Electronics

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Module No. # 04

Feed Back in Amplifiers, Feed Back Configurations and Multi Stage Amplifiers

Lecture No. # 05

R C Coupled Amplifiers (Contd.)

We continue our discussion on the frequency response of an amplifier, and we were talking about the lower cut off frequency. I am sure you remember that a coupling capacitor is responsible for the lower cut off frequency and the expression which we arrived, which we can put in a generalized form the condition for cut off was when the capacitive reactance is equal to other serial resistances in the circuit.

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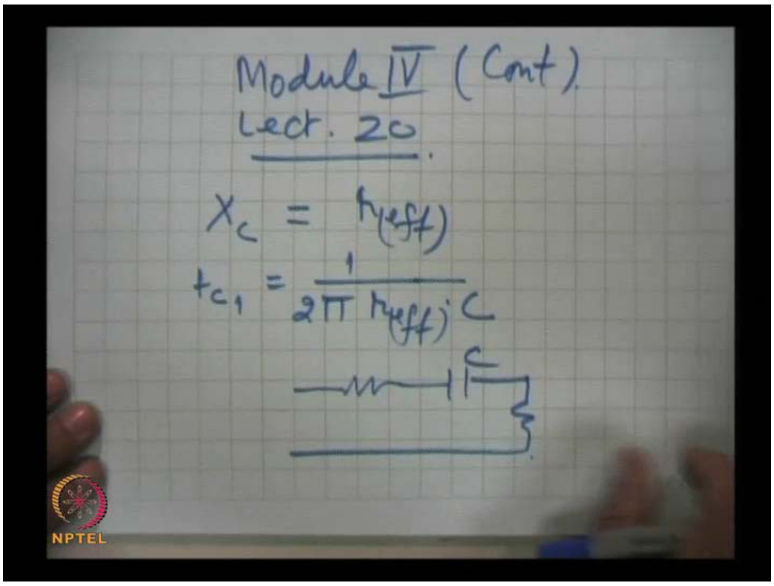

So, in general, we can write that capacitive reactance X, this has to be equal to r effective serial resistance. And f c the cut off frequency the lower cut off this comes out to be one by two phi r effective into C.

So, this is the expression by which we can calculate the lower cut off frequency, and that depends on two parameters the effective serial resistance in the circuit and the value of capacitance which we are using, this is true for any r c network and the amplifier network, or any circuit can be converted into the prototype.

In the prototype, this is the effective resistance and this is the capacitance and this can be converted into that prototype and here the r effective will be the effective resistance of these two resistors and this capacitance.

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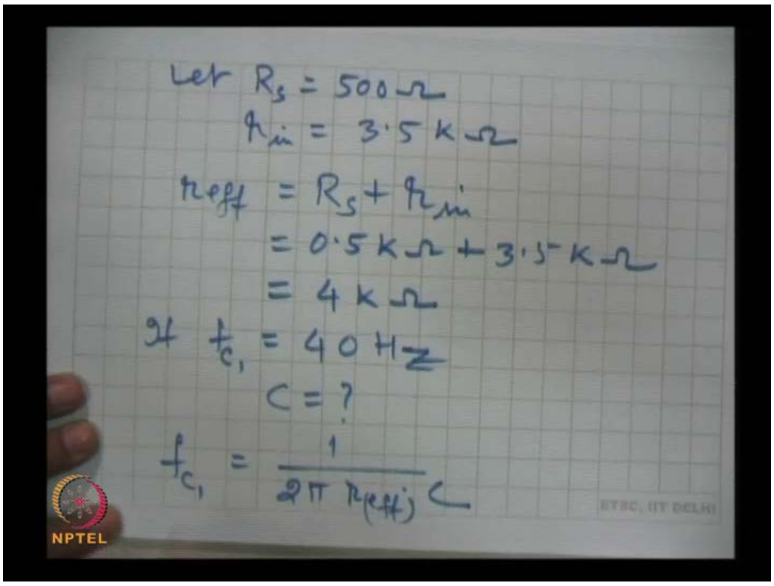

To give you an idea of the quantities involved, let us take an example, as an let in a amplifier the source resistance is five hundred ohms and the effective resistance between base and ground is, r in this is equal to three point five kilo ohms than r effective becomes equal to R s plus r in, and this is equal to five hundred ohms which we can put as five hundred kilo ohms, plus three point five kilo ohms, so this is equal to four kilo ohms this is r effective.

And let us say that if lower cut off is to be kept at forty hertz, than let us find out what is the value of capacitance which we are suppose to use, so we can use that relation that f c one the lower cut off, this is equal to one by two phi are effective into c.

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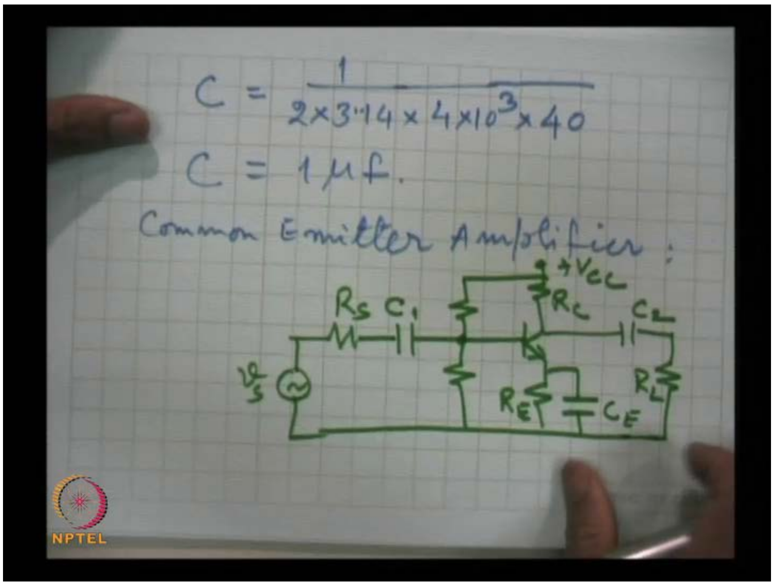

This we can apply and we can calculate, C comes out to be one by two phi is three point one four into, effective resistance which is a four into ten to power three because we have to substitute in proper units and the proper unit for resistance is ohm and into that frequency in hertz, so it is forty hertz.

