Electronics

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Module No. #06
Power Amplifiers
Lecture No. #03
Power Amplifiers (Contd.)

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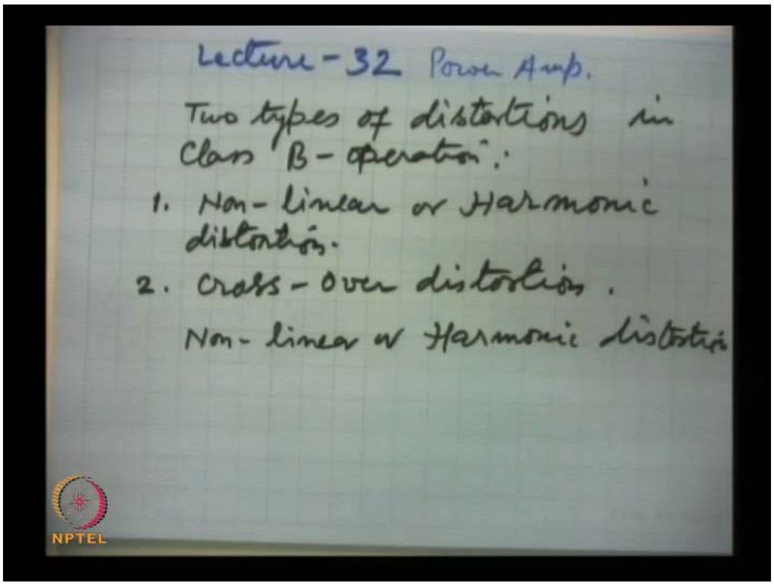

We were talking about the distortions in the output signal in the class B operation, and we said that there are two types of distortions. One is two types of distortions in class B operation: one was the non-linear, which is also called harmonic - harmonic distortion, and the other one is cross over distortion. Distortion implies these two kinds; for example, in the first one the signal frequency as well as its harmonics that is if omega is the angular frequency of the input signal, then at the output other than omega frequencies like 2 omega, 3 omega, 4 omega the harmonics will also be present, they are distorted, and they are distortions.

And many applications will not except this distortion, the other one is cross over distortion. Now, we not only talk about these two distortions in details, but also the remedies; that means class B operation finally we will see is free from both these kinds of a distortions. So, first we study the non-linear or harmonic distortion, we know that the current and voltage swings involved with the power amplifiers are large.

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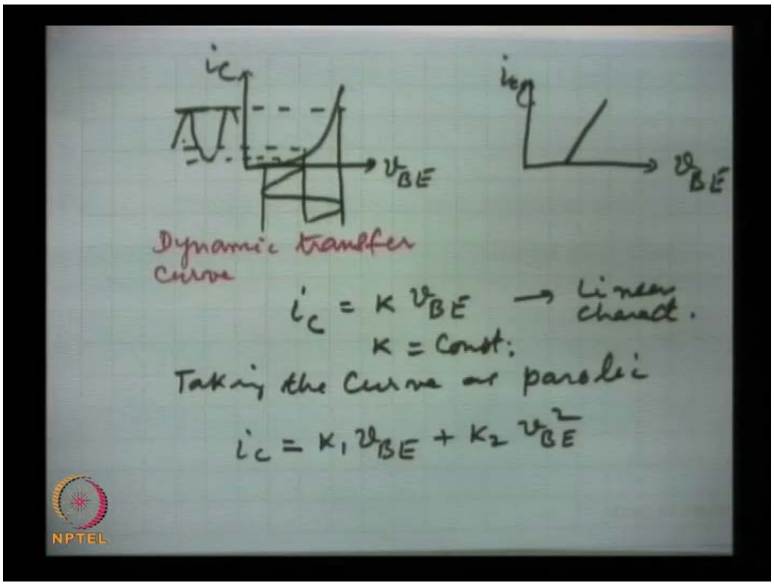

Now, let us look at the trans conductance curve, dynamic trans conductance curve this is the output current and this is the voltage the input voltage now see here then the whole region of this characteristics will be involved when the output current swing for example has to be high, so let us look here; see the different regions of the input voltage they will give rise to different asymmetric output currents, and this is the net distortion, this is the dynamic transfer curve, in transfer curve 1 property, 1 parameter of output port is involved and the other parameter is from the other port, here output current versus input voltage that is transfer curve and it is non-linear, and we are going to use the whole part of it and this is bound to give the distortion and as a result of this non-linearity other than the signal frequency the multiples the harmonics will also be present,

Now, we analyze it and we will see that the output finally in the push pull case then there is a symmetrical design then the output will be free from even harmonics like the biggest distortion will be from if omega is the input frequency then 2 omega the second harmonic will be have an largest magnitude amplitude of distortion that will be absent not only that although even harmonics will be absent finally, and odd as the number the 3 omega 5 omega they will be there, but their contributions will be negligibly small, so we continue with the simple analysis of these this distortion caused by this non-linearity.

