Electronics

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Module No. # 03

Small Signal BJT Amplifiers

Lecture No. # 13

Small Signal Amplifier Analysis using r-parameters

We were discussing Analysis of Small Signal Amplifier and as mentioned earlier, this can be used by using hybrid parameter or r-parameters. Hybrid parameter analysis, we discussed, now we will be taking r-parameter analysis. There are various reasons, which of course, I will specify because of these reasons, r-parameter analysis has become quiet popular in recent years; and in fact in many times, it has been preferred over h-parameter analysis.

Now, before taking the actual analysis, let us talk about important thing that is source and load impedances often; because is often half set that when the frequency is low, impedances resistance does not differ. And hence, we loosely talk at low frequencies at about resistances or impedances.

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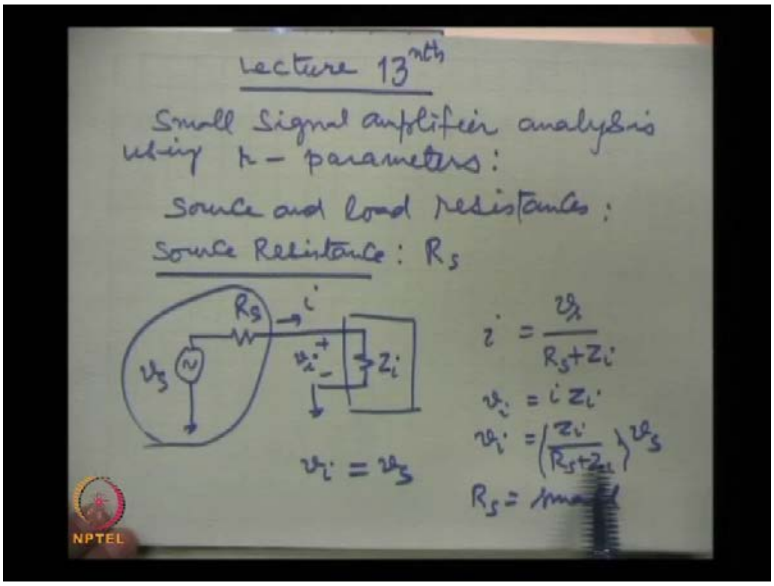

So, source resistance first we talk, this is often written as R s. Every source, which we connect at the input of the amplifier; this may be micro phone, this may be some other oscillator or the previous amplifier stage to which is this stage is connected, they have all impedance.

And a circuit can always be thevenised like this (No audio from 02:16 to 02:37). This is the source impedance v s (Refer Slide Time: 02:38) and this can be thevenised with the voltage source and resistance. Now, this current i as, we simply we can write, this will be v s the signal voltage and the two resistances are coming in series, R s and Z i.

Now, the voltage which is available for amplification actually is v i. So, v i is equal to i into Z i. So, when I substitute the value of i here, I get v i is equal to Z i R s plus Z i into v s. Now, from this expression you can see that, v i will be equal to v s; that means, there is no signal loss as much as we are applying the same is applicable for amplification at the amplifier.

This is amplifier, Z i is the input impedance of the amplifier, R s is the source resistance source impedance that is, if it is oscillator then the oscillator what impedance it has. Now, this is obvious from here, that v i will be equal to v s, if a R s is small and it is small enough as compare to Z i. So, if the input impedance is the high, I write the expression.

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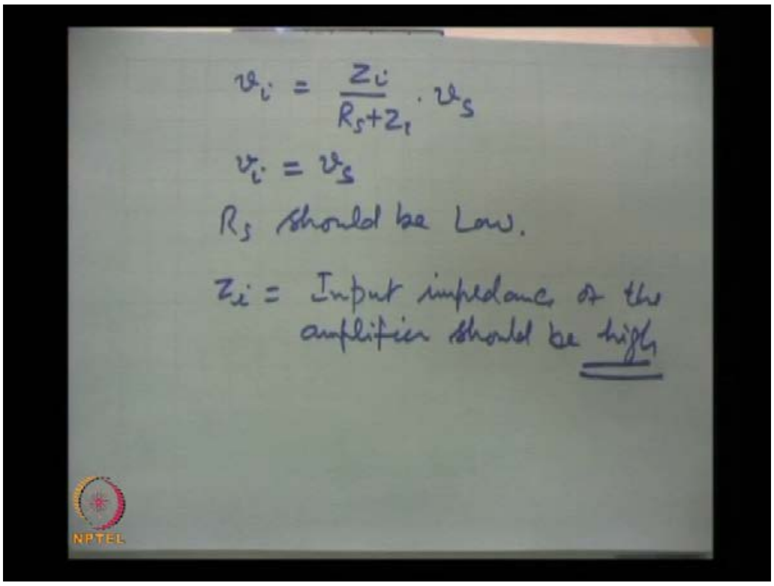

v i is Z i R s plus Z i into v s and the condition that v s v i v equal to v s, R s should be low, so we should use a source which has low resistance, R s should be low. And this condition can also be satisfied that, Z i that is the input impedance of the amplifier, input impedance of the amplifier this should be high should be as high as possible should be high.

