Microelectronics: Devices to Circuits
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Basic Feedback Topologies
Mod 10
Lec 46

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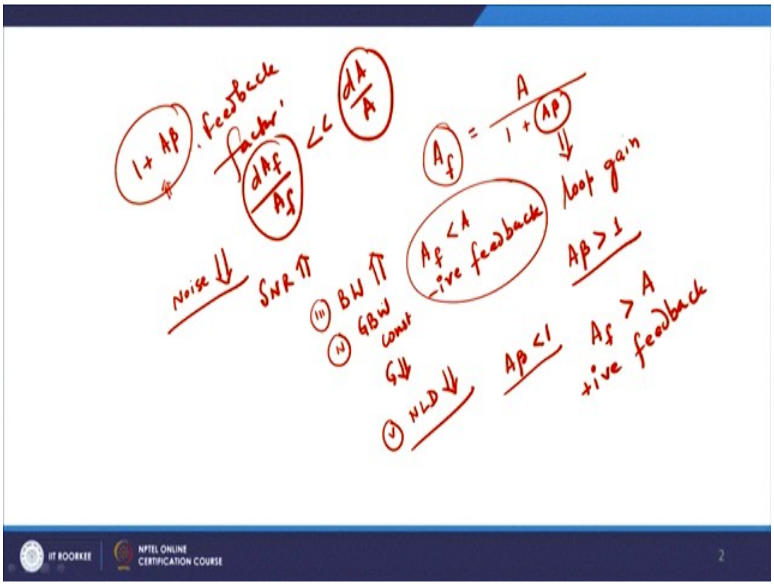

Hello everybody and welcome to an edition of the NPTEL online course on microelectronics devices and circuits, what we will do today is look into the basic feedback topology, if you remember in our previous module we had discussed about the concept of negative feedback, what is the meaning of negative feedback? We have seen that in order to have a negative feedback the general scheme is basically with the amplification, with feedback is equals to amplification without feedback A/(1+Aβ).

Where Aβ was referred to as the loop gain right and as long as Aβ > 1 right, you will automatically have $A_f < A$ and we refer to this as a negative feedback, that means, with feedback the gain is reduced, similarly, if Aβ < 1, then you get your $A_f > A$ because a denominator actually becomes less than 1 and this is refer to as a positive feedback right, so in most of the cases which we will be encountering, we will be concentrating on negative feedback, per say, right and we have also seen that with this loop gain, 1 + loop gain if you see and that is known as the feedback factor.

So this (1+Aβ) is refer to as a feedback factor right and if you look at the feedback factor higher the value lower is your A_f and therefore in most practical cases we try to keep this one as high as possible, but the advantage of all this things is that, that your gain desensitisation takes place, so dA_f/A_f is reduced drastically as compared to dA/A, so this is gain without feedback, this is relative gain with respect to feedback right, so your gain becomes most stabilised, what you lose is basically the gain, so gains falls down, but your gain becomes much more stabilised with respect to variation in temperature and output electrical characteristics.

Similarly your noise also is reduced, noise is also reduced and your signal to noise ratios becomes larger, provided you are able to have a preamplifier which is less noisy in series to the noisy amplifier right, if you do not do that, then it is not possible. Otherwise, we generally have a lower SNR, the third thing which is, this is second part, the third part is basically your bandwidth increases right, so bandwidth increases because lower cut-off frequency goes smaller and the higher cut-off frequency goes higher and therefore the bandwidth increases.

But your gain bandwidth product, which is basically GBW is constant and therefore what happens to the gain is that the gain starts to fall down, so your bandwidth increases, gain falls down more stability, less of noise and there will be non-linear distortion will be also reduced right and these are the very important points of negative feedback.

