Introduction to Electronic Circuit
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Lecture 33
More of Power Amplifiers and an Introduction to Small signal Modelling of the BJT

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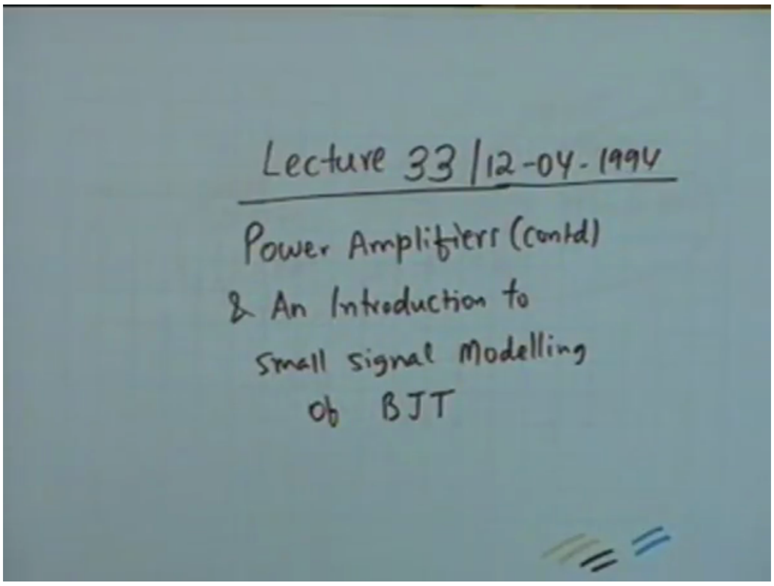

33rd lecture and I continue our discussion on power amplifiers and if time permits we introduce this small single model of the bipolar junction transistor the BJT. In the last lecture 32 lecture we had discussed the power amplifier with the transformer coupling that is what we had was we had the usual transistor biasing circuit.

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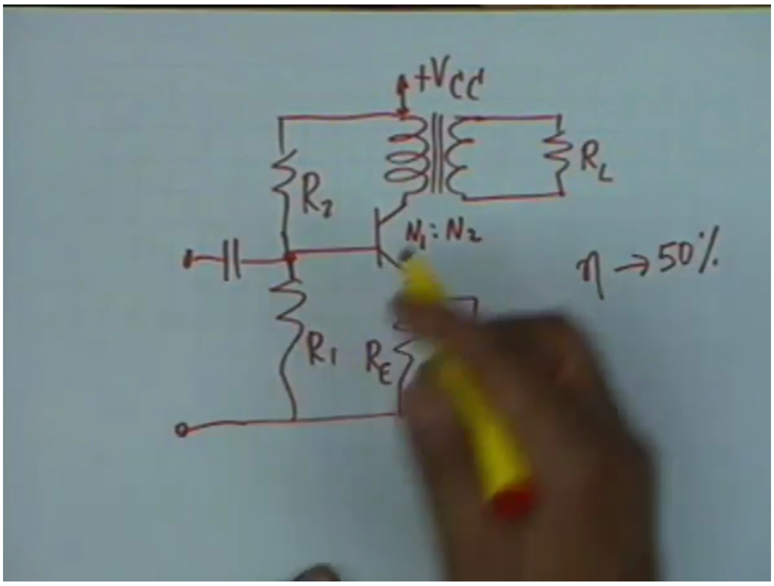

Instead of a resistance in the collector we had the transformer primary and to be secondary is connected the load, actual load RL which could be a loudspeaker and then this goes to plus VCC and usual biasing circuit there is a resistance R sub 2 and there is a resistance R sub 1 the input signal is applied between these 2 points (()) (2:07) voltage source or a current either a voltage source or a current source this is RE and this is a bypass capacitor.

And we saw several advantages, the first was that the efficiency Eta could be raised to 50 percent ideally; eta could be raised to 50 percent that happens because there is no DC loss of power in the collector resistance. Number to the load is isolated from DC, no DC flows to the load that happens because of the transformer, what is the third advantage? Matching, it affords the means of matching by varying the transformer ratio N1 as to N2.

And what is its disadvantage, if any? It is costlier, also as you know a transformer is bulky it has to be iron core if it is to be for audio frequencies and therefore its weight increases it becomes bigger in size, the whole other rest of the circuit could be accommodated in a very small space may be within a Matchbox or even smaller than that maybe transformer itself will occupy most of the space I mean account for most of the weight, nevertheless.

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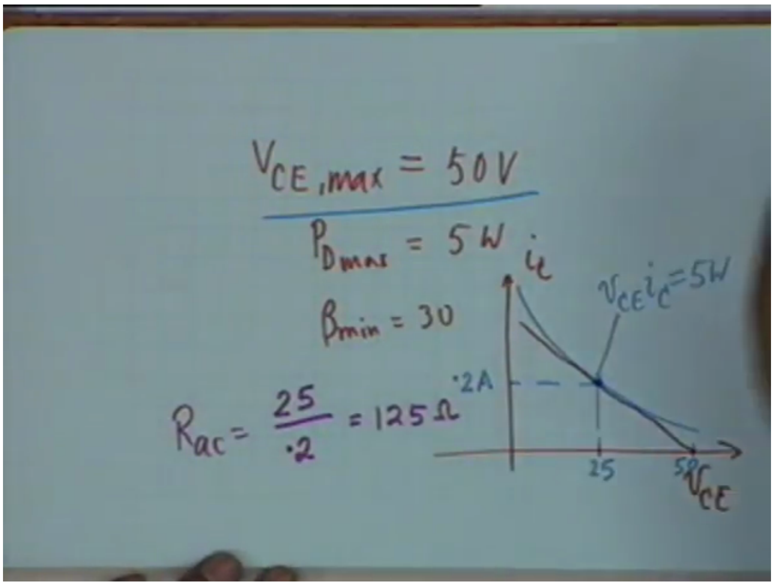

Illustrate the design of a transformer coupled amplifier, we take a typical example in which the same specifications for the transistor hole as was used in the previous example of transformer less power amplifier that is resistance load. Suppose we have a transistor in which the maximum VCE is 50 volts, the maximum power dissipation is 5 watt let us say beta min is equal to 30 the same specifications we have used in the previous example.

Then obviously what you do is you look at the transistor characteristics I sub C versus VCE characteristics. In this characteristics you draw the PD Max line that is a line in which VCE times i sub C is equal to 5 watt, alright. Then your VCE Max is 50, so you prefer to go to the high voltages rather than high currents because the characteristics are more linear. So you mark point 50 volts here, alright.

Then obviously the maximum voltage swing can be 25 volts, if the characteristics are ideal, so you mark the 25 volts point and you know that for maximum power output your Q point must be on the PD Max hyper Bola and therefore you go up and see where it meets, obviously the current here shall be 0.2 ampere and therefore your Q point is now returning 25 volts and 0.2 ampere not only the Q point but the AC load is also determined.

VCE load line shall be tangential to this and must pass through the 50 volts line. In other words Rac as we have calculated as time shall be given by the slope of this line which shall be 25 divided by 0.2 which is equal to 125 volts, alright.

