers this will be largely absent. Any signal common to both will be largely absent, but little bit few percent may still be there. So this property this property of the differential amplifier that to what degree it eliminates any signal which is common to both inputs that is measured by this ratio common mode rejection ratio. I hope I had made the point clear; common mode rejection ratio CMRR is a parameter, which is the measure of the of the ability of the differential amplifier, which it states that to what extent the common signal common to both inputs is absent in the output, and this is defined as CMRR common mode rejection ratio is defined as the ratio of the magnitude of differential gain and magnitude of gain in CM common mode.

So that is where A d is differential gain. Gain of the differential amplifier gain of differential amplifier in differential in differential mode, so this is called commonly differential gain differential voltage gain or some play differential gain and this is A, this A CM, this is common mode gain common mode gain, so this ratio gives CMRR and normally the CM, the common mode rejection ratio is expressed in decibels; in dBS and then, CMRR becomes this is equal to 20 log base 10 A d by A CM; this is in dBS common mode rejection ratio in dBS. Now, how to measure this two gains we have to measure.

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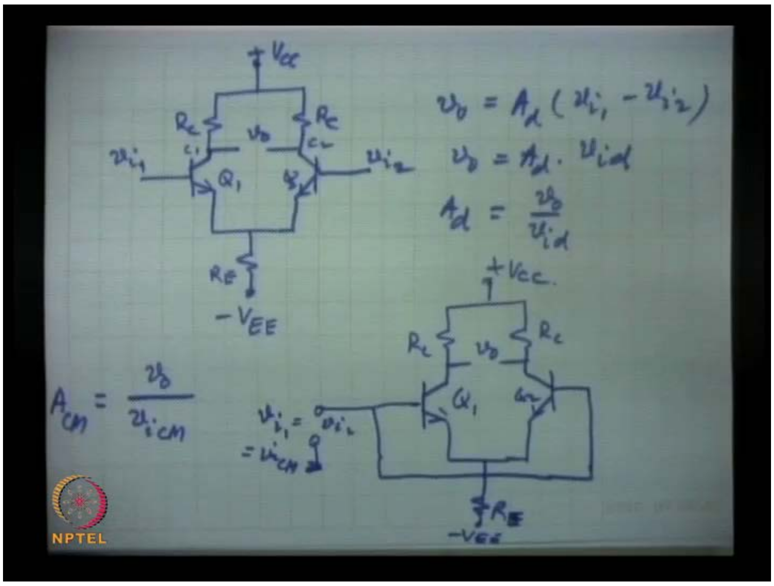

So, let us take the basic circuit, this was the circuit which we have been talking. The basic circuit this was V i1, V i2 R C, R C and this is V out, C 1, C 2, Q 1 and Q 2; so we give two signals the deform slightly say for example, 0.5 mille volt and then we measure this output so the difference of the two output is suppose to be A d Vi1 minus V i2 or this is in differential mode; so V O is A d into V id and so we can measure A d s V out by V i difference. This is the way we can measure the differential gain; we apply two signal, two input signals slightly different in magnitude by say 0.5 or 1 mille volt and we measure the output and from this expression, we can find out the differential gain.

And the common mode gain, we can measure by supplying the same signal to both for example, here R E here the two inputs are sorted and we feed with respect to all voltages are with respect to ground what we measure is here with respect to each other of course, but just we give V i1 which will be same as V i2 and which is same as V iCM common mode here; we apply a signal which will be common to both and we measure the output here R C, R C plus V cc we measure the output here; we can get these are direct couple amplifiers and hence, they will respond to even dc.

So, we can use dc voltages two dc voltages in the first case difference slightly you measure the difference and we measure the output in the from the two collectors. In this case also, we apply the same signal; we sort the two inputs and half Q 1 and Q 2 and apply the same input to both; so this is input in common mode and we measure the output and A CM will be equal to V 0 by V iCM common mode whatever signal we give. Now ideally, for the common mode V 0 should be 0; so ideally, this gain for common mode will be 0, and then according to this definition common mode rejection ratio ideally is infinity.