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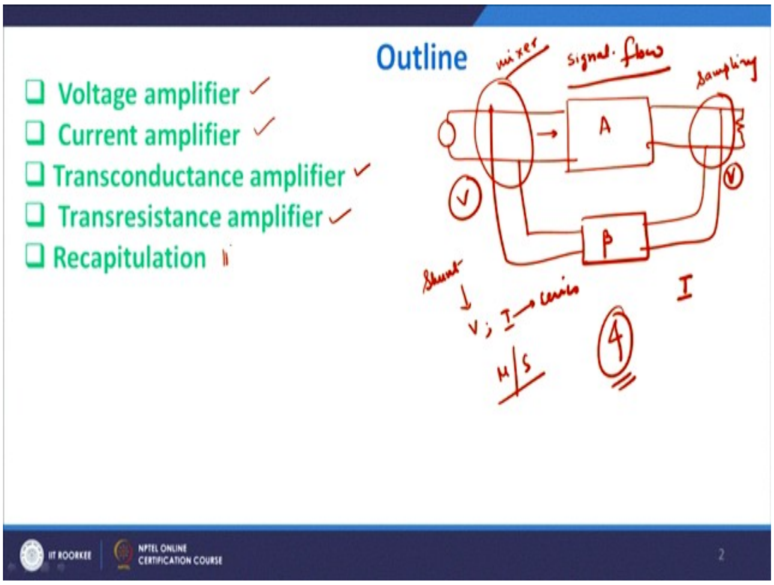

Today, what will be looking into is, we will be looking into the various topologies of feedback amplifier and if you remember, in our previous talk, in our previous discussion, the general scheme of things was the signal flow diagram if you look was you had A and then you had β here, so β was basically my feedback factor and then you have a source of voltage source or a current source here, which was feeding the amplifier, then you have a load here right and this load was talking to my β here and a part of β was fed into this amplifier, and as a result, you will have a feedback factor.

So this was your basically your signal flow diagram, if you remember from my previous discussion, now, depending on how you manage this side and this side, this is known as sampling portion and this is known as a mixture portion, so depending how you sample and mix, you get a four types of configurations available to me, whenever you sample in a parallel form, you are actually sampling out voltages and whenever you are sampling in series you are, so this is basically voltage, this is also voltage right, because this is parallel, this is parallel, so parallel, parallel basically, means that your voltage, voltage feedback network is there.

Similarly, if you have series extraction, then you have current extraction taking place, so we have got two notations, current and voltage right, so current voltages shunt because it is parallel and this is basically your series right and then you also have, you have two voltage on current as a two-part and you have therefore two mixers, mixer and samplers, so in effective here are kind of 4 configurations available to me right and these 4 configurations are written here, one is a voltage amplifier, another is a current amplifier, you will have transconductance amplifier and trance resistance amplifier and then we will recapitulate the whole discussion once again right, so we start with voltage amplifier and then you go to current amplifier, transconductance amplifier and so on so forth, now if you go at, if you go to the voltage amplifier right.

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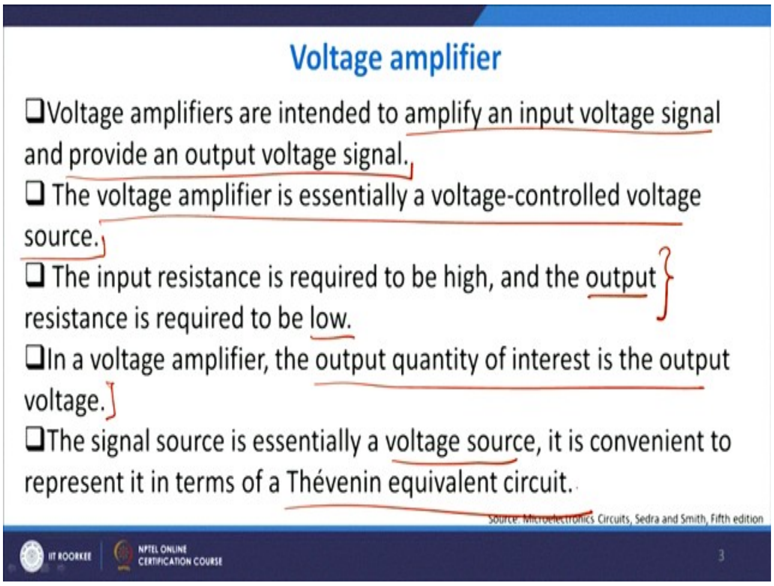

Let us discuss the voltage amplifier first, so voltage amplifier's main job is to amplify a voltage, as the name suggests, so you will amplify an input voltage which is very, very small in dimensions, peak to peak and will provide output voltage signal, so at this stage we are not talking about, at this stage at least we are not talking about frequency change or for that matter, the change in the frequency of the inputs source, so on and so forth, we are keeping the input stable at, say, omega and we are trying to find out the variation in the peak to peak signal of the output with respect to A and β, A is the feed forward amplifier, configuration factor and β is the feedback network exponent.