So, remember a voltage amplifier should have high input impedance. This point we have been emphasizing so far and this become very obvious here, that for a voltage amplifier, input impedance should be high and output impedance should be low; and that point we shall take now and that is the load impedance (No audio from 06:14 to 06:23) load impedance.

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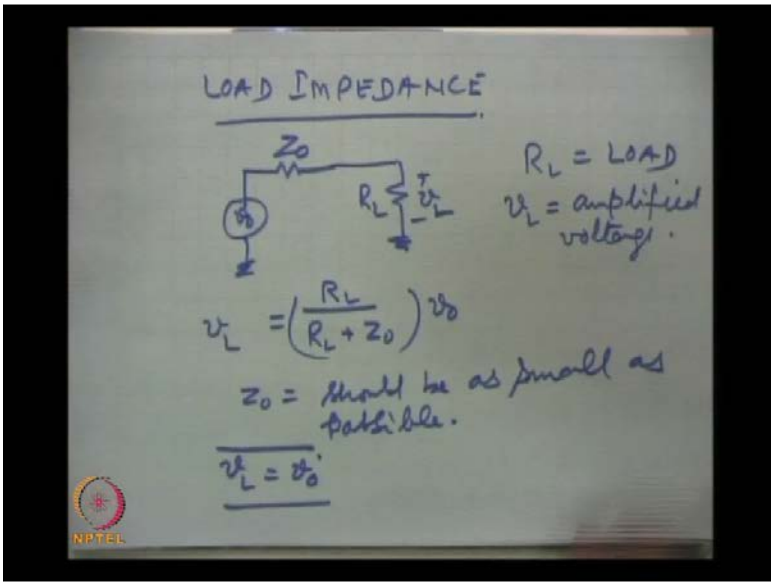

The amplifier the output of the amplifier will give the output v 0 and every amplifier has the output impedance, which we are writing at Z 0. Now, to this we connect the load, so this is R L; and across this is R L is load and across R L, we measure what we call the amplified amplified voltage at the load v L, v L is amplified voltage ac voltage.

Now, from this figure we can make out that, v L v L is equal to R L R L plus Z 0 into v 0, this is the voltage which we will be observing at the load resistance. Now, there is there should not be loss of voltage, this will require that, Z 0 should be as a small as possible only then, v L will be equal to v 0.

So, this is the justification for the statement, which we have been making that the output impedance of the voltage amplifier should be low. When this is low then, the two impedances are equal and there is no loss of impedance. So remember that, source which we used with the amplifier; it impedance should be input impedance should be low, R s should be low. And the output impedance of the amplifier should also be low, if we proper voltage at the load. Now, we come to r-parameter analysis, r is tends for resistance. And soon, we will realize we will look at the good features of this analysis and that is why, this has become quiet popular, first why r-parameters analysis?

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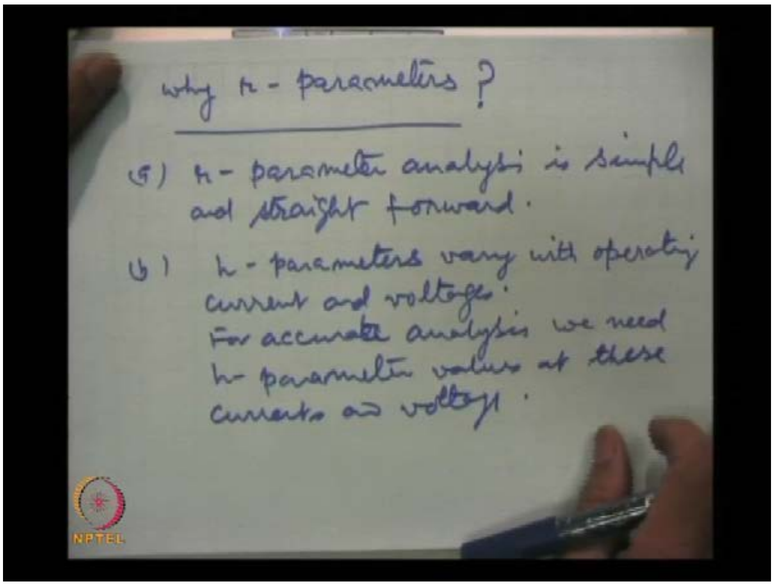

Why r-parameter? First reason is that, the r-parameter analysis is simple and is straight forward. Second point is, we have seen in the h-parameter analysis and these h-parameters vary with operating current and voltages. For accurate analysis for accurate analysis we need h values h-parameters values at these currents and voltages, which is again it is not very straight forward.

And the r-parameter analysis on the other hand requires only one parameter r-parameter r-parameter analysis requires only one parameter and this is actually calculated for the case for our circuit; and hence, it is very accurate that makes analysis very simple and the calculation of the one parameter as we will see is very straight forward and very simple. The performance, the third point which goes in favor of the r-parameter analysis that, the equation performance equation, which we will soon be getting they are very simple not as complex as in the case of s-parameter analysis.