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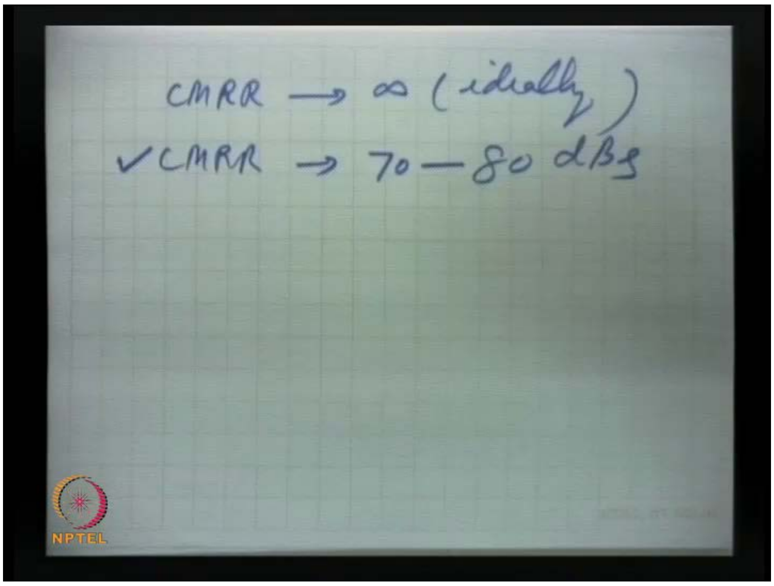

CMRR approaching infinity ideally, but in with the presently available advance technologies this CMRR, it was of the order of 70 to 80 dBS, which is also very high and so the CMRR higher it is, better it is. And practically, this goes up to 80 to 85, 90 dBS which is really high value. So this way, we have done with the differential amplifier. Differential amplifiers they form the first stage of operational amplifiers, which we are going to study now.

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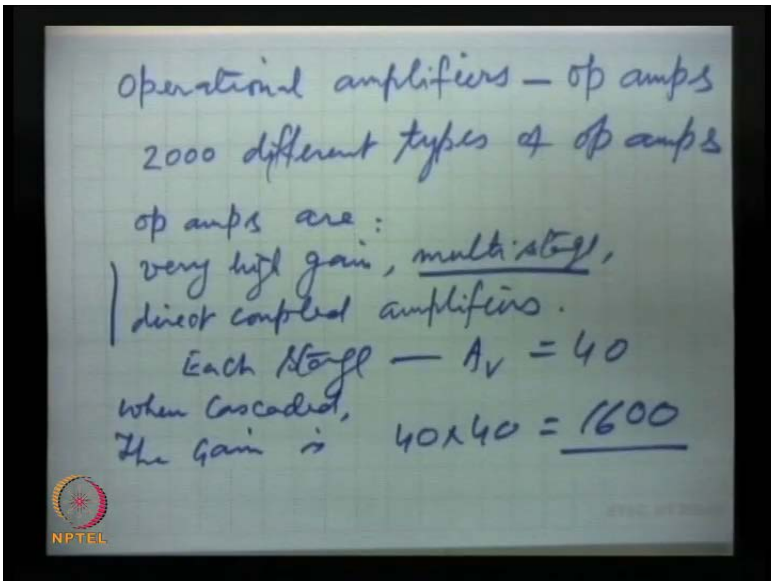

So, we take up now operational amplifiers in brief and most commonly they are called op amps; from operational amplifier we call them popularly op amps; op amp today is a very important component in every digital and analog system. You will hardly find a system in which, op amps are have not been used, they are very widely used. There are 2000 different kinds of op amps, more than 2000 different types; 2000 and more different types of op amps are now commercially available. There are very inexpensive, and we and why so such a large number, because different applications will require different characteristics. So to meet those requirements, these operational amplifiers have been developed with different characteristics.

Now what are the op amps? Op amps are operational amplifiers are very high gain very high gain multi stage direct coupled amplifiers. This is the major main important points about operation amplifiers. What are operational amplifiers? Operation amplifiers are very high gain, how high? 10 to power 4; that is 10000 and above 100000 is the gain, and this gain cannot be achieved from a single stage. It has to be multi stage, so it is a multi stage amplifier.

About multi stage, we have studied and the major point I repeat, if we have two amplifiers for example, they have gain of 40 and 40 individually when they are cascaded, connected in series to form a multi stage two stage amplifier then, each stage has a gain A V equal to 40; so the combined gain for two stage when cascaded the combined gain is the product of the two gains. So the gain is 40 into 40; that means, 1600 this way; so this is a very high gain multi stage direct coupled. Now avoid about coupling though we have talk this points again but here, it is for the sake of revival of the concept that, what is the influence, what is the implication of this direct coupling. I said in differential amplifier that we can use sinusoidal signals or even dc voltages at input signals.

