Electronics

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Module No. # 04

Feedback in Amplifiers, Feedback Configurations and Multi Stage Amplifiers

Lecture No. # 06

R C Coupled Amplifiers (Contd.)

We continue our discussion on the frequency response of the amplifier. We have seen that there are three factors, which make result in three different values of lower cut off.

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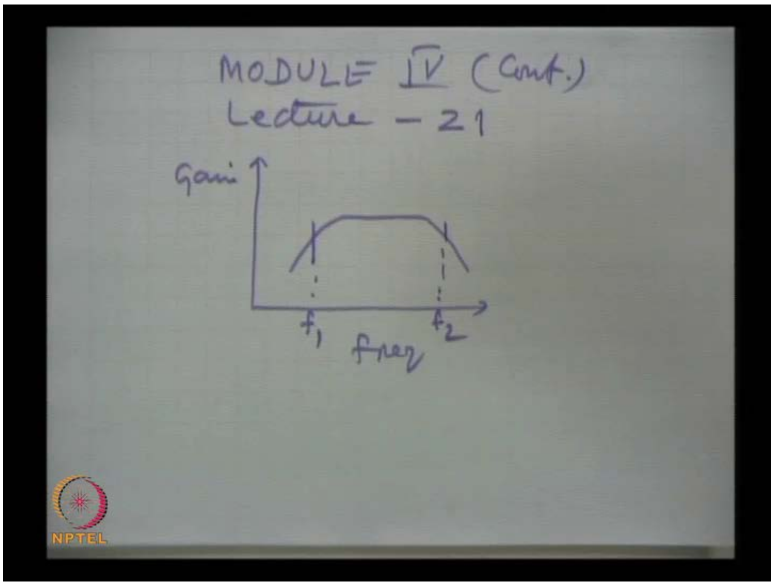

But in the graph when we plot frequency versus gain, then we get actually just one lower cut off which is f 1. Now, three factors may contribute to the lower cut off, one arises from the first coupling capacitor at the input. The other cut off may come from the second cut off at the from the second capacitor at the output. And similarly, bypass capacitor which we use with R E to enhance the gain, that may also give the third cut off. But as in the plot we get only one value f 1.

So, which of these three f 1 f 1 prime f del f 1 double prime we have to consider, the one which is out of these three, which is having highest value of cut off, higher value of frequency at that will be the one with that we call f 1. Similarly, we discussed that for the upper cut off for the upper cut off the coupling capacitors, and bypass capacitors are not responsible, they have no role to play beyond these frequencies they behave like a short. So, why the gain falls at higher frequencies? And as said in the beginning that this fall occurs, because of the contributions of a junction capacitances.

Now, junction capacitances we have seen that the analysis will require the use of Miller's theorem. Miller's theorem is the one which we use to to reduce the the impendence. Whose one end is connected at input and other end connected at the output to its equivalent value at the input terminals and the equivalent value at the output terminals, these are given by Miller's theorem. And we have seen that for example; the junction capacitance between collector and base.

That is the situation suitable for the application of the Miller's theorem and so, at the input the Miller equivalent of this capacitance is multiplied by the gain and gain is quite high. We are talking about for example; for common emitter amplifier in which the gain is 100, 80, 200. So, a small capacitance gets magnified to 200 times or 100 times, 150 times and it is responsible to give you the upper cut off.

So, this is one capacitance. Similarly, at the output there is the effective equivalent capacitance from by using Miller's theorem we get that may give another cut off. And, third cut off we were talking that comes because current gain beta which is the ratio of I C the collector current output current to input current, that is base current. And this falls at very high frequencies. And this fall we can express in terms of the value f t which is the gain at which the frequency at which the gain falls to unity which is provided by the manufacturer.

And out of these three whichever has the lowest of the upper cut off lowest of the upper cut off that is the frequency f two here that we get in the plot. So, having said this now, we should see how multi stage amplifiers will behave.

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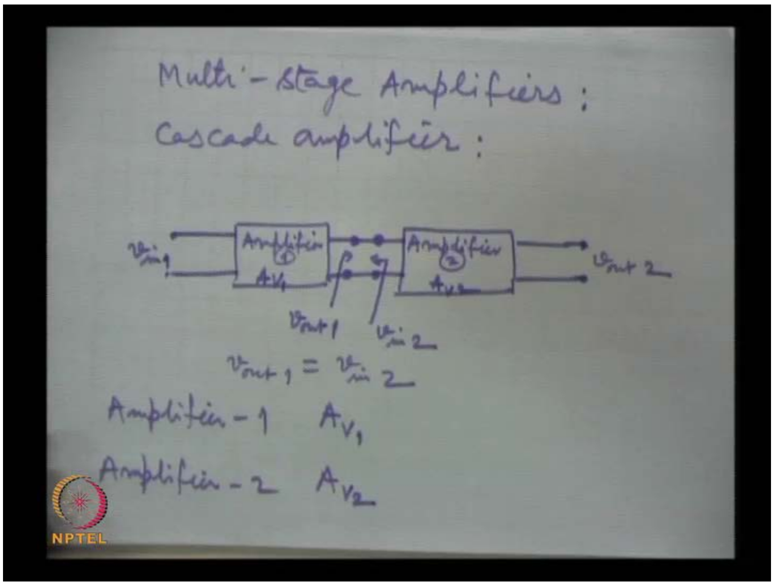

So, we take next the multi stage multistage amplifiers. We have been considering so far single stage amplifiers. That means, one transistor with its biasing network and coupling networks that forms a single stage amplifier. The gain of the single stage amplifier may not be sufficient for many applications. Whether the application includes, running of a motor or some other equipment that may not be sufficient. In practice actually, single stage amplifiers are having less use. multi stage amplifiers are used. What is multi stage amplifier?

