Electronics for Analog Signal Processing - II
Prof. K. Radhakrishna Rao
Department of Electrical Engineering
Indian Institute of Technology – Madras

Lecture - 24
Class-B Power Amplifier
Load and Drive Requirements

Now, let us consider some of the other points connected with the design of power amplifiers.

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Load & Drive requirements
Power
amplifiers

EXAMPLE 20
For the example 19
problem determine the
load and drive requirements

These are primarily left out in the earlier discussions. The load and the drive requirements for power amplifiers...That can be illustrated by trying to solve the Example 20 wherein for the Example 19, which has already been solved, we can determine the load and the drive requirements.

That was a Class C power amplifier that we had designed with a tune circuit load. Let us say, this is the effective load, considering the transfer from the other side of the secondary also. So, this is V c c. Let us say, if this is R L, R L, this will be R L into n square which is the turns ratio of the coil and parallel, whatever loss component is there of the tank circuit. Effective R L is R L into n square. This is the...so the turns ratio is n is to 1. Then this resistance gets reflected as R L into n square and this...parallel R total, which is going to take care of the loss component in the capacitor and the loss component in the coil, all put together. So, this V c c was taken as 28 volts for that example and... Let this be L and let this be C. So, this is the tuned load. As far as Class C power amplifier is concerned, load is tuned. So, this is important. Tuned.

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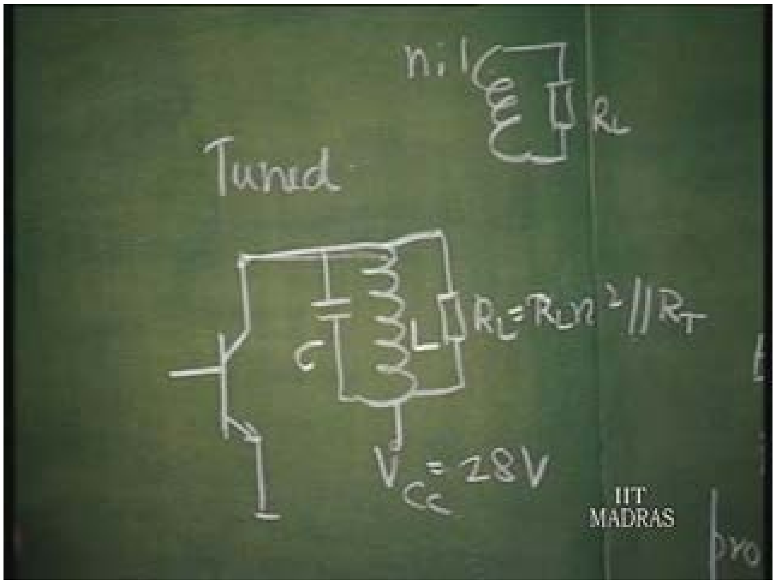

What it means is Omega is equal to 1 over root L into C. This should be Omega naught which is 2 pi into f naught. The frequency at which we want to transmit - that was 108 megahertz; 2 pi into 108 megahertz, from which we can evaluate the L C product that is necessary to establish this.

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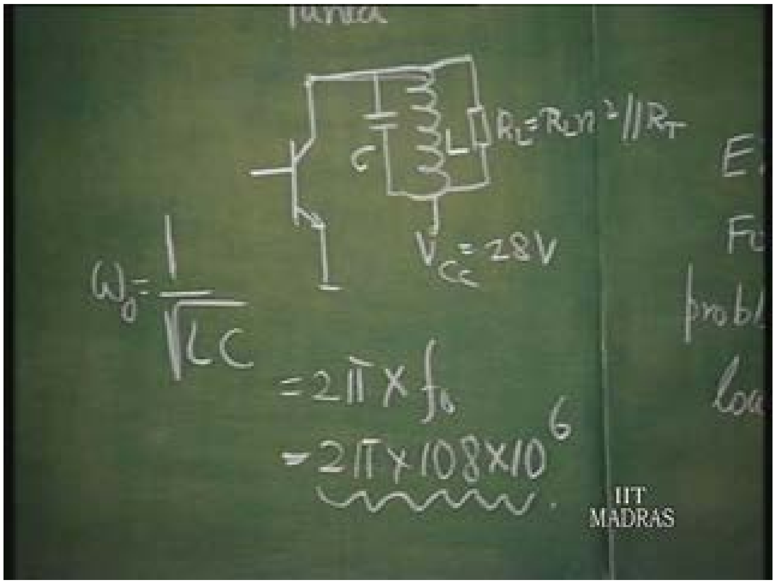

Normally, what you should do is the C should be greater than the stray capacitors so that this tuning becomes stray insensitive. So, if you reduce the stray considerably, you can use lower value of C and higher value of inductor. Otherwise, you might have to put fairly large amount of capacitor and be satisfied with...that is, corresponding value of inductor for this. So, that is how you will determine this...this thing; and then, as far as the load, effective load R L is concerned, this is going to be determined by this method.

Now, we said there is a current pulse for this whose peak amplitude has been chosen by us as 10 amperes for this problem and Theta is taken as 120 degrees. This is the current pulse that we have chosen for this example.

So, ...and we have established that the tuned circuit will only sustain a voltage corresponding to this frequency; and therefore, the voltage developed will be corresponding to this frequency with peak swing being made equal to very nearly V c c. Otherwise, it is V c c minus V minimum, whatever minimum value you can choose. So, we have said that therefore the voltage swing is going to be...at the output V c c. This will be the voltage wave form - sine Omega naught t.

And let us therefore imagine that the current swing, I naught, corresponding to the same frequency is going to be I. Let us say, we will call this I 1, indicating it is the fundamental frequency component in this, that which is going to be selected.

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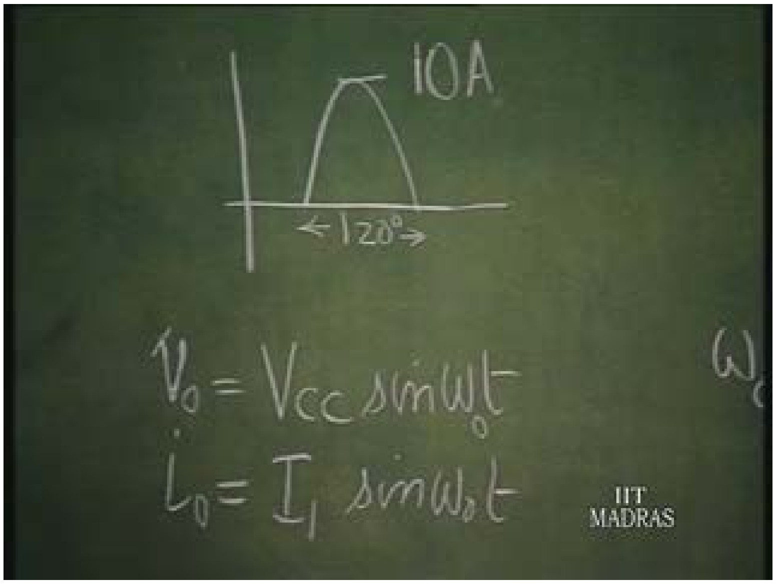

$$v_0 = V_{CC} \sin \omega_0 t$$
$$i_0 = I_1 \sin \omega_0 t$$

So, if this is the case, we have to find out what I 1 is for this waveform. So, that can be found out by I 1 is equal to... it is 1 over pi or 2 over t minus pi to pi, if the waveform exists throughout. Here, the waveform is existing, again from pi by 2 minus Theta by 2 to pi by 2 plus Theta by 2, which once again we can say is going to be sort of double the value taken from here to here; and this waveform we have already defined which is I, is going to be...we have defined this; 20 sine Omega t minus half, because Theta is taken as 120. This, we had derived in the earlier, this thing. So, 20 sine Omega t minus half.

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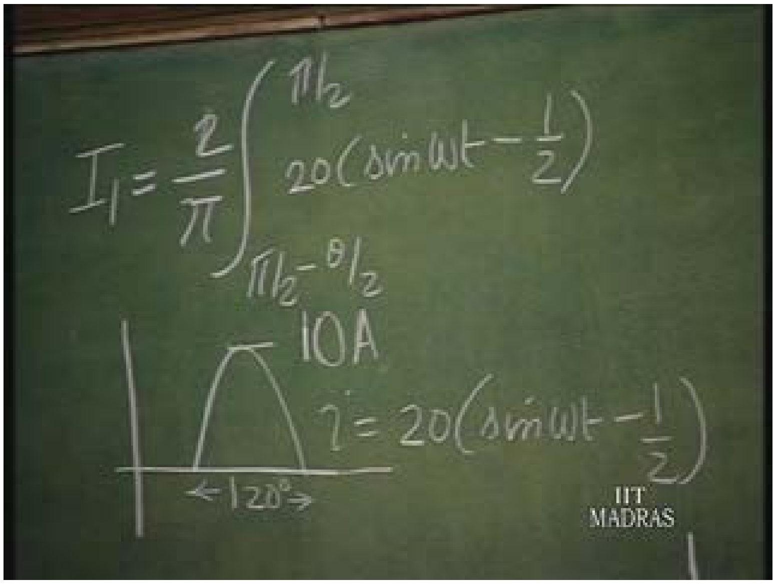

This into...we would rather retain this in the same waveform, this thing, so that we can use the same formula later also. This was cos Theta by 2. Only at the end, we will substitute this so that we can get for a general situation like... This is considered as... What did we put this as? I? Is it I p? I p. We put it as I p. I p sine Omega t minus cos Theta by 2 into sine Omega t d Omega t.