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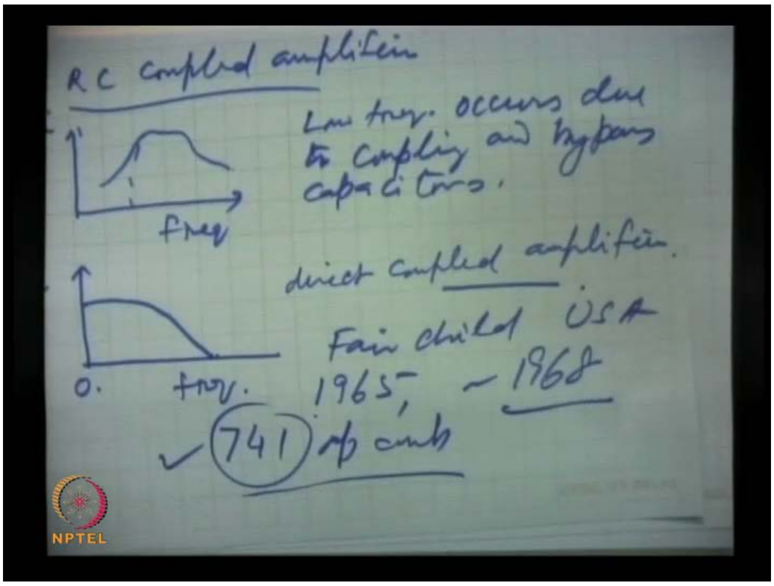

So, this is possible only with direct couple. There are R C couple amplifiers, R C coupled which we have studied and for that, gain verses frequency. This is frequency; this is voltage gain; and the response is like that. And this fall, this occurs because of low frequency cutoff; this occurs because of due to coupling and bypass capacitors. In direct coupling there is no bypass and coupling capacitor. So the response for direct couple, this is R C couple; for direct couple response is like this. This is gain; this is frequency; and this is 0 frequency. That means including dc right from dc the gain it will amplify the signals and this is response for a direct coupled operational amplifiers. The first operational amplifier just to give the few lines the history of the development fair child.

Fair child United States of America the semiconductor company, this brought out the first operational amplifier in 1965, but it has certain drawbacks. Two major drawbacks were that, the output may latch then it will not vary with the input. In amplifier, we expect that the output should vary in according to the inputs except that they will be amplified. So that while latching of the output was one problem and oscillations, unwanted oscillations was second, but the same company fair child after three years that means around 1968 brought up the most widely used circuit. One of the most widely used op amps which took here of these problems and that was the real revolution.

After that of course, there are several countries met Motorola and semi conductor limited and so many companies are making with their trade name the op amps and now, as I said in the beginning that there are roughly 2000 of them different types to meet all the requirements. Why it is called operational amplifier? This is called operational amplifier, because besides a simple amplifying circuit, it can function as a summing circuit as a summing, subtracting, differentiation, integration and many other mathematical operations can be performed by this operational amplifier.

So, because it is capable of performing many mathematical operations it is called op amps. We will when we go for the applications of op amps. We will study these quite a few of applications of these operational amplifiers. So, the most out of these 2000 different types, 741 this is the number of op amp. This is very widely used; it is a common purpose op amp for many level experiments and in many circuits this is very widely used 741. So we will take this as a model, but replacing by any other number the basics which we are going to consider we are not going to change. Operation amplifier is a multi stage amplifier. So the design is complicated, but I will demonstrate that what are the various stages that make a op amp and what are the function of those stages.

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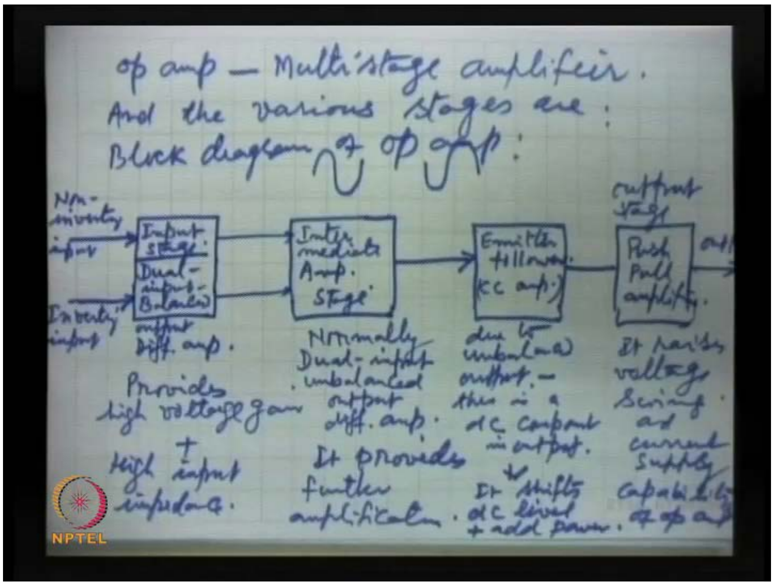