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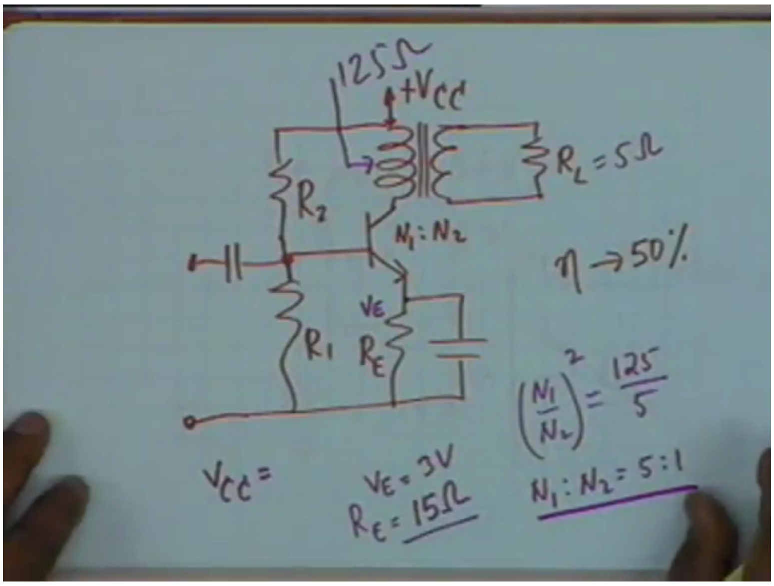

Now suppose in the transformer coupled amplifier the actual load could be as low as let us say 5 volts. Suppose this is 5 ohms, what you want here is 125 ohms and therefore N1 is to N2 whole square should be equal to 125 divided by 5 in other words N1 is to N2 should be equal to 5 is to 1 that means if the secondary has 10 turns then the primary should have 50 turns okay.

So the trans ratio of the transformer is determined N1 is to N2 is equal to 5 is to 1. Now under this condition what VCC shall be needed? Well to determine VCC you notice that the transformer primary because of 0 resistance we assume it to be ideal it does not drop any voltage and therefore the only drop that shall occur shall be across R sub E and you can set at this drop almost arbitrarily and as I said 3 volts, 2 worlds these are typical figures.

If you said these at 3 volts let us say, if VE is set at 3 volts then obviously RE (()) (7:35) shall be equal to, the current is 0.2 ampere, 0.2 plus, 0.2 divided by beta but since beta minimum is 30 we can ignore that term and therefore what shall be RE 15 ohms, 0.2 ampere flows and I resumed VE equals to the world and therefore RE is equal to 15 ohms, alright.

Do not be scared about the low value of the resistance, this is inevitable when your A/C load is of the order of 125 ohms and low resistance load, all resistance in this circuit I going to be low, alright. So RE is 15 ohms then what is VCC that is needed?

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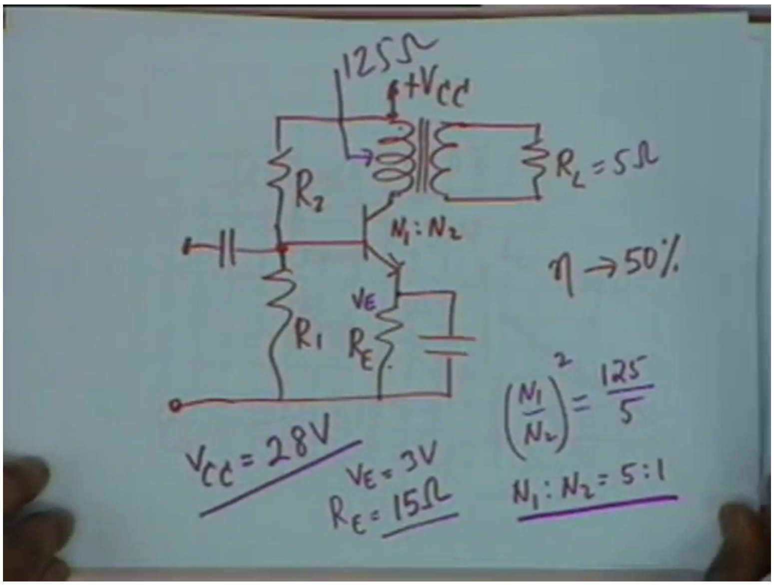

25 is given by the load line, 25 is a Q point, alright. That is this will be the VCE plus the voltage drop across the emitter resistance that means not 0.7 we are not going to (()) (8:43) which is still 25, VCC shall be able to drop in the transformer 0, the drop in the collector to emitter 25 plus 3 volts and therefore VCC shall be 28 volts, alright.

If you take nominal beta if you take nominal beta equal to let us say 100, beta minimum is 20, if you take nominal beta equal to 100 then you can calculate R1 and R2 in the usual manner, okay. RB that is the parallel combination of R1 and R2 shall now be beta min that is 30 multiplied by RE that is 15 divided by 10 and therefore RB should be equal to 45 ohms, alright.

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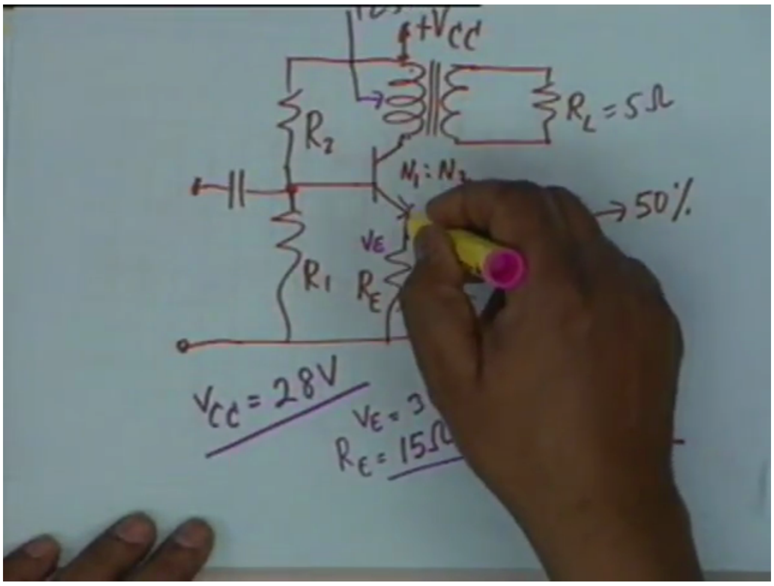

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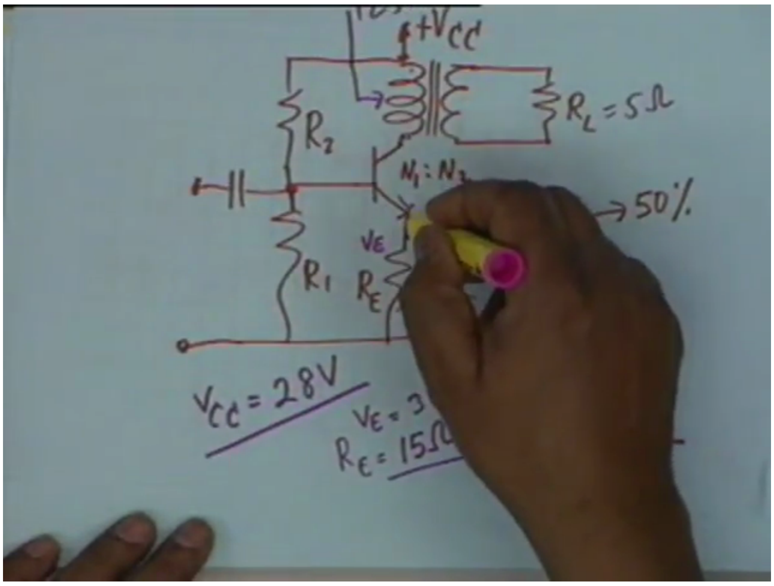

And you can calculate VBB from the requirement that VBE is 0.7, this voltage is 0.7, this is 3 volts, so this is 3.7, alright. VBB minus 3.7 shall be equal to IB times RB from which you can determine RB and therefore you can determine both R1 and R2 this calculation is routine and I shall not carry this out.

