Electronics

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Module No. # 06

Power Amplifiers

Lecture No. # 02

Power Amplifiers (Contd.)

We continue our discussion on power amplifiers, just to remind you few points in power amplifiers, because almost the whole region active region is used, because of large current and voltage swings. So, non-linearity's are required and are there are present, and because of this non-linearity's the analysis which we did in the small signal case based on some fixed parameters like current gain beta and so on, that does not prove to be accurate. So, graphical analysis is done and for the graphical analysis as we were discussing that load line is very useful, and ac and dc load line are different, because the impedance seen by the by the collector is different in the two cases.

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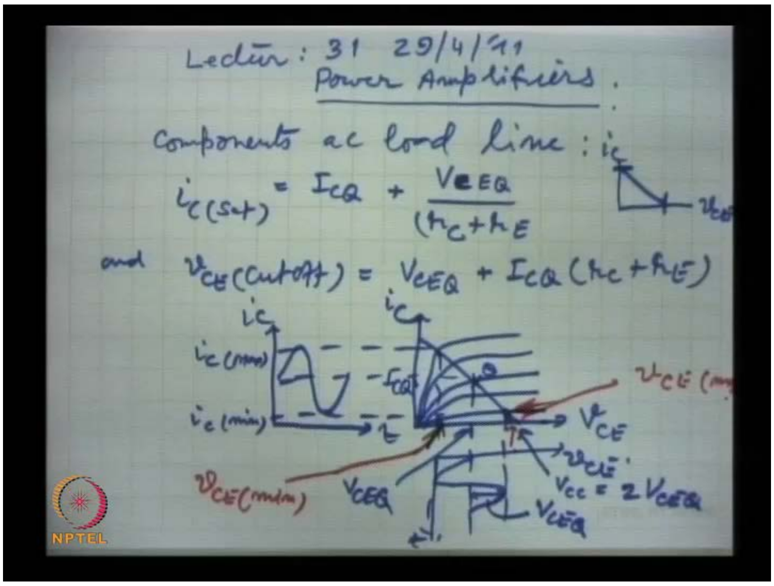

And when we were discussing the a c load line, then the components of a c load line; these were i c saturation is I CQ plus V CEQ by r c plus r E. And V C E cutoff is V CEQ plus i CEQ r c plus r E. This two expressions we got and they represent the true points of exchange points of the load line this is the saturation point this is the cutoff point and this two expressions were obtained. Now, with this what we have said is this is i c and this is V CE and this is the Q point, then this is how this is the operating point value I CQ and this voltage here this is V CEQ and this current will vary across this operating point from this region to this region similarly, the voltage will vary.

From this region to this region so this is from center to the peak is V CEQ and this point this point is V c c which is equal to actually because , for the central point V twice of V CEQ this common this is minimum voltage this is maximum voltage similarly, here this is the minimum current i c maximum and i c minimum. And the minimum and maximum voltages are here this is minimum voltage this is maximum voltage. We can write here V C E minimum and this point is i CE maximum and this we are going to use this concept of ac load line we are going to use for the analysis. Now actually, we start the analysis of a class A power amplifier and for that we find out

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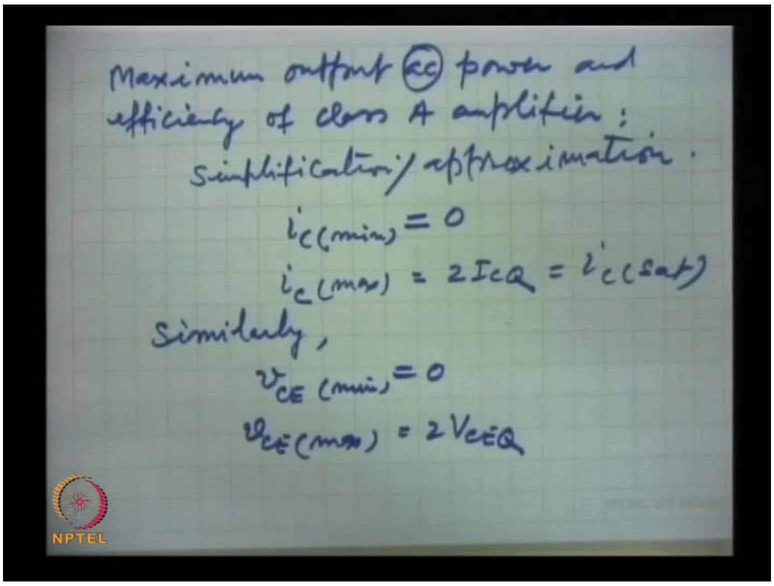

What is the maximum output power output ac power? We are concern with ac power and efficiency and efficiency of class A amplifier. To carry the analysis, we do some simplifications and these simplifications are that i c minimum this 0 starts from here and this is slightly actually more than 0. So, we take it as 0; i c minimum we take a 0; so the first simplification or approximation is that i c minimum, we take at 0 and this maximum current we take slightly above this point which is actually the twice of I CQ point just ever i c set we take. So, i c minimum we take as 0 and i c max this points will become again clear and the approximation which they will be bringing to the analysis is just few percent which is tolerable in all electronic circuits and this i c max is taken as 2 I CQ.