So, op amp multi stage amplifier and the various stages are various stages are these; this is the input stage, which is a dual input; this is a differential amplifier. Dual input dual input balanced output balanced output differential amplifier. And obviously, it will have two inputs, one and two; this is non inverting input and this is inverting input.

We have talked about in great detail that this is non inverting that means, when we give any signal then without changing its polarity, the output of this amplifier will be there. If it say dc signal; if we give positive here, because it is non inverting input at the output it will be positive; if we give a negative voltage at the output it will be the amplified negative voltage. While here inverting input, if we give a ac signal like that, then at the output it will be inverse in phase; if we give a positive signal, it will appear as a negative and if you give a negative signal, it will appear as positive; that it will change its phase.

So this is the input impedance; this is the input stage and which is a dual input balanced output differential amplifier, and this stage provides high voltage gain high voltage gain and remember, that we said the differential amplifier has a very high input impedance, so high input impedance. This is the first stage then, this goes to the other stage secondary stage; this is intermediate amplifying stage intermediate amplifying stage. To further amplify the signal and this is again normally a differential amplifier. Normally, this is dual input unbalanced output differential amplifier. Now I am sure you are familiar with the terminology dual input, balanced output; this is unbalanced output that means, from collector c 2 of differential amplifier the output is taken. So this provides obviously this is, it provides further amplification.

Then, it goes to the next stage which is a emitter follower stage emitter emitter follower stage, which is common collector amplifier; and what does it do? Because all the this we are talking the block diagram this is the block diagram of block diagram of op amp; various stages of them are these. If you remember in unbalanced output differential amplifier, we said that because direct coupling is used, so the output will contain ac as well as dc voltages. So it will have dc as well. So this emitter follower, this takes care this changes the level the dc level so this stage shifts dc level; first I write due to unbalanced output there is a dc component in output; so it shifts dc it shifts dc level plus at power. You remember emitter follower we studied in details that, there is a high voltage gain sorry there is no voltage gain, but there is a current range; so there is a power gain because power gain is the product of current gain in voltage gain. So it adds power to the signal, and then the last stage, this is the output stage and this is a improved push pull amplifier.

Push pull amplifier in a modified form and modification is between two transistors which sit one over the other, there is a diode and diode, it takes care that when one transistor conducts other is off and this is known as (( )) output and so, it raises it raises voltage string and current supply capability of op amp. So this is the output here, this is output. So these are various stages of the op amp and there may be some variations as I said that, there are very different large number of different types of op amps had been developed. So, some small variation are there, but basically these are by stages which form a op amp. Op amps are available as integrated circuit and the circuit symbol.

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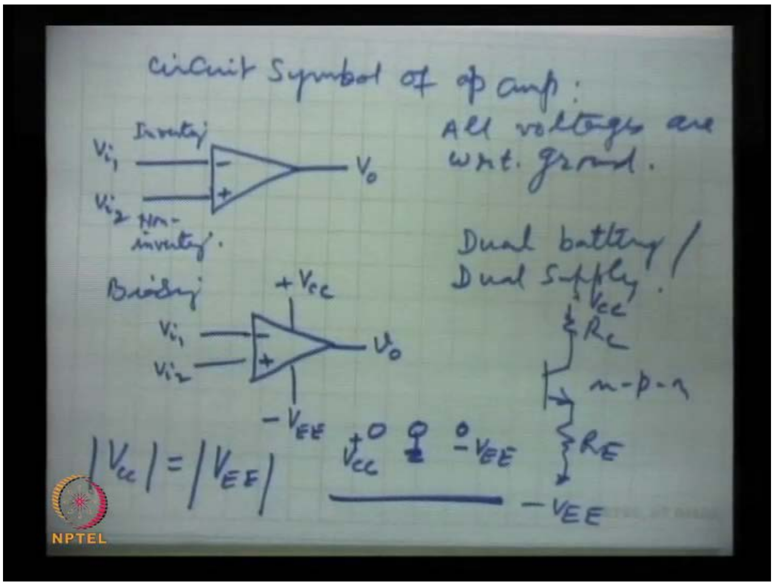

I draw the circuit symbol is circuit symbol of op amp; this is inverting input; and this is non inverting two inputs, and this is the circuit symbol for a op amp. All voltages are with respect to ground and for biasing is assumed that it has been connected, but to simplify the circuit it was not shown. So actually, the biasing is sometimes some people prefer to show this circuit like this as well, but this is the generally accepted circuit, where it is implied that these biasing have been provided.