For linear curve for example like this, this is the linear curve here it is i c and this is a vBE we can represent the for this linear case ic the collector current this is ic this is equal to K which is a constant that means k is proportional to the voltage this is the linear case where k is constant k constant and this is for linear characteristics but our curve is like this and this we can approximate for the simple analysis we can take it parabolic across the operating point, So, taking the curve as parabolic we can write this ic as k1, vBE plus k2, vBE square this is the equation parabolic, equation of a parabola.

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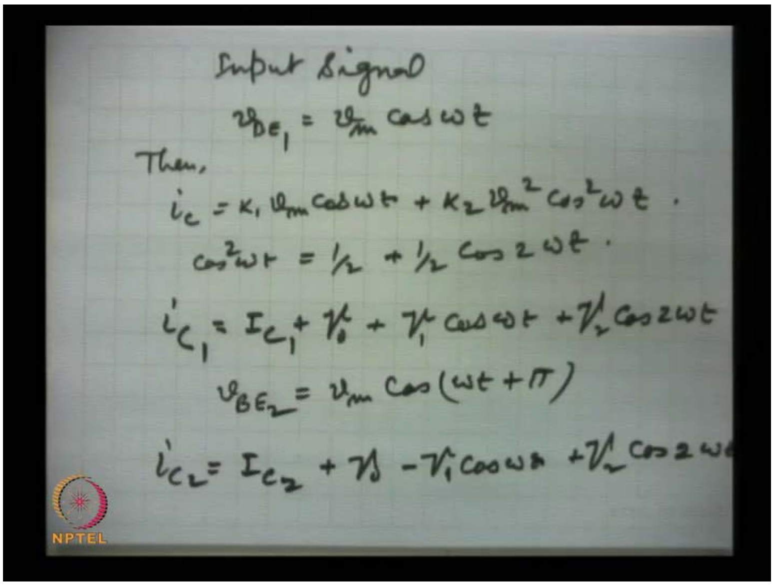

Now, let the input signal we take as a sinusoidal and it has the form the input signal vBE is vm the maximum amplitude cos omega t where omega is the angular frequency of the signal so this is the equation of the input sinusoidal signal, then if we put this in this equation then we get ic is k1, vm, cos omega t plus k2. k1, k2 are constants vm square cos square omega t, now this cos square omega t term can be written in a different form using the trigonometric relation and that relation is cos square omega t is equal to half plus half cos 2 omega t, so we can replace that and then ic will be any dc component present that is taken care by this term, plus these constants gamma 0 plus gamma 1 cos omega t plus gamma 2 cos 2 omega t this is the expansion, Now, for this in the push pull as we have talked that there are 2 transistors and the input signals are differing in phase by pi, the upper one responds the positive half of the input signal the lower half responds to the negative half, so writing the input for the second transistor as 2 equal to vm cos omega t plus pi, since now we are using 2 transistors to this we can say 1 this is for upper transistor and for lower one we are writing, so we will get another equation ic2 in the similar way a simple equation and this ic1 for the upper half is ic2, gamma 0 minus gamma 1, cos omega t plus gamma 2, cos 2, omega t, and if the final because both these currents are flowing through the common load.

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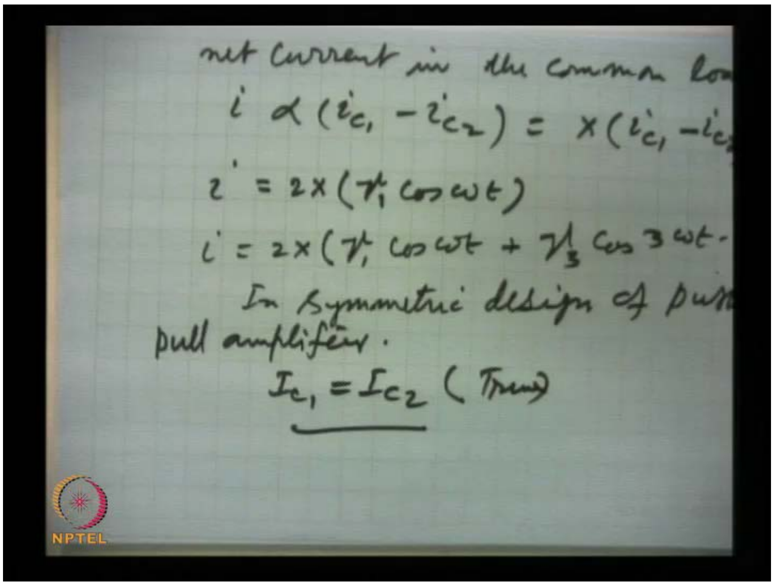

Then net current in the common load will be net current in the common load of the amplifier will be proportional to the difference i will be proportional to the difference of these 2 currents, and therefore we can write i will be equal to some constant X this is equal to X, ic1 minus ic2 so that will be gamma 1, cos omega t, so we are seeing that second harmonic is completely absent and only pure signal frequency is there all harmonics are absent, but if we take a general case we took approximately parabolic shape of the v of the trans conductance curve, but in general case when Taylor series is used then actually this i we will find 2X into gamma1, cos omega t plus gamma3, cos3 omega t and so on,

In fact all the odd modes are present, but as I said as the order of the harmonic increases the amplitude falls, So, the contribution of gamma3 will be there but it is very small and gamma5 will the cos that 5omega term that will be still a smaller, so this way and here we see the which take consideration of the dc currents, for the symmetric case have cancelled in this expression we have cancelled these capital c1, c2 the dc current, and this expression which has been written this is for the symmetric design which is always carried out for push pull amplifier, So, in symmetric design in symmetric design of push pull amplifiers in the above analysis we have taken ic1 equal to ic2 which is true for symmetric design so this is what we conclude from here.

