Analog Electronic Circuits
Prof. Pradip Mandal
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology, Kharagpur

Lecture – 99
Applications of Feedback in Amplifier Circuits (Part-C)

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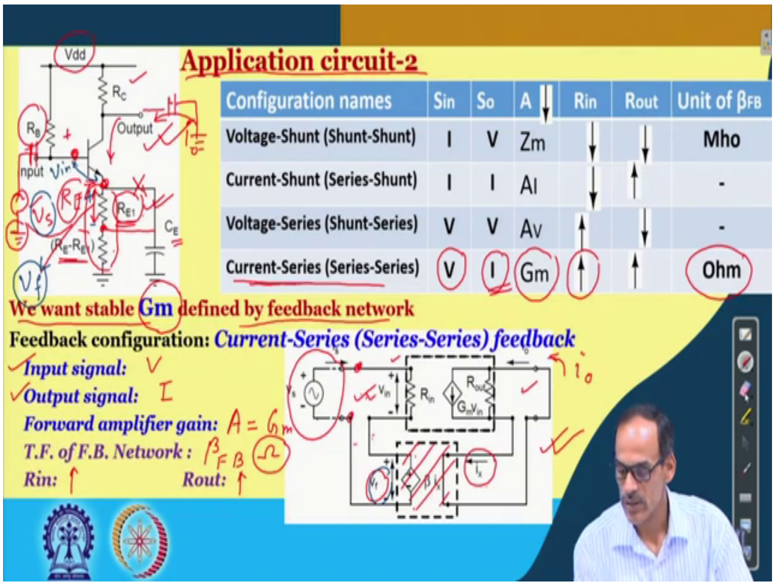

Welcome back after the break into our Analog Electronic Circuits NPTEL course. So, we are talking about Application of Feedback Circuit and in the circuit 1 we have seen voltage shunt feedback and now we do have the second example and we do have the circuit given here.

So, the main circuit it is given here and the along with this we do have an intention to get Gm trans conductance of the circuit defined by feedback network. So, if I consider this Gm, if we see the Gm in the this summary table of feedback effect, what we can see here it is suggests that we need to have current series feedback or series series feedback. And for series series feedback, what we have the input signal, it is voltage and the output signal it is current.

So, we can say that input signal it is voltage and then output signal it is current and then forward amplifier gain it is transconductance amplifier. So, I should say A equals to Gm and the transfer function of the feedback network beta FB which converts the output signal into input signal of voltage which means that it is unit it is ohm.

So, here also from the table we can see that unit of the feedback network it is ohm and what we can say that while we are making this circuit, it is anticipated that the input resistance it will increase and also the output resistance it will increase. And here we do have the model of the on a feedback circuit where we can see that at the sampling point we do have series connection and the mixing point also we do have the voltage mixing in series. And this is the primary input and the primary output here it is the current through the circuit which is we may call it is i o.

Now, while we do have the main amplifier where R B it is the providing the base bias arrangement and then the resister here at the emitter. So, this is R E and then we do have the collector resistors R C along with the supply voltage and here we do have the provision of the feeding the signal, but we like to keep the signal of course, it will be in voltage, but then while we are feeding the signal it should be through coupling capacitor. So, that the DC operating point of the amplifier should not get disturbed by the DC voltage at the input.

And while we will be observing the output, output it is as I said that it is in the form of current. So, to get a current here what we can say it is we can connect a capacitor to ground and then we can see how much the current it is flowing through this circuit which is referred as i o. Now while we are planning for current series feedback so, we want this I o should be flowing through a resistor and that resistor supposed to develop a voltage and that voltage it should be coming to the input port along with the main source here v s.

So, if you look into this model given here, the developed R f sorry, V f voltage which is equal to the output current hm. In fact, i o it is same as i x while it is flowing through this feedback circuit feedback network it is developing a voltage here and that voltage need to be mixed here.

So, if I correlate the input port of the model here we do have positive side. So, this is the positive side here of the input voltage, negative side we do have at the emitter. So, we do have the negative side and then we do have the voltage coming here with respect to the negative terminal of the source voltage; which means that we like to give a signal here with respect to this ground.

So, we like to have a signal here. So, what we can do? This emitter resistor total emitter resistor you can split into two elements; so, one is R E 1 and then rest of the things it is here which is R E minus RE 1 and then instead of connecting this C E bypass capacitor at the emitter we can connect it here. So, instead of connecting the C E here you can connect at the middle of this resistor keeping R E 1 and bypassed and then rest of the things which is RE minus RE 1 bypassed.