The negative sign indicates inverting input and plus sign that indicates non inverting. So these are the biasing; we have done this biasing that, if we have a dual battery or dual suppliers usually it is called. For this you need a dual supply; this V cc and V EE, these are two voltages; one is positive with respective to ground; the other is negative. For example, in the transistor you remember this here, minus V EE, this is R E; this takes care for forward biasing; this is n p n transistor. So this will forward bias the emitter junction and this will reverse bias the collector junction. So dual power supply that is with respect to ground, there are these voltages; this is V cc plus and this is minus V EE; this is the dual supply. There is no condition that both these voltages have to be always identical, but in practice they are used identical; 9 volts, 12 volts, 15 volts this is the range in which V cc and V EE are used. Dual power supplies are available to supply these voltages and normally, the magnitude of V cc is identical to V EE; one is positive with respect to ground; other is negative. These are available very low cost starting from 7, 8 rupees for one op amps.

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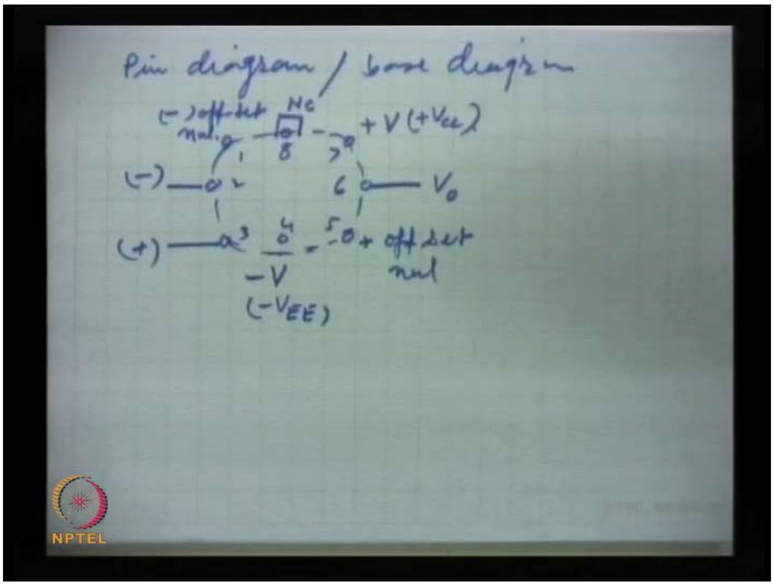

May be 10 rupees and then the range goes and the diagram base diagram, pin diagram this is like this; these are 8 pins 1, 2, 3, 4, 5, 6, 7, 8 the output is here V out and the two inputs are here at 2; pin number 2 and 3; this is the inverting and this is the non inverting. This is the connection for minus volt that is for minus V EE and this is the 7 number is for plus V; this is plus V cc and these are offset; we will talk it later about that little adjustments are required for improving the performance of the op amp. So this is positive offset null, and this is negative offset null, and this is closed an n c normally close terminal; so this is the 8 pins of the op amp. The base is available we have to insert the op amp and you have to connect the negative supply at 4; positive supply at 7 and inputs at 2 and 3; output is to be taken 6 and 5 and 1 are for negative and positive offset null adjustment. So this is about the base diagram, the pin diagram for the op amp.