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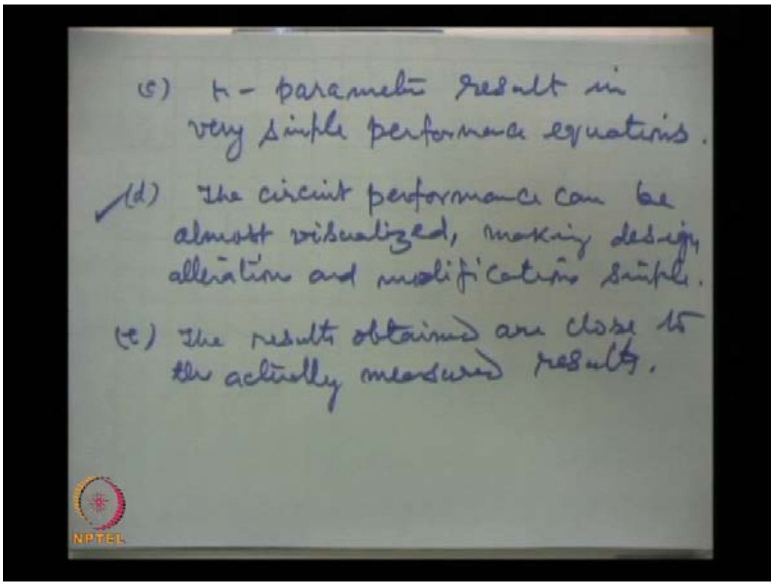

So, r-parameters result in very simple performance equations. You will see it soon that for example; the voltage amplification with h-parameter that was the equation was quiet complex. Here, it will be extremely simple, so this is that point and then very important two points, one is that the circuit performance is almost that can be visualized the circuit performance can be almost visualized, making design making design alterations and modifications simple, this is very important (Refer Slide Time: 14:01).

And lastly, the results obtained by r-parameter analysis are very close to the experimentally observed results; that is, this results obtained are close to the actually measured results. So, this is the reason, these are the reason why r-parameter analysis is becoming popular.

Now, there is one limitation of this r-parameter analysis also and that is, this analysis actually does not take into the account the feedback effect you know, what is feedback effect? That, the two junctions in the transistors, the emitter junction and the collector junction, do not work, do not operate totally independently, there is some little dependency; and this dependency is for example, the input current (( )) becomes a function of the collector junction voltage, this is because of feedback effect, this is one of the feedback effects.

Now, r-parameter analysis normally ignores does not take into account this feedback effects; but, feedback effects are very small and they are influence on the performance can often be neglected; the magnitudes which are affected, those magnitudes are really negligibly small. So, this is not something very serious. So now, we will come to the r-parameters, what are the r-parameters?

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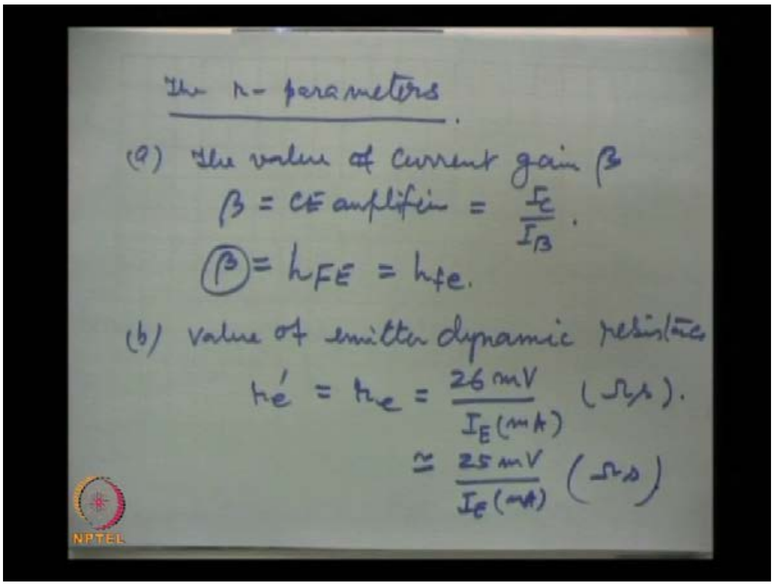

The r-parameters, there are only two parameters required for this analysis, one is the value of current gain beta you remember beta, we define for C E amplifier and this was the ratio of the output current to the input current. And this beta is seen as in h-parameters the forward current gain h F E forward current gain or sometimes this is for dc and as I said that, dc and ac parameters current gain do not differ significantly with hardly difference of 1 or 2 percent, so they are the same, so this is beta which we need.

The other parameter is which is required for this r-parameter analysis and this is that is the value of emitter dynamic resistance, emitter dynamic resistance which is which we have talked earlier also, when we developed with the small signal model of the transistors and this is r e prime, which is sometimes written just simply r e and this is 26 millivolts by I E in milliampere; then it is the value in ohms.