The simple analysis shows that harmonic distortions are there but the biggest contribution in the distortion will come from the second harmonic which is absent in this because of the design of the push pull amplifier and in fact all the even harmonic are absent only odd harmonics are there but their amplitudes are negligibly a small then the cross over distortion.

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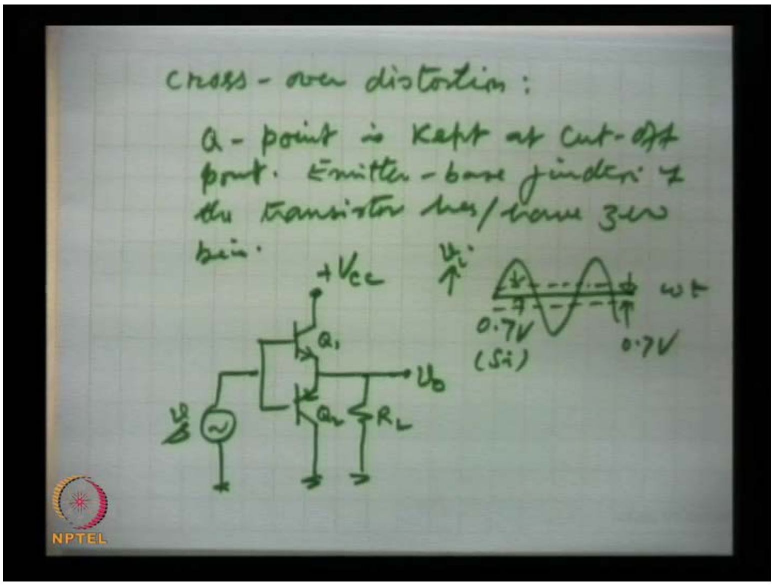

The next 1 is a cross over distortion, in class B operation the cut off condition is achieved by keeping the Q point at the cut off, Q point operating point is kept at cut off point, let us and at this point the emitter base junction emitter base junction of the transistor has or both have 0 bias, look at this design and then we will be able to explain that these are the 2 transistors Q1 and Q2, Q1 is n p n type and the other 1 is a p n p and both are biased by a single source V CC, and output is taken at the common load Rl, if the input signal is like this; this is the input signal where this is voltage vi and this is omega t or time, now in strictly speaking in the B operation the emitter base junction is at 0 potential, so and we remember that if the devices are of silicon then this transistor will not come to conduction state unless the emitter base junction is forward biased by 0.7 volts that is required.

In this case that means when the signal goes from 0 then first 0.7 milli volts will be used to forward biased only after 0.7 volts the conduction will start, similarly in the lower case up to 0.7 this transistor Q2 will not conduct, any nut shell here when this voltage is of 0.7 volts for a silicon device this transistor will not conduct for this part, similarly in the lower 1 this part of 0.7 it will not conduct, the 2 transistors will not conduct this 0.7 and this will amount 2 distortion in this fashion.

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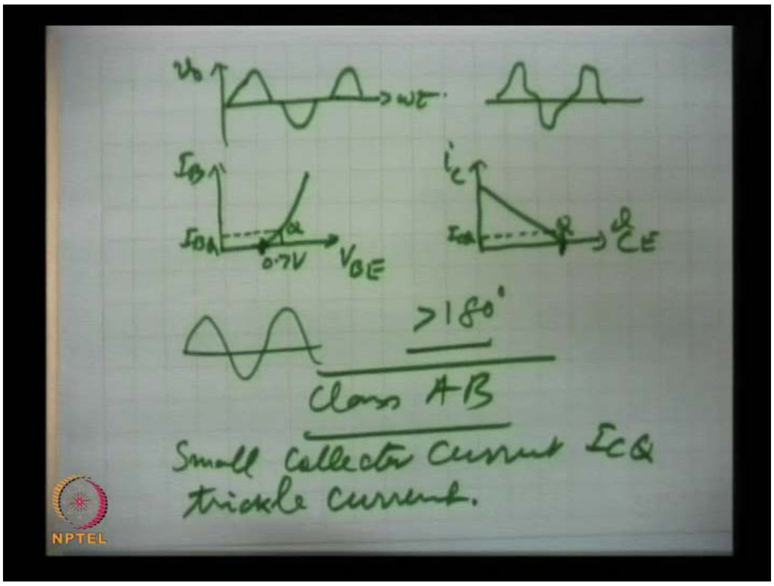

Output will be in little execrator format it will be like this is V out and this is omega t, but in practice also the outputs are like this, they are not the exact replica of the input signal, So, this distortion is known as cross over distortion, and this can be taken care of how to take care of that our input output curve is like this, IB, this is base current and this is VBE and this is the input curve, the strict B operation will imply to take the operating point here, instead of here we take a little we shift our operating point from here to here so this becomes the operating point, and this becomes the base current at the operating point, Correspondingly this is the load line and the this is ic and this is vCE, at for class B operation the operating point at exactly cut off, but now we have moved so that the quotient current is not 0, here when this is done this is the Q has been shifted to this, this will take care of that 0.7 bais if that means this voltage this is 0.7 volts after we choose the operating point here, then these transistors are ready to conduct right from the beginning because 0.7 volt is already have been provided, similarly here 0.7 has been provided, so the output will be the way we expect replica of the input it will be only much higher in power.