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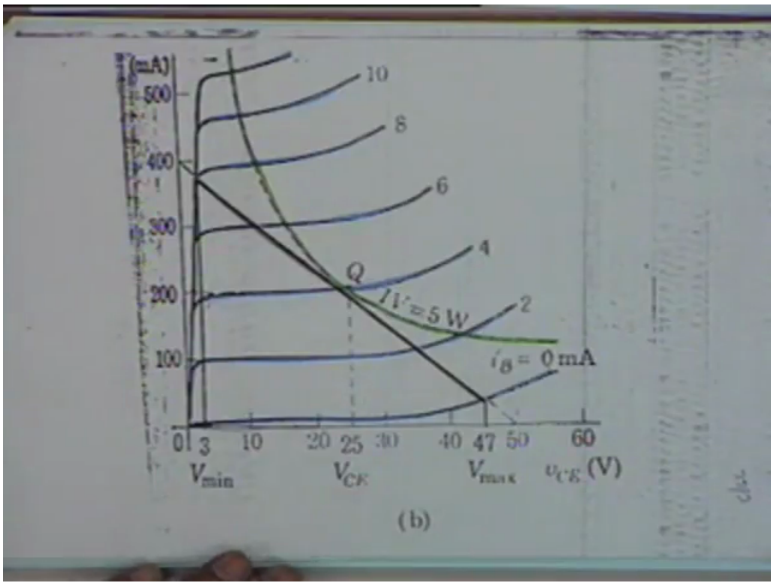

But the next question is, how is the efficiency affected? What is the efficiency of this particular circuit, for that of course we shall have to look at the exact characteristics and the characteristics of this transistor are depicted here? Now comes the question of practical considerations, alright. You see this is the 125 ohms line. 25 volts, 0.2 ampere this is the Q point and these are the actual characteristics, the blue lines, alright.

Now if you look at the actual characteristics you notice that the AC load line, the Red Line cannot quite go to 50 because it crosses the iB equal to 0 milliampere line and therefore this must be the maximum VCE you cannot go to 50, you can only go up to about 47, alright. In a similar manner you notice that thecurve cannot go right up to this point because the saturation part of the characteristic is to be exceeded.

Therefore you notice where does it cut? It cuts iB equal to 8 milliamperes, so this is the maximum I sub B that can be allowed. Small i sub B can range from 0 to 8 milliampere and because of saturation voltage cannot go below 3 volts and therefore VMax is 47 and Vmin is 3 volts, alright. And therefore the root mean square value of the output signal can be 47 minus 3 that is 44 divided by 2 that is the peak value 22 and the root mean square value shall be 22 divided by root 2, alright, is that clear? We are not taking the current into consideration, why? Because we are not going to the maximum possible current swing, alright.

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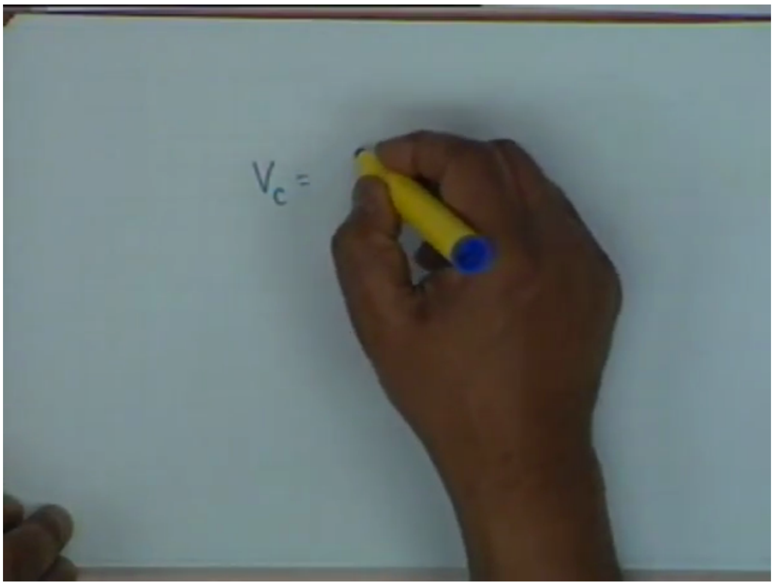

So my root mean squared value of the load voltage V sub C shall be 22 divided by root 2, all of you understand why it is 22 by root 2? Maximum V minus minimum divided by 2 is the peak value, peak value divided by root 2 is this and therefore the output however P0 shall be VC squared divided by RAC, so 22 by root 2 whole square divided by RAC which we have already determined to be 125 ohms and this calculates out to 3. I am sorry 1.94 watts, alright. This is the output power.

The input power P sub C, input power P sub C or let us call it P sub I, capital P sub capital I the input power is simply VCC multiplied by whatever current is drawn from the battery. Well, from the battery is drawn a current for the collector circuit and also for the base circuit but the base circuit current is much smaller compared to the collector and therefore we simply multiplied by I sub C which will be equal to 28 multiplied by what is I sub C? 0.2, this is equal to 5.6 watts (()) (13:53), does that bother you? Where is the PD Max? The maximum dissipation that a transistor can tolerate is 5 Watts. So where does this .6 watt, where does this go?

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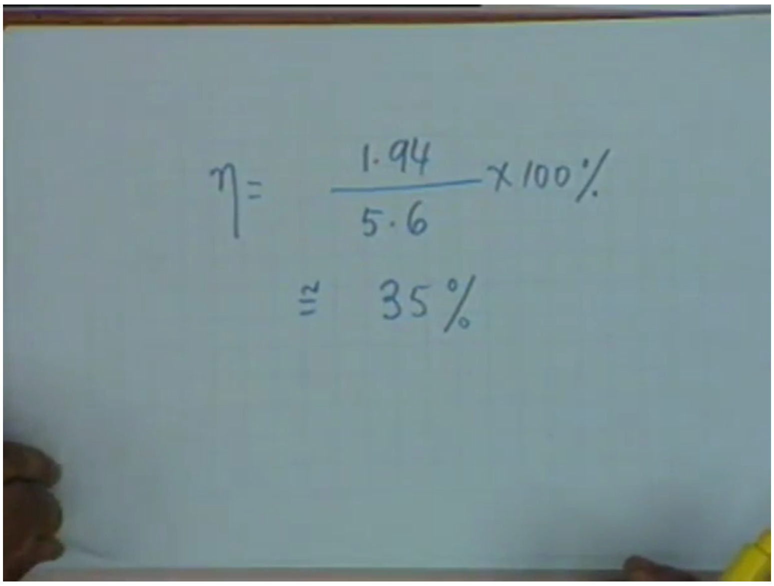

This goes into RE, it is not the dissipation in the collector, it is the dissipation in the emitter resistor and therefore the efficiency Eta will be 1.94 the load power divided by the power that is supplied at the battery multiplied by 100 percent and this calculates out to approximately 35 percent that theoretical maximum is 50, what you can achieve is approximately 35 percent and this is effective life, alright.

The design has to be very carefully than by looking at the transistor characteristics. For power amplifier is transistor characteristics are a must, if you wish to keep the distortion to within reasonable limits.