And this 26 millivolts is also sometimes taking just 25 for the shake of the convenience of calculation 26 millivolts, one in the same thing it will not incur much in accuracy. And this is I E in milliamperes then we get the values in ohms. So, these are the two parameters we required. Now, you remember that we developed a small signal model for moderate frequency application, when we talked about when we are talking about the transistors BJT.

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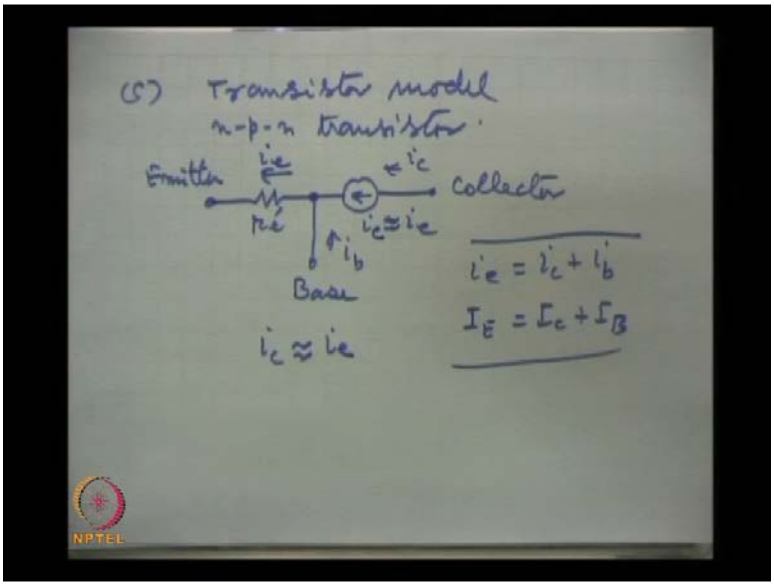

And you will recall that, this is what we arrived is simple model transistor model, that we will be using in this analysis, transistor model this model was for n-p-n transistors. This model was which is of course, equally applicable for p-n-p transistors only difference will be in the direction of the current, that is it. So here, this is collector, this is base and this is emitter and this is the current source, which is i c and this is equal to very close i e and this resistance is the r e prime (Refer Slide Time: 20:07).

The emitter dynamic resistance which we were just talking and this will be the direction of current, this is i c, this is i b and this is i e. Few things are very fundamentals for the analysis of transistors. One thing is that, i e is equal to i c plus i b this is for ac currents. And this is the same similarly, for dc currents i E is equal to i c plus i B, this is the very fundamental.

And i c is I have written here is very close to i e because, the base current which is (( )) current is often two orders of magnitude are higher three orders of magnitude this smaller than emitter current or collector current. Now, we take the amplifier which we are going to analyze. Let us, take C E amplifier.

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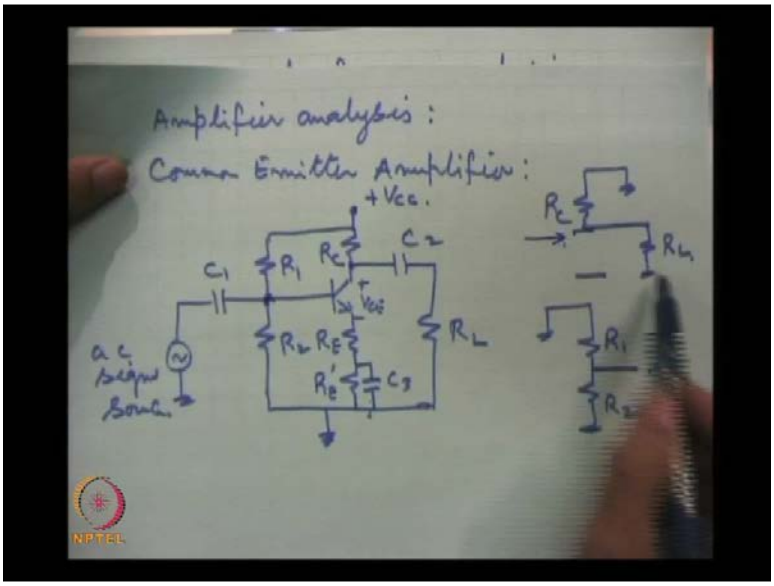

So, we start from here the amplifier the amplifier analysis the amplifier analysis. And we first take C E amplifier, Common Emitter amplifier. We take first the common emitter amplifier in the complete amplifier is this (No audio from 22:43 to 23:12). This is the circuit must be looking familiar to you, because we have ground it several times. (No audio from 23:22 to 23:42) This is the circuit, these are the resistances which are used to provide in a proper bias.

And always remember that, the emitter junction has to be forward biased, collector junction has to be reverse biased. So that, we are in the active region and then, we have to choose proper vales of the dc currents, the i c and this voltage drop here V C E q, this we have to derive properly; So, that the circuit function.