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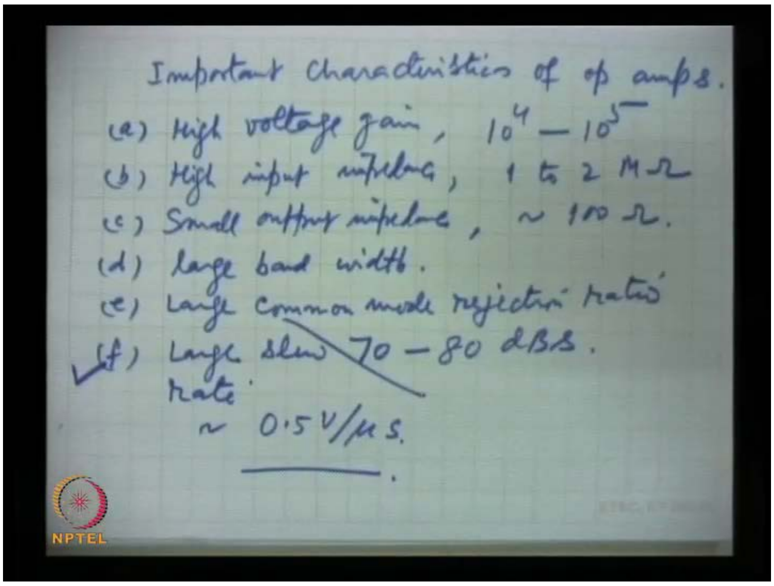

Now, important characteristics important characteristics of op amp important characteristics of op amps; this is just what I have made statements already, but let me summaries that high voltage gain high voltage gain in the values 10 to power 4, 10 to power 5, this is the gain and high input impedance high input impedance; how high? They are 1 to 2 mega ohms, very high and a small output impedance. These are high input impedance and low input impedance are the characteristics of a good voltage amplifier. So a small output impedance and this is around 100 ohms also then, large bandwidth large bandwidth of several. Practically, we will see that in open loop without feedback, the bandwidth is very small because gain is very high 10 to power 5, but without feedback op amps are rarely used. As we further move towards understanding various circuits then we will see this points. And with feedback when we use then, several kilo hertz is the bandwidth which is sufficient for a large number of applications.

And, the next is the large CMRR common mode rejection ratio large common mode rejection ratio and this is in the range, because this is expressed in dBS so 70 to 80 dBS for most of the op amps. And one parameter which we have not yet discussed and that is, it has large slew rate large slew rate. We will talk about this point later, but because we are talking about the important characteristics of op amps. So I thought that I must mention at least. And this is, but we will talk it say it say distortion actually and it puts a limit that, if amplitudes are high then, frequency we cannot use very high and so on. So normally, this is to the tune of 0.5 volts per micro second (( )). So these are the characteristics about this slew rate, we will be talking later. Now briefly, I talk about the op amps in open loop, which is a rare use for op amps and why it is rare; this also will become clear to you; so op amps in open loop.

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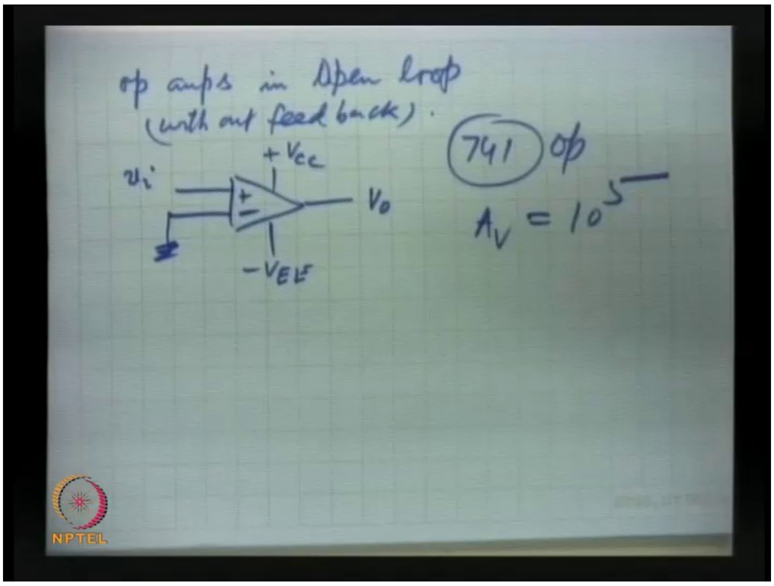

That means without feedback without feedback, we will talk about this point in details, but one thing I just make clear by open loop we mean this, that this is of course the voltages we have to supply; the output we will take and here suppose, we ground one and we give a small voltage here, and the gain for 741 op amp, which we will be taking for our discussion; this voltage gain is 10 to power 5; so this voltage will be multiplied by this quantity at the output, no matter how small is this voltage; it is 0.1 mille volt even then, it will becomes 100 volts at the output, but 100 volts are impossible, the voltage will saturate either with plus V cc or minus V EE. So and saturation we mean that output will not vary with the input. We will talk about these points next time.