Electronics for Analog Signal Processing - II
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Lecture - 22
Power Amplifier (Continued)

Now, let us consider an example.

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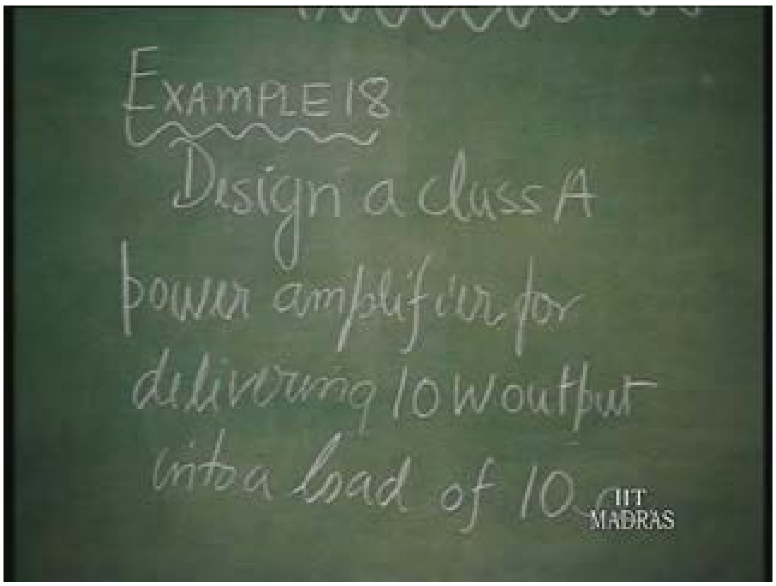

Example. Design a Class A power amplifier for delivering 10 watt output into a load of 10 ohm. So, this is a typical design of power amplifiers.

The R L is given as 10 ohms; power output is given as 10 watts; and from our discussion earlier, we had the configuration that has been chosen. This is 10 ohms, this is V c c. So, we know that V c c square by 8 R L... please remember that the maximum swing was V c c by 2. And therefore, the peak voltage across the load was V c c by 2; and therefore, the r m s value of that voltage is V c c by 2 root 2; that squared... V c c divided by 2 root 2; v square by R L is the power output. So, that is actually V c c square divided by 8 R L.

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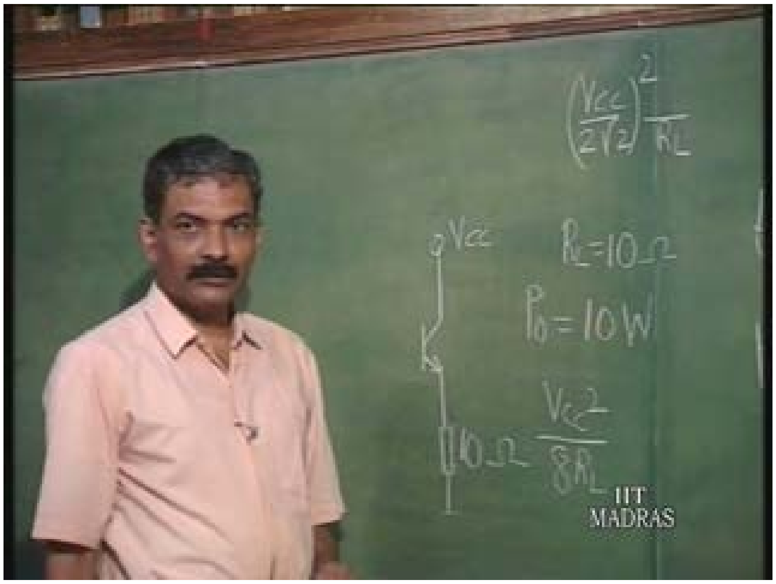

So, if you use a load of 10 ohms therefore, V c c square divided by 8 into 10 is going to be equal to 10 watts.

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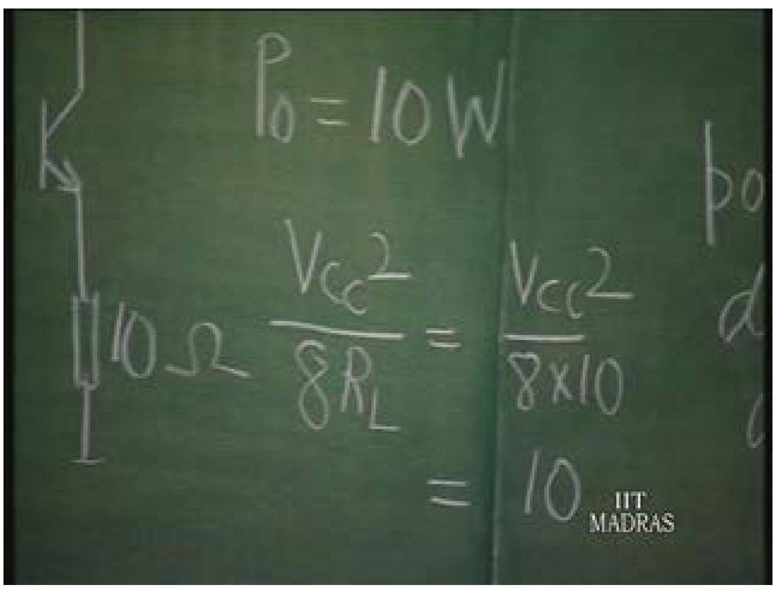

So, the minimum value of V c c you should use... you can use higher value if you want, but then you are unnecessarily wasting power. So, the V c c minimum can be obtained from this; V c c square is going to be equal to 800.

V c c square divided by 80 is equal to 10 watts. So, V c c square is equal to 800 or V c c is equal to root of 800 which is 400 into 2; that means 20 root 2. 400 into 2; so, 1 point 4. So, this is actually 10, 28 volts.

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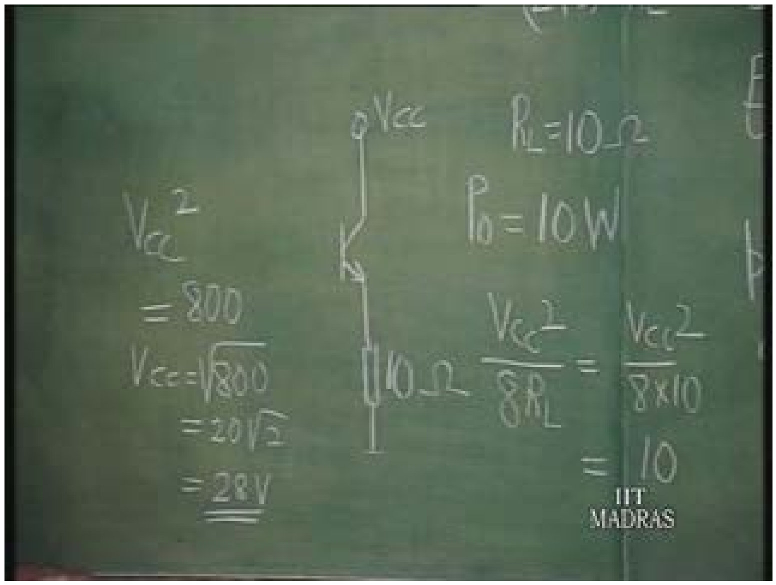

So, you can now see that supply voltage, minimum , is 28 volts. May be, you will fix it at 30 volts; see if you want it. So, this is the supply voltage. If this is taken as a supply voltage, V c c equal to 28 volts. What is the quiescent current? We would like to know. So, V c c by 2 is the quiescent voltage at this point; that divided by 10 ohms - that is going to be the I Q. Is it clear? V c c is already known as 28 volts by 20. So, you have to operate it at 1 point 4 amperes.

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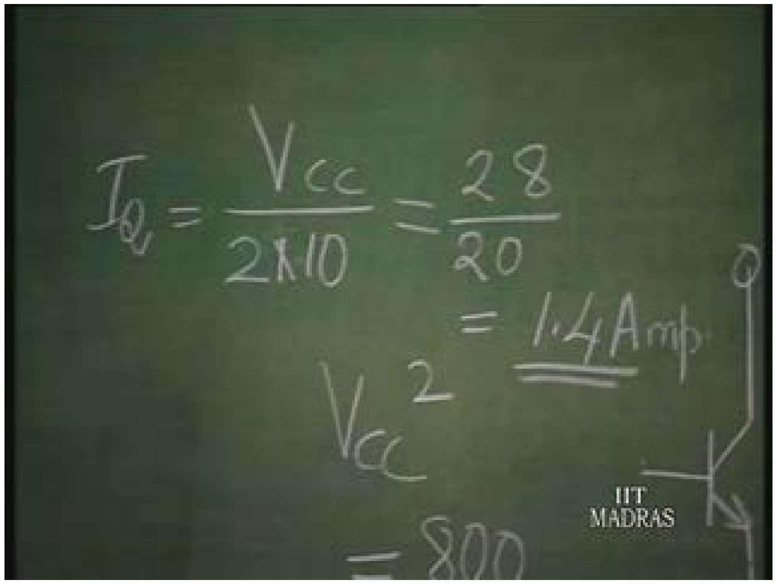

So, in order to get 10 watts output, our quiescent current should be 1 point 4 amperes.

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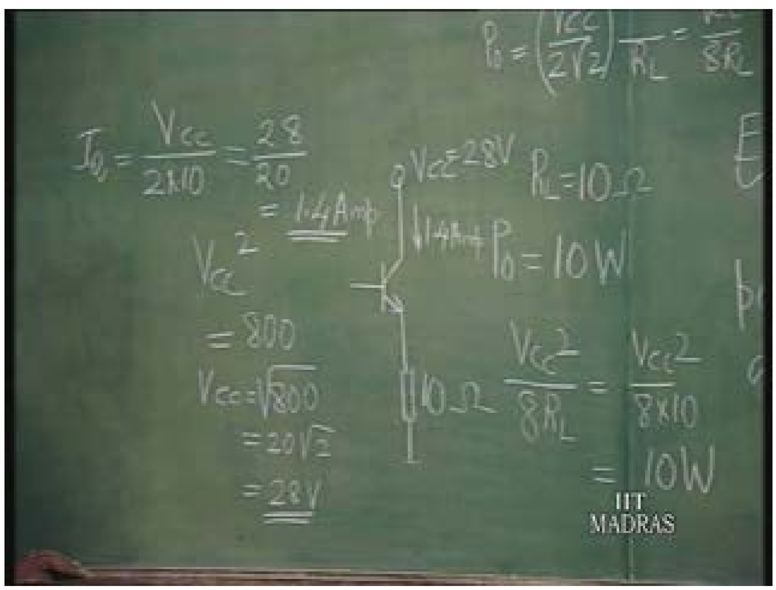

Now, how to make it operate at 1 point 4 amperes? This 1 point 4 amperes flowing through 10 ohms will generate here 14 volts. That is understandable because 28, half of that. So this 14; so, quiescent voltage here should be 14 point, let us say, 7 volts. That should be the V B Q. So, we have now got V B Q.

So, we have to put here a resistance arrangement R 1 by R 1 plus R 2; from 28 volts, R 1 by R 1 plus R 2 into 28 shall be equal to 14 point 7 volts; it is about almost half. R 1 is very nearly made equal to R 2 because this 14 point 7...that is the situation.

