**Electronics**

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**Module No. # 03**

**Small Signal BJT Amplifiers**

**Lecture No. # 04**

**r-analysis (Contd.)**

We continue our analysis - r parameter analysis and common emitter amplifier was under discussion and we obtain an expression - a simple expression in terms of resistances for voltage gain. Now, we talked about what we mean by swamping of emitter and if we do not swamp the emitter then what happens?

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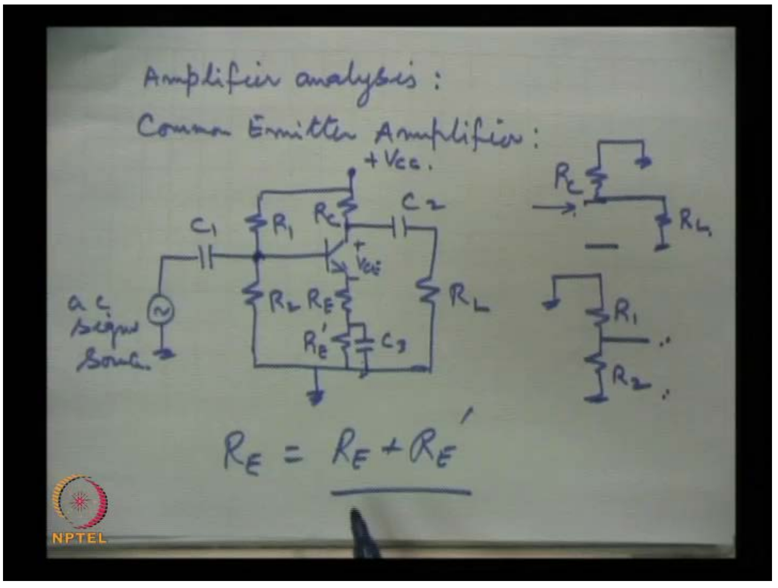


Now, let us take this as an example, we were here that actually a best compromise between stability and high voltage gain can be obtained by breaking the resistance R E into two resistances R E plus R E prime. Now, so these are the two resistances, this may be small resistance as compared to this, but not small enough to to in comparison with the dynamic emitter resistance. So for example, it may be 200, this may be 800 and so on, so that is the best way and this design feature is often incorporated in the amplifier design by the manufacturer. Now we take few examples.

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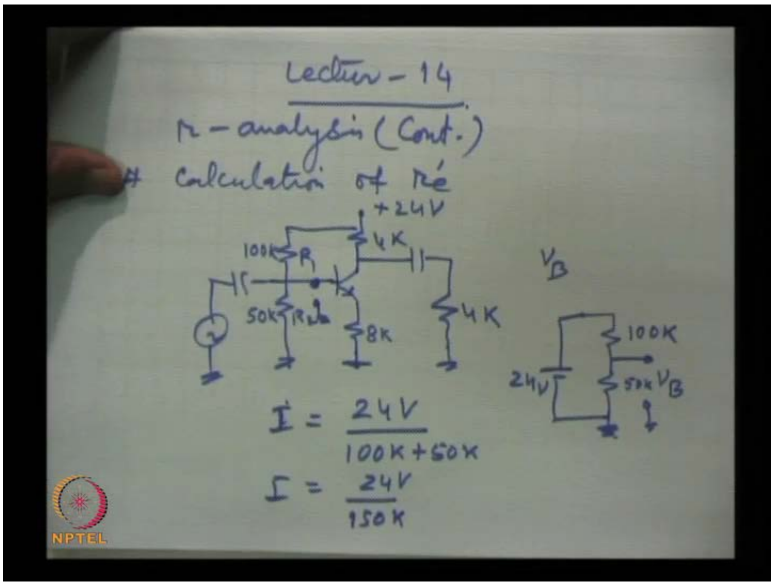


We take one example, just to remain how we can calculate, so how we can calculate the value of dynamic resistance. Now this is calculation of R E prime. Let us consider this circuit (No audio from 02:19 to 02:35) this is the amplifier circuit which is under discussion. (No audio from 02:42 to 02:59) All resistances we are taking in kilo ohms, this is the the amplifier. Now we have to calculate the emitter this dynamic resistance of the emitter R E prime. So first we should get what is this voltage between this and ground we call this voltage here as V B; V B that means base voltage with respect to ground; now this can be calculated. We complete the circuit at the input like this; this is the point we are we are seeking this voltage, this is 100 k 100 kilo ohms this is 50 kilo ohms and this battery is 24 volts 24 volts then what will be the current through it - the current through it will be this voltage divided by 100 plus 50.So the current will be current will be 24 volts by 100 k plus 50 k and this is equal to 24 volts by 150 k and this is current and the voltage across this current into this resistance.

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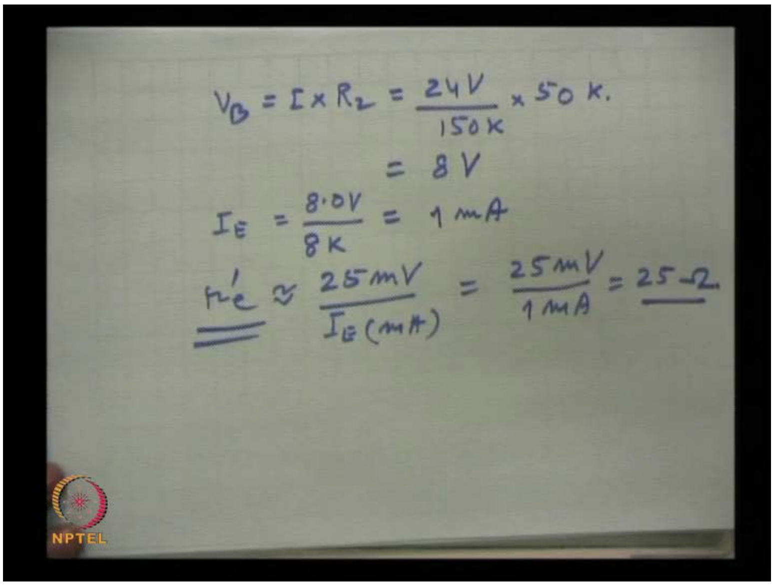


