Microelectronics: Devices to Circuits

Professor Sudeb Dasgupta
Department of Electronics and Communication Engineering
Indian Institute of Technology, Roorkee

Lecture 47

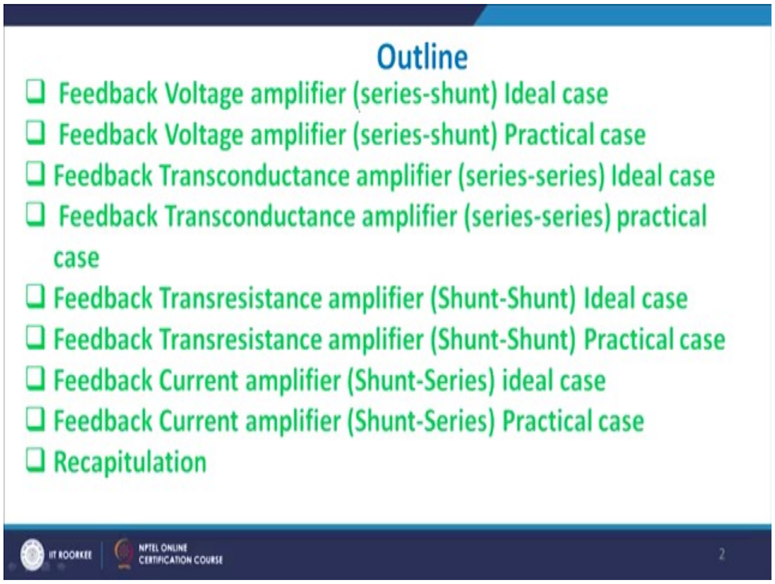
Design of Feedback Amplifier for all Configuration

Hello everybody and welcome to the next edition of NPTEL online course on Microelectronics Devices to Circuits. Today we will look into the design of feedback amplifiers against configuration various configurations of the feedback amplifier. In our previous module we had looked into the fact that what is a negative feedback? How does a negative feedback work? What are the criteria for the multiplication of A and β which is basically the forward feed forward amplifier and β which is basically my feedback ratio so that I am able to achieve a value of negative feedback.

And we saw that when Aβ is greater than 1 we will automatically get a lower gain. The advantage of a negative feedback we get a higher bandwidth, we get a less distortion nonlinear distortion. We also have a much more stabilized gain in the output side. And these were the few advantages which we saw. We also saw in our previous term that when you do have those configurations of series shunt or shunt series network we generally are able to modify our input impedance and output impedance of an amplifier.

And the advantage of such therefore negative feedback is that I am able to therefore have my output impedance change with various configurations. Now, since the amplifier output drives the extensive load and the load will be varying load, I can therefore match the output impedance of the amplifier with the load itself for the maximum power to be transferred. And I can use, how can I do that, by applying various configurations of negative feedback. So, we have learnt 4 series shunt, series series, shunt series and shunt shunt, right? And we have seen how the input impedance and the output impedance change.

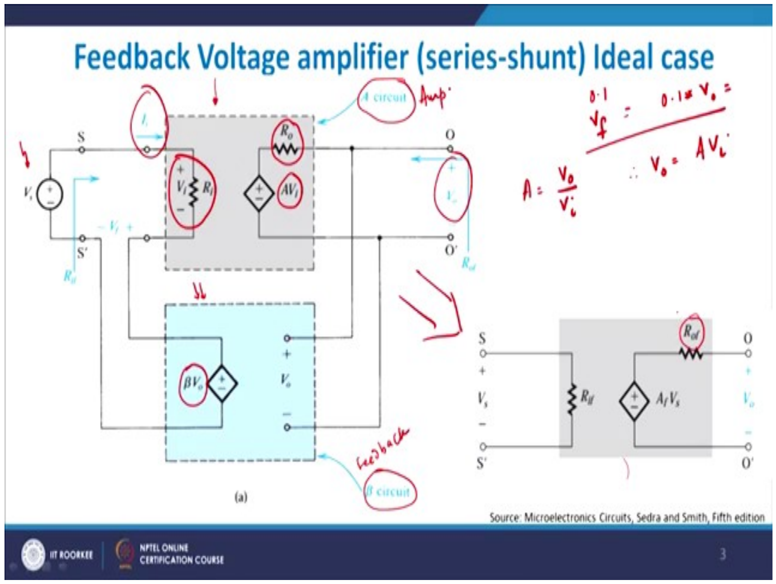
(Refer Slide Time: 2:31)



Today we will the topic today's topic is basically by feedback voltage amplifier. So, we look at ideal case of a series shunt amplifier, right? And then we will look into a practical case of ideal of the series series shunt. Then, we will look into an ideal and real case of series series feedback network, right? So, we will look into series series feedback. We will also look into shunt shunt case. So, for all the cases we will look into ideal case ideal case when you do not have any loading, right?

Which means that your feedback network does not load your amplifier and your amplifier does not load your feedback network and there are 2 independent entities that we have assumed. In the second case we will take a practical amplifier; we assume that there is a loading effect coming into picture. So, we have all the 4 amplifier voltage amplifier, current amplifier, transconductance amplifier and transresistance amplifier for ideal case as well as the real cases.

(Refer Slide Time: 3:32)



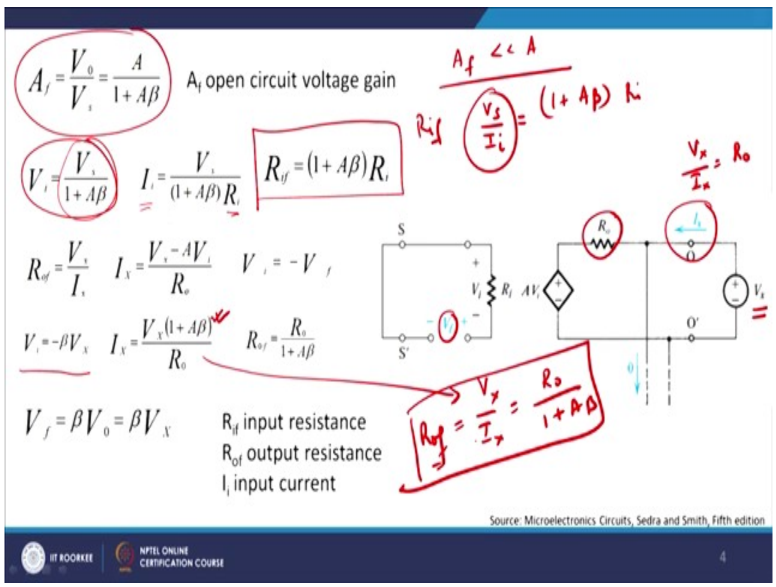
So, let us look at the feedback voltage amplifier. This basically is series shunt and let me let me show you the series shunt feedback network here. As you can see here this part which is basically my dotted part here is basically the amplifier. So, this is the A circuit when I say it is basically your amplifier circuit and the blue one is basically my β circuit, which is basically my feedback circuit. So, this is my feedback circuit, right? And this is my amplifier circuit, right? So, amplifier is a feed forward and this is basically my feedback.