So therefore a voltage amplifier is actually a voltage-controlled voltage source, I suppose you can understand this why, because if you look very carefully you are actually extracting voltage from the sampler and you are feeding voltage into the mixers, so both are shunt, shunt configuration or both are basically parallel configuration, now why it is known as a VCVS or voltage control voltage source, the reason is that you are, this is basically voltage amplifier, so the output is basically a voltage which you are getting right.

So therefore output is the voltage source, so that is the reason it is said to be voltage source, why is it voltage control because the amplifier which you will be using typically here, will be controlled by a voltage right and therefore this basically a voltage controlled voltage source, in this case, as we will see the input resistance is quite high and the output resistance is quite low right, just like an op-amp , so op-amp is an example of a voltage amplifier, we already know that and therefore if you look at op-amp, its input resistance is infinitely large or very large and output resistance is very, very small, same thing happens to a voltage amplifier here.

What we will be looking into is that the output quantity of the interest is the output voltage, so we will looking at the output voltage and since the signal source is essentially a voltage source, it is always advisable that you use Thevenin equivalent right, so what will do is that we will use and Thevenin equivalent when we do a voltage amplifier action or a voltage amplifier division.

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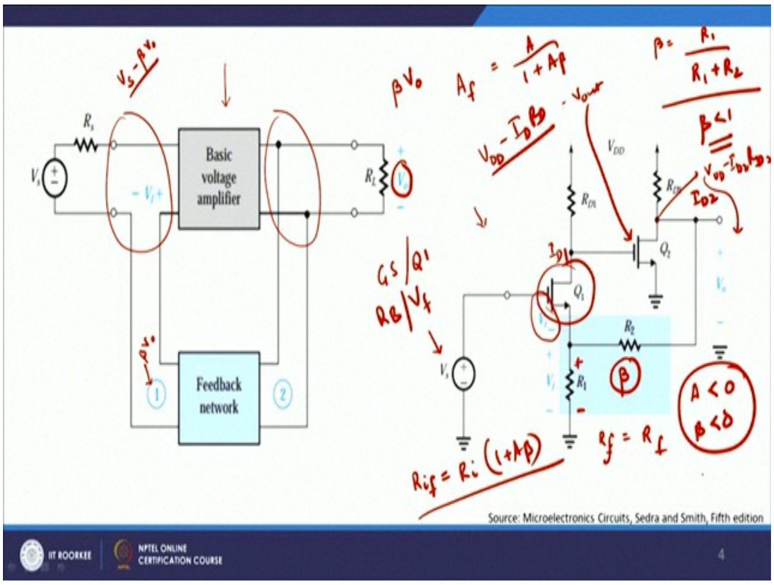

So this is the basic architecture of your voltage amplifier here, basic amplifier so as you can see this is your sampler right and this is your mixer here right, you do have, this is the load and what you do is that this feedback network tries to take a portion of this V_0 and therefore you will have a output β times V_0 coming at this point, so this will be β times V_0, which will be coming here, then you will have a feedback network and therefore you will have $(V_S – β)V_0$ will be coming at this basic network here.

And then what you get from here or what you get from this basic configuration is that in this case also you will have A_f the feedback with will be equals to $A/(1 + A β)$ right and that is what happens to a larger extent right, now if you go ahead and do it, for example I will give you an example, for example, the actual voltage gain series network which you will see is, if you see here, this is basically an example of a voltage amplifier, the circuit here.

This R_1 and R_2 is basically your β right, so β is basically the parallel combination of R_1 and R2 which you will see here and therefore if you are taking out the voltage out of this particular form, I get β to be equals to $R_1/(R_1 + R_2)$ right, and as a result β will be always less than 1, so when $\beta = 1$, it primarily means that your all of the voltage in the output side is fed back in input side, if $\beta < 1$ that the percentage of the output voltage is fed back.

Now if you see very carefully the input voltage, this is the source voltage which you are giving right, the input voltage which appears between the gate and source of Q_1 is referred to as V_I, so this is my V_I right, so this my V_I right, input voltage and this gives you a current here I_D right and I_D current flows through this point, this generates a voltage, how much voltage will be generated, it will be $(V_{DD} - I_D R_D)$ right, that will be V_{out}, this V_{out} will be fed where, will be fed into the gate of Q_2, this Q_2 gate will generate a current here which is I_{D2} right.

