Electronics

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Module No. #06

Power Amplifiers
Lecture No. #01

Power Amplifiers

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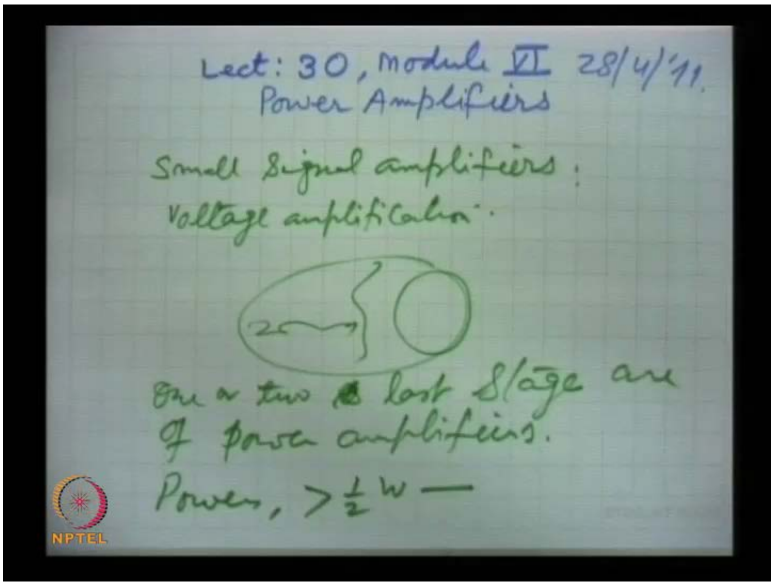

We now move to the next module, and this is on power amplifiers. So far, we have been talking about a small signal amplifiers a small signal amplifiers. We have discussed, the by small signal we mean, that current and voltage swings are very small as compared to the maximum current in the collector circuit, which is possible an maximum voltage. We are here in a small signal amplifiers, the voltage and current swings are a small. Now, all the common emitter, common collector or even in the FET circuits, the common source, common drain; we discussed all them, they were a small signal amplifiers. A small signal amplifiers are used in almost every system for data processing or for signal processing. Now after signal processing, we need power at the output stage of the system that is required. So all electronic systems actually, the initial stages are the a small signal amplifiers, which are used for data processing and signal processing, and the properties which we discussed in the small signal amplifiers. They are used for the best purpose.

In the small signal amplifiers, the major thrust was on distortion free voltage amplification, distortion free voltage amplification that was the main objective. Now, as I was talking that a system a electronic system that contains one or in fact several stages of a small signal amplifiers the first, second, third several stages are there. But at the output, we require power to be delivered to the load; so one or two one or two last stages, last stages are of power amplifiers. And power amplifiers, they deliver required power to the output device and for example, power is required to run a motor at the end; a motor or a printer or in a for example, in a public address system; a large volume of audible sound is required, so a large power is to be delivered to the speakers and so, the last one or two stages are power amplifier stages.

In power amplifiers, the boundary between a small signal and these power amplifiers they are normally arbitrary. But in power amplifiers, we talk of powers in axis of half watt to several tens or several hundred watts and even more. While in a small signal amplifiers, these are quite small less than 500 milli watts in general. So we go for power amplifiers. In power amplifiers, the requirements, the characteristics, performance characteristics of the amplifiers are entirely different as compared to the a small signal amplifiers. I said in the small signal amplifiers, our main objective is to get a distortion free amplified voltage amplifier voltage amplified signal. Here in power amplifiers, we are concern for example, what is the maximum ac power? We are always concern, when we talk of high power; we are concerned with ac power, because that is the one which is the useful power. So in power amplifiers, the power amplifier can deliver how much power to the load this is the consideration.

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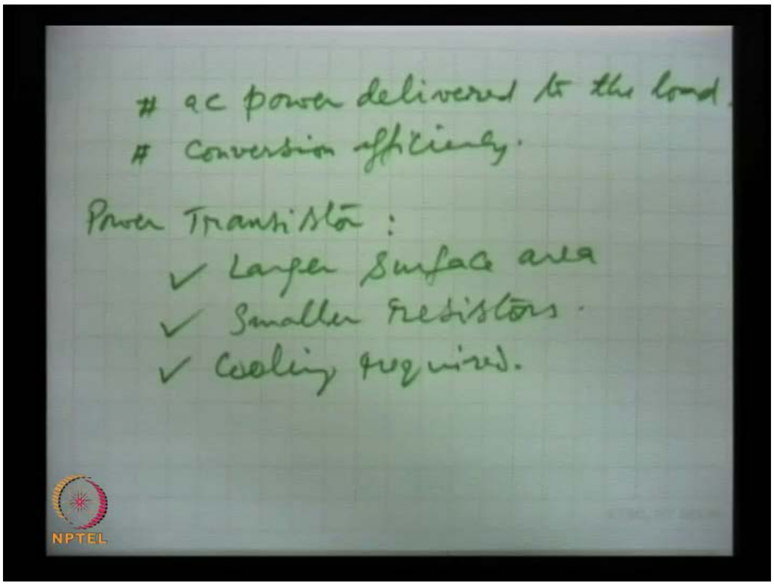

