Video Course on Electronics

Prof. D. C. Dube

Department of Physics

Indian Institute of Technology, Delhi

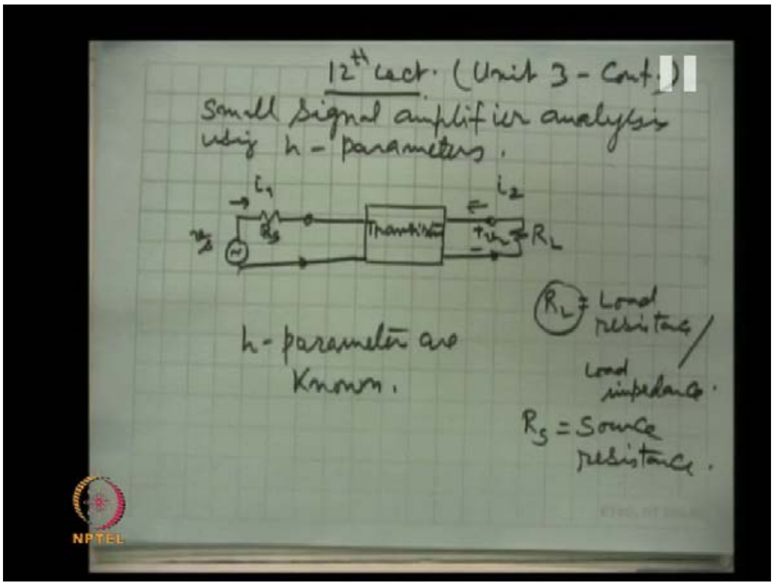
Module No. #03

Small Signal BJT Amplifiers

Lecture No. #12

Small Signal Amplifier Analysis using h-parameters

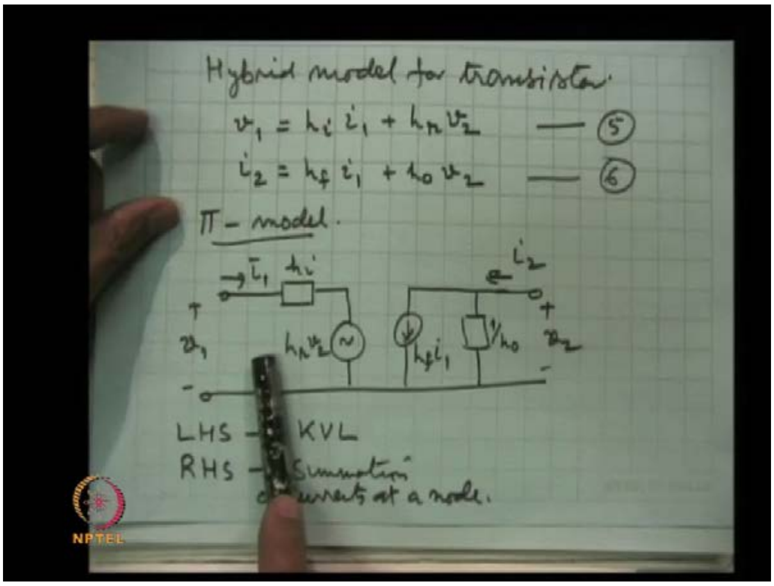
(Refer Slide Time: 00:32)



Now, we will use these modules, which we have just discussed for the analysis of a small signal amplifier. And by analysis I mean that we want to drive expression for the parameters of interest. As I said in the beginning that the parameters which characterizes an amplifier. Some of the parameters are the input impedance, the voltage gain, the current gain and the output impedance. These expressions are to be derived; and once we have this equations, which will contain only the as parameter and certain resistances like load resistance or may be in some cases, the source resistance in the equations.

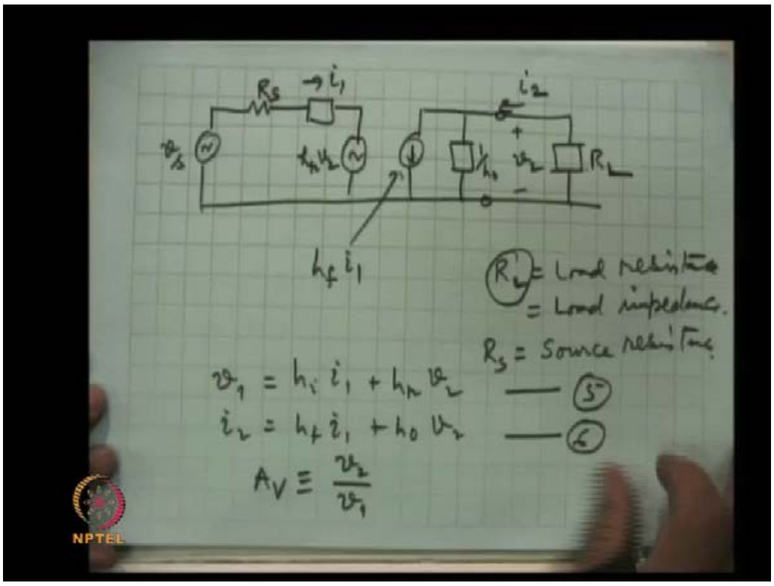
So, if you substitute the value of these impedances, which are known, and the values of S parameters in the equations, then we can calculate the voltage gain, current gain and the two impedances. Now the circuit which we are considering basic circuit is this, where this is the transistor for which h-parameters are known. Normally, they are given by the manufacturer for each transistor. So, we can take the values from the manual. And if we want a very precise value of h-parameter we can measure the way we have described the way we have defined these h-parameters.