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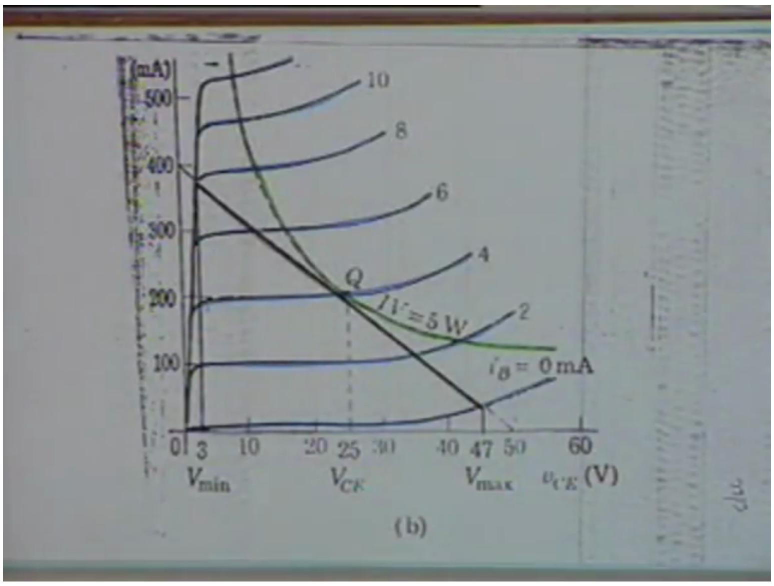

Now if we go back to this operation to this transistor characteristic once more, you notice that if we choose our Q point here then for the input current, what is the input current? The base current, the base current is 4 milliampere, now suppose the base current the AC input is such that the base current varies from let us say 2 milliampere to 6 milliampere.

Then obviously for the total cycle of the base current, the base current would be 4 milliampere plus an AC of peak value to milliampere, suppose it is so then for the total duration of the base current cycle the collector current flows, the collector current flows for all times, alright. On the other hand if we had chosen of Q point let us say somewhere here, alright.

Then the collector current would have flown only for a part of the base current cycle or maybe the Q point is here. If here we apply let say 2 milliampere peak AC then for the positive half cycle there is no point, there is no problem is but for the negative half cycle you shall have a problem.

Now if it is, if the peak value is more than 2 milliampere, let us say 4 milliampere then obviously for the positive half cycle the current shall flow but for the negative half cycle only up to 0 milliampere only this much inflow. In other words there shall be distortion it is as if you take a pair of scissors and cut the negative half cycle alright.

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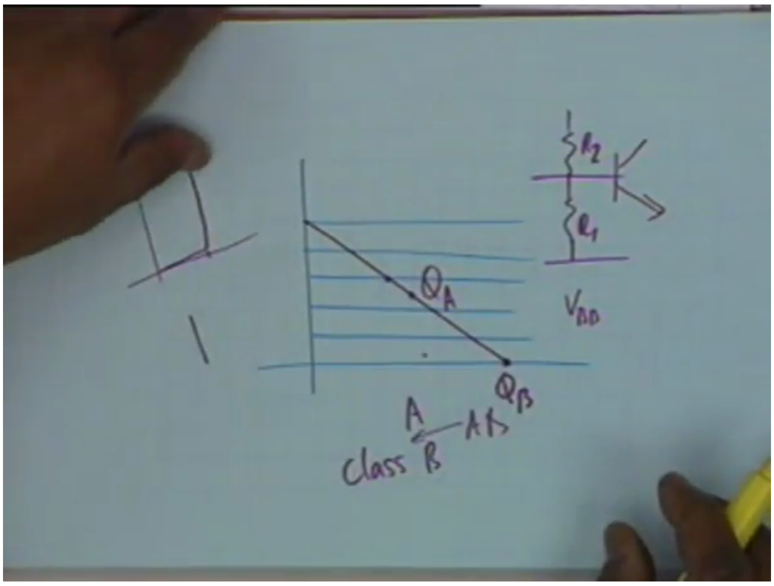

Suppose we go to an extreme, suppose we put our Q points, let us consider this, consider ideal characteristics, ideal characteristics would be like this and suppose your load line is this.

As I said there are many choices of Q point, Q point could be here, could be somewhere here and you could arrange so that for all times the base the collector current flows but suppose Q point is here then obviously it is only the positive half cycle of the base current which will cause a collector current to flow.

For the negative half cycle the collector current shall not flow because I sub B cannot go negative, alright. This is the maximum, the current is not injected and therefore the collector current has no obligation to flow, the collector current shall not flow. In other words if the Q point is here, QB then it acts more like a rectifier, is not that right? It only takes the positive of cycles.

Now how is this achieved? This is achieved by biasing the base by choosing R2 and R1 in such a manner that VBB is just 0.7 volts, agreed? It is so arranged that VBB is just 0.7 that is in the characteristics the transistor the base emitter junction is biased exactly at 0.7, so that if the base voltage is less than 0.7 your transistor does not conduct, alright. This operation, this Q point is called the class B operation.

Class B in which the current in the collector flows for only one half cycle of the base current where as if it flows for the total cycle then it is called class A operation. In class A operation the collector current flows throughout the duration of the base current cycle. In class B operation the collector current flows only for half cycle of operation. If it is in between, between half and full that it is called class AB it is neither class A or class B it is somewhere in between, class AB there can be intermediate class AB.

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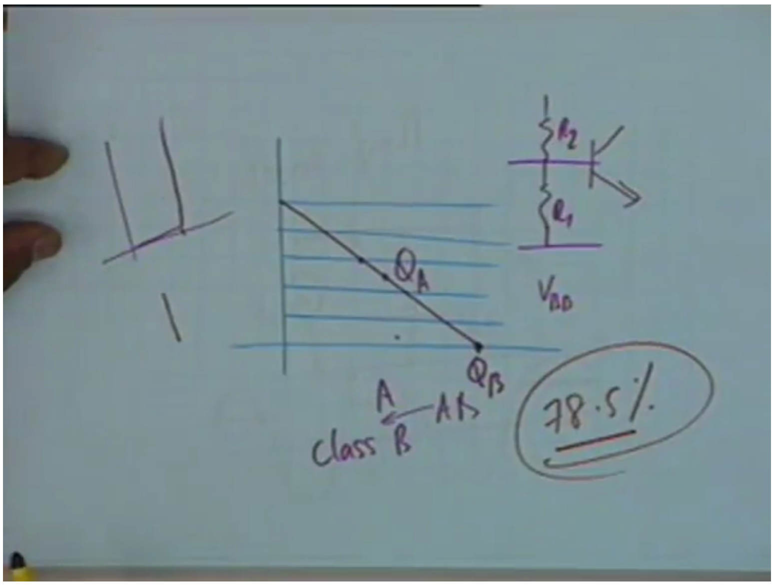

Now suppose you go to the other extreme that is you take a transistor let us look at the base side base circuit only. Suppose instead of a positive battery here, instead of positive VDD you connected negative VBB, alright. Then you see if you are applying A through a capacitor, if you are applying an input signal here which varies like this, alright. Then transistor will conduct only when Vi exits VBB, is not that right? By at least 0.7 volts otherwise the transistor will not conduct.

And therefore what will happen is the collector's in the collector circuit only a part of the positive half cycle shall make the (()) (20:50) during a part of the positive half cycle the collector current shall flow. In other words if I continue this then what you will get is pulses like this in the collector. Now in my task this is obviously very highly distorted collector waveform, what is the use?

The use is the following, in class B operation, in class we only the positive half cycles allow the collector current to flow then what is done is, transistors are used in a configuration known as push-pull configuration. The basic idea is that one of your transistors conducts during a positive half cycle, second one conduct during the negative half cycle and the outputs are so combined that there is no distortion, alright. This is the advantage of class B.

Now what is the advantage? Why should one do that? The advantage as you see, if this is the Q point then what is the quiescent collector current? 0, is not that right? Without the signal collector current does not flow at all and therefore power dissipation in the transistor is minimized, alright. Power dissipation in the transistor is reduced drastically and therefore the efficiency improves.

The efficiency improves, as you will see the efficiency as much as 78.5 percent. Let us remember efficiency class A with a resistance load maximum efficiency is 25 percent class A with a transformer coupling maximum efficiency is 50 percent, class B the push-pull operation maximum efficiency can go to 78.5 percent.