And actually, this we are taking as i c set; and similarly, minimum voltage this voltage is V CE minimum we are taking it at 0 and look here this was the maximum voltage which we are taking at this point. So, this approximation brings V CE minimum as 0 and V CE maximum as two V CEQ. These simplifications approximations, they are just very near to the real situation and the analysis because of this, simplification becomes very simple just we will see that, the analysis becomes very simple. So, what actually with these simplification is mean that, the whole region of the output characteristics we have slightly extended little towards the cutoff that also we have included in the active region and the portion a small portion in the saturation region that is all now becomes the part of the active region.

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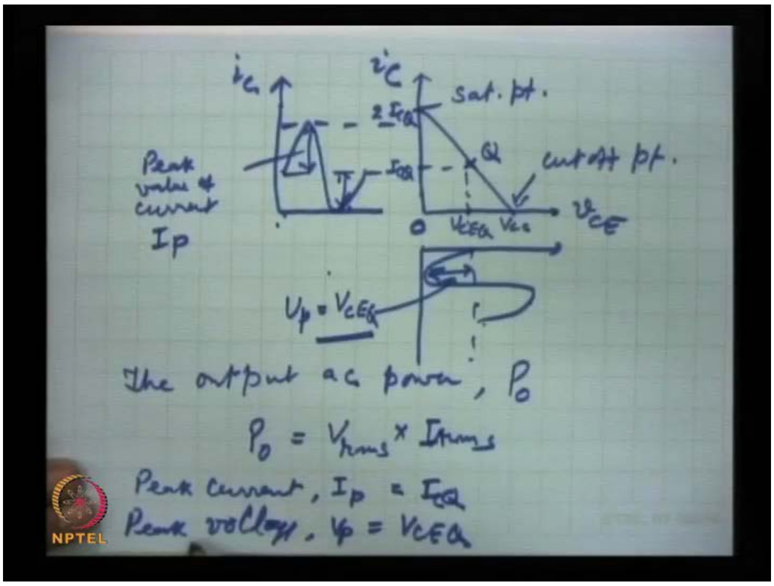

So, the whole the active region has been slightly extended because of these approximations and what we get is this here, and this is V CE and this is i c this is the saturation point saturation point this is the cutoff point and this is the Q point and for the optimum use maximum power delivery to the load we will have to use this whole extending from 0 to this point which is V cc and since this is V CEQ so this is double of that because it is in the center similarly, this is I CQ so this point is 0; this is in the center since this becomes twice I CQ. And now here is and similarly, here this will be the current i c.

Now, this is the peak value of the voltage V p, this is V p; this is equal to V CEQ similarly, here same and here this is the peak value of current peak value of the current peak value or peak value current is this. Now, once we know this peak values this is the ac current in the output circuit this is the voltage ac voltage then the output ac power because our objective was what was the maximum output power in class A amplifier and what is the efficiency conversion efficiency of class A amplifier. So, the output ac power this is we write P o for output power so P o is rms voltage into rms current product of rms voltage to rms current. Now, from this figure we see that the peak current peak current I p; this is I p peak current; I p this is equal to I CQ because this is I CQ. And the peak voltage from here peak voltage V p as here V CEQ therefore, we said this are the peak value rms values.

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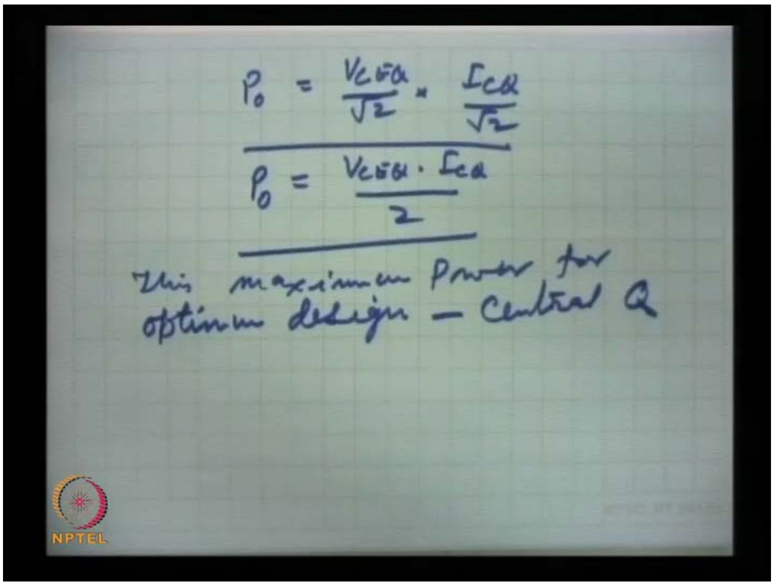

