Electronics for Analog Signal Processing - I

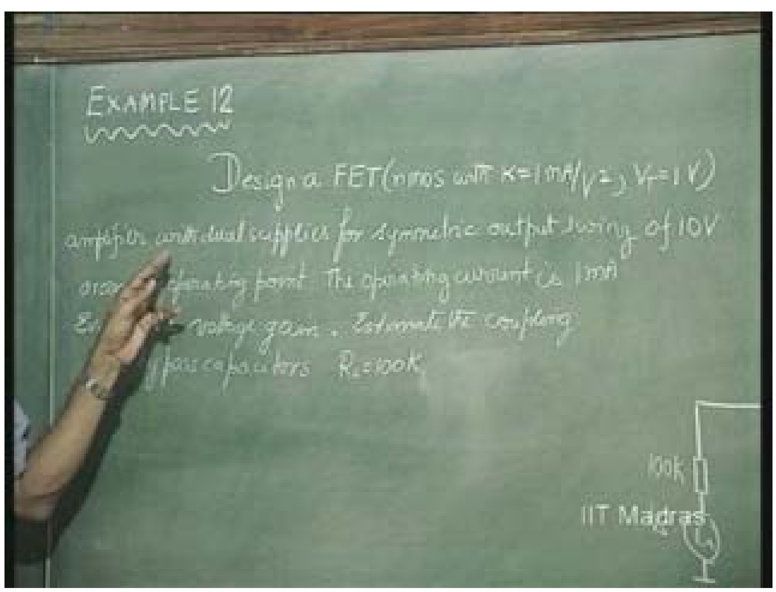
Prof. K. Radhakrishna Rao
Department of Electrical Engineering
Indian Institute of Technology – Madras

LECTURE - 30
CASCADING AMPIFIERS

In the last class, we took an example where the FET was biased using a single power supply and we also had an example in which we had worked out how to operate the FET in a particular operating region; 1 milliampere, 10 volts, etcetera. I D S is 1 milliampere and V D G equal to 10 volts. Now, the same example, we will consider here. The same FET is used.

Design a FET and MOS with K equal to 1 milliampere per volt square and V T equal to 1 volt with dual supplies now, 2 supplies. The supply voltage is not yet fixed. We have to fix it for certain design criteria. Supplies for symmetric output swing. Now, I am treating this in a different manner. I am designing this amplifier for symmetric output swing of 10 volts. I want a symmetric output swing around the quiescent of 10 volts, on either side of quiescent voltage.

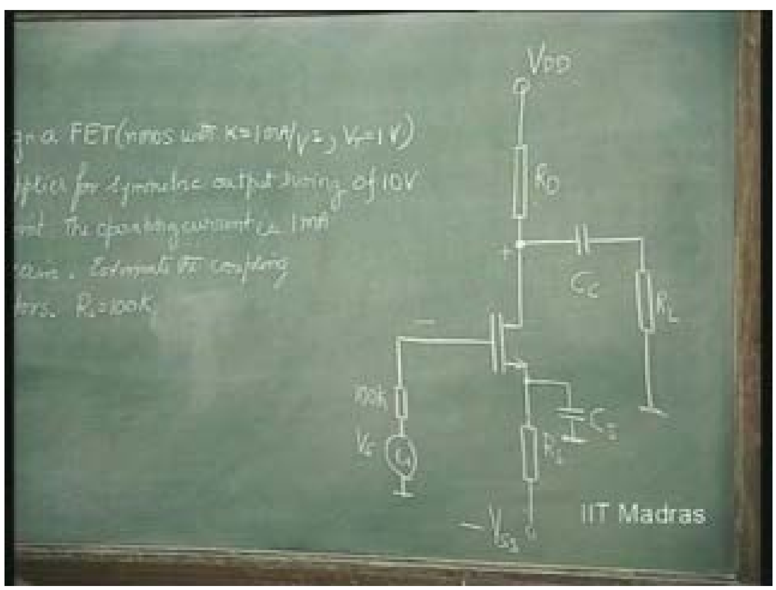
(Refer Slide Time: 02:05)



So this, if it is having a quiescent voltage of some value, on either side of this, there should be a swing of 10 volts at the output, around the operating point. The operating point is 1 milliampere. This should be a stable operating point of 1 milliampere, I D S Q. Evaluate the voltage gain. Estimate the coupling and bypass capacitors. This is similar to the bipolar situation for R S equal to 100 Kilo ohms.

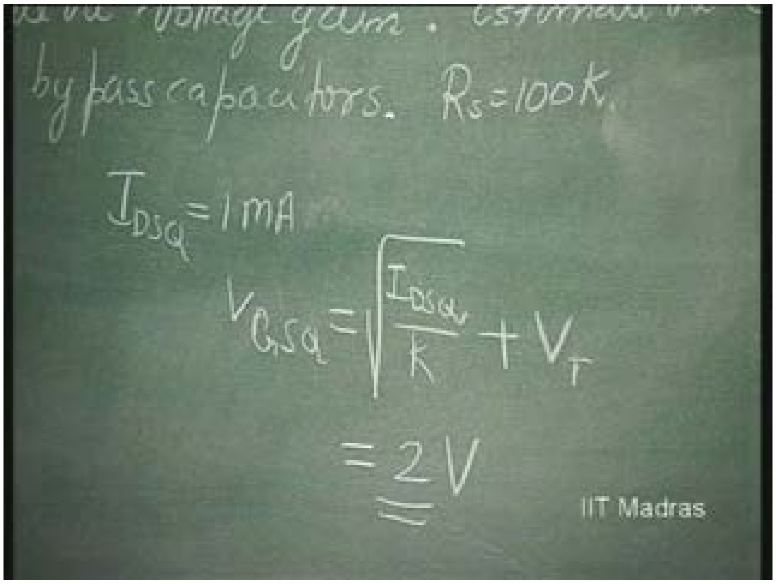
Now, the amplifier configuration is already known to us. Here the source is directly coupled because you are using dual supplies. You can directly couple the source. There is no D C current that is likely to flow through the source. No problem. So, this is the advantage of using dual supplies; direct coupling of the source possible at the input. Then we have R D as the resistance to be fixing the V D G and, let us say, we have possibly an R L coupled to R D through a coupling capacitor C C. And R S to fix the I D S Q at 1 milliampere in a stable manner and that is bypassed by C S.

(Refer Slide Time: 04:05)



So, for 1 milliampere operating current I D S Q, the V G S Q needed V D, V G S Q is equal to, we know, root of I D S Q by K plus V T. This is from that relationship I D S Q is equal to K into V G S Q minus V T whole square. So, from that we know V G S Q is equal to 1 by 1 that is 2, 1 plus 1 that is 2 volts.

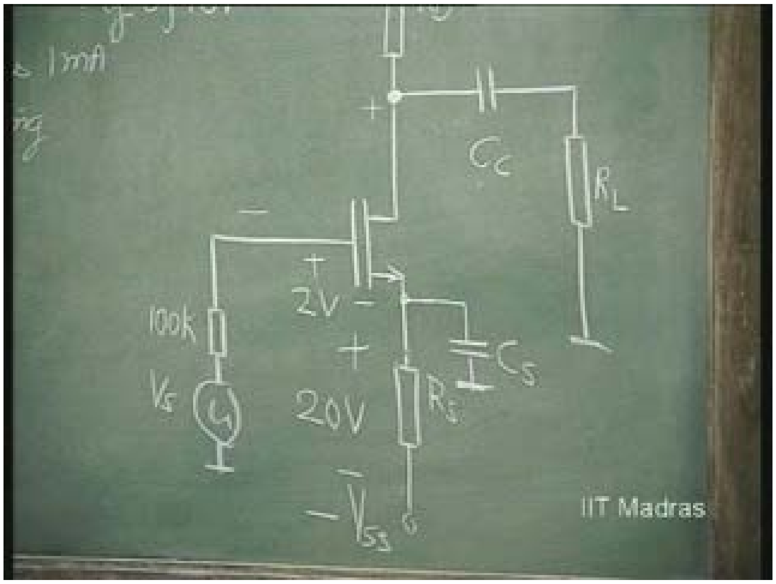
(Refer Slide Time: 04:53)



This we had earlier also evaluated. So, V G S Q is equal to 2 volts. Now, we have this fixed at 2 volts. As I told you, I know that the operating current is 1 milliampere. I want this 2 volts to become negligible compared to the drop across R S. That is what is meant by stable way of biasing.

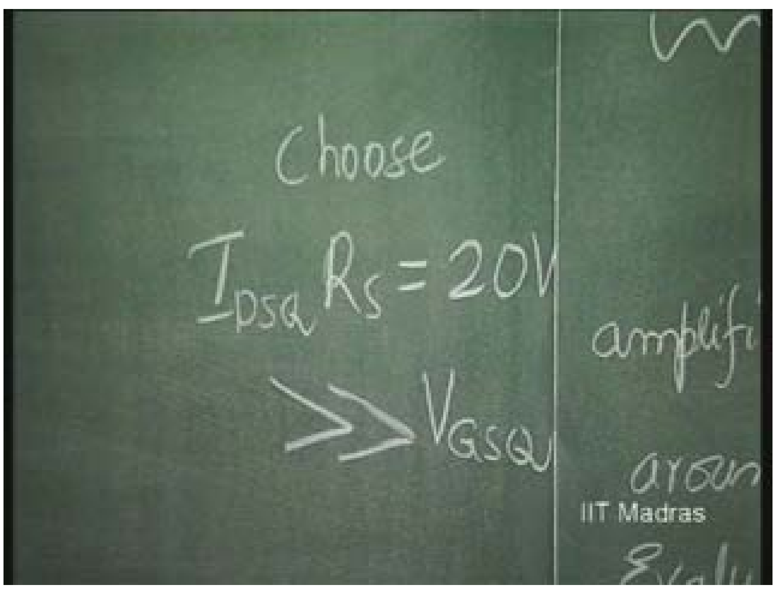
So, that means I should have the drop of the order of 10 times 2 volts, which is 20 volts. So, I am now therefore making the operating point very stable; the operating point becomes relatively independent of the field effect transistor. So, if this is 2 volts, I am selecting to make the operating point independent of the FET characteristics, this drop as 20 volts.