A amplifier in which more than one stage it may be two, three, four they may be identical or different type of a stages they are joined together, they are connected normally in series and so, this is also known as Cascade amplifier. So, multi stage amplifier or Cascade amplifier we have when more than one amplifying circuits are connected. Like, we take for simplicity a two stage amplifier which is a multi stage amplifier. And we talk about the salient features of this.

So, here there are two amplifiers. This is amplifier 1 having voltage gain A V 1, this is amplifier 2 having gain A V 2. This is the input and this is the net output V out. Now, 1 and 2 i am writing this is the input to the first amplifier and this is the output from the compound amplifier. Now, here this output here is, V out 1 from the first amplifier whatever is the output that is here.

And this is the, here we feed what is known V in 2. And obviously, the output because the output of the first amplifier is fed to the input to the next amplifier. So obviously, V out 1 is equal to V in 2. The output of first stage is equal to the input to the next stage. Now, in this two cascaded stages, what is most important? There are few things which are most important; one is what is the overall gain? If the individual stages, individually amplifier 1 has a voltage gain A V 1 and amplifier 2 has a voltage gain A V 2. Then, what is the net voltage gain in this amplifier?

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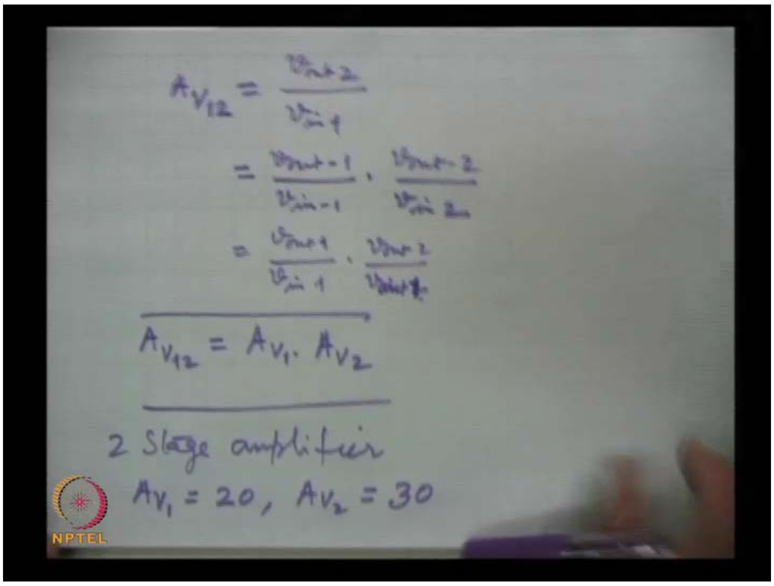

This is A V voltage gain of 1 and 2 combined that is why, i have written the gain as 1 2. And this is obviously, look at this circuit the gain the the input here is V in 1 and output is V out 2.

So obviously, the gain is output voltage to the input voltage. So, here it is V out 2 V in 1 and this can be written in the form V out 1 V in 1 into V out 2 and V in 2. But this is equal to we have seen that V in 2 is equal to V out 1. So, this is further V out 1 V in 1 and V out 2 V out 1. Because V here (Refer Slide Time: 05:23) V out 1 is equal to V in 2.

So, V in 2 i have written as V out 1. So, this cancels out and we are left with what we have written V out 2 by V in 1. And this is therefore, for the compound amplifier the gain is this is A V 1 and this is A V 2 very important relation. The what if individually the two amplifiers are coupled or cascaded having the individual values of the gain A V 1 and A V 2? Then what is the value of the net gain? That is the product of the two gain. Remember product of the two gains. Let us, take an example; that in a two stage two stage amplifier, let A V 1 be equal to 20 and A V 2 be equal to 30 they may be identical or they may be different. So, i have taken 20 and 30.

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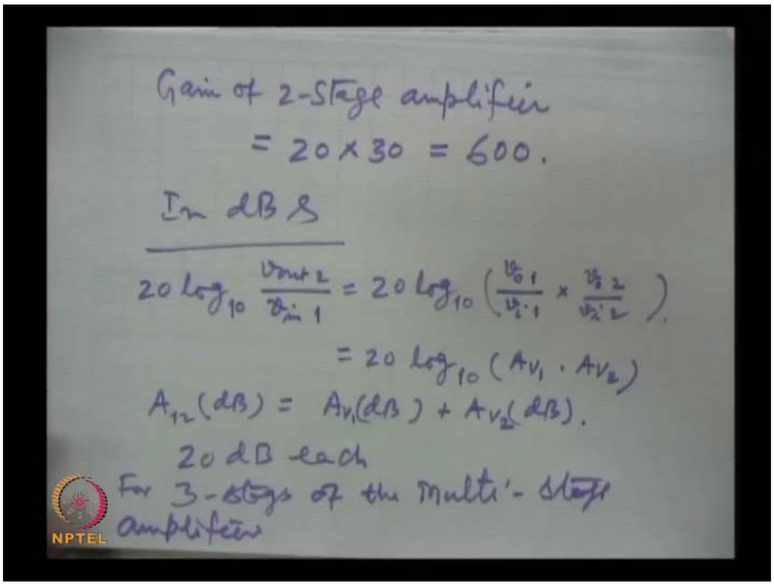

Then gain of the two stage amplifier gain of 2 stage that is multi stage amplifier. That is the product of the two so, 20 into 30 this is 600 it is the product. If we feed here 1 milli volt this will appear at the output of 600 milli volts. If the gains of individual stages are 20 and 30 so, it is a big gain.

Now, we have talked about decibel scale d B scale. When gains are expressed in d B(s) then for multi stage multistage amplifier the d B(s) are additive. Because d B is a log scale so, the product becomes a addition in in a logarithmic ah algebra. So therefore, we can write when we talk of voltage gains then in d B(s) we can express 20 log 10 V out 2 V in 1 and this is equal to 20 log base 10.