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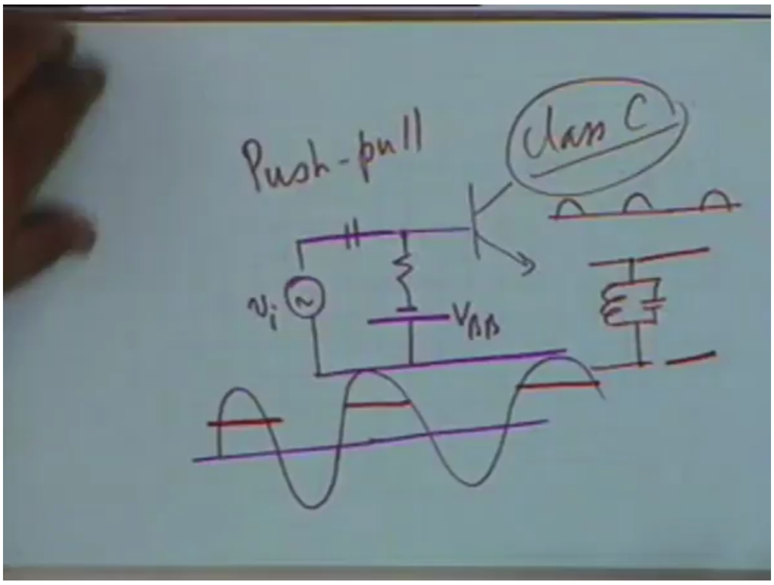

And class C the efficiency can go further up, it can go to as much as 85 percent or so, alright. 85 percent, now the problem of distortion as you see in class B operation, as I said 2 transistors are used one takes care of positive half cycle the other of the negative of cycle and the 2 outputs are so combined that a full-cycle of the output is obtained, so there is no distortion.

In class C this not possible because even a half cycle is not is not obtained. So what is done is from these pulses, little pulses you know that such pulses and be decomposed by Fourier analysis entries fundamental and harmonics. What is done is, this pulses of current are passed through a tube circuit, a Parallel resonant circuit which is resonant at the fundamental frequency, alright.

Resonant the fundamental frequency which means that at the fundamental frequency the impedance of this is very high, at all other frequencies impedance is low. So the voltages that will be developed across this tube circuit it will mostly that of the fundamental frequency and that is our sinusoid is restored. Now this is a operation class C is the operation that is used in all transmitters, radio transmitters because of the higher efficiency.

Radio transmitters if you had 100 kilowatt transmitter then cooling 100 kilowatt the the power dissipation in the transistor shall be let us say 50 kilowatt. Cooling 50 kilowatt of heat is a very elaborate job, so higher the efficiency the lower will be the default in cooling the station, alright. Very elaborate arrangements have to be made and therefore class C operation is restored to in radio transmitters.

And in any case, in any case you transmit only narrowband frequencies centred around a particular a particular frequency then B per example 1000 kilohertz and the speech band around it and therefore all you have to do is to make a tube circuit of 1000 kilohertz, alright. So this is the operation of class A, class B and class C, we shall not have occasion to look at class C but class A class be definitely we are going to look at.

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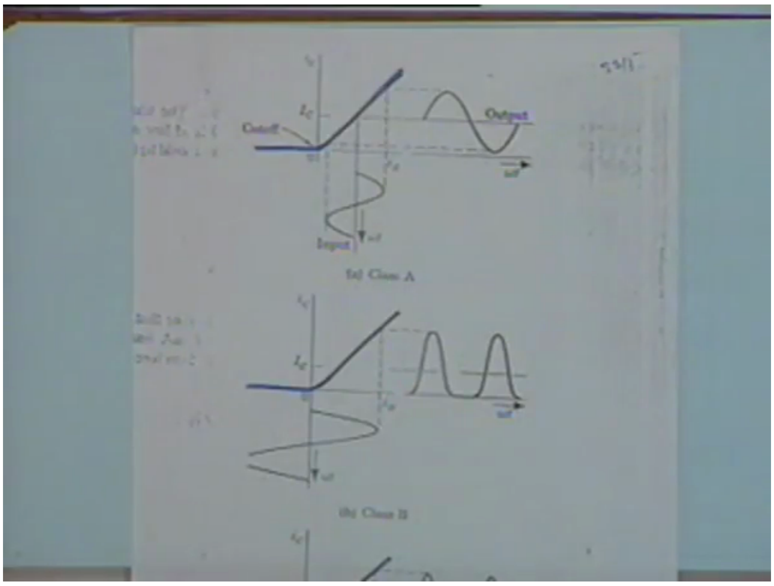

This is a pictorial representation of the 3 classes operation. You see this is a plot of I sub C collector current versus I sub B the base current and this card is linear For equal implements of base current in that equal impedance of collector current provided the base current is positive we are talking of what kind of transistor?

NPN, for PNP it is the other way down this current has to be negative it has to go out of the base, alright. So if this is the Q point then obviously if the base current varies like this, the collector current varies like this. So the collector current flows from the complete cycle. If the Q point is shifted here then it is only this part of the base current which makes the collector current flows. So the collector current is simply half sinusoid.

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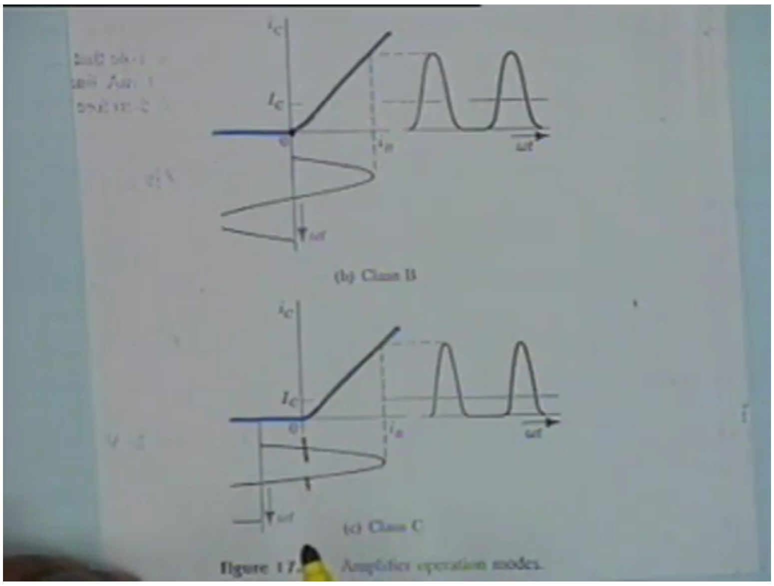

On the other hand if the Q point is shifted somewhere here that is the base is negatively biased. So that the signal has to rise above this limit to make the transistor conduct then you can get only arcs of the positive half cycles and this is a class C operation, these 3 terms should be remembered, what we have discussed so far is class A only.

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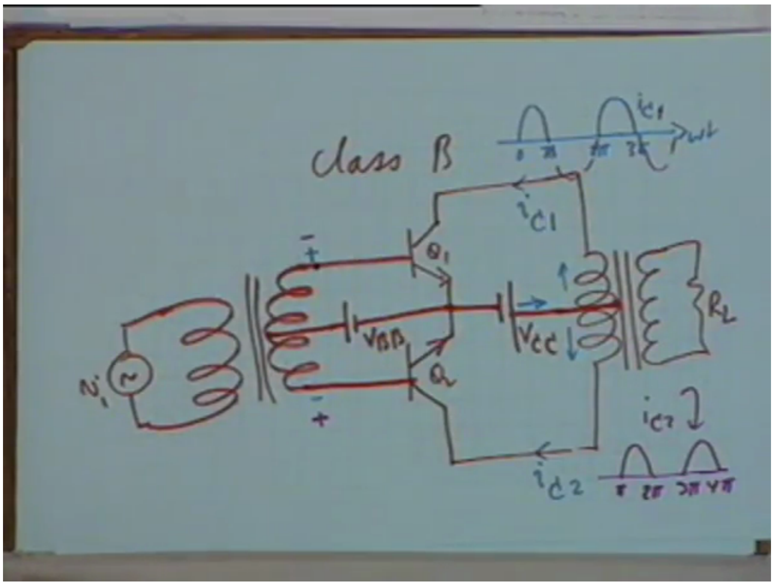

Now let us look at the typical class we operation. As I said in class B operation you use 2 transistors, okay. You use 2 transistors like this and in the base circuit you take this signal through the transformer, this is your signal to be amplified Vi, alright. And the base bias is provided by VBB like this. This VBB I have shown it schematically but it is obviously derive from VCC through a potential divide.