(Refer Slide Time: 02:24)



So, in this pi model which we have arrived yet, now the transistor will be replaced by this and we have we have to add this part and this part to the pi model. So, what we get is this.

(Refer Slide Time: 02:43)

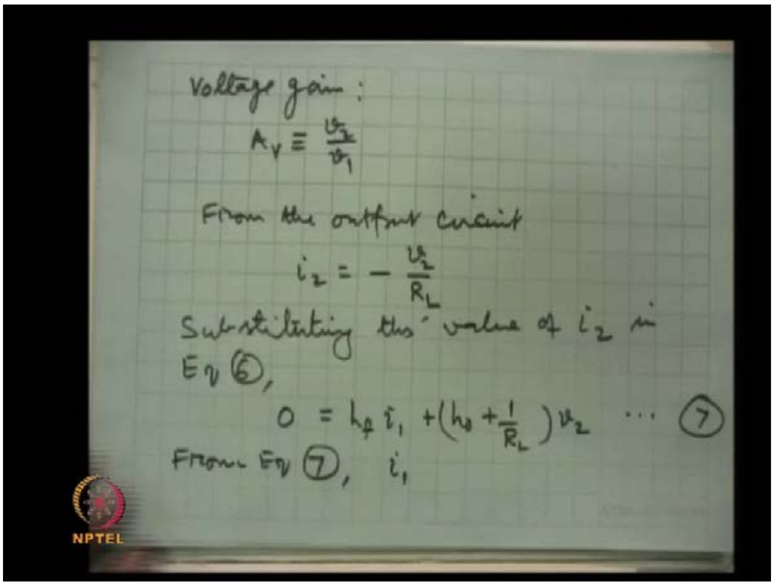


This is the current i 1 and this is the signal source this is the and the module we have h r v 2 and this is the current source which is h f i 1 and this is 1 by this is impedance inverse of admittance in h 0 is output admittance and this is plus minus v 2 here and the current i 2, this is load resistance or load impedance R L load resistance which is same as load impedance for no frequency, but in general and this load impedance. Popularly it is known as and it written as R L so, I have written it as RL this is never circuit there for example, if it is a amplifier for audio frequencies then here we will attach the coil of the speaker that will be the impedance the load.

Similarly, this is source source whether it is a generator as we do often in the lab or it is a transducer like microphone then the resistance of the coil is what is known as source resistance or source impedance, but popularly it was written as R s so, source resistance and the two equations are here it we have written earlier because, now we are going to use these two equations very much. So, I write once again, the v 1 is h i, i 1plus h r, v 2 and i 2 is h f, i 1plus h o, v 2 this was equation 5 and this is equation 6. Now the voltage gain A V this is defined as the output voltage by input voltage.

So, from these equations now we have to manipulate equations such that we get this ratio v 2 by v 1 and no other unknown parameter and unknown parameters are this currents and voltages while the h-parameters are known and this should also the expression. Now contain these impedances which are also known. So, we have to manipulate with the equations to get these values.

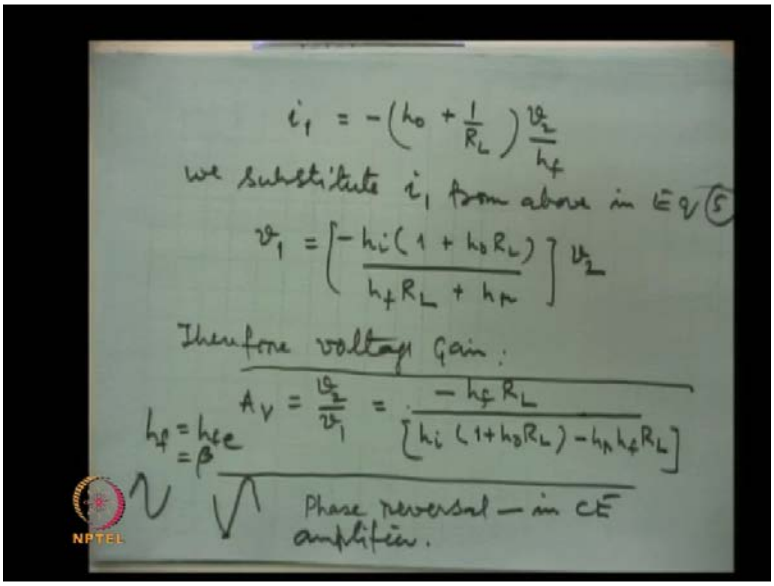
(Refer Slide Time: 06:41)



So, first we derive a expression for voltage gain. We now get an expression for voltage gain and which as I said is equal to A V as the ratio of this two voltages. Now from the as I said we will have manipulate this so, that we get this ratio to and this should not involve any unknown parameter.