So, this is the value of capacitance when we calculate, it comes out to be c comes out to be one micro farad, one micro farad is to be used with a amplifier in which we have taken the source resistance as equal to five hundred ohms and the impendence looking between base and ground, we have taken as three point five. Than the capacitor which we have the coupling capacitor, which we are suppose to use that comes out to be of one micro farad.

Now, if the lower cut off frequency what we have taken as forty hertz, if it changes to further lower for example, if it is to be kept to twenty hertz than this will be doubled, the capacitance by the same expression it will come out to be two micro farad and if the frequency increases if it goes for example, to eighty hertz than half micro farad, point five micro farad capacitance will be enough to couple effectively and to give that a value.

Now, let us see this was the general discussion applicable to any kind of a circuit, any kind of amplifier whether it is c b or a c e and c c whatever it is. Now as I said common emitter amplifier is most widely used. So, let us take the case of the common emitter amplifier, the circuit is this (no audio from 06:54 to 07:42) these are the coupling capacitor c one and c two and this is the bypass capacitor c e, and here we connect the input signal V s and this is R s.

Now, since there are three capacitors, I said that the expression which we have developed that is true for coupling capacitors as well as bypass capacitors, than there are three capacitors and hence there will be three cut off frequencies and expressions, basic expression we have developed earlier.

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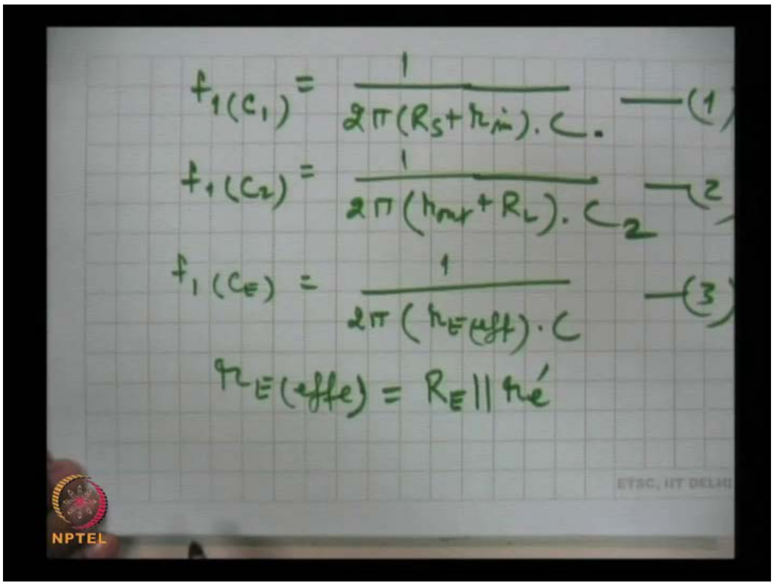

So, because of the first coupling capacitor the lower cut off f one due to capacitance c one, this will be equal to one by two phi R s plus R in into c, R in is, this is R one this is R two. So, whatever is the impendence here this is R in effective value we are suppose to know. This is the first cut off, than similar expressions will be f one because of the capacitance C two at the output circuit, here one two phi R out, plus R l into C. What is the impendence this is a seen here, this is equal to Z o Z out or R out and this capacitance C two couples the signal to the load.

So that capacitance C two will come, this is the second cut off. Third is because of this bypass capacitor C e and that expression we can write f one because of C e this is equal to one by two phi r e effective, that means with the emitter lead what is the effective capacitance and into C this is the third cut off, here r e effective this is equal to normally the resistance which we are using with the emitter lead in parallel with R e prime that dynamic resistance of the emitter, so this effective will be equal to this.

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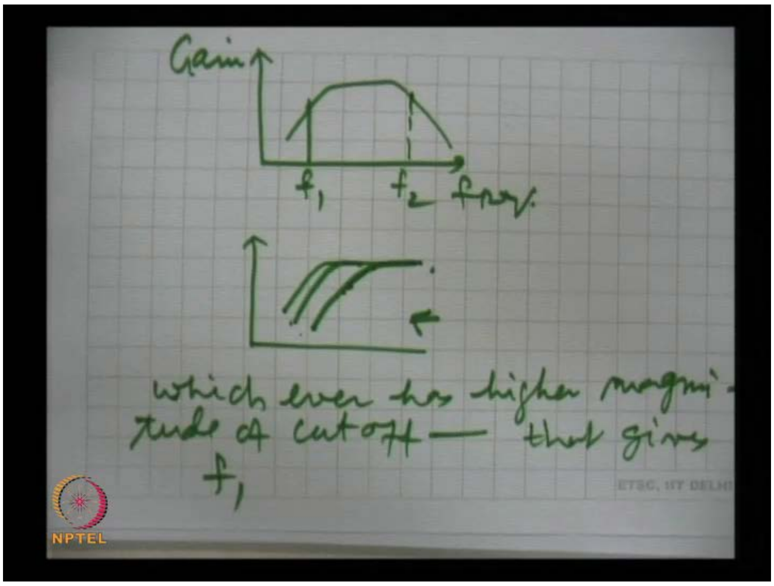

Now, the three values we will get but in the in the response is, this is the response here this is the gain and this is the frequency and this is f one, now here we are getting in three cut off’s for the lower cut off.

Now whichever, this is important, out of these three the magnitude of highest one whether f one C one or f one C two or f one C e, whichever has the highest that will be responsible to give, that will be the lower cut off and why the highest one? For example, if these are three cut off’s one is for example, here the other goes for example, here and the third one goes here, than obviously this cut off will come because of this, because when we decrease the frequency of signal than the cut off will you start right from here, they will come later on. So, out of the three whichever has higher magnitude of cut off, that gives f one in this the lower cut off.