I have simplified this circuit by showing another additional battery but actually VBB is derived from VCC, only one power supply by an appropriatepotentially division of voltage. VBB if it is to be class B operation it has to be just on the verge of conduction, that is about 0.7 volts if it is silicon. Now in the collector circuit, you see there are 2 transistors Q1 and Q2.

In the collector circuit the 2 collectors are connected through a transformer the centered type of which is connected to this point and the battery VCC is connected here, VCC, alright. And the load is the secondary of the transformer, is in the secondary of the transformer let us call the load as RL. This is the circuit, do you understand the circuit?

There are 2 transistors in it, one is the input and the other is the output. Both transistors operate under class B condition that is normally it does not conduct, if there is a signal, in the absence of the signal there is no collector current. Let me show the directions in the collector current this is i sub C1 and this is i sub C2. So if you see I sub C1 and I sub C2 flow in opposite directions in the transformer, alright.

That means if it tries to create a flux in the positive direction this tries to create a flux in the negative direction, is that okay, is that clear? And the battery has to give out i C1 plus i C2 by KCl. By KCl the battery has to deliver i sub C1 plus i sub C2. Now let us look at what this i sub C1 plus i sub C2 consist of. You see when the AC is such that this is positive and this is negative, when the signal is such that the upper terminal is positive with respect to the lower terminal, obviously Q1 shall conduct, Q2 shall not conduct, alright.

When this point is positive with respect to the lower point, Q1 shall conduct not Q2 because Q2 base is the negatively biased, alright. Alright, so i sub C1, iC2 does not flow. How much, for how long does iC1 flow, only for half a cycle, only for half a cycle therefore if you plot iC1 it would be like this. iC1 will be pulses like this, half cycles if you plot versus omega t, 0 pi, yes how much is this? 2pi then 3pi and so on, alright.

Now when the polarity is reversed, that is this becomes positive with respect to this point then the opposite thing happens. What happens is, Q2 conducts Q1 does not conduct, if Q2 conducts i sub C2 flows. Now i sub C2, obviously shall also be like this where it will start from pi and it will go to, yes, 2pi then this will be 3pi and this will be 4pi and so on. This is i sub C2.

Is this too small, can you see this? Okay and the current that flows in the transformer primary, obviously is iC1 minus iC2, agree? Because they flow in the opposite directions, now if you take iC1 minus iC2, what do you get? You simply get the full wave here, alright. iC1 minus iC2 and therefore what flows to the primary over a certain duration of time?

Is the complete cycle and therefore in the secondary across RL we also get the complete sinusoid and there is no distortion, alright. But the advantage is, what is the advantage? That it is only one of the transistors which come back, normally without signal there is no power dissipation and therefore the efficiency should be high, alright.

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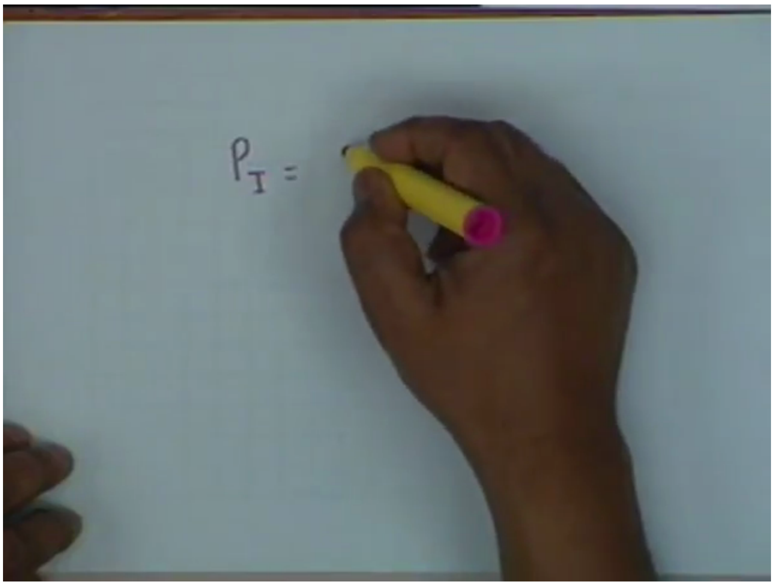

Let us look at what can be the ideal efficiency? Is the operation clear? Is there any question? No. Is there any question? No. What is the input power? Input power obviously is VCC.

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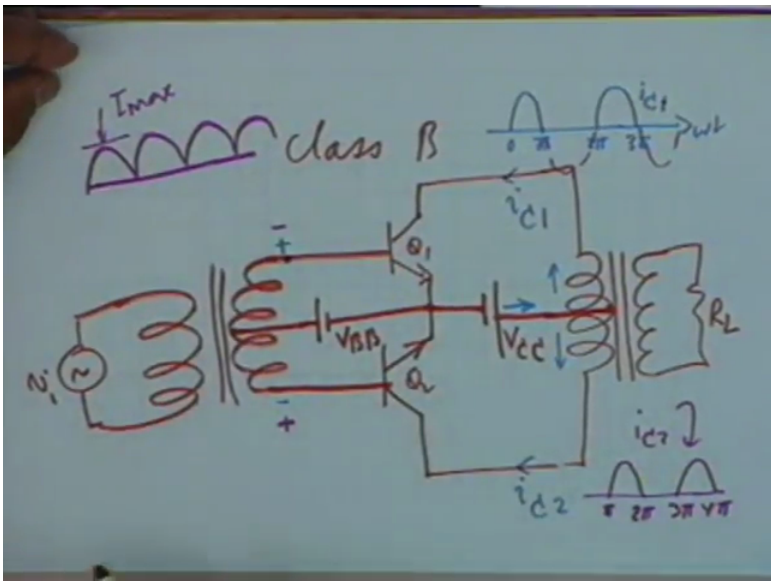

Let us look at these once more. Input power, what does the battery give out? iC1 plus iC2, now iC1 plus iC2, obviously is the full rectified sign, is not that right? And what is the DC that is drawn from the battery? The average value of this, ifthis is Imax then what is the average value? 2 by pi multiplied by Imax.