That is map the ac power delivered to the load, this is one consideration. Another consideration is that, with what conversion efficiency the amplifier provides this ac power. By conversion efficiency, we mean after all from where a dc power ac power will come. If a amplifier delivers for example, 50 watts of useful ac power to the load from where this power will come? It comes from the dc power which is supplied to the system, so that is known as conversion efficiency.

Conversion efficiency with what the efficiency, the amplifier converts dc into the useful ac signal. So in these amplifiers, these are the considerations which we are going to study. And now what is, how the power amplifiers, the devices and circuits are different than a small signal. When we say that, the amplifier is suppose to deliver large power; that means, it should the device, the transistor should be capable of handling that much power; and so in general, the power transistors for example, they have a larger surface area for example, the small signal transistors they are few millimeter in size. Here, surface area is a 1 centimeter, 2 centimeter or higher so that, they can deliver and handle larger currents and larger voltages. So that is the device, the transistor, the power transistor rather power transistor should have larger surface area as compared to a small signal transistors, so that it can deliver and it can handle large powers. Now, in large when the device is dealing with large powers then heating will be created. So the there are two requirements on the circuit, one is large currents power is the product of current voltage. So when we say large current, then currents will be quite high. They may be several 100 million amperes or several amperes and so, these are possible when we use a small resistances in this circuit.

So power amplifier circuits will normally make use of a smaller resistances, so that larger currents are possible in the circuit. So a smaller larger, these are in comparison to the values which we use with small signal amplifier. So a smaller resistors, then these power amplifiers because the transistors will dissipate lot of heat; they will be heated so cooling arrangements are required, cooling required. For this often, you must have notice with several instruments, that there is a fan associated with the unit itself; so that fan cools the transistors and if, this is not that high power, then instead of using a fan many times the transistors. First thing is, the transistors have a metal casing, so that heat can be dissipated through metal more conveniently and more efficiently as compared to plastic bodies. So power transistors are often with the metal cases and these large size transistors many times are put at the portion of the unit. For example at the back, so that they get automatically cooled by convection, because the air flows and that takes away heat from the device. So this is the difference between power transistors and power circuits.

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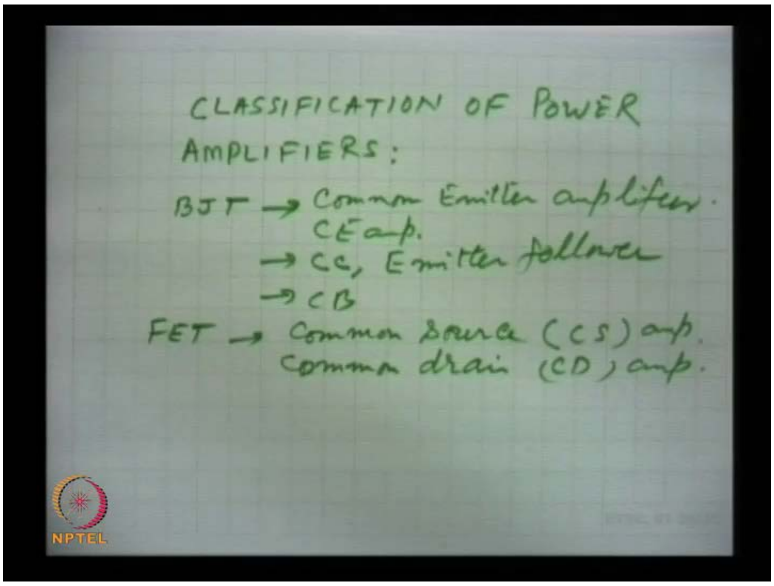

Now, classification of power amplifiers; classification of power amplifiers a small signal amplifiers they are classified for example, BJT a small signal amplifiers they were classified as common emitter amplifier or in brief CE amplifier and CC common collector or emitter follower, this was another amplifier. And similarly, common base, common emitter, common collector, common base; this was the classification for a small signal amplifiers. Similarly, in FET or MOSFETS the classifications was common source, common drain this is CS amplifier and common drain CD amplifier or drain follower. As it is emitter follower, this is drain follower and so on. So this was the classification of BJT and FET, a small signal amplifiers.