So, the voltage V B is current into the resistance R 2 which is 50 ohms, so I is 24 volts 150 k into resistance R 2 which is 50 k and this is equal to 8 volts. So this resistance this voltage is 8 volts and this is flowing, so the I E here this is the voltage if we just neglect this voltage which is less in comparison to this then this total voltage will appear across this that will give rise to the current I E. So I even if we taken to account that is 0.7 volts for a silicon transistor we can take, but often that can be neglected. Now this voltage (( )) volts drops across this by simple ohms law we can find out the emitter current I E is equal to 8 volts by the resistance 8 k. So this is this is in volts this is in milli amperes, so this is this is kilo ohms. So, the current will be in milli amperes and that is one milli ampere and then r e prime which is very close 225 milli volts by I E in milli amperes which is one, so 25 milli volts by 1 milli ampere, this is 25 ohms and if we take the exact expression, then it will be 26 ohms. So this is the calculation of the calculation of the emitter dynamic resistance. Now, let us take one more example to illustrate that what is the implication of bypassing the the emitter resistance?

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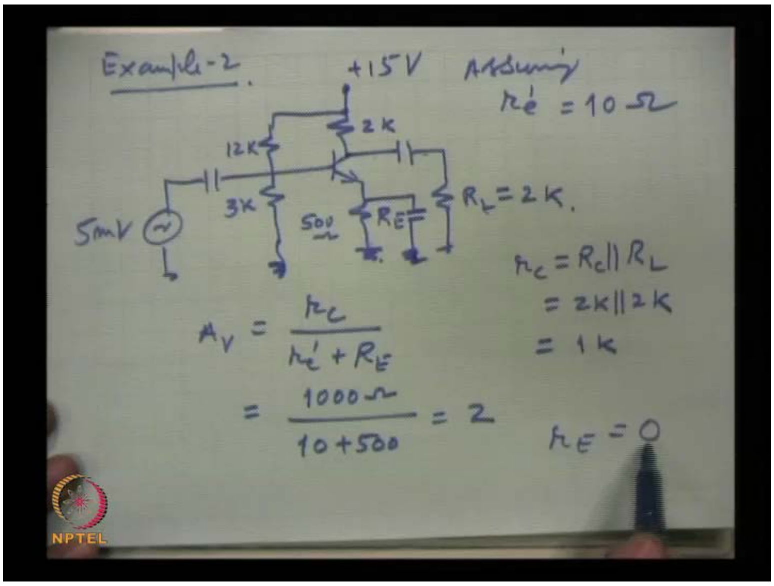


So, let us consider, this is example 2, (No audio from 07:32 to 07:50) this is 15 volts and this is 12 K, this is 3 K again in kilo ohms, this is 2 K and this resistance is half K that is five hundred ohms and the this is our source say five milli volts peak value and here is the load resistance R L which we take again as 2 K. Now in case we swamp we swamp the the effect of R E, if completely it is kept like this then the voltage gain A V which is equal to r C by r e prime let us assume R E prime calculation we have done here for this circuit also we can calculate.

But let us assume - assuming that the dynamic resistance is equal to 10 ohms, then this is R E this is R E if we substitute here you remember that the effective a c impedance seen by this collector is the short this capacitor, so r C which is equal to r C in parallel with R L that means 2 K in parallel with 2 K and you solve it, it will come out to be one kilo ohm. And so, if we are swamping it the gain, suppose to reduce quite a bit; so this is 1000 ohms divided by 10 plus 500, now 500 is again negligible with 10 is negligible in comparison to 500. So this is the gain is only 2. So this 5 milli volts, if we assume that this is available for for amplification, then only two times it will be amplified, so roughly 10 milli volts we will get here which is very small and if we make this bypassed then a c will pass through it and effective a c resistance that is r E this becomes 0. So in this expression, this r E will be zero here.

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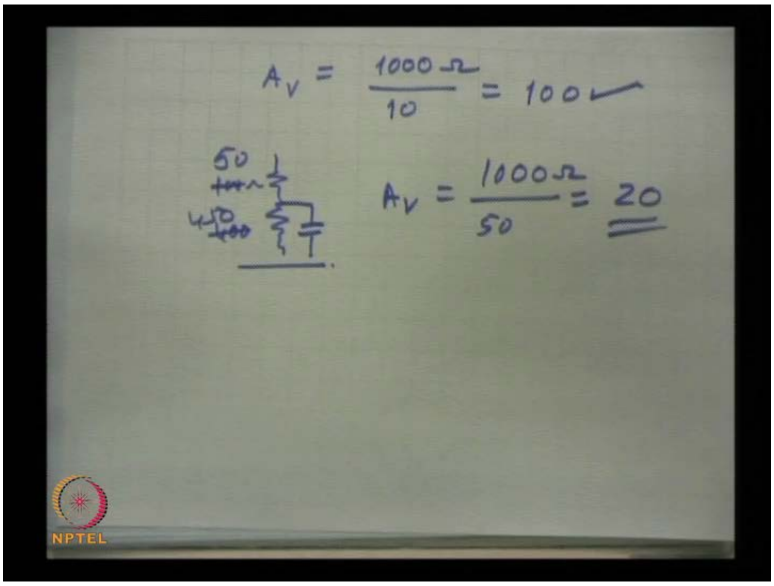