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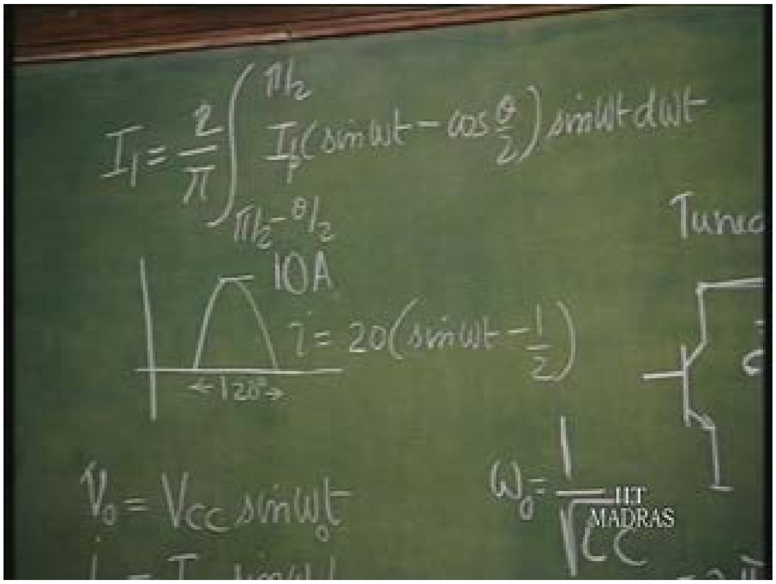

This integral, we had already had opportunity to solve because similar integral came in deriving P d also. And the value of the integral becomes I p divided by 2 pi, because this integral will be resulting in Theta by 4 minus sine Theta by 4. That 4 will get cancelled with this 2 as 2... Here, I p by 2 pi Theta minus sine Theta; and we can verify.

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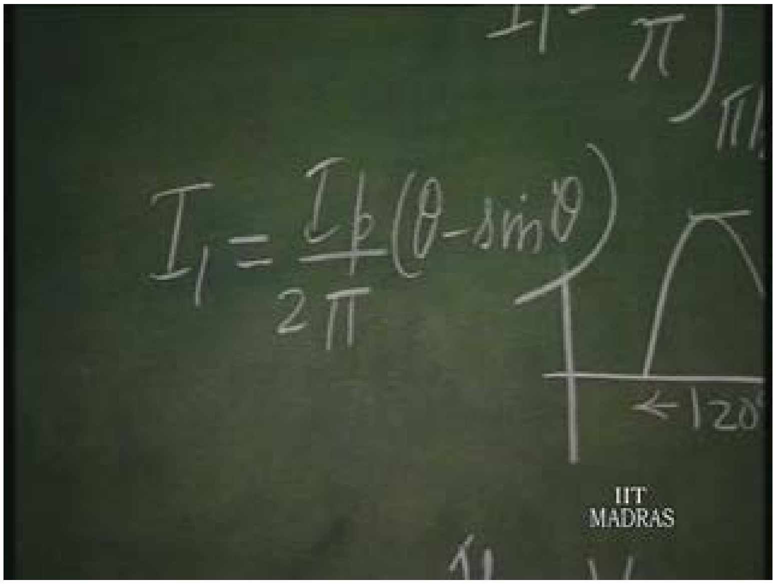

P naught therefore is simply equal to I 1 into V c c. V c c is the peak of this. I 1 is the peak of this. I 1 into V c c by 2 because V c c by root 2, I 1 by root 2; that divided by 2, which is nothing but I p Theta minus sine Theta by 4 pi into V c c.

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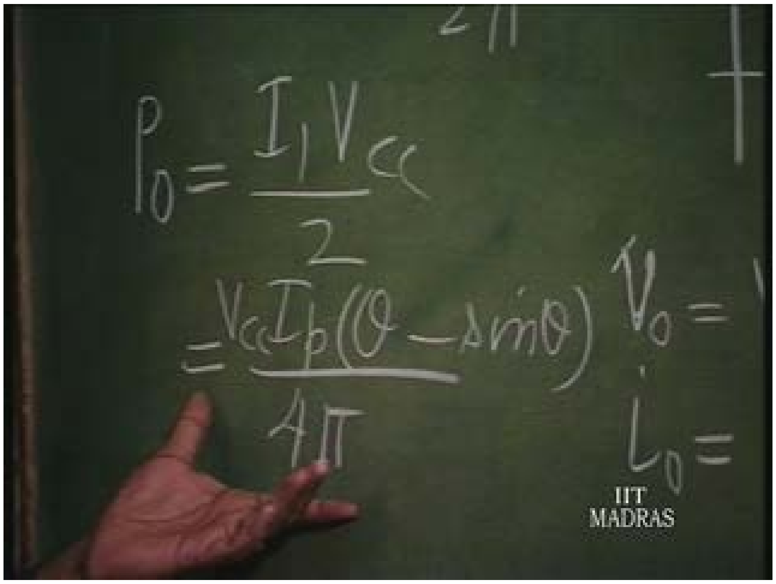

$$P_0 = \frac{I_1 V_{cc}}{2} = \frac{V_{cc} I_p(\theta - \sin\theta)}{4\pi}$$

$V_0 =$

$i_0 =$

This is what has been earlier derived as output power. That, we did it by another method. We obtained P i. Then we obtained P d; and we said P naught is P i minus P d. Here, we are doing that independently. We are obtaining P naught directly.

So, this is one way to confirm that what we have got earlier is correct. So, this is the output power which we have already evaluated for this case, about 56 watts. Now, as far as this current is concerned, this is of no concern for us. This is only for verification.

So, this is important in finding out what kind of load we are working with because as for the load is concerned, it is tuned to Omega naught which is 108 megahertz and therefore it is going to be purely resistive for that frequency and that resistance is going to be this R L. This is going to be tuned. So, that R L is the load resistance. What is R L?

R L is simply going to be V c c divided by I 1 because across R L now, the peak voltage developed is V c c and the peak current developed at that frequency is I 1. So, R L is V c c by I 1. V c c is already known to be 28 volts. It is necessary for us to evaluate I 1.

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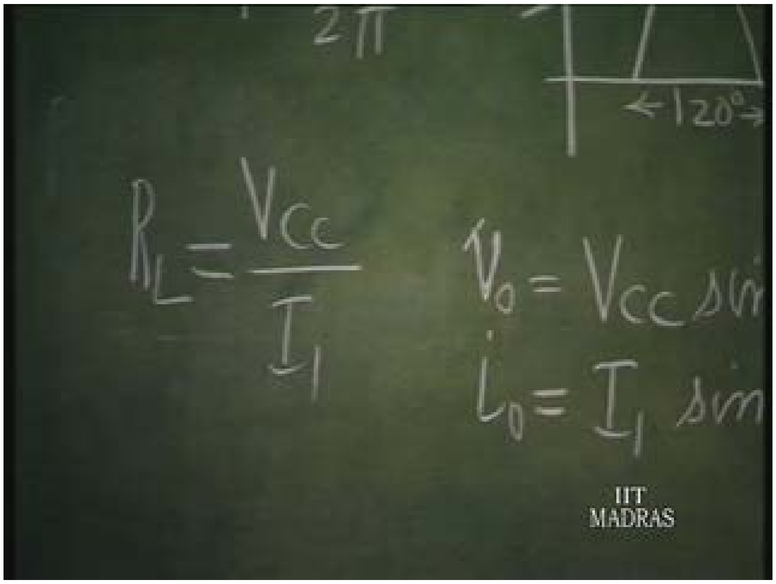

So, what is I 1? I 1 is I p...is nothing but 20... I p is 20 divided by 2 pi into Theta. That is 120 degrees. That is 360 by 3; that is 2 pi by 3 minus sine Theta. Sine Theta is sine 120 which is sine 180 minus 60 which is sine 60 itself, which is point 866.

So, this is point 866. So basically, we get 2 pi which is 6 point 28 by 3. That is 2 point 093 minus point 866. So, this is going to be how much? 7, 2, 2 and 1 point 2 2 7 which... We had earlier got this value while evaluating the power outputted. Anyway 1 point 227 into this value, 20 by 2 pi.