Therefore this is I_{D1}, this is I_{D2}, then I_{D2} will generate a voltage here which is given as $(V_{DD} - I_{D2} R_{D2})$ right, let us suppose, this is the voltage here, now that voltage is your V_{out}, so a fraction of that depending on the value of β is again fed back negative, why negative? Because if you see very carefully that this voltage is, this is positive and this is negative and this will be reversed biasing my gate to source of Q_1 right, so my gate to source of, gate to source of Q_1 will be reversed biased with respect to V_F, because V_F this is positive, just like a source degeneration resistance remember, exactly the same happens here as well and therefore he tries to reverse bias this transistor Q_1 right and therefore you have negative feedback network here.

The obvious reason why generally we have two transistors is that one is a driver transistor another is a transistor, which is being driven by this Q_1 and therefore that is the voltage which you see from the outside world right and you are able to sustain this formulation here, depending on how you look into it, we will see automatically that the by application of a reverse bias here your input impedance actually rises with feedback.

So with feedback R_f if I want to find out input, so if I want to find out R_{if} which is input impedance with respect to feedback I get without feedback $[R_i (1 + A\beta)]$ as the increase in input impedance, in this case you will see that this is negative feedback primarily meaning therefore that $A < 0$, $\beta < 0$, so when you multiply both of them you get a positive sign and therefore you will get a negative feedback.

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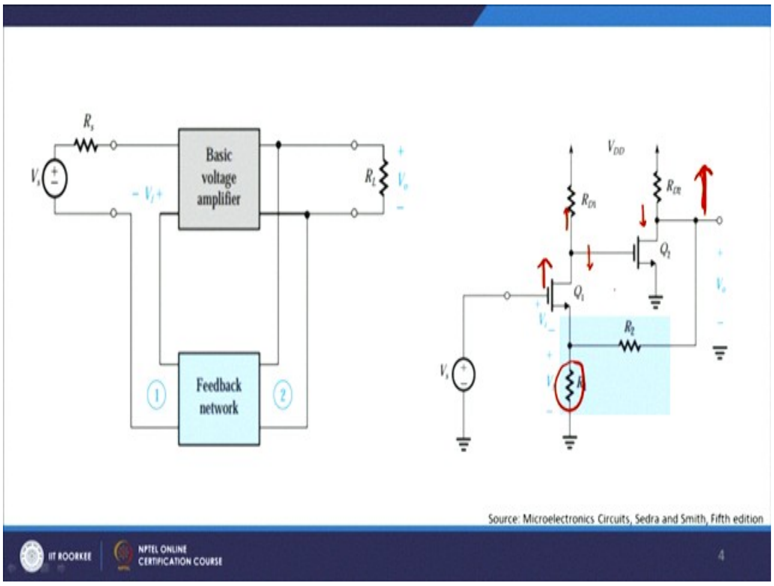

From this physically, let me explain to you how I get negative feedback, so as I discussed with you as this VS increases, this voltage increases, this current increases, so your this voltage drops down, which means that this current here will drop down, which means that this voltage will increase, so with increase in V_s here I get an increase in voltage here right, but this increase in voltage is primarily means that my V_f we also go on increasing.

And as a result, it will negative feedback my Q_f in a much more larger term and that is the reason, that is the basic origin of negative feedback here and as you can see here, therefore, that depending on the effective values of the gain of Q_1 and Q_2, this factor will be typically very large, you can get a very large gain here at the output of Q_2 and that will be fed through R_1, R_2 network back as a negative feedback on to Q_2.

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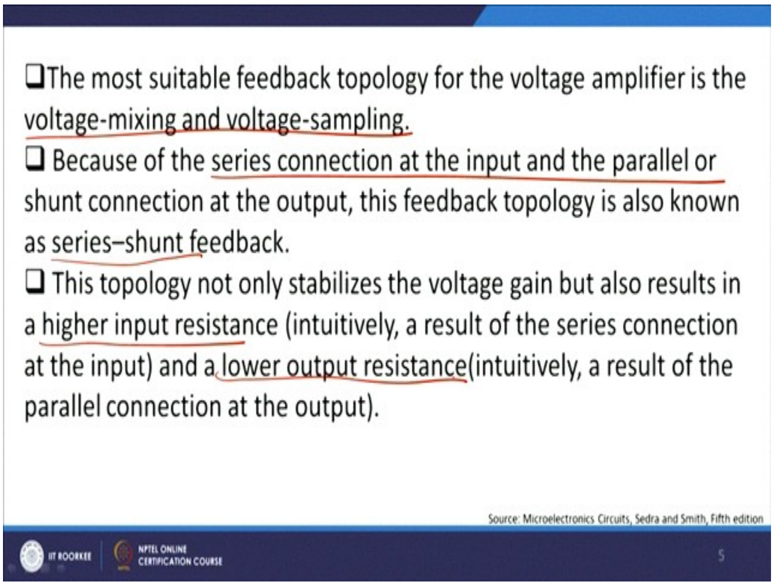