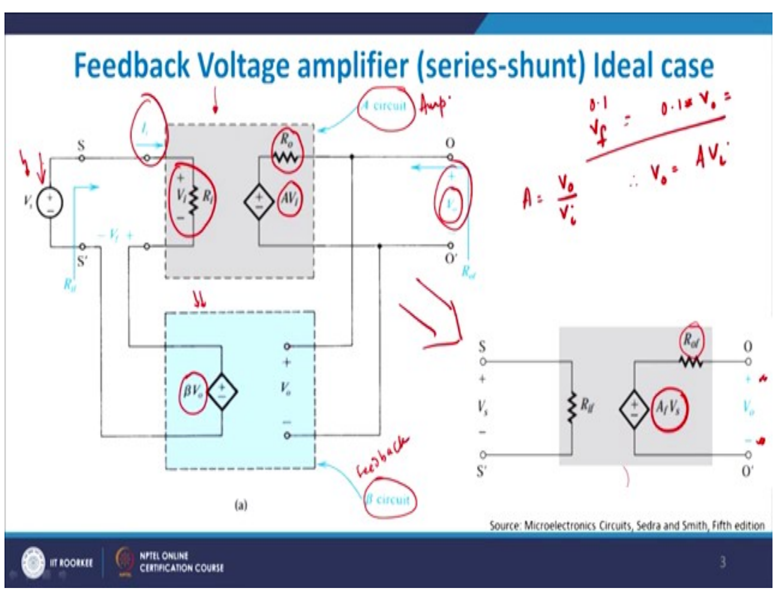
Now, this is series shunt which means that I will be extracting voltage from the output and feeding it in the form of current in input side. So, the input side will be input current here, right? And you have an output voltage which is V_0. At this V_0 therefore appears here, right? And a part of V_0 appears as a voltage source in the output feedback network. So, say your β is equal to 0.1. It primarily means that 0.1*V_0 will be your output voltage here of this network, right? of this network. So, your V_f will be equal to 0.1* V_0.

And as a result this is how we will generate the feedback ratio. V_i is basically V_s is the source voltage which you see out of which a particular voltage V_i appears here depending upon the value of R_i which is input resistance of the amplifier. Now, typically if it is voltage gain $A=V_o/V_i$, right? And therefore, $V_o = A V_i$. That is what is written here A* V_i which you see. You also have a output impedance of the voltage source here and therefore, that maintains and the output side, right?

And depending on the value of β and A_0 we will see how it works out. So, therefore we can converge into this factor in order to get this form that I have a source voltage which terminates onto R_{if} which is basically my input resistance with feedback. I have a output resistance with feedback R_{of} f suffix means feedback. And my voltage gain is given as A_f * V_s, right? And my input voltage will be given by V_0 here; it is given by V_0 here.

(Refer Slide Time: 6:05)





So, with knowledge or this basic idea let me show to you how I am calculating the R_{of} and R_{if}. Now, we know that A_f will be equal to V_0/ V_s, right? A_f means that amplifier gain with feedback, right? Amplifier gain with feedback primarily basically it effectively means that that I am trying to look at this voltage divided by this voltage, right? And that is what we are trying to find out when we say A_f. And if you if you solve it you get A/(1 + Aβ) which we have already earlier also and we saw that A_f therefore is always less than A, right? Therefore, there is a drop in the gain.

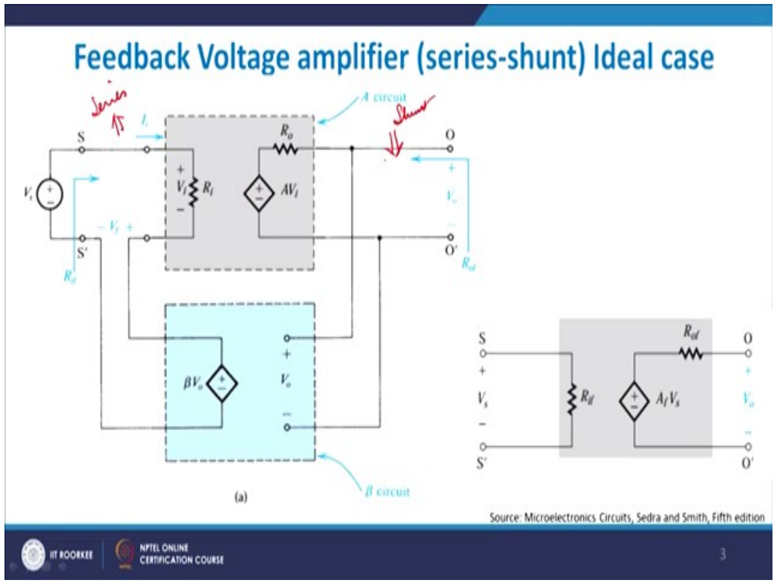
Now you see V_i will be equals to V_s / (1+Aβ). From where did you get this V_i, V_s / (1+Aβ) is basically that so what is V_i is the input voltage. Where is the input voltage actually referring to? Input voltage is basically this voltage which you see, right? So, I am looking at V_i / V_s this by this will nothing but be a voltage divided network and I get V_s / (1+Aβ). Therefore, if you want to find the input current, you have to divide this whole quantity by R_i. That is what I am doing here.

Now, so therefore, if you look very carefully if you transfer this to right hand side I get V_s / Ii is basically equals to (1+Aβ)*R_i. This is nothing but R_{if}. So, R_{if} equals to (1+Aβ) * R_i which means that input impedance rises with feedback. Look at the output impedance. How do you find output impedance is very simple. You try to short the input and give a feedback voltage here and then apply a source voltage V_x at the output side and try to find out the current. V_x/I_x will be equals to R_o, right?

And with respect to feedback I will get the value of ro. So, I write V_i is equal to - β * V_x. Why this why there is a negative sign? Because you are doing a feedback. So, a part of V_x appears as V_i input side - β *V_x. So, if I want to find I_x which is the current flowing through this R. This this current I want to find out. Then this will be nothing and V_x is the voltage divided by R_o which is this 1, right into (1+Aβ), right? Into (1+Aβ). And therefore, if you want to find out you will get so this equation you will get basically V_x / I_x will be equal to R_o / (1+Aβ).

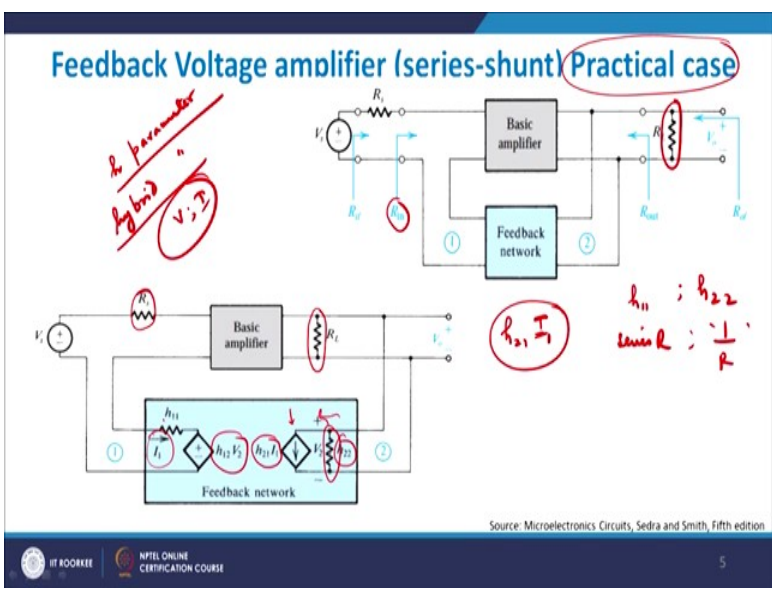
And this is nothing but R_{of}. So, I get R_{of} is equal to R_o / (1+Aβ) which means the output impedance which we feedback falls down by falls back to the (1+Aβ). But my input impedance rises by a factor of (1+Aβ). So, my input impedance rises and output impedance falls down. You can see it physically also.