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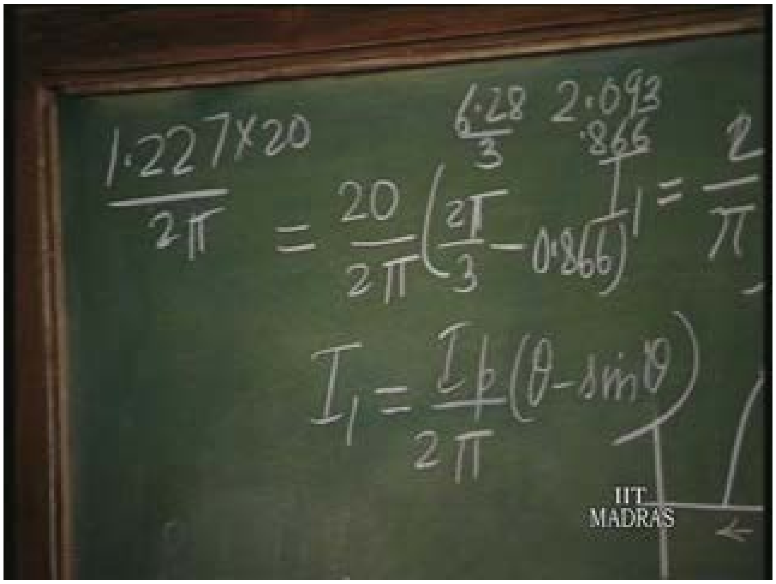

$$\frac{1.227\times 20}{2\pi}=\frac{20}{2\pi}\left(\frac{2\pi}{3}-0.866\right)$$

$$\overset{6.28}{3}\quad 2.093 \quad .866$$

$$I_1=\frac{I_p}{2\pi}(\theta-\sin\theta)$$

So, how much is this? Let us quickly calculate that. This 2 goes here. This is 10. So, this is about 12 point 27 divided by pi which is roughly about 4 amperes. 3 point 9. So, this is 3 point 9 amperes. So, this is the peak current of the fundamental of this current pulse - 4 amperes.

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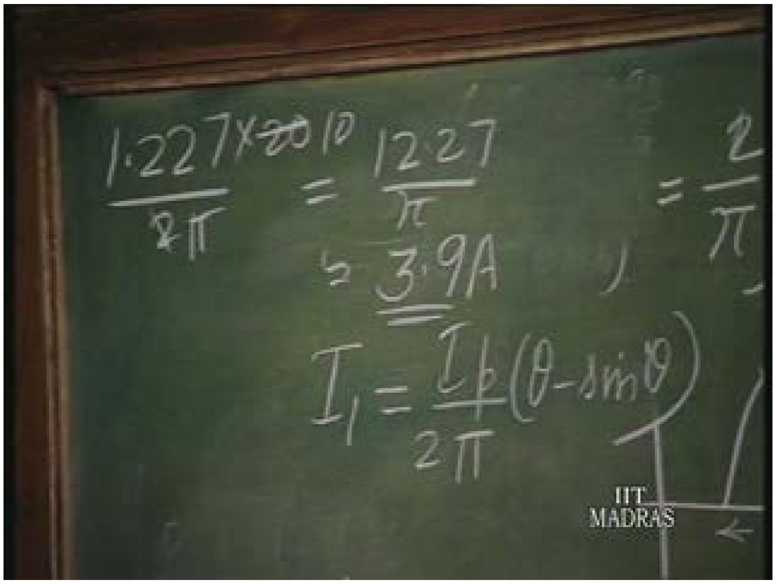

$$\frac{1.227\times \cancel{20}\,10}{\cancel{2}\pi}=\frac{12.27}{\pi}\simeq \underline{\underline{3.9A}}$$

$$I_1=\frac{I_p}{2\pi}(\theta-\sin\theta)$$

We can now use this for obtaining the load resistance R L as equal to V c c is 28 volts divided by 3 point 9 ampere which is very nearly equal to 7 point 18 ohms. That is the load resistance that we must have as the effective load resistance.

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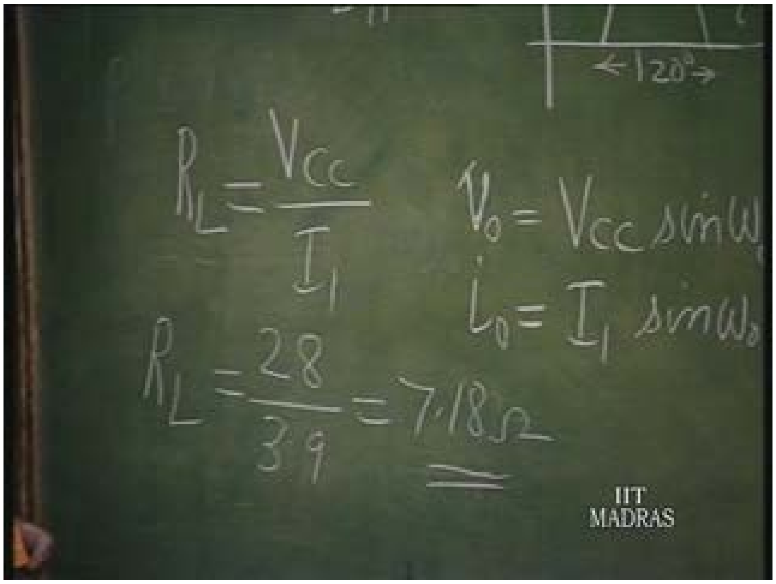

$$R_L = \frac{V_{CC}}{I_1} \qquad v_0 = V_{CC} \sin \omega$$

$$i_0 = I_1 \sin \omega_0$$

$$R_L = \frac{28}{3.9} = 7.18\,\Omega$$

This load resistance is made up of the reflection of the antenna resistance and the coil loss. Most of what is transferred is going to be transferred to the antenna, if the coil resistance is going to be not so high. Not coil resistance...coil resistance is getting converted as an effective parallel resistance which is q squared...coil q squared times the coil resistance R s. If R s is low, q of the coil is high and therefore q squared R s is going to be very high. So, this resistance value has to be restricted to this for this design, for obtaining this much amount of output power.

Now, the load is completely defined. R L is fixed; and L and C are fixed. Let us discuss about the drive requirement. Before we go to the drive requirement, I would like to mention something here that we have already discussed about the power dissipation ability of the transistor; and we have also discussed about the maximum current that is likely to flow. And, we have chosen the current less than the maximum; 16 amperes was the maximum. We have chosen it as 10 amperes. That is how we have done the design.

Now, the voltage on the other hand swings, we said, by an extent V c c on either side. So, this will go up to twice V c c. And therefore the rating, V C E O rating of this transistor should be greater than twice V c c, which is in this case equal to 56 volts. This is what is to be remembered. It should be greater than 56 volts.

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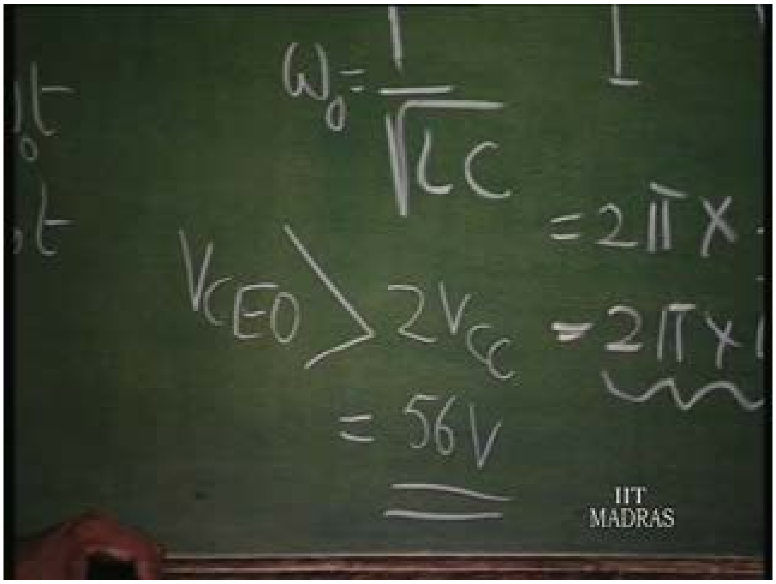

So, apart from the power requirement of the transistor, the V C E O rating and I c max reading, these are the ratings for the transistor. Here, we have used a given transistor for this particular application.

Next, obviously, since it is greater than 56 volts, he has recommended the choice of 28 volts. That is how we have started with that. Next, we have to also worry about the drive requirement at the input. As this is going to be a power transistor, the V b e when it starts conducting for small signal transistors, is typically point 6 to point 7.

Here, since the current of operation is of the order of amperes, strictly we can obtain the characteristics, input characteristics of all these power transistors and from that obtain what is the order of magnitude of V b e variation, when this current is varying by this much. That is typically going to be about, between 1 and 1 point 5 volts.

So, we will assume that it is going to be about 1 volt. So, you have to take this from the specification for the diode. They will give the input characteristics and from the operating current, we know the current of operation that the collector current has to go to a maximum of 10 amperes here; and therefore, we will automatically know what kind of waveform, current waveform, we should have at the input. That is, that divided by Beta is what we should have and it should start conducting for a voltage which is greater than 1 volt.

So, we should therefore input a current waveform like this which is divided by Beta. Assuming that Beta is known, we will therefore design the drive requirement of this particular power transistor in the following manner.

As I told you, we can use a resistive network to introduce whatever voltage you require here so that conduction can be done, much delayed, and Theta can be reduced. Otherwise, in the case of a transistor, it starts conducting only after cut-in voltage is reached. That itself can be used for obtaining the waveform that you require.