And this we have talked that, choosing appropriate values of the voltage as in current dc currents in voltages in the circuit that decides the operating point. And operating point should be nearly some where in the middle of the active region of the characteristics. So, any way this is the C E amplifier circuit, this is the source ac signals source and amplified output is taking at the load.

Now, we applied we apply the rules of the analysis which of course, we applied even in the case of hybrid parameters analysis and I summarize just in two lines, these rules again.

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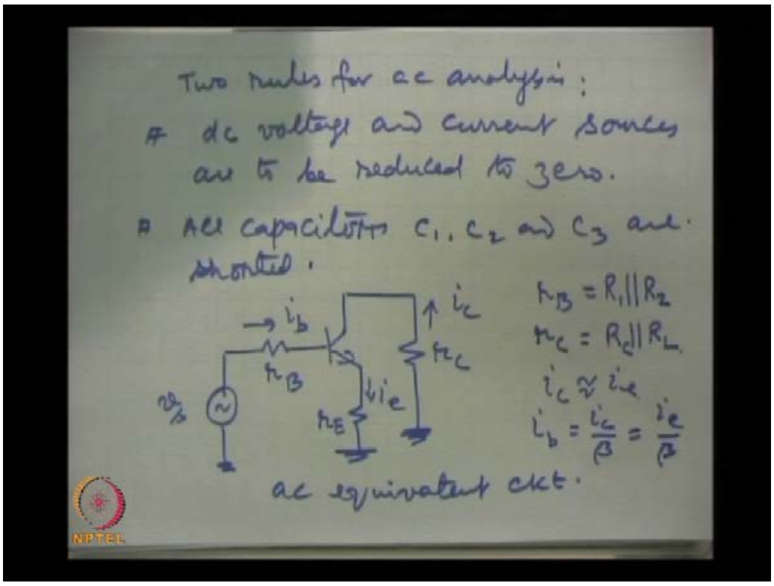

So, the two rules for ac analysis, this is true for ac any ac analysis actually that these rules this have to the followed. The one is that, dc voltage and current sources are to be reduced to 0; that means the dc voltage source when we are conducting ac analysis then, dc voltage source is to be grounded.

And current source to reduce it to 0, this is to be open, open circuited and this is to be grounded, voltage source. And all capacitor C 1 look here in this circuit C 1 C 2 and C 3 all these capacitors we have chosen of the right value and taking in to the account, what is the frequency region in which (( )) suppose to work. So, one they will offer hence the negligibly small impedance. And so we short them C 3 are shorted.

Now, if we follow this rule of the analysis then, the C amplifier which we have shown here this gets reduced to its ac equivalent circuit. So, the ac equivalent circuit will be (No audio from 27:29 to 28:15) this is the ac signal ac circuit, ac equivalent circuit ac equivalent circuit. The actual circuit is this (Refer Slide Time: 28:33). And when we short this, we short this, we short this and dc voltage source is have to be grounded, so this point is grounded.

Then we will see that, r B this r B this is actually when we when we ground this terminal, they actually become like this, this is grounded and this is R 1 and this is R 2 then, as seen between this two points this two resistances will be in parallel and there that is why the R is R 1 in parallel with R 2 (Refer Slide Time: 29:06).

Similarly, on the output side when this is grounded, this terminal is grounded, this is R c and this capacitor grounded and this is R L. So, R c R L as seen between these two points here and here, these two resistances will be in parallel. This is the parallel combination is the impedance, which is seen by the collector (Refer Slide Time: 29:59). So, this is the effective value of base resistance, this is the effective value r c is the combination of the collector resistance with the load resistance.

And also all we remember that, collector current is very close to the emitter current. And i b you know is i c by beta and this can also be written as i e by beta. So, I hope things are clear. Let me, recollect things, this is the actual common emitter circuit (Refer Slide Time: 30:53). And we are going to apply r-parameter analysis for its analysis. Now, the rules are that dc current and voltage sources are reduced to 0.

This is the dc voltage source, so we ground for ac analysis (Refer Slide Time: 31:10). And this capacitors are shorted we take them of appropriate value, so that they offer negligible impedance as compared to the other impedances in the circuit. And hence, they are shorted. And when we do that then as I have shown here that, if this is grounded (( )) complete the circuit at the input then the between base and ground; the impedance is r B this r B which is parallel (( )) of R 1 and R 2.

Similarly, on the collector side when this is battery is grounded. Then, R c and R L (( )) seen by the collector, they are in parallel. And hence, R c is this and these of course, have been talking. And i b as you know i c by beta, which is same as i b by beta. Now, we replace in this model these models which have developed ac equivalent circuit. We replace this transistor by model, which we developed.

And you will remember that, the model was this, this is the emitter, this is the collector very simple one resistance is there, which is emitter dynamic resistance and this one is the current source (Refer Slide Time: 32:30). And this we a write at when we discuss the transistor. So, now we replace this transistor in the circuit, in this ac equivalent circuit we replace this we will keep of i r B, we will keep r E, we will keep r C and this transistor we replaced by that model.