The power amplifiers are classified differently and the criteria is different. Now, the power amplifiers have been classified based on of what portion of the input signal the conduction current in the output flows. I repeat, that power amplifiers make use of this criteria in classification because here, the criteria is that what portion of for what portion of the input signal the output current flows. In these amplifiers, a small signal amplifiers, we have seen that in all these type of amplifiers, there was the complete signal at the output, which was just the replica of the input in the amplified form that is it. But here, we are talking of which portion of the input will be available at the output that decides the classification and here, the classification based on this I will just further explain.

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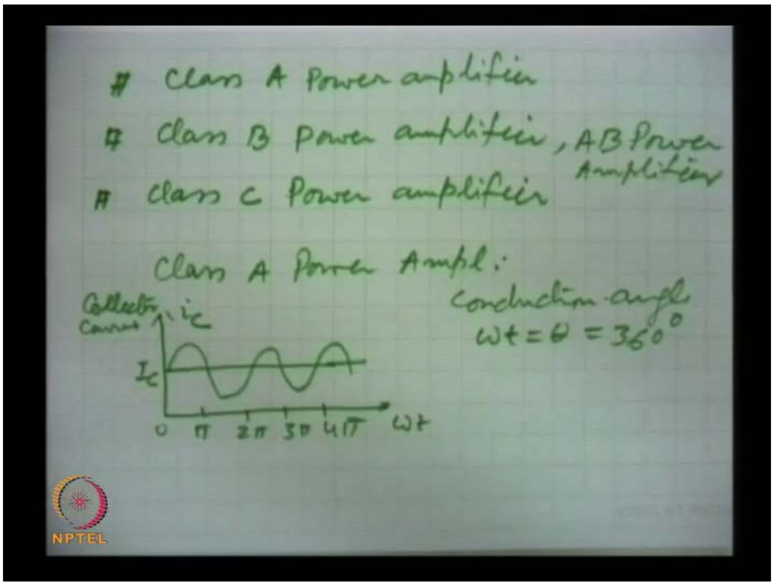

We have three broadly three types of power amplifiers; and these are class A power amplifier, class A power amplifier, class B power amplifier and class C power amplifier. These are broadly the three types of power amplifiers; class A power amplifier, class B power amplifier, class C power amplifier. In class B amplifier, we will when we go for details, we will see that when a transistor is operated in purely class B amplifier as a class B amplifier, there is some distortion; and the distortion can be removed by making this B operation instead of pure B; it is AB operation, AB amplifier, AB power amplifier. So there are actually three classes class A, class B and class C; all are quite different; their circuits are different; their efficiencies are different and so on. But in class B, more widely used is a slight modification of pure class B and power amplifier and that modification is known as AB power amplifier. The details we will see, when we go for these amplifiers.

Now, what is class A power amplifier? In class A power amplifier, we bias the device, the transistor in such a way that the conduction, that means the output current, the collector current flows for the whole input cycle. We choose the operating point such that, the current, the output current flows for the all the 360 degrees angle and that is written as conduction angle. So class A power amplifier here, this is represented by this. This is the conduction angle omega t conduction angle omega t. Sometimes written as theta and this is all 360 degrees. That means here, this is the collector current ic and this is dc; that means, the dc current over which so there is a conduction the collector current flows for all 360 degrees. This is class A operation or class A power amplifier. Here, this conduction occurs even for all these transistors also. So in fact, these small signal amplifiers invariably they all operate in class A amplifier from this angle, but as I said considerations will be entirely different. Here, this current and voltage swings they will be very large and we are concerned with the efficiency of the circuit and what is the maximum power the circuit can deliver, this we will be seeing.

So remember in class A power amplifier, the conduction current flows for all the conduction angle 360 degrees. That means, the whole wave is reproduced which is of course in power it will be much higher than the input, but it flows for the whole 360 degrees.

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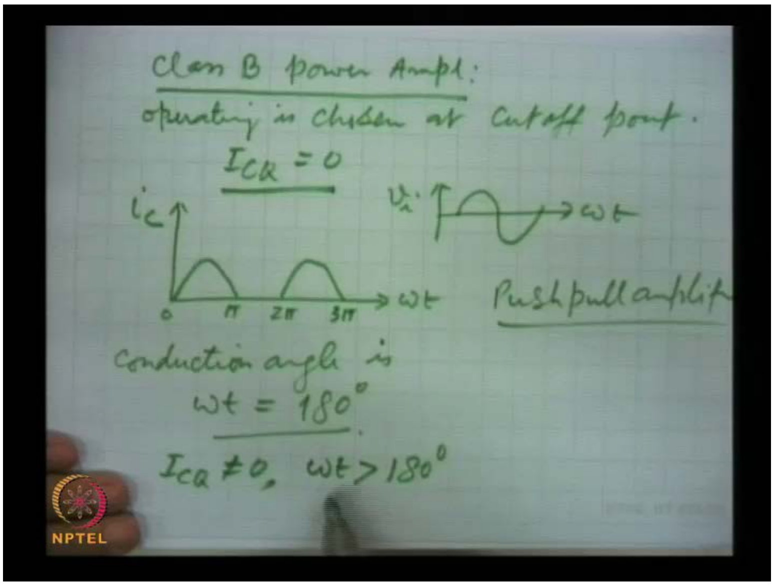