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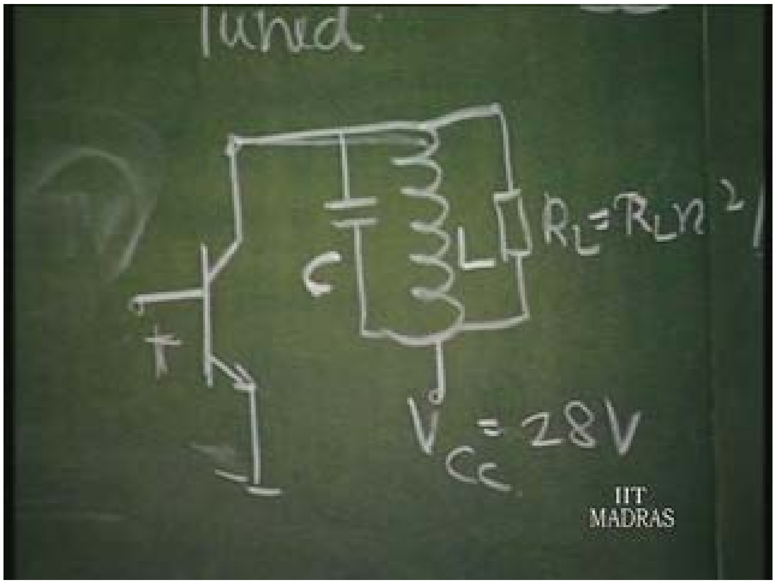

So, let us assume that we are not using additional voltages. We do not need all these variables. We will put a resistance here to restrict the maximum current, as soon as it starts conducting; and it starts conducting, we will assume, only when 1 volt is reached. This is an assumption. If you know the input characteristics, you can design the the input drive more exactly than this.

So, we will now put here a V p i sine Omega t waveform which will look like this. V p i sine Omega t minus V Gamma. That is, when it starts conducting...divided by R s should be the current waveform, which is nothing but... We have this 20 sine Omega t minus half. This is how it is. This is the current waveform. This divided by Beta. So, 20 sine Omega t minus half divided by Beta is the current input that we require.

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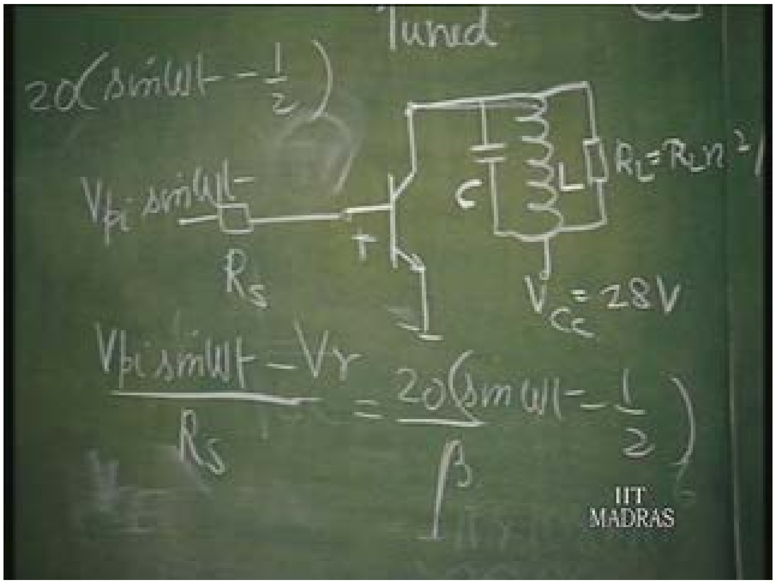

So, these things are exactly similar in nature. So, what it simply means is that V p i by R s should be equal to 20 by Beta; and minus V Gamma by R s shall be equal to minus 20 by 2 Beta, minus 20 by 2 Beta. So, is this clear?

So, if V Gamma and, in fact let us say Beta is known, Beta is known, V Gamma is known; let us say, V Gamma, we have taken as 1 volt. So, R s we can fix up as...R s is going to be V Gamma; that is 1 volt, divided by 10 into Beta. We have assumed Beta in the yesterday's lecture as 50 or so, typically. So, let us assume that. So, 5 ohms.

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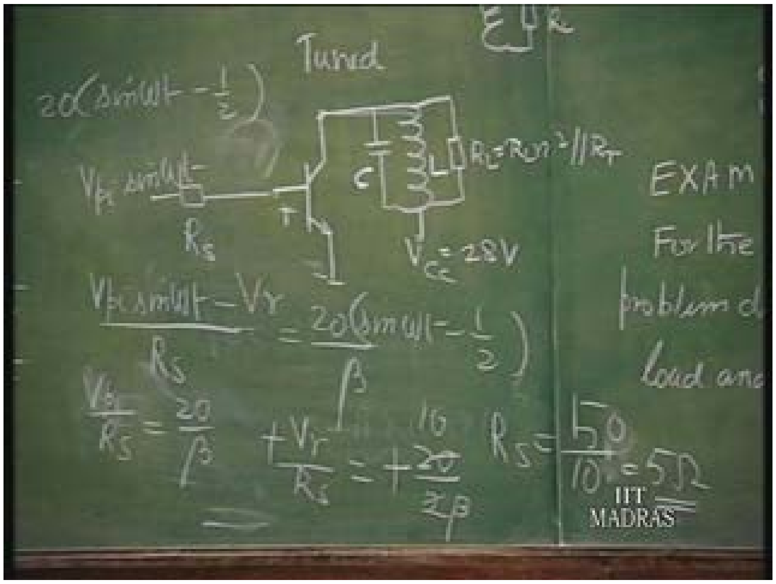

So, this is the value of resistance that you have to put in order to satisfy this condition that it conducts there. Now, we have to select V p i to satisfy this condition. So, V p i shall be...R s is 5 ohms into 20 by Beta is 50; 2 volts.

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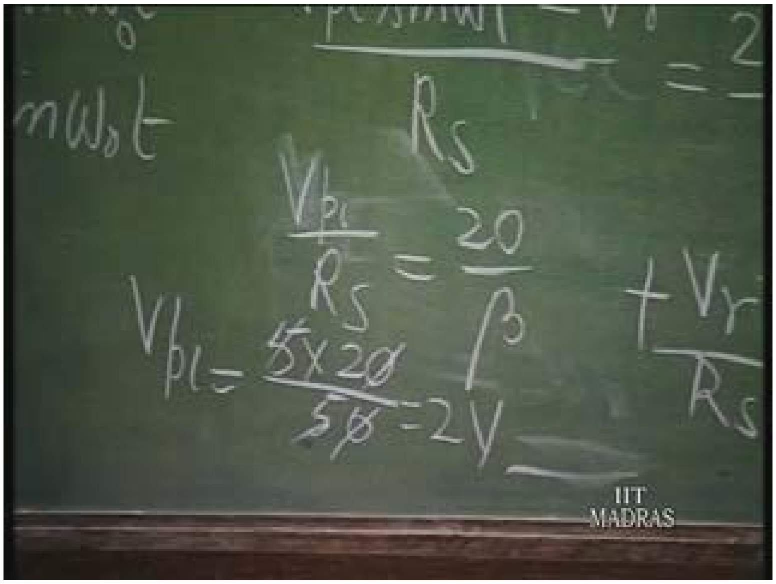

So, this is a very crude way of obtaining the input drive requirement. I would say crude because you can actually...if you have the input characteristics, you can do far better and find out the peak current more accurately than this. So, this way, we have fixed the input drive for this particular stage.

Now you can see that as far as the input of the transistor itself is concerned, there is a certain amount of power dissipated at the input itself because we are assuming this at to be about constant, about 1 volt. And therefore, there is going to be some average current that is going to flow through it because there is a current pulse. That average current which is having 10 by Beta as the peak; and the value of the average current, we all already know because, in terms of that formula...

So, that average current into V Gamma is the input power for the transistor. Not at this point. At this point it is more than that because some amount of power is lost in the base resistance also. So, input power to the transistor is going to be this and power dissipated at the output is known.

So actually, power dissipated in the overall manner is going to be...considering the input power also into account, strictly speaking, unless it is very small. The current is Beta times less; so, it is going to be pretty small; but it may not be negligible.

So, this is the effect of the current drive for the Class C output stage. This completes the complete design of a power amplifier. So, you must provide this kind of output waveform V p i sine Omega t. That is 2 sine Omega t with current being equal to something like this - 10 divided by Beta. That is point 2 amperes. So, the drive stage should be able to give that much amount of current with peak voltage being 2 volts.

In the example just previously chosen, we had for simplicity used the drive in such a manner that the cut-in voltage of the transistor itself could be used for restricting the current drive into the base of the transistor.