And we are left with the voltage gain in this case is simply 1000 ohms divided by 10, so that is 100. So, what is the purpose of of putting a bypass capacitor across this emitter resistant should become amply clear to you. Now these are two extreme the voltage gain 2 the voltage gain 100 this will be in stable in stable, because the dynamic resistance is temperature sensitive. So, we can make a best compromise and we can settle for example, at a value gain of sixty seventy eighty by breaking this five hundred into two resistances hundred and four hundred, so if we use a 100 ohm resistance and five and 400 ohms resistance still just 500, but then this 400 one is bypassed. So the the gain will be now much better than two and we can calculate that here, this will be only 100; so, actually it is 10, we can still take it 50 and this as 450 then this gain will come out to be 1000 ohms by 50, so this is 20.

So like that I mean this is just an example we can choose these values differently and we can manipulate the voltage gain. So you see the simplicity of the r analysis that it gives a very simple relationship and we can manipulate the value of the… For example, we are considering voltage gain and we can achieve any value by simply adjusting these resistances with the emitter lead and the simple - this common emitter circuit. So this was about the voltage gain of a amplifier. Now we take input impedance of c e amplifier.

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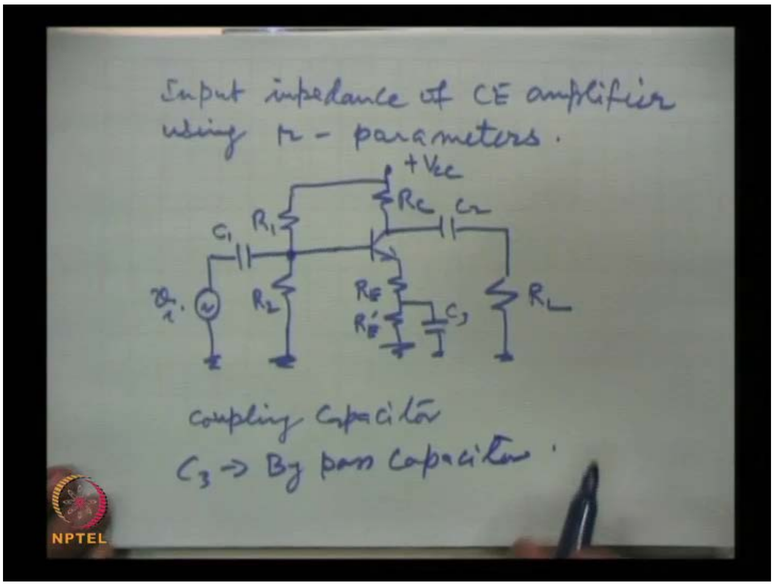


Input impedance using r parameters, the circuit under consideration I redraw(No audio from 13:50 to 14:19) plus V C C this is the coupling capacitor, this is the load across which we will measure the output voltage and here, this is the input signal and this is resistance R 1, this is R 2, this is R C and so on and these capacitors - these are coupling capacitors and this is called bypass. So remember these names coupling capacitor and this is C 3 is bypass capacitor.

Now, again to know our objective is to find an expression for the input impedance of the amplifier, we have in the beginning emphasized the importance of input impedance and for a voltage amplifier the input impedance is supposed to be high. Now, to find the value of effective impedance, we draw the equivalent a c circuit for this and remember the ground rules - the thumb rules for the analysis that d c source is to be grounded; the coupling capacitor and the bypass capacitors all have to be shorted then what remains in the circuit. The a c equivalent of this circuit will be this. (No audio from 16:12 to 16:57)

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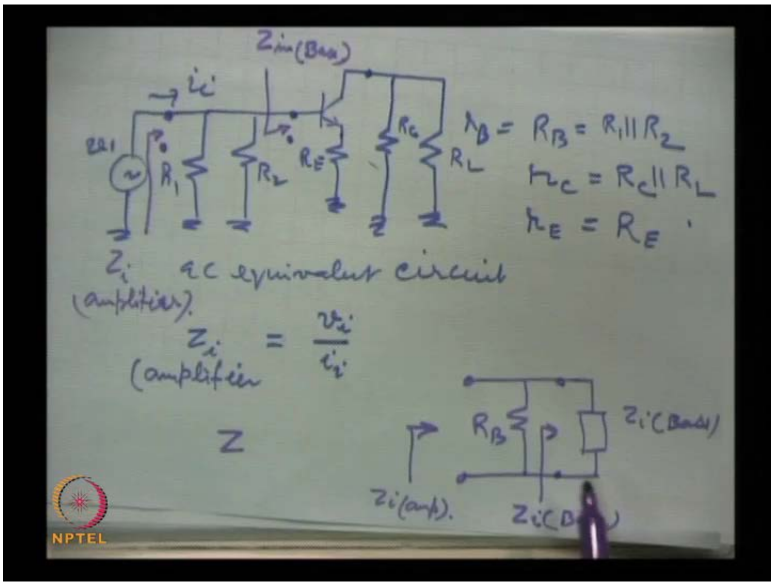


This is the a c equivalent circuit. So, we remember that R B these two resistances are coming in parallel; so effective what is the value of the impedance seen by this is R B which is R 1 in parallel with R 2 and R C what is the effective, this is the capability collector. So, what is the effective impedance which the collector will be seen these two are in in parallel. So r C r C is simply. This capital R C the the resistance which is used with collector in parallel with load resistance and r E - this is this we can write in small also R B one in the same thing and r E is the effective resistance as seen by the emitter. Now, this cap this resistance we are bypassing, so in a c equivalent circuit this when it is shorted this disappears and what remains is r E, so this r E is this.