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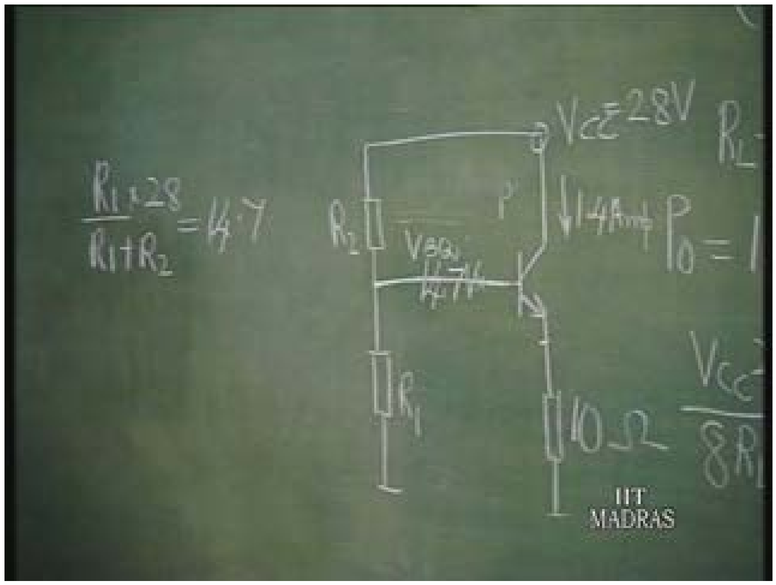

And if you know the Beta of the transistor, this divided by Beta... Let us say, Beta is 100. So, 1 point 4 by 100 is going to be about 14 milliamperes.

So, 14 milliamperes should become small compared to the current in this. That means you might have to at least spend about 140 milliamperes here. So, if Beta is, let us say 100, this current is about 14 milliamperes. So, this current is about 14 milliamperes. So, this current at least shall be 140 milliamperes, let us say. You cannot make it more, much more than 140 milliamperes because that will become comparable to 1 point 4 amperes. So, it is one tenth of this; but 10 times this.

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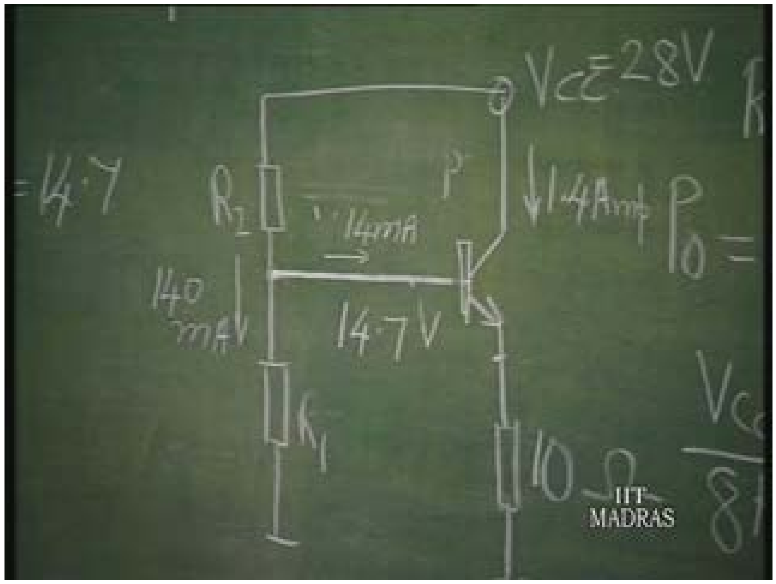

So, you can see this; therefore, R 1 plus R 2, 28 divided by R 1 plus R 2 is equal to 140 milliamperes. So, R 1 plus R 2 is equal to 28 by 140 K. So, about 200 ohms.

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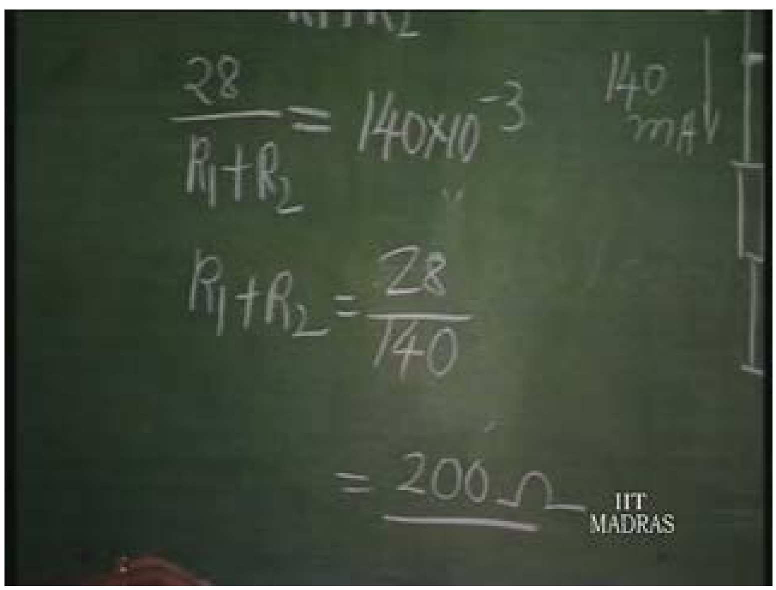

So, from these two, these things, you can find out the value of R 1 and R 2. R 1 is very nearly equal to R 2. That means, this is very near 100 ohms, this being slightly greater than 100 ohms. You can find out R 1 and R 2. I will leave it as an exercise for you. From this.

So, this is the complete design of my power amplifier. Now I have to specify the transistor. The circuit is completed.

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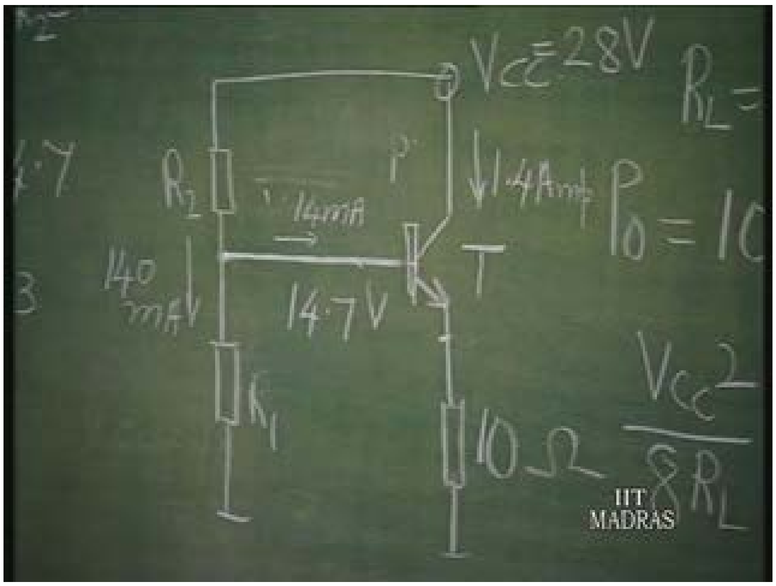

Transistor T; 10 watts power is dissipated, actually speaking, in the output. What is the power input? Let us see. 28 into what? Actually speaking, 1 point 4 plus point 14; so actually, 1 point 54 watts. That is the power input. How much? 43 point 1 watts.

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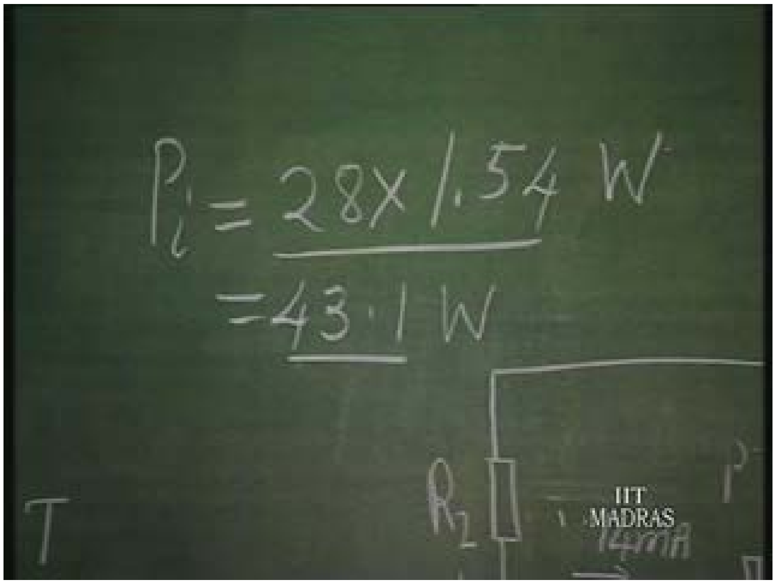

So, you can see that that is 10 watts; this is almost 4 times that. Now, because particularly we have included other bias, these things, etcetera, so it is less efficient than what we have considered. Best efficiency is 25 percent. So, less efficient than that. Then, what is the power dissipated in the transistor? If 10 watts is the output power...you can see that power dissipated in the 10 ohms is going to be power dissipa... This 1 point 4 amperes is flowing through this 10 ohms and the transistor. So, the transistor voltage is 1 point 4 into 28 minus 14. That is 14 volts.

So, 1 point 4 amperes into V C E. V C E is 14 volts. So, that is the power dissipated in the transistor. How much is this? 19 point 6 watts. The resistance dissipates about 14 watts, 1 point 4 into 10, 14 watts. So, 19 point 6 watts is the maximum power that is dissipated in the transistor under quiescent condition.

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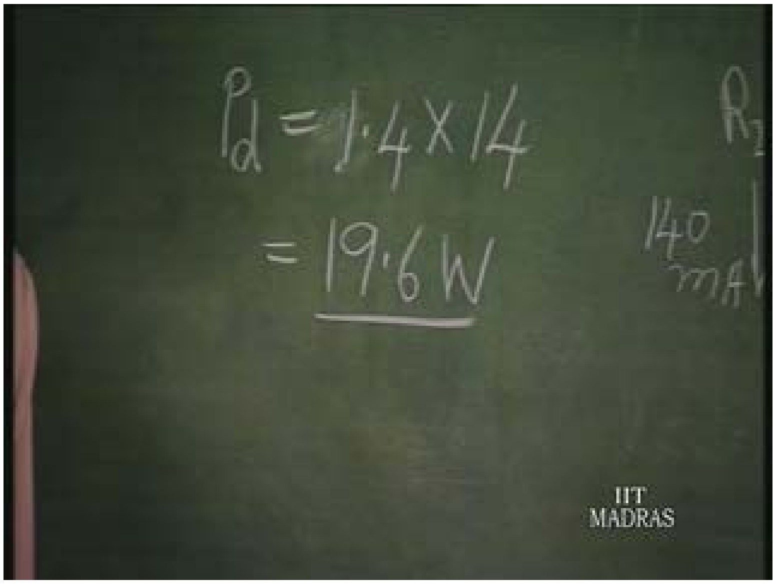

43 point 1 is dissipated overall just to get 10 watts output signal power. So, the transistor has to be rated for 19 point 6 watts greater than... So, transistor power dissipation should be greater than 19 point 6 watts. Some 20 watt transistor or something like that, you can select.