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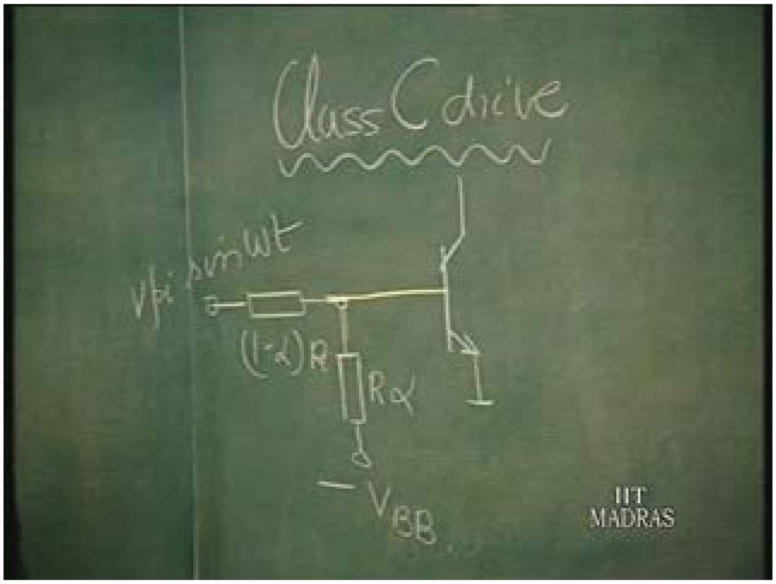

The more elegant way which we had earlier indicated in our earlier example was to use two resistances with bias here, voltage negative in this case, so that this voltage can really determine the angle of conduction rather than this. So, we can say that the voltage here is now going to be fixed as V p i sine Omega t; and as long as the diode is not conducting, transistor not conducting, then V p i sine Omega t into Alpha, that is, the contribution due to V p i sine Omega, signal; and contribution due to V B B is minus V B B into 1 minus Alpha. This is the resistive attenuator.

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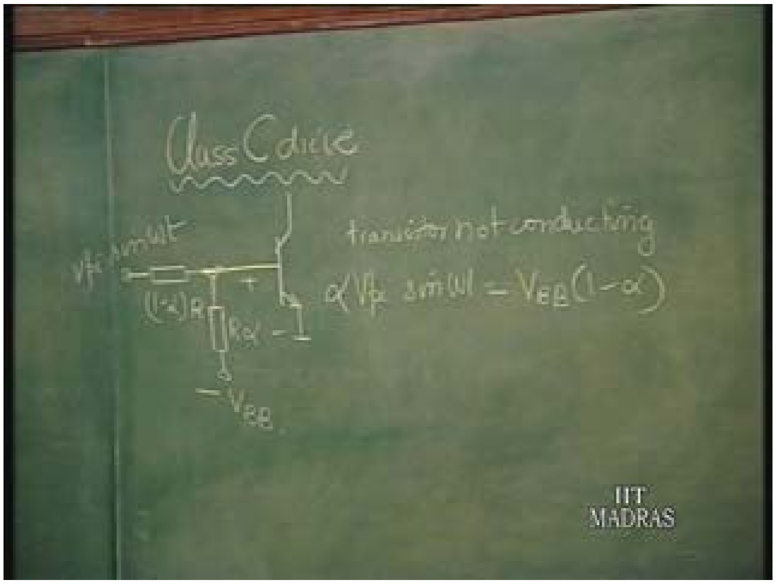

So this... when it becomes equal to, let us say 1 volt which is V Gamma, the cut-in voltage, this particular thing, when it becomes equal to V Gamma, the conduction takes place. So, that means we will say Alpha V p i and we know that conduction starts happening when the angle is pi by 2 minus Theta by 2. So, sine pi by 2 minus Theta by 2; at that point, the voltage should be equal to V B B 1 minus Alpha. This is one equation; at the point of conduction, this is what should have just happened.

So, Alpha V p i - this is sine pi by 2 minus Theta by 2, is cos Theta by 2 minus V B B into 1 minus Alpha should be equal to V Gamma. This is one equation for design.

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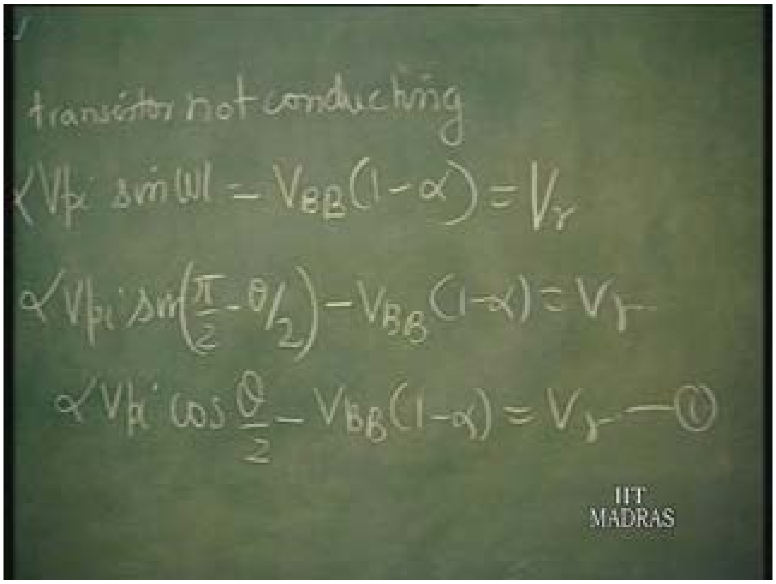

transistor not conducting

$$\alpha V_{pi} \sin \omega t - V_{BB}(1-\alpha) = V_\gamma$$

$$\alpha V_{pi} \sin\left(\frac{\pi}{2} - \theta/2\right) - V_{BB}(1-\alpha) = V_\gamma$$

$$\alpha V_{pi} \cos \frac{\theta}{2} - V_{BB}(1-\alpha) = V_\gamma \quad \text{—①}$$

There are lots of variables here. Alpha is not fixed. V p i is not fixed. Theta is already fixed because this is based on output design. V B B is not yet fixed. So, three variables are there for us to control.

Next, we also know that after conduction takes place, this is going to be a voltage source of V Gamma, 1 volt. Then we can forget about the constant current that this is going to drive. This will take away certain amount of constant current. This will drive certain amount of current. So basically, we have now V p i sine Omega t. Thereafter, once it starts conducting, minus V Gamma, this is the V Gamma; that divided by R into 1 minus Alpha.

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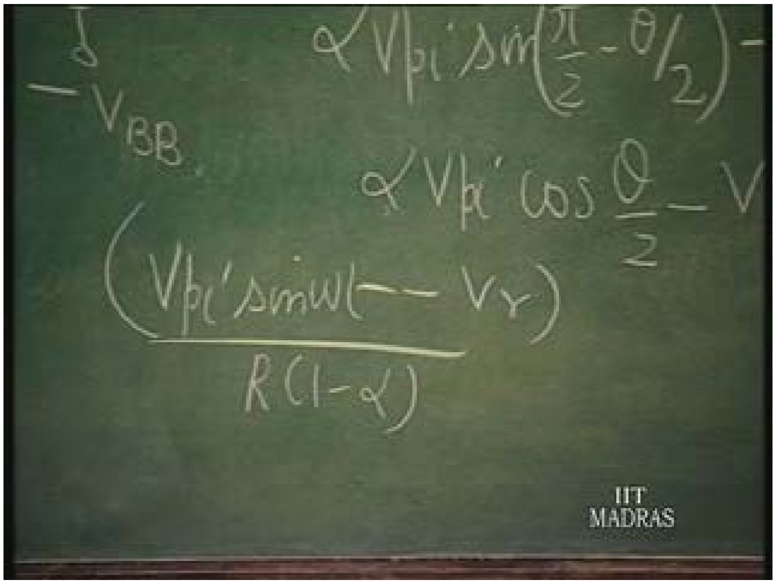

This is the current that is driven, driven in... minus...obviously, there is certain amount of current; that is 1, a constant current is removed. V Gamma plus V B B divided by R Alpha V Gamma plus V B B divided by R Alpha. So, this current is going in; this current is... So effectively, there is some current going into this.

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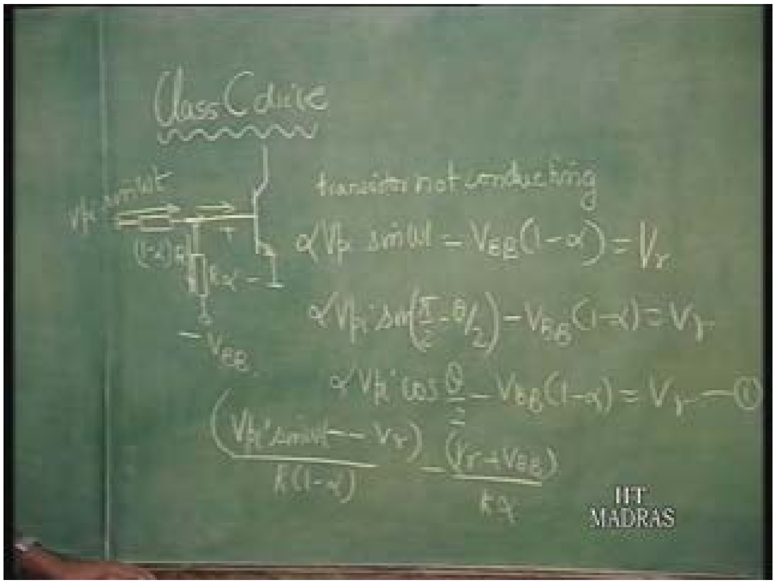

So, this is the current waveform going into the base and that should be equated to the current pulse during that duration. So, this is going to be... we have called this as the peak current I p, into sine Omega t minus cos Theta by 2 divided by Beta, because that is the base current. I p sine Omega t minus cos Theta by 2 is the current pulse at the collector; that divided by Beta shall be equal to this.