Now, in shifting this the conductance is now more than for 180 degrees conduction angle little more, and this operation is class AB, why we do class AB operation because we want to get rid of the distortion which is called cross over distortion how we can take corrective measures by shifting the operating point from ICQ 0 to a little bit value which may be 5 percent of the maximum value or even less and this operation is called class AB operation, and this current is small a small collector current collector current ICQ is known as trickle current, trickle current so this trickle current provides the forward bias required and both the transistors are in the exact conduction state.

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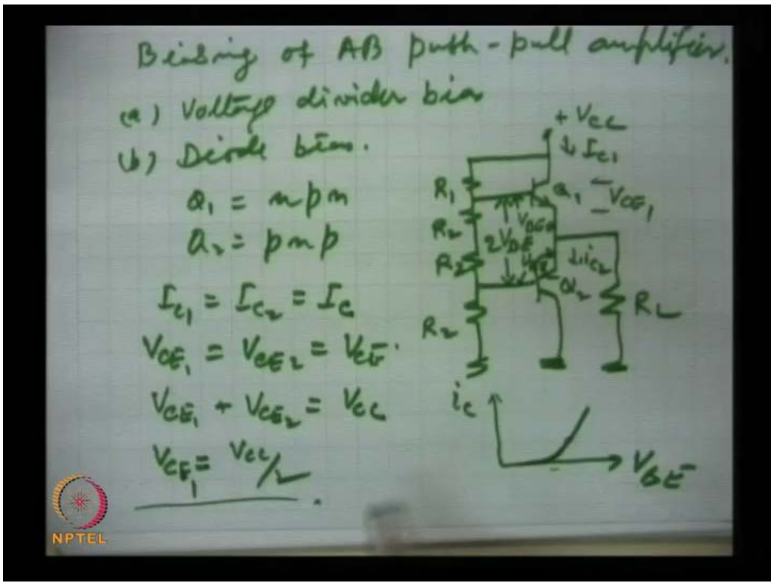

Now, briefly we take biasing of class AB push pull amplifiers biasing, there are 2 methods for biasing one is voltage divider, voltage divider bias and the other one is diode bias, now this is the complete design of class B push pull amplifier, Q1 is this is voltage divider bias and here this resistance R1, this is also R1, this is R2 this is R2, and this R1 and R2 they have been chosen such that the voltage developed across here is vBE for this and vBE for this transistor, that means 2VBE so we have done voltage divider bias in the normally small signal amplifiers by very simple means we can calculate this resistance R2 which is to be used, and Q1 is of npn type and Q2 is pnp type this is the push pull. circuit which is very widely used,

And for the analysis purposes only half of the circuit can be taken because they are symmetric, so normally half is good enough to be taken into consideration, this voltage is VCE1, similarly this voltage will be VCE2 this current is Ic1 and here it will be Ic2 and Ic1 is equal to Ic2 is equal to Ic, and VCE 1 is equal to VCE2 which is equal to VCE, and VCE1 plus VCE2 this is equal to V CC, and hence VCE1 alone VCE 1 this is V CC half, if this is 10 volts 5 volts will be dropped here 5 volts will be dropped here that is the meaning this is showing, and so this is very simple design, and as I said we can take just upper half and we can calculate R2, same R2 we have to use we have to take R2 such that the voltage this voltage should be 0.7 volts, we can find out and this is the voltage divider bias.

There is a problem in the voltage divider bias if you look at the curve it is very sharp in the just one condition here, therefore a small changes in voltage VBE, ic trans conductance curve here the changes are very fast, and remember this thing and when we were talking of BJT

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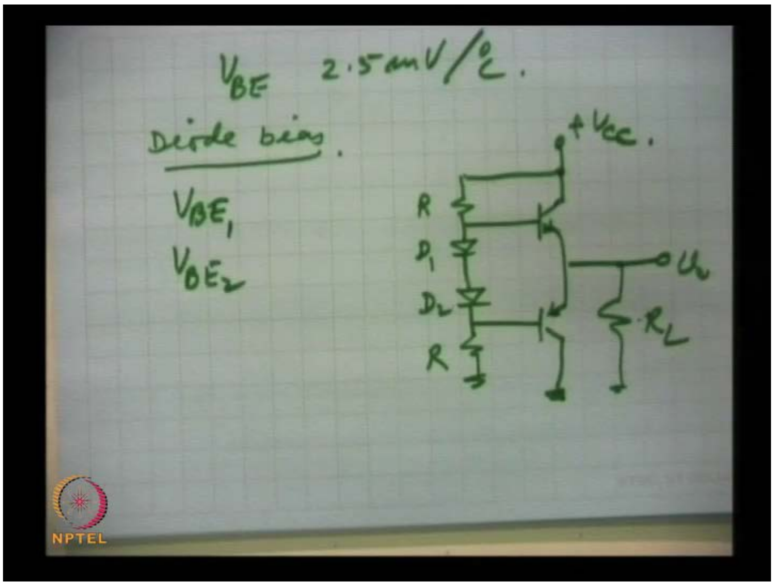