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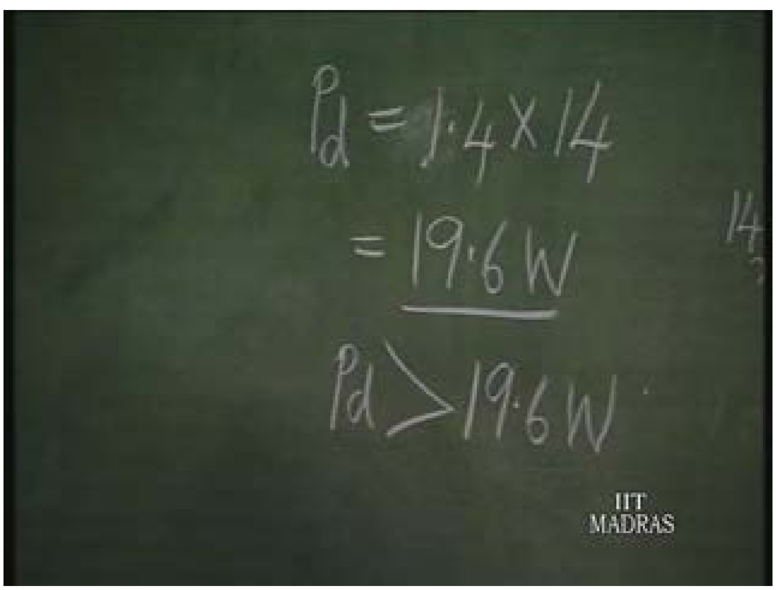

The current, the maximum current through the circuit is going to be 28 volts divided by 10 ohms. Then this goes to V c c. So, that is maximum current. 28 volts divided by 10 ohms which is 2 point 8 amperes. So, the current rating of the transistor should be greater than 2 point 8 amperes; so something like 3 amperes or so, the current rating. And voltage rating obviously is 28 volts. V C E max should be greater than 28. So, these are the ratings of the transistor, required.

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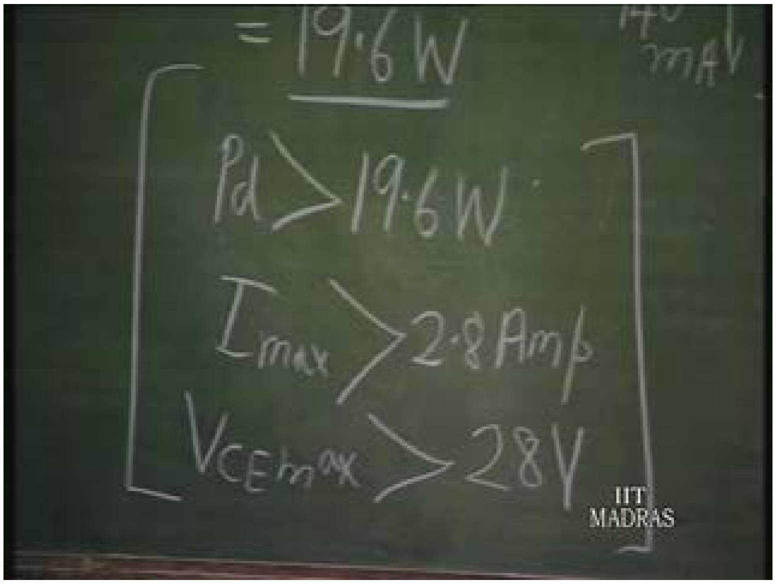

So now, the design is complete. You can therefore specify what kind of transistor is required here, put the circuit and it should work satisfactorily.

Now that we have seen Class A power amplifier, how inefficient it is. For delivering a power output of 10 watts, we had to spend something like 43 watts or so; totally inefficient. Now, we are coming to one of the most efficient power amplifiers existing today. This is covering 90 percent of the Classical power amplifiers available to us. So, this is Class B power amplifier. What we have discussed is Class A power amplifier.

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What is Class A? Class A says that if you have a transistor operating at 1 milliampere current, quiescent current, the current can change up to zero milliampere to 2 milliamperes. That is all. If you have it operating at 2 milliamperes, it will change up to zero milliamperes, up to 4 milliamperes on the other side.

So, this tells us that transistor has to keep waiting with a quiescent current, constant current and keep dissipating lot of power before it encounters the signal. This is not a very efficient way of doing it.

Instead, we just mentioned last time also that the transistor will be permitted to sleep and is woken up only when the signal arrives and that kind of operation is Class B operation. That means transistor is off when the signal is not there and signal itself makes it go to on state.

So, the transistor is now biased to V at off state. Let us say, transistor is simply ground... grounded here or there on the... Let us consider the same common collector state, for example. How do we work this out? Normally, I connected I to V B Q. Now, I do not want to connect it to V B Q at all. It is just simply grounded, let us say.

So, this is actually off even though the load is still connected here; but then, the moment the signal comes, I will make this signal itself conduct. But the only signal that will conduct this transistor is positive going signal. That much I know. And that also, it has to cross V Gamma. This is called the cut-in voltage.

So, if that is not a problem because V Gamma is only point 7, my signal is going up to, I say, 20 volts or 30 volts. So, I can just say that as soon as that finally comes, it conducts. So, this is going to conduct only for positive going cycle. So, that means, one half of my sine wave, we can make this work. When this sine wave comes, the output will be a sine wave. There is no quiescent current. Quiescent current is zero. So, the power supply is not delivering any power, as long as the signal is not there. When the signal is there, it is delivering power.

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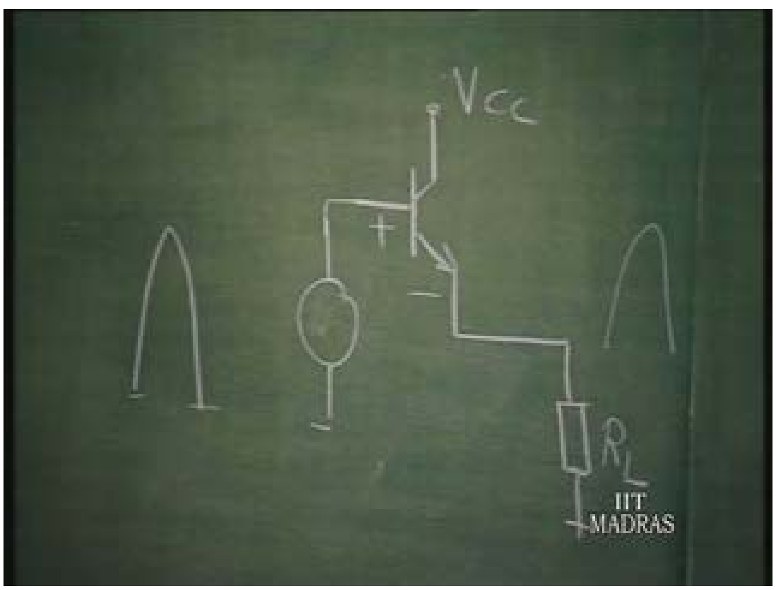

Let us look at it. If this is the wave I want to amplify, only one half of the sine wave...the other half, I will take care of by using another transistor which is connected to minus V c c, let us say. So, that will be... if this is n p n, this will be p n p and this will be connected to minus V c c; and it will be connected to the same input so that this can go both positive and negative. This is the famous complimentary symmetric pair: p n p, n p n, p n p pair, Class B. Necessarily, for Class B to be operative, one half of the wave form is to be taken care of – n p n. The other half of the wave form is to be taken care of by p n p, both working on to the same load from the same input.

So, this structure is one of the most popular structures because it does not need any biasing arrangement. Signals itself is biasing it and the quiescent dissipation is zero. Now, let us see the efficiency. Obviously, when one half of the signal comes, let us say, this is going to be V p, this is V p sine Omega t. Output is going to be V p sine Omega t. It is unity gain, one half being produced by n p n, the other half being produced by p n p.

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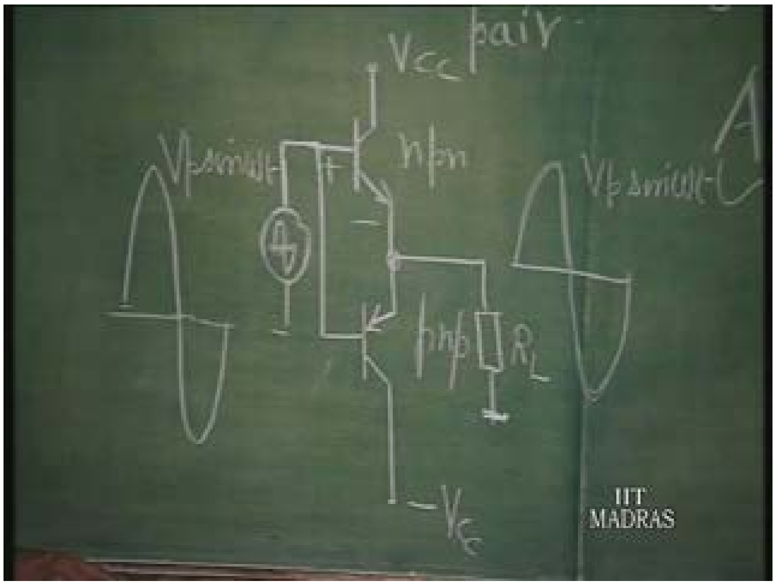

Now, of course, there is going to be a small amount of distortion. This is called cross over distortion. At the point of cross over, there will be small gap because until the voltage reaches V Gamma, none of the two transistors conduct. When it goes to V Gamma, this will conduct. When it goes to minus V Gamma or lower, this will conduct. So, in between therefore, there is going to be some gap like this. If I exaggerate it, or, if the peak voltage is low, you can see this; and this is called cross over distortion.

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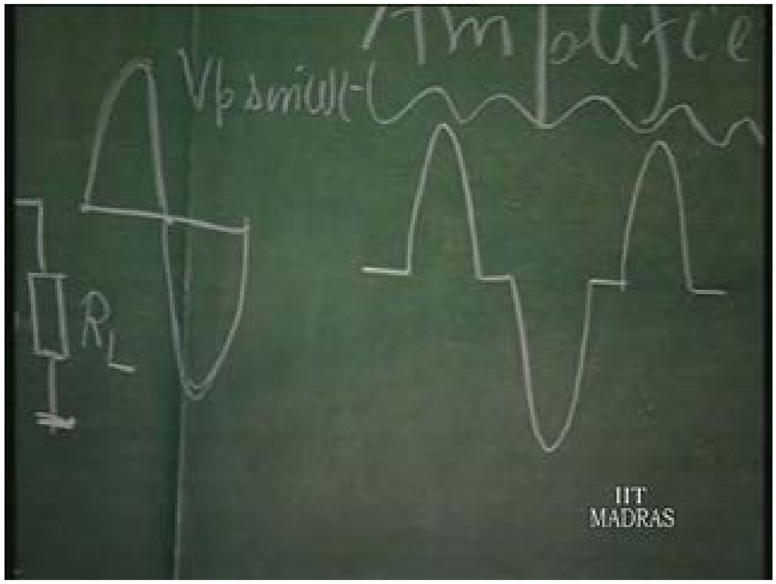

Unlike other distortions, this...this distortion is more when the signal is small and distortion is less when the signal is large. Other distortions are the other way about. When the signal is small, the distortion is less and the signal is large distortion is more; whereas, cross over distortion - when the signal is small, distortion is more and signal is large compared to V Gamma, the distortion is less.

So, this cross over distortion is one thing that will come... We will see how we can get rid of this distortion; but this is a very useful configuration. Suppose it is something like full swing of 28 volts, etcetera. This cross over distortion will not be visible at all to you; and when you feed a sine wave with the peak amplitude of 28 volts, you will get a sine wave of 28 volts output or 30 volts output, depending upon the V c c. Suppose therefore, V p sine Omega t is the input; we are now able to produce that output without much of a problem, let us assume.