So, for small signal model we can say that this un bypassed resistor, it is developing a signal voltage across it while the i o current it is flowing through collector to emitter and eventually it is flowing through R E also. So, the developed voltage here developed voltage here let me use different colour here. So, the developed voltage here you may call it is v f.

So, this is the v f voltage we may say that this is plus side and this is minus side. So, this v f it is getting mixed with v s to produce the input voltage v in here. So, let me clear and then again summarize it.

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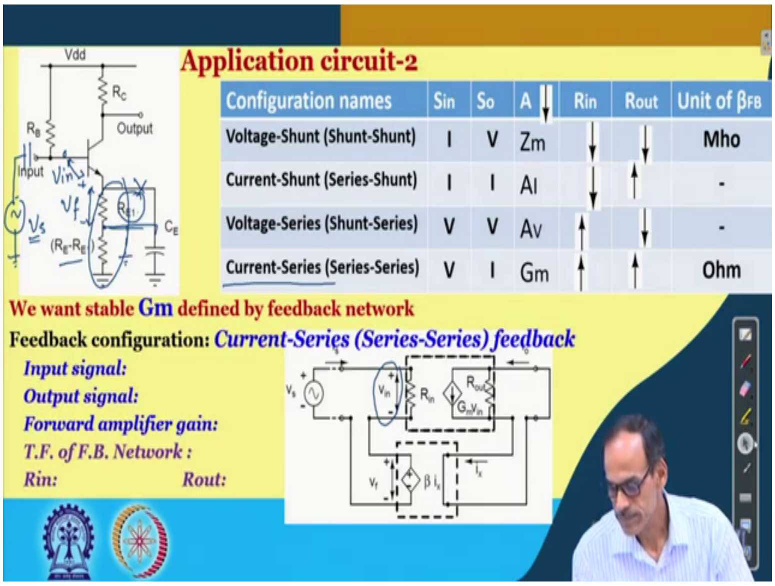

So, what we said is we do have primary input signal here, we call it is v s and then the voltage getting developed here across this R E 1 called v f particularly if we connect the bypass capacitor here instead of this node and of course, this will be AC ground and. So, this is the v f part and then from base to a emitter we do have the input voltage v in.

Eventually this is vbe of the transistor, but here in terms of a model we can say that this is input voltage going to the amplifier. So, this v s and v f it is developing the or generating the v in or preparing this v in for the amplifier to get the signal.

So, to implement the corresponding feedback here the series series feedback here what we have to simply do it is that you have to partially bypassed this R E only R E 1 it will rather only R E minus R E 1 it will be bypassed and R E 1 it will be working as feedback a network.

So, in in a next slide, we will continue with this circuit and then we will go for the corresponding analysis.

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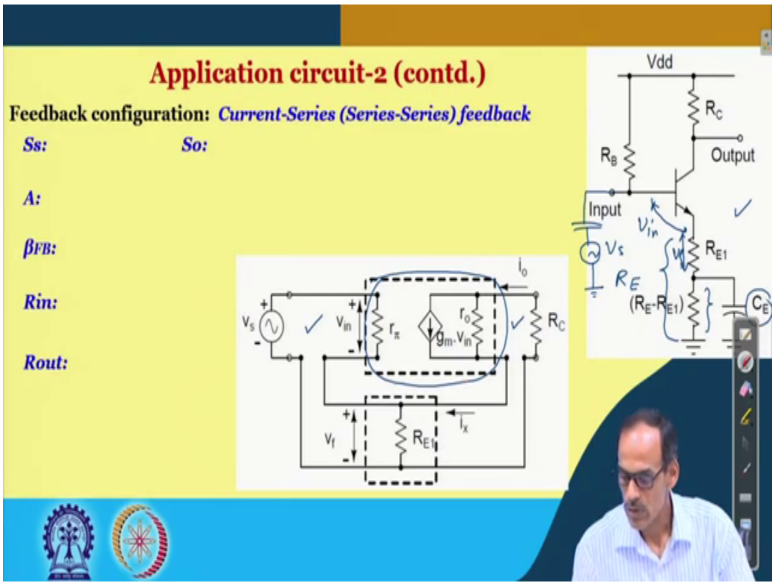

So, here we do have the circuit given we do have the circuit given here and what we have as I said that out of this total R E this part it is getting bypassed by C E and the remaining portion this R E 1 it is working as feedback element developing a voltage v f and of course, we are going to feed the signal here v s and this is the voltage we can say this is the input voltage going to the circuit.