We can write we can write the expression for the output current. output power the output power P o therefore, is V CEQ by root 2 into I CQ by root 2 therefore, in class A operation the maximum power is half of the product of V CEQ I CQ by 2; this is the maximum value, so that will depend on what is the current here, what is the voltage here and depending on how much power you want you will have to use a transistor of that power for example, if this current here is a 2 milli amperes and this is a 5 volts then, 5 into 2 amperes 10 watts this product divided by 2. So, the maximum output power will be 5 watts.

So, this expression we have to keep in mind and remember that we have derived for the central Q and when the whole region of the active characteristic active region of the characteristic is been used. So, this is a the maximum power maximum output power for optimum design amplifier design that means, central Q and swing is in the whole region.

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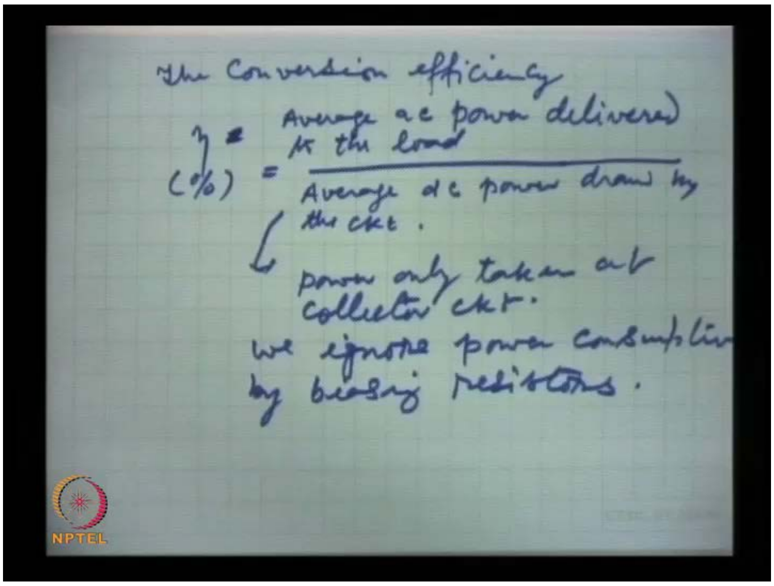

Now, what is the conversion efficiency, the next thing we are going to have is the conversion efficiency. Conversion efficiency and as i said in the beginning by conversion efficiency we mean what fraction of a dc power which we are supplying to the circuit is available as a c. so, because after all from where the a c power will come as for example, we say the a c power but from where will it come it comes from the dc power. So, eta the normal efficiency is written and eta it comes from the dc power, so eta the normal efficiency is written in eta and it is expressed in percent. So, this is average a c power delivered to the load and this is the average dc power drawn by the circuit.

As a conventional in this dc power we consider only the power which is taken at the collector circuit. So, this power only taken at collector that means we are ignoring we ignore the small. Power which is taken by biasing registers we ignore power consumption by biasing registers always when we take the conversion efficiency then we talk every ac power deliver to the load by average dc power taken by the collector circuit. So, this we will calculate and calculation is a very simple that the dc source voltage source here, this is V cc which is of course, equal to 2 V c cube.

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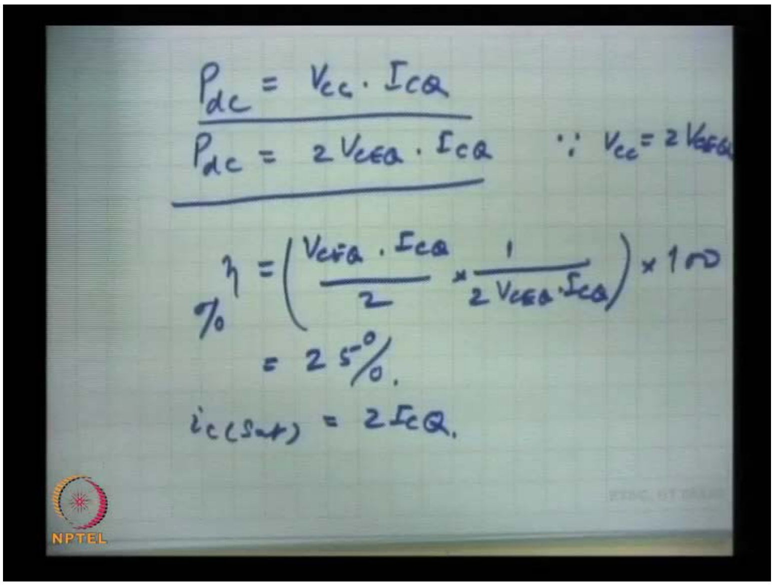