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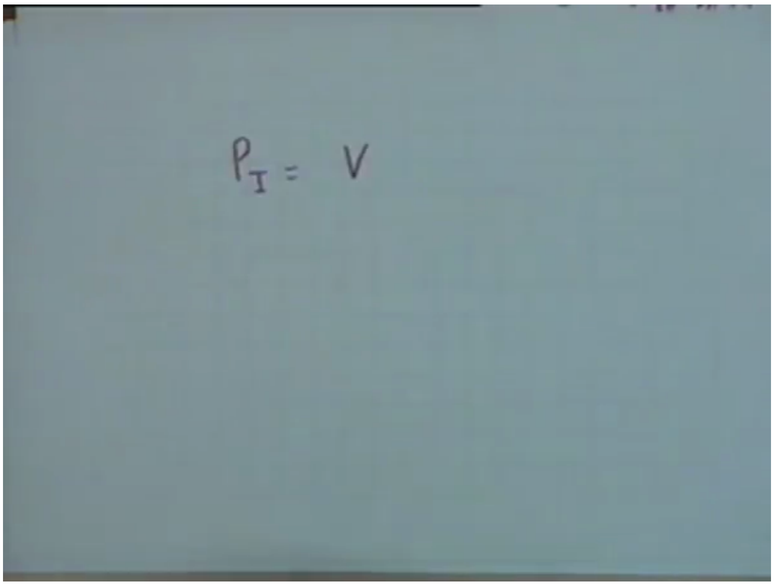

And therefore it is VCC times I sub C, where I sub C is Imax divided by pi, no twice Imax by pi. So this is equal to twice VCC Imax divided by pi. What is the relation between VCC and V-max? What is the relation between VCC and V-max?

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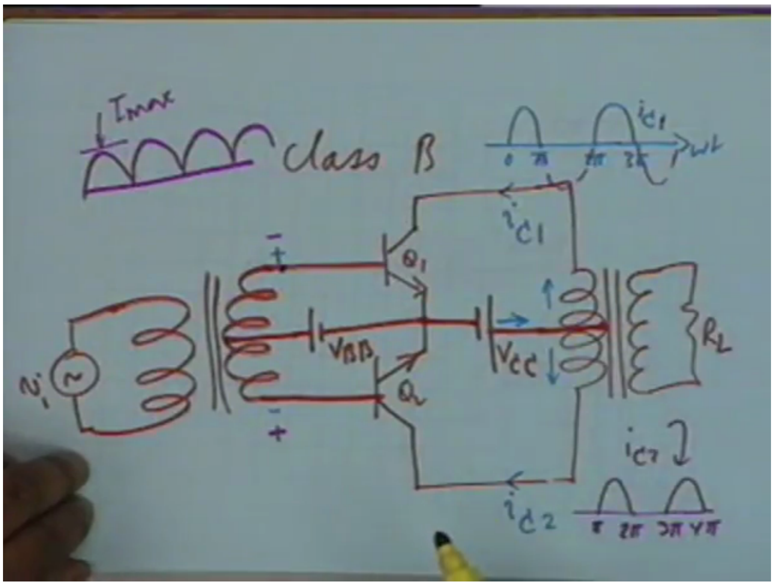

If you look at the circuit again is there any drop here in the transformer, no. And therefore VCC must be the Q point, agree? The load line must we, the DC load line is a vertical load line, agree? Is this point clear VCC is equal to V-max? No, it is not clear, alright.

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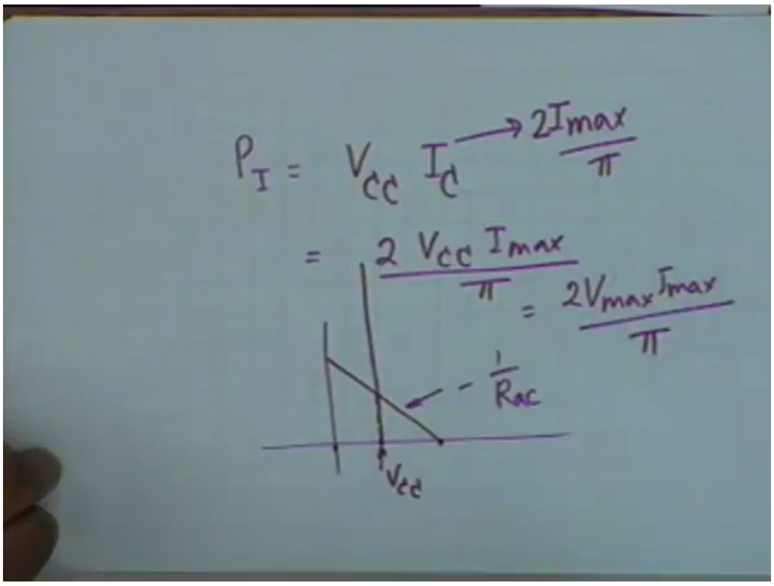

You recall this in the characteristics if this is the AC load line then the middle point is the Q point. This represents minus 1 by Rac this is the Q point, alright. Now what is this? What is the relation between this point and VCC? This must be the VCC because the DC resistance of the transformer primary is 0 and therefore the DC load line must be vertical wherever the DC load line cuts is VCC, alright.

So what is the maximum possible swing? Obviously the collector voltage can swing from 0 to twice VCC and therefore the peak value of the AC that is V-max shall be equal to VCC, alright. And therefore my input power is twice V-max IMAX divided by pi, alright. Twice V-max IMAX divided by pi.

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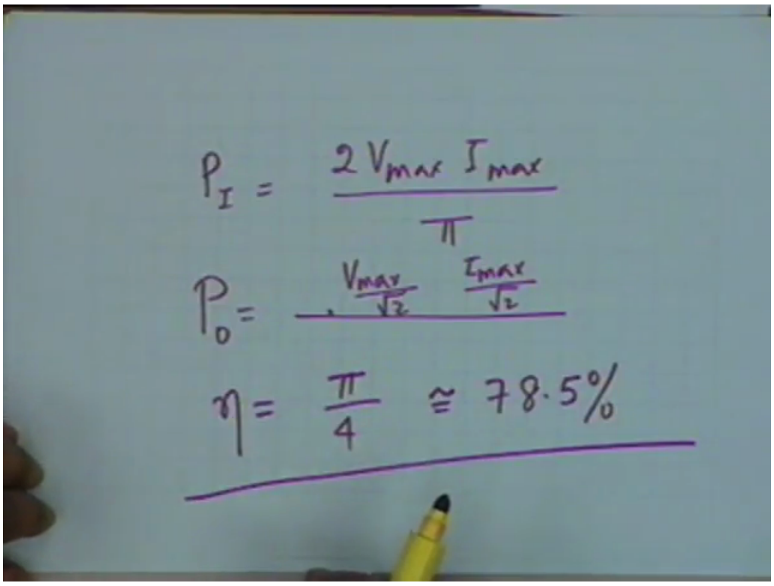

This is the input power P sub I equal to twice V-max IMAX divided by pi then what is the output power? Output power shall be the root mean square values, the product and the root mean square values of load voltage and load current. So it is the V-max divided by root 2 and IMAX divided by root this is my P0 and therefore the efficiency is if you divide this by this you can easily see that this is equal to pi by 4.

Root 2 multiplied by root 2 is 2 and this 2 pi by 4 which is how much? Approximately 78.5 percent this is the maximum efficiency that you can get from class B operation and most will be stereo amplifiers and probably your system amplifiers that you see operate under class B conditions because efficiency is important there.

Any question at this point? One of the greatest disadvantages of the power amplifier class B operation is that the cost increases due to the 2 transformers. One is required at the input the other at the output, 2 transformers are needed. Of course the input transformer is much smaller transformer, why? Because it does not have to dissipate, the input signal usually a very small signal, alright.

The question is can we reduce that cost? Can we avoid these 2 transformers? Yes, indeed it is possible only in semiconductor devices, this is something new as far as semiconductor devices are concerned it is pretty (()) (38:56) the electron tube did not have anything like this because in electron tubes we did not have complimentary transistors. In semiconductor devices we can have an NPN and PNP transistors by making a combination of 2 such transistors instead of using 2 NPN or 2 PNP in a class B push-pull amplifier.