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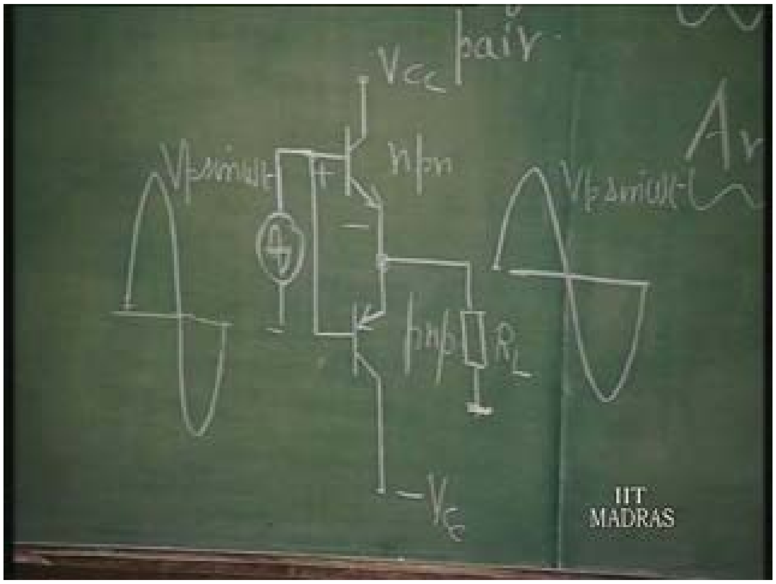

Now, let us try to find out what the output power is. Output power is V p squared...V p by root 2 is the r m s value; V p square by 2 R L, V p square by 2 R L. Always. If V p is the peak, V p square by 2 R L is the output power.

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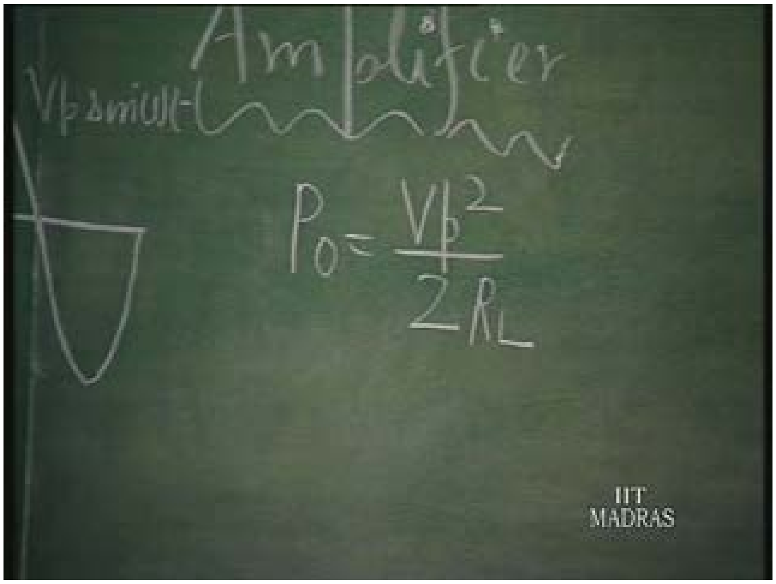

Now, as far as V p is concerned, in this case, let us say V p can go as much as V c c and on the other side, it can go to minus V c c. So, V p is V c c maximum. So, maximum power output is V c c square divided by 2 R L. Let us keep that separate. This is power at any peak swing V p. This is the maximum power output.

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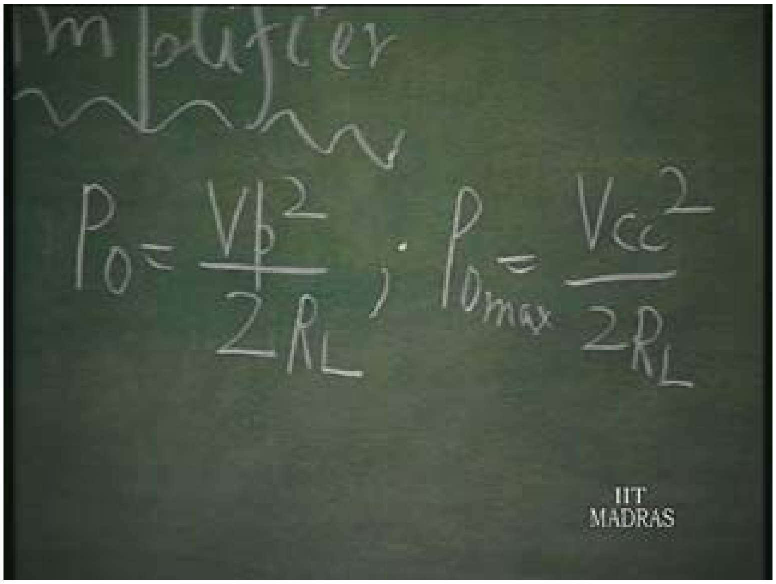

Power input. This is very interesting. One half of the cycle, one half of the cycle... This conducts; and it will produce a current which is V p sign Omega t divided by R L across the... So, this is the current wave form.

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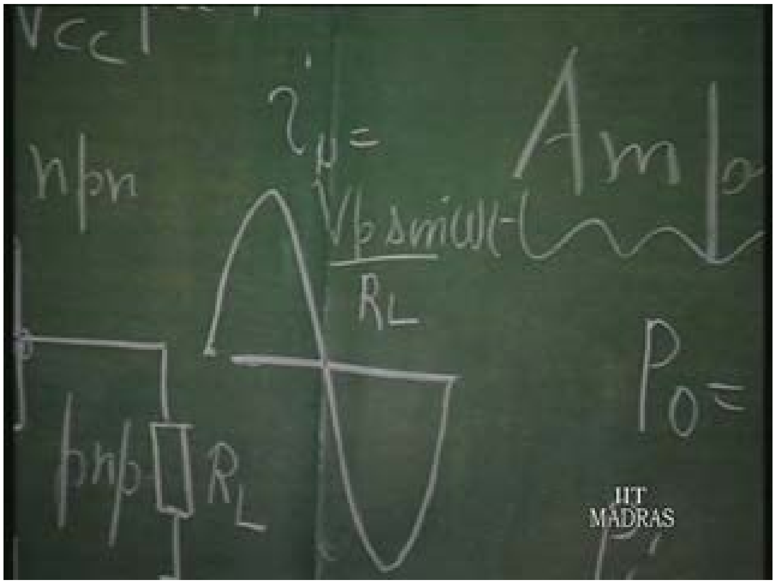

Now you have current wave form, half, half wave form current for this and other half is giving to be for this. Though, only for half the period... This is the period. For T by 2, each transistor conducts.

So, this is going to be the current wave form into each of the supplies. Let us consider now what is the average current. If this is V p, average current, if this is V p by R L, let us say, peak; average current is going to be V p by R L divided by pi. We know. For the half wave, rectified sine wave, average is V p by pi into R L. This we had discussed long ago in electronics. Rectifiers.

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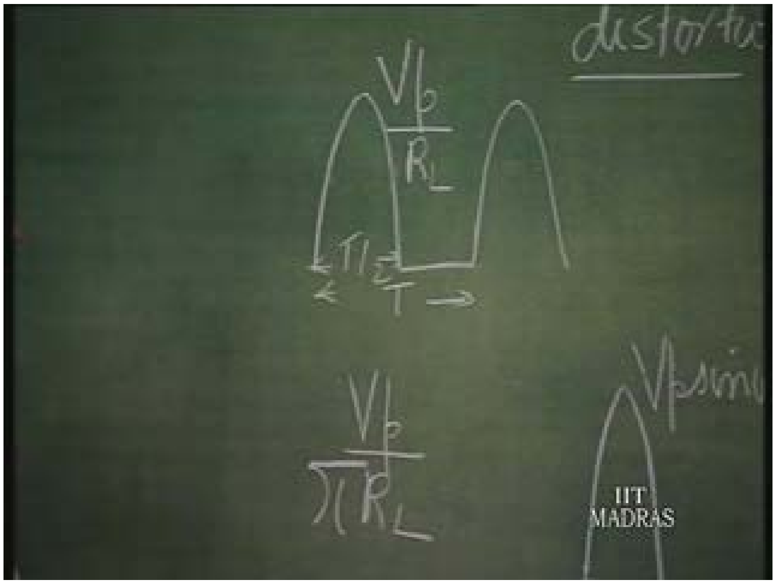

So, this into V c c is the power delivered by positive supply. This is the average current; this into V c c is the power delivered by the positive supply. That again into another V c c is going to be power delivered by the negative supply also. That into, therefore, 2. This power is going to be delivered by positive supply and there is same power dissipated in the negative supply also. So, total power dissipated is 2 times that. So, this is the power input.

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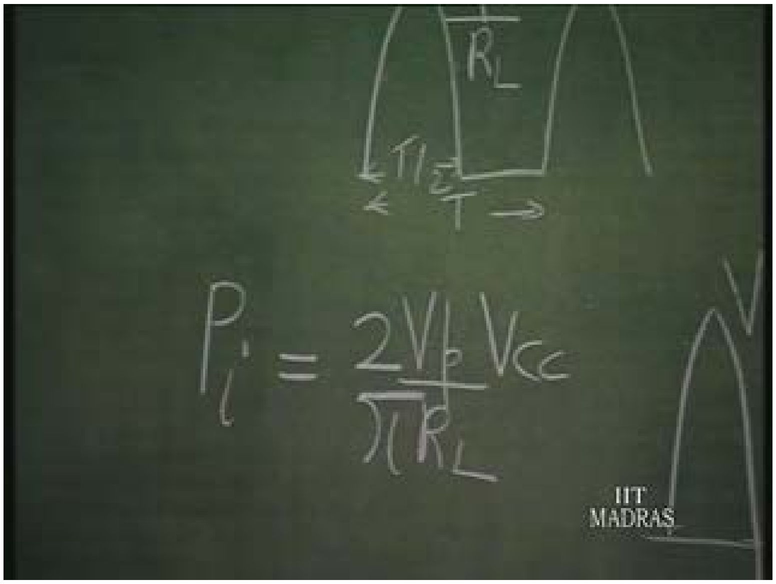

So, we can now say that the power input in general is twice by pi V c c into V p by R L, in general.

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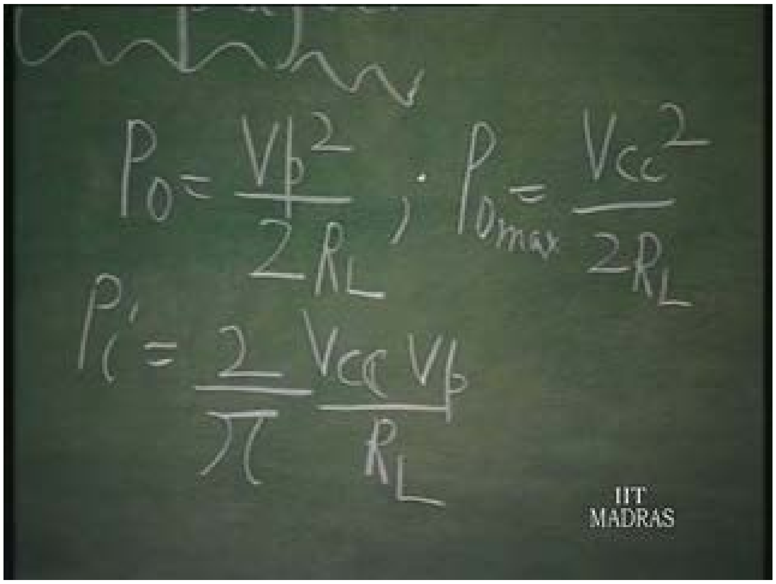

So, what is efficiency? Efficiency is output power divided by input power. So, P out by P i is equal to V p square by 2 R L. That is the output power. Input power is twice V c c V p by pi R L.