(Refer Slide Time: 05:58)



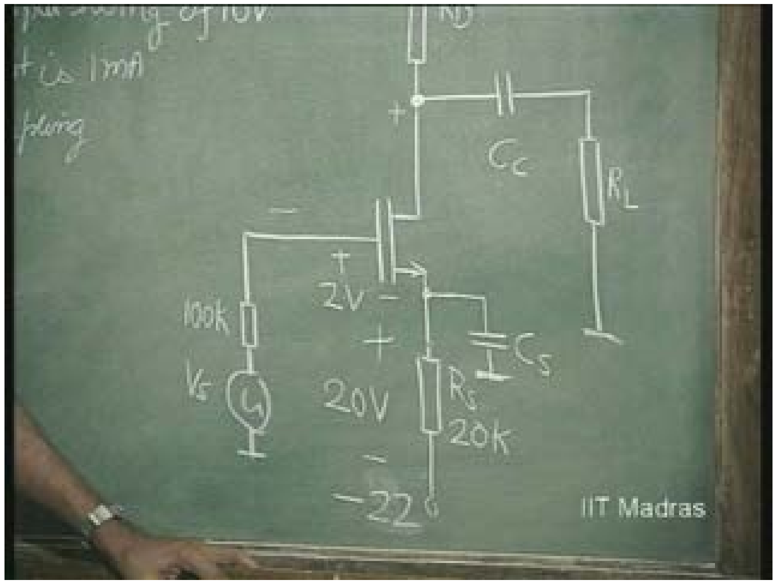
So, if this drop is chosen as 20 volts, I D S Q into R S is chosen as 20 volts. Why is it chosen as 20 volts? It is much greater than this V G S Q. That is the idea.

(Refer Slide Time: 06:20)



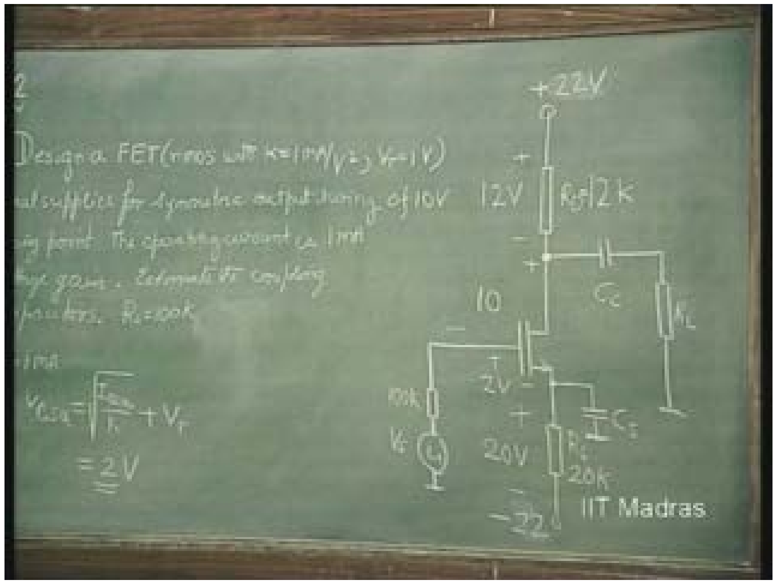
So, R S therefore becomes equal to 20 K because I D S Q is 1 milliampere. So, R S is now fixed at 20 K. If R S is 20 K and this is 20 volts, V S S is automatically fixed at 20 plus 2 volts; that is 22 volts. So, this is 22 volts.

(Refer Slide Time: 07:01)



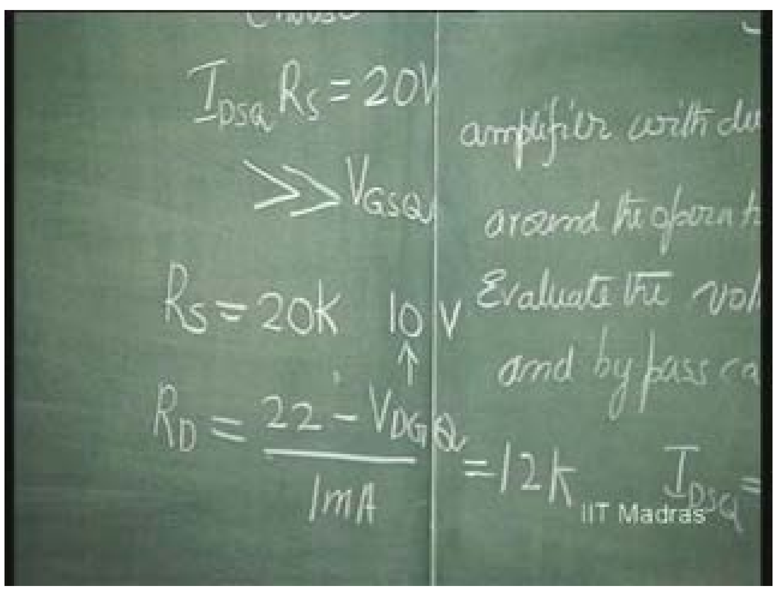
If it is dual supply, if this is minus 22 volts, I would definitely have V D D also as minus, plus 22 volts; and if this is 10 volts that is what this swing should be. Output swing corresponds very nearly to V G D Q in one direction. So, if this is 10 volts - Is this clear? - on one side, before it goes to triode region. So this is very nearly equal to 10 volts. Actually, you know that this can now go to minus plus 1 volt. So, there is a swing possibility of 11 volts on this side. So anyway, I am fixing this as 10 volts. Then, this drop is going to be how much? 22 minus 10 volts, which is 12 volts. So, if this is 12 volts, R D is going to be equal to 12 K because I D S Q is 1 milliampere.

(Refer Slide Time: 08:33)



If R D is 12 K, R D is equal to 22 minus V D G, V D G Q divided by 1 milliampere. This is equal to 12 K, this being chosen as 10 volts.

(Refer Slide Time: 09:03)

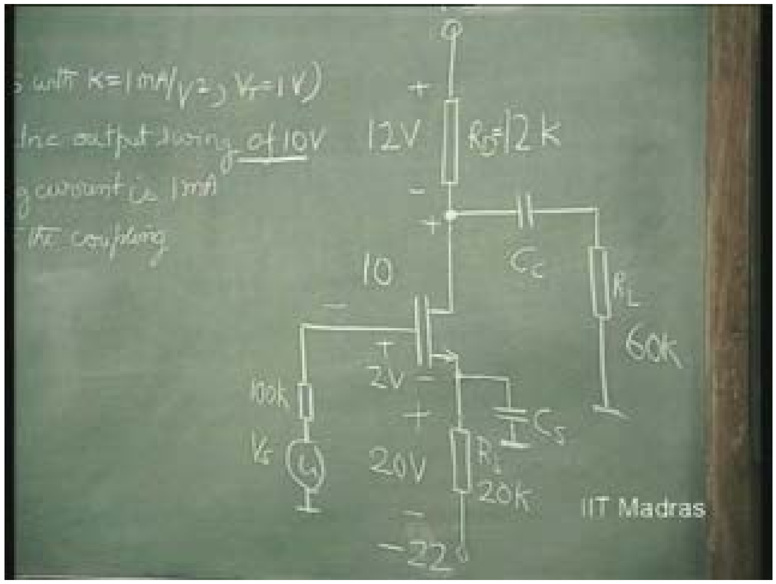


That is because of the swing possibility. Now, this is 12 K. R D is 12 K and therefore other swing is I D S Q plus Delta I ds. That Delta I ds can become equal to 1 milliampere now. So, I D S Q into 12 K parallel R L is the other swing possible. If current swing possible is I D S Q, then the voltage swing, because of I D S Q swing of current, is equal to 12 K parallel R L, which is 12 K into R L divided by 12 plus R L. And that should be equal to how much? – 10 volts, because we want symmetric swing. So, this will give R L as how much? Please find out. 120, 10 R L. That is, this is 1 milliampere, 60 K. That will be 72, 12 into 60. That is how we get it. So, R L is 60 K.

(Refer Slide Time: 10:40)

So, this completes the design as required.

(Refer Slide Time: 10:54)

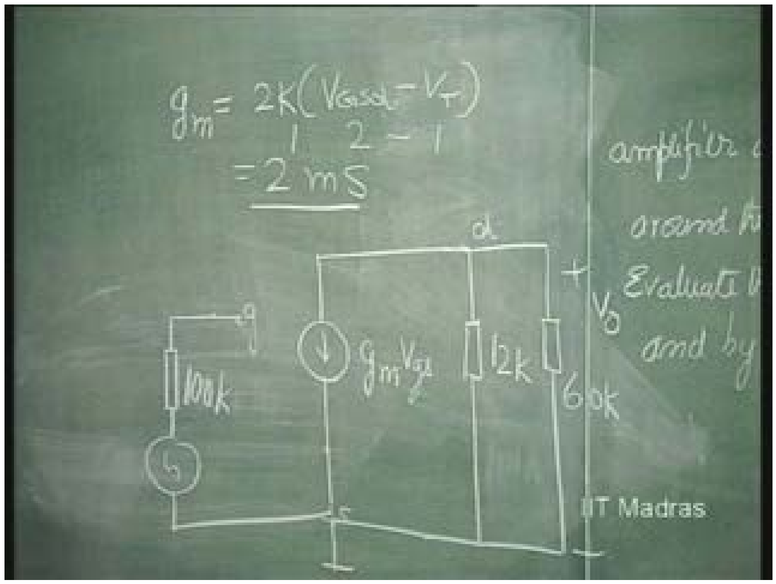


What is it? It is going to definitely give you a symmetric swing of about 10 volts on either side of the quiescent. Now this, under the assumption that this side, it can go up to zero volts; but it can actually go up to 1 volt. That means, on one side, there is a swing of 1 volt, extra given. That is because, we do not know that there is going to be some swing here; it is not going to remain constant. When this goes down, this will go up.

So definitely, we are going to give some amount of leverage for this voltage to increase here so that it will definitely be less than 11 volts. Is this clear? So, it is not going to be full 10 volts. It is going to be, strictly speaking, 11 volts on one side; but since this voltage is going to increase, it will reduce the swing. So, once this design is over, we can now go to evaluating the performance of the amplifier.

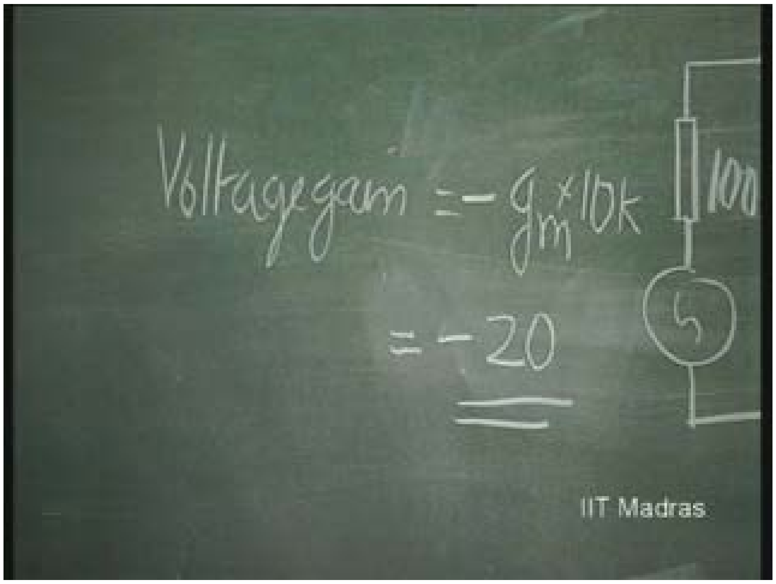
So, we will put down the equivalent circuit now as 100 K, V S coming to gate and then we have g m into this, V g s, this is V g s and R d s. R d s is not given. So, we will take it as infinity; and then R d, which is 12 K shunted by 60 K which is the effective resistance. So, this is the equivalent circuit of our amplifier there, simply. Now, what is the value of g m? g m at the operating point is 2 K into V G S Q minus V T. So, this is equal to 2; K is equal to 1; V G S Q is equal to 2; this is equal to 1. So, this is actually equal to 2 millisiemens, as before. So, we have here this kind of output.