So, remember that lower cut off comes from coupling and bypass capacitors, normally it will come out of the three the C one will be responsible that first coupling capacitor will be responsible for the cut off. Now, from where once the frequency we increase than the voltage a c signal drops across these a coupling and bypass capacitors, this keep than that the reactance will go on decreasing and finally, that the drops will be so small that we can neglect and when we come to the mid frequencies, with we are we can assume this bypass capacitors, coupling capacitors as short, they are as best acting as a short.

Now what give raise to this upper cut off beyond a certain frequency for example, from f two this gain falls further keep on falling as we increase the frequency, here for the upper cut off this is important for the upper cut off there is that the role of coupling capacitors and bypass capacitors is completely ruled out, they are taking a short and keep on increasing the frequency than they are better shorts, than what gives raise to this fall in gain? These are the junction capacitances every device, every active device whether it is a bipolar transistor or a field effect transistor or a mosfet, they all have junction capacitances associated with it and they are responsible for the upper cut off.

Now, in this upper frequency analysis we will be needing one more theorem and that theorem is Miller's Theorem. Miller's Theorem in electronics we are using few theorems the Kirchhoff's voltage law and a Norton's theorem these we have been now very familiar.

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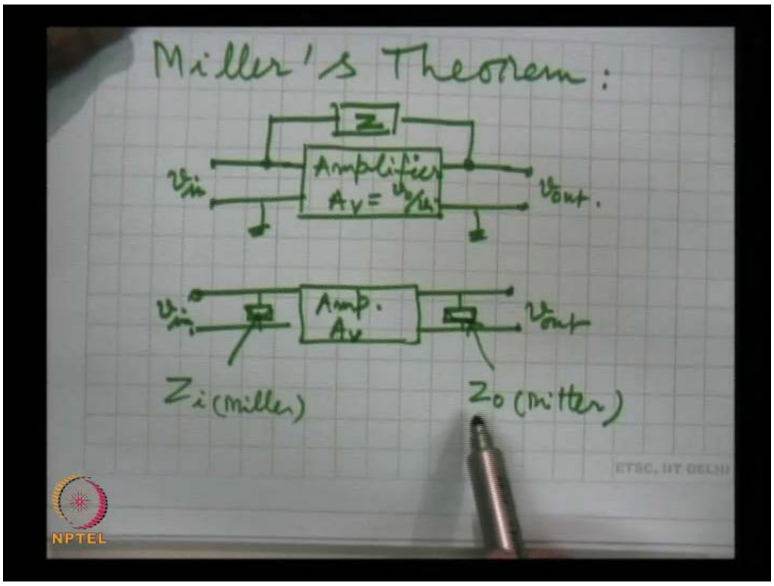

This is Miller's Theorem, which transforms the circuit for our advantage and we can get the values which we can use for analysis for example, where the Miller's Theorem is applicable, if we have a situation like this, this is an amplifier and its gain A v which is the ratio of V out by V in. Here these are, this is the input port this is the output port, we give a signal V in and we measure V out and the ratio of the two is gain.

Now here Z, if this is the situation, what is the situation? That the one end of the impendence is connected at the input of the amplifier and the other end of the impendence is connected to the output. How to analyze the circuit, how when we are taking for example, the impendence at the input into consideration, so what will be the effect of this Z, what will be the magnitude of Z at the input how we can know. Similarly, what will be the impact, what will be the magnitude of this impendence at the output terminal; so that we can further take the analysis?

This Millers Theorem gives this transformation and this circuit from Miller's Theorem can be converted into the equivalent circuit. This is V in this is V out and this is impendence what we call Z i miller and this is the impendence that is Z out miller, this is the amplifier with gain A v.

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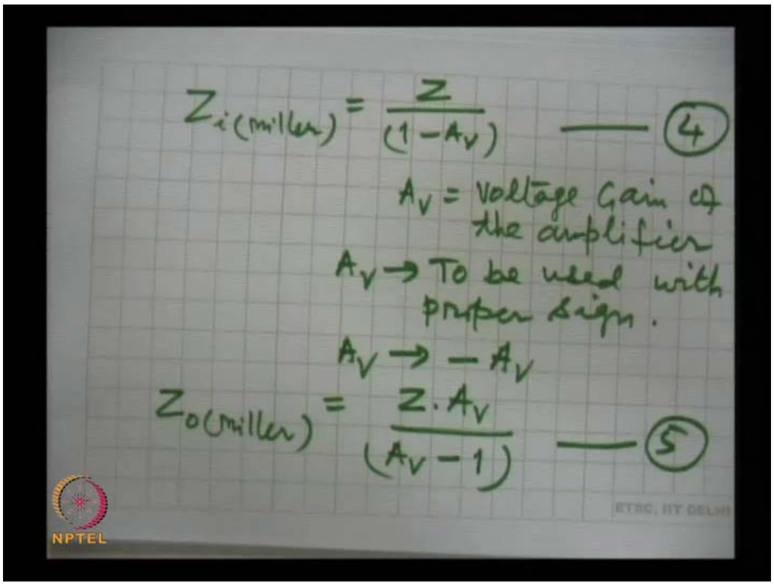

This can be transformed into this where this is the equivalent impendence which is given by Miller and I write the expression for it similarly, at the output what will be the effect of this Z that is Z o miller and the expressions for the two are, Z i Miller is equal to Z is that impendence, and one minus A v, this is Miller's Theorem. Miller's Theorem gives that if you phase a situation such that the impendence has one end connected at the input, and the other end connected to the output, then at the input this will be the value of the impendence, here A v is a voltage gain, voltage gain of the amplifier and this has this is very important, this has to be taken with proper sign, A v to be used with proper sign.