Now the input impedance, how we define? How we find input impedance for any circuit? We simply apply a test voltage and we measure the current flowing; so the ratio of the two by simple ohms law will be the impedance. So, Z i i Z for impedance, i for input, this is for the amplifier and this we can define by v i by the current i i by the ratio of this that will be the impedance here; now this important, it is convenient to find this expression to break the input impedance of the amplifier into two parts and these two parts are the R B part and Z in Base, that is what we see here between this and ground, this impedance seen here, this we call Z in base. And the impedance as seen here between this point and ground; this is for example Z i amplifier.

So the two parts Z i here, if we know what is the impedance here I redraw in another simplified manner that suppose, this is the impedance here Z in Base for this circuit Z i Base and this is what we have called R B which is the parallel combination of these two resistances, then here considering both it becomes Z i amplifier while looking here which means these two points simply is Z i Base. So therefore, the input impedance of the amplifier.

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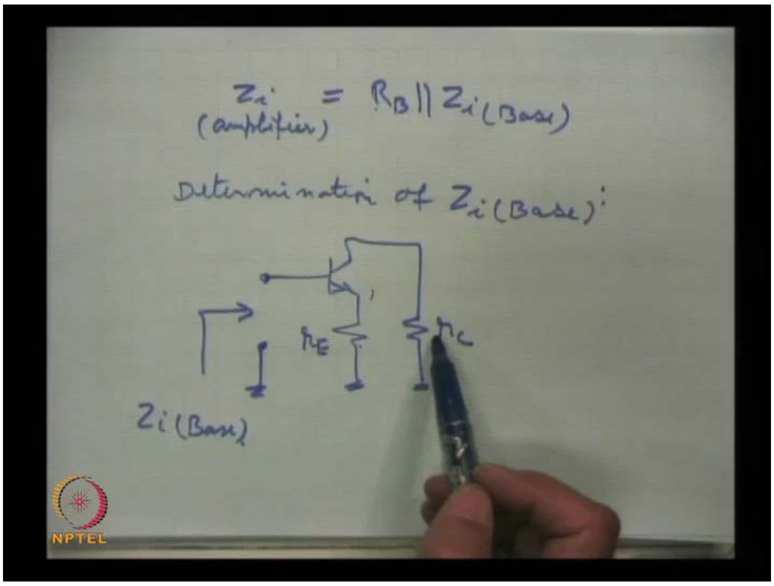


Z i of amplifier is obviously when we divided into two parts R B here, amplifier is in two parts R B and Z in Base, then this impedance is the combination of the two in parallel. Now, this is known by design for d c analysis, what are the values of R 1 and R 2 resistances? So this we know our task of calculating the input impedance of the amplifier is reduced to finding out Z in Base. So, determination of the input impedance at the Base which we are calling Z i Base, this is there. Now, so our circuit is basically this, this is r E and this is r C and we are finding the value Z i Base. We replace the transistor by its model which we have earlier used; so by replacing we retain these two resistances.

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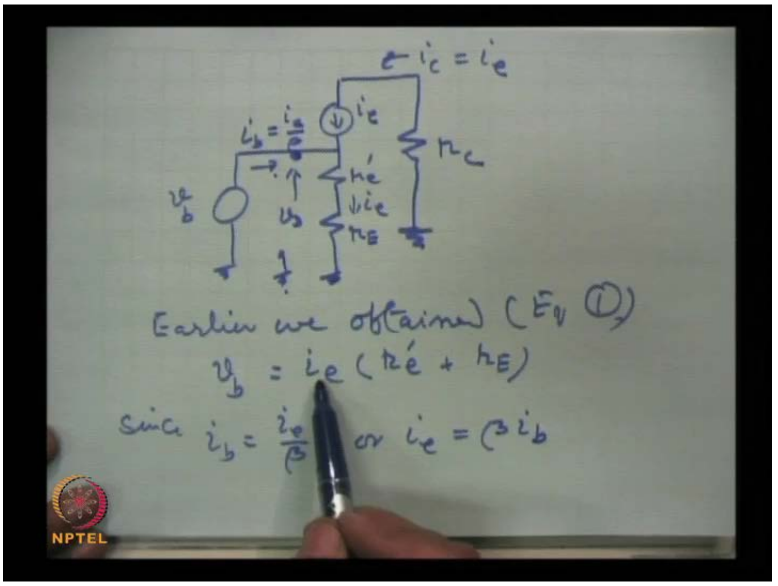

And let us see what we get when we replace that with the model, we get this one. (No audio from 23:15 to 23:36) We send a signal v b and here this is i b which you know is equal to i e by beta; this is the current and what the voltage v B is here, this is r e prime, this is the current i c which is equal to i e and this is current i e in the model and this flows i e through this resistance which is r e, this is r c. So these are all effective a c resistances with the leads. Now earlier we have derived you will recall equation one for example, here these three equations I said that we will be using in future analysis also, so these are the three voltages, now we are using i b equal to i e r e prime plus effective value of emitter resistance, so this we are using and we get. Earlier we obtained that is equation 1 v b equal to i e into r e prime plus r e. Now since the base current is i e by beta or i e from here is beta times i b; so we substitute this we replace this i e with beta i b.