(Refer Slide Time: 13:53)



So, what will be the output voltage here? V naught. 12 K parallel 60 K, which is anyway known to us. That was 10 K. We wanted to make to make it equal to 10 K earlier. That is how we selected the value of R L. So, this effective combination is 10 K. So, gain, voltage gain, again minus because this becomes plus and that becomes minus actually; minus g m into 10 K which is minus 20. It is a good amplifier. Gain is fairly high compared to what we got yesterday, which was minus 4.

(Refer Slide Time: 14:43)



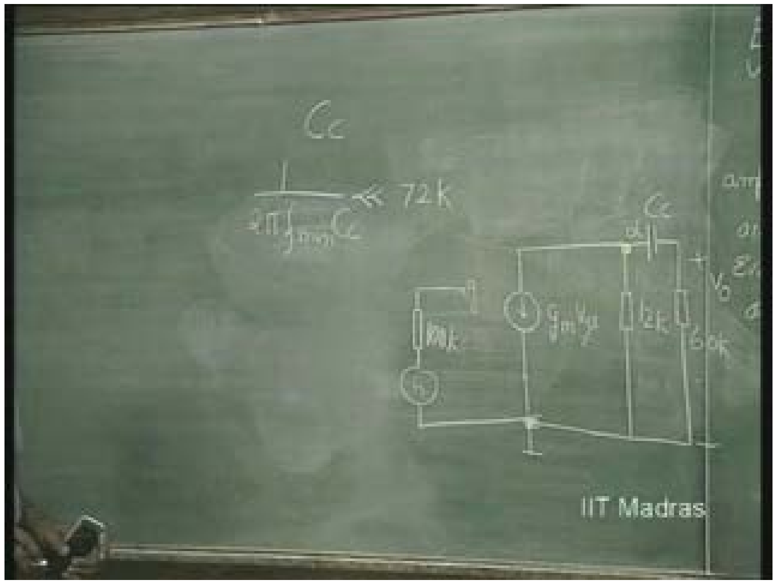
So, this amplifier has a fairly high gain, in which case, I could really consider that this voltage is very small; and therefore, V d g swing is the same as V naught. Otherwise, V d g is going to be evaluated from the fact that there is a voltage going down here, there is a voltage going up here. So, it will be reduced and therefore this particular thing is so small compared to output swing that we can now neglect this variation; consider that this is very nearly at ground potential, in this case.

Is this understood? So, we have the voltage gain. Next, we have to determine the coupling capacitors and bypass capacitors. Now, we will say that the minimum frequency of interest is equal to 100 hertz. So, the capacitor should be short circuits compared to the impedance, resistance coming across the capacitors at the minimum frequency of interest.

Short circuit means we will make the reactance of the capacitor equal to one tenth the resistance seen from across the capacitor. So, this is the guideline for designing it for a specific minimum frequency up to which it has to function satisfactorily. Now, let us consider the coupling capacitor C C. The reactance of the coupling capacitor 1 over 2 pi f minimum into C C should be much less than... What is the impedance seen from there?

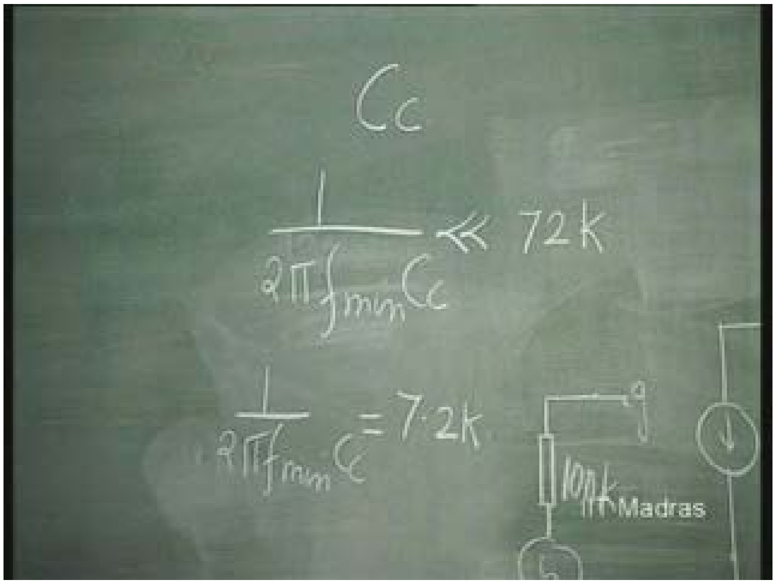
That is very clear. C C comes here. So, this is current source. We have 12 K in series with 60 Kilo ohm. So, 72 Kilo ohms.

(Refer Slide Time: 17:13)



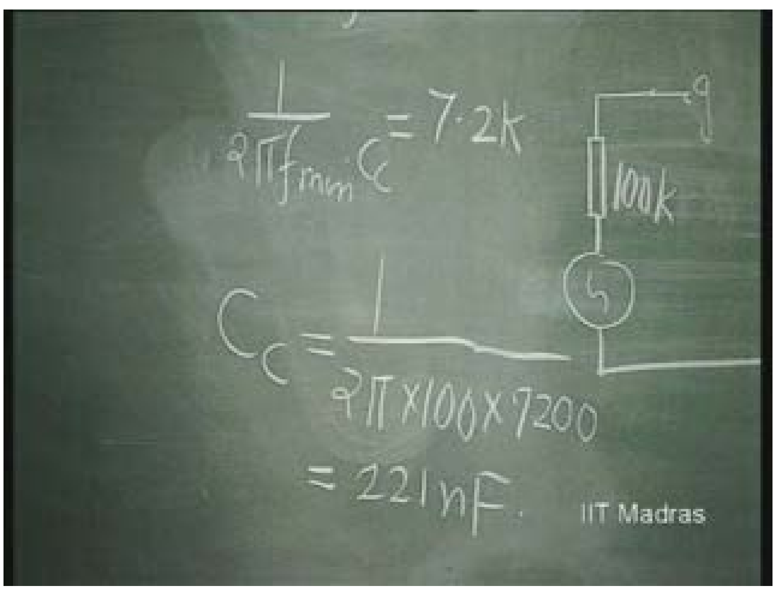
Now, there are two things. If you want this to be a short circuit, then, 1 over 2 pi f minimum into C C is taken to be equal to 7 point 2 Kilo ohms. But, if you want C C to fix up the lower cut-off frequency ... What is the lower cut-off frequency? It is the frequency with which the gain falls to 1 over root 2 times the higher frequency gain. At that frequency, what happens is the reactance of the capacitor will become the same as that of the resistance. So, you will simply equate. If you want C C to fix up the lower cut-off frequency, you will simply equate this reactance to 72 Kilo ohms. If you do not want it to fix the lower cut-off frequency, then you want it as... to act as a short circuit, then, this will be chosen as 7 point 2 Kilo ohms.

(Refer Slide Time: 18:20)



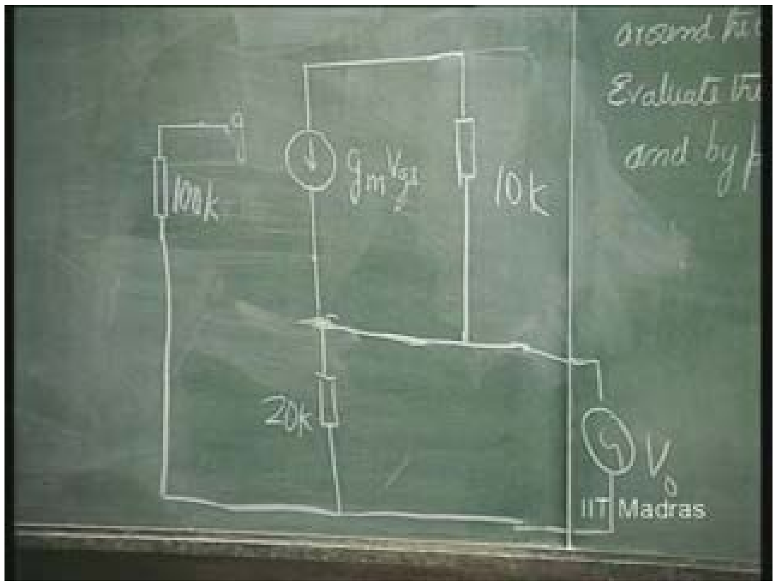
So, CC can be now evaluated accordingly. That is equal to 1 over 2 pi; f minimum is 100, into 7200. How much is this? This is about 220, 221 nanofarads or point 221 microfarads. These capacitors are readily available to us.

(Refer Slide Time: 18:56)



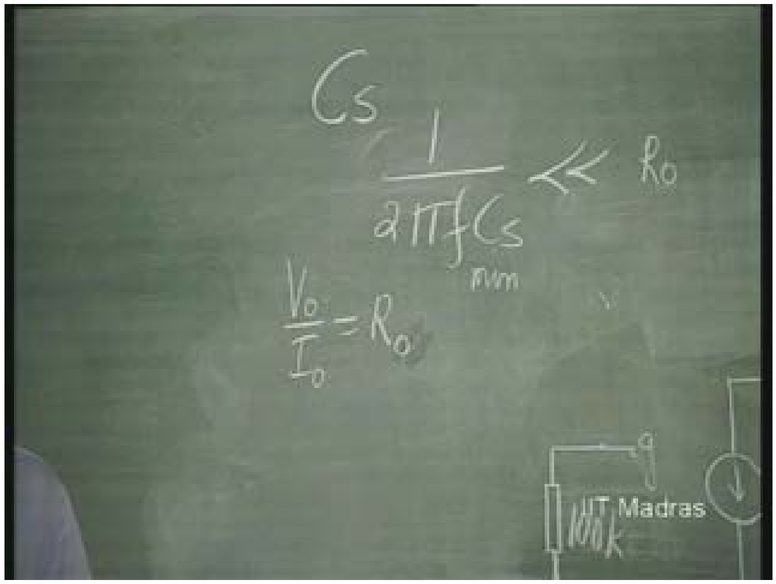
So, you can now see how the coupling capacitor is fixed. Next, we will consider how to fix the bypass capacitor C S. This is an important aspect of design. Once again, it is now assumed that this is a short circuit. This is important. So, that means this is going to be 10 K. So, we will put down this. Apart from that, now, this is not... We have this which is 20 K as the source to ground resistance; and therefore now, we have to apply a voltage here source V naught, then remove this because, this has now ((replaced Refer Slide Time: 20:00)) short circuit all other independent voltage sources.