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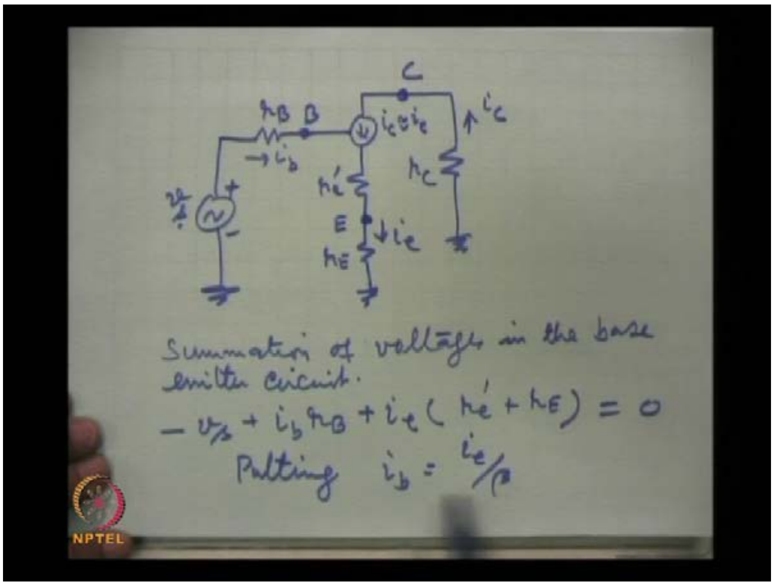

Then, what we get is this, (No audio from 33:08 to 33:30), this is emitter lead, this is collector lead and this is base lead, this is r B, this is r C and this is the dynamic resistance r e prime. And here, this is our ac voltage source v s. So, this is actually the equivalent circuit of this is the transistor, which is being replaced by this and this source is i c or equal to i e.

Here is the current i e, this is the current i c and this is the current i b, these are all ac currents (Refer Slide Time: 34:25). Now, we so I am sure (( )) clear that, how we arrive at this the basic circuit of the amplifier. First we came to the ac equivalent circuit and in the ac equivalent circuit in the ac equivalent circuit we replaced the transistors by its small signal model and we get this.

Now, we are ready to go for the analysis. So, summation of voltages summation of voltages in the base emitter circuit in the base emitter circuit, this results in for example, at any instant we take the polarity like this we start from here. So, we write minus v s plus i b into r B plus i e is flowing here, so i e into r e prime plus r E. These are the two resistances in series, this is r E and this is r e prime that dynamic resistance (Refer Slide Time: 36:02). So, we get this.

Now, in this equation this is equal to 0. Now, putting i b equal to i e by beta actually the base current equal to the collector current by beta, but collector current and emitter current are taken as equal, so this is that. Then, this equations becomes I e by beta r B plus i e r e prime plus r E equal to v s.

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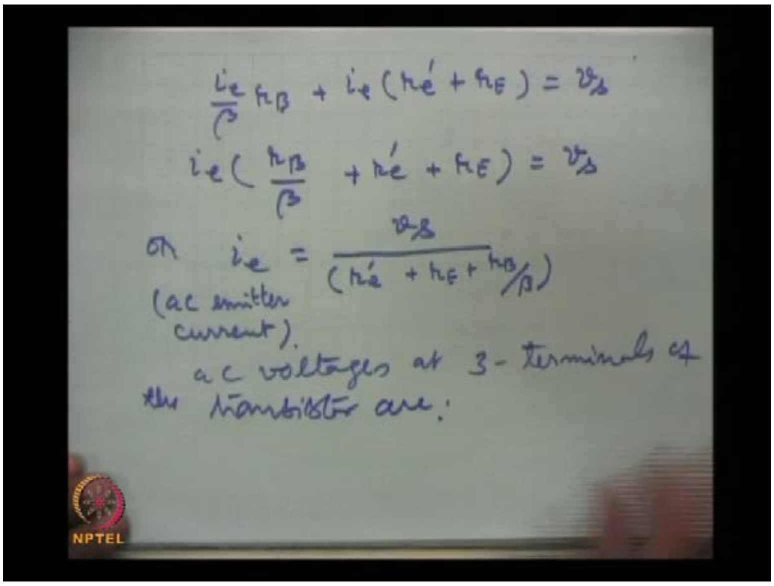

Which can be written as, i e we take out and r B by beta plus r e prime plus r E is equal to v s. Or the emitter current ac emitter current this is I will write this is v s r e prime r E plus r B by beta, this is ac emitter current. Now, we can write ac voltage is at the three terminals, the basic current; if we known i e, we know all the current. We know i c, which is equal to this. We know i b, which is equal to i e by beta; beta as I said in the I said in the beginning (( )) the value of beta for the amplifier.