(Refer Slide Time: 8:52)



Why because if you look very carefully then you will see that that this is basically a series addition here. And therefore, the impedance levels will go high. This is a shunt or a parallel addition here and therefore, impedance is lower down. That takes cares of approximately all the understanding here.

(Refer Slide Time: 9:09)

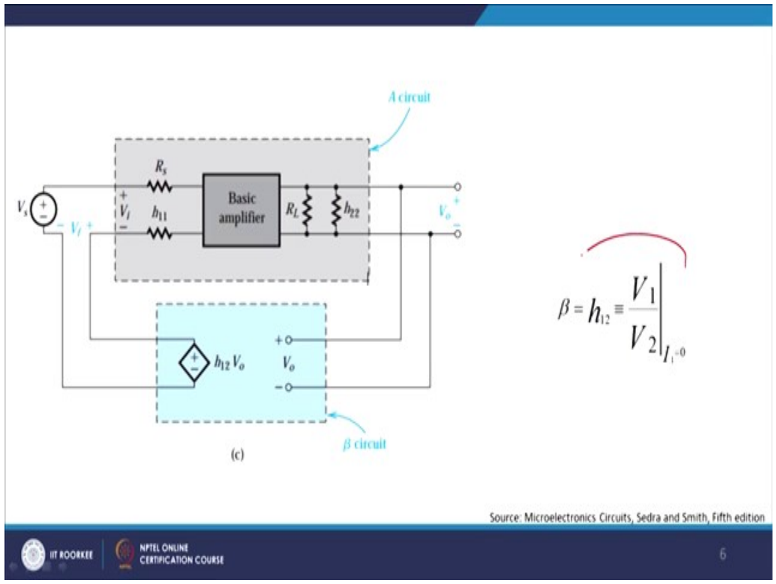


Now, we do the same thing for all the 4 networks and see how it works out. This is basically a series shunt the previous case but let us look at practical case in in reality which means that you do have a loading here. I do have a load here and I have R_{if} is input which you see, R_{in} is input resistance without any feedback and R_{if} is input resistance with feedback. Now, R_S is basically the voltage source here. What we try to do is that we try to we try to convert into a 2 port network, right?

Which is basically my h parameter h parameter analysis which we do h parameter analysis. h parameter is also referred to a hybrid parameters and it correlates voltages and currents together, right? So, so what we do is basically is that we design the feedback network properly and we say that there is a load resistance which affects your basic amplifier. I have a source resistance here. Out of the voltage available at this point which is V_0 I say that I can model is h_{21}. h_{21}I1 and this will be basically h_{21} will be basically a current amplifier and into I_1 if you do I will get the overall current flow.

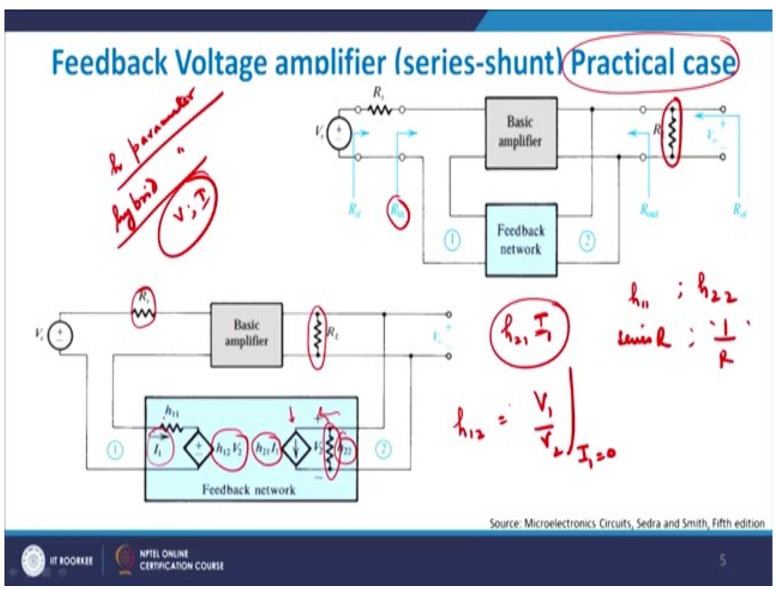
Therefore, this is represented by current source and similarly h_{12}*V_2. So, there are 2 terms here h_{11} and h_{22}. h_{11} is nothing but basically a series resistance series resistance. h_{22} is basically 1 over resistance term. You see it is coming parallel to the current source, right? As you can appreciate as well because current source is ideal current source is we automatically have a large output impedance and that is taken care by h_{22} in reality. h_{12} V_2 is nothing but the voltage source you see here. So, it is basically a voltage source here and current I1 is flowing through this R. And current I_2 is flowing through this R and this is I_2 in a 2 port network. This is h_{11} and h_{22} which you see.

(Refer Slide Time: 11:19)



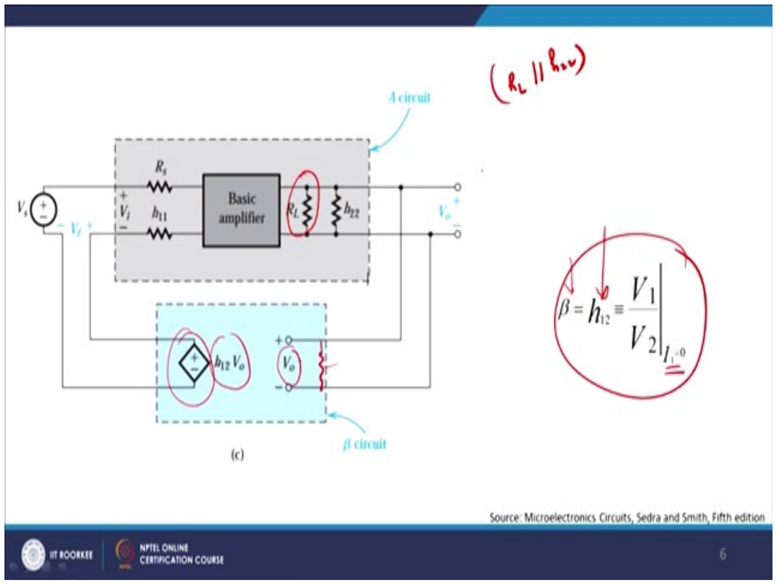
With this knowledge you can safely write down h_{21} is nothing but V_1 / V_2 with I_1 equals to 0.