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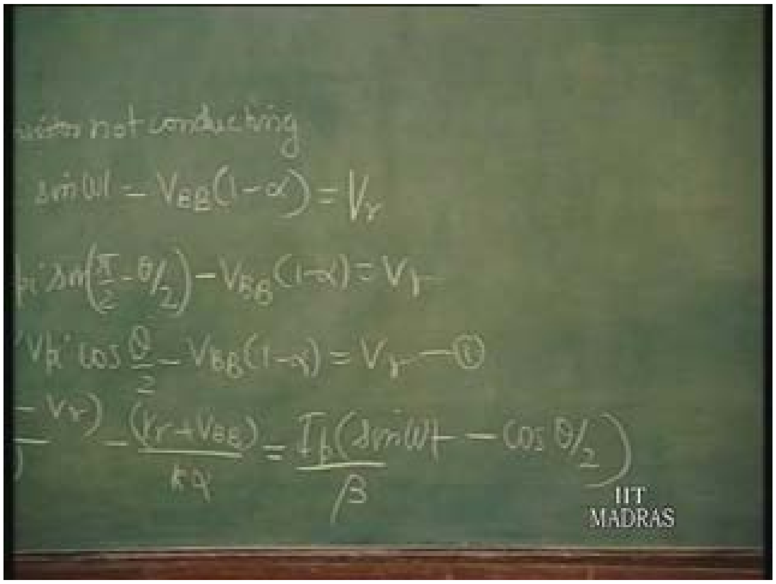

So, this is the second equation that one should use. There are three variables: Alpha, V p i and V B B. There are two equations. So, we can easily, happily, select one arbitrarily and obtain the other two.

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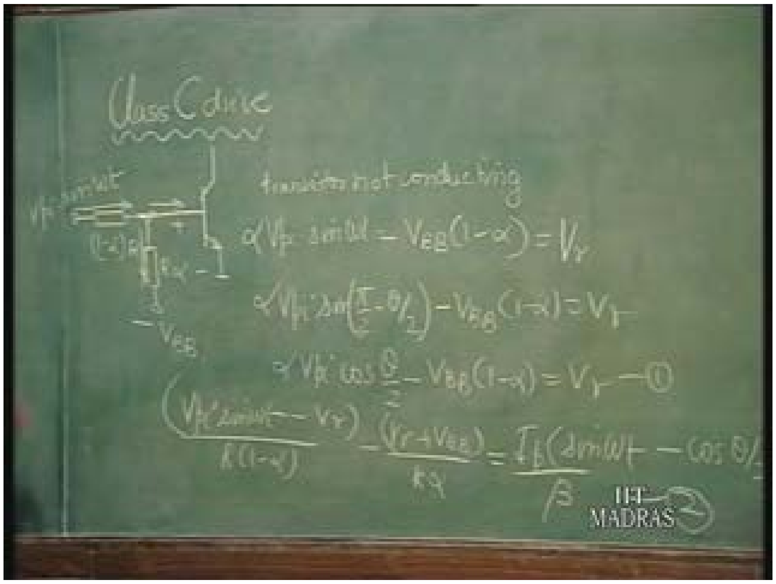

Now, there is only one word of caution in this. There is a maximum base current also. Like maximum collector current, for every transistor, there is a permissible maximum base current. It should not be exceeded. It is not really always equal to I C maximum divided by Beta. It might be more than that. So, there is one thing.

So then, when this is not conducting and then this goes to negative, this voltage will go to the most negative potential. That means minus V p i into Alpha; this is going to minus V p i into Alpha; minus V B B into 1 minus Alpha. That is the negative voltage, maximum negative voltage. Then, the transistor is not at all conducting. That negative voltage should not be causing break down of the base emitter junction.

That means this voltage should be less than V B E O. This is called the breakdown voltage with collector open, V B E O, rating of the transistor. This is an important requirement; that means you cannot now be quite arbitrary about the third variable. So, you should carefully select V p i Alpha and V B B in such a manner that this requirement is going to be adhered to.

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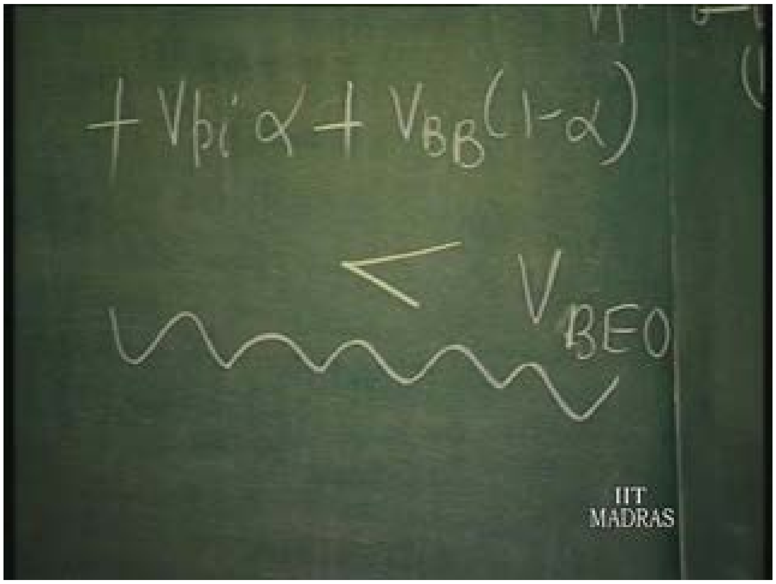

So, particularly, in our earlier problem Example 20, we had just not chosen V B B at all; and therefore, this was 2 sine Omega t. And therefore this was becoming minus 2 volts. So, the reverse bias voltage was only minus 2 volts. So, it was always restricted to minus V p i. So, we can always select then V p i in such a manner that this, it does not break down.

Once we introduce V B B, this requirement will go up. So, you have to be cautious about this, even though there is considerable flexibility now in your design; and we can really use resistors here in such a manner that all these requirements are met. In fact, resistor does not come as a variable. So, this resistance, it comes as a variable only in this equation. So, that will automatically be chosen such as to fix the maximum current. So, this resistor is going to be chosen based on what current you want to inject as the maximum current.

Now, since we have finished discussing Class C drive which was pretty complicated and not so common as in other amplifiers, we have to also discuss Class B drive because basically these are amplifiers which have no quiescent state, no quiescent current.

Class A amplifier drive is pretty simple because there is a certain quiescent drive in it and therefore that determines how it is...how much it is capable of delivering; where as in Class B and Class C, that is not the case. So, these are special drive schemes. When drive becomes very important, the signal itself is going to make the transistors conduct.

So, let us consider the complimentary symmetry transistor here drawn in this red color here with load also indicated there.

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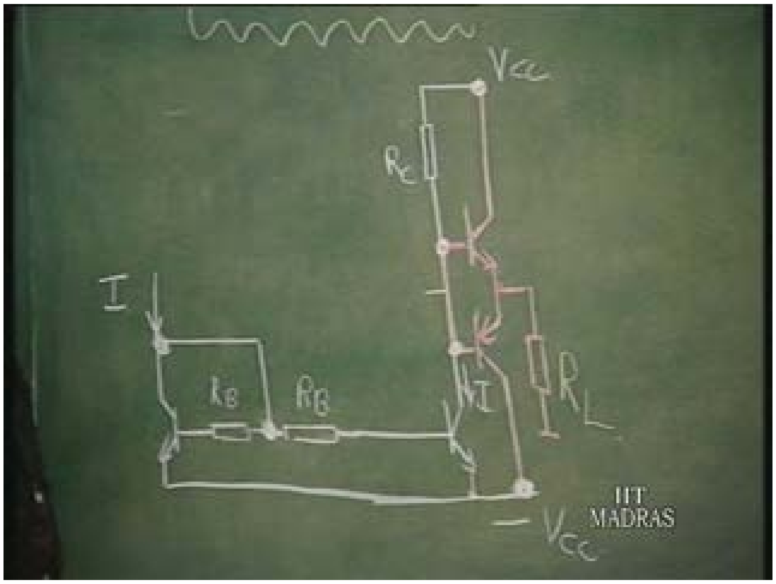

Load is an important part because unless we put the load, even if these are biased properly, these are not going to conduct. So, we must put the load in order to make these conduct.

So, once you put the load, that is, load is in terms of drawing off current... We have a common emitter amplifier here. This...if you forget about this...this is nothing but collector resistance and the emitter is connected to minus V c c. So, the drive of this amplifier can go up to plus V c c to minus V c c. That is the drive requirement for the Class B output stage. So, the drive of the amplifier should go, in terms of voltage, almost up to V c c on this side, and V c c on the other side. What it is capable of going is V c c minus V Gamma because there is...V c c minus V Gamma for this and minus V c c plus V Gamma.