So, this is the corresponding model of this circuit and as you can see it is having series sampling and then series mixing circuit and then also we do have the amplifier circuit here and it is parameters are given in terms of a small signal parameter of the transistor. So, let me explain that how we obtain this model. So, let me again clear yeah.

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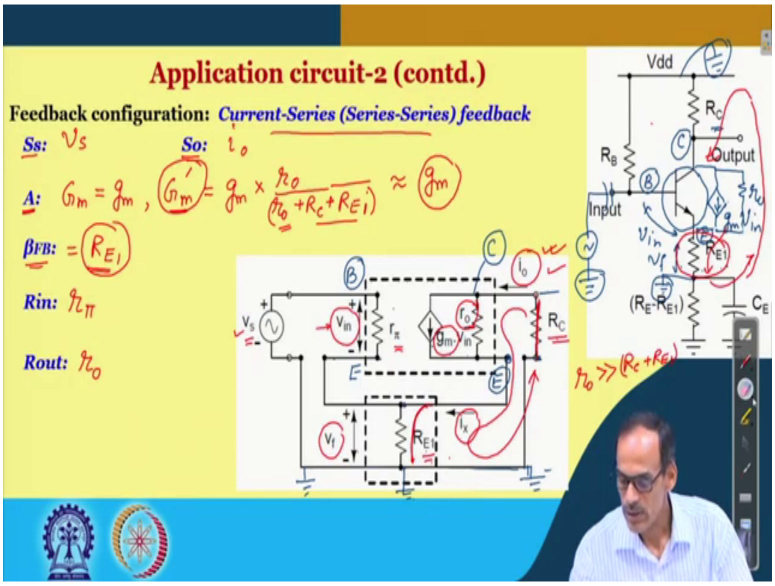

So, if I consider this transistor and if I draw the small signal model, what we have it is Gm into vbe and this vbe it is eventually v in. So, this is v in along with that we do have the resistor r naught and this is the output node, the collector node it is the output node. So, we can see that this node it is collector which is eventually the positive side of the output port.

And then we do have the R C the bias resistor R C it is connected to DC voltage which is for signal wise it is AC ground. So, the other end of the R C it is connected here which is, we should say it is ground and. So, this not an equivalent circuit it is given here Gm into v in is the current source voltage dependent current source and r o is the resistance inherent resistance of the transistor and then from base to emitter.

So, base to emitter we do have r pi here. So, this is base terminal and this is emitter terminal this is of course, this is emitter terminal if I look into the device so in fact, this is this node and this node they are same and at the emitter terminal we do have R E 1 and through which the current is flowing. So, from emitter to ground or this AC ground here so, this AC ground node it is shown here. So, for small signal this is ground, this is also ground, this is also ground. So, this ground is the ground or the signal source or negative terminal of the signal source.

So, we do have this ground, this ground and this ground, they are a shown here. Now this the R E 1 it is as I said that it is generating a voltage which we call it is v f. So, the output current it is flowing. So, let me use different colour here to miss show you the flow of the current.

So, the current it is essentially flowing through this circuit and that current is flowing here and this is ground and again it is going back. So, we can see that in the model we can see that the flow of the current it is in this direction. And the voltage drop across this one it is v f it is getting mixed with v s to develop this v in. So, now, I think we can fairly correlate the actual circuit and the corresponding feedback circuit a model or the model of the specific configuration.

Now the primary input in this case Ss is v s here and S o in this model it is output current i o and the A the circuit gain it is basically in this case it is Gm. And Gm if you see it is eventually this is same as gm of the transistor trans conductance of the transistor. Ideally, we want this port should be unloaded and since the signal here it is current, it supposed to be theoretically should be short. In fact, here also we need to be having a short, but we do have practically we do have R C and R E 1.

So, now, if you if you see the output internal output resistance r o it is much higher than R C and this R E together. So, as a result you can all practical purposes if the internal resistance is r o you may say that the circuit is really not getting loaded. In other words if I consider the loading effect and if I say that what may be the expression of Gm dashed; that means, what may be the current here in terms of v in to get the corresponding Gm it can be easily shown that this is the inherent gm multiplied by the factor which is coming due to the current bifurcation.