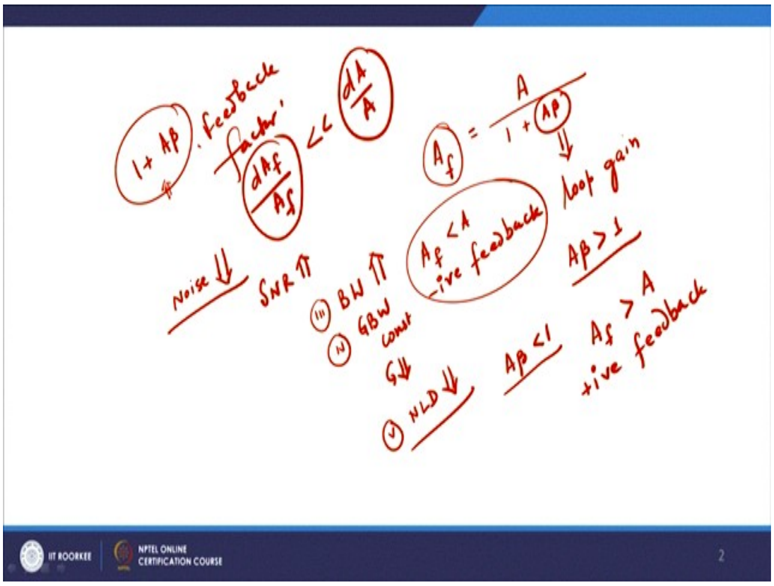

So this is your voltage feedback network, the most, as I discussed with you, the most convenient form is basically the voltage mixing and voltage sampling, no need to say we have discussed this point time and again, because of the serious connection at the input and the parallel connection at the output, this topology is also known as series shunt feedback, because we referred to this, mixer side as the series first and the sampler side as a shunt and therefore we referred this to as a series shunt mechanism or a series shunt mechanism which we see.

Now if you look at the series shunt feedback amplifier what we can and what we can write down is that as we discussed just now that we get a higher input impedance and a lower output impedance right and that we will just show it to you through a derivation maybe and this derivation will remain the same for almost all the cases, the methodology by which we have adapt.

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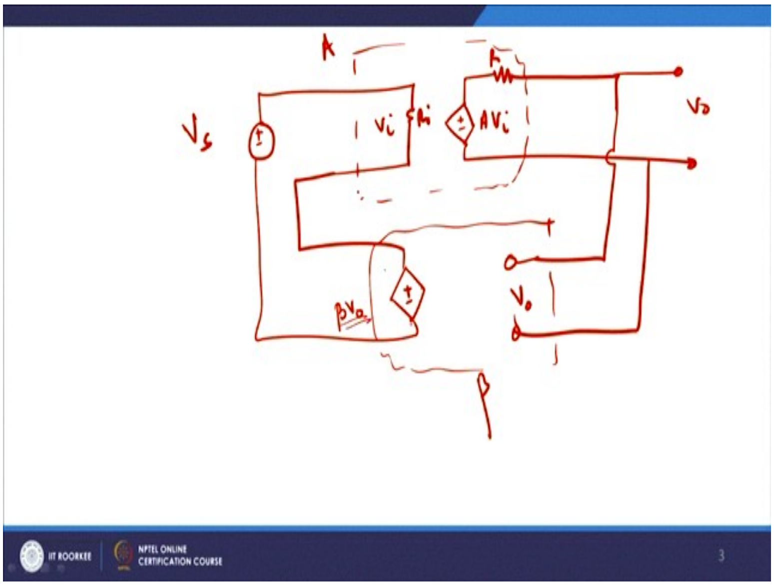

So if we, let me draw you the effective diagram of a series shunt feedback network and explain to you how it works out right and I will explain to you how this is being done, so it is AV_i, I will explain these one of them individually, then you have R here and then this is your V_0, this is output voltage and then you have, you take a parallel combination out of it, assuming V_0 is the output here, we take a factor of it given as βV_0 and I get this factor and then this is connected to this side and then we get something like this right.