You remember that C amplifier which is most widely used there is a phase inversion at the output, that means input and output have a phase change of phi.

So, for C amplifiers we will take examples and we will see that A v is to be used as minus A v, where this minus sign indicates phased reversion, when we are going to use it for common collector the emitter follower than there is no phase inversion and A v has to be used as A v.

So, this at the input side this is the impendence and at the output Z out Miller, this is equal to Z A v by A v minus one, this is the expression four and five. This comes from the Miller; this is Miller effect, Miller Theorem. Miller Theorem gives the transformation of the impendence at the input and output, if the configuration is such and we will take examples where this will be the real situation, were one end of the impendence is connected at the input other end is connected to the output, than it will have a equivalent of this impendence at the input and this at the output.

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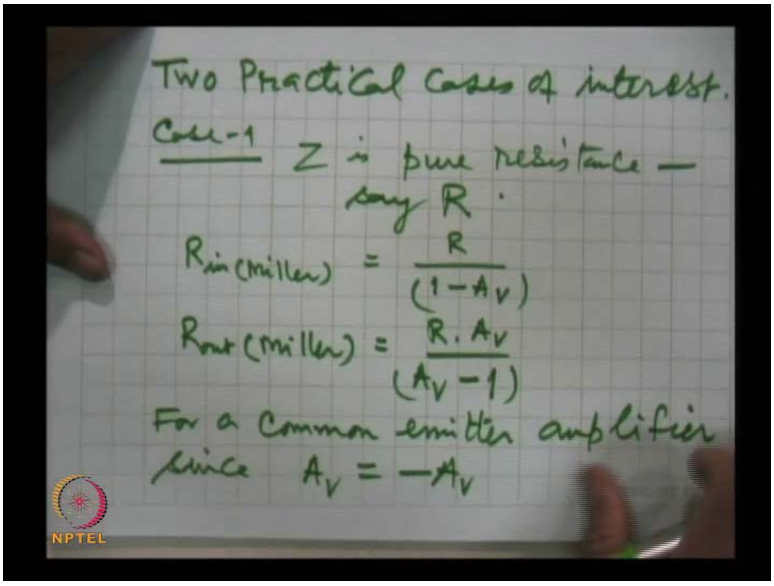

Now, two practical cases Z we have taken in general but now I will take the two special cases of interest, two practical cases of interest. Case one where Z is a pure resistance that means a resistance is connected appears in the circuit such that its resistance in the one end is connected to input other end is output. So, case one Z is pure resistance pure resistance let us call this say this resistance is R, than instead of Z in the above expression four and five we can write Z in Miller, that means at the input end what will you the influence of this resistance R, this is Miller R over one minus A v and at the output R out Miller this is equal to R A v, A v minus one.

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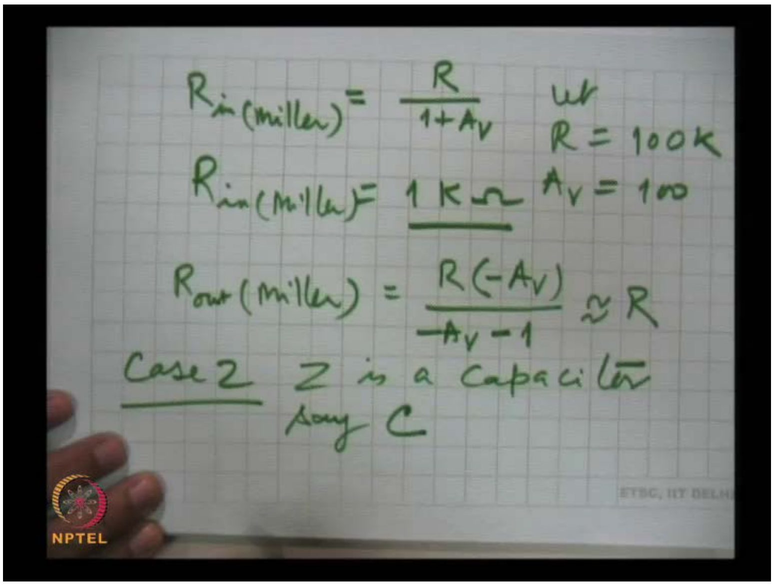

Let us see for a C amplifier, for a common emitter amplifier since A v is equal to minus A v because of the phase reversal, than we substitute here with the negative sign so that R in Miller becomes equal to R one plus A v, A v is very large say hundred.

So, the influence of this resistance when Z is equal to R the resistance, this is the shunting effect much reduced, here in this configuration and this is much reduced if it is say R is hundred K. Let R be hundred kilo ohms and if gain also we take as hundred than R i effective due to Miller will be just from a hundred K it will be reduced to one K kilo ohms in shunting, in parallel between this terminal and ground, because normally this terminal, one terminal at the input and the other terminal at the output they are grounded. So, this is the impendence at the input due to Miller's Theorem and this may be a deciding factor, this is a breaking big influence at the input impendence and at what happens at the output for the C amplifier. R out at the Miller, this is R minus A v by minus A v minus one, so this is obviously very close to R, so whatever is the value of resistance that appears in shunt form to the to the circuit, so this is when R was purely a resistance.

Now, let us take the because we will be concerned with the capacitances, when we say junction capacitance and some junction capacitances will appear in Miller's configuration and their influence, we will see that the magnitudes are drastically change into Miller effect. See here, case two this is when Z is a capacitor, let that capacitance we say a capacitance C a, if in this configuration a capacitor is connected than what will be the effective value of capacitance at the input and at output that we will see.