And this current bifurcation is expression of the attenuation factor due to the current bifurcation it can be expressed in terms of r o divided by r o in series with R C and R E 1 ok. So, yeah. So, assuming that this resistance the input input resistance we are not considering, but once you consider that resistance of course, that resistance it will come in parallel with R E 1 also. But, anyway this resistance it is much higher than rest of the things. So, you can approximate this by again gm.

So, in summary we can say that Gm dashed it is also it can be well approximated by gm. Input resistance of the circuit it is of course, r pi of the transistor and then r out of the circuit main amplifier it is r o. And then, what is the feedback factor? The which converts the signal the current signal into voltage it is it is equal to R E 1, the un bypassed part of the R E. So, with this information now we can go for finding appropriate value or range of this R E 1. So, that probably we can intuitively explain the effectiveness of the feedback circuit.

So, in the next slide, we are going to see what may be the guidelines to find the range of this RE 1 or rather the portion of R E which need to be un bypassed show that the feedback configuration it is really working as a series series feedback and it is formula can be utilized.

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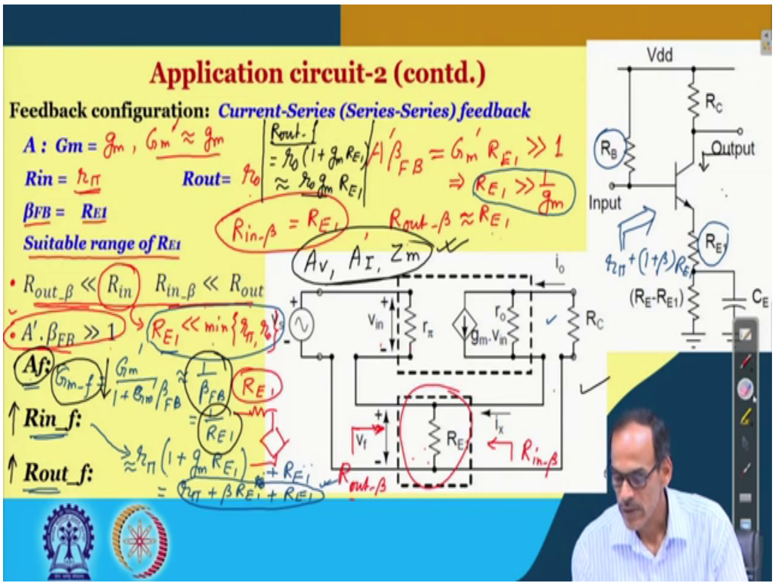

So, in the next slide we are going to discuss about the range yeah. So, quickly we can say that this Gm it was gm of the transistor. In fact, Gm dashed also we said it is well approximated by gm of the transistor and R in it is r pi, R out it is r o. And of course, beta FB it is R E 1. Now to find the suitable range of R E 1, we need to consider this three conditions which gives us that the magnitude of the loop gain it is much higher than 1 and then here the loading effect of the input resistance of the feedback feedback network sorry, output resistance of the feedback network we can compare with input resistance of the circuit and on the to avoid the loading effect of the input resistance on the feedback network.

On the other hand if I consider this condition it is it is suggesting that if you follow this one then loading effect of R in of the feedback network, R in beta it can be ignored. So, and and of course, this is R out beta and if you look into say this network and it is very simple network. So, it is easy to see that R in beta it is nothing but R E 1. In fact, R out beta it is also equals to. So, this is also equal to R E 1.

In fact, so, whenever we look into the output port of the feedback network it works as a voltage source and this voltage source it is having a Thevenin equivalent resistance and this resistance it is R E 1 and that is what the output resistance of the feedback network.

So, if I know this R in beta and R out beta they are approximately equal to R E 1. And in addition to that if I know the R in it is r pi and R out it is r naught. So, from that we can say ha that R E 1 should be much less than minimum of the two; r pi and r o all right. So, these two conditions it is giving us upper limit of R E 1. On the other hand if I consider this condition which is giving me that. So, A dashed, A dashed it is A dashed it is Gm dashed Gm dashed and this is R E 1.

So, this need to be much higher than 1 and so, this gives me R E 1 need to be higher than much higher than 1 by gm. So, in summary we can say that yeah in summary we can say that this is giving me lower limit of R E 1 and this is giving me the upper limit of R E 1.

So, from these two we can say that if we set the R E 1 satisfying both the conditions then, we can directly use the feedback formula namely, A f which is Gm of the feedback system it is equal to Gm dashed divided by 1 plus Gm dashed into beta FB. And this is approximately equal to 1 by beta FB and that is equal to 1 by R E 1.