We said that voltage VBE is temperature dependent, with the it changes 2.5 milli volts per degree centigrade. So, this is for silicon transistor 700 milli volts, by if the temperature rises by 20 degrees then 50 milli volts change will be there, and 50 milli volts will amount to a large variation in this current here, therefore many times the resistance R2 is replaced by the diode and then we call what is called diode bias. The characteristics of this diode are same as the characteristics of the emitter base junction of the 2 transistors, there is one thing that the pair of these 2 transistors along with these 2 diodes is available in the market for different power ranges for 5 watts, 10 watts, 50 watts.

The all the 4 pieces these 2 transistors complementary transistors 1 npn other pnp and these 2 diodes they are sold in a single pack and that makes life little easy, So, this is R, this is R, this is diode 1, this is diode 2, and this is the common route and we take the output here this is plus V CC, this is the design of the diode bias, any changes of temperature will change VBE1 also VBE2 because the characteristics of these transistors are same as of these junction base emitter junctions are same as these diodes, So, same changes will occur in these diodes, they are and that will take corrective measures and the operating point will not shift because of this variation, temperature variation in particular, so this is about the diode bias.

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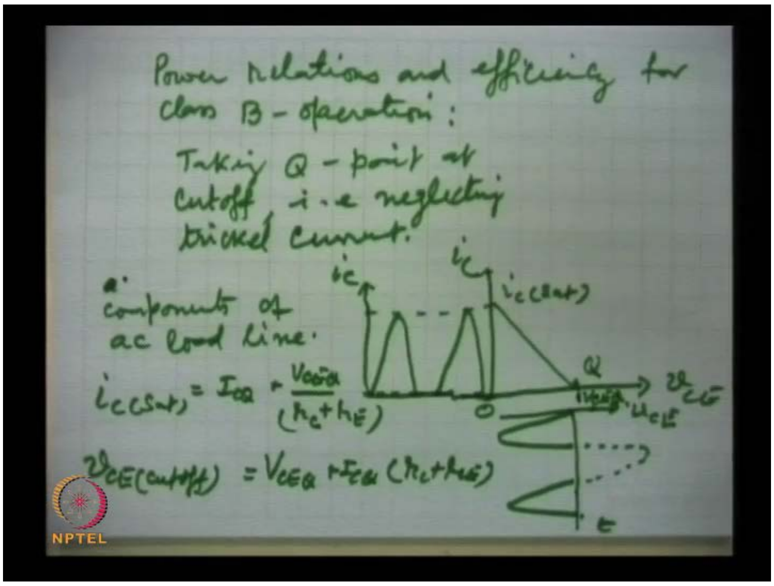

The next thing which we take are power relations and efficiency; efficiency for class B operation, this analysis is strictly for B operation that means we are neglecting the small effect of the trickle current which was required to eliminate cross over distortion, by neglecting by taking this trickle current is 0, we make the analysis much simple, and accuracy as I said few percent accuracy variations are always acceptable in electronics. So, not a big deal so taking the operating point taking Q point at cut off that is neglecting trickle current.

Then our this is the situation this is the ac load line and this is the operating point here this is ic this is vCE and this is t and this is vCE and the corresponding currents this is ic set this is ac load line and this is Q point this is 0 this is VCEQ and the current will flow only for these half's, and it will be ic like that, and we will take now that ac load line components you remember when we were talking about in the beginning of this module we spoke about the ac load line, the 2 equations which we got the ac components or the components of a c load line, we got two expressions ic set was ICQ plus VCEQ by effective collector and effective emitter resistance, and similarly we got vCE at cut off equal to VCEQ plus ICQ into rC plus rE, this 2 equations we got when we were talking about the ac load line, in this present case because the operating point we have taken at cut off and that is small trickle current we have neglected for the simplicity of the analysis, so ICQ we are taking as 0, So, if ic u is kept 0 here in these 2 equations

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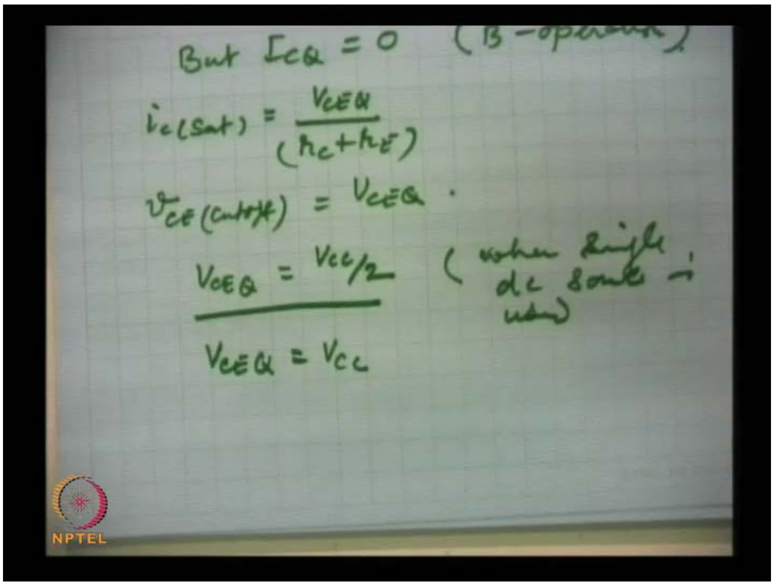