(Refer Slide Time: 20:09)



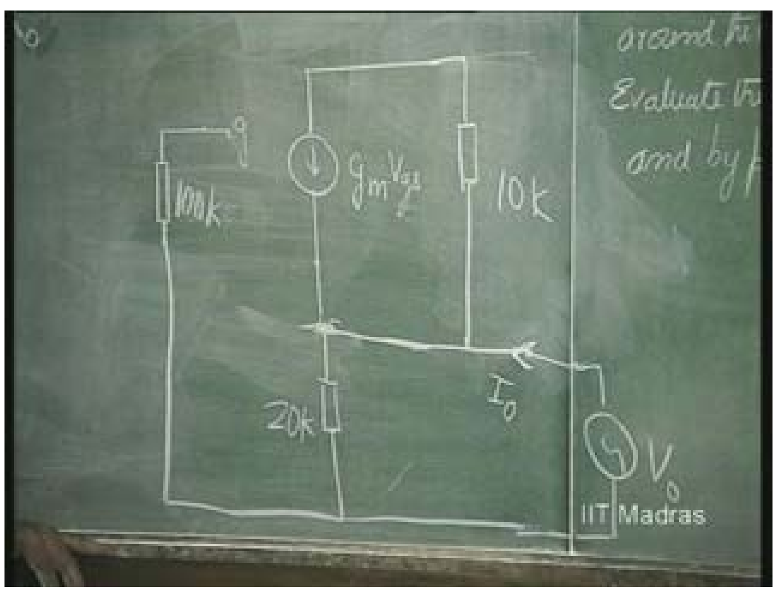
Apply V naught and find out the current I naught; and V naught by I naught is the impedance seen across R S, C S. Therefore, let us call it R naught. So, this C S should be such that 1 over 2 pi f C S, minimum frequency of interest, should be much less than what? – this impedance, R naught, if you want it to function satisfactorily up to f minimum. But, if you want this f minimum frequency to act as the lower cut-off frequency, then, we will equate this to R naught.

(Refer Slide Time: 20:52)



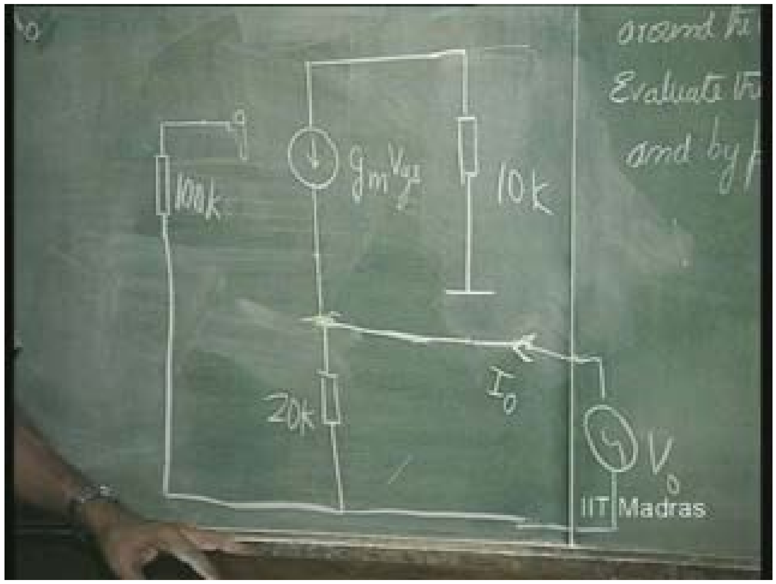
So otherwise, you will make this, this thing, one tenth of this reactance, one tenth of R naught. Now, let us find out how we can determine R naught. Once again, this is an important aspect of design. Here, please look at the circuit, in this case. This 10 K is connected; one end of 10 K is connected to this.

(Refer Slide Time: 21:26)



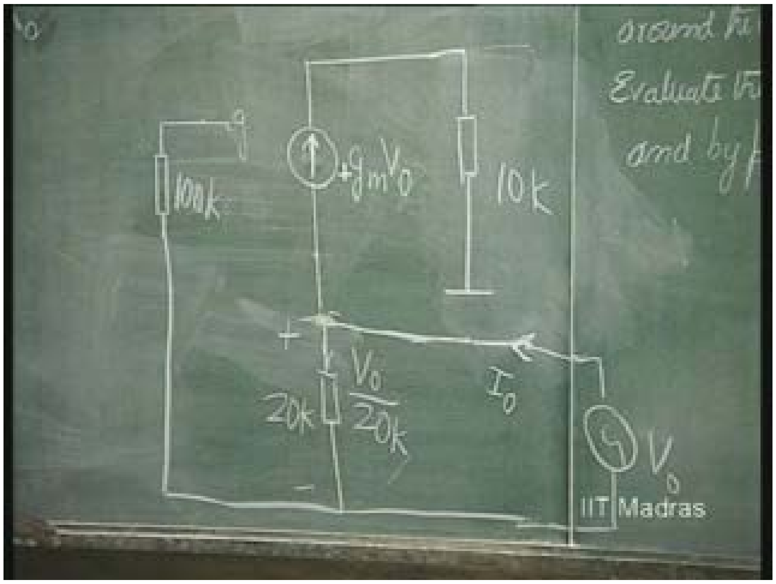
Now, so this is not correct. R d s is equal to infinity; so, no R d s.

(Refer Slide Time: 21:50)



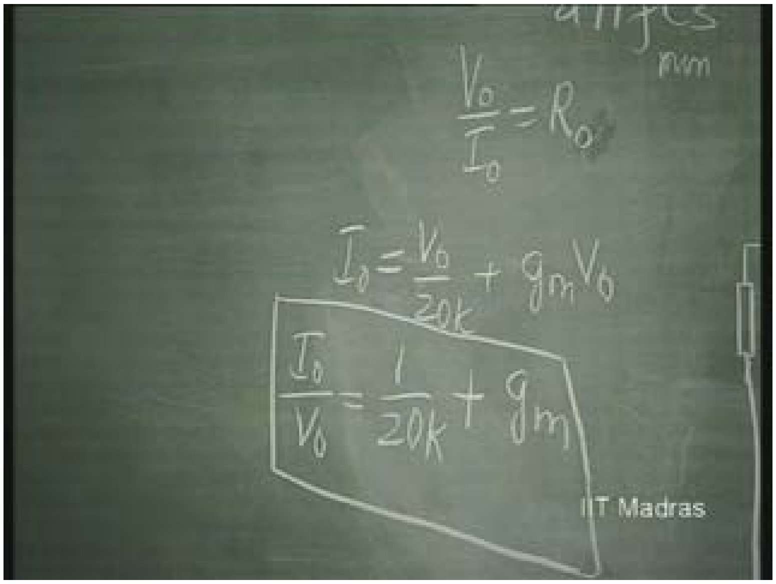
So now, if this is V naught and I naught is what, we have to find out. This voltage...this current is V naught by 20 K. This is simple. This is V naught. This is V naught and V G S, V G S is minus V naught. So, this becomes, V G S becomes minus V naught. So, this is a minus g m V naught current source in this direction or plus g m into V naught in the opposite direction. So, I will make this plus and change the direction of the arrow, this way.

(Refer Slide Time: 22:44)



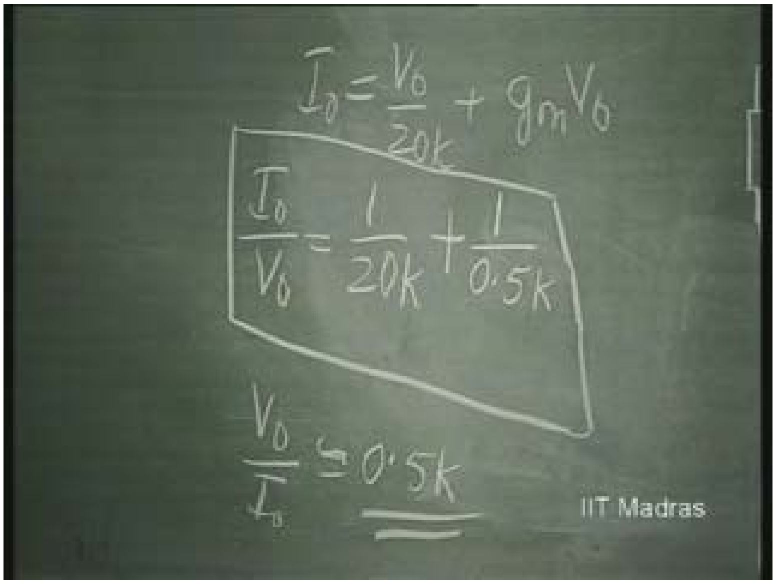
So, you can see that there is a current dependent upon V naught flowing in this direction as well. That means this can be replaced by a resistance of magnitude 1 over g m because current, voltage across this is V naught and the current flowing in, out of this, is g m into V naught. So, the resistance seen from here like this, this is, voltage across this is V naught and the resistance is 20 K. So, the current is V naught by 20 K. So, the total current I naught is equal to V naught by 20 K plus g m into V naught; or, I naught by V naught is equal to 1 over 20 K plus g m. This is an important relationship.

(Refer Slide Time: 23:46)



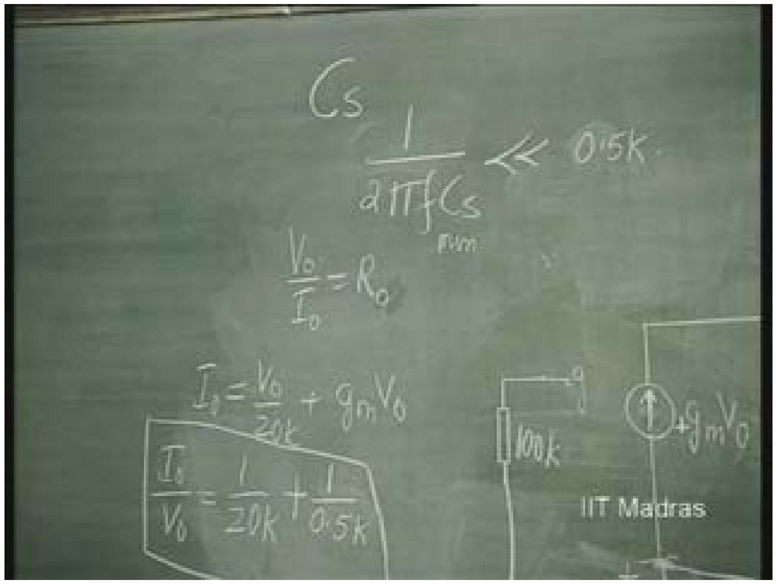
What it simply says is that when I look at it from source to ground in a circuit of this type, always, the impedance seen is impedance across it, which is 20 K shunted by 1 over g m. 20 K shunted by 1 over g m. In this example, g m is 2 millisiemens; so, which is, this is, 2 millisiemens; or, 1 over point 5 K. So, it is equivalent to point 5 K here, shunted by 20 K. So essentially, it is going to give you V naught by I naught, which is equal to, very nearly equal to, point 5 K.