So, and also then input resistance we can see that this is input resistance it is getting increased original input resistance it is r pi. So, that is getting increased by the desensitization factor which is 1 plus A dashed into beta. So, this is equal to g m into R E 1. In fact, this is of course, it is good approximation strictly speaking the actual expression of R in f you if you directly analyse this circuit we do get an expression which is very close to this. In fact, that is having also one more term plus R E 1.

But all practical purposes you may ignore this part and so, this part it is giving r pi plus beta into R E 1, if we ignore this part. And if you consider this part, then of course, we will be having one more small entity and hence if you are constructing this circuit namely if you keep this portion un bypassed the input resistance of the main circuit excluding of course, the bias circuit the input resistance it will be r pi plus one plus beta into un bypassed R E.

So, this is very much consistent to with whatever we know. So, we can correlate the direct analysis and the feedback circuit analysis. Now on the other hand output resistance of the feedback system since it is a series connection it is expected that the output resistance we will also increase by this factor. So, let me use different colour here yeah I do have this option yeah. So, let me use this space for R out f. So, R out f it is equal to the original r o multiplied by 1 plus A into beta which is g m into R E 1.

So, this also I know the we know that the output resistance looking into this circuit it is quite high and this can be well approximated by this r naught into gm that is the intrinsic gain of the transistor multiplied by the un bypassed R E. So, that again correlates that if you directly analyse this circuit whatever the output resistance you do get it is consistent with the feedback theory.

So, now let us look into we can use this circuit and then we can go for a numerical example, but before that while we are making this connection we know that Gm got decreased and the corresponding Gm it is becoming 1 by this un bypassed R E 1 along with this we also like to know the information about the other parameter or we can say the change in other parameters namely, the voltage gain, current gain and also maybe trans impedance of the circuit.

So, in the next slide what we can do, we can look back the summary table as we have discussed in our previous lecture. So, let we let we discuss about what kind of effect do we expect here, but then you have to keep in mind that in this feedback both or rather all of them rather A f or Gm f it is getting decreased and both input resistance and output resistance are getting increased by the common factor desensitization factor.

So, with this information let us I will see you what kind of changes do you use observe in voltage gain and current gain and trans impedance.

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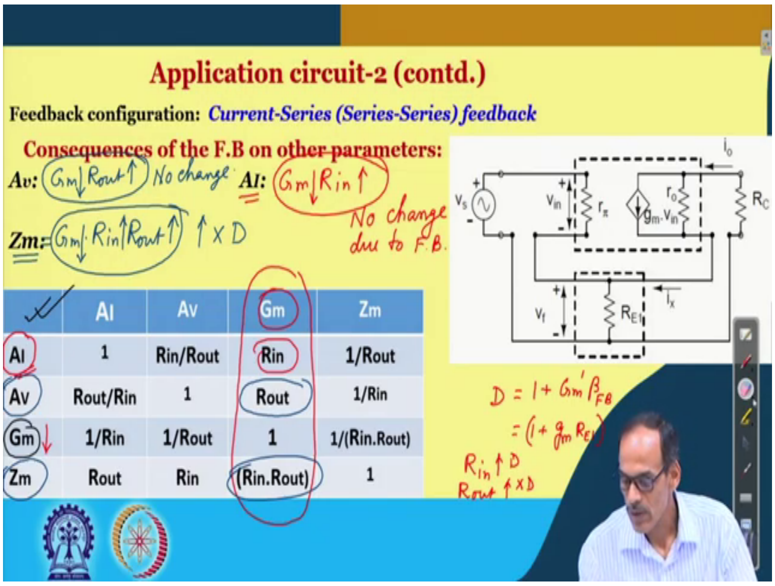

So, yeah. So, here we do have the table and so, this table it is it will be helping us to see what kind of changes so we do get. In fact, we are making this Gm getting reduced by a factor of that desensitization. So, this is getting decreased by 1 plus so, D is equal to 1 plus Gm into beta FB and this is 1 plus gm into R E 1 un bypassed R E. And also we know that input resistance getting increased by this factor, output resistance it is also getting increased by the same factor D.

Now if I want to see what kind of changes do you expect or do you see for a current gain then, we have to look into the expression of the current gain in terms of gm. And this column gives us the corresponding expression. So, AI it is gm multiplied by R in. So, we can say that the current gain it is Gm into R in. And note that this is true for the circuit before and after the feedback connection and we know that Gm it got decreased and R in it got increased by the same factor.