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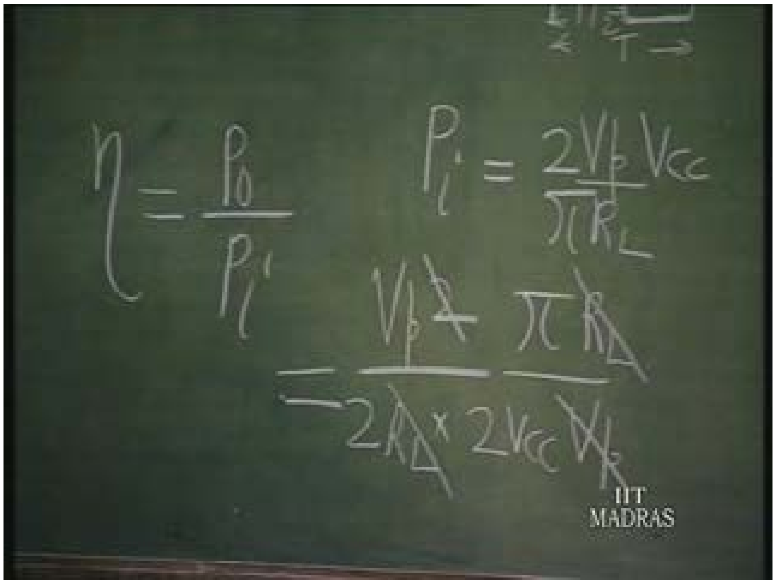

So, efficiency is... at any point; this is at any point; efficiency is going to be pi by 4... pi by 4 into V p by V c c. What is therefore the maximum efficiency? Maximum efficiency occurs when maximum power output is got. You can see that because it is directly proportional to V p by V c c. When V p becomes equal to V c c, maximum efficiency is got. That is for maximum output power.

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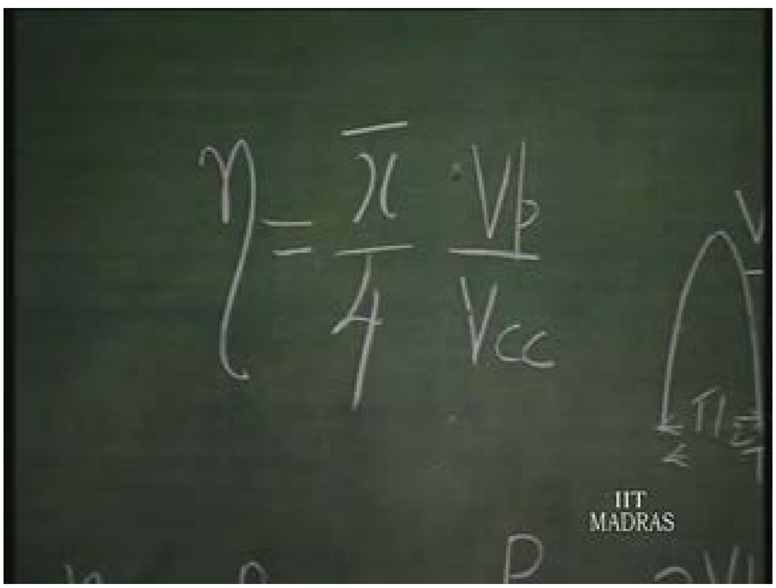

So maximum efficiency occurs for V p equal to V c c. That corresponds to P naught max; and therefore that is going to be equal to pi by 4; very important relationship. What is pi by 4? pi is 22 by 7, 28 or 11 by 14 is going to be point... So, point 78 or about 78 percent efficiency.

This is the best possible efficiency you can think of for a Class B power amplifier. That is, when you are getting the maximum output power. So, it is always less than 78 percent. What it means is, if 20, let us say, 78 percent efficiency simply means that the wasted power is only about 22 percent. 78 point 6. This is... very useful to remember this because it is nothing but pi by 4. 3 point 14 divided by 4.

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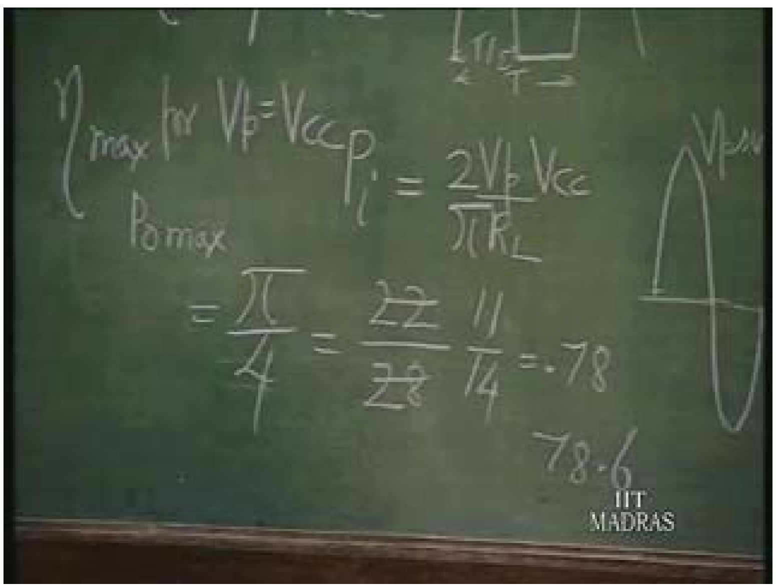

Now, I would like to point out something that is very important. This is not 100 percent. It is pretty close to 100 percent, very nearly 80 percent; but this is good enough. For most of the linear amplifiers, this power amplifier is quite often used.

Now therefore, let us see what is the power dissipation maximum required for the transistors now, because the transistors do not dissipate any power when the input signal is zero. Again when the input signal is maximum, they will dissipate least amount of power because most of the power has been transferred to the load. So, the transistors will dissipate power, maximum, only somewhere in between; not for the maximum drive. This can be illustrated mathematically also.

So, what is the transistor power dissipation? We have to find out the maximum dissipation that is likely to occur in the transistor for the certain specific signal condition and then put that transistor with that power dissipation or higher power dissipation there. So, let us see how to select this kind of transistor.

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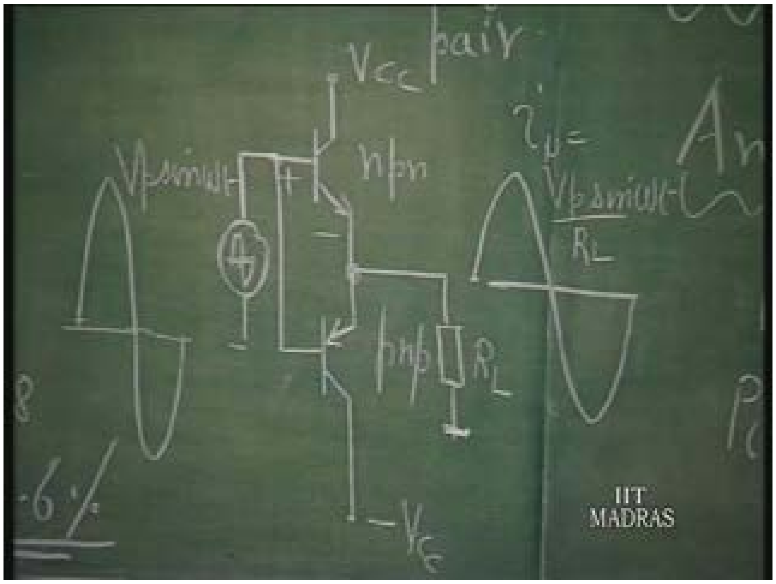

P i is given as 2 by pi V c c V p by R L from that. This is the input power. Output power is V p square by twice R L. What is the power dissipated in the transistor? Output power is coming across this load and input power is being taken from this. The entire power now is dissipated only in the two transistors.

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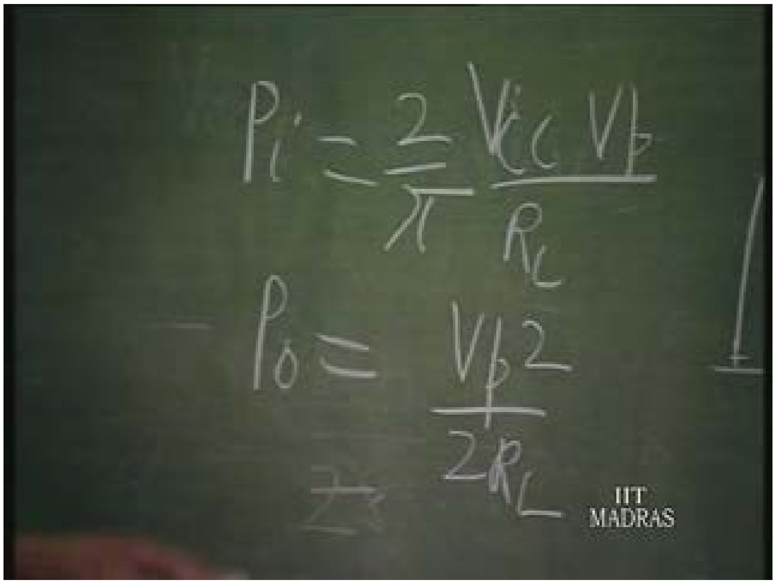

So, the power dissipated in the two transistors, two transistors mind you, is going to be input minus output, simply. So, power dissipated in the transistors is power inputted minus power output, is 2 by pi V c c V p divided by R L minus V p square by twice R L.

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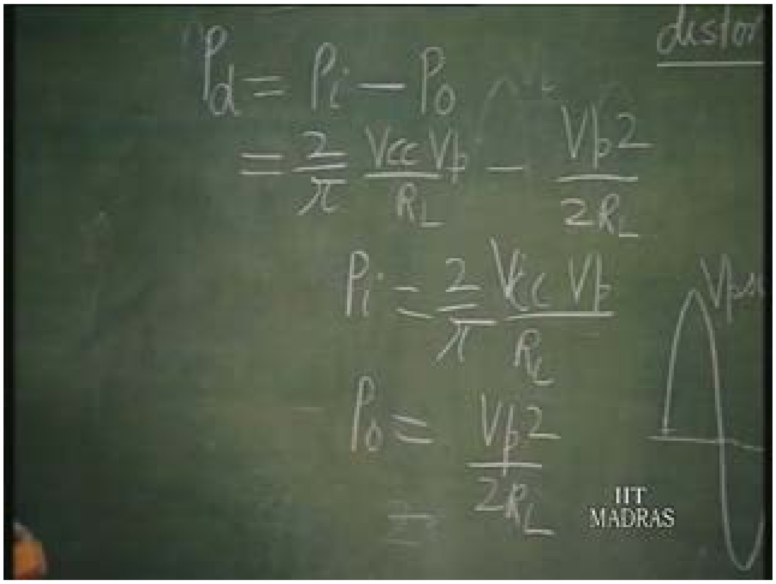

So, this is the power dissipated in the what? - two transistors. This is therefore...we can find out when this becomes maximum. So, we just simply differentiate this with respect to V p. V p is the variable. Delta P d by Delta V p, when it is going to be maximum, has to be equal to...equated to zero. So, let us find Delta V p...P d by Delta V p. So, this is 2 V c c by pi R L here, minus twice V p by 2 R L. So, that should become equal to zero;

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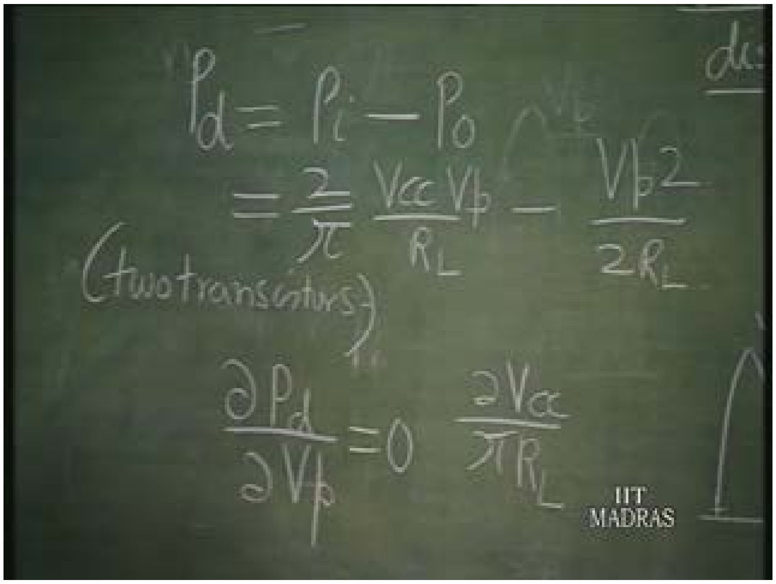

And therefore, we get this condition. V p should be equal to twice V c c by pi.