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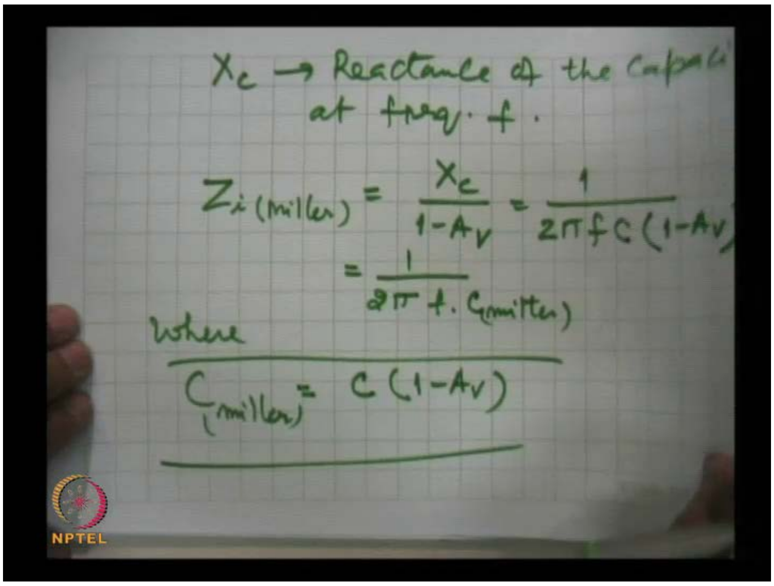

Let X c is the reactance of the capacitor at frequency f, signal frequency f. Than according to this expression Z the impendence at the input due to Miller is X c by one minus A v, which is one by two phi f c, into one minus A v and this can be put in the form, this is equal to one by two phi f into Miller C, where C Miller we have put for C into one minus A v this is at the input remember this expression C into one minus A v.

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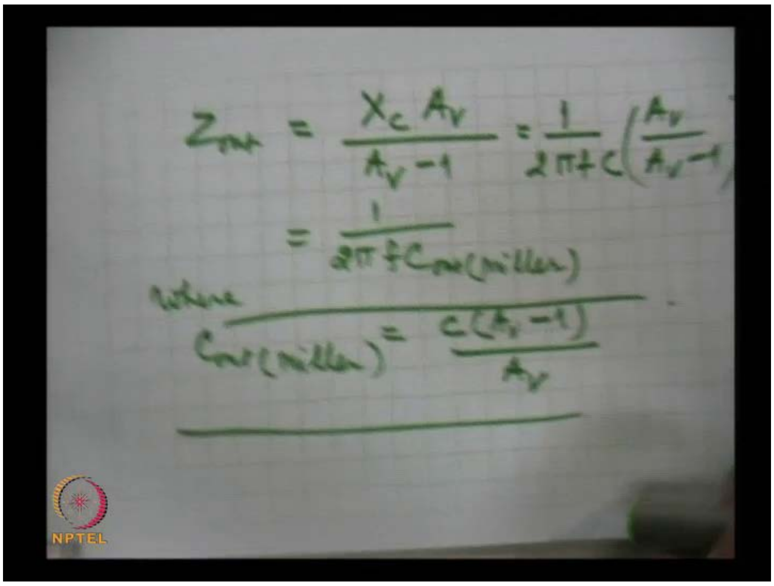

And at the output Z out is equal to X c into A v, A v minus one and this we can write as a one by two phi f c A v, A v minus one and which can be put in the form again as one by two phi f c out Miller C out Miller, where C out Miller is equal. We have written for C A v minus one by A v.

So, these are the two expressions, this is at the output and that is at the input, and let us see what they will be for a C E amplifier.

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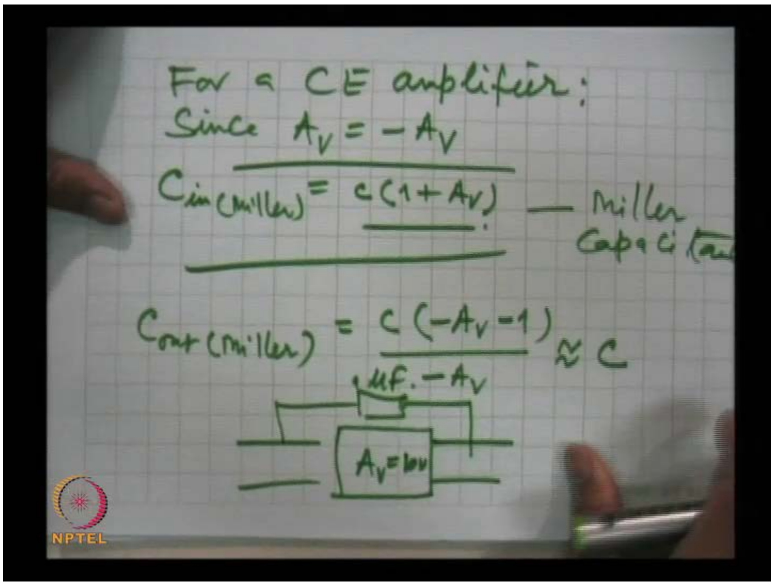

For a C E amplifier, for a seen C E amplifier since A v is equal to minus A v, than C in Miller, this is equal to C into one plus A v the capacitance at the input which will come in the shunt at the input is multiplied almost by the voltage gain. As I said for a same C E amplifier voltage gain is quit high and so capacitance which will come in shunt form, will be increased from C to C into the product C into A v the voltage gain, very high value and this is miller capacitance very high value, because of this high value of A v and at the output, C out Miller is equal to C minus A v minus one by minus A v, so this is equal to C at the output.

So, what will be the value? here this the amplifier, let us say voltage gain is hundred, and if this capacitance was one micro farad, this value is one micro farad than the value at the input and output we can calculate from here.