And here V out, out i am writings in brief V o 1 V in i 1 into V out 2 and V in 2 and this can be written as, 20 log base 10 A V 1 into A V 2 which is A 1 2. That is gain of the multi stage amplifier in d B(s) this is A V 1 in d B(s) plus A V 2 in d B(s) additive. And, we are for simplicity considering only 2 stages. Actually, there can be many stages.

So, for example; if 3 amplifiers having gain of 20 d B each, then for 3 stages of the multi stage amplifier gain will be

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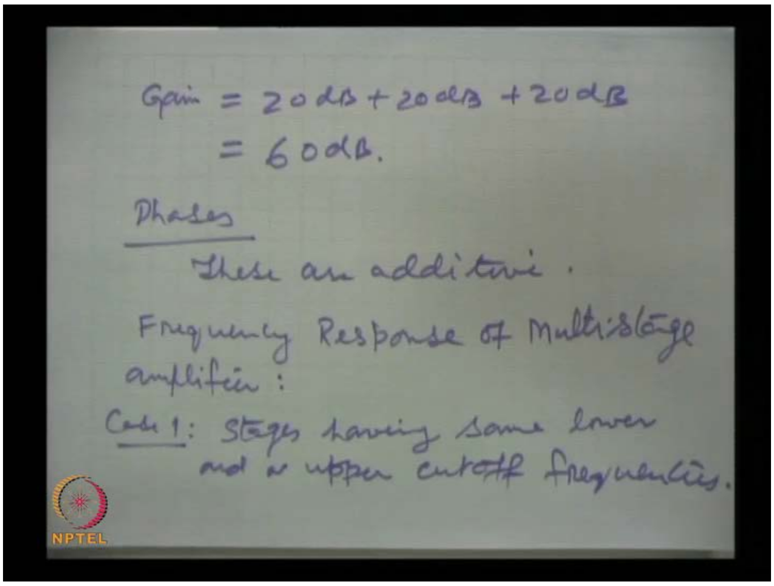

Gain for 3 stages will be 20 d B plus 20 d B plus 20 d B for 3 stages gain will be 60 d B. So, while the gains when not express in d B(s) they are product but once they are expressed in d B(s) they are additive. So, this is about gains.

I repeat that gains are the product of individual gains and when products when the gains are expressed in d B(s) then they are additive. This is about the gain. Gain may be voltage gain, current gain anything or power gain. Now, and we can extend it to any number. Two stages we are considering three, four, five n number of stages the same rules are applicable. Now what about the phases? These are algebraically additive.

These are by simple intuition we can see that they have to be these are additive. So, if we couple two amplifiers for example; both have a phase difference of pi. Then if there are only two stages, then pi plus pi so the phase difference will be 2 pi. That means, output will be in phase with the input. So, phases are additive. And, if one has a phase of pi other has a phase of minus pi then 0 phase will appear and so on. So, phases are additive.

Now so, these are two important considerations about multi stage amplifiers, how the the voltage gain or current gain so, in general how gains are related with the individual values. So, they are normally products and when expressed in d B(s) they are additive. And phases they are additive algebraically. Now, frequency response frequency response of multi stage amplifier frequency response of multi stage amplifier. It is now very clear that, by adding a stages we amplify the signals much more and gains go very high.

If you remember we have said that gain and bandwidth product is constant. This is constant for a individual circuit this is constant for a system. System means multi stage amplifier. So, when the gain goes high, the bandwidth has to fall. So, remember that in multi stage amplifiers the gain fall at the gain increases bandwidth falls.

Now, numerically we have to calculate this a fall in bandwidth. The calculation of bandwidth of the multi stage amplifier is not difficult in two cases and the two cases are; case 1, case 1 when stages which have identical lower cut off and upper cut off, when they are coupled when they form the cascading cascade amplifier, the multi stage amplifier, then the calculation is simple. And, I repeat what am saying, suppose we connect two amplifiers, they have identical lower cut off and or identical out of the the the upper cut off then it is very easy to calculate the cut off lower as well as upper for the multi stage amplifier.

And the expressions are, so the case 1 is: stages having same closely equal lower and or upper cut off frequencies. If for an example; lower cut off is the same uppers they are different then this calculation in case 1 what we are talking will be valid only for the upper, for the lower cut off which are identical.

And if only upper is is identical, then the rule which I am just putting here that will be applicable to the upper cut off. And if both are identical, then these both expressions can be used.

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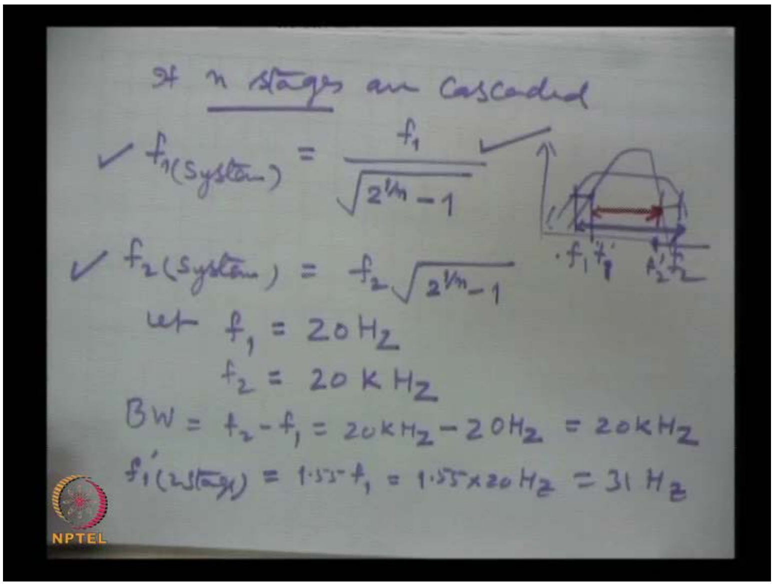

So, if n stages are cascaded, then the lower cut off for the system that means, for the multi stage amplifier this is f 1 is the cut off for the individual stage. Then this is 2 to the power 1 by n minus 1 and f 2 of the system is equal to f 2 by 2 to the power 1 by n minus 1. This is the expression for lower cut off, upper cut off of a multi stage amplifier, if they have same lower cut off(s) and higher cut off(s), if only 1 is identical then only corresponding expression is to be used.