they are reduced to but ICQ is 0 that is in B operation,

Therefore ic set is equal to VCEQ by rC plus rE, and similarly when we substitute ICQ 0 in the voltage cut off at cut off equation we get it simply VCEQ, So, this these 2 equations will help us in arriving at the maximum ac output power, further as earlier we have shown that VCEQ is equal too, because the total voltage V CC which we are applying here this is half appears here and half appears here, So, VCEQ is equal to V CC by 2 this is when we use single source voltage source, we can have a choice instead of biasing both transistors with a single source a positive voltage can be given at this collector in negative voltage we can give here, So, that this negative voltage will bias this collector in the reverse, and the upper one will be reverse bias by plus, so in that so this is single source when single dc source is used when 2 sources will be used then VCEQ this is just for the sake of knowledge, we are using only one battery so for as this is true but other choices applicable that one voltage plus here, negative voltage here to reverse bias this collector in that case this VCEQ will be equal to V CC whatever we use so then we can write the expression the peak a c voltage.

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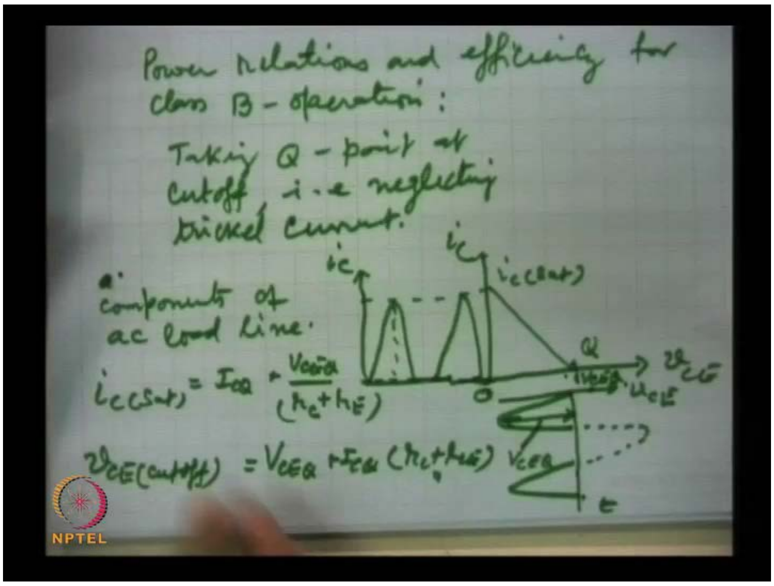

Let us this figure we should note this voltage here is VCEQ so this voltage, this is VCEQ, and this current is ic set current because this point is 0 ic current.

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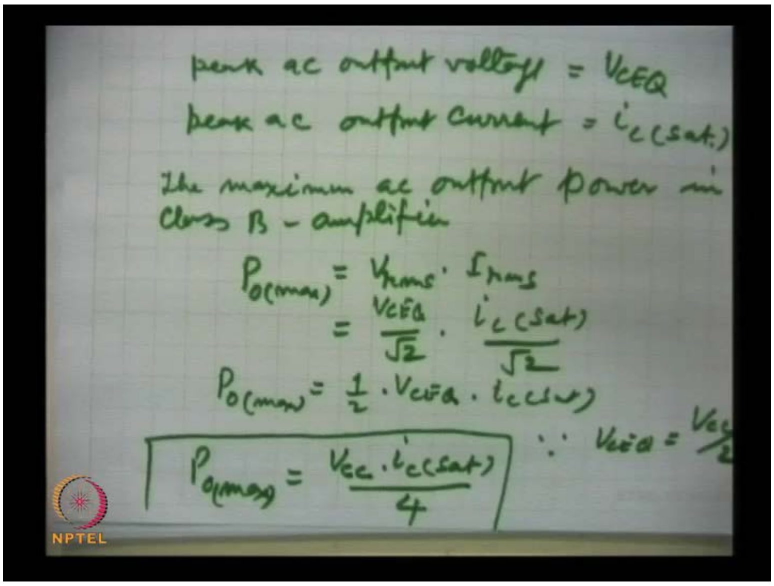

So, the peak ac output voltage is VCEQ, and peak a c output current this is ic set saturation, then the maximum ac output power will be the maximum ac output power in class B amplifier this will be Po max maximum is equal to Vrms into Irms, and voltage rms this is the peak value and hence this is VCEQ by root 2 this is ic set ic set by root 2 so this is Po maximum is equal to half VCEQ into ic set since VCEQ is V CC by 2 so Po max is equal t V CC into ic set by 4, this is a important relation and this will we know the value of ic saturation and what V CC single dc source we are using to bias both the transistors, we know the magnitudes of these 2 parameters we can find out what will be the maximum output ac power available from the push pull amplifier.