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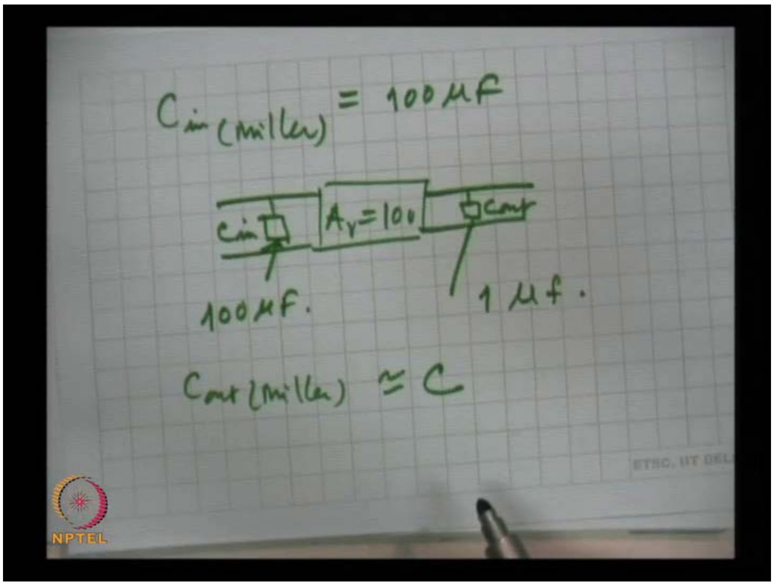

Gain we have taken as a hundred so C in Miller in this particular example will be equal to hundred micro farad, from one micro farad so here this is the amplifier A v hundred and this capacitance C in miller this will be hundred micro farad and what will be at the output. This capacitance C out this is C in, because of the Miller effect will come out to be just one micro farad because the C out Miller comes out to be close to C and C we have taken as one micro farad, so at the output it will be one micro farad. This is a big fact at the input at the output it remains the same as it appears in the circuit.

So, this is about the Miller effect, Miller Theorem and we will use this results, so remember the fundamental expressions of that how the impendence gets modified in the two cases, that that we have to take and the fundamental relations are these, that at Z i Miller Z divided by one minus A v and Z out is Z into A v by A v minus one. Where A v the voltage gain is to be used with proper sign and A v is negative for C but it is passed it for common base and common emitter circuit.

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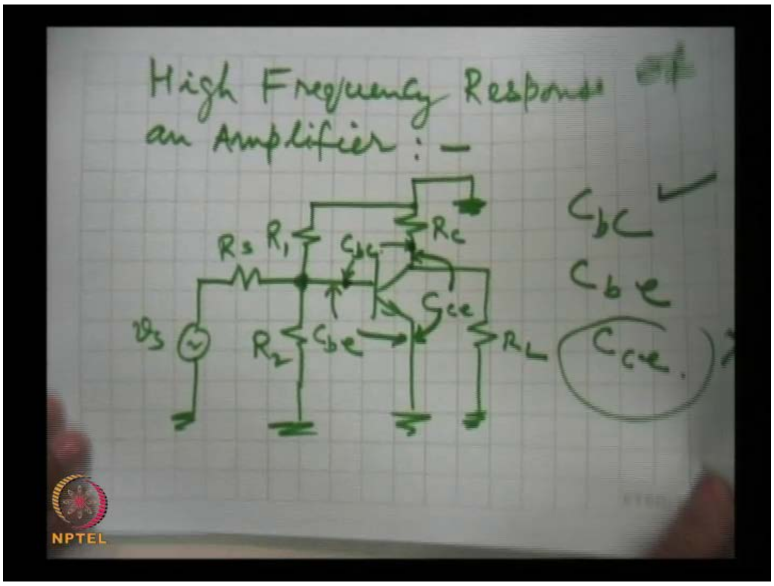

Now, we can go ahead with high frequency response of the amplifier, high frequency response of an amplifier by high frequency response that what will happen when the signal frequencies are above the lower cut off and mid band frequencies, where coupling capacitors and bypass capacitors have no role to play I said that junction capacitances are responsible for the upper cut off. And these junction capacitances they are modified when we actually taken to account the Miller's theorem, and some are amplified drastically and they have an effect; they affect our performance quite a bit.

So, let us first draw the circuit and I can just to save time, I can go a straight for the A C equivalent circuit of the C E amplifier, which I have drawn earlier and we can take these capacitance, coupling capacitances and bypass capacitances we will take as a short, so when we short it for example, this resistance disappears and so on. So the A C equivalent of the amplifier circuit is this, I am sure you remember that when we draw the A C equivalent circuit capacitors, we have taken a short that was one condition and the other is that D C voltage sources have to be brought to zero they are grounded.

So, v c c be ground and that Capacitor once it is taken shorted this is R c, this is R l and these are the two resistance, this is the source resistance and this is the A C signal V s. This is the equivalent circuit A C equivalent circuit of the amplifier. Now, what are the capacitances associated with it, one is between base and collectors there is a junction. Now, there are two junctions, the emitter junction and collector junction and hence we will have three capacitances this between base and collector, this we say C b c. C b c is the junction capacitance between collector and base and this capacitance, we call C v e that is capacitance between base and emitter C b e. And third one is this one from here to here and this we say as C c e, C c e that means capacitance between collector and emitter this is C c e.

So, what is the effect at the input of these capacitances and that we have to see. Now here comes the Miller Theorem, first things that we are not concerned at the movement for the output therefore, we can drop this capacitance between collector and emitter, when we are talking of input than these two capacitances will be coming in the calculation. Now, the first capacitor between base and collector, this is in this will come in the Miller configuration because its one end is connected at the input the base and the other end is connected to collector the output.