So, dc power delivered to the circuit is the voltage is V cc and the current drawn is I CQ that is the current and the absence of the signal, it draws the current I CQ and the voltage which we are applying is V c c and this becomes p dc is equal to 2 V CEQ into I CQ; this is because V cc is equal to 2 V CEQ. So, this is the dc current and this is the a c current a c power, dc power the ratio of the two is V CEQ I CQ by 2 and then divide by this. So, 1 by 2 V CEQ and into I CQ and when we are interested as i said normally, they are expressed in percent multiplied by 100. So, this cancels and this is 100 by 4; so 25 percent. Conversion efficiency in Class A operation r c coupled the circuit which we took in the beginning say r c coupled circuit, and for the r c coupled class A coupled amplifier efficiencies 25 percent that means for getting 10 watts of power in class A operation we will have to supply 40 watts of dc power.

So, this is the efficiency and mind it, this is the best possible and for the optimum design by the optimum design again I repeat that we have taken the operating point at the center of the load line and the whole region of the active region is been is been utilized. Now, in fact we can find out the condition whether the design of the circuit is really optimum or not. For that there is a very simple test that for the optimum result as we are seen that i c set this is equal to 2 I CQ, this point i c set is 2 I CQ. Now, in the equation which we derived here, in the beginning that i c set is equal to this now if we put this as 2 I CQ we get a condition and that condition is we remember if i c set is 2 I CQ.

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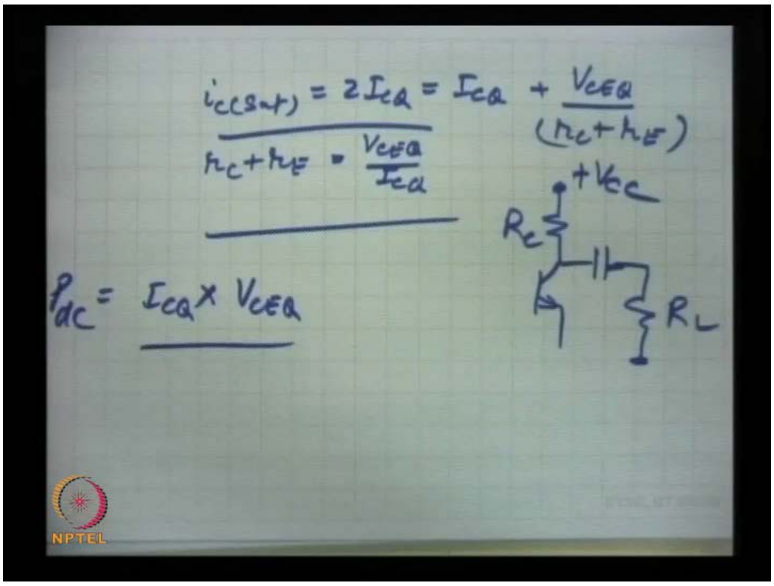

So, i c set equal to 2 I CQ which is equal to I CQ plus V CEQ by r c plus r E. And from here we get a simple relation that r c plus r E should be equal to V CEQ by I CQ. If this condition is satisfied, then we can directly use this expression what does this condition say this condition says that the effective a c impedance seen by the collector plus the effective impedance seen by the emitter if you sum up the two this should come equal to the ratio of the voltage v.

CEQ at the Q point and the current I CQ, if this condition is satisfied then, we can directly use this expression and the efficiency will fine maximum is 25 percent. Or if you are giving just any circuit, you find out your what is V cQ and I CQ and use this exact values in the expression then we will get the efficiency for that circuit. So, this is about the r c couple class A amplifier power amplifier, and just to remind you r c couple this is r and this is this was load this is r c plus V cc. So r c coupling very widely used but for that the efficiency is 25 percent but then, the question comes can we increase this efficiency. For r c coupled maximum theoretical efficiency is 25 percent, if we replace r c coupling by instead of r c couple load if we take a transformer coupled load then the efficiency can be increased to 50 percent.

You realize one point that even in the absence of the ac signal because the quotient current the operating point current it is I CQ and the product is the voltage which will be existing this current this much power even in the absence of the ac signal continues to be consumed by the circuit and this is actually, this can saved. If this resistance is replaced by the primary of a transformer then, this much power which is half of the dc power you remember dc power ever, we have seen is twice of this only. So, half power we are wasting in this R c.