So this is your amplifier A, for feed forward amplifier A, where this is your V_i and this is your R_i and this is your R_o or R output resistance and this is your voltage, so this is your feedback network, this is your β, feedback network and this is your feed forward amplifier and this is a voltage source V_S, so if you see very carefully AV_i is nothing but the output voltage which you see in the output side of the amplifier and that is the reason I refer to this as AV_i and out of V_0, βV_0 is the output voltage of the feedback network, so this is the effective circuit diagram which is seen and can be explained to you.

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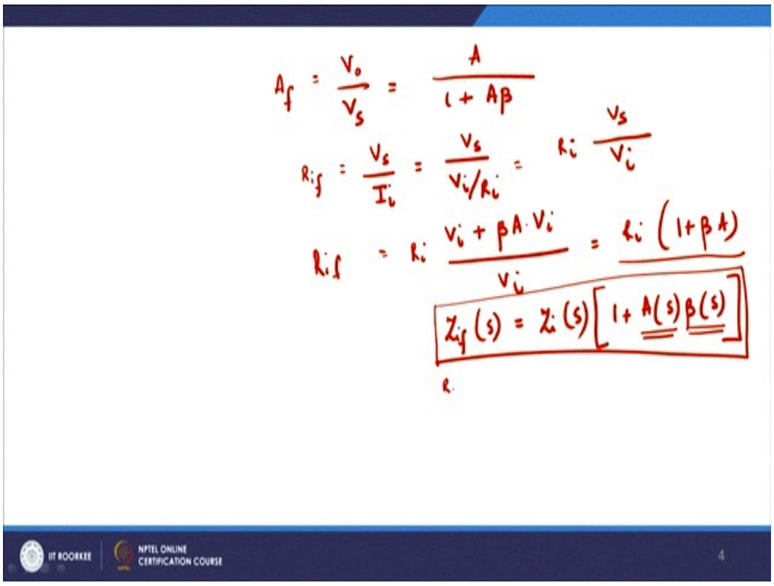

And let me write down therefore that with feedback I get V_0/V_S and that is equals to A/(1+ A β) and that is a standard form of you see but let me write down, let me show a derivation of good impedance with feedback I get V_S/I_i output, source by current, I get $V_S/(V_i /R_i)$ because I_i is the input current, which is nothing but the voltage, input voltage by input current and this can be written as resistance times V_S/V_i right.

So this can be written as $[R_i(V_i + \beta\ AV_i)/V_i]$, so I get this to be equals to $[R_i(1+ \beta A)]$ as the value of R_{if}, so your R_{if} shows increase by a factor of $(1+ \beta A)$, so in general, if you want to generalise at I can write down Z_{if} which is impedance with respect to frequency, now I am writing now is equals to $Z_i(s)[1+A(s)\ \beta(s)]$, see what we are assuming till now was that, we are assuming that the feedback network is not loading your amplifier, neither your load which is there, RL is loading your amplifier, so just they are working on a standalone basis right, in reality this is not true, there is always a loading and then second thing is that it is also frequency dependent.

For example, the gain of the amplifier is again a frequency dependent quantity, you must have known by this time, that in the mid frequency only your gain is stabilised and gives you a constant value, at very low frequencies and high frequencies the gain starts to fall down, so therefore it has to be a frequency dependent quantity and therefore I right down to be as A(s), similarly β if it is a purely passive network it will be independent of frequency but if it is an active network it will be also having a frequency dependent term coming into picture and that is the reason I write a generalised formula for any voltage, voltage amplifier in this form, in the form given here.

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Let me show you for R_{of} which is the output impedance here, let me do it in the next page, maybe, R_{of} which is the output resistance, is given as V_i / I, where I is given as (V_i - AV_i)/ R_o because you see its - because you are doing a negative feedback, now what we do is that, for finding out the output impedance we shot the input and therefore $V_s = 0$, I get $V_i = -V_f = -\beta V_0$, which is nothing but ($-\beta V_i$) because V_i and V_0 are constant in this case.