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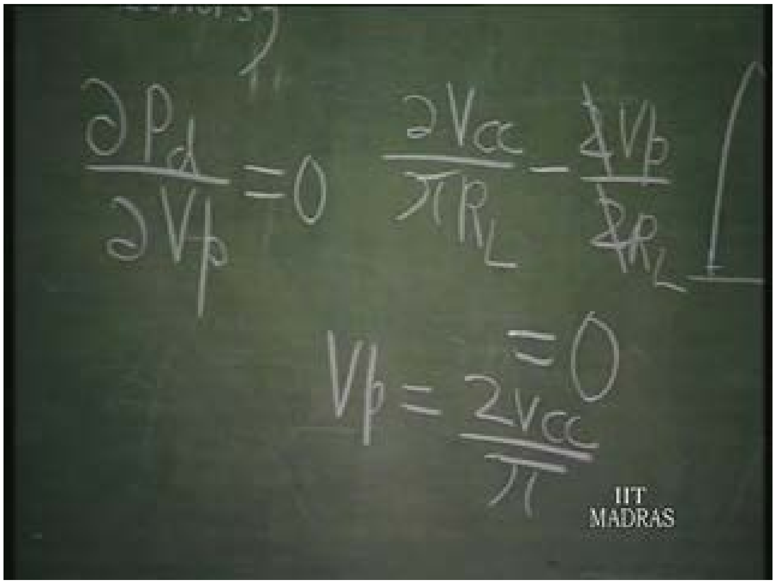

This is the signal drive. It is not the full signal drive. Full signal drive corresponds to V p equal to V c c. It is almost two-thirds that. At that signal drive, output power is not maximum; but the power dissipated in the transistor, two transistors is maximum. So, let us find out what that power dissipated is. So, the power dissipated in the transistors is...You can substitute this V p into this equation.

And, this is going to be equal to 2 V c c by pi R L into V p which is 2 V c c by pi. That means 4 by pi square V c c square by R L minus 4 V c c square by pi square R L by 2.

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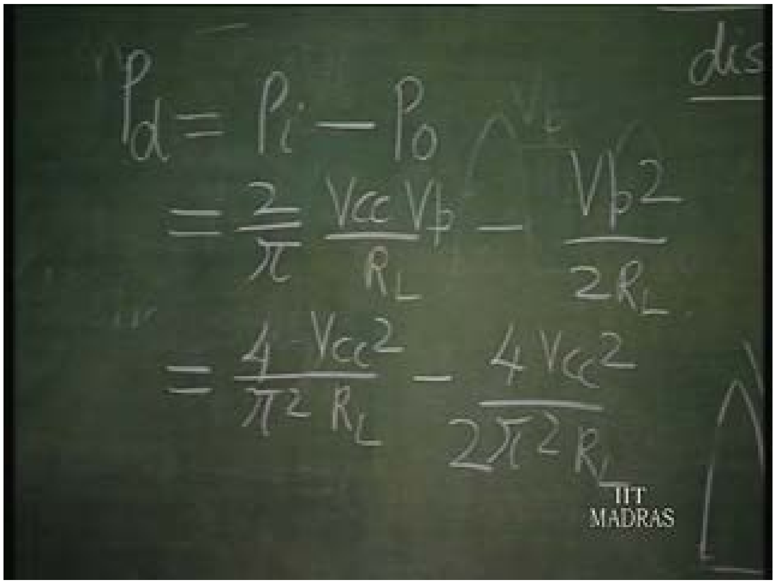

So, 4 V c c square by pi square R L minus half of that. So, it is nothing but half of this; or, 2 by pi square V c c square by 2 V c c square by pi square R L. That is the power dissipated in two transistors.

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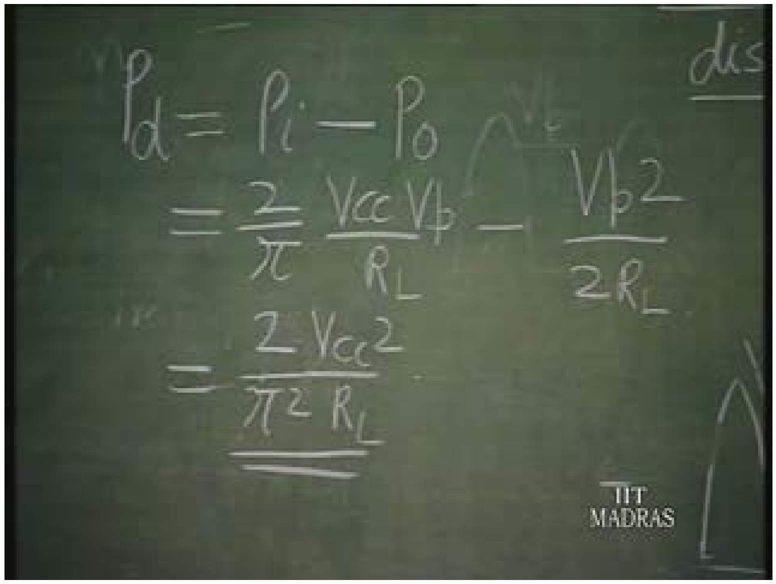

So, power dissipated in one transistor equals half of this, which is 1 over pi square V c c square by R L. 1 over pi square is nearly one tenth; pi square can be made equal to 10. So, one tenth of V c c square by R L. You can see this. V c c square divided by 2 R L is the P naught max, maximum power output you are capable of getting from this arrangement of complimentary pair with V c c here and minus V c c here, is equal to V c c square divided by 2 R L.

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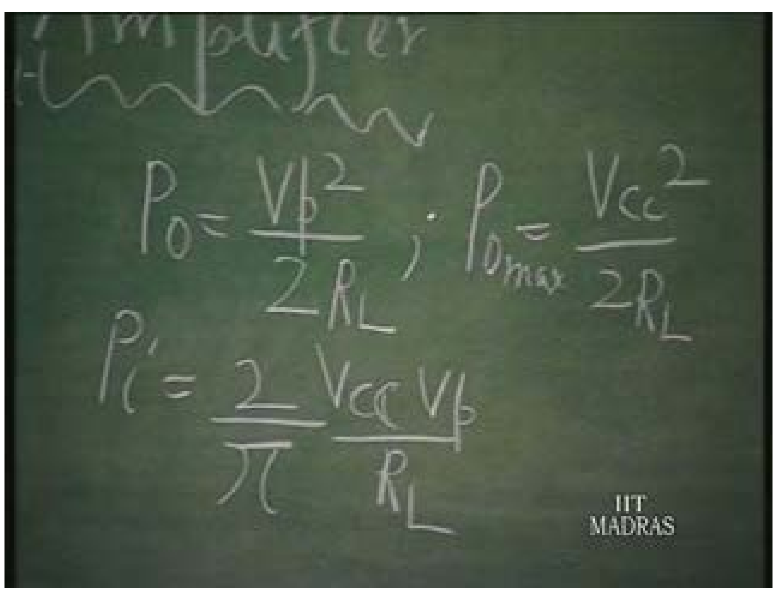

So if this is equal to, let us say 10 watts... The same example, let us say. If this is equal to 10 watts, then V c c square divided by 2 R L into 2. V c c square by 2 R L is the output power maximum. One fifth of that is what is required for the transistor, P d max. That means 10 watt output power if you want, you have to have a transistor whose power dissipation ability is only 5 watts, 2 watts - one fifth of 10 watts, which is 2 watts.

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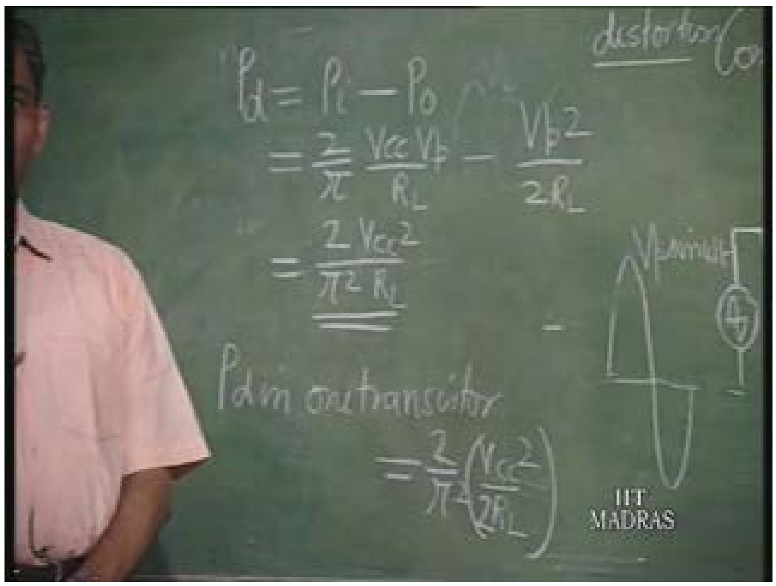

So, if I want 10 watts power, I have to have only transistors which can dissipate 2 watts. Consider this earlier situation - when we had output power of 10 watts, we had to have something like 20 watts for the maximum power dissipated in the transistors. Is it clear? So, this is the difference between Class A power amplifier and Class B power amplifier.

Now, let us work out an example. Design a Class B power amplifier delivering a power, 10 watt power into a 10 ohm load.

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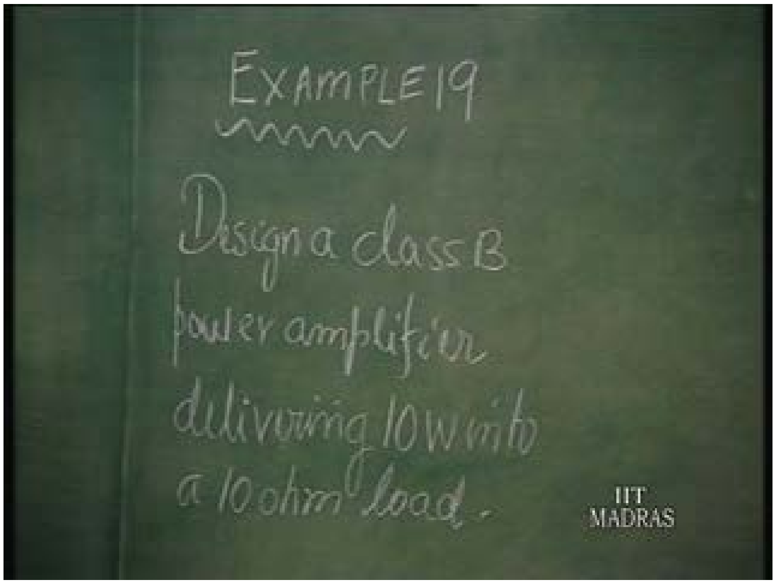

So, the circuit configuration that we are going to select is the same thing. Only thing is now, this is the 10 ohm load and we have the complimentary symmetry stage connected to V c c and minus V c c.