So, now from the output circuit the output circuit of the of this figure here this is the output circuit we get this is i 2 this is the voltage v 2 which appears across this load R L and hence i 2 is equal to i 2 is equal to minus v 2 by R L. Why minus sign look here at the direction, we have taken it at the higher potential v plus and v minus while the current is flowing in this direction. Normally we will recall the current flows from higher potential towards the lower potential side. So, this is the particular choice of the directions which we have taken. That is why this negative sign comes, if we substitute this substituting this value of i 2 in equation 6, what is the equation 6 is this equation this is the equation. Now we substitute the value of i 2 what you have determined here and so, we get let us called this equation 7 and then or from here actually we can write i 1 equal to from equation 7, i 1 comes out to be…

(Refer Slide Time: 09:28)



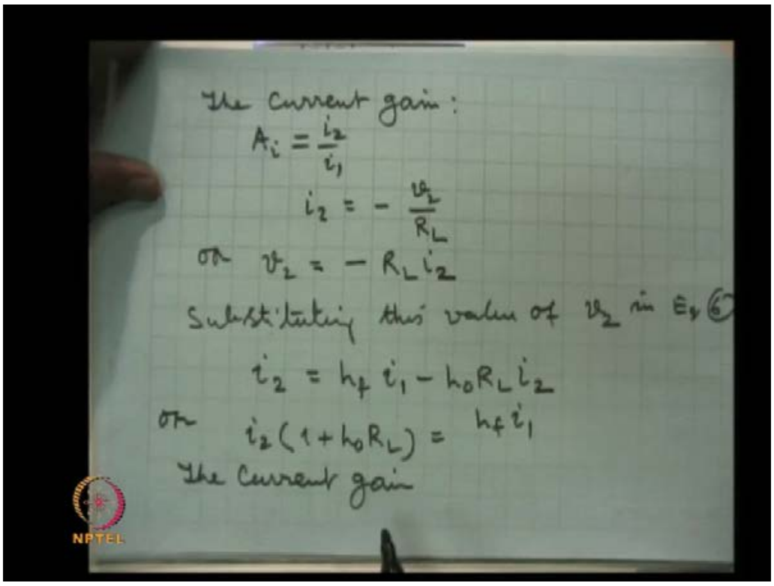
i 1 is equal to minus h o plus 1 by R L, v 2 by h f. We substitute for i 1 we substitute i 1 from above two equations 5 this is the equation. So, i 1 because here we want the ratio of v 2 by v 1 we we are finding the voltage gain which is the ratio v 2 by v 1. Now here i 1 should be replaced by the known parameters and here there are mostly the known in fact this will be taken care of automatically.

So, when we put this value in equation 5 what we get is this v 1 minus h i 1 plus h o, R L by h f, R L plus h r by into v 2. From here we can get the expression for voltage gain therefore, voltage gain of the amplifier A V which is equal to v 2 by v 1 v 2 by v 1 and this comes out to be this is the expression for voltage gain of the amplifier. Here all parameters are known all these h-parameters are known and there are just these node resistances. So, on the voltage gain depends on the value of load resistance so, this is the exact expression for the voltage gain. We will simplify it further we can approximate it without losing much the accuracy this is the exact expression and we will derive we can neglect certain terms under certain conditions which are practically absorbed in the amplifiers.

So, we will see later, but this is the expression for the voltage gain, now this minus sign this finally, we will see that for example, when we write the voltage gain for a common emitter amplifier then this h-parameters have to be replaced by the h f becomes equal to h f e that means for common emitter and which is same as beta the current gain which we have discussed earlier. So, that has to be done and when this negative sign is still remains with the expression this will indicate phase reversal phase reversal as it will happen in the case of in C E amplifier.

By phase reversal we mean that the output and input signal will have a phase difference of pi. We mean when input is maximum on the positive side the output will have maximum negative this is phase reversal and in common emitter this happens and it does not changes anything because this is all continuous, but there is a phase reversal that will be indicated by this negative sign. Then we want another quantity that is the current

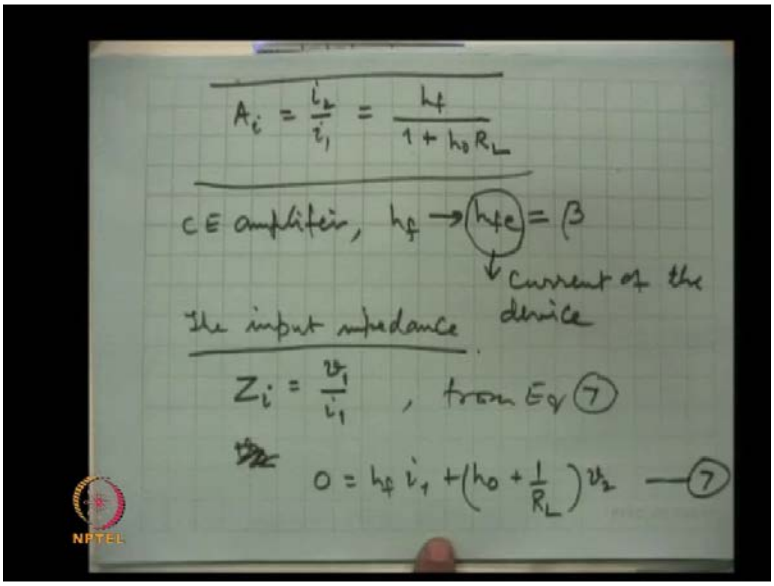
(Refer Slide Time: 14:28)



gain, current gain will be it is written as A i and this will be the ratio of i 2 over i 1. So, again we have to clear with the equation we have to manipulate the equations in such a way that this ratio is equal to the terms and which each parameter is known that we will see.