In class B amplifier power amplifier, we choose the operating point at cutoff operating point. These things will become more clear when we go for circuits, but you understand what is the meaning of choosing a operating point, that dc current and voltage we choose. And then, when we apply ac signal then over that dc values like this, the current and voltages vary. So here, the operating point is chosen at cutoff point; at cutoff point that means, I CQ is 0 in class B operation is 0 in class B operation. The transistor is in cutoff state and the emitter junction will be forward biased only by the positive half of the cycle and for negative this will not conduct. Therefore the output, this is ic the collector current and this will be 0 pi, 2 pi, 3 pi and so on. So that means when input signal is this, the output will be like this. Now, this is highly distorted. This indicates that half of the information will be will not be there in the output. So, how to make class B operation class B power amplifier useful? Instead of one transistor, two transistors are connected in a special circuit which is known as push pull amplifier push pull connection.

In the push pull amplifier, that amplifier which makes use of pull push pull connection of two transistors is known as push pull amplifier which is a class B amplifier. So that, we the upper half is available from one of the transistors and the lower half will be available from the other transistor. So that, way the output finally will be the complete way. You may ask, what is so good about class B amplifier, that this is highly distorted and to compensate it, we have to use two transistors in a special arrangement. That is known as push pull amplifier. The reason is much higher efficiency of class B amplifiers; the efficiency in the class A amplifier is 25 percent. Meaning, if we want 10 watts of output power in the class A amplifier, we will have to provide 40 watts dc power. Out of that from 40 watts 25 percent that is 10 percent 10 watts will be converted by class A amplifier.

The efficiency of class B amplifier is more than 75 percent more than 75 percent. So with 40 watts, we will be able roughly to get around 30 watts of power in class B amplifier. That is the biggest advantage and we will see that all these public address systems, where the output power is in kilo watts in several hundred watts, these are all class B push pull amplifier circuits. So this is class B operation in which, we choose the operating point at the cutoff point so that conduction angle is omega t is equal to 180 degrees. As I said pure B operation will incur some distortions which are often not acceptable. To remove those here, I CQ is 0; instead of 0, we choose I Q roughly 10 percent of the or less 10 percent or less of the peak value of the device. So this is small I CQ is not 0; conduction angle is slightly above 180 degrees and still it is slightly higher that means 200, 220 degrees around that.

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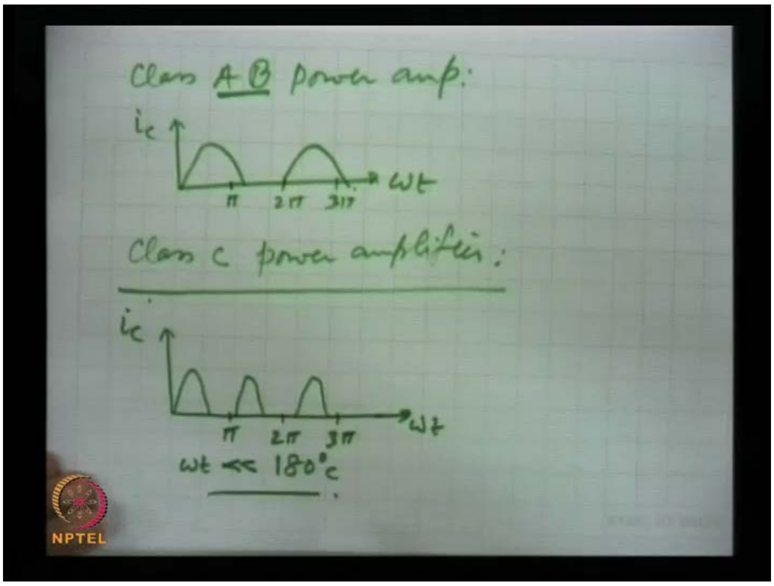

And then, the operation is called class A B amplifier class A B power amplifier. And this can be shown like this; this is ic and this is pi, 2 pi, 3 pi and so on. So here, more than pi similarly here, this is A B operation which is the one which is used in push pull amplifiers and the efficiency is slightly lower few percent lower than pure B, but the output is distortion free and hence this is the one which is used. Now finally, class C power amplifier; in class C amplifier, the operating point is chosen such that collector current flows for much less than 180 degrees; the conduction angle is much less than 180 degrees. We will choose the operating point much blow the cutoff point so that the transistor is not input to the active region for a very major portion of the input positive side of the pulse. When this happens, the output will contain sharp pulses only like this. This is pi, 2 pi, 3 pi and this is omega t; here, this is the collector current then like this, where conduction angle omega t is much less than 180 degrees. These in class C operation, we get sharp pulses in the collector current.