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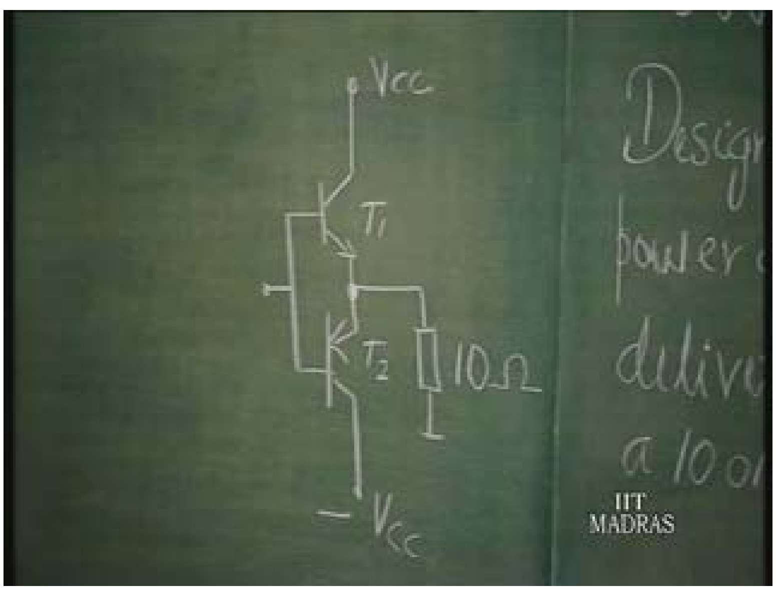

This is the simple circuit. So here, we have to only find out what the specifications are for the two transistors. That is all the design is. And, find out the value of V c c minimum that we should have for delivering 10 watt load into 10 watt...power into 10 ohm load.

So, we have earlier found out that the swing being V c c, V c c square divided by 2 R L is the output power maximum. That is given as 10 watts for a 10 ohm resistance. So, V c c is square route of 200 which is 14 volts. So, we have this already decided. So, the design is over except for the specification of the transistors T 1 and T 2.

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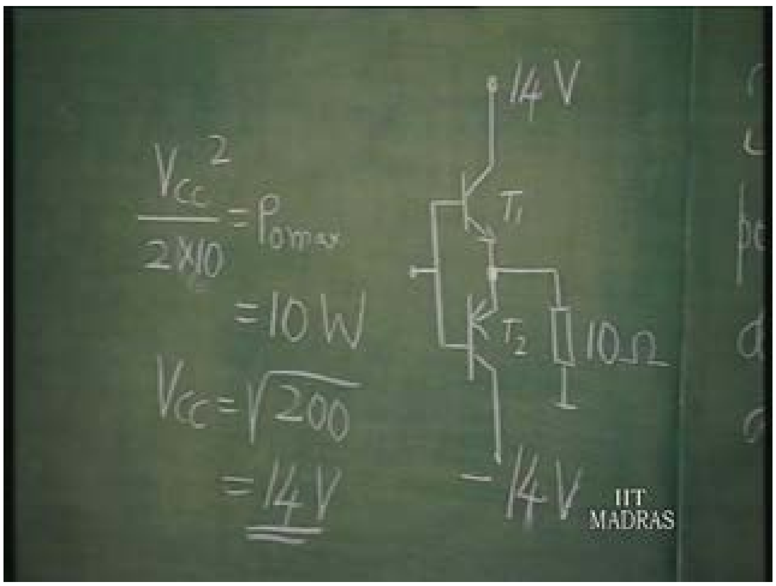

T 1 is n p n; T 2 is p n p. Now, when this goes to...is 14 volts, this can go to minus 14 or 14. So, the maximum V C E for each of these transistors should be greater than 28 volts. This is 14, this can go to minus 14 and this can go to 14. At that time, this will have the maximum voltage - 28 volts.

Then, I C max... So, either this will go to 14 when this conducts or, this will go to minus 14 when this conducts. So, in either case, the maximum current in these two transistors will be respectively 14 by 10 volts which is 1 point 4 amperes...should be greater than 1 point 4 amperes.

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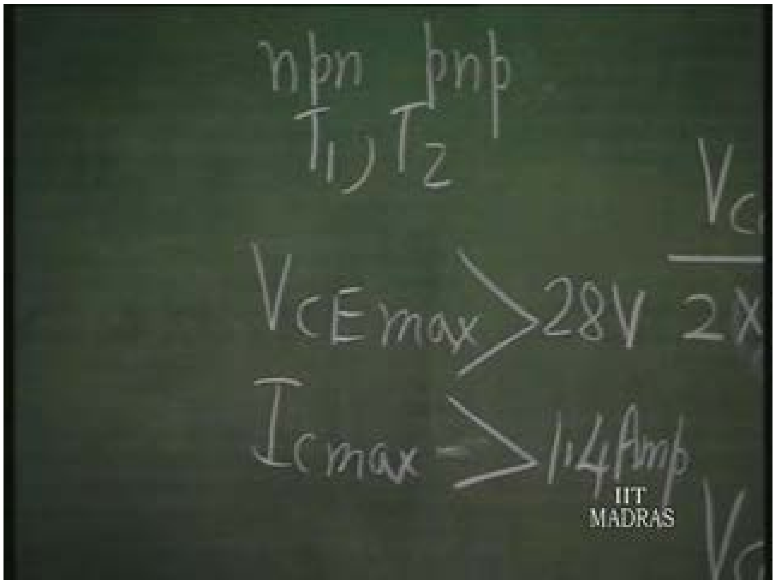

So, compare this with earlier, this thing. Earlier also, we needed a transistor; one...only one transistor, with the same kind of V C E max, but we had a quiescent current of 1 point 4 amperes there. But the peak current was 2 point 8 - double this. But these are shared now by the two transistors. At one time this conducts, at the other time this conducts. So, 1 point 4 amperes.

And the power max, P d max, has to be greater than...we have seen, 2 by pi square times P naught max which is greater than about one fifth the power, 10 watts. So, one fifth the 10 watts greater than 2 watts.

So, this... these specifications... this circuit, will function satisfactorily.

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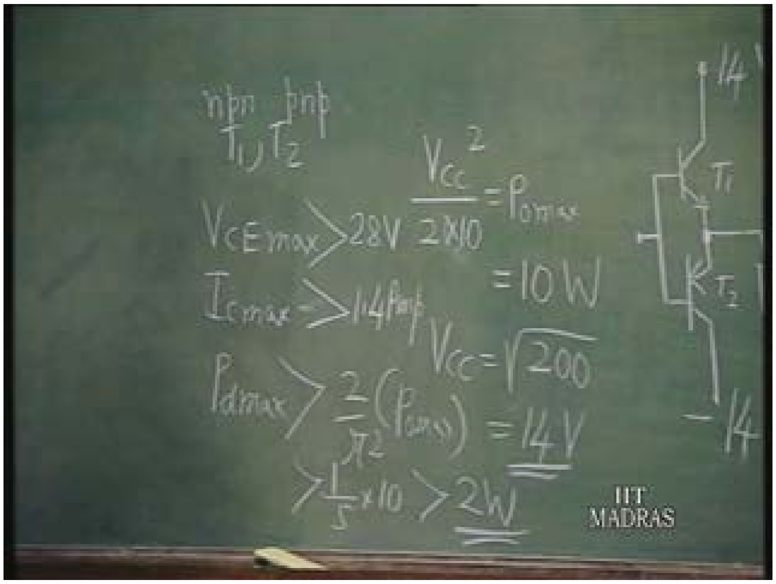

Now, let us come to the last topic of discussion in Class B. The major problem in Class B, it is the cross over distortion, I may point about. It is very efficient. 78 point 6 percent efficiency; but distortion for low signal level is pretty high.

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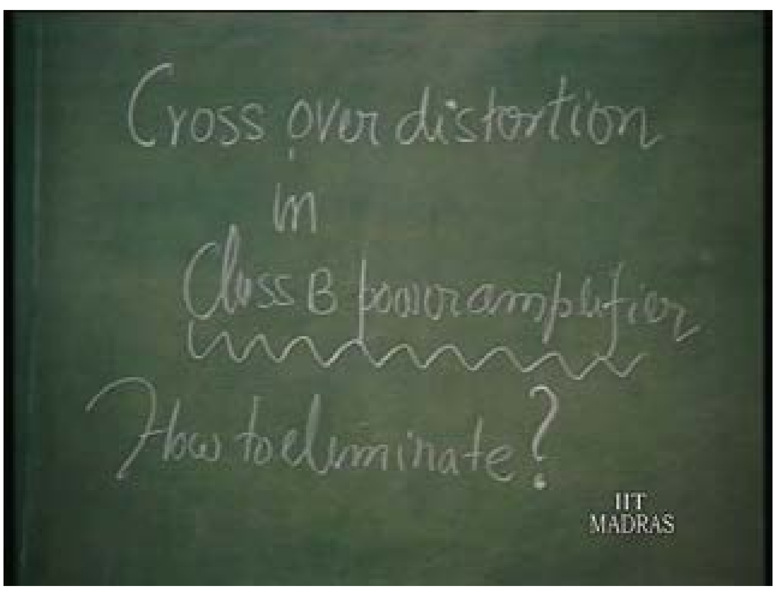

That is because of the fact that the transistor, this or this, they do not have any bias applied here; and therefore the cut-in voltage of let us say, point 7 or point 7 here, that must be cross. So, that means, actually speaking... when the signal comes, the signal itself is required to bias it first to a voltage, which is greater than point 7 and then start conducting.

This makes it difficult to use signal drive here, which is less than point 7. If it is less than point 7, signal drive, peak drive, output will not come here at all. The transistors will not conduct here; so, output will be zero. So, the extreme limiting factor is when the peak amplitude of the sine wave is of the order of point 7. Nothing comes at the output or less.

So, what to do about this? For this, we do what is called pre-biasing. That means we will put a voltage here which is, let us say... if 1 point...point 7...V Gamma plus V Gamma is equal to twice V Gamma that is required here; it is point 7 plus point 7, which is 1 point 4. We will apply here a voltage of 1 point 3 volts.

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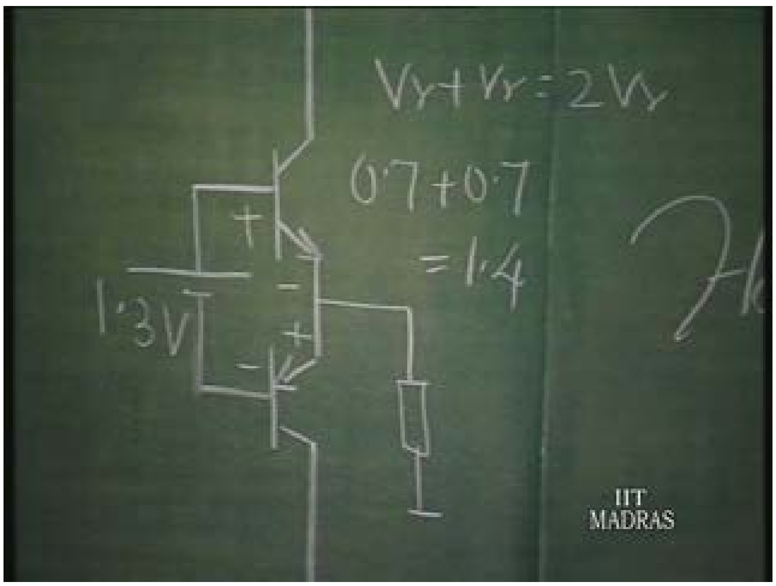

Why? That is, it is just about to start conducting; the signal has to only come in and give a voltage of about point 1 volts rather than this point 7 on one side and point 7 on the other side. So, to this extent, we will bias this.