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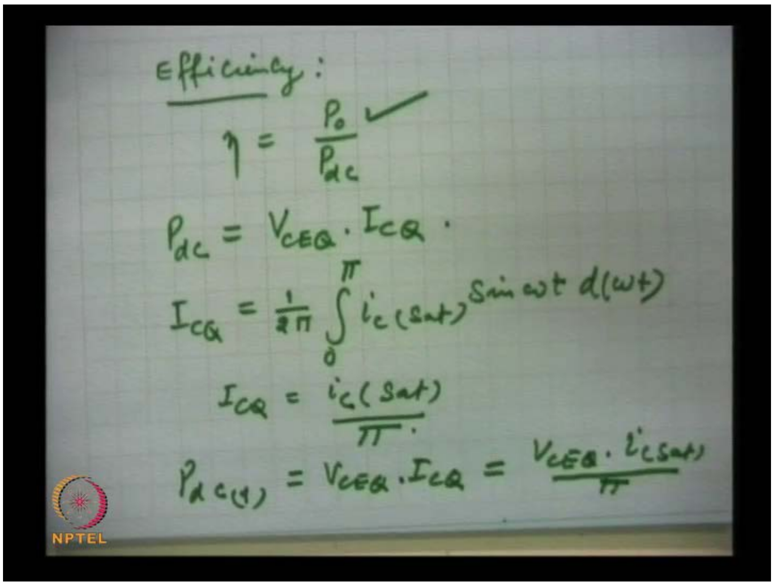

And then we can go for efficiency; and the efficiency this is convergence efficiency, that what fraction of the dc is available as ac, so convergence efficiency and this is we write as eta and this is equal to Po that ac output power by dc output power, and when it is to be expressed as a percent then we multiply this by hundred and this we have already find out the maximum output power, what will be the Pdc this is the maximum dc power which will be supplied to the circuit. The voltage is VCEQ and this is ICQ, now one thing is very important to remember that ICQ is 0 because we have chosen the operating point at the cutoff point so in the absence of the signal the ICQ is 0.

The transistors will come to the conduction state by the upper transistor will conduct because of the positive half, when positive half input signal is there then the transistor conducts, and when it conducts then we will have it draws dc power from the source, similarly; the lower transistor will be conducting for the negative half's of the input signal and then that transistor will consume the dc power and the current this ic the current will flow, now so we can find out what is on an average what is the value of the collector current which is drawn from the battery, and this you might have done the average over the period by using integration, so ICQ in half wave rectifiers this analysis has been done.

But, I just do it here; ICQ 1 by 2 pi 0, 2 pi ic set sin omega t, d omega t, we have taken the signal as sinusoidal and the current which flows is this is the maximum current, and this is that sin part we solve it and we find that ICQ is ic set by pi, therefore Pdc for 1 transistor is VCEQ, ICQ which is VCEQ now we substitute for ICQ so ic set by pi, When similarly there will be a expression for the second transistor

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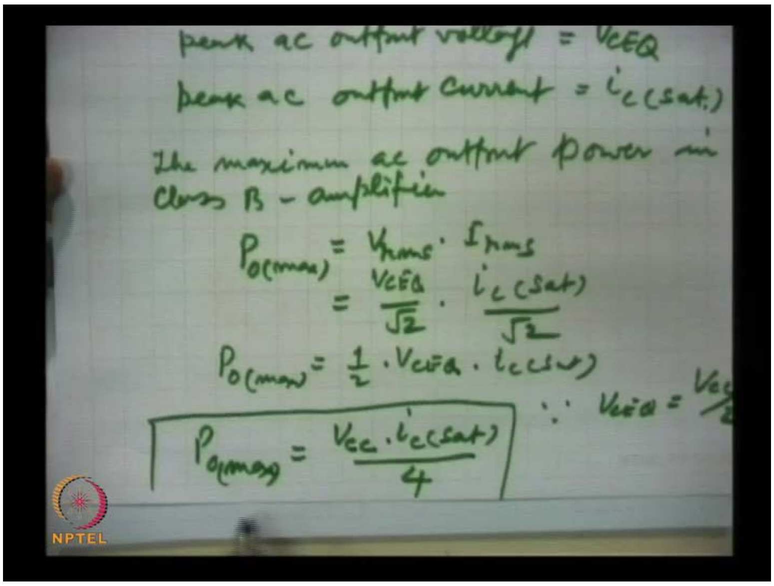

and therefore Pdc for transistors 1 and 2 that is for Q1 and Q2 both, Pdc this will be double of Pdc 1 which we have calculated, and this is 2VCQ into ic set by pi, but 2VCEQ is equal to V CC, therefore Pdc is equal to V CC, ic set by pi, this is the expression for the dc power which is taken from the dc power source, and we have already obtained the expression for the ac power which will be available at the load.