(Refer Slide Time: 24:40)



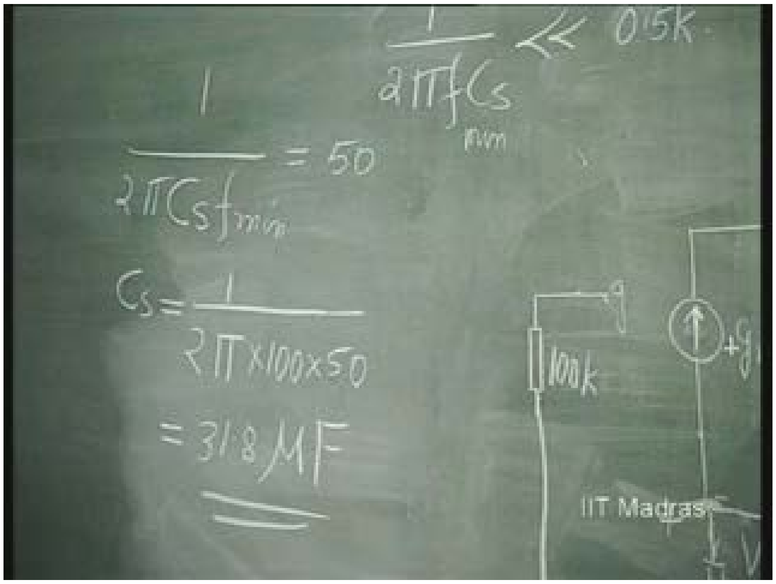
That means this is essentially equal to point 5 K.

(Refer Slide Time: 24:51)



That means if I want this to act as a short circuit, C S is going to be chosen such that 1 over 2 pi C S into f minimum is equal to 50 ohms; one tenth that. So, C S therefore is equal to 1 over 2 pi into 100 into 50. This is again 100, 100. That is equal to about 31point 8 microfarads.

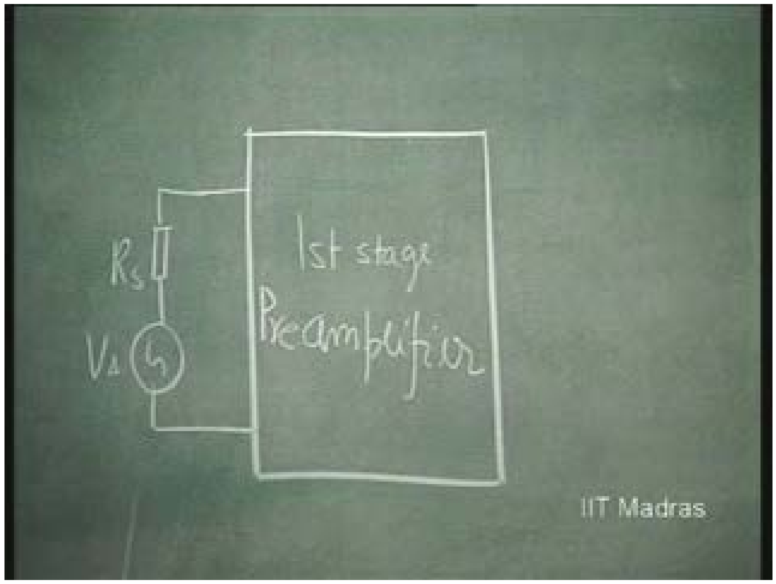
(Refer Slide Time: 25:45)



So, the next topic of interest for us... now that we are aware of how to design a basic amplifier configuration, whether it is common emitter or common source, it does not really matter, we know how to design it for a swing or for a particular gain, etcetera, and how to evaluate its input impedance, output impedance, etcetera; and also how to estimate the lower cut-off frequency and upper cut-off frequency, etcetera.

Now, we should also learn about an important aspect of design. In case our amplifier gain by a single stage is not sufficient, how to improve it by what is called as cascading amplifiers. This is what is done in order to improve the gain, over and above what a single stage can give. So, cascading means, we have basically a source and a first stage amplifier. This is normally called preamplifier.

(Refer Slide Time: 27:15)



In fact, we worry about all these aspects simply because designing a preamplifier is different from designing other amplifiers. This has lot of responsibilities. This is what is called the front end amplifier. It is facing signal in some form or other. We do not know how it is facing the signal. It may be that the antenna signal comes here or a transducer signal comes here. So, it is going to face a variety of input voltages ranging from some value to some other value and, output impedances, source impedances.

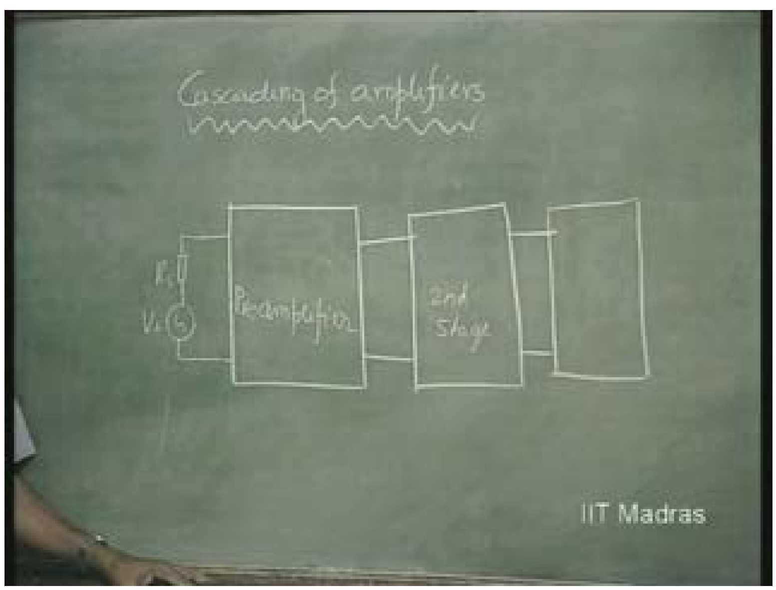
So, this characteristic of this drive might keep changing from time to time. So, this preamplifier is an important thing. It is required to normally act on very small signal level and therefore it may not really operate at what? – large currents. Now, operating point is basically going to determine the output swing that we have already established. If I have an operating current of 1 milliampere, I can have a swing of 1 milliampere. If I have an output operating current of 2 milliamperes, I can have a swing of 2 milliamperes.

Now, when you are required to have only a current swing of, let us say, point zero 1 milliampere, as might be required in the case of a preamplifier, why should you operate it with 1 milliampere? You might say, why not? Obviously, when the signal is not coming, it is still continuing to take that 1 milliampere current from your battery and will dissipate the battery; loss of power, unnecessarily. This is what happens when even the signal is absent.

So, this kind of thing should be avoided. So, when the signal is present, anyway, it is required to amplify. Therefore, it has to operate at a certain current. So basically, the preamplifier operating current has to be chosen as small as possible. For that matter, any amplifier operating current should be chosen as small as possible because, even when it is not amplifying, it is drawing that much amount of current from the battery.

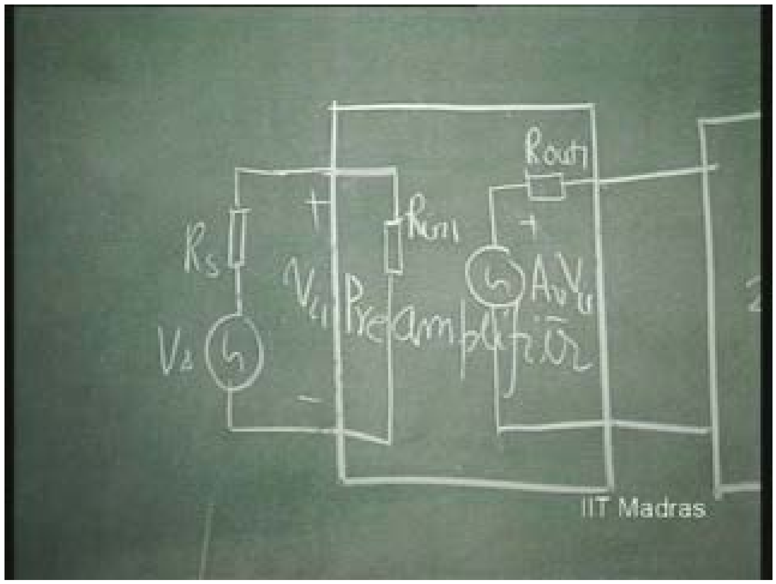
So, this is an important aspect of design. In which case, these amplifiers operate at low currents? And next, the responsibility of this is not so much as the responsibility of preamplifier because this is facing the same species. An amplifier here is what it is facing as its input. Already, certain things are automatically fixed for this. So, this is may be a second stage, so on... You might have to cascade so many amplifiers.

(Refer Slide Time: 30:45)



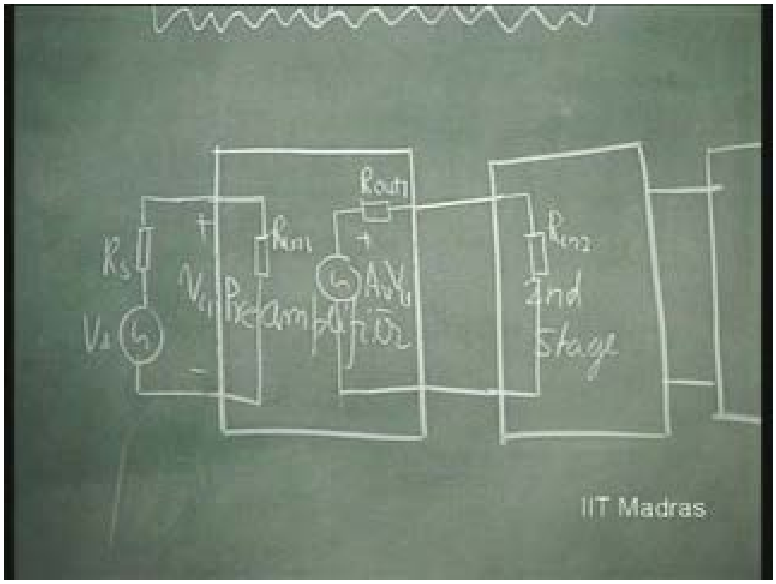
Now, what is the effect of cascading? If we know that this amplifier is non-ideal, once we know that this is non-ideal, what do we mean by that? We know that it has a finite input impedance, finite output impedance; and of course, gain. So, it has its input impedance. It has its output impedance. And, it has its voltage gain or current gain, whatever it is. So, we will consider here. This is V i 1 and therefore it is A V times V i 1, is the voltage gain, let us say.