So, all the currents are known and once we know all the currents we can find out all the ac voltages. So, ac voltages at the three terminal of the transistor are these are, so these equations are v b, which is i e into r e prime plus r E, let us call this equation 1.

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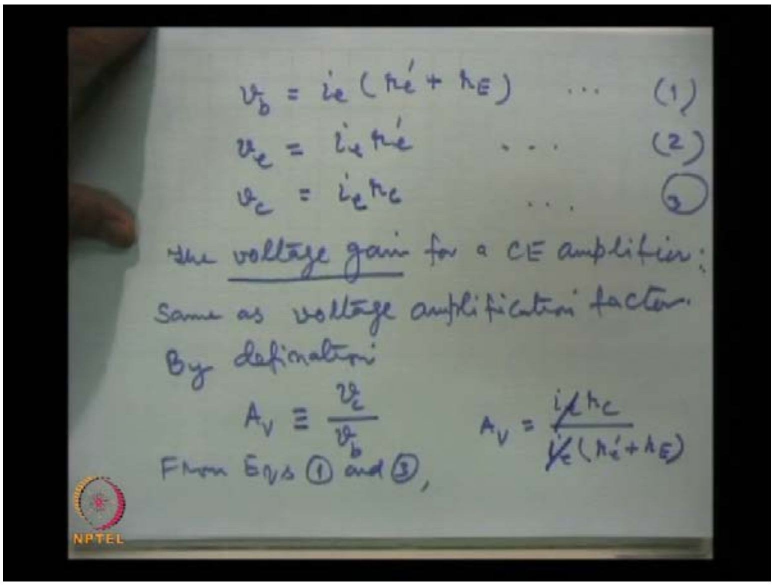

How, what is this v b, the base terminal and ground what is this voltage here, this is v b b between base and ground. Now, these two resistances are in series and the current flowing from here is i e. So, obviously the voltage which we will get will be what I have written, i e into the two resistances in series. And v e is equal to i e r e, this we call this we will be using further, so that is why you should note down these equation numbers also.

What is v e, v e is this voltage here this is plus minus v e the voltage across this is emitter lead and this is the (( )) resistance and this is current is flowing. So, between this end ground will be this voltage actually I am sorry this is not, this is (Refer Slide Time: 40:55), so that is v e. And then, v c the collector current is i c which we can write as i e and r c this i c which is same as i e is flowing through this lead.

Then, what is the voltage which we will observe across this, this is i e into r c. So, these are the three voltages and once we know them, then we find out the value of performance parameters of the amplifier. So, first we write an expression from these equations is very simple to get the voltage gain. The voltage gain for a Common Emitter amplifier C E amplifier, this voltage gain is sometimes called amplification factor voltage amplification factor.

So, this is same as voltage amplification factors same and by the definition by definition this is written of course, as A v. And this is output voltage to the input voltage and you will recall that, output voltage is v c by input voltage is v b. This output voltage and this is v c and input voltage is v b, so this is that (Refer Slide Time: 43:24). Now, value of v c is here, the value of v b is here (Refer Slide Time: 43:35). So, this from equations 1 and 3, this becomes A v equal to v c we substitute as i e r C divided by r i e divided by v b, v b is this r e prime plus r E prime and this get cancelled.

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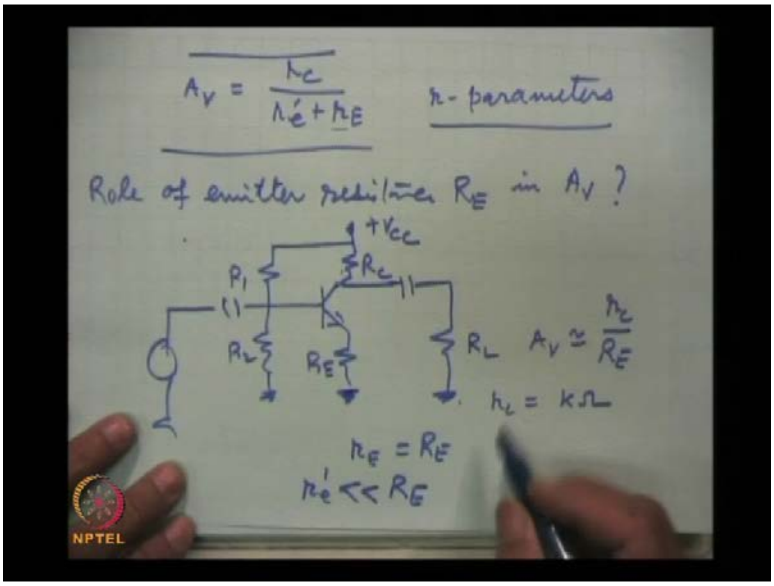

So, this simple expression for the voltage gain r C r e prime plus r E, this is very important, this is the expression for the voltage gain. Now, look at the simplicity of this expression plus these are all resistances, the expression is simple it contains the resistances only and that why it is called r-parameter analysis.