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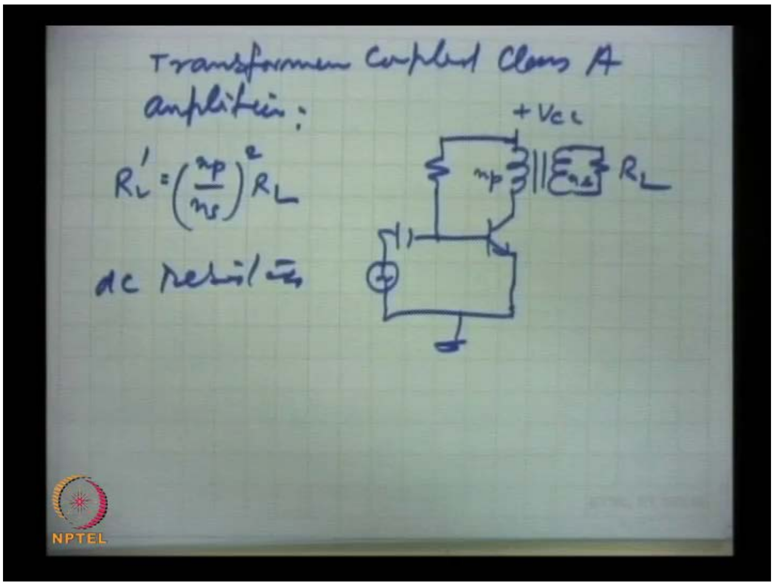

And this can be saved but then, we move to transformer coupled transformer coupled class A amplifier.

Now, here that this is a simple design this is the primary of the transformer, and this is the load R L. Where we are using the capacitor coupled load and this capacitor and this load can be coupled through the transformer also. Where this is the number of primary terms and this is n s secondary terms, and the effective load R L prime reflected load will be n p by n s, where n p is the number of terms in the primary; n s the number of terms in the secondary, this is squared into R L; this will be the effective load. The dc resistance dc resistance of the primary is almost 0. So, the dc load line will be vertical see here.

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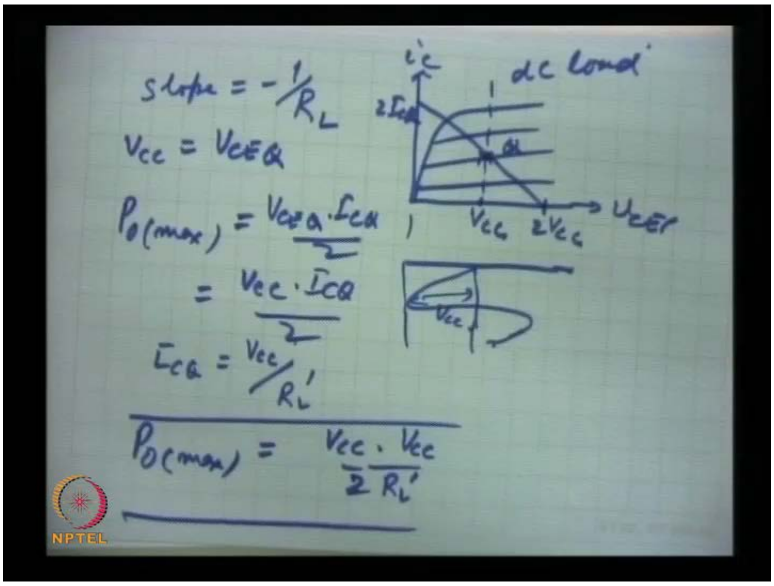

These are the characteristics so this is here, this is the Q point and this is dc load line, because resistance dc resistance is almost 0 and you remember that the slope. Slope is minus 1 by R L or r c whatever now this is close to 0. So, slope is infinity that means, it is vertical and of course, this is i c; this is V CE and this is the ac load line, where this is twice I CQ and this is twice of now. We can use directly V cc as Q point. So, this will be twice V cc and this will give like that across this point there will be this kind of variation and this is V cc; in this case, V cc is V CEQ.

And the a c power as we have done ever this was V CEQ I CQ by 2 and because these are equal so, this can be written as V cc into I CQ by 2. And I CQ is I CQ is equal to V cc by the effective load R L prime and dc power; this is so the ac power becomes we substitute for i c P o maximum is V cc into I CQ and for I CQ we write V cc by R L prime and two this two. So, this is the for the transformer coupled class A amplifier this is the maximum output power.