(Refer Slide Time: 11:27)



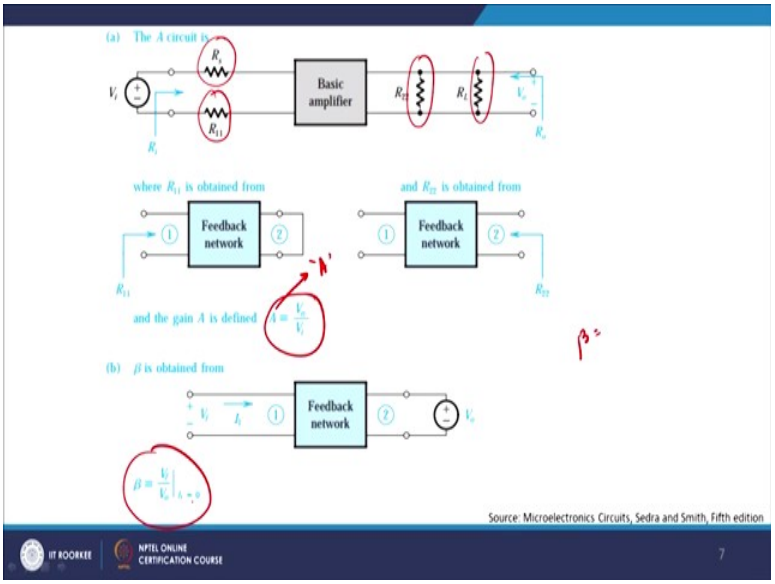
What is h_{12} therefore? h_{12} is nothing but if you look very carefully h_{12} I am referring to as V_1/ V_2 with I_1 equals to 0. I_1 is open I_1 is equal to 0. I_1 0 primarily means that you are opening the input site and that is pretty important that you are opening the input site. So, the input site is open. In this case this is the input side and this is considered to be open. In that case I get h_{12} equals to ratio of the 2 voltages V_1 / V_2.

(Refer Slide Time: 11:59)



And therefore you write here V_0 which is the voltage source and then h_{12} V_0 because this is the input voltage. This input voltage multiplied by h_{12} will give you the value of the output voltage and there is also referred to as β and also referred to as h_{12}, right? And I get therefore I get so what do I do is that I shift this h_{22} which was initially here back to this place. So, now you have got R_L parallel to h_{22} as overall loading on the output side, right? Similarly, the h_{11} which was initially here comes in series to R_s we place it in series to R_s. And then, that is what we are trying to do in this case.

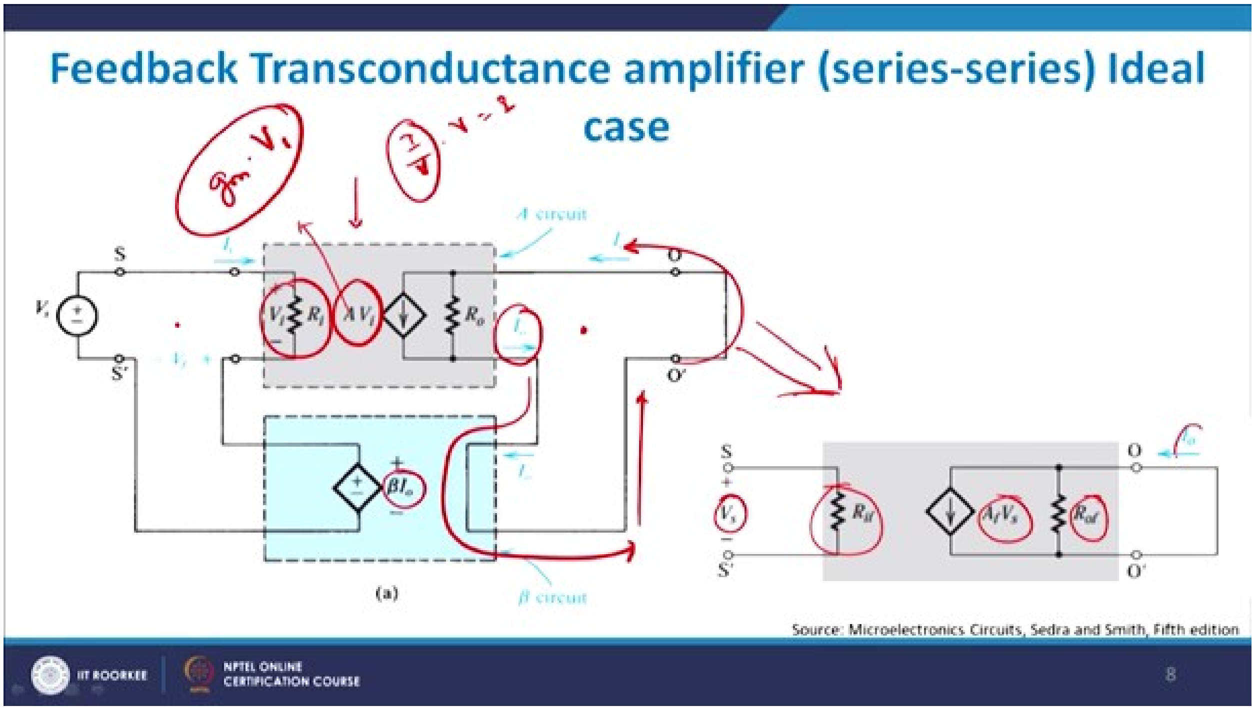
(Refer Slide Time: 12:39)



So, if you therefore fall back and let us see what or how it works out we see that the amplifier circuit will be modelled as in R_{11} in series to basic amplifier. And R_{22} and R_L parallel to the basic amplifier in terms of loading, right? So, as I defined to you the gain a is V_0/V_i which is where V_0 is the output voltage and vi is the input voltage and V_0/V_i will give you the amplifier gain which is basically a here, right? How do you obtain the how do you obtain the value of β which is the feed? So, β is referred to as V_f/V_0 when I1 equals to 0 and β is obtained from this network that what you try to do.

You try to open circuit the input side. When you open circuit the input side, I_1 equals to 0. And then what you do? You do voltage V_0 and then try to find voltage at these 2 points by V_0 using the value of feedback factor β, right? And that is what an interesting part of this whole network part is there.

(Refer Slide Time: 13:30)

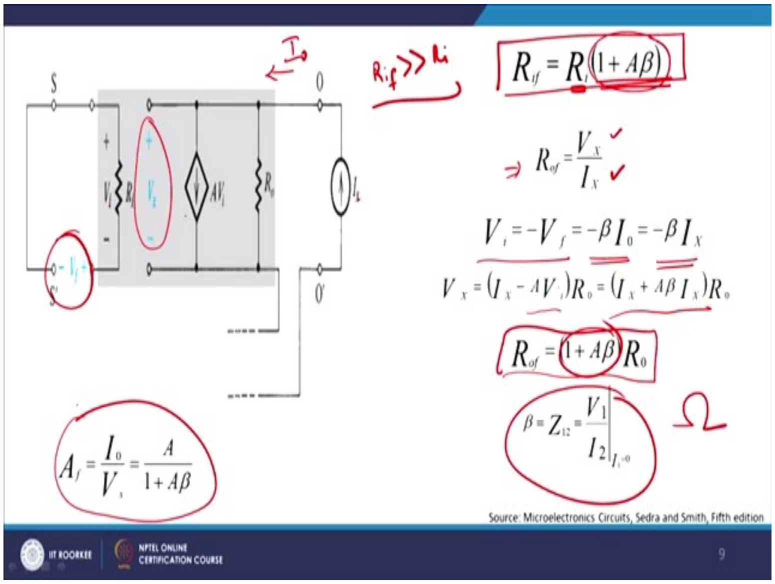


We come to now the Feedback Transconductance Amplifier and this basically is a series series case. Series series as you can see that I am adding the voltage and current here in series and extracting current here in series as well, right? So, I have a current source here which is giving me I_0 output volt current. This flows through this path, right? And you get this into consideration and this current flows back into the system and therefore I can replace it by giving R_i here and V_i here as in the previous case.