We can see that how the lower cut off is increased and upper cut off falls. Here the gain if this is f 1 this is f 2 if this falls then we are talking about something of this kind. It has fallen and this increases. So, earlier bandwidth was this one. And now, the bandwidth will be reduced to 1. We take an example; let f 1 that means, the lower cut off for for the individual amplifier is 20 hertz and upper cut off is 20 kilo hertz the bandwidth is f 2 minus f 1which is 20 kilo hertz minus 20 hertz. 20 hertz is negligible in comparison to 20 kilo hertz so, this is simply 20 kilohertz. This is the bandwidth of the individual amplifier.

Now, suppose 2 stages are cascaded, then f 1 for the two stage amplifier from this expression 1 by n becomes equal to 1 by 2 because n is equal to n is number of stages n is number of a stages. So, that gives 1.55 f 1 that is 1.55 into 20 hertz and it comes out to be 31 hertz. Lower cut off increases from 20 hertz to 31 hertz when 2 stages are joined together to form a multi stage.

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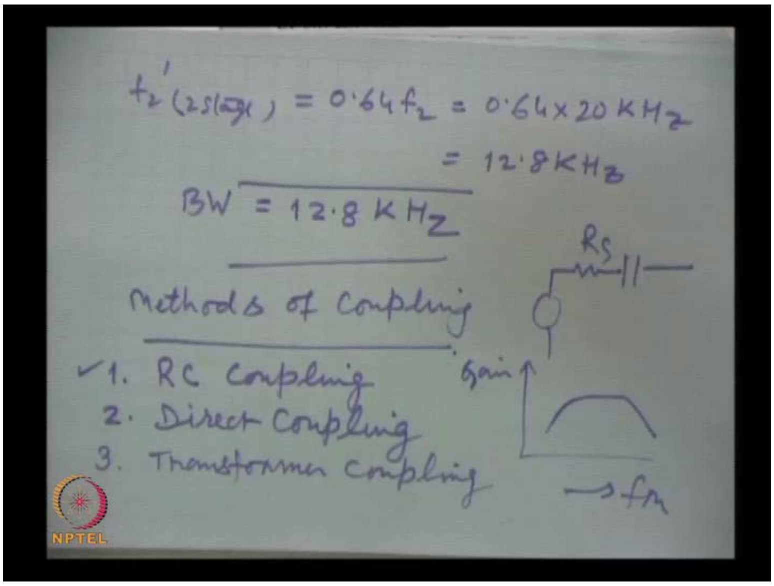

And the upper cut off f 2 prime two stage amplifier this is 0.64 f 2 from this expression 2 to the power half minus 1 when you solve it it comes 0.64. So that, this is reduced from 20 kilo hertz to 12.8 kilo hertz. And because 31 is very small so, bandwidth for this two stage amplifier actually is reduced from 20 to 12.8 kilo hertz.

So, if more stages identically even this is stage if you solve for four this will be much reduced, bandwidth falls and the the physical reasoning we can get from the fact that, gain bandwidth product is constant. So, we have seen numerically that while the gains are enhanced drastically but the bandwidths fall. So, in a multi stage amplifier to maintain a reasonable bandwidth even for the multi stage amplifier we have to start with individually stages which should have much higher bandwidth than required in the application.

How multi stage amplifiers are obtained? What are the methods of coupling? Either a stages or even I mean how we couple a source source signal source to the amplifier? There are three methods methods of coupling there are 3 methods; one is R C coupling, other is direct coupling, third is transformer coupling these are the 3 methods, which can be used to couple either various stages of amplifiers or at the input the source can be coupled to the amplifier by any of these three methods.

And similarly at the final stage the load can be a loud speaker, a printing machine or some other ah gadget, that can be the power can be coupled by any of these 3 methods we discuss one by one R C coupled, this is what we have been discussing the lower cut off, upper cut off we have said and that was the R C coupled amplifier. When we take a source here and we source resistance r s and this was the capacitor and we have derived the expressions also for it, that was R C coupling.

R c coupling is very widely used because it is most convenient it is integrable but only difficulty is as we have seen in our studies that it puts a restriction on the lowest frequencies which can be amplified, the graph for a R C coupled amplifier gain versus frequency goes like this so, this is the lower cut off. So, for example; 0 frequency d c signals cannot be coupled by R C coupling, the signal will not go to the next stage.

So, anyway we have discussed enough the all analysis of the R C coupled circuits that we have discussed.

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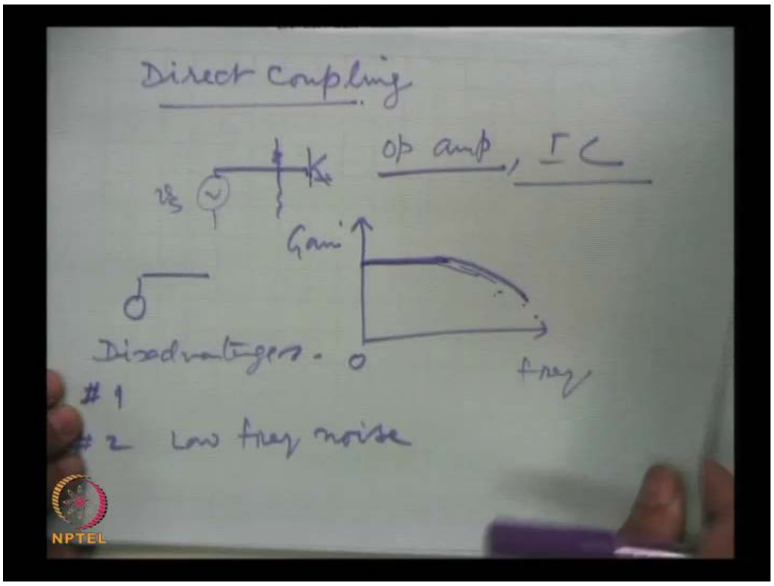