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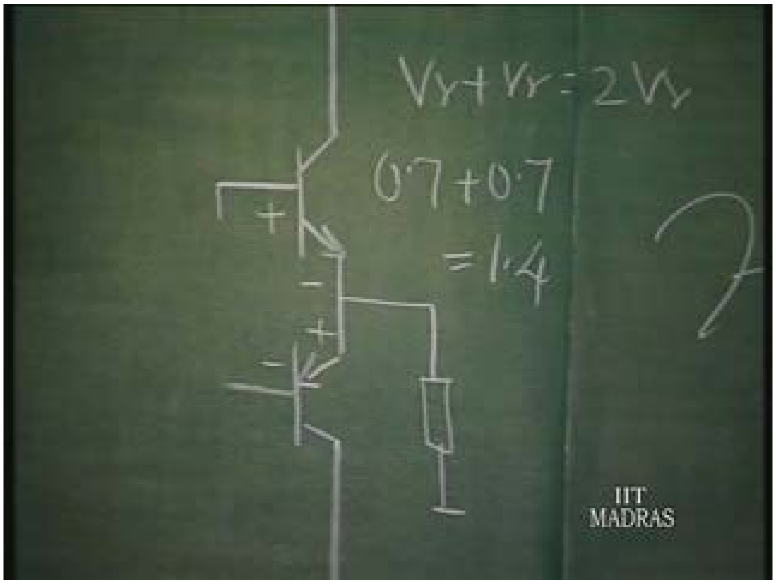

How to do this biasing? So, this biasing can be done by using resistance now, like this. One way of doing it... This is V c c, this is minus V c c, and this potential we want it to be ground potential. That means, if this is, let us say, R 1, this is R 2; this is also R 1 and this is R 2. This potential will be zero because this is V c c, this is minus V c c; and on either side of this, we have R 1 plus R 2. It is perfectly symmetric. So, this potential here is going to be ground potential. Is that clear?

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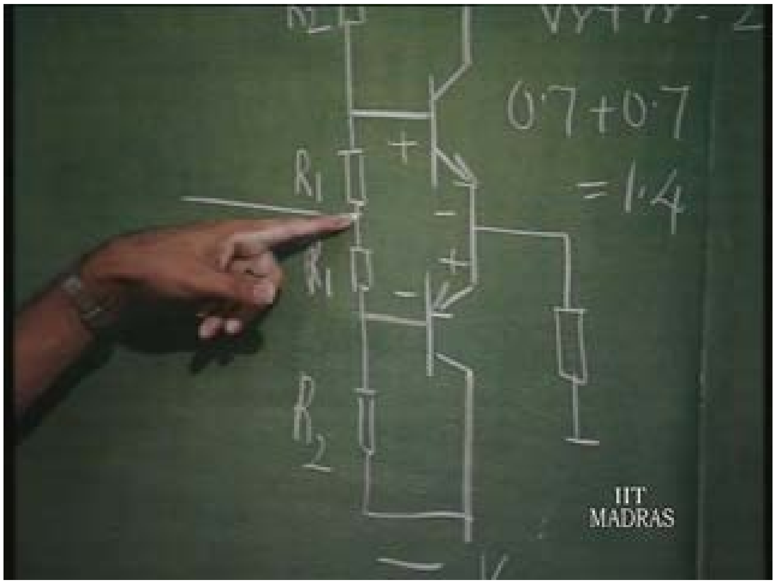

So, I can therefore connect this signal here. So, I am provide adequate bias here - point 7 on this side and point 7 on this side. So, let us say, this is about point 7 here, point 7 here, across this. Then, what will happen? The signal will appear. Already there is point 7; and this gets cancelled with this, that is required here.

So, the signal, when it comes to the base, comes with the bias, add around to it so that, the moment this crosses zero, this transistor will start conducting. Similarly, the moment this goes below zero, this transistor will start conducting.

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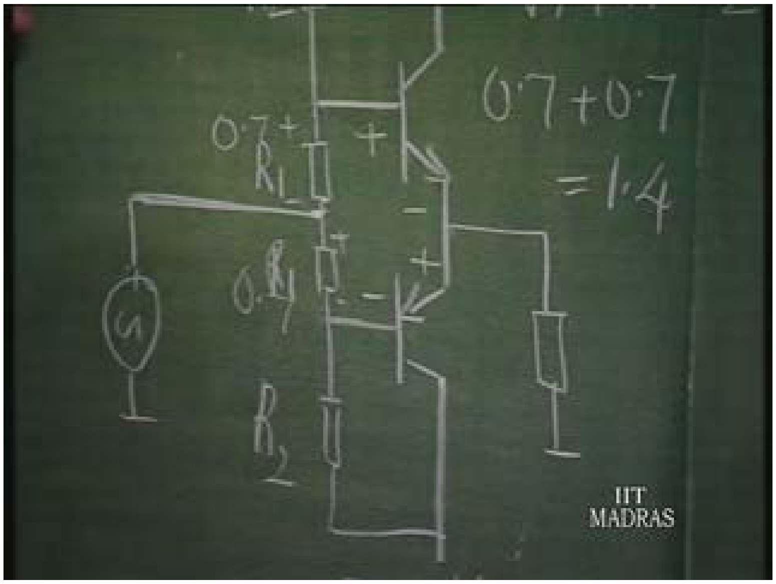

This is called Class A B operation. What does it mean? It is just... if it is point 7 that is required, you might provide point 65, and point 65, so that it is just about to start conducting. That means the quiescent current is still not as much as the Class A amplifier; but it is going to be there, small amount. Point 65 does not mean that there is no current. It is just that at point 7, it really starts conducting. Point 65, the current is going to be extremely small compared to the current that is required for it.

So, there is going to be some amount of bias current such that, that bias current into V c c is a small quiescent dissipation that is going to be tolerated in order to prevent this cross over distortion from taking place. So, this biasing is called Class A B biasing. Now, it may be fairly difficult to find out the precise resistors here so that this is just less than what is required.

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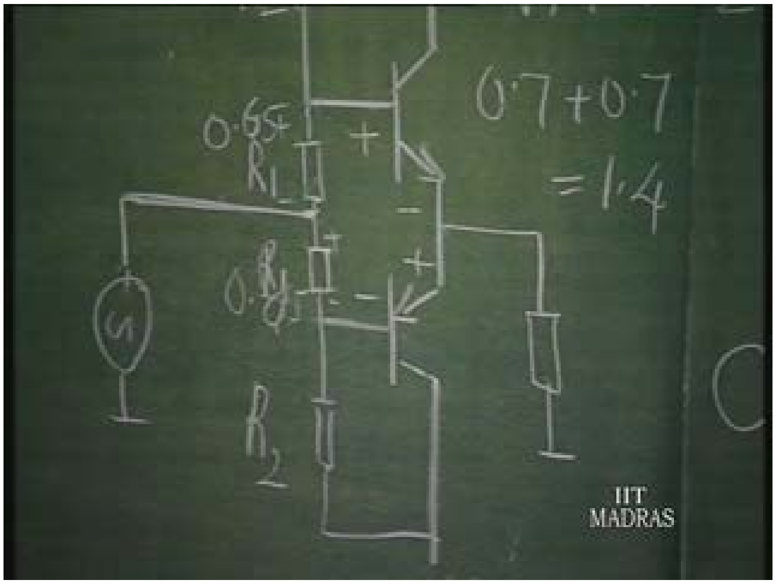

For that purpose, what is done normally in integrated circuits is that you put here just two diodes so that you have two V Gamma straightaway provided for this to be biased. So actually, when this... there is some current flowing through this like this, this is still going to be at ground potential; and therefore this is going to provide V Gamma, cut-in voltage, for making this conduct straightaway and this is going to provide the minus V Gamma that is necessary to make this conduct.

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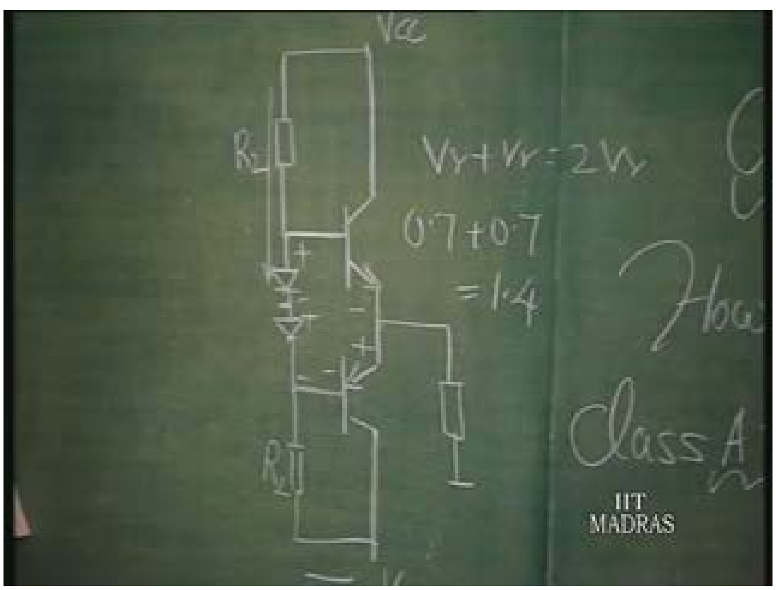

If these diodes and the transistors are made out of the same geometry, then this current is going to be same as this current. This is nothing but a current mirror that I had earlier talked about. So, this current is going to be same as this current. The load current will be still zero because this current is exactly same as this current. Load current is still zero, but you can make any quiescent current pass through the power amplifier which is quite low.

So, it is in readiness to conduct the moment signal starts coming into picture. So, this kind of Class A B biasing is what is normally adopted in power amplifiers to reduce the distortion.

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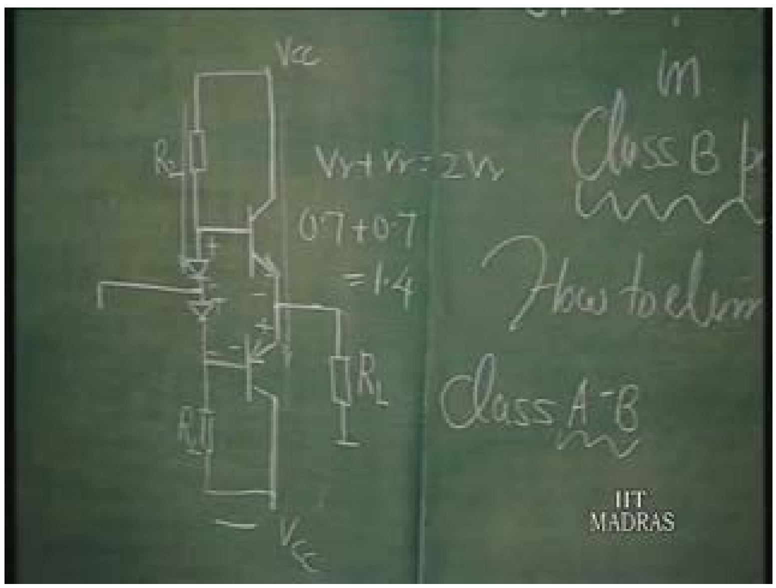

The price here paying is that the efficiency is now going to be still much less than 78 because of the fact that there is some more quiescent power dissipated here.

Earlier, there was no quiescent power dissipated at all. Now, there is certain amount of, small quiescent power dissipated here. That is the price you are paying to eliminate the cross over distortion.