So, as a result if I combine this two effect, then we can see that there will not be any change. So, no change due to feedback all right. Likewise, if I consider the if I consider the voltage gain and if I see the expression of the voltage gain from here which is Gm times R out. So, A v equals to gm times R out and here again Gm it is decreased by desensitization factor on the other hand output resistance got increased by the same factor D. So, altogether they are getting cancelled and hence no change.

On the other hand, if I consider Z m and it is expression can be obtained from this column; namely, it is Gm; so, Z m equals to trance impedance Z m is equal to Gm into R in multiplied by R out. And due to the feedback connection Gm got decreased R in got increased and R out also got increase.

So, altogether we can see whole thing it is getting increased by a factor of desensitization. So, we can say that Z m it is getting increased. So, that gives us the overall consequences of the different parameters due to the feedback connection. Now let we go into a numerical example. So, so, we do have a numerical example yeah.

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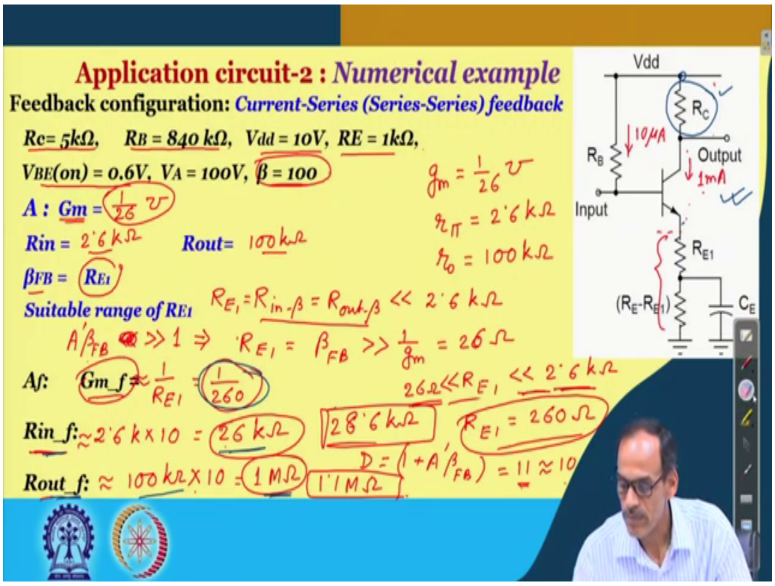

Yeah So, here we do have the numerical example, what we have here it is the circuit is given here and value of different bias circuits are enlisted; namely, R C it is 5 k R B it is 4 sorry 840 k, supply voltage it is 10 volt, R E; the total resistor it is 1 k, base to emitter on voltage it is 0.6 and beta is 100. So, if you consider this parameters we can say that the bias current here it is 10 micro ampere.

And because of the beta 100 the corresponding collector current it is 1 milli ampere and then yeah. So, the drop across this one it is 1 volt and drop across this RC it is 5 volts so, we do have 4 volts. So, the device it is in active region of operation. So, it is really working as a good amplifier.

Now, with 1 milliampere of current gm of the transistor it is 1 by 26 mho and r pi on the other hand which is beta divided by gm. So, that is equal to 2.6 kilo ohm and then r naught it is early voltage 100 divided by 1 milliampere so, that gives us 100 kilo ohm.

So, with this information we can directly say that Gm or Gm dashed it is approximately equal to 1 by 26 mho, R in it is 2.6 k R out it is 100 k and the feedback factor R E 1 we need to find. So, to get this value here again we may recall that different conditions and what are the conditions we do have? The R in beta which is also equal to R out beta need to be much less than minimum of this two; so, this should be much less than 2.6 kilo ohm and so, these two are essentially R E 1 right.

And the on the other hand the lower limit for R E 1 it is coming from A dashed beta FB should be much less than sorry, much higher than 1, which means that this beta FB which is also equal to R E 1. So, this beta FB should be much higher than 1 by on A dashed which is Gm dashed and this is 1 by Gm and this is equal to 26 ohms. So, in summary we can say that the suitable range of R E 1 it is it should be well within sorry, this is 26, 26 ohms to 2.6 kilo ohm.

Now, whenever we do have this requirement much less or much greater then at least we can say it is better to have one order of magnitude lower or higher. So, based on these two conditions; we may say that we can select say R E 1 equals to 260 ohms, satisfying both these two conditions.