And now, we take another method of coupling which is Direct coupling. In Direct coupling the signal is coupled just it is connected by a conductor. For example; in direct coupling if this is the signal source or the previous stage it is just coupled to the base of the next. Direct coupling there is no capacitor involved in it. This is also quite in recent years say last 20 or 25 years, this coupling has found big applications and for example; in operational amplifiers op amps. Which we are going to study in details in later modules.

So, op amps most of the op amps make use of direct coupling. Their I said if you remember that, op amp is a multi stage amplifier and there are several stages which are directly coupled. So, there there will not be any restriction on the lower cut off. When this is connected directly even if it a d c signal, it will be able to propagate to couple.

So, the response for direct coupled will have no cut off lower cut off no but upper cut off for which this is gain this is frequency there is no lower cut off we start from zero frequency is still the gain will be there and the upper cut off falls if you remember because of the junction capacitances. And whether we are using a bipolar transistor or a F E T this is always there so, this cut off will be there this will be there.

So, in direct coupling in I C(s) and in operational amplifier, operational amplifier is also in a I C form. So, integrated circuits and op amps etcetera they make use of direct coupling. So, while the biggest advantage, there are two advantages. There is no need of capacitor. So, capacitor formation in I C will not be required, other thing is there is no limit on the lower frequency right from d c 2 higher frequencies you can couple. Of course, the higher fall at very high frequencies beyond mid band the cut off will be there and that is because of the junction capacitances.

Now, there is one disadvantage with the direct coupling. That the disadvantage is rather one is not very serious, though it is a disadvantage. When we couple these stages directly, then even d c are coupled. If we put R C coupling then we have seen that the capacitor isolates one stage with the other. Capacitor acts as a block for d c. So, we can design the amplifiers more accurately individually and then we can use R C coupling and because for d c purposes the capacitors will keep them isolated.

So, the biasing etcetera are not affected the queue points the operating points are not affected. But when we use direct coupling then we are connecting them for direct voltages also d c voltages also and hence, the design has to be done more carefully. But more serious than this we will take a design example to illustrate it what i have just said.

And more serious than this is that low frequency noise also gets amplified. Because, that capacitor will block it capacitor with block this low frequency noise. Here in direct coupling there is no blockage, there is no restriction on the frequency. So, even noises will propagate through the amplifier and they will be amplified. Now, this problem can be taken care of by taking more advance circuits like differential amplifiers. Where we can filter out these noises by a different mechanics that we will see then we talk of differential and operational amplifiers.

Let us, take so direct coupling is nothing, simply a connector connects the sample the signal or the output from the last stage to the load directly by a connecting wire. If it is a individually I mean, if it is discrete amplifier then a connecting wire otherwise a conducting path on the I C will do the direct coupling, we take a design example;

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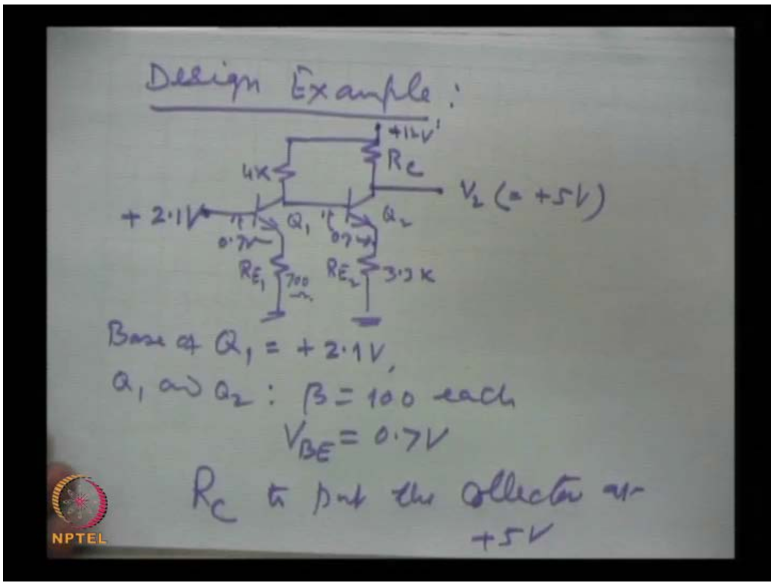

Let us, consider this circuit. This is a direct coupled two stage amplifier (no audio from 38:46 to 39:30) I take just one design example; this is plus 12 volts, and there are two transistors which are directly coupled. And let us say that base of transistor Q 1 initially is at plus 2.1 volts, that is 2.1 volt is available here. And, these resistance are given this is 700 ohms, and this is 3.3 kilo ohms, this is 4 k and what is given is that for both these transistor Q 1 and Q 2 the current gains are same, beta is 100 each. And the voltage drop this drop here, this is 0.7 volts here, and this is also 0.7 volts here. So, V BE as we call it this is 0.7 volt. So, the problem now is that what should be the value of R C to put the collector to put the collector at plus five volts, we have to find out the value of this resistor.