Results are obtained in terms of the resistances and (( )) one more parameter which may be there, that is beta which is we had talked. Now, you know what are these r C r C is this parallel (( )) of the load resistance with the collector resistance. And r E r E is the effective resistance seen by the emitter and this is the emitter dynamic resistance.

So, if we know the values of the three resistances we can immediately and very easily calculate value of the voltage gain. Now, let us consider the some discuss the role of the emitter resistance. The role of emitter resistance R E in the voltage gain often, you look at the original circuit here, suppose we use only one resistance here like this. If I use one resistance here, so that this circuit is becomes this, this is R E R 1 R 2 R C and from here this capacitor another capacitor (Refer Slide Time: 46:57).

Suppose, we use this resistance and we do not by pass it then, what is the influence? In that case, this r E will be equal to R E. And this will be this dynamic resistance is few (( )) only just 10, 15, 20 ohm's. And this will be R E we will be using same 500 ohms 800 ohms 1 kilo, so we can neglect. In this case, r e prime is very small in comparison to the resistance which we are using.

Then, the voltage gain will be close to r C by R E the collector resistance will be also in kilo-ohms 1 or 2 kilo-ohms 3 kilo-ohms and this is also in kilo-ohms. So, the gain will be extremely low, because r C is in kilo-ohms and this will also be almost the same order. So, the gain A v will be low 3 4 5 it will be drastically reduced. But, why we use R E? If R E is made 0 then of course, the gain will increase, because this resistance will be 0 and I come to that, one important thing is that here we have made the voltage gain independent of R E totally, this is known as swamped of the emitter. Emitter has been swamped.

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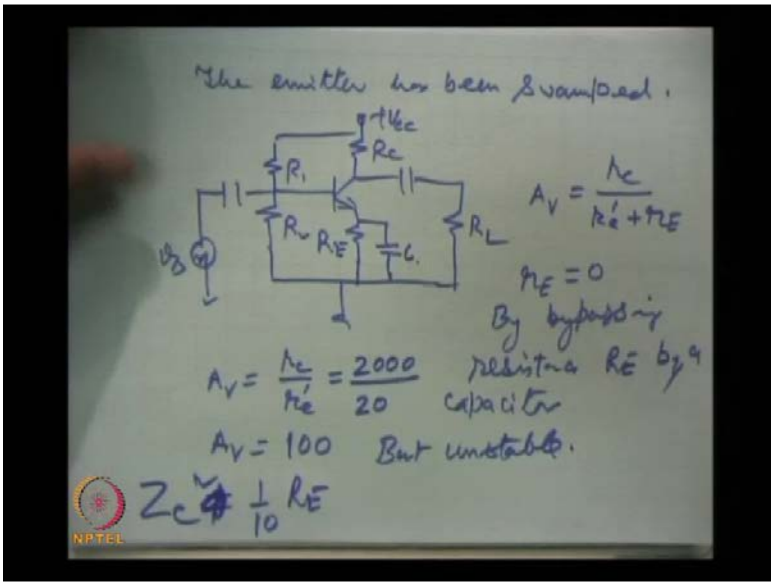

And this process is called swamping. What is swamping? Making the voltage gain independent of r e prime, because r e prime is temperature sensitive as you will recall it was said earlier. So, making their independent of the changes in the value of r e prime, this is known as swamping. We have swamped the emitter, but what praised we have paid that we have the gain is reduced quiet a bit. We will take some example to illustrate this point.

So, what is the other way, other way is that we can by pass the capacitor r E and that case if we by pass it, this circuit become this we by pass it (No audio from 50:50 to 51:14) we have by passed it. And then, original relation was r C by r e prime plus if we by pass then this resistance simply 0, r E has been made equal to 0 by bypassing resistance R E by a capacitor.

We use this capacitor then then we get for voltage gain r C by r e prime but this way actually the gain has become very large, because this is in kilo-ohms. If r C suppose is 2 kiloohms; that means, 2000 ohms and this is 20 ohms, then the voltage gain is 100 it is very high. But this is temperature sensitive; this is will be high, but unstable.

So, if we do not use this by pass capacitor let me talk little more about this by pass capacitor; how we choose the value of bypass capacitor bypass capacitor. What is the purpose? Purpose is ac will find a path of least resistance through this capacitance; this is higher impedance as compared to this.

Now, how high it should be or in other words how low this capacitance should be, this is the thump rule is that the impedance at the lowest frequency signal frequency should be one-tenth. The impedance Z c should be one-tenth approximately should be one-tenth of R E, this is the thump rule. So, we choose this like that. And but then, it becomes unstable.

So, there is intermediate position, which is often taken the designer will make the circuit, which from where we started that one resistance is maintained in the circuit and one part is bypassed. So, this will be best compromise, this will be smaller resistance than this and this will be this best part. So, (( )) will not be as low as in the case of not bypassed, and it will not be unstable, because of the effect of dynamic resistance. So, as a compromise we break that resistance R E into two resistances; a small resistance, a little higher resistance and this higher one is blocked. So, we will continue this analysis further.