We have obtained earlier the expression for i 2 minus v 2 by R L, simple from the output circuit we see this here that the voltage v 2 appears with this polarity we have assumed across R L then i 2 was equal to this or this is or v 2 is equal to minus R L into i 2. We substitute this v 2 substituting this value of v 2 in equation 6. Sixth equation is here so, when we substitute for this v 2 this value what equation results is this i 2 is equal to h f, i 1 minus h o, R L, i 2. From here or we take this is i 2, this is i 2 so, we take this term on this side so this will be i 2 1 plus h o, R L is equal to h f, i 1 and from here we can get the current gain. The current gain i 2 by i 1 so, this divided by this we get very simple expression.

(Refer Slide Time: 17:05)

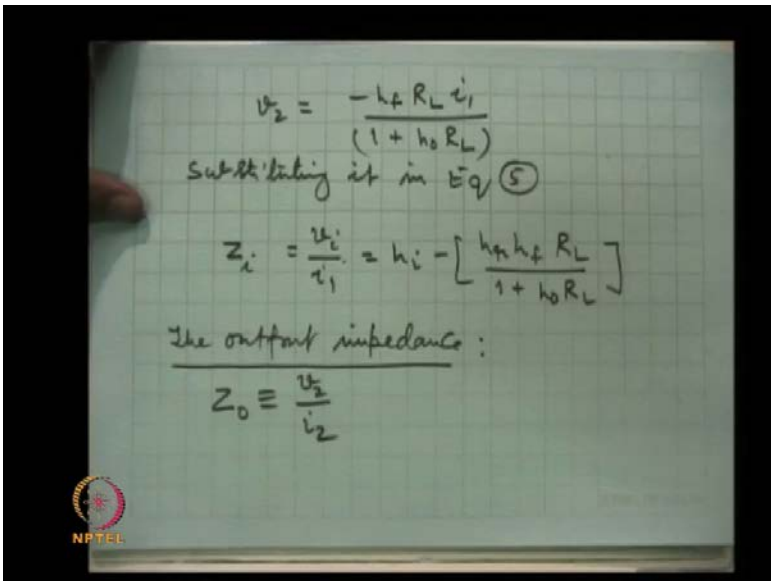


That current gain a i is equal to i 2 by i 1 and that is h f 1 plus h o into R L. This is the expression for current gain of the amplifier, I have said that if we talk of the common emitter circuit C E amplifier then this h f is to be replaced by h f e which is forward current gain and which was which is identical as the current gain beta which we talked earlier. So, this is very significant point that h f e represents the current gain of the transistor not of the circuit very important point that this represents the current gain of the device current gain of the device and this is the expression for the amplifier circuit. That means this current gain is reduced by this factor 1 plus h o, R L and you remember that we measure h f with shorted output shorted output.

So, if R L is reduce to 0 then current gain will be equal to h f same as of the device, but this is for the amplifier. So, h f we represents the maximum value of current current gain which is possible from the circuit, but normally because R L will have a finite value and this h o is finite. So, this is current gain is reduced in the amplifier circuit, if we take this 100 then this may be 80, 60 or in low depending on what is the value of R L and of course, h o. So, this is the expression for current gain then the input impedance the input impedance input impedance we write impedance as Z and Z i that is input i stands for input impedance this by definition is v 1 by i 1.

That means we apply a test signal here and what is the ratio of this voltage this is v 1 what is the ratio of this voltage in this current that will give the value of input impedance and this we can get that, let us substitute the value of v 2 we have got the value of v 2 from this equation 7, from equation 7 we obtain this is the equation 7 i repeat 0 h f i 1 plus h o plus 1 by R L, v 2.

(Refer Slide Time: 21:24)