So I get current to be equals to ($V_i + A\beta V_i$)/R_0, so I get therefore R_{of} right, $R_{of} = R_0 /(1+A \beta)$ because you see we take V_i common right, you take V_i common and so this will be I = $V_i(1 + A\beta)/R_o$ right, so if you take this to this side and just vice versa, I will get $R_o/(1 + A\beta)$ right is equals to V_i / I, now V_i/I is nothing but R_{of}, so $R_{of} = R_o /(1+A\beta)$ right and that is what you get and in general, we can write down therefore Z_{of} with feedback output impedance can be given as $Z_o(s)/(1+ A(s) \beta(s))$ and this is what we get from the overall discussion, this value which is available with me, so we have seen that the input impedance rises and the output impedance falls down.

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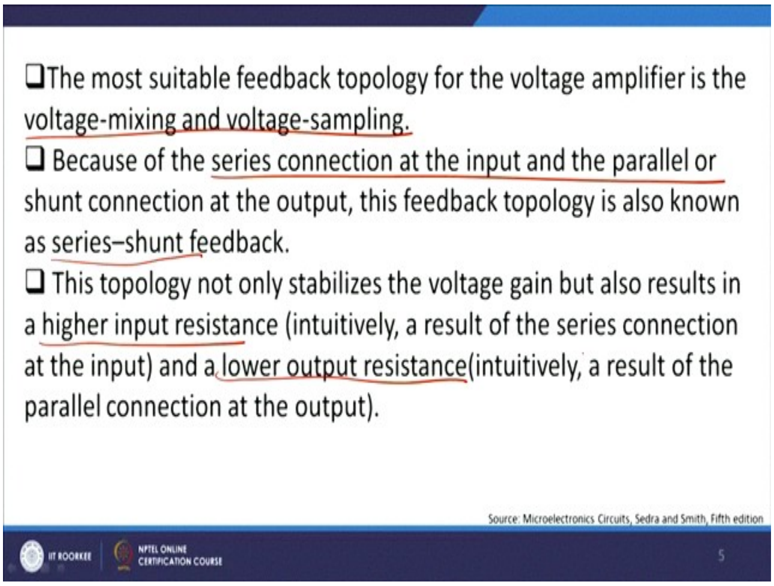

And that is the intuitive result of which we have already found out because it is a parallel, output is a parallel connections, output parallel connection primarily means that output impedance will fall down right and that is the reason you get a reduction in the output impedance.

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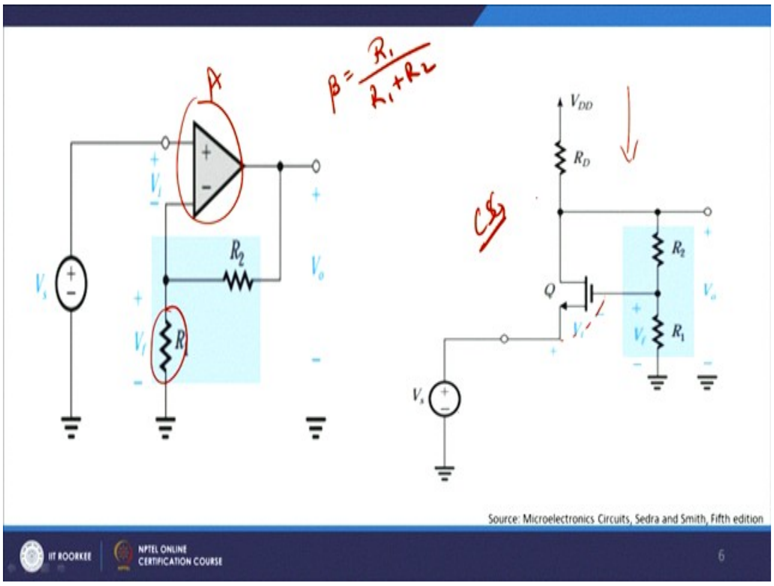

Let me show to you now an example, wherein you have another example here, which is basically, just let me, this is your current amplifier, another example is basically this one, wherein you have got your amplifier here, this is your A, so this basically an op-amp and this gives you a feedback region and this R_1 is responsible for giving you a feedback to the amplifier and β therefore will be equals to $R_1 /(R_1 + R_2)$ right, because there are in series with respect to each other.

Similarly, if you want to make it much more simpler, you will see that it is exactly the same as this one here right and this is the feedback network which you see here right, this is a common source stage because, sorry common gate because you are giving the source input signal to the source side of it and so source, so V_i will be between V_{GS} which is between this two points and therefore you will automatically get a variation in the output frequency, output voltage here.