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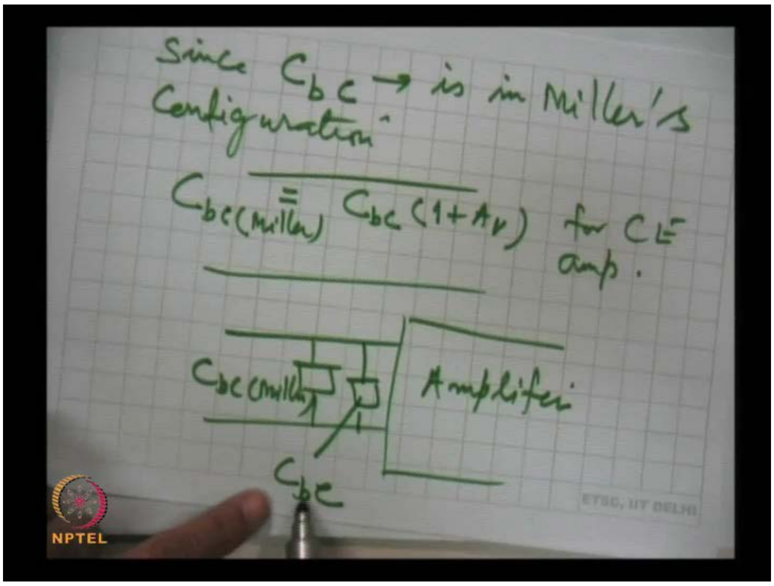

This is in miller's configuration and hence what will be the influence of this capacitance C b c at the input, this we can know only from the Miller's Theorem and we have seen the capacitance that is effectively multiplied by A v and so, since C b e C b c is in Miller's configuration, what will be the influence of this at the input it will comes from Miller's Theorem and this is C b c Miller, this is equal to C b c actual capacitance multiplied by one plus A v, where A v I have taken for C amplifier this is the C amplifier for C E amplifier. A v is very large if it is A t, this may be a small this is normally they a small capacitance but when multiplied by A v becomes large, so and this is going to affect the high frequency performance of the circuit. You remember that this comes in shunt form, this is the amplifier, and then this is capacitance C b c Miller, very high value because of the product of C v c with A v.

And the two are in series, so this will be added up. They will come in parallel I am sorry because this is between base and ground and this is also between base and ground, this and than the other capacitance here which is C b e between base and emitter therefore, at the input what will be the capacitance.

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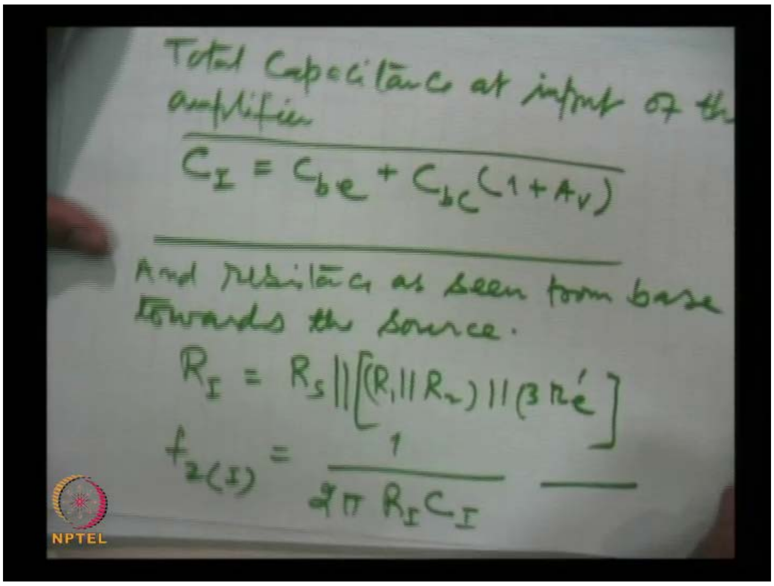

Let us call total capacitance at input of the amplifier, this is C i for input this will be C b e plus C b c into one plus A v, this is the total capacitance junction, these junctions originally they are from the junction capacitances. And resistances as seen from base towards the source, and resistances as seen from base towards the source this will be R i at the input this is R s in parallel with R one R two combination, the biasing resistances in parallel with the input impendence when we draw the equivalent than these two resistances will come in parallel and to this will come in parallel this impendence and this is we have call it Z i base, when we calculated using our parameters than we called this as Z i base.

And if you remember that this was, you should remember this is equal to, if beta is the current gain than r e effective, here effective is only whatever the dynamic resistance of the emitter junction is. So this has to be in parallel with this, so this is beta r e prime this is the total input resistance as seen between the base terminal and the ground will be this, were this three will be in parallel and then the upper cut off can be written from the general principal, upper cut off is actually one by two phi R c what are the values of R, what are the values of C they will decide the cut off and these are the values of the input capacitance is this much and input resistance is this much and so upper cut off we may call it the first. This comes out to be one by two phi R i and C I, this will give the cut off frequency. Here we have, so this is one value let us call equation six and then, so for we have been neglecting one resistance that is base a spread resistance.

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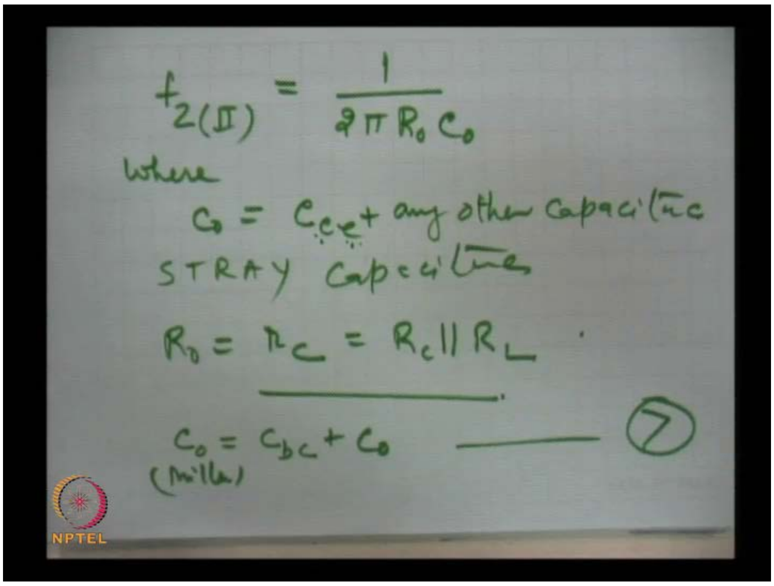

Now, so this is from the input and because of the output, if we look at the output than another cut off will appear and we call it two and this is equal to one by two phi R zero C zero. Where C zero is what is the capacitance at the output, now this will come C c e, between capacitor and an emitter and any other any other capacitance. In any other there are two things, we have been neglecting the lead capacitances and the S T R A Y capacitances. S T R A Y capacitances are when there are several conductors close in close proximity, and the currents are flowing through them and they are separated by insulator, they also have a capacitance associated with that and that we call S T R A Y capacitances.