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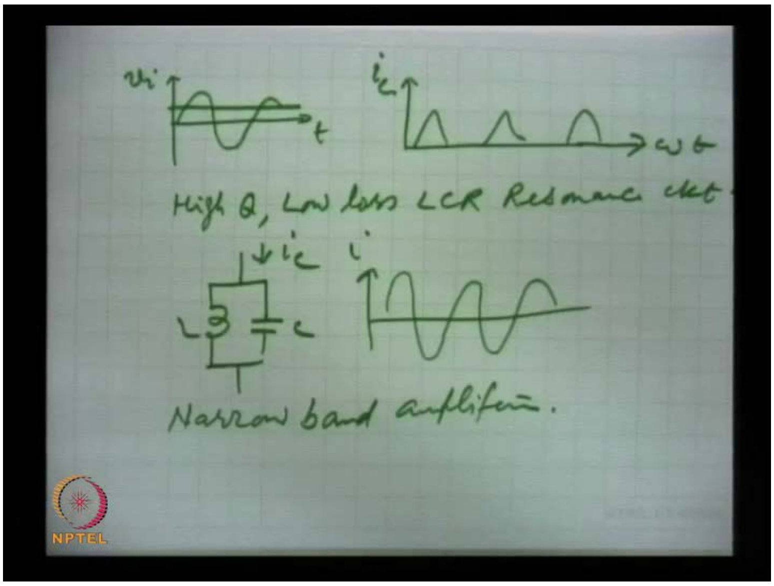

And what is the purpose these pulses will serve. Because, for a input sinusoidal input of this kind, this is v i the function of time, we are getting sharp pulses like that. That means, lot of information that will be absent in these pulses. So what is done; how to make these pulses useful. These high current pulses, they excite a tank circuit tank is (( )) circuit high Q. That means low loss resonance LCR resonance circuit like here. When these current pulses, they excite this LCR circuit, then at the output the total sine wave is retrieved, the output available is this. So this way, class C amplifiers why class C amplifier? What is the advantage? Efficiency? The efficiency of class C amplifiers is above 95 percent; for class A amplifier 25 percent; class B amplifiers seventy more than 75 percent and for class C amplifiers, this is in excess of 95 percent. So this is a big consideration, but there is a limitation. Class C amplifiers will be tuned narrow band amplifiers so they are, they can used for a specific purposes. In one purpose in which they are most widely used, this is the carrier waves for radio and television signals. The carrier waves, they are required high power carrier waves are to be generated their efficiency will be a big consideration; and class C amplifiers, they are the LCR circuit is tuned to the carrier frequency and this is the part of the class C amplifier and from here, the pulses, high power pulses will be transmitted.

So this is the classification of amplifiers; class A amplifier, class B amplifier, A B and class C amplifier. Now, as we have said that in power amplifiers large swings of currents and voltages will be required and in which, the whole active area of the i v characteristics for example, the collector characteristics of the transistors BJT the almost, the whole area will be used in this and the whole area means that there will be non-linearity is involved.

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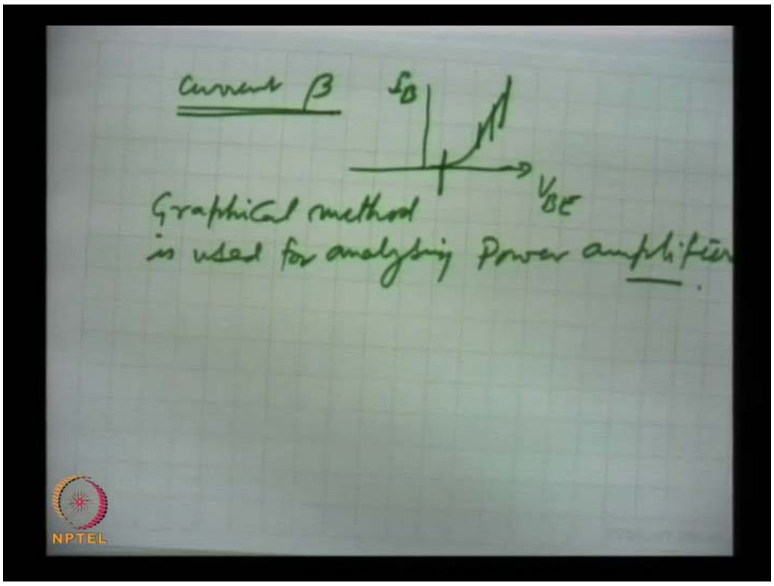

Therefore, the data or the parameters which we have used in the a small signal analysis like current gain beta, we took it linear. But here, because of the non-linearity by non-linearity see here, the input characteristics of the transistor are like this. In a small signal this is I B and this is V BE. In a small signal, we used a small portion of this and there the linearity is perfectly all right, but when we talk of power amplifiers large signal that means, the whole region from here to here is involved and this is the slope is varying and there is lot of non-linearity involved. Therefore, now this is important that the way the power amplifiers are analyzed they are different because, we cannot use these parameters as we have done in the a small signal analysis. So graphical methods graphical method is used for analyzing power amplifiers and how we do this analysis, this will soon be clear.