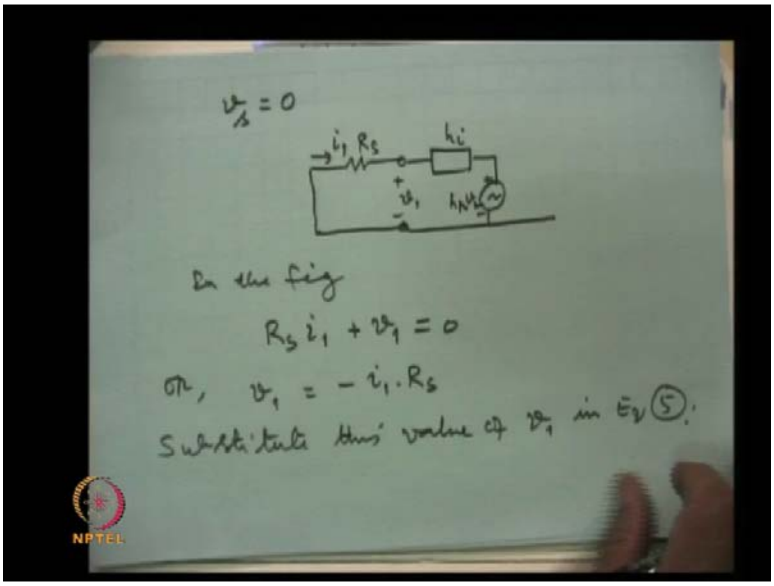


This was equation 7 and from here we can get the value of v 2. So, value of v 2 comes out to be this is from this equation 7 this is the value of v 2, we put this in equation 5 here v 2 we replace here then we can get this ratio v 1 by i 1 which is required for determination of the impedance 2. So, substituting it in equation 5 we get Z i, this is the expression for input impedance. Now input impedance this is also input impedance, but again this is the input impedance of the transistor. When we use this transistor which has its h i parameter like this parameter is reduced, because of the other part of the circuit and interestingly.

Note, here that input impedance this input impedance this ratio is also it depends on R L that means the value of load resistance which we are using with the circuit and this is again to conform that the two junctions two sides of a transistor do not function in complete isolation. There is a kind of feedback there is a kind of coupling between the two sides which is reflected in this expression, that if we change in this expression the load resistance then this ratio will be affected. Another point was I said that the impedance of the amplifier is different from the input impedance of the transistor and this is reduced by this parameter so, this is the impedance.

The next we consider the output impedance and while we are doing this manipulation I again repeat for example, if we get this v 1 by i 1 from directly from equation 5, v 1 by i 1 it will contain v 2 which we do not know so, the value of v 2 is to be substituted in terms of known parameters and hence. The expression contains only s parameters and the known value is of the impedances or resistance. So, we continue this analysis and finally, we will we getting an expression for the output impedance and this is by definition this will be Z impedance o for output and this is equal to v 2 by i 2 this the ratio.

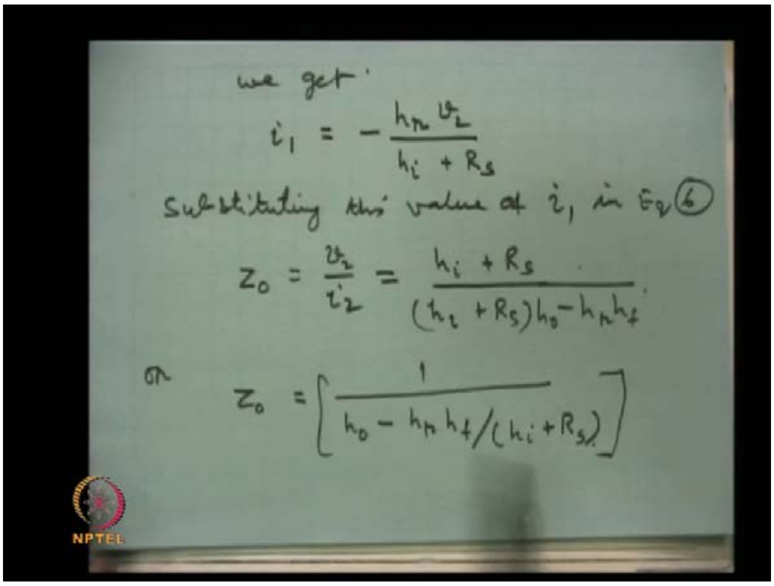
(Refer Slide Time: 25:55)



How we arrive at it for this for determining the output impedance the input side as to be the v s the source has to be reduce to 0 v s is reduce to 0. So, what is the this value is reduce to 0, but we will have to (Refer Slide Time: 26:00) keep in the circuit its impedance will just switched it off we have not looped it from the circuit otherwise we will miss the parameter R s on which the output impedance will depend. So, the input circuit becomes like this v s is removed from here. Now here, this is the situation we put v s to ground to 0 this is the situation. Now you may say that if this is 0 from where this i 1 will come this will come because of the source v 2 so, there is a finite value of this current and in this figure in this figure in the figure we get R s, i 1 plus v 1 equal to 0.

Here again the summation of of voltages the voltage drop this represents the voltage drop here and this is this and this should be 0 in the circuit. So, we get this and this from here or v 1 is equal to minus i 1 into R s. We substitute this substitute this value of v 1 in equation 5, the equation 5 was this this contains v 1 so, v 1 is replaced by this value.

(Refer Slide Time: 28:50)