So, this much voltage drive is going to be required. In fact, minus V c c, there is plus V Gamma here and another V Gamma, minus V c c plus 2 V Gamma on this side, V c c minus V Gamma on the other side, so that this is capable of giving pretty full output swing.

So, please remember that the driver stage should be giving you a full voltage swing that is required for the Class B output stage. Only the current swing is going to be Beta times less because when this is V naught, the current in this is V naught by R L. V naught can go as much as V c c minus V Gamma on one side, minus V c c plus 2 V Gamma on the other side.

We are going to assume that V c c is so large that V Gamma can be ignored. So, it is essentially V c c on either side. So, V c c by R L is the maximum current. That is what we had assumed in derivation of the efficiency, etcetera also. V c c by R L is the maximum current that is required in this stage at the output.

So, voltage swing should be almost the supply voltage itself. This is the driver requirement. It should be capable of going up to this and current should be... Now, let us see what...V naught... That means V c c by R L divided by Beta. That will be the base current drive for each one of these trans... When it is positive, the base current required for this, maximum base current is V c c by Beta into R L; and when it is negative, it is the same thing by the other transistor. So, the current swing should be V c c by Beta R L, maximum current swing.

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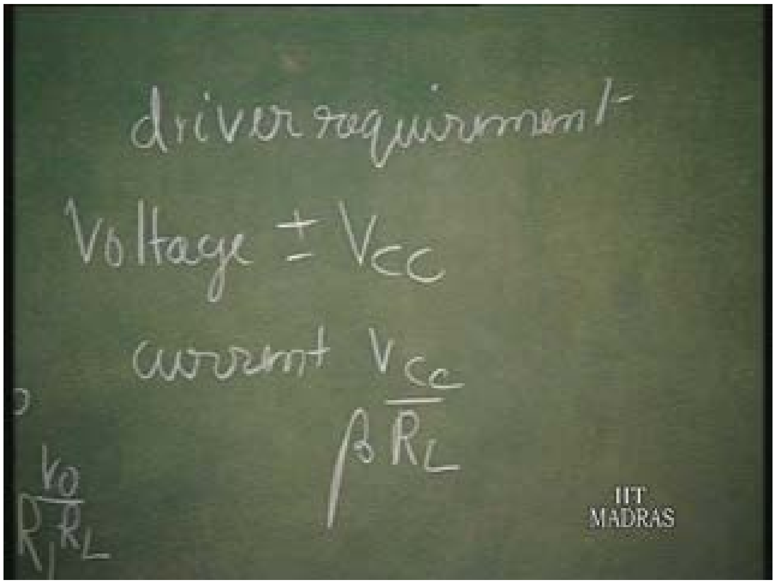

Now, what does it do to our... This is the driver requirement. That much is demanded by the output stage. Now, driver is a common emitter amplifier. I have biased it using a current mirror here. You can see this. this is a transistor connected with the collector, normally connected to the base, as a diode. But I have put... Suppose you do not put this resistance. It will be just this. It is a current mirror. I will explain to you why such resistance is put presently.

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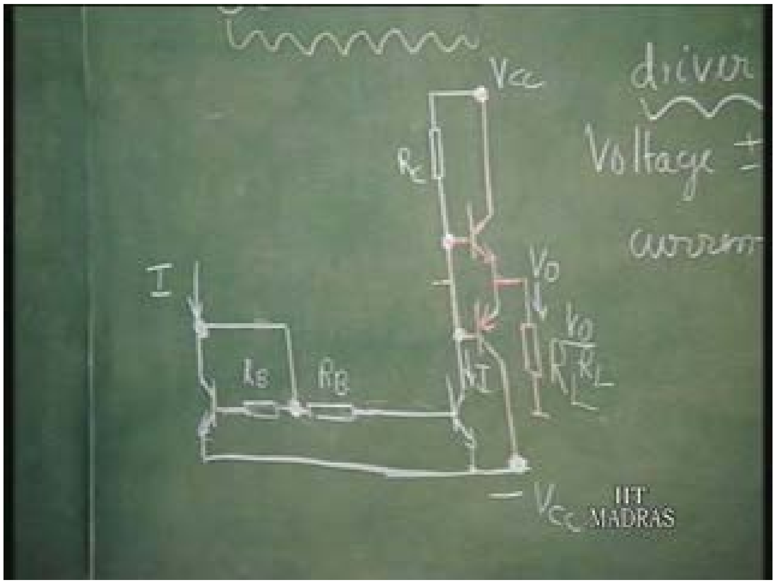

If you do not put a resistance, let us say, it is a straight forward current mirror. If there is I here, there is I flowing there; current mirror. This, we had discussed earlier. Now, I should feed the signal to the input. Let us say, we will capacitively couple the signal here; audio, this is a audio power amplifier you consider.

So, this is the driver. This is getting its input. This may get its input from the pre-amplifier but we are not concerned about that. So, this is getting the input here to the base; A C wise, this is grounded.

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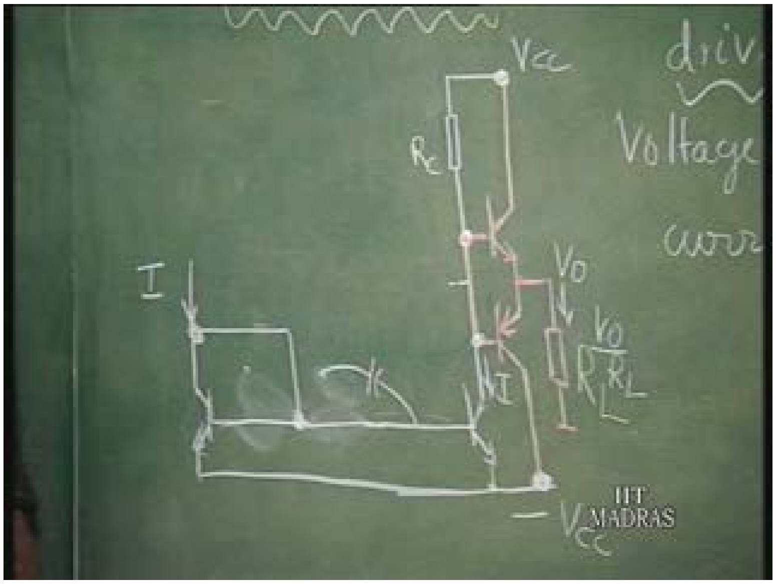

So, but most of the current will go into the diode because this impedance is Beta plus 1 times R e; and this is only R e because this is connected as a diode. So, lot of power is going to be wasted here.

So, in order to prevent that, we put same resistance here as well as here. As far as D C is concerned, this drop is same as this drop. So, the current mirror action still continues because it is symmetric with respect to this point. Voltages are the same on either side. So, currents must be the same. So, it is symmetry; but now, as far as signal drive is concerned, it is not fed here, which is a low impedance point. It is coming through this transistor to this and through this resistor and then the diode.

So, this particular thing, resistance can be chosen to be high so that most of the signal current will go into the transistor rather than into the...this biasing circuit. So, this will bias the circuit as well as...in a stable manner, as well as permit signal to go into the driver stage completely.

So, this is a common way of biasing a transistor in common emitter mode without using an emitter resistance in a stable fashion so that the current is independent of Beta of the transistor and also sort of feeding this signal so as to make the amplifier take most of the signal current rather than the biasing circuit. So, we will put this R B here, R B here. R B should be of the order of kilo... hundreds of Kilo ohms so as to make this transistor take the signal current and less of power gets dissipated in this.

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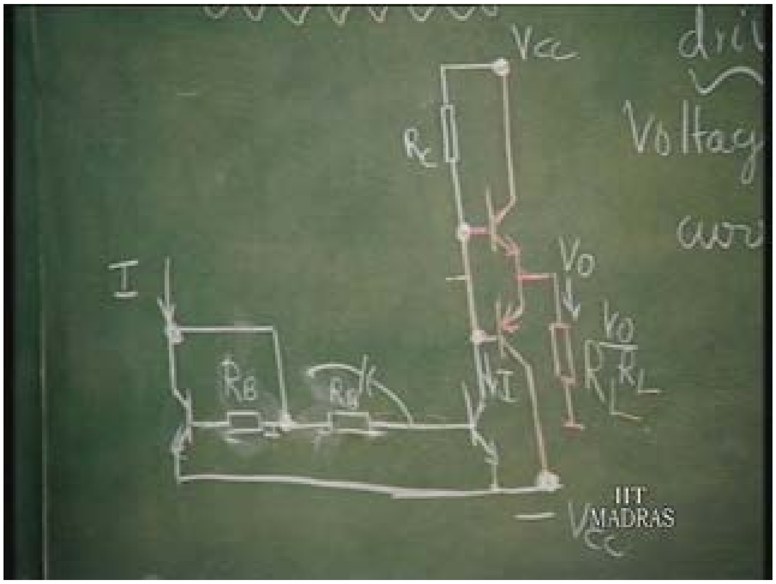

Now, this is the place where we feed the V i; and therefore, the gain of this is going to be g m into R c. g m into R c, minus g m into R c, g m being equal to 1 over R e, R e being equal to V T divided by I; V T divided by I. So, this is the gain of the stage.