And then I say that $A*V_i$ is the voltage which you see here and parallel to that. But this will be a basically current source here. So, A_i is basically I/V which you say, right I/V which you say. Multiplied by V gives you current and therefore, that is a current source here $A*V_i$. Here, A_i is basically my $\partial I/\partial V_G$ which is basically transconductance. And that is the reason a will be referred as transconductance.

Many people refer to it as g_m * V_1 here also. And they get a reason for that, right? And the current source I_0 and then β * V_0 is the voltage which you see here. And that gives me the value of output voltage which is the feedback voltage at this particular point. You also therefore, can come back to this equation this diagram and show that therefore I have therefore my input resistance feedback resistance here. I have my output with feedback R_{of} here. And then A_f * V_s is nothing but a current source which appears to me by virtue of my feedback current or feedback values. So, this is my source voltage and this is my output voltage in practical sense.

(Refer Slide Time: 15:11)



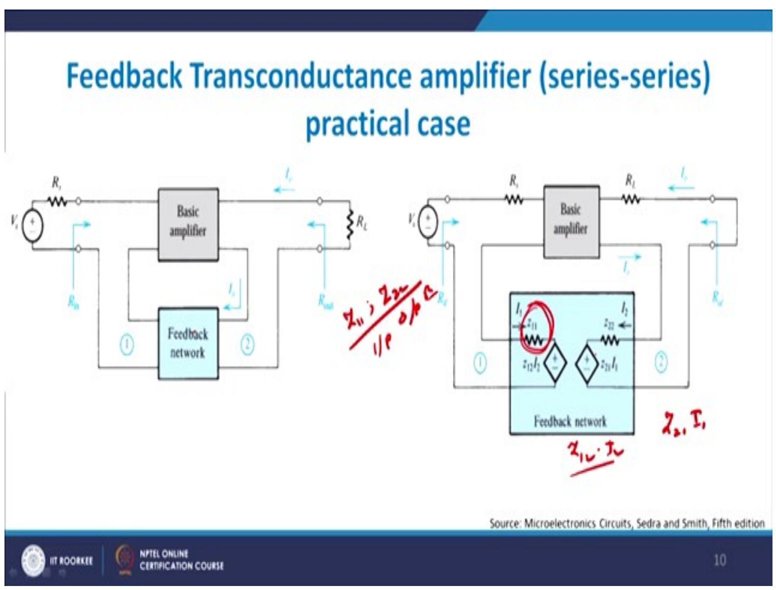
Now, the same thing we bring it back here. I will show to you what is what is the implication here. And in the both the cases you will see R_{if} I am not doing the whole derivations given in all the standard books. I get R_{if} basically equals to R_i (1+Aβ) which means that the input impedance of the transistor in this case an amplifier depends on the factor of Ri which is basically without feedback the resistance available to me on the side multiplied by (1+Aβ). So, what happens is that R_{if} is obviously greater than R_i by a factor of (1+Aβ). Since, Aβ is relatively larger as compared to 1 I can safely say that R_{if} is equal to R_i* Aβ.

Now, R_{of} if you want to find out which is basically the output impedance then I can say simply it is equal to V_x / I_x. Where is V_x? V_x is this voltage which you see in front of you and this is the voltage which is appearing here upon I_x which is the total flowing through the device. And that is your R_{of}. So, if I get V_i equals to - V_f because of negative feedback V_i equals to - V_f and therefore I can replace V_f by β * I0 by my previous definition which can be also referred as - β * I_x.

So, I0 is the output resistance output current which you see here which is exactly the same as value of I_x here. So, now what I try to do is I get V_x equals to $(I_x - AV_i)* R_0$ because AV_i will give you the current here multiplied by R_0 and then if you solve it I get A times. So, V_i will be broken up into $A*\beta *I_x$ into R_0 and therefore, R_{of} is equal to $(1+A\beta) * R_0$. So you see now as I was predicting earlier also the input resistance with feedback and the output resistance with feedback both increases by a factor of $(1+A\beta)$, right?

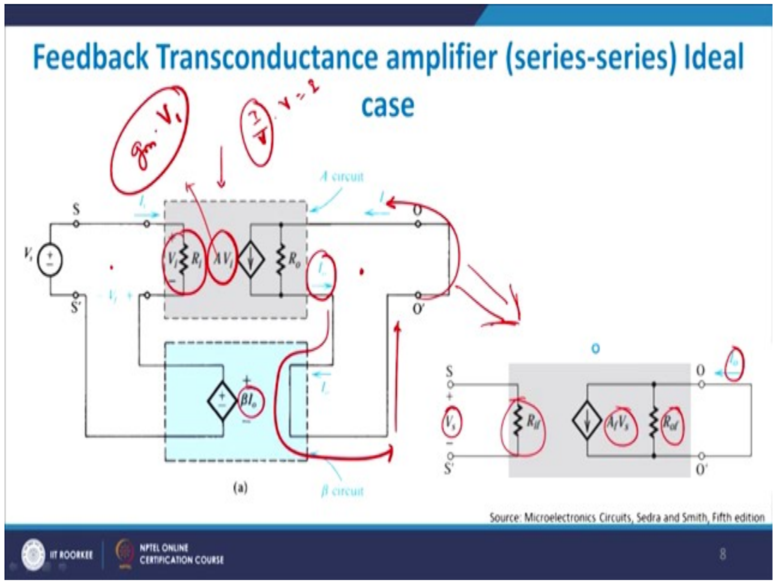
Now, that is quite a heavy increase here where A is the feed forward open loop up to the amplifier and β is the feedback fraction. β in this case is again referred to as Z12 and is given by V_1/I_2 and its dimensions in the order of ohm with I_1 equals to 0 primarily means that your input is basically open. So, you see that the input has been kept open here, right? I am trying to find the current available at. So, A_f will be defined as $A/(1+A\beta)$ as per my previous definition as we have already discussed this point in details.