And if you take this R E 1 equals to 260, then Gm f it will be 1 by R E 1 it can be well approximated by 1 by R E 1 which is equal to 1 by 260. In fact, if you see the desensitization factor D which is 1 plus A into beta FB and if I put the value of this beta FB of say 260. So, this is equal to 11, you may say that this is approximately equal to 10.

So, we can see that Gm, Gm of this one it is getting reduced by A factor of 10. Likewise the input resistance it is getting increased. So, that is equal to 2.6 k multiplied by this desensitization factor approximately 10. So, this is equal to 26 kilo to be more precise it should be multiplied by 11. So, instead of 26 to be more precise we can say that 28.6 kilo ohm.

And then the output resistance on the other hand it is approximately so, this is 100 k multiplied by desensitisation factor. So, that gives us 1 mega ohms or if I put the D equals to 11. So, that gives us 1.1 mega ohm. So, in summary what we can say here it is due to the feedback connection, trans conductance it is 1 by 1 by 260 instead of 1 by 26. Input resistance it got increased to 26 k from 2.6 and R out rather output resistance instead of 100 k it is now it is 1 mega ohm.

So, you might have observed one thing that while we are doing this analysis we are keeping this R C outside of this circuit and that is very obvious that if you really want to take this R C to be inside the circuit the other end here it need to be connected here then only you can consider R C it is part of the current source.

So, in this configuration; we have to keep the R C outside of the amplifier otherwise the analysis it will be it is possible, but it will get really fairly complicated. Now coming to what are the consequences on the other parameter namely the voltage gain and current gain and trans impedance as we have discussed that we are anticipating that the voltage gain and current gain will not be having change. And, however; trans impedance will be having a change rather trans impedance it will increase. But we like to add something to that. So, let us go into the next slide to discuss the one very important point.

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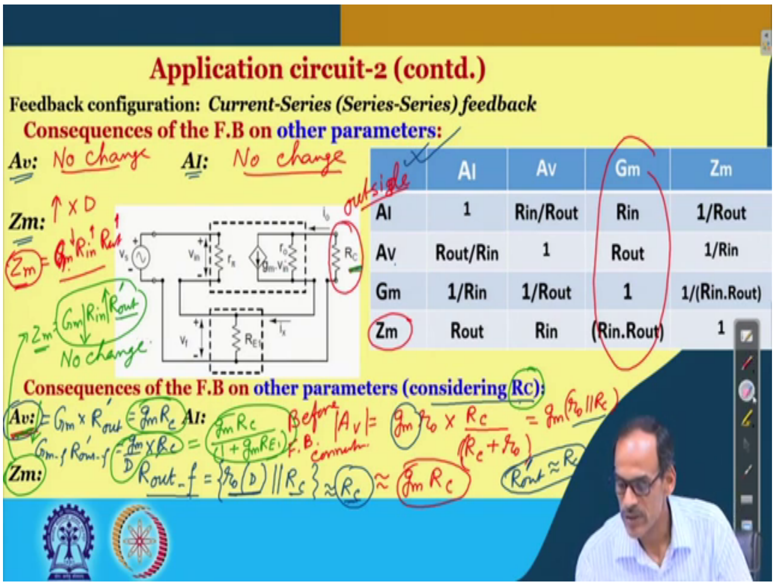

So, yeah. So, again we can to understand what kind of changes it will be there in voltage gain and the current gain and the transimpedance. We refer back to this relationship table, the let me change the colour of this. So, we do have yeah so, we do have as I said that we are anticipating that the voltage gain and current gain will not be having any change and this will be getting increased by desensitisation factor D.

And trans impedance if you see. So, if you see this column . So, trans impedance of course, it is Gm. So, Z m initially it was gm into R in into R out and gm with the feedback connection this gm it is that circuit gm capital Gm I should write. So, circuit Gm it got decreased, this got increased and this got increased. So, as a results the whole thing namely Zm got increased by a factor of d which is equal to 1 or approximately 10.

And this is this result or this observation definitely you will be able to see only when you consider this R C it remaining outside. We can say that if I consider this is remaining outside or if I am consider it is external load then you will be getting this situation.

Now, if I consider this is part of the amplifier and then if I try to see what kind of changes do you expect in the voltage gain particularly what you will be getting here before we make the feedback connection, the voltage gain it is equal to gm into r naught, if I consider magnitude of the voltage gain gm into r naught multiplied by the loading effect which is equal to loading effect due to RC . And so, the loading effect or factor it is R C divided by RC plus the output resistance r o.