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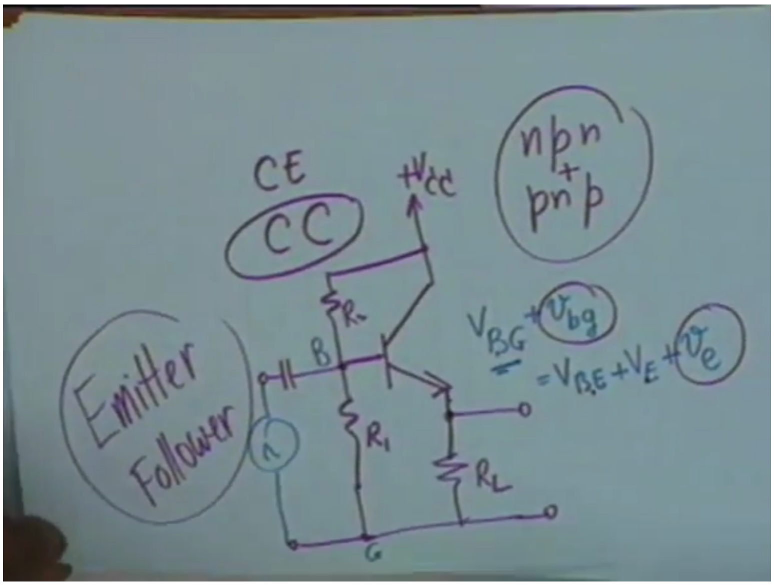

If you make a combination of NPN and PNP then you can avoid the transformer. Let me draw this circuit first then I will explain. The circuit the circuit uses what is known as, we have known common emitter amplifier, circuit uses common collector stages that is each of these stages NPN and PNP stage which are connected in a push pull configuration they are instead of CE the CC that means the collector is common between input and output.

While the actual circuit is like this for each transistor, I am showing an NPN first then I will show the PNP. There is connected directly to VCC, the collector is connected directly to VCC and as far as this is concerned this collector is grounded, agree? As far as AC is concerned collector is grounded and this is why the common collector then the input circuit the usual circuit that is you have R1 and R2 the load now, the load is not in the collector because collector is common.

Load is in the emitter, this is the load and the output voltage is taken from here. Input is applied between this point and this point. This is a typical circuit for common collector amplifier**,** Now if you take the voltages, voltage between B and G, if you call this as ground if you take the voltage between B and Q, VBG is the DC part of this voltage and there is an AC part also, let us say small v sub small b small g. This is the DC part and this is the AC part, alright.

This voltage has 2 components, one is prescribed by VCC, R1 and R2 and the other is a voltage that comes from the input signal, alright. It is important that you are listening what I am writing. The total voltage here is the sum of an AC part and the DC part. Now obviously this must be equal to B VBE, VBE which is DC which is a constant when the diode is conduct plus VE, VE as the voltage across RL has an AC part as well as a DC part.

So VE plus small ve, is that clear? And if the transistor is working in the linear region (()) (42:44) then obviously the AC part on the left hand side must be equal to the part on the right-hand side that means whatever you apply here must have come here. In other words the voltage at the emitter obviously then follows the voltage between the base and ground, is the point clear?

It is the AC part or the signal part not the VC that is why DC is considered VBG is equal to VBE plus VE, alright. In absence of a signal this is what will happen. in the presence of the signal whatever we apply between B and G shall now appear across RL and therefore this circuit is also given the name emitter follower which means that the emitter voltage follows the base voltage.

So what is the voltage gain? 1 then why should one use the circuit? Where is the current gain? If the base current is IB the emitter current shall be? Beta times IB, now if the voltages are equal input voltage is equal to output voltage but the output current is beta times the input current; obviously there is power gain, alright. And therefore this circuit can be used to advantage. This circuit is known as an emitter follower.

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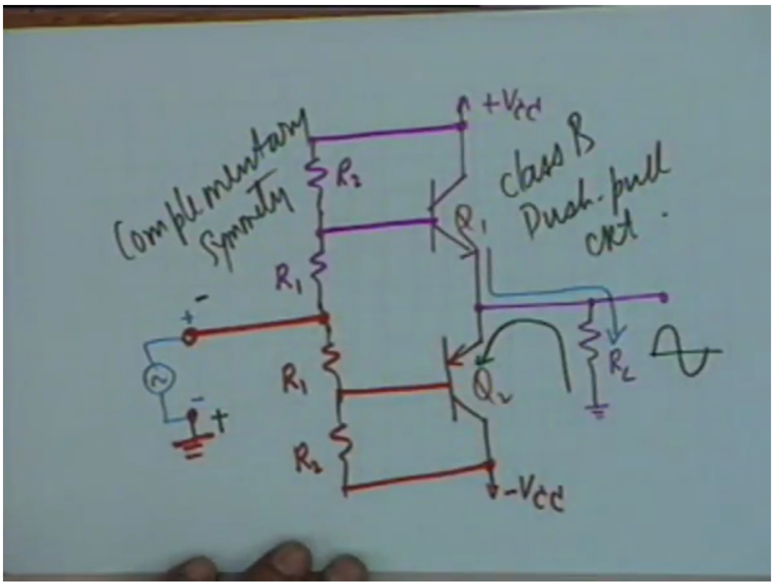

Now let us look at the power of the fire transformer less power amplifier using complimentary transistors the total circuit is known as complementary symmetry circuit.

Now try to draw with me. We have plus VCC; let us draw the NPN transistor first. You see there is nothing in the collector because it is to be an emitter follower and the emitter is then connected to an RL as you saw earlier. and the output is taken here, alright.

The base is biased in usual manner that is you have an R2 and then and R1, I have not complete the circuit here because I have to draw the other transistor also, alright. Then the other transistor, the other transistor instead of NPN let me show it in a different colour. It is PNP and therefore the emitter goes in, emitter goes in the collector comes out and to what kind of a supply should this go?

Obviously to negative supply, so minus VCC, you could have a signal supply, this is a positive terminal and this is negative terminal or you could have 2 supplies, alright. There supplies available plus 12 0 minus 12, alright. So this is the condition and then usual biasing circuit, the biasing circuit is again the same R1 R2, obviously in order that the push pull circuit works the 2 transistors must have identical correct mistakes.

So Q1 and Q2 are 2 identical transistors except that they are complimentary symmetry that is one is at NPN and other is at PNP, now where should this go? These 2 are also connected and the input is applied between this point and ground. The output is taken from here to ground. Let us see what happens when you connect an AC source let say here?

When you connect a signal source here, when this terminal is positive with respect to this terminal then current flows like this, the current flows throughthe PNP transistor, so the PNP transistor conducts I am sorry not PNP, NPN transistor conducts and it allows the current to flow like this, is that clear?

Why does not the current flow in this direction? Because Q2 does not conduct, is the point clear? R1 and R2 are so selective that if bases are just on the verge of conduction, so as soon as this terminal is positive the current flows like this through the transistor Q1 to the load RL, alright. On the other hand when it goes negative, when this becomes positive and this becomes negative Q2 conducts, there is the current now comes from the base of Q2, right?

It is a PNP transistor, current comes from the base of Q2 and flows like this and therefore what happens is, the current comes into the emitter and flows like this, agree? And therefore what does the load see? Load is never deprived of any current, it gets current due to the positive half cycle from Q1, it gets current then the negative half cycle from Q2 and it gets in the correct direction and therefore the voltage across RL is simply the full sine wave and the circuit is the most popular power amplifier circuit which is called the complimentary symmetry power amplifier.

Complimentary symmetry you can give other adjectives class B push pull circuit. A complimentary symmetry requires, we wanted to avoid transformers, right? And therefore the collectors have now been declared as dead they are connected to ground, collectors. You take the output across the emitter and this is where I have to introduce the emitter follower circuit, alright.

This, as I said is the most popular circuit. In the next class we will start a small signal model of the bipolar junction transistor.