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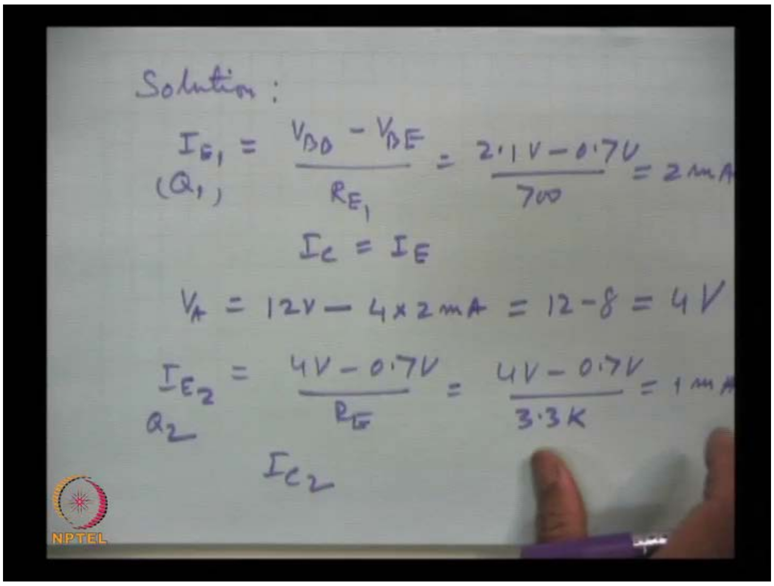

Now, the solution I give. The emitter current in Q 1, so I E 1 for Q 1 this you know now, what we have done earlier in our earlier module. That how to calculate this voltage minus this divided by this will give you the I E. So, I E 1 of Q 1 is V B B minus V B E divided by R E 1 and this is 2.1 volts minus 0.7 volts by 700 ohms, and this gives is 2 milli ampere. And, so these two milli ampere I C and I E, they are the same I C always in transistor, bipolar transistor analysis is equal to I E. So, 2 milli meters flows through here, then we know how much will be that at what voltage base of Q 2 will be.

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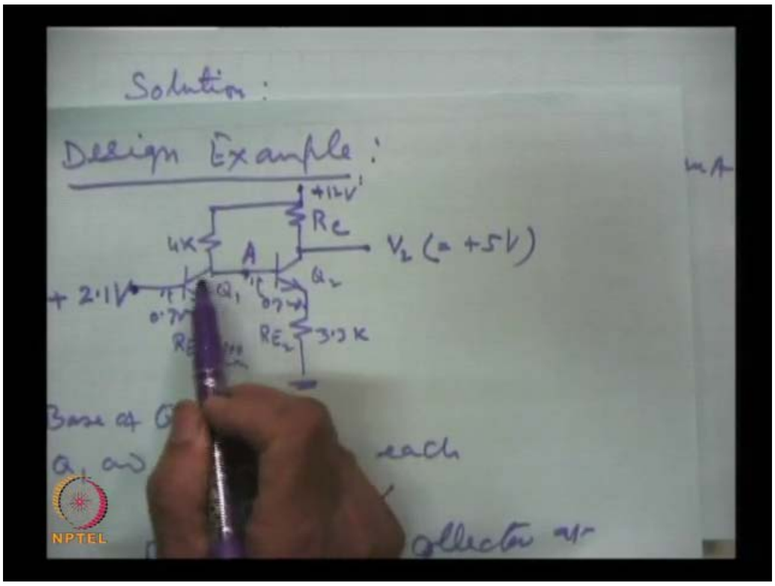

Let us, put this point A here. What is point A? That is the same the potential here will be the same as the collector of Q 1 or base of Q 2.

So, here V A will be simply Kirchhoff's voltage law you apply 12 volts here. (Refer Slide Time: 42:19) This is connected to 12 volts and 2 millli ampere current is flowing. So obviously, 4 K into 2 milli ampere current is flowing through that so, this is 8 and so, this is 12 minus 8 is equal to 4 volts. So, the potential here is 4 volts 4 volts now we proceed in the same way here out of 4 volts 0.7 volt drops across this junction.

Which i write the i 2 i e 2 this is for q 2 this will be equal to 4 volts minus 0.7 volts divided by R E so 4 volts minus 0.7 divided by R E is 3.3 K and this is also 3.3 volts. So, 3.3 volts divided by 3.3 K gives 1 milli ampere 1 milli ampere current, this is same as I C 2 here. (Refer Slide Time: 42:19) This current is flowing through this resistor, with this we have to find out and again we apply remembering that this is to be maintained at 5 volts

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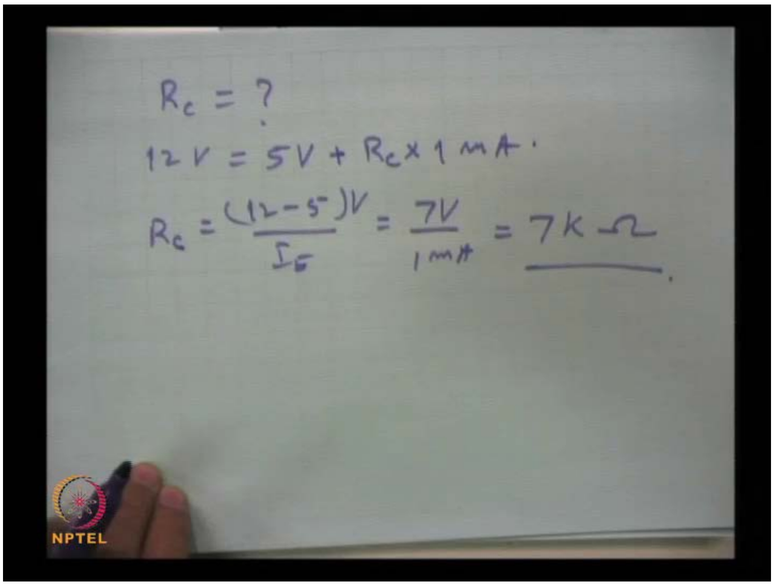

Then, R C we can find out like this, that 12 volts out of that 5 volt is the requirement that the collector should be collector should be at 5 volts. (Refer Slide Time: 42:19) And what is the drop here? I C into R C. So, plus R C into I C and I C we have found out to be 1 milli ampere and from here, we can find R C and that comes out to be twelve minus 5 volts divided by I E, which is 7 volts 1 milli ampere so, this 7 kilo ohms.