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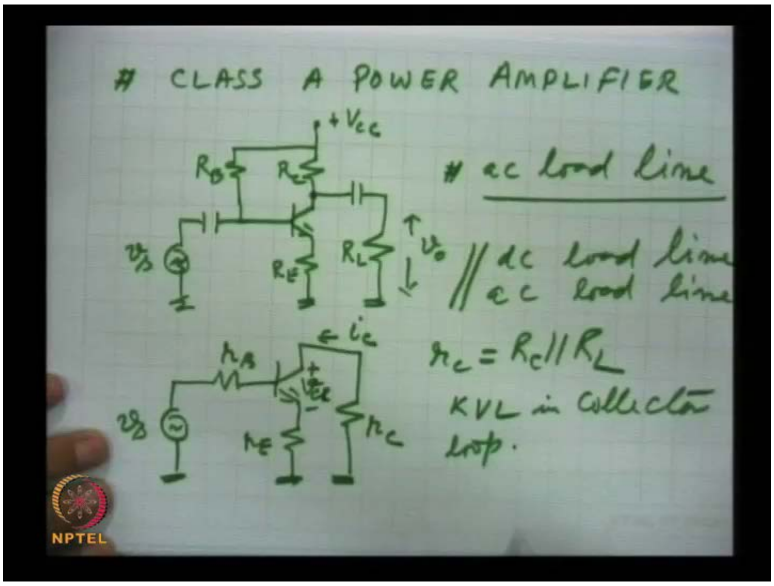

So let us now go about the amplifiers. First we take class A amplifier; class A power amplifier class A power amplifier. A simple circuit for class A amplifier can be drawn and let us that this is the simple circuit. This is R L; this is R E; this is r c collector resistance and this is R B and here is the input signal; and this is plus V cc; this is v s this signal. This is given to the power amplifier and output is taken at the load here. Now you may say that design of this is same as for low a small signal amplifier. I said small signal amplifiers are operated as class A so design is a similar, but considerations will be totally different as we will see. Here, we first draw the ac equivalent of this circuit and then, we require for the analysis graphical analysis requires ac load line ac load line.

Load line concept we have already discussed when we discuss the bipolar transistor. But now, we require ac load line so there are there is a dc load line and then there is a ac load line. Why the 2 L load lines are different? Because see here, the collector will see different impedances for different resistances for dc and for ac. For dc analysis, this we said earlier that this capacitor has to be taken as infinite resistance so we remove it. So the collector will see as the resistance r c, but when we take ac equivalent then, dc power voltage sources have to be grounded and capacitors are taken as short. In that case these two resistances, the collector resistance R c and R L the load resistance, they will come in parallel. If this is 4 k or say 100 ohms and this is 100 ohms then, the effective resistance will be 50 ohms.

So while this collector will see for dc the 100 ohms, but for ac it will see 50 ohms and hence, the ac load line and dc load line they are different, because impedances seen by the collector at dc and at a c they are different. So we require ac load line which is very useful as we will see in the analysis. For that, we draw the ac equivalent of this circuit and for that, the thumb rules have to be used; the dc voltage source have to be grounded; capacitors have to be taken as short, so this is the circuit. Here, I have instead of R E, I have written this r E; this is the effective ac impedance as seen by emitter. Similarly, this is the effective so here, the r c actually will be R c in parallel with R L, the effective value of ac impedance seen at the collector. And now in this circuit, the this is plus minus V CE and this is the collector ac component of collector current. Then we apply the kirchoff’s voltage law to the circuit. We sum up of summing up the voltages in the collector loop in collector loop.

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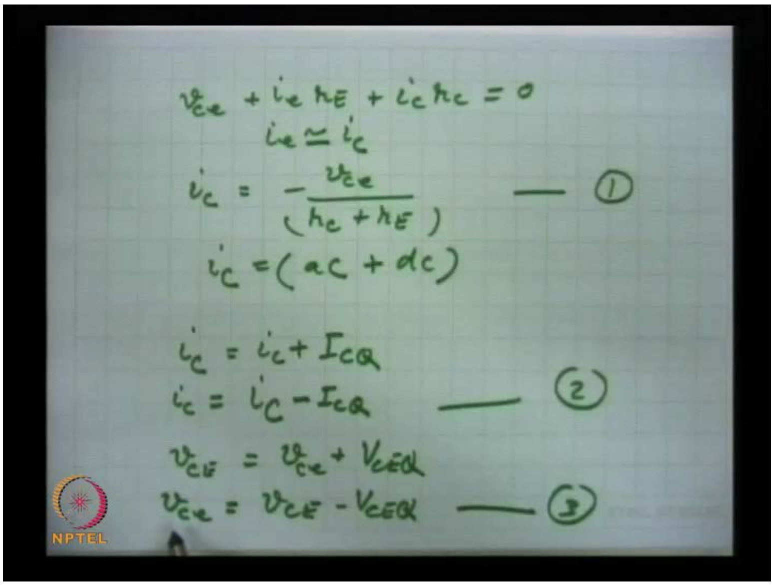