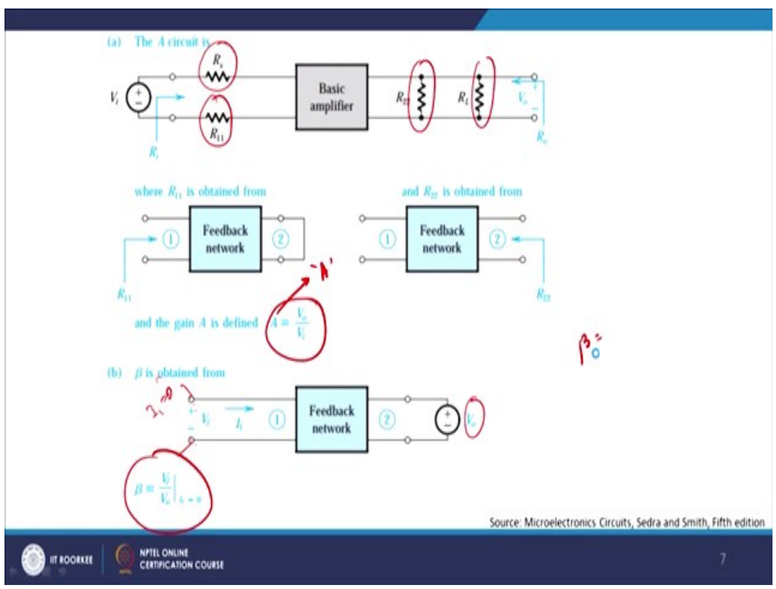
(Refer Slide Time: 17:35)

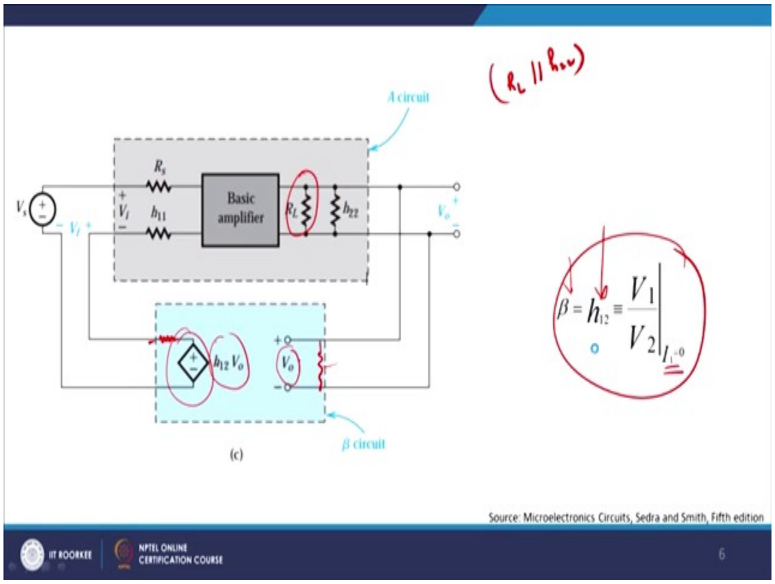


Now, let me come to a practical case of series series amplifier and you see here that I have broken down the feedback network into Z_{11}. So, it is basically a Z parameter which is available to me. So, Z_{11} and Z_{22} are basically the resistance input resistance and output resistance offered to the device and I get Z_{21} $I_1$and Z_{12} * I_2. So, you see your feedback network is changing.

(Refer Slide Time: 18:02)

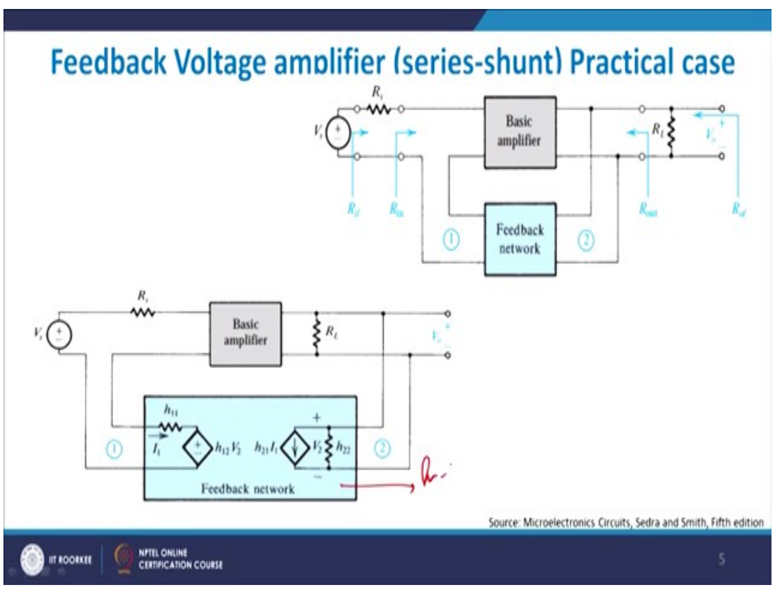






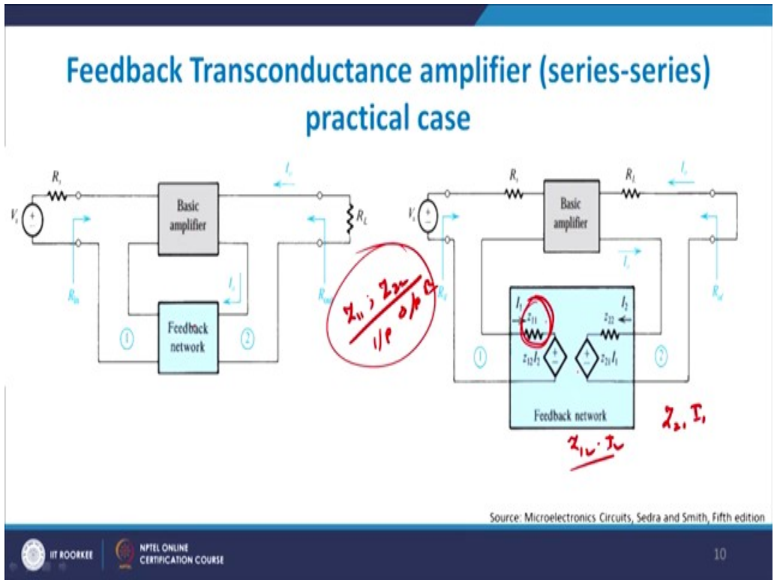
If you look back here previous discussion here, here or maybe this previous case that if you look here and you try to find out … if in this case you see we were talking in terms of.

(Refer Slide Time: 18:22)



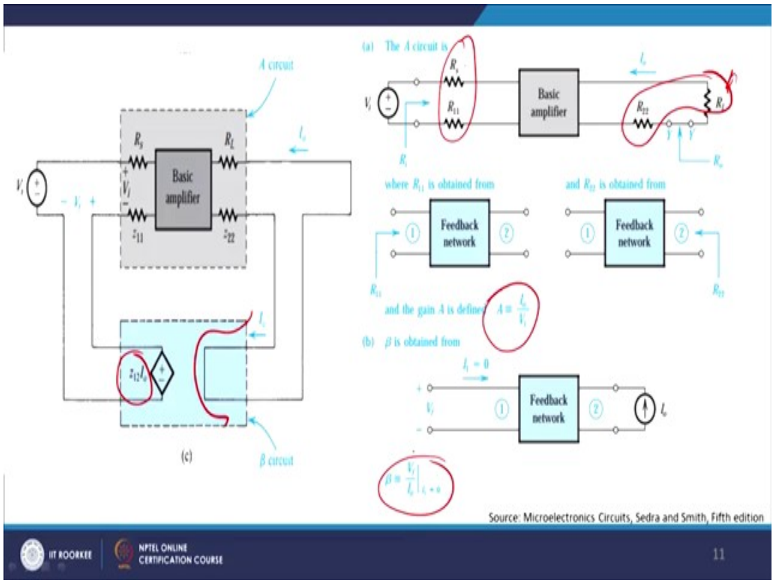
If you look very carefully here what we were talking was that your this was your h parameter network, right? h parameter h parameter because you are dealing with both current and voltages here.