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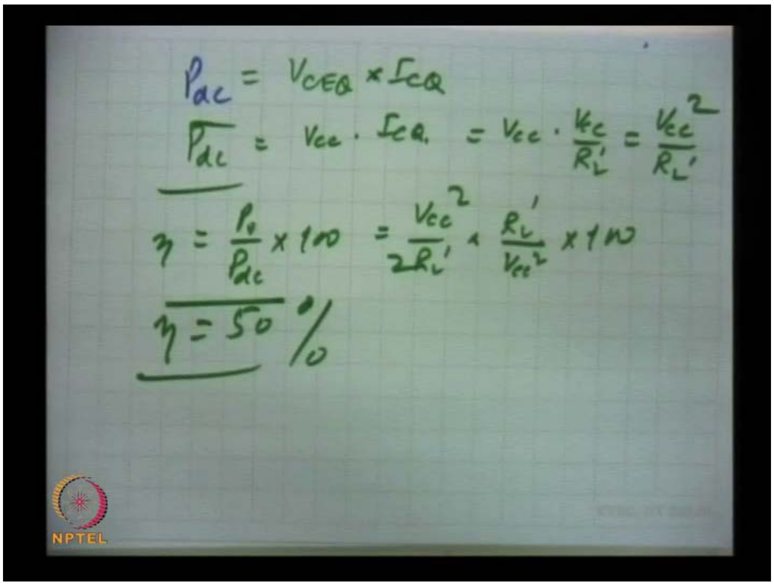

And dc power is V CEQ by i c into I CQ but as i said V cQ now we have taken earlier in the earlier case half of the power was being taken by the coil by the resistance r c, but now that resistance has been replaced with almost 0 resistance of the primary of the transformer hence we are saving that much consumption. So, this is equal to P dc is V cc into I CQ and I CQ; we replace by the expression V cc by R L prime. So, this is equal to V cc square R L prime this is dc power ac power the ratio is p 0 p dc into 100 and this is V cc square R L prime R L prime by V cc square into 100. So, this is eta comes out to be 50 percent. For transformer coupled class A amplifier efficiency will be close to 50 in practice 45 percent 48 percent will be there, and this transformer also saves the capacitor effect that means this will not permit dc to be coupled to the load as this capacitor does through this capacitor dc cannot pass.

So, in the load only the ac operates same is true here because through transformer through this transformer the dc will be Checked plus this relation effective load this also has the advantage because by adjusting this ratio we can get the max load for maximum transfer with the load. So, these are the advantages, but is still the use of transformer coupled class A amplifier is a limited restricted because the transformer is bulky and frequency responds if it has to be good then these transformers are expansive. Now, the last thing about what is the requirement how much power the transistor device transistor has to dissipate. Because in power amplifiers if you transistor is capable of dissipating 5 watts then obviously, you cannot use you cannot get power 10 watt from these transistors that high current will burn the transistors.

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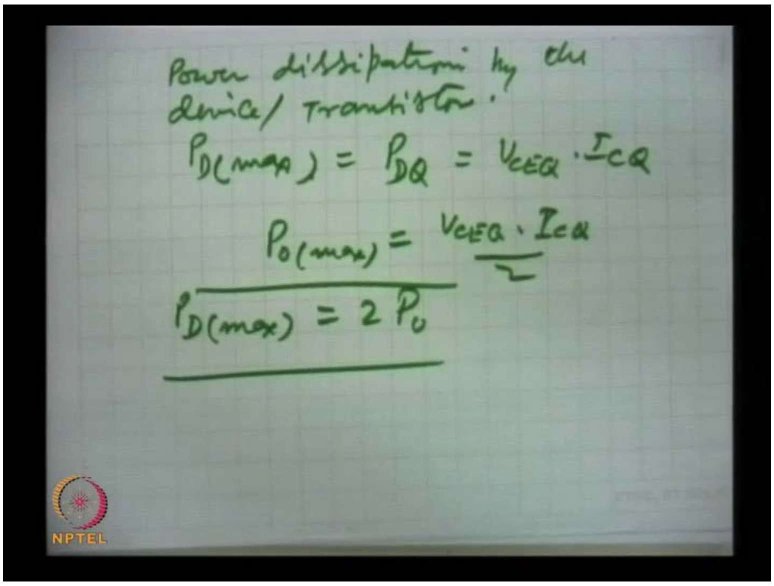

So, this is power dissipation by the device by the device the transistor, and this is written as p d dissipation max. Now, in the operation we have seen that actually a c currents and voltages they will vary the currents will vary from 0 to 2 CQ similarly, the voltage will vary therefore, the dissipation will keep on varying the dissipation will be highest here and least here but it can be shown that maximum dissipation occurs in the absence of the signal that means at the Q point. So, the P D max is actually the P D at Q point and which is equal to V CEQ into I CQ you remember that P o max was half of it so V CEQ I CQ by 2; so there from these two equations we can write that P D max is equal to twice P o very important relation for class A operation.