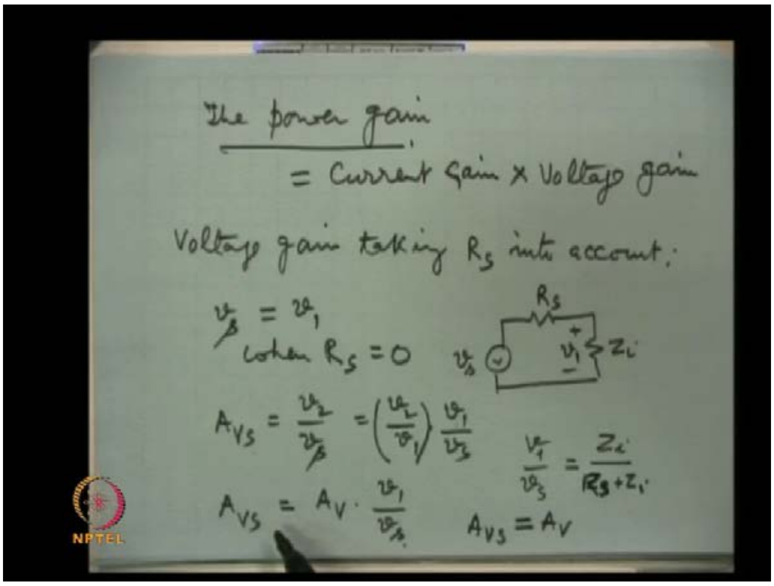


Then what we get we get the value of i 1 i 1, then we will get equal to h r, v 2 by h i plus R s. When we substitute this value substituting this value of i 1 in equation 6, which is this equation. So, that will result in this is this ratio v 2 by i 2 will give us the output impedance. We get this expression which can be put in this another form or Z 0 equals. This is the expression for the output impedance and this shows that output impedance depends on the value of R s the source resistance; this source resistance affects the value which we measure here.

This is again the fact that what we do at the input side will affect what will be the performance at the output circuit. So, this is again the kind of fact of the coupling between the two junctions. So, these are the parameters which we have obtain so, we obtained all the four parameters of the amplifier the important all the four parameters are very important the current gain, the voltage gain, the input impedance and output impedance. Now remember one thing that as parameters also give these values like h f, h f is the forward current gain, but that was the current gain of the device the transistor alone without any circuits in isolation.

So, these parameters h-parameters vary for the device in what we have, now derived these are the expressions for the parameters, which characterize which characterize the the amplifier. For the amplifier as a whole and it is a very important because once we know the h-parameters of the device, then we can substitute these expressions and knowing the for example, source and load resistance and we get the value of this. Now we can continue with the and power gain of course, we are not concern with the power gain in a small signal amplifiers, power gain will be a consideration in the case of a power amplifiers which will be taking later.

(Refer Slide Time: 33:25)

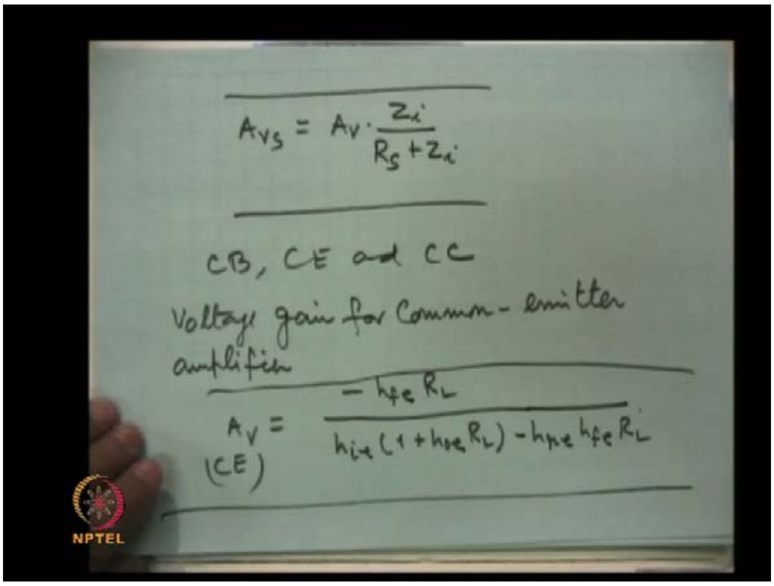


But if still we want then power gain this is always the product of current gain current gain into voltage gain, current gain into voltage gain gives the power gain. That as I said this is of not much value in this small signal amplifiers. Now the voltage gain which we absorb that was without taking into account because you see what we have derived. For voltage gain we took the ratio v 2 by v 1, what was v 2 the voltage across the load, what is v 1 this is v 1 which is different from v s, v s is our real source, but we have taken out this ratio. So, we have ignored actually this part in deriving this expression. So, we can do that this is voltage gain taking source resistance R s in to account, voltage gain voltage gain taking source resistance into account. I made that circuit again here small part of it in the derivation of this expression, you have ignored this part. Now, we can see through this voltage divider circuit, this is the input impedance of this amplifier.

The two voltages v s is equal to v 1 when source resistance is 0 when R S is equal to 0, but we want to take a finite value of the source resistance into account. So, this a A V S that means this will be the voltage gain in when we take into account the source resistance as is stands for source resistance and this is equal to v 2 by v s. Look the difference here we took v 2 by v 1, now we are taking this into account. So, we are taking the ratio of v 2 by v s which is the actual strength of the signal. So, when we do this this we can write as v 2 by v 1 and v 1 by v s, this is same this is this is written by dividing and multiplying with v 1 for a specific reason that this is what we called A V.