(Refer Slide Time: 18:38)



Whereas now when you are dealing with both sides current or both side voltages or both side current maybe then you need to deal with the fact that you should have a current amplifier with you and that is what the reason is current amplifier is with us and therefore, Z_{11} and Z_{22} are nothing but voltage sources or the impedances seen to it. Z_{12} I_2 is the current flowing through the device and Z_{21} I_1 is the current input into the device in the feedback network, right, and I get I_0 as the total current flow into the device.

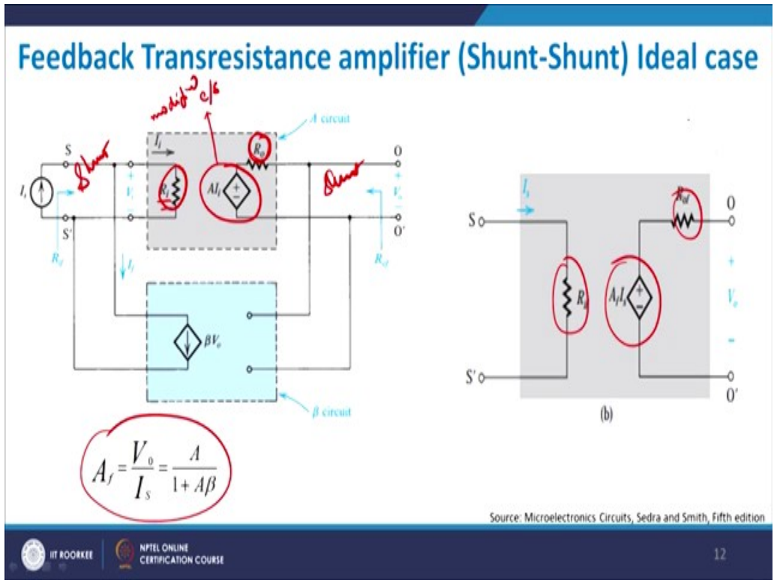
(Refer Slide Time: 18:59)



Now, we will look at the basic amplifier and then we will just take Z_{11} from its initial position and make it into the R_{SS} series value. And Z_{22} in parallel position to in parallel position to R_L and then I get Z_{12} I_0 as the input current source here, right? So, I have a current source here which is shorted and I get Z_{12} I_0 as the output current source which is fed back into the basic amplifier which converts the current into a voltage corresponding voltage and the output value is created. As I discussed with you in a typical example which we follow we see that these 2 are in input side and these 2 are in output side, right?

And we say that R_{22} and R_L which is the load external load are related to each other just like R_s and R_{11} is related to each other. We also define gain to be equals to I_0 by V_i which is basically output current by input voltage. Now, β is obtained from the fact that if I_1 equals to 0 , I get β equals to V_f/I_0 with I_1 is equal to 0. This is how you calculate the value of β, right? So, its feedback voltage by input current that is how you define your β value in all respects as far as this feedback this feedback is concerned.

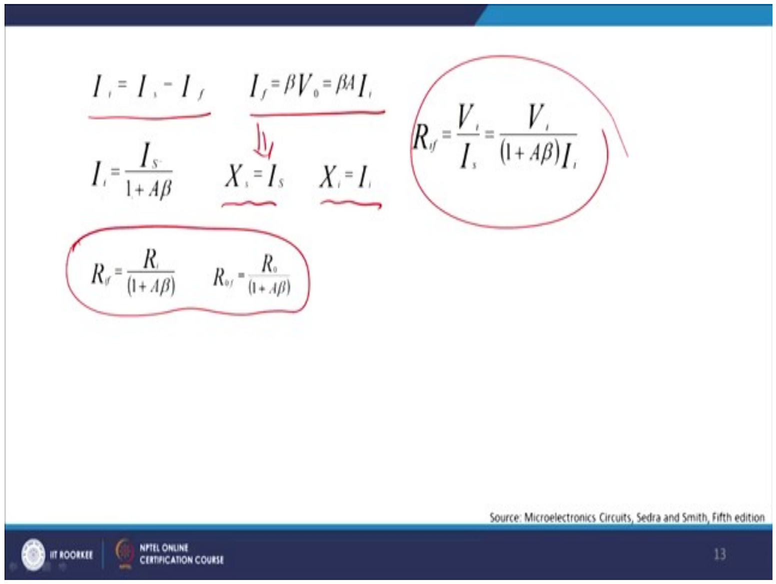
(Refer Slide Time: 20:19)



Now, let me come to the shunt shunt ideal case. The shunt shunt if you remember will be both sides parallel and therefore, you see this is R_i which is the input resistance which you see and then you will have output resistance R_0 and this A into A_i or A into I_i is nothing but a current source. What do you say? A current source which is basically your modified current source as compared to an ordinary one and this is R_i which you see and therefore, this R_o is the output impedance you see here.

They are parallel with respect to each other because both sides you have got shunt and shunt, right? And therefore, I can write down A_f equals to $A/(1+A\beta)$, right? And if you look if you go back to your ideal shunt cases I get R_{if} I get R_{of} and you have got A_fI_s which is basically a controlled current source which gives me a value of output current for various values of A_f chosen, right?

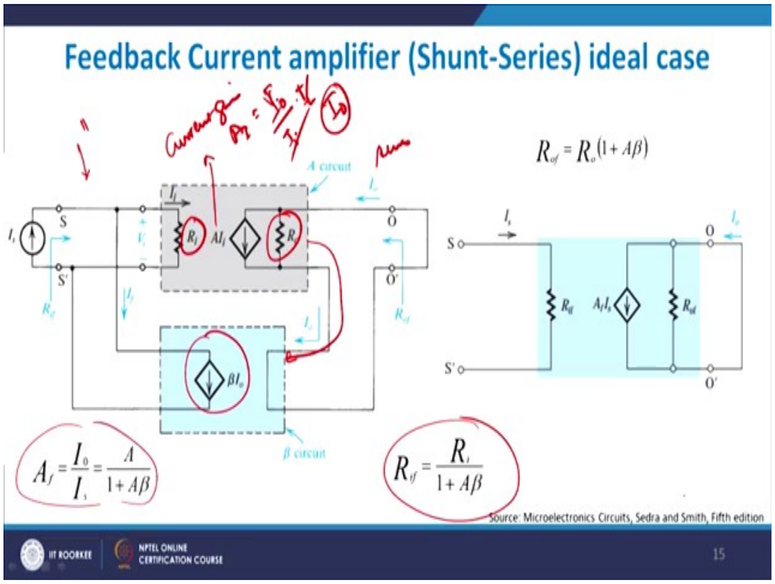
(Refer Slide Time: 21:14)



Now, therefore I get Ii the input current equals to I_s-I_f because of negative feedback. We already if to be equals to β * V_0 and this is V_0 is nothing but A*I_i. I can safely write down if to be equals to β * A*I_i, right? So, I get I_i equal to therefore equals to I_s / (1+Aβ) and therefore I can safely write down input impedance or input source is basically X_s.