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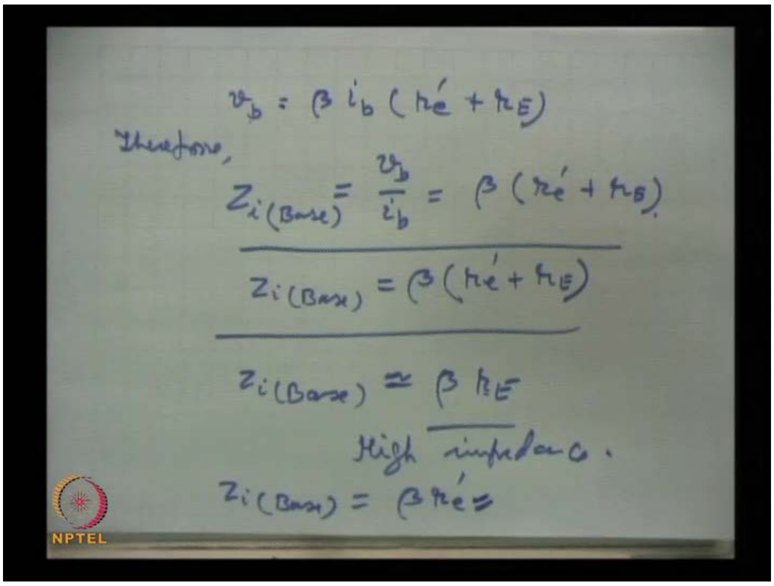


So, this is v b is equal to equal to beta i b r e prime plus r E and so. Therefore therefore input impedance as seen at the base becomes equal to v b by i b v b by i b which is simply very important relation Z i base is equal to beta times r e prime plus r E, because two most important parameters for a voltage amplifier are the voltage amplification that is voltage gain and input impedance. And this is the relation for the base and then of course, we can find out the impedance if we multiply and from here we can get what will be the impedance of the amplifier, but let us discuss first this when we swamp the emitter, then r E has a finite value say 800 ohms or one kilo; this is very small and it can be neglected.

In that case Z i base will be very close to beta r E and very high value high - high impedance and if we bypass this completely, then in that case Z i base will be reduce to beta. Now this is few times of ohm; beta is of course high; it may be 50, 80, 100. So, this is this is certainly not as high as this, but the defect with the problem with this will be that this parameter being temperature sensitive, this impedance as temperature changes will keep on changing.

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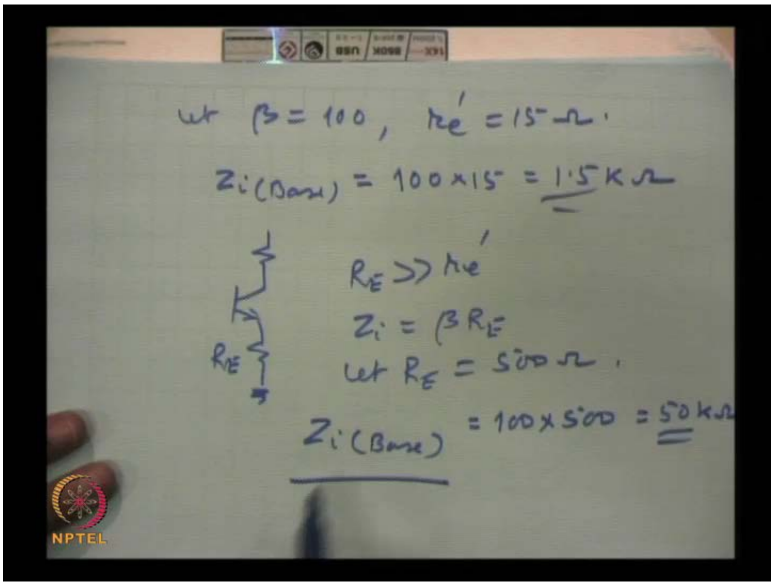


So, we have this, let beta be 100 and dynamic emitter resistance as 15 ohms, then Z i Base equal to 100 into 15; so it becomes 1.5 kilo ohms, but it is temperature sensitive and if we swamp that then so that the case is this, where this is R E then R E being normally very large as compared to this Z i Base in this expression, we neglect this and it becomes this one. So this will be equal to beta R E, let R E be 500 ohms then let R E be 500 ohms beta continues to be 100 then Z i Base is equal to 100 into 500, this is 50 kilo ohms. You just compare 50 kilo ohms with 1.5 five kilo ohms and that is this. Now, this is one component of the input impedance, the impedance of the amplifier as I said earlier.

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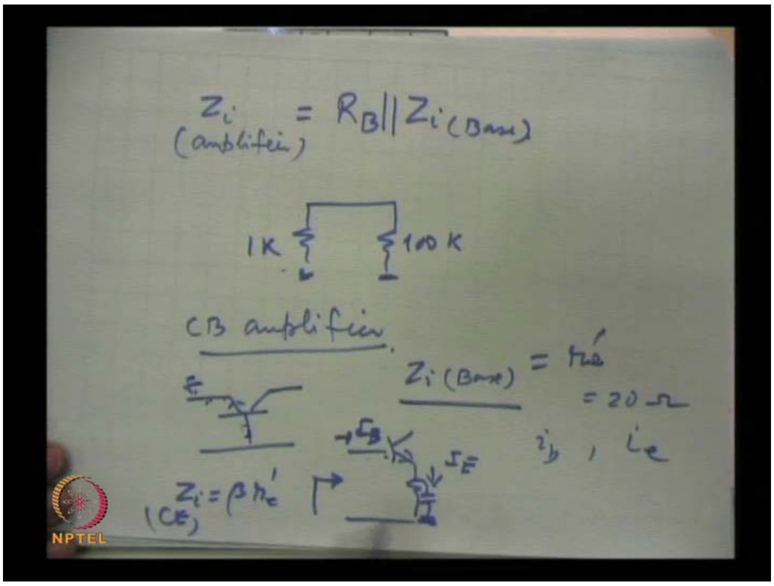


Z i for the amplifier, this is equal to R B in parallel with Z i Base here, because the two are in parallel, so Z i Base has to be high only then this combination will give high amplifier input impedance. Remember when two resistances are in parallel then the parallel combination results in a impedance less than the smaller resistance I take another just I do not know if you have our thought on that, if there are two resistances the 1 K and say 100 K, these two resistances in parallel they will result in a effective impedance will be the parallel combination of the two and the effective value will be less than 1 K in this case.