When we do that, we get a equation v ce i e r e plus i c r c equal to 0 and you will remember from our discussion on the bipolar transistor, that i e is equal is almost equal to i c. So using that, we can get the expression for i c as minus v ce r c plus r E; let us call equation 1.

This ac current, this will be superimposed over the dc. So they will the current and voltages will keep on varying and the total current capital, this is bigger C capital C; total current, this is this will be equal to the summation of ac component plus dc component. Similarly voltages and hence, we can write for the total current and total voltage at the output circuit of the amplifier as i c with the small c, this is the ac component of current and this will be superimposed over dc; and from here, i c is i C minus I CQ; this is equation 2. And then similarly, we can write the voltage v CE is the ac part plus dc part at the Q point; and from here v ce is v CE, these small letters we are using for ac components everywhere and the larger ones are for dc. So this is minus V CEQ, this is equation 3. Now in equation 1, we substitute for i c and v c e, these we substitute from equation 2 and 3.

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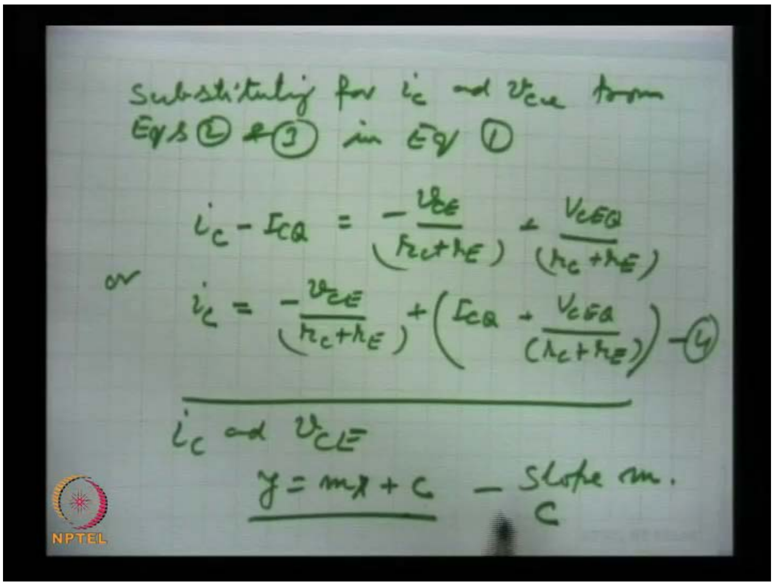

So, substituting for i c and v c e from equations 2 and 3 in equation 1, and this gives us i c minus I CQ; this is minus v CE by r c plus r E plus V CEQ r c plus r E and from here, we get i c or i c is the total current; this is v CE r c plus r E plus I CQ plus V CEQ by r c plus r E, this we get and we call this equation 4. This is the equation, linear equation in i c and v CE; this is like y is equal to m x plus c like that and this will have a slope; this equation has a slope of m and intercept vertical intercept as c. Similarly, we can do it here. So this will have slope; this is the equation of the straight line equation of the straight line like y is equal to m x plus c and this can be plotted by taking i c equal to 0 or v CE equal to 0; the two points, this how the straight lines are plotted.

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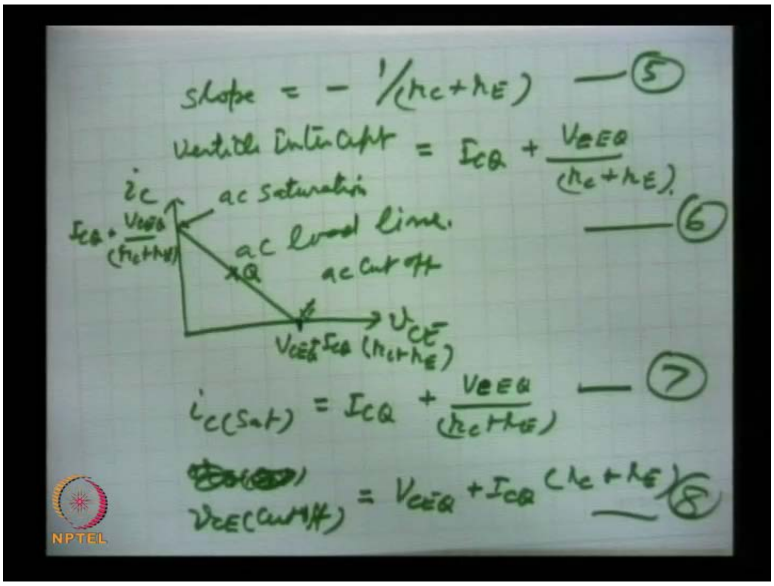