(Refer Slide Time: 31:40)



For example, for the example that we had just now worked out, A V came out to be 20. So, in this case, A V came out to be minus 20 because it was an inverting type of this thing. So, I have now used a non-inverting amplifier. So, 20. And, input impedance was infinity. Output impedance was equal to, I think, 12 K. So, 12 K was the output impedance and that was shunted by 60 K, which was considered as the load. Now for this, the load is going to be the input impedance of the next stage; so, R in 2. So, this is important.

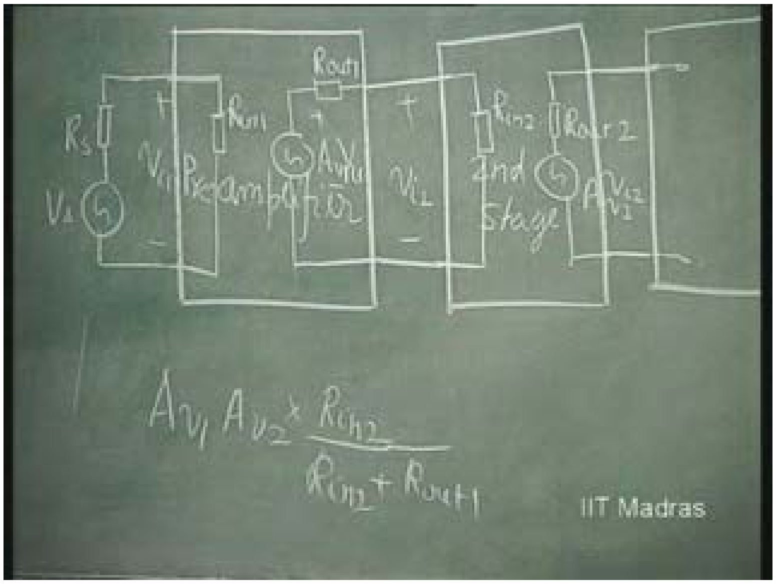
(Refer Slide Time: 32:46)



Input impedance of the next stage is going to be the load for this. And again, we have output impedance of that R out 2 and A V 1, we will call it, A V 2. A V i 2, A V i 2, so on... So, what happens now due to cascading? We can see here that the gain is reduced compared to open circuit gain; gain is reduced by a factor of R in 2 divided by R in 2 plus R out 1. So, R in 2 by R in 2 plus R out 1 is the gain reduction factor here. And therefore, if you now have requirement of finding out the overall gain, it will be from here – A V 1 into R in 2 by R in 2 plus R out 1 into A V 2 into R in 3 by R in 3 plus R out 2, so on...

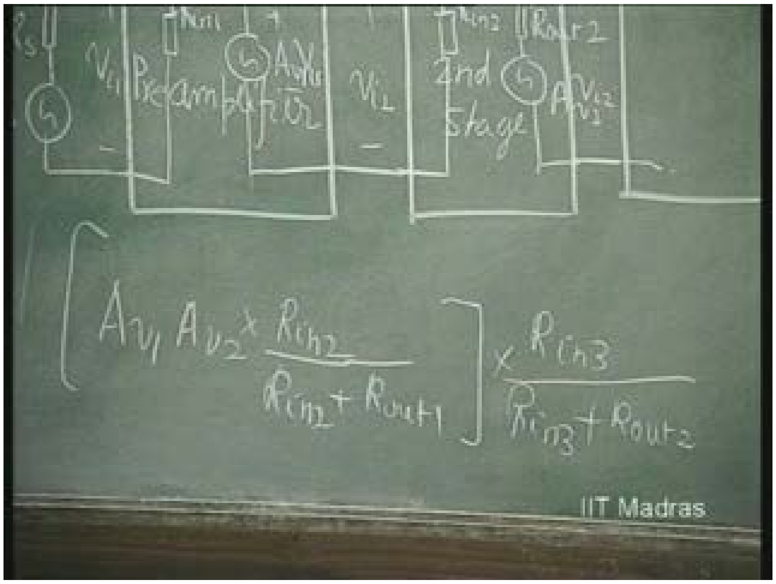
So, we can therefore see that while cascading, we will get all these gains as multiplication factors; but all these gains will be reduced by a factor of the next stage input impedance, by next stage input impedance plus this stage output impedance, so on...

(Refer Slide Time: 34:32)



Is this clear? And coupling, we can keep on doing this; R in 3 by R in 3 plus R out 2. So on it will be...

(Refer Slide Time: 35:12)

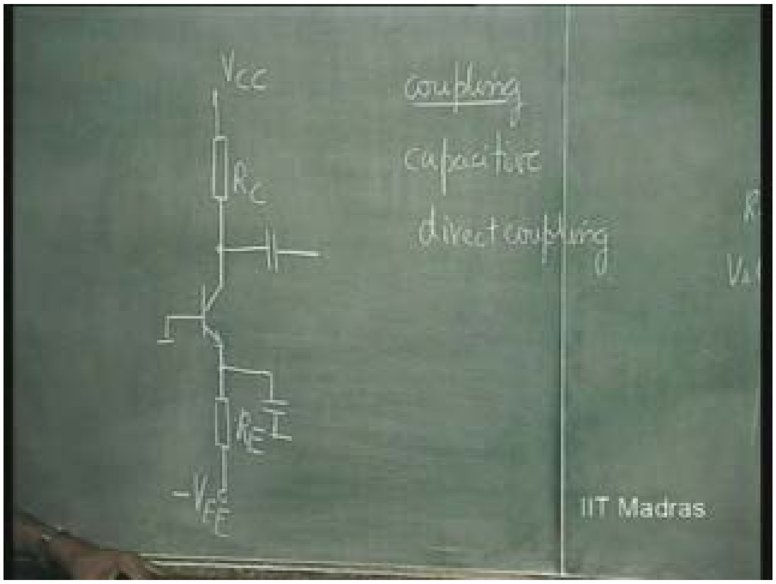


Now, what about coupling? Obviously, one stage can be coupled with the other stage using capacitive coupling or direct coupling. So, it could be capacitive or direct.

Obviously, this capacitive coupling has this advantage that one, operating point of one and the next one can be independently chosen and this capacitor will isolate the D Cs.

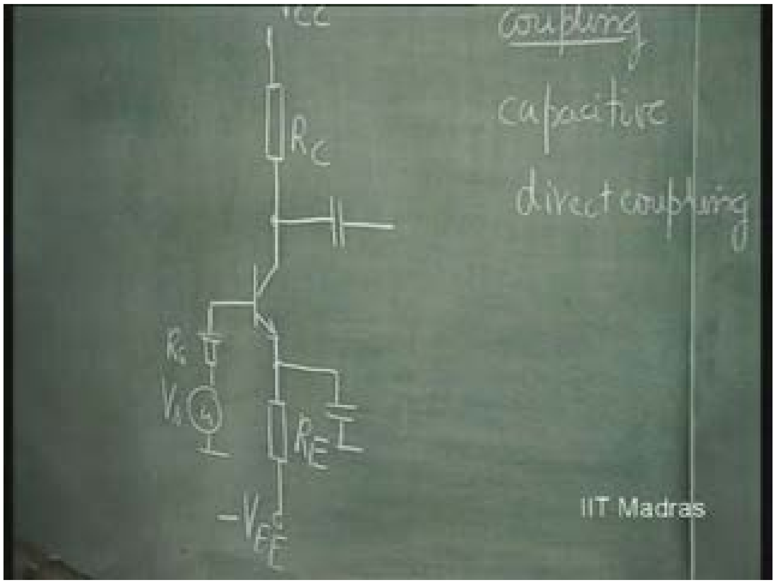
Now, if it is direct coupling, let us illustrate this by taking an example. This is the first stage. Let us say, it is, V C C, R C. I am taking a bipolar stage. I have bypassed this. Now, I can couple this on to another stage. The next stage is also a common emitter, let us say.

(Refer Slide Time: 36:50)



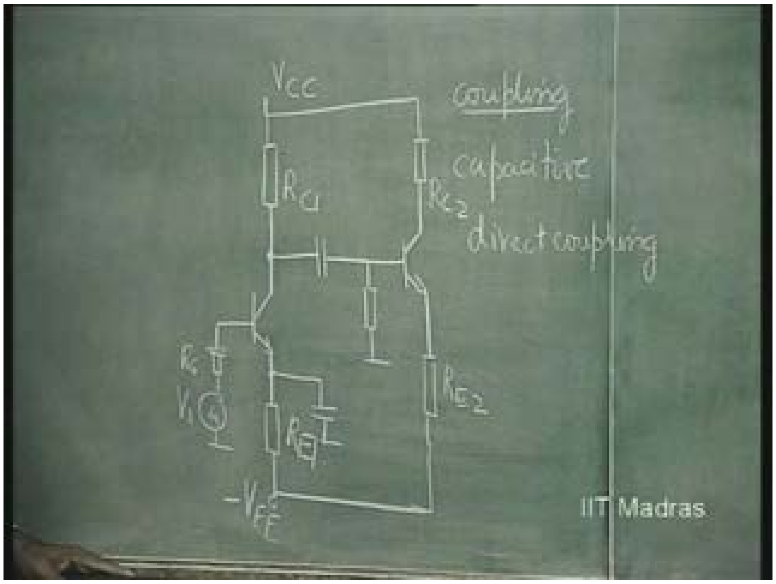
This common emitter is using dual supplies. So, I can directly couple my signal on to this. So, I do not have to worry about capacitive coupling here. I can directly couple the source here just as we did in the last example of common source amplifier. This is a common emitter amplifier.

(Refer Slide Time: 37:07)



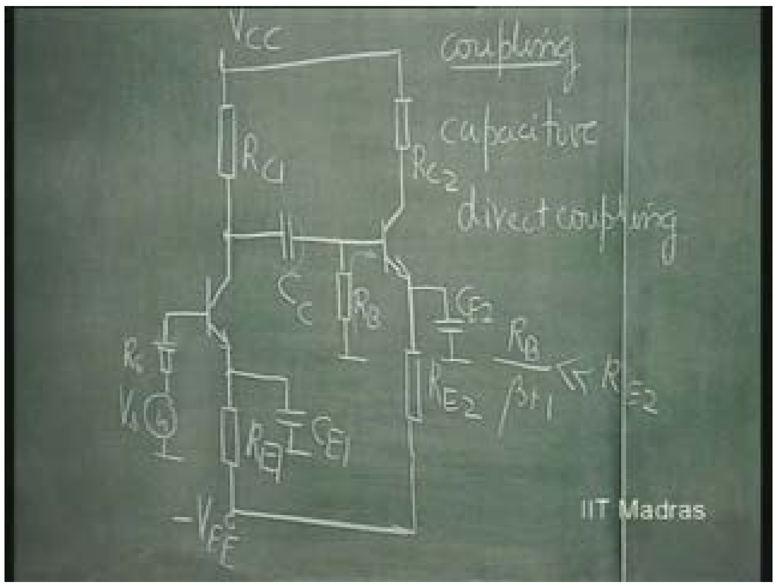
So, how do I do it? In the next situation, I have to put a resistance here so that this voltage is coupled on to the base of this; and then, it will have its R E 2. Let us call this R E 1. This one, R C 1. And so, this is how I can couple.