So, this is the expression of the voltage gain before we connect the circuit in feedback configuration. In fact, this can be written in this form gm into r o in parallel with R C and all practical purposes you can approximate this by gm into R C. As you can see that numerical value wise R C it is 5 k and r naught it is on the other hand 100 k. So, definitely this is what you can expect.

Now this is before we connect feedback, feedback connection. Now after we make the feedback connection what do we expect it is the following. So, the gm it got changed . So, also the output resistance got changed. So, if I say that R out in this case with R C it is r it is approximately R C on the other hand with feedback this is equal to r naught got increased by the desensitization factor.

Now along with this R out of the feedback system if I consider R C coming into the loading then the corresponding R out we can say R out f dashed is equal to r o multiplied by D in parallel with R C. So, if I consider this resistance in parallel with R C, this can be well approximated by r c.

So, what we can say that if I include, if I include this R C within the circuit to get the voltage gain not for gm, but for voltage gain. What we can see that this R out initially it was rather R out dashed, R out dashed it was initially R C and R out f dashed it is also remaining R C, which means that the R out if I considered this R C within the circuit rather R out dashed it is not really changing, it is remaining to R C.

As a result if I see the voltage gain and it is expression it is Gm and then if I consider R C into it so, R out dashed. So, this is equal to gm into R C. And after the feedback connection then we do have Gm f then R out f dashed is equal to g m divided by D into R C. So, as a result what we can see here; interestingly, what we can observe here is that the voltage gain it is actually it is getting changed from gm into R C to gm into R C divided by D.

So, this is this is the situation when you consider R C into the picture which means that the gain it is voltage gain it is dropping to this. In fact, this is what we know it is gm into R C divided by 1 plus gm into R E 1 all right. So, this is what we know.

So, if I do not consider R C into the circuit then we claim that the voltage gain it was not changing, but we know that the voltage gain of the common emitter amplifier it is it is dropping particularly in presence of un bypassed R E 1. In fact, similar kind of conclusion you can also find for Zm , but so, as I said that expression of the Z m it is it is Gm into R in into R out.

Now if I consider R C into the consideration then we have to consider R out dashed. And what I said is that Gm it is getting decreased by the feedback R ins circuit R in got increased, but then R out dashed it is not changing. So, overall the Z m, if I consider R C into the consideration it is not having any change. So, in summary let me clear and then let me write this summary if I consider R C yeah if I consider this R C .

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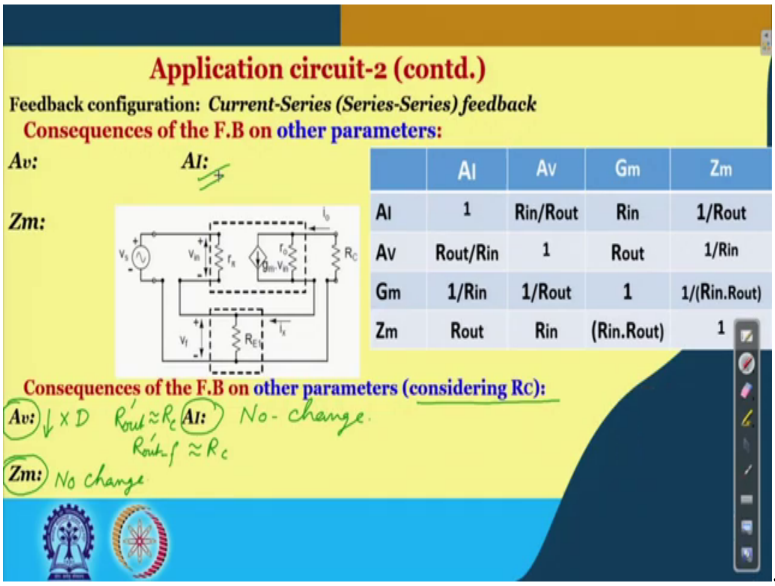

Then we can say that the voltage gain it is getting reduced by D all practical purposes that short it will happen, mainly because R out dashed it is approximately R C, R out f dashed it is also equal to R C. On the other hand Z m it is remaining unchanged, no change and on the other hand of course, the current gain it is not having any change, similar to whatever we have seen here yeah. So, let me take again short break and then we will come back to another example and there we will see how we can handle multiple loops in a circuit ok.