So Z i Base should be high and R B then we can use high, then the effective value of the input impedance of the amplifier will be high. Here, one more point needs discussion this is a very finer point and I think you must learn that also. In the common base circuit common base amplifier common base amplifier the input impedance here, this is very small. The input impedance Z i Base is simply r e prime the dynamic emitter resistance I am telling you now very finer point and you must listen carefully. This in common base, it is simply r e prime and this is equal to say 20 30 40 ohms.

Now the same junction, this is emitter base we are using in common emitter as well. (No audio from32:53 to 33:03) If we take a c values even then it is simply i b and the emitter current is i e. Same junction here emitter base, here also we are using the same junction, but the impedance as seen here becomes instead of r e this becomes Z i in the case of c E becomes beta times suppose this is just we are using the same way swamped or it is not connected r e prime beta times how is that same junction same junction here.

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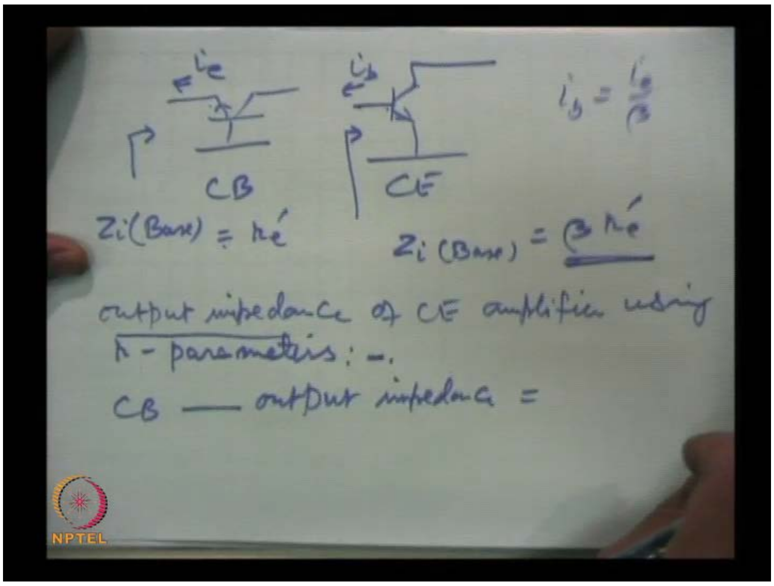


This is common base and this is common emitter c E this is c B, in this case the impedance as seen here Z i Base is equal to r e prime; the impedance in this expression in this expression here r E is 0. So, it is beta r e prime, so in this case Z i Base is beta times r e prime. So the important point is same junction gives here much higher this impedance looking at the base then in the case of c b, why it is so? Not difficult to find the reason. The impedance, how how we know the input impedance for any circuit? It depends what current it draws, if it draws a very small current then the impedance is high maintaining the same voltage, if it draws here the current is i e which it will draw here it will draw i b, input current is this here input current is i e. Now i e is beta times higher than i b or in other words i b is beta times not beta times divided by beta, i b is equal to i e by beta.

So this is much less current, hence the impedance is high and high by how much amount by one by beta times. Therefore, the impedance is beta times r e prime I hope I have made this point clear. Here the current which if you will draw is i e here from source this will draw current i b, i b is i e times e divided by beta. Therefore, this is having a higher impedance equal to beta r e prime; so this is about the input impedance. The another parameter the output impedance output impedance output impedance of c E amplifier using r parameters. The output impedance we can find out as we have done for the input impedance, but the question is that the analysis becomes complicated and instead of replacing the transistor by its equivalent circuit and we try to find the expression for the output impedance in a c E amplifier. Let us take a simpler route to find and logically we can understand that in c B the output the input impedance was r e prime in c E amplifier it becomes beta times that. Similarly, in c B case the output impedance the output impedance is equal to what the collector effectively sees?

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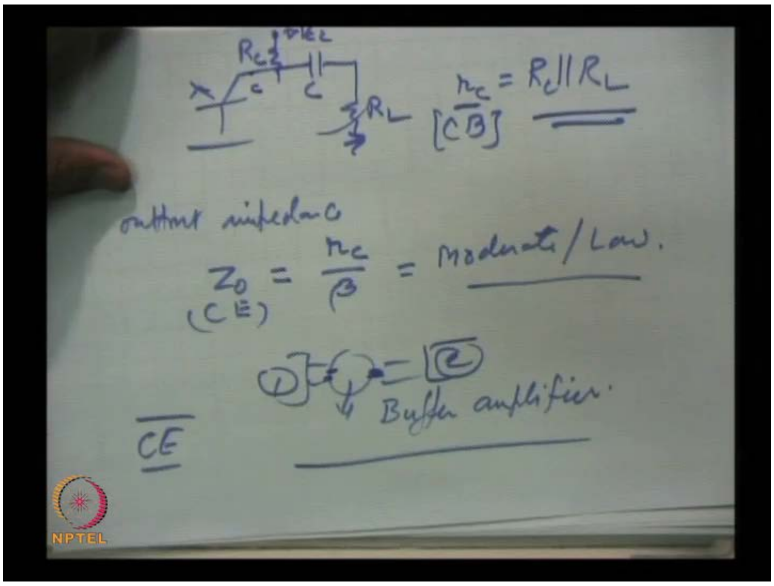