So, slope of the straight line will be minus 1 by r c plus r E; this we call equation 5 and vertical intercept, I will plot this line actually and Vertical Intercept, this is equal to I CQ plus V CEQ by r c plus r E; we plot this. This is to be finally plotted on the output characteristics, but this is the load line ac load line; where, this is i c and this is v CE and operating point, we will talk little later. This point is ac saturation and this point is ac cutoff ac; this point is V CEQ plus I CQ into r c plus r E; while this point is I CQ plus V CEQ by r c plus r E; these points have to be remembered. This is the ac load line ac load line and in this expression by putting i c equal to 0, we get this point, here i c is 0; and if we put v CE is 0 then, we get i c equal to this much; so this is saturation point and this is the cutoff point. So these points have to be remembered that i c sat at saturation, this point i c saturation, this is equal to I CQ plus V CEQ by r c plus r E this; and similarly, v CE saturation, this point ac cutoff point saturation ac cutoff not saturation; v CE at cutoff; this is equal to V CEQ plus I CQ into r c plus r E. These equations, this is equation 6; this is 7; and this is 8. The 7 and 8 equation, this is the i c saturation point and v CE cutoff point, we will have to remember because, we are going to use that; a c load line plays an important role when we plot it over the output characteristics of the power transistor, so we will be doing that. So this is and then, I will show you that how to choose the operating point, the operating point because the swing will be very large, almost the whole portion will be used and hence, it will be wise to choose the operating point somewhere in the middle for class A operation; this is what we do now.

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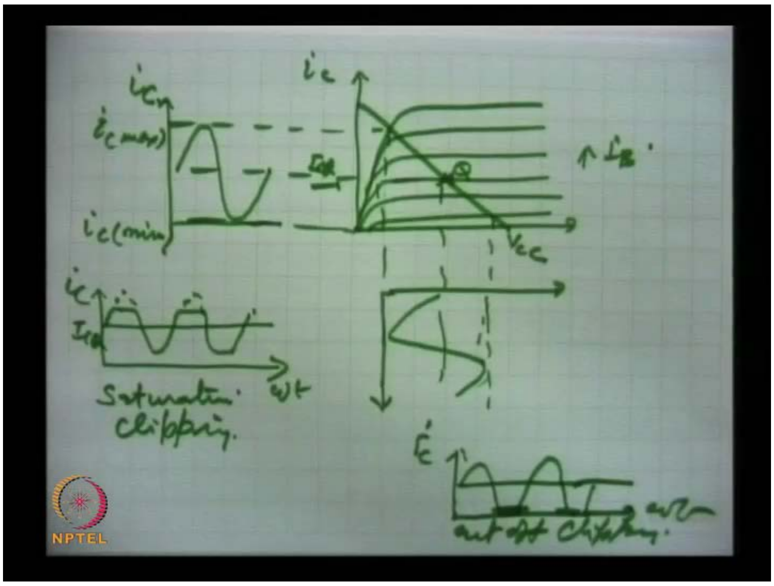

These are the output characteristics; this is I B that varies this way, and this is i c, and we draw the ac load line, where we choose the operating point here Q; and now see, using almost the whole range of the active region, this is V cc; and this is how the voltage across this transistor; how this voltage will vary? This is this way; and accordingly, the current will vary; this current varies like that. This is the very large voltage swing, large current swing; this is i c; this is i c max - maximum; this is i c minimum; and this is I CQ. Across, this dc current, the because it will swing, the current and voltages will swing, because of the ac operation, and this voltage varies and current varies.

Now, this I made clear that to take the maximum advantage of undistorted output, the operating point has to be chosen at the center. If it is towards the saturation point, then part of this voltage will result in a distortion and that distortion will be like this. This is ac; and this is omega t; and this is i c; this is I CQ; then distortion will occur like this. This portion is absent in the output, and this is distortion. Similarly, if we choose the operating point towards the cutoff, then this is saturation clipping, and if it is chosen little down, then it will be here; this is the cutoff clipping cutoff; this is i c; this is omega t; and this is cutoff clipping, the distortion. So we have to choose the operating point in the center. We will continue the analysis that these concepts, which we have developed, we will use for getting maximum output, power and efficiency of class A amplifier. That we will continue in the next lecture.