And it says that, if output power is say 10 watt then 10 into 2 that means 20 watts the device should be capable of dissipating 20 watts that means, double of what you are getting as at the output. This is another thing which is not very favorable in the case of class A operation. For 50 watts of output power, we require transistor which can dissipate 100 watts. So, that is a big power and the cost of the transistor will be much higher. So, this is all about class A operation just in summary for r c coupled load the efficiency of class A operation is 25 percent and but out of all class A, class B, and class C, amplifiers class A gives the most distortion free output.

So, that is the point and the efficiency of course, can be increased in transformer coupled amplifier and maximum power to be dissipated by the device is twice that of the output power available. Now, that finishes our class A operation.

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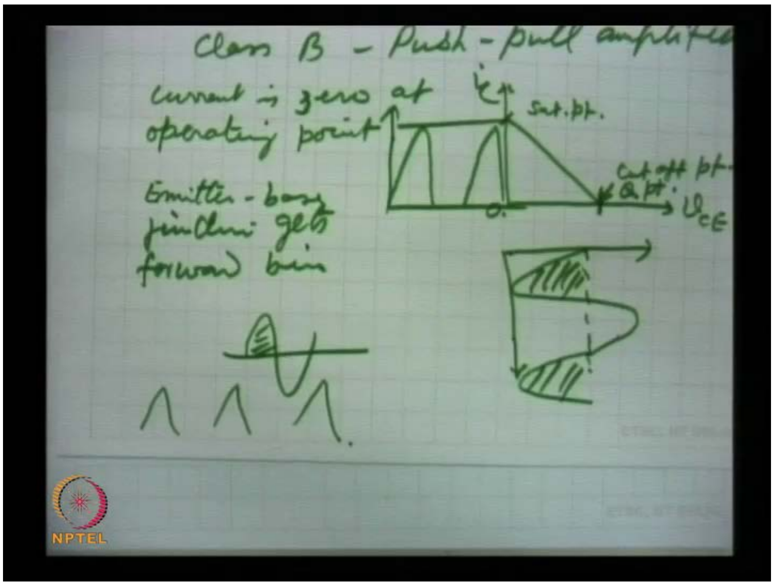

We now go for class B amplifiers, and a particular amplifier which is actually most widely used that is the one which is used that is class B push pull amplifier push pull amplifier. We said that, in class B operation the operating point is chosen at cutoff point that means here. This is the a c load line this is the saturation point saturation point and this is the cutoff point this is i c; this is V CE; and this is cutoff point and this is also Q point the Q point. And see what will happen that means that current is 0 current is 0 at operating point current is 0 at operating point. Now, how we get this? This means that, the emitter junctions initially will have no biasing voltage they will be half, but emitter junction emitter base junction gets forward bias from the input signal here when we apply the input. I will show you this will become clear when we take the actual circuit, but you just understand that the emitter base junction will get forward bias by for example, by the by the part of the input signal and then it will move to the active region and conduction will occur.

So let us see this way actually, this is the circuit this part will go towards the cutoff. It will not apply only these portions will appear in the current. This is current and this will appear like this these half's will forward bias the the input signal is here and depending on the device either this will forward bias the emitter base junction or this you will see soon. So, this portions will appear in the output current while they will be absent like here it is absent blank only the output will contain pulse is like that, they are not useful as I said in the beginning.

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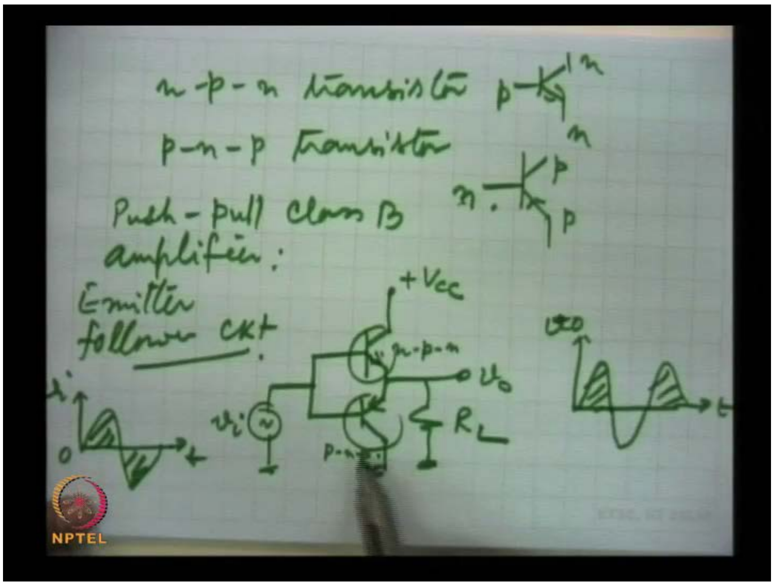

So, we use two transistors these are complimentary transistors one is n p n transistor n p n transistor here n p n. So, n p n and the other is p n p transistor and that is this is p; this is p this is n. So, they are connected what is called push pull amplifier push pull connection very special connection push pull class B amplifier. And this is this simplified form actual forms we will draw little later, but to understand the principle these are the two transistors this is n p n and this is p n p. This is p n p and their emitters are connected together and to the common emitter the load is connected. So this is actually, the connection of the transistors are being used because we are taking output from the load connected to the emitter. So, it is emitter follower emitter follower circuit which is most widely used this can be constructed with the common emitter configuration also, but most common is this.