So, we have to use a resistance of 7 kilo ohms to get the voltage at 5 volts. So, this is the design principal i will have illustrated through this example.

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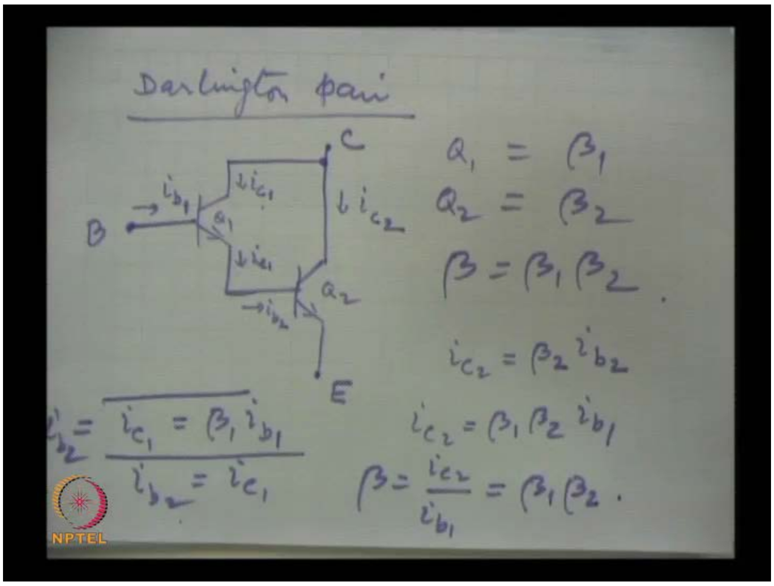

Now, one of the very popular direct coupled multi stage circuit is what is known as Darlington pair, Darlington pair is a 2 stage amplifier where two transistors are actually directly coupled, the circuit is this. This is sold in the market as a single device. This is all enclose these are two transistors Q 1 and Q 2; this is Q 1 this is Q 2 and this is base, this is collector and this is emitter and here the current i b 1 flows and this is i C 1 this is i e which is same as i c 1 and the same current becomes i b 2 and here it is i c 2, as i said this is enclosed as in a single packaging and the three leads like a transistor they are available.

And what is the use of why we are doing this? Voltage gain we have seen now, this is the example of current gain. That, if the current gain for q 1 is beta 1 and current gain for 2 is beta 2, then for this Darlington pair the current gain beta will be the product of the 2 and this we can very simply see that what will be if the input current is i b 1 what will be this current? i c 1 you know it is beta 1 times i b 1 and i b 1 this is i b 2 is same as i c 1, this current is the same as this current and this current is going on, so i b two is equal to i c 1.

And then i c 2 is beta 2 times i b 2 and i b 2 is simply i b 2 is same as here, this is same as i b 2. This we substitute in this so, i c 2 becomes beta 1 beta 2 into i b 1 and what is the current gain? The current over all current gain beta which is the the ratio of output current to input current.

Now, for the collective compose it direct coupled amplifier output current is i c 2 input current is i b 1 and from here we find that, this is the beta 1 into beta 2. This is a very useful connection. Because, from a single transistor many times the current gain is a not very high. It is 100 200 maximum three 400. But this is the product, if we couple this way we form a Darlington pair out of the two transistors then given will be very high.

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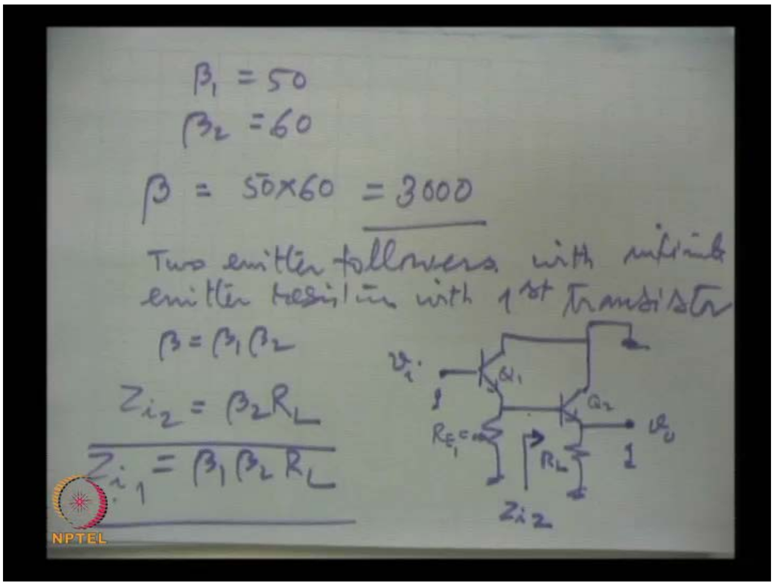

As an example, let beta 1 be 50 and beta 2 be 60, then for the compound this Darlington pair the current gain will be equal to 50 into 60, which is 3000. Darlington pair which has been formed with two transistors individually having current gain of 50 and 60. When they form a Darlington pair then, the current gain available will be 3000. This has wide applications it is formed even in integrated circuits and otherwise also in discrete circuits Darlington pair is widely used.

Darlington pair is actually in reality these are two emitter followers two emitter followers with infinite emitter resistance, emitter resistance with first with first transistor with first transistor. How we can show? That, this is this. For a c purposes we ground this otherwise it will be a biasing we will have to provide and this is what we said, this r e 1 is infinitely high and this the load this is emitter follower we are connecting the output from emitter to the next stage and at the next stage this is q 1, this is q 2 we are taking the output here and we are giving input here with respect to ground of course, here also with respect to ground the output is taken and this is r l. Then since, beta is beta 1 by beta 2 now, see here there is another advantage gain, current gain of the Darlington pair is very high.