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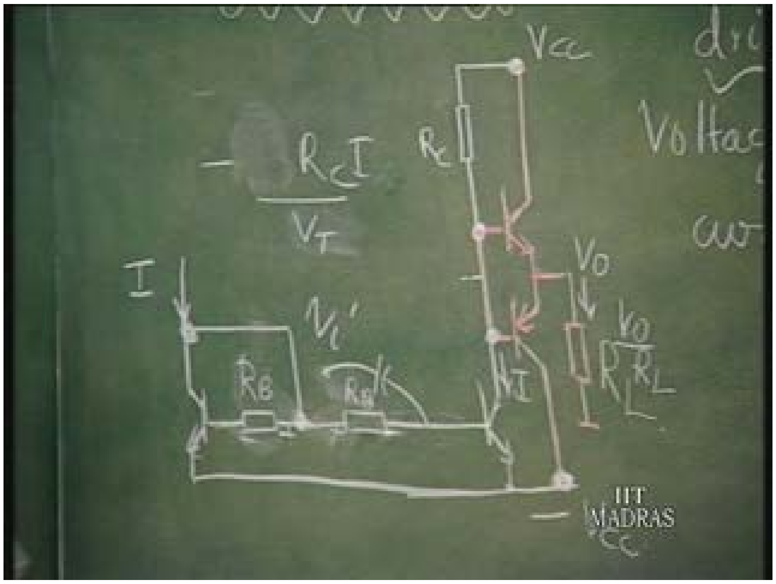

Let us say, how do we design this so that the swing is proper; so the quiescent voltage should be zero so that the swing can be zero to V c c on this side, and zero to minus V c c on the other side? So, this voltage should be zero. That means this current should be, quiescent current should be, V c c by R c. This voltage should be zero and therefore this quiescent current should be V c c by R c. That means I is fixed as V c c by R c.

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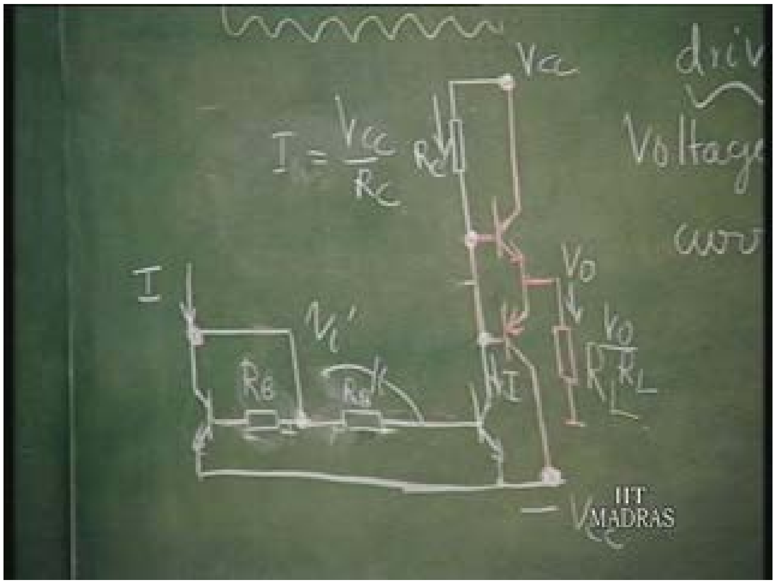

Let us take an example. R c is 10 K, let us say; and V c c is 10 volts. So, V c c by R c is 1 milliampere. That means I have to drive this by means of a 1 milliampere current. Is this clear? So, this is 1 milliampere current. Then automatically, the voltage, quiescent voltage here, V naught, is going to be at zero volts. So now, it can drive swing fully up to plus V c c and minus V c c.

And this current V c c by R c should be, V c c by R c should be greater than what? V c c divided by Beta R L. This is a Class A operation. This is operating in Class A. So, the current, quiescent current should be greater than the maximum current swing that is required of it. So, this is the basic structure for this particular thing. If therefore, if we have V c c by R c chosen to be greater than V c c by Beta R L, then you know how R c can be chosen because V c c gets cancelled and it will give you a limitation that Beta R L should be greater than R c.

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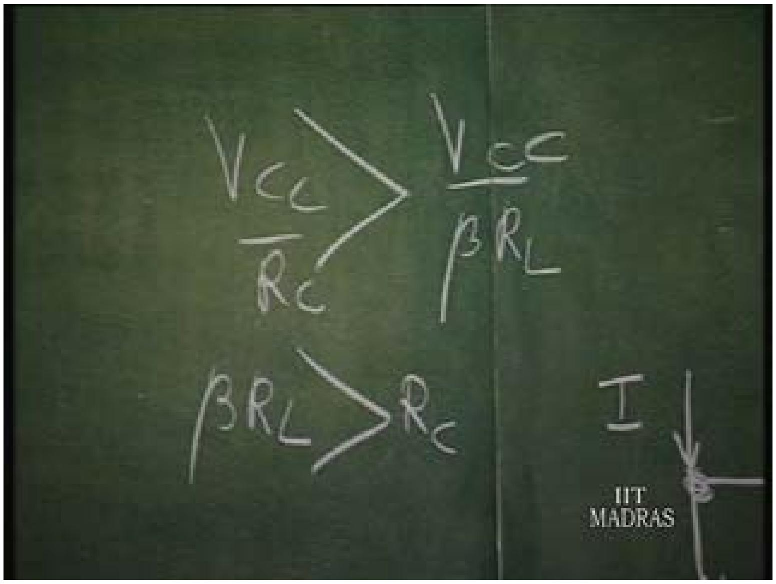

So, Beta R L should be greater than R c. This is therefore restriction on this. If the drive requirement is large, obviously, R c has to be low. So, the quiescent current will be pretty high. This is the way you have to carefully design the driver stage also so as to fulfill all these requirements of the output stage.

So far, we have been discussing Class A, B and C. So, in any subject, you have to know the A B C D of the subject, so that is the introduction. So, Class D power amplifier forms such a thing without which we cannot really say discussion on power amplifiers is complete. Class D power amplifier is the most popular power amplifier for audio as well as control applications. Even in communication area, Class D amplifiers are quite often used.

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So, let us now discuss what is meant by Class D as against Class A, B, C. Class A - the situation was this; that the amplifier was kept in readiness to receive the signal. So, it was working continuously. Whether signal was there or not, the amplifier was dissipating considerable amount of power. When the signal appeared, the power that is dissipated in the active device gets converted into useful signal power. With this resultant defect, it became an inefficient scheme.

Next, we had gone for Class B. Here, it was not bothered about working when the signal was not there. Only when the signal appeared, the signal was driving it into conduction and therefore the quiescent power dissipation was zero. The signal power when it was work... when the signal was appearing, it was converting part of the power into useful power. Something was getting dissipated. So, it was still not very efficient. It was dissipating less power than what it was giving. So, that is why it was quite useful output stage.

Only disadvantage was, non-linearity started increasing at...even when the signal was small, it was non-linear; where as in the Class A, for small signal, it was perfectly linear and for large signal it has started becoming non-linear. In this case, for large signal, it is perfectly linear; for small signal, it is non-linear.

So, this was the difference between Class A and Class B. Then we said Class C. Class C again, it was perfectly non-linear here. It was not even conducting for half the period. It started conducting only for less than half the period for a small angle and it was able to deliver quite a large amount of power, useful power, by reconstructing the signal from current pulses using a tuned circuit, tuned to the fundamental frequency; and since it was a tuned circuit, the power dissipated in reconstruction was almost negligible.

Most of the power could be transferred as useful power and therefore it became fairly efficient; and since the transistor was conducting only for a short duration, it was quite efficient. The efficiency could be above 70 to... In fact, theoretically, close to 100 percent; but practically, it could be 70 to 80 percent because of the various losses that can variably occur in the whole structure.

Next, we are now considering a situation where the amplifier is not at all acting as amplifier even for a small duration. It is acting as a switch. So, using the switch, how can we do linear amplifications of signal? That also, power amplification? This is the topic in Class D power amplifier.

So, consider a switch. If this active device is being used as a switch, when the switch is open, there is no power dissipated. When the switch is closed, again there is no power dissipated. When it is open there is no power dissipated because current is zero. When it is closed there is no power dissipated because voltage is zero.

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So basically, the active device does not have to dissipate any power. In all the other stages A, B, C, you had seen that some power has to be dissipated in the active device, ideally also; whereas here, ideally, there is no need for any power to be dissipated in the device. That means it can convert all the power inputted into useful power.

Therefore, the efficiency is theoretically 100 percent. Practically, again, there will be problems because the switch cannot be an ideal switch. There will be some current even when it is open. That is called leakage current and some voltage even when it is closed... That is called saturation voltage.

And apart from that, the circuits that will eliminate the harmonics will also have certain amount of power loss. Such is the case with Class C amplifier also. So, with the resultant defect, efficiency will come down and still it is going to be the most efficient power amplifier existing today for linear power amplification applications.