(Refer Slide Time: 37:51)



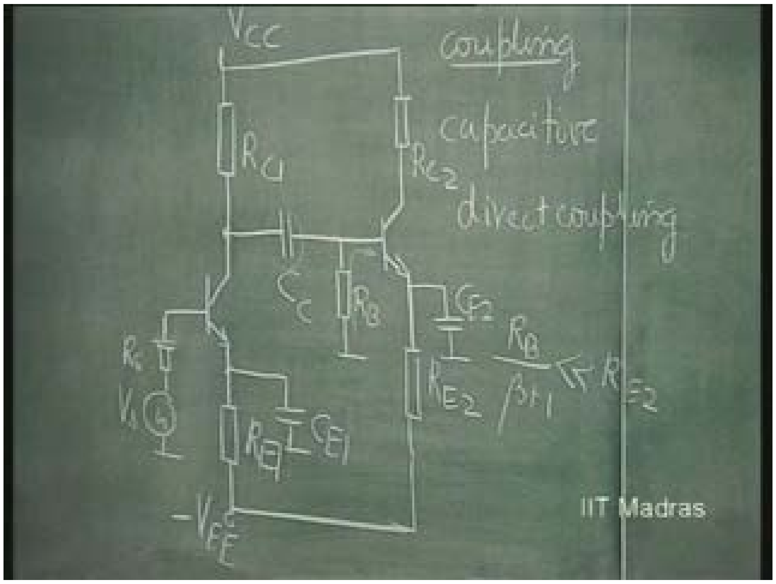
Is this clear? This capacitor C C can couple this output directly to the base. Why is this resistance needed? This resistance is needed because that is a D C base current which has to pass through. So, this resistance is a must. We cannot avoid this resistance; and, if the A C coupling is done by the capacitor. So, this, we will call it as R B. How do you select R B? R B divided by Beta plus 1 should still be small compared to R E 2. This I have told you earlier. R B divided by Beta plus 1 should still be less than R E 2 for stable operating point, so that this drop across R B can be neglected as far the D C is concerned. So, this is how the capacitive coupling can be done. Now obviously, this is also common emitter. So, we will put it C E 1 and this is C E 2, bypass capacitor.

(Refer Slide Time: 39:15)



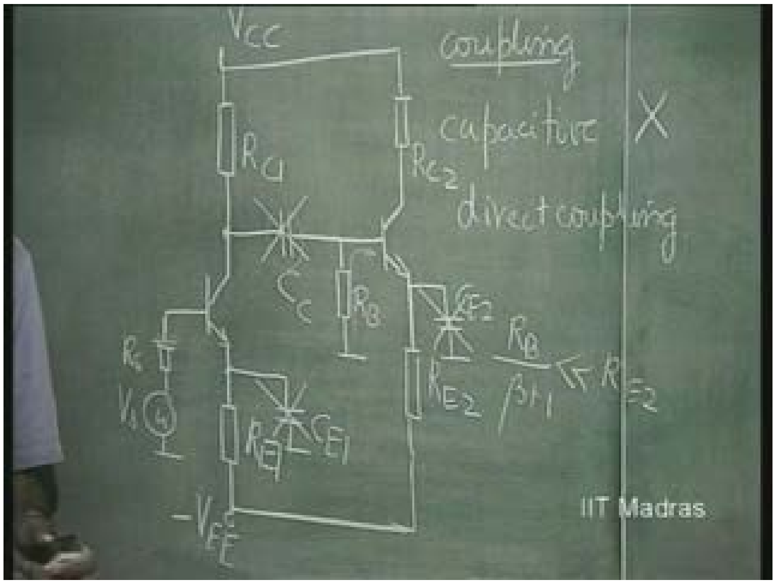
You can see that the order of C E and C E 2 will be of the order of tens of micro farads. That we had seen in the example. May be, even hundreds of micro farads. C C, of course, will be of the order of micro farads. So, these are all huge capacitors and in this day of microminiaturization, when all these other circuits including these active elements, transistors and resistors, are becoming smaller and smaller, these capacitors of the order of micro farad still remain to be very big in size. So, if it is a micro miniature circuit I am planning, there is no place for these capacitors. That means what do we do? There is no other way other than take recourse to direct coupling.

(Refer Slide Time: 40:17)



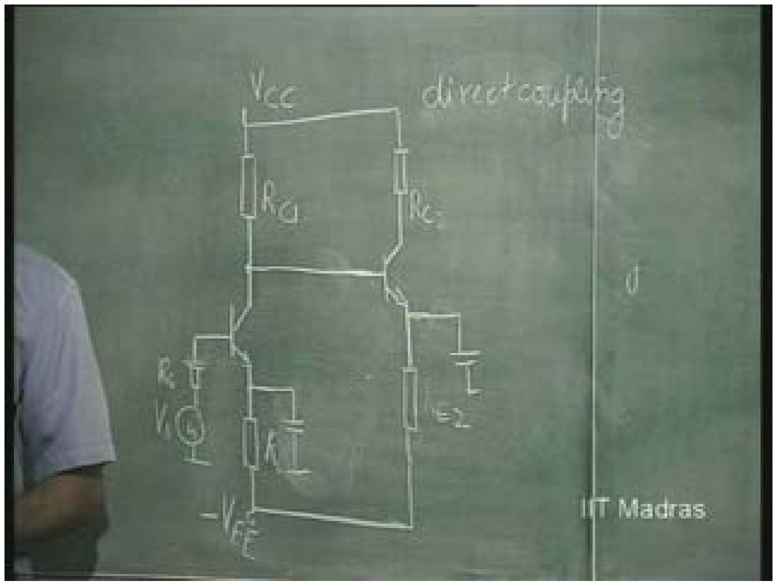
This is avoided simply because large valued capacitors cannot be fabricated by present day technology of monolithic I Cs. So, these capacitors are not available. I cannot make an I C out of it, if you say that these capacitors must be used. If you say that it must be used, it should be put externally. If it is to be put externally, imagine the number of terminals I have to bring out. So, just for an amplifier, I might have to bring out several terminals.

(Refer Slide Time: 40:36)



So, this is avoided by simply direct coupling. We will come to this later. So, coupling is made direct. Obviously, if you can do direct coupling, it avoids large value capacitors being used for coupling and saves a lot in terms of area. And, circuit can become monolithic I C, micro miniature I C, without any problem.

(Refer Slide Time: 41:26)



Now, what are the disadvantages? This is important. Suppose I go to direct coupling. What do I lose in terms of flexibility in design? Now, we have just now seen that the swing of the stage, symmetric swing, output swing, depends upon the operating point.

What are the two factors that determine the swing? Operating current; in this case, operating current; and collector base voltage; V C B Q and I C. One swing is determined by V C B Q. If V C B Q is 10 volts, it can swing up to 10 volts; and operating current. If it is 1 milliampere, it can swing by 1 milliampere. So, these two are important factors which determine the swing.

Now consider here; there must be some V C B Q. Of course, this V C B Q at the preamplifier stage could be made very small because, if I am designing for certain volts swing, let us say, 10 volts swing, and the amplifier gain is 1000... If I am designing for 10 volts output swing finally and the amplifier gain is 1000 and 1000 is not got by one amplifier. Let us say, it is split between several amplifiers. First stage, second stage, third stage, something like that.

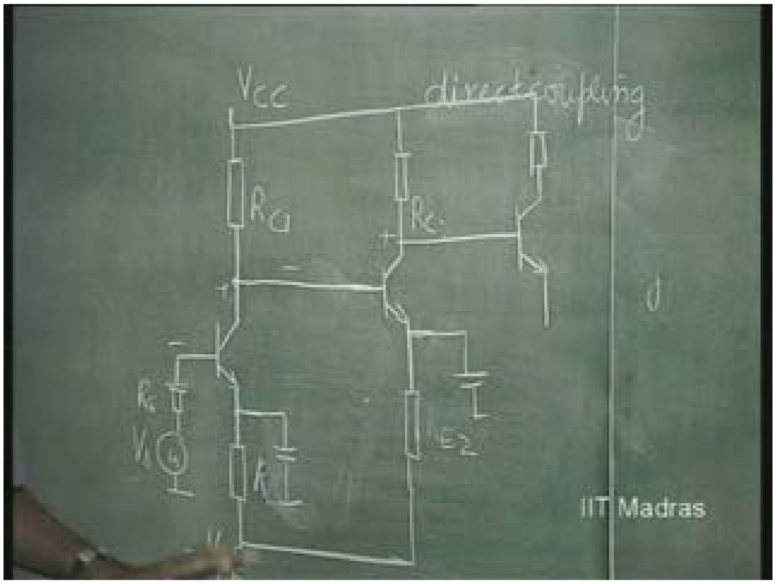
First stage gives, let us say, gain of 10; second stage gives gain of 100; third stage gives gain of 1; something like that. So, if it is distributed like that, then obviously the first stage is handling a signal of only how much? – 10 volts by 100. So, output stage is handling 10 volts. So, this output of the first stage is handling only 10 volts by 100. So, this is an important aspect.

That means the swing, voltage swing, needed for the preamplifier is normally extremely small. So, you do not have to provide, actually speaking, any V C B at all; or, even if you provide, you provide of the order of few volts or hundreds of millivolts, that is sufficient. Same is the case with current swing. If the final stage has to have a current swing of 20 milliamperes and you are having large number of stages, the first stage might have to handle a signal current swing of only few microamperes; and therefore, the operating current of the first stage need to be of the order of few tenths of micro amperes.

So you do not have to select this operating current to be very large. So, these are the things... But, while now, direct coupling, what happens? This has some voltage because of its swing we have provided. The next one will have more swing. So, the next voltage, the quiescent voltage, has to be higher. Let us say, we provide 1 volt here. We provide 10 volts here. Suppose the third stage is coming. It will be still higher. So, what is happening now?