Output input current source is Xi and therefore, I can safely write down R_{if} equal to V_i/[(1+Aβ)*I_i] and R_{if} equals to R_i/(1+Aβ) and R_{of} is equal to R_o/(1+Aβ). Which primarily means that whenever I try to find out an impedance (1+Aβ) term will surely come in the denominator. And that will make my impedance level go down with feedback. We can change the value of A and β and get the new values of R_{if} and R_{of}, right? So, this is what we have learnt in this module. In general, we have learnt this basic concept here.

(Refer Slide Time: 22:31)

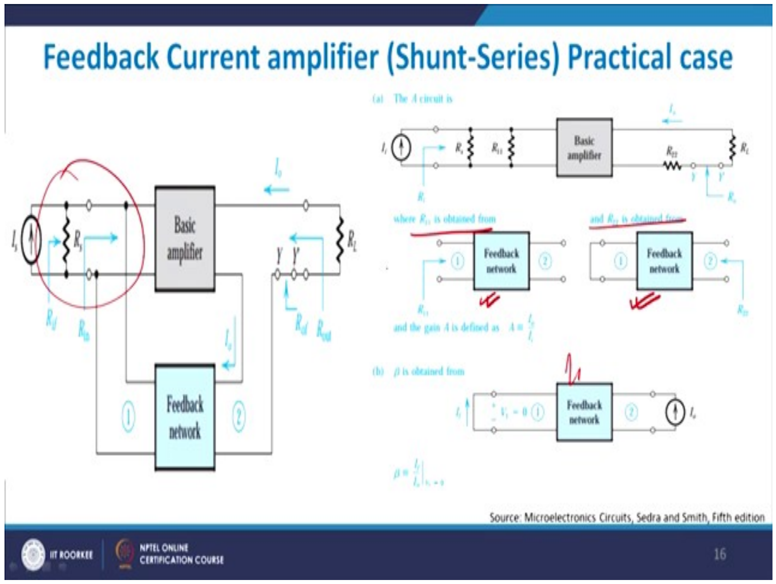


Now, let me come to the case of feedback sorry feedback resistances over here, feedback shunt resistance feedback shunt series resistance. So, I get a shunt series basically means that I will take a parallel output here. And I will do a series input at this particular point, right? And therefore, you see I have got R_i here and then $A*I_i$. A is basically my current gain, right? And is given by A_i and this will be current gain which is which is visible to me.

So, the total current would be nothing but I_0 / I_i multiplied by I_i. I_i gets cancelled and we get A_i is equals to I_0, right? So, when you short and the resistance is low your current becomes large. And as a result, we also get a large current on the output side which is beyond our control on an extent. All the current is now being routed from the upper arm.

So what we do is we put an extra resistance here which is basically in parallel and then try to route this current through this arm onto a onto a device which is basically takes care of the increased value of voltages and therefore, increases the current flow through it. So, as I discussed with you as this is a shunt series feedback I will get my input impedance lowered by R_i is equal to $R_o/(1+A\beta)$. However, my output impedance will also get lowered by $(1+A\beta)$. So both the input impedance and the output impedance falls by a factor of $(1+A\beta)$.

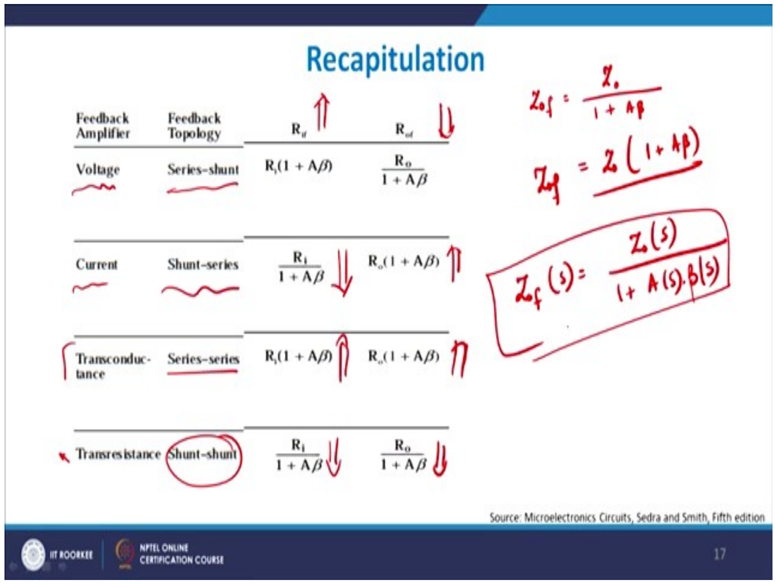
(Refer Slide Time: 24:11)



Let us look at the feedback current amplifier. It is basically a shunt series application so I have got a shunt here, right? And I have got the series application here. So, I get R_s is parallel to R_{11} and I get R_{12} here in this place multiplied by R_L, right? And this is output impedance I have shorted it because any output impedance to confuse at this point of time.

Where R_{11} is defined from this network from this network and R_{12} is obtained from this feedback network, right? And from these two feedback networks they can actually find the value of the resistances or the impedances which is there in the system. β can be obtained from this feedback network in a general in a general manner. Okay!

(Refer Slide Time: 24:45)



To recapitulate, therefore let me show to you few recapitulation points that when you have a series series topology or a series shunt topology your feedback amplifier is generally a voltage. Whenever you have shunt series it is basically your current, whenever you have series series trans conductors and whenever you have got a shunt shunt you do have a you do have a 1 of the 1 of the scholars take care of your problem, right? That is basically the transresistance shunt shunt shunt shunt resis transresistance shunt shunt. So, in transresistance shunt shunt both the resistance fall down, right? In case of series both the resistance goes up input output.

In case of shunt series input falls down, output increases and in case of series series this rises and this falls off. So, depending upon whether you are having series or shunt the resistance offered will be always increasing or decreasing depending upon the virtual position of the human being, right? And that is what we learnt from this whole idea; that wherever you are placed in circuit tree depending upon whether it is series or shunt, you will be able to predict first principle from first principles whether you get a low resistance path there or high resistance path in that case.

Okay! So, I have got 4 types of network available with me series shunt, shunt series, series series and series shunt. Whenever you get series you get an increase in impedance, shunt you get a loss in the impedance. If you want to generalize the whole term I get Z_{of}. Z is the impedance which you see with feedback equals to Z just Z you can write down. Z_o which is basically your output impedance into 1 / (1+Aβ) when you want to show a decrease and this is how when you want to show an increase.

We have already discussed this point earlier. We also can show you that overall if you want to make it as a function of frequency, then $Z_{of}(s)$ equals to $Z_o(s)/[(1 + A(s)\beta(s)]$, right? And that is quite critical if because we have till now believed that the amplifier is basically frequency independent and basically we are talking about the mid frequency gain which your as will be independent of the frequency, right? And that is the reason this is a safe way to play out values of Z_{of} and Z_{if}, right?

And you can actually get those values in a detailed manner here. And if you remember what we did therefore, was applying Kirchhoff's law first order Kirchhoff's law to get the values of the impedances here, right? With these words, let me thank you for your patient hearing and we will take up the next module of stability and pulls and zeroes applied to amplifier in our next module. Thank you very much!