So, A V S is equal to A V the voltage gain the expression which we got into v 1 by v s and this simply gives the voltage division and from this circuit we can be easily see that v 1 by v s is simply this Z I by Z S plus Z i simple this is the voltage divider circuit where this voltage is divided between two parts and they they will be in this ratio. So, therefore, for any if we want that this A V S should be as close to A V. Then this factor should be unity that means we should use a source if Z S is neglected here then this term will be 1 this term will be 1 and we will have simply A V S equal to A V. So, this is the the actual inclusion of the source resistance R S actually R S is to reduce the voltage gain and this reduction is obvious. Here because we took v 2 by v 1 these expressions so, there we have assumed v s is equal to v 1, but this will happen. Only when R S is 0 when R S is finite then this is we will have to take into account this resistances.

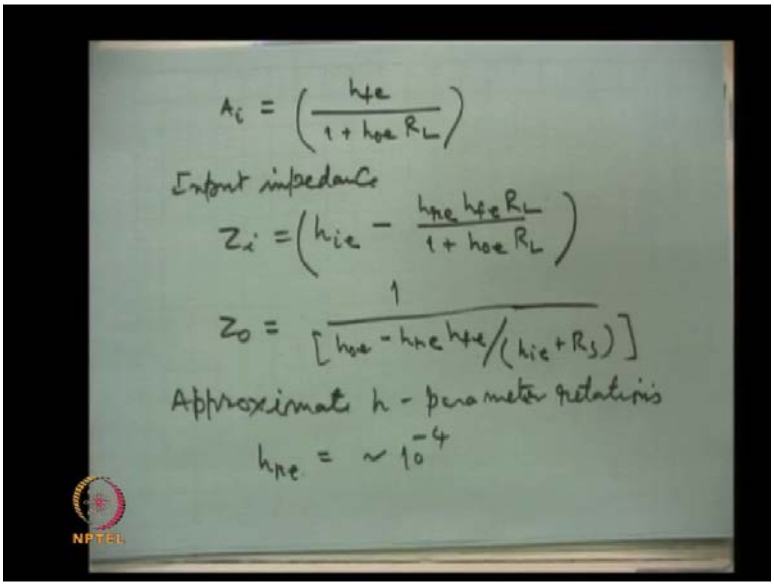
(Refer Slide Time: 40:01)



And the gain the voltage gain with R S into account becomes A V S equal to A V into Z i by input impedance R S plus Z i. So, this is the expression the size expression when we include this source resistance and we can generalize this expression the the expression which we as I said, this equations which we have obtained for all the current gain and voltage gain they are applicable to all the three cases; C B, C E and Common Collector common base common emitter and common collector circuit they are applicable for them.

If we write for voltage gain for C E for common emitter amplifier then we have to replace these parameters for common emitter and this gain becomes for C E amplifier minus h f e R L by h i e, 1 plus h o e R L minus h r e, h f e into R L. This is the expression which we get for the voltage gain. For C E amplifier exact expression for voltage gain for C E amplifier in the same way, we can write for now I am writing all these parameters for common emitter. So, voltage gain for common emitter, we have written.

(Refer Slide Time: 42:23)



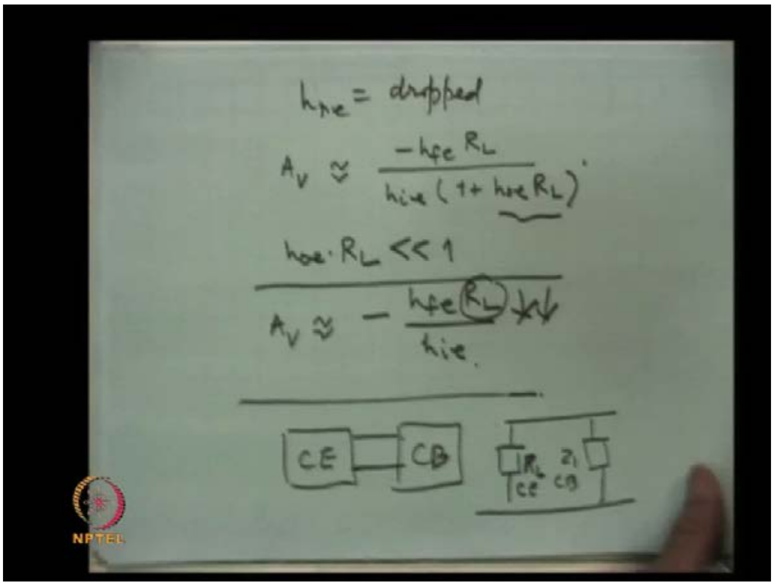
And the current gain for the common emitter amplifier is h f e by 1 plus h o e, R L this is the expression exact expression for the current gain of the common emitter amplifier. We have input impedance input impedance and that is for c amplifier Z i is equal to h i e minus h r e, h f e R L by 1 plus h o e R L and finally, the output impedance Z 0 for common emitter amplifier 1 by h o e minus h r e and h f e divided by h i e plus R S.

These are the four expressions for the common emitter circuit: the voltage gain of the common emitter circuit, the current gain, the input impedance and output impedance.

I said that, these are exact expressions and we can use them, but they can be simplified also. So, let us take the simplified expressions because out of the four parameters some have very little effect if we neglect those h-parameters in these expressions then expressions get simplified and the accuracies suffered is insignificant highly 1 or 2 percent the accuracies is declaim, but that is acceptable in most electronic circuit. So, let us take the approximate hybrid h-parameter relations, the first parameter which can be dropped without much suffering in the accuracy without bringing in accuracy to our result is the h r e reverse voltage transfer ratio.