So, is the input impendence what is the impendence here? That is z i at the second stage you remember the fundamental thumb rules, that for a circuit in which the input is given at base whether it is common emitter or this emitter follower. This is equal to the beta into load resistance. Load is here. Now, r l at the emitter because it is emitter follower. We always connect load at the emitter.

So, this will be z i 2 is equal to the current gain into the load resistance r l, this we have done earlier and i am sure you understand that, this is the beta times the load so, it is this. And, this will act z 1 will act this is infinity this is in parallel with infinity. So, the result will be simply z 1 2 z i 2 z i 2 is the load for the first stage because this is infinity resistance and this in parallel.

So, the input impendence at the first stage here this is equal to the beta of it beta times the the input impendence seen here which is beta 2 r l very high input impendence. Beta 1 into beta 2 into r l in the above example, if r l is 1 kilo hertz and this collective beta which is the product of the two is 3000 so, from 1 kilo hertz it will show a input impendence of 3 mega hertz very high impendence. So, sometimes Darlington pairs are used to achieve very high degree very high magnitudes of input impendence.

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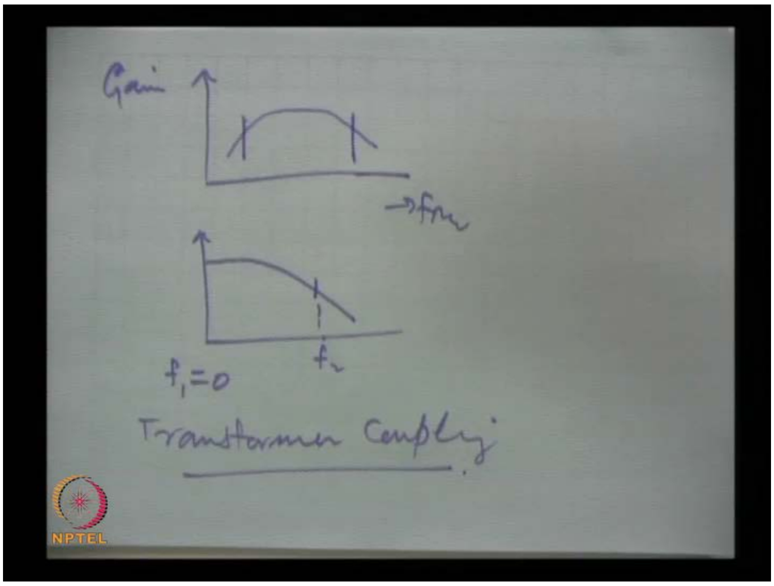

So, we talked about the R C coupling in details and a the response of a R C coupled amplifier was like this. This is gain versus frequency and these two cut off frequencies we defined. In direct coupling there is no limit on this lower cut off. And hence, the frequency response of that direct coupled amplifier is like this. Where that upper cut off of course, will be here, but lower cut off is 0 this is gain.

And now so, this is the direct coupling and the a special case of direct coupling we talked Darlington pair which is the direct coupled two stage transistor and which is sold as a unit. Now, finally, very briefly because ah we have to talk about transformer, the third coupling transformer coupling, transformer coupling is very rarely used and there are few reasons for it.

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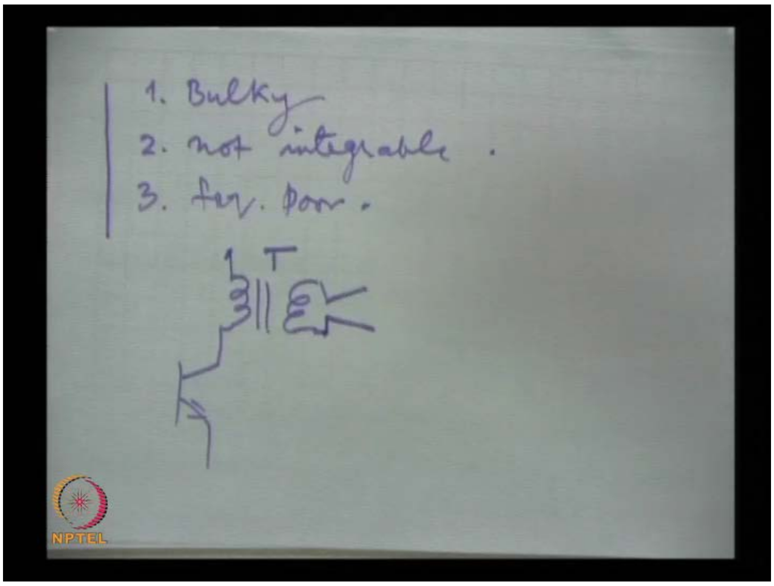

One reason is transformers are bulky they are bulky, they are they cannot be integrated not integrable and their frequency response in general is poor and to have a high frequency response the transformer becomes very expensive. So for frequency response poor for these three reasons transformer coupling is not used. But few applications is still (( )) reserved for example, often now, how the transformer coupling for example; this is the final stage. Where this is the primary is connected to the collector. And here directly a load like a speaker is connected this is transformer coupling, this is transformer.

And it is used if you open your radio sets, transistor sets then the a speaker you may find connected to a transformer. So this is transformer coupling, in which a it can take a large currents and hence, a large signals can be can be passed through the transformer and without and d c will be checked, no d c will propagate in the transformer so, that is the advantage.

But, these three disadvantages they restrict the use of a transformer coupling and it is very bulky they are having much weight as compared to other parts and not integrable transformers cannot be integrated like capacitor can be integrated transistors are of course, integrable and frequency response in general is poor. So, that finishes our module four.