S T R A Y at low frequencies they are magnitudes are negligibly small and we never talk about these capacitance, so self capacitances of leads S T R A Y capacitances they acquire significant magnitude and they start influencing the high frequency performance. So, this is the capacitance and the R r will come out to be R zero is the effective value of the resistance with the capacitance lead.

So, this is the two resistances are in parallel this is ground, this is ground, so what is the impendence, equivalent impendence between this collector and ground that is equal to R c in parallel with R l. So, this is the actual and in addition to this capacitance there will be that because of Miller effect, you remember that C b c at the output from Miller's Theorem comes out to be of the same magnitude. So, the total capacitance will be, this is C b c plus let us call it into Miller, this C o which contains C c e and other capacitances and this will give another cut off frequency and this will be the second cut off frequency, upper cut off, we are talking of upper cut off.

First, we have seen that the utter upper cut off comes because of this capacitance at the input which gets magnified because of Miller's effect, the other is at the output there are other junction capacitances which are equal to this and resistance is equal to this, this will give another cut off and that cut off is this.

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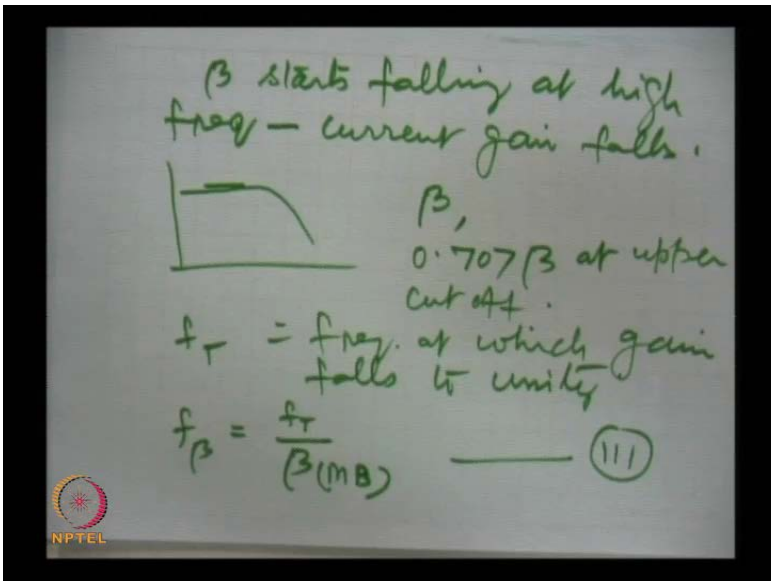

There is the third cut off at high frequencies beta false. Beta starts falling at high frequencies, this is because of the transport processes involved, that what gives raise beta as a high value when we increase the frequency of operation, than those processes are not as complete as a at the low frequencies and hence the current gain falls and if at mid band here, at mid band if the gain is beta than you remember that it has to be at cut off frequency, it has to be 70.7 a fraction of this that means 0.707 beta at upper cut off.

Now, manufactures give another value which we have talked earlier f t. F t is the frequency at which gain falls to unity and it can be shown that f beta is related with f t by beta at mid band. So, this will give the third cut off, at input there were three cut off frequencies arising from the three capacitors, two coupling capacitor C one and C two and one bypass capacitor that was C e and whichever was higher frequency that will be responsible for giving f one, so that f one will be equal to that frequency.

In this case, there are three frequencies arising from three different factors, this third one is from the fall in gain beta with the frequency and that we have seen this is equal to this. And the other two are because of the junction capacitances at a seen at the output an input of the junction of the circuit.

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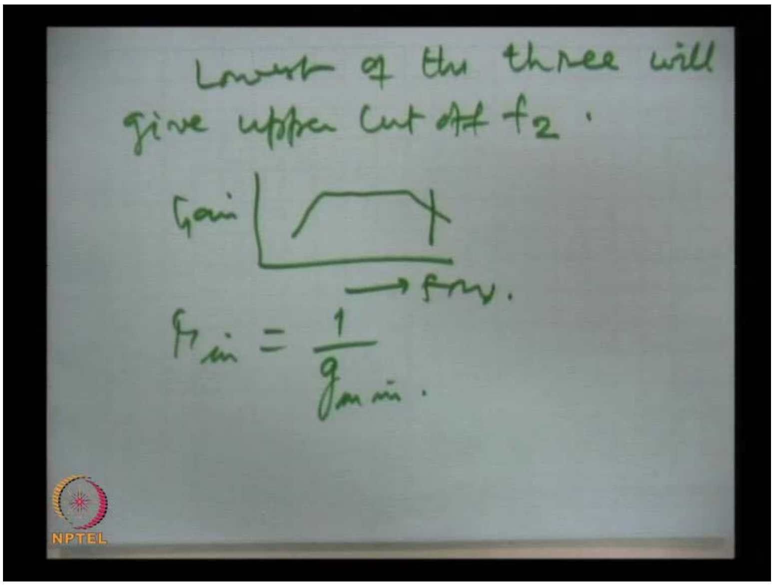

So, the three will be and which ever has lower, this is important, lower cut off has to be the highest one gives f one here the lowest of the three will give upper cut off. This analysis is applicable for a bipolar transistor or for a field effect transistor, in field effect transistor this r in is normally given as g m the transconductance, so in this will be equal to g m because conductance is inverse of resistance. We will continue.