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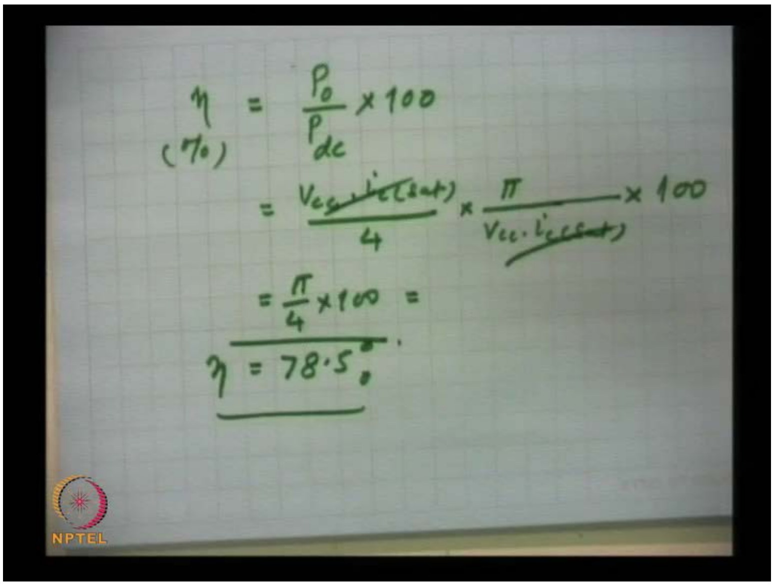

Therefore, the efficiency eta in percent this will be P0, Pdc into 100, and this is we substitute the values V CC, ic set by 4 into pi by V CC, ic set into 100. So, they cancel and we are left with pi by 4 into 100, and that comes out to be eta comes out to be 78.5 percent, very high efficiency. So, this is of course, the theoretical highest possible efficiency 78.5 percent when the transistors are operating in class B as a class B amplifier. This efficiency for the class A power amplifier when the load was the (( )) coupled it was 25 percent, here it is 78.5 percent which is quite high very high, and that is the reason one of the important reasons that class B push pull amplifiers are very widely used,

All the almost all public attires systems are class in fact A B operation because distortion has to be completely taken care of, So, A B operation and there the efficiency will slightly fall so the practical efficiency will be close to seventy or so, So, this is this, the last thing about class B operation;

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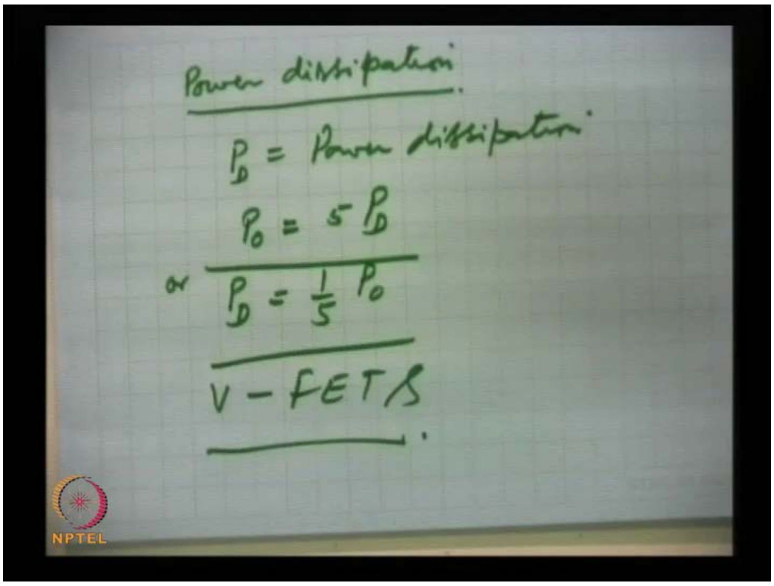

We can say and that is about power dissipation that means how much power the transistors are suppose to dissipate the cost of the transistor will vary a transistor which can dissipate say 2 watts of power and 5 watts of power they will be quite different, 5 watts power dissipation transistor will be quite high in this case in class B operation, this power dissipation is very small the P D dissipation power dissipation, this is 1 5^{th} of Po, output power is 5 times of P D or P D is 1 5 th of Po. This is another point which goes in favor of class A class B push pull amplifiers, for if we want output power as say 50 watts or 100 watts, let us say Po is 100 watts then we need transistors which can dissipate only 20 watts of power, So, this is a big game with game, with class B power amplifiers.

We have been discussing this these power amplifiers with BJT circuits, in fact MOSFETS can also be used instead of 2 transistors BJT we can use MOSFETS, and they are a special fat devices, fat transistors where there is a V grove in the device and these are called V type FETS V FETS, these can be used and the power amplifiers this class B amplifier can be constructed instead of by B J T we can use this.

Specially designed field effect transistors also, and another thing that we took a emitter follower circuit for the for the push pull amplifier, we can use the common emitter circuit also, and the design is quite simple, and in that case normally the transformer coupling will be used at the output, So, many times the push pull amplifier is constructed using 2 transistors in common emitter, and the output is coupled to the load through a transformer coupling. So, this is all about class B operation, class B power amplifiers and the most popular one of this was push pull amplifiers.