So, if you remember the common base circuit. Here I jutst draw a part of it; this will be this is plus V C C, this is coupling capacitor this is R C and this will be R L and this is the emitter circuit, but at the moment we are talking of the output side. So, what will be the effective value of impedance seen by the collector? For any a c analysis we ground this terminal then these two becomes in parallel. So r C will be the effective value of the output impedance in C B case. In C B case this becomes r C r C is the effective value. Now s the input impedance is divide is the product of beta into the r e prime; the output impedance in c e output impedance Z 0 in C E amplifier is divided by beta, this becomes r C by beta. Should I repeat? I think I should, because we can analyze it, but analysis runs into complicated stuff and we can use a simpler approach and that we can do that.

Here this we have derived that input impedance in common emitter circuit comes beta times the impedance of the c b circuit r e prime. Here for the common base circuit, output impedance is simply r C and it can be worked out that output impedance comes out to be divided by beta - it is less. So it is moderate or low and you remember, we talked that for a voltage voltage amplifier the output impedance should be low and input impedance should be high; so C E amplifier C E amplifier gives that this is much reduced beta, beta is eighty hundred two hundred, so this is reduced. And hence common emitter amplifier common emitter amplifier gives us a good performance and I I tell you that when we make systems where single stage is normally not sufficient and multi stage amplifiers which we will be talking in the next unit the multi stage amplifiers are used. In multi stage that the stages have to be have to be coupled together.

Now, unless the impedances are of the not exactly identical, but of same order of magnitude we will require a third intermediate stage between this stage the previous one and the next one. And this is called buffer amplifier buffer amplifier which is which will match the two impedances which are suppose to be drastically different into into two amplifiers. So this will match, so this is a matching stage amplifier which is called buffer amplifier. So, but C E amplifiers can be coupled, can be cascaded, can be connected in series without the need of this buffer amplifier. Now, we have done the r parameter analysis for the common emitter amplifier, let us look on the two other amplifiers first I take the emitter follower or common collector amplifier.

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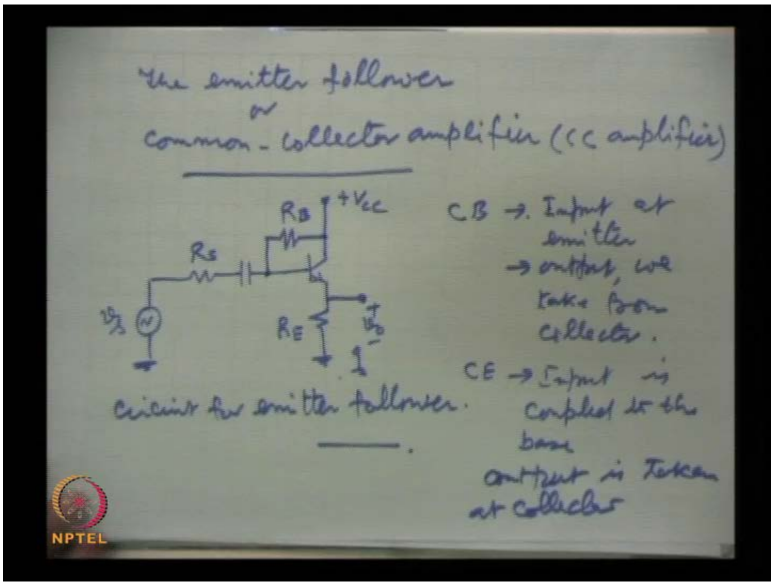

Common collector amplifier C C amplifier is popularly known as emitter follower and why it is called emitter follower that we will soon discuss. Now, what is the circuit? Circuit for this emitter follower, (No audio from 43:33 to 44:25) this is the circuit for emitter follower circuit for emitter follower. Now, here one thing is very striking in emitter follower the input signal is fed to the base and it is coupled to the base and the output is taken from the emitter. It is very important to note this difference, because in common base we connect the input to emitter input at emitter and output we take from collector - input we give to emitter, output we take at the collector. In the C E common emitter amplifier input is given to base, input is coupled here you have coupled the input is coupled to the base and out output output is taken at collector. The difference input at emitter, output at collector; here input is coupled to the base and output is taken at collector; this is what we have been earlier doing. In this case this is input is base and output is at the emitter.