Now, you will understand what i said n p n transistor now input signal is this. This is V i; and this is 0 volt; and this is time n p n meats the base meets positive pulse positive voltage for forward bias. So, this portion will forward bias the n p n junction at the same time, so reverse bias the emitter of the p n p transistor hence, p n p will be non conducting for this part and the upper transistor the n p n transistor will conduct. Therefore, we will get the output this is V out; and this is time amplified output you will get because of n p n. In the same way, this negative pulse will forward bias the emitter junction of p n p. So, and this will conduct and this voltage will reverse bias n p n. This will not come, so the other half's will appear because of p n p this portion from n p n similarly, this will continue and the lower portions will be coming from p n p; this is push pull action and we get a complete wave form from the sinusoidal input wave form and the two transistors have be have to be used in the push pull connection this is push pull action.

I briefly repeat that we take the operating point at cutoff and if we use just one transistor then the portion of the input signal will forward bias the emitter and only that part will appear not the other. So, that will not be of much use as in this case. So, we make use of the circuit in a different form we notify the circuit use push pull connection and make use of two transistors and they give this complete output because , the upper half will forward bias n p n transistor and lower half will forward bias the p n p transistor and hence complete wave forms we will get. We are continuing with the analysis of this, but before that we should see that in class B operation signal distortion occurs actually,

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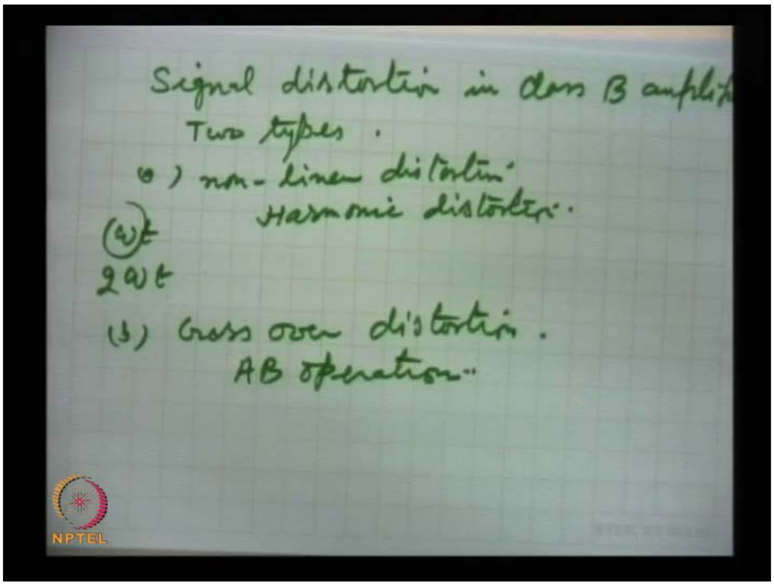

And there are two types of signal distortion; signal distortion in class B operation; in class B amplifier.

There are two types of distortions which occur and this is two types one is non-linear distortion, which is also called the harmonic distortion harmonic in which the the the frequencies in the output will be multiples other components of you can see will also with there for example, if omega t is the input frequency omega then, 2 omega, 3 omega, 4 omega; these are the harmonics, which may also appear in the output and the reason for this distortion is the non-linearity and we will see that in a well symmetrical design two half's of the push pull amplifier when they are made symmetric then actually, this is largely taken care of largely taken care of and the other kind of distortion is called cross over cross over distortion; this occurs for a different region and this will amount for a distortion which can be corrected by moving the operating point not exactly at the cutoff, but slightly above and this is called current. We will see this and how it is provided and then this distortion can be taken care of.

But, once we move the operating point from the center slightly above in the active region then, it is not a pure B operation. In that case, it will be called A B operation because , this cross over distortion is a important and we can get read of by choosing slightly different operating point. So, almost all class B amplifiers push pull amplifiers are actually they are operated A B, AB, A B amplifiers and this will be seen this will be seen. Now, the distortions can be tackled and we will finally see that, the outputs are largely free from all kinds of distortions and we will continue the analysis. The efficiency of class B amplifier is very high, its more than 75 percent. Practical efficiency is also met 70 percent or so which is much higher.