This is having very small value, if you look at the rough magnitude estimates which I gave in the table in the beginning then this is approximately 10 to power minus 4 very small that means the effect of the output voltage at the input side is very week and many times is can be dropped. If we drop that then our expression for example, for voltage gain can be drastically simplified this h r is extremely small and that the relation then becomes only this much. So, under this condition when

(Refer Slide Time: 46:51)



We drop h r e dropped then we get the approximate relation and again I repeat approximate means within few percent which is acceptable and most of the applications in electronics. So, a accuracy does not suffer significantly and this is equal to minus h f e

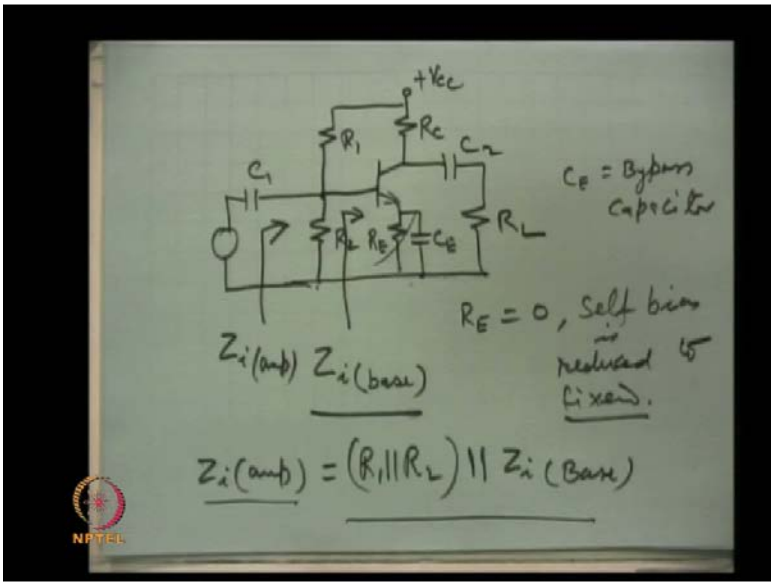
R L by h i e, 1 plus h o e, R L. This is the approximate relation, we can further simplify it actually because this term h o e into R L this is normally very less than 1 it may be 0.01 or 0.02 like that. We substitute the value of load resistance which we use in our amplifier and we take parameter then we will find that this will be less than 1. So, actually it may be dropped and then the expression becomes very simple minus h f e into R L by h i e. So, this we can remember also and I repeat that by bringing this simplification the accuracy of estimation is that suffers very little highly few percent which is tolerable in most of the electronic designs.

So, we see that load resistance is equal to h f e which is like beta the current gain and the common emitter circuit and R L the load resistance if load resistance is low this is one reason that the voltage gain will fall and this is of course, h i e and under this condition if with these modifications if we see then our current gain also become simplified and the input impedance and output impedance all those relations they get simplified. Now I said that common base circuit is not much used because input impedance is very low, here this is another reason that why common base cannot be cascaded easily.

If we have a common emitter stage and then we connect here a common base stage then the input impedance of this C B state this input impedance Z i of common base will come and parallel with the load resistance which will be there and the R L of C E stage. Now this is very low few 50 ohms, 80 ohms, 20 ohms very low resistance and normally R L will be in kilo ohms, but when we connect the we make a multi stage amplifier. If we connect a C B state then the effective load will be drastically reduced and hence the effective load if it falls very much the gain that means the performance of the of the c amplifier will be very much effective the gain may come from say 100 to 20.

So, that is why C B state is not used much it has few applications in high power circuits and that was get. We can find these parameters for any actual circuit and we can we can take up certain problems to find this parameters for actual circuit and the actual circuit of a common emitter amplifier.

(Refer Slide Time: 52:10)



For example, this this is the complete amplifier circuit, this is the transistor, this is that self bias network which we have discussed in biasing of the transistor and this is bypass C E is the bypass capacitor bi pass capacitor and this bypasses the loss of ac signal across resistance R E. Resistance R E is essential for for bias stability we have discuss this point, if we remove R E if R E is made 0 then instead of self bias is reduced to fixed bias. This is never to be used, here that operating point will shift significantly and that may result in to a distorted output. So, as far as dc is concerned that will see this that will not see this capacitor because that dc will be blocked by it it will be post a infinite impedance for dc. So, for dc purposes R E is there and we bypass it. So, that the ac signal is not significantly reduced because, whatever ac signal falls here that is the net loss and the the signal a strength will fall at the load resistance.

So, this is the meaning of bypass the another significant point the impedance, which we have just determined above that was the impedance looking here, that is actually we called Z i base looking into the base on discussing the C E amplifier, which is most important and this will be actual input impedance will be when we include the effect of this. So, this is the input impedance of amplifier which is Z i amplifier is equal to R 1 into R 2 the effect of this this in parallel in parallel with Z i base. So, there are two components of input impedance; one is looking into the base, where we do not take into account the effect of these resistances, but when we are finding the impedance of the amplifier we cannot neglect and that will be this.