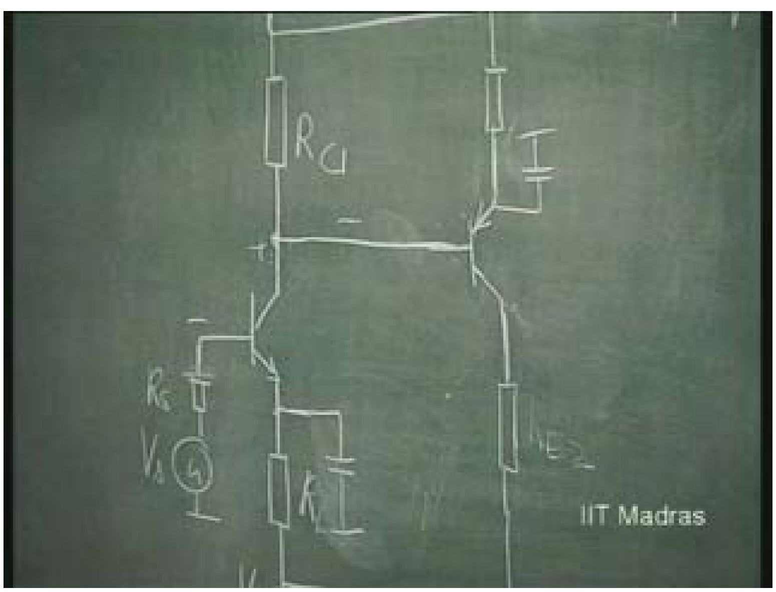
This voltage is fixed. So, I am actually getting lesser and less swing possible for the output stages because of direct coupling. So, this is the disadvantage of the direct coupling. As the gain keeps on increasing, this voltage has to be progressively higher and higher for obtaining higher and higher swings. But that is going to reduce the swing available at the output.

(Refer Slide Time: 45:41)



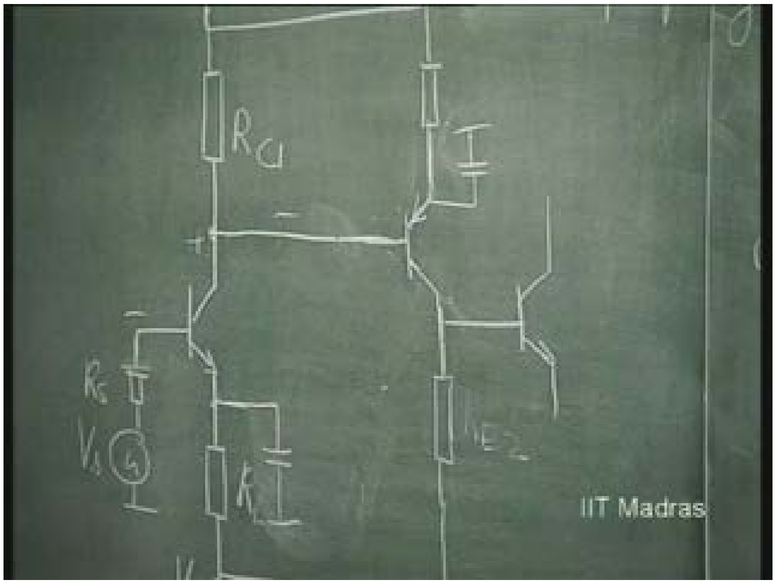
Now, this can be tackled, obviously, by using... if this is N P N, the next stage I use, if it is made equal to, not this, I use what? – P N P. No problem. So, this has gone higher. Because this has gone higher, this swing here is going to be still higher. So, you can now see therefore that by using N P N and P N P, we can get rid of this problem of swing limitation for higher stages, later stages, by using... What is this? These kind of complementary transistors, we can avoid this.

(Refer Slide Time: 46:53)



So the next... again, you will use what? N P N. So again, this, this has got enough swing. Let us provide enough swing here. That means this has gone down further. That means again, the collector to base potential can be kept pretty high for each one of these stages.

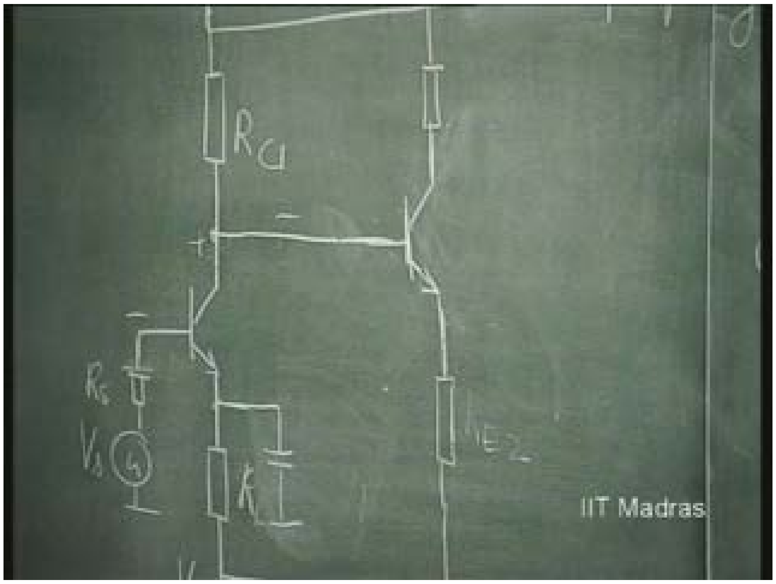
(Refer Slide Time: 47:23)



Is this point understood? This is one way to avoid being limited to small swings at the output by using N P N and P N P transistors. But in some technologies, you do not have both types of transistors, equally good, available for you.

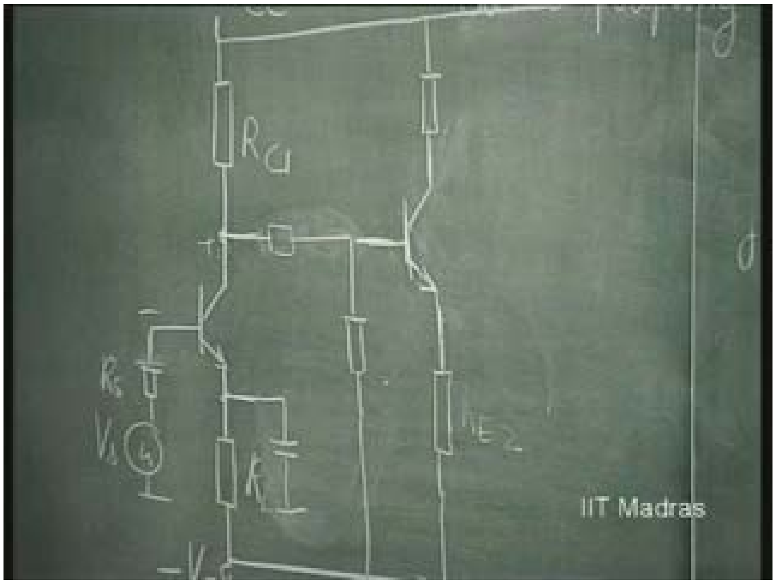
Suppose you have to design amplifiers using only N P N; then, what is the problem? The problem is how to reduce this voltage.

(Refer Slide Time: 48:08)



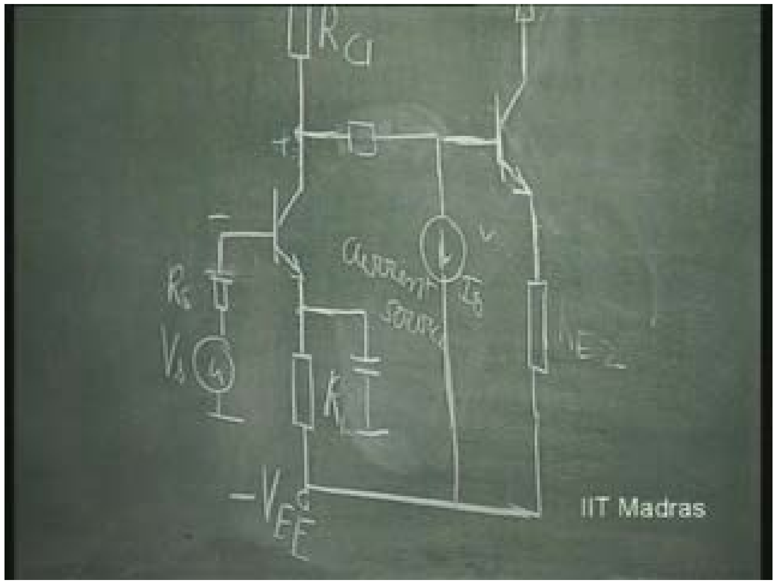
We can reduce this voltage by what? – potential divider, something like this.

(Refer Slide Time: 48:24)



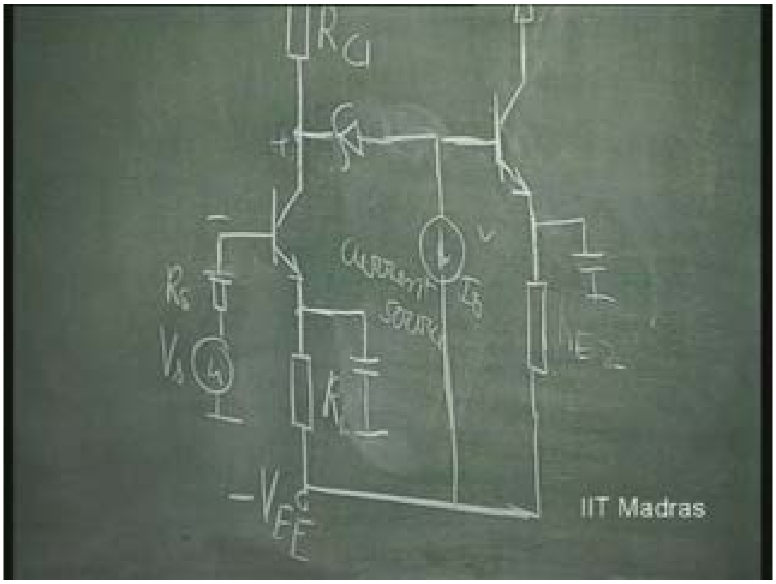
Reduce the D C voltage here. This has gone high, reduce it; and then apply. But what happens? This will also reduce the gain; because this, whatever D C voltage undergoes, the A C voltage also undergoes, the signal voltage. So, this is not a good scheme. You should not affect the A C; you should only affect the D C. That means we can introduce a current source here because this is the one responsible for attenuating. So, I put a resistance and a current source. So, this kind of...

(Refer Slide Time: 49:14)



Again, this is going to drop it by... if this is R, this is going to drop it by I naught into R. You can reduce it. These are called level shifting circuits. This kind of putting a resistance also is not very good because, even if you, let us say, put a current source, there is going to be input impedance of the next stage. And, if you put a resistance, again A C is going to be attenuated. So, you have to put, instead of a resistance, a battery. That kind of battery is available in circuits as Zener diodes.

(Refer Slide Time: 49:58)



So, Zener diode will drop a D C. As far as the A C is concerned, it is very nearly a short circuit. So, this kind of thing requires the need of something like a Zener diode and a current source.

So, we will discuss in the next class how to obtain these current sources. We will discuss also later how to get rid of the bypass capacitors because, we have got rid of the coupling capacitors. How to get rid of these bypass capacitors also will be discussed in the next class. Then, how to generate this current source.