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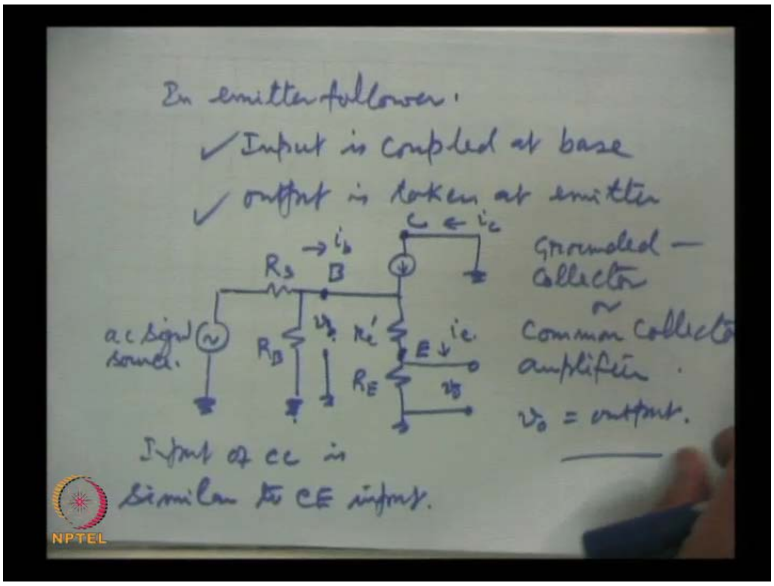


Input in emitter follower in emitter follower the input input is coupled at base of the transistor and the output is taken at emitter. This is the distinction - this is the only amplifying circuit in which the output is taken at the emitter. Now in general when you look at a complicated circuit there will be several stages, if you found if you find that the output is being taken from the emitter then be sure that this is you can be sure that it is a emitter follower circuit, because the circuit design which we have done shown here. This is in isolation just one stage; so it is very easy to look at it that output is being taken has been taken from the emitter; so it has to be a emitter follower. So this you must remember when look at the complicated circuit where several stages of amplifier are there, then wherever the output is taken at the emitter this is the emitter follower.

So in this circuit, to perform the analysis we will replace this transistor by its model; so we do that. (No audio from 48:30 to 48:47) The d c source V C C is to be grounded. So the cathode is grounded so many times emitter follower also called grounded collector - grounded collector or common collector - common collector amplifier or circuit. And here this is R e prime, this is R E and we are taking output, this is the emitter lead, this is the collector lead, this is the base lead and this is R B. This is the source resistance of the signal source, this is a c signal source. Now, here the current i b is flowing this is i c and here this is i e and we are taking output here - v 0 is output.

Now this circuit as far as the input goes this voltage is v b, what is the potential at which the base terminal of the transistor is with respect to ground? Now you will recall that this input circuit is same for C C as used in the common emitter case. So input, because they are also in common emitter circuit also we have connected the signal source to the base, here also we have connected to the base. So input of common collector is similar or other same to common emitter amplifier input. Therefore, we can use the expressions which we have arrived earlier the equation one two three, the two equations certainly can be used in this, so the base voltage v b if you remember look at turn the earlier pages and you will find that v b was equal to i e r e prime plus r E.

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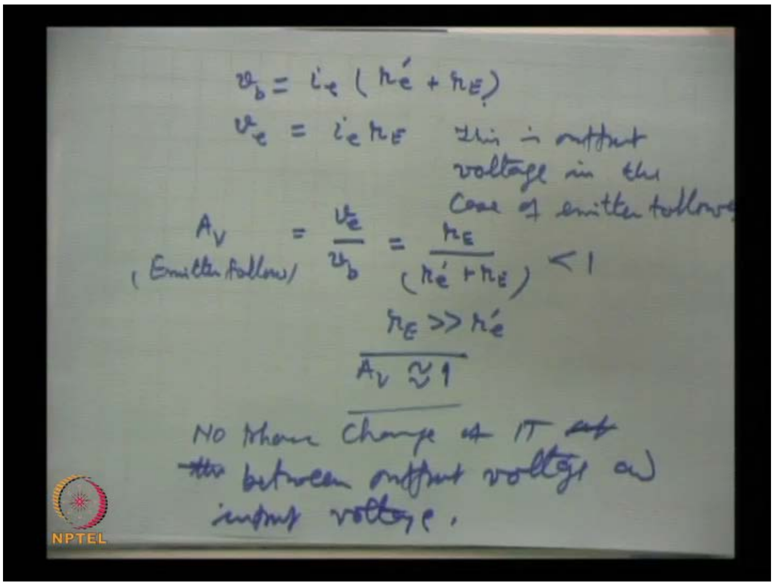


The current flowing through these two resistances are in series r e prime and r e through which the current i e is flowing. So simple ohms law tells us what will be the voltage between this terminal and this terminal this is simply i e into these two resistances; this is what i have written. And the other equation v e this is i e into r E, what is the voltage? This is the emitter lead; so, what is the voltage here and here? This is simply this current and this effective value of this resistance. So therefore, the this is now the output v e is this is output voltage in the case of emitter follower which is under discussion at the moment; therefore, the voltage gain for the emitter follower this is simply v e and this is output voltage and the input voltage is v b; so we divide the two and we get r E r e prime plus r E.

This is the expression what does it say that this is r E this is r dash prime r E; so this is less than one, but because r E will be very high in comparison to r e prime; this may be one kilo or so and this is hardly ten twenty thirty ohms. So this will be very small we can drop it in that case the voltage gain is very close to unity. So remember there is no voltage gain there is no voltage gain in common collector that is emitter follower. Emitter follower does not show any voltage gain, but we will see we can find out the current gain and here let us look at the phases when this there was a there was a phase reversal in common emitter. In this case there is no phase reversal when this signal goes up in the positive direction this will enhance i b, if i b increases then i e will also increase and so they are in phase. So there is no phase - no phase change of pi at between between output voltage and input voltage; there is no phase change and there is no voltage gain, but current gain is there we will find the expression which is equal to actually beta - the beta is the current gain and there is no voltage gain. The output follows in magnitude and in phase the input that is why it is called emitter follower. The output is in equal in magnitude and there is no phase reversal, so they are in phase.

So, we will continue our discussion on common emitter, common collector that is emitter follower amplifier, the other parameters we will derive. And then we will briefly take common base amplifier using r parameters will continue.