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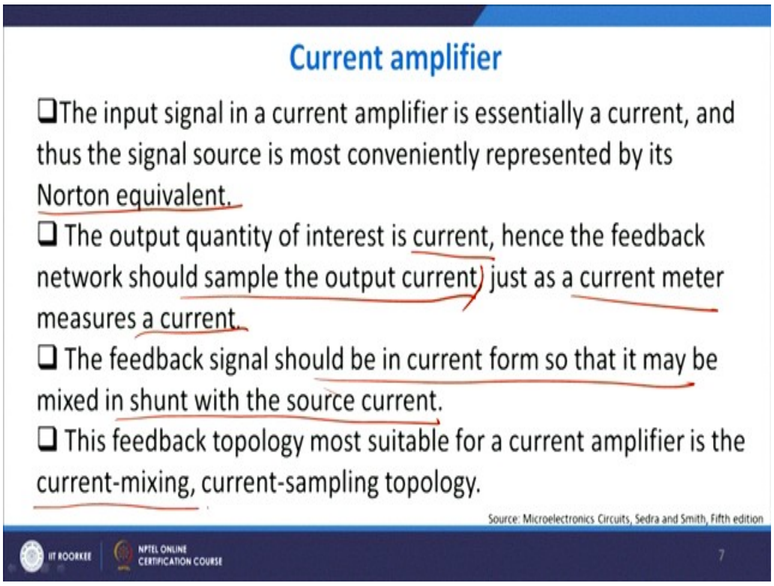

Let me come to the current amplifier here now, first was a voltage, this is the current, so input is a current output is also a current, so and therefore since it is a current amplifier we represent it by a Norton equivalent right, so if it is a voltage, you must be knowing from your basic network theory courses or you electrical technology courses that voltage sources or voltage related can be done very well with Thevenin and current can be done very well with a Norton equipments.

The output interest as I discussed with you is current hence the feedback network should sample output current and therefore output current will be sampled in the output side, the feedback signal should also be a current, so it may be mixed in a shunt with the current source and the feedback, most feedback topology is basically current mixing and current sampling topology and I will see to you how it works out.

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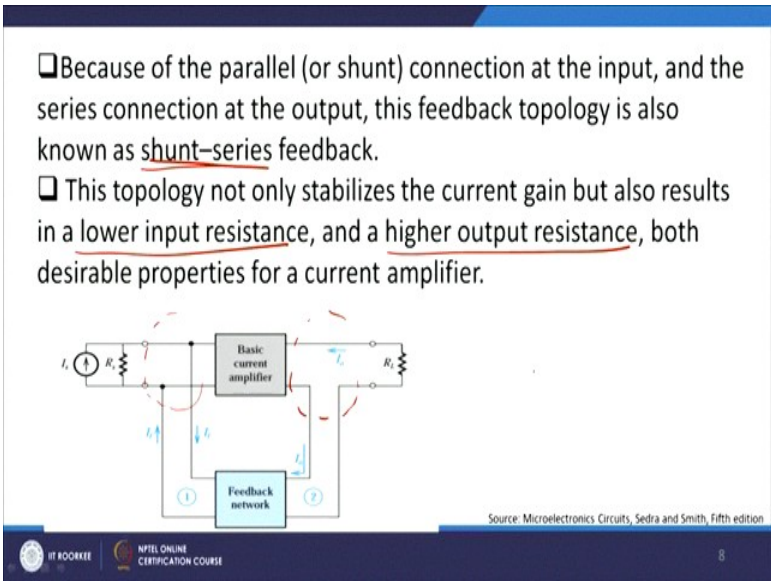

Because if you have understood voltage amplifier, this is just a complimentary form of voltage amplifier, this is basically, the previous one was series shunt, this is basically a shunt series amplifier, so we take series in the output side because we are trying to take out current, so the output side, you will have a series connection and the input side your feeding a voltage, so you will have automatically a voltage consideration right, as I discussed with you, you will have a lower input resistance and a higher output resistance, just the reverse of the previous cases and please understand that when you are discussing a shunt series amplifier for example, you have to be very cautious that it is basically a current source right, it is basically a current source, which you are referring to.

Now if you remember a current source output impedance is infinitely high right and as a result what will happen is, when the current source infinite is relatively high, you want your output impedance to be high with feedback because if your output impedance is high with respect to feedback, you automatically get much more stabilized current source with you and that is the reason currencies feedback or a current, current series helps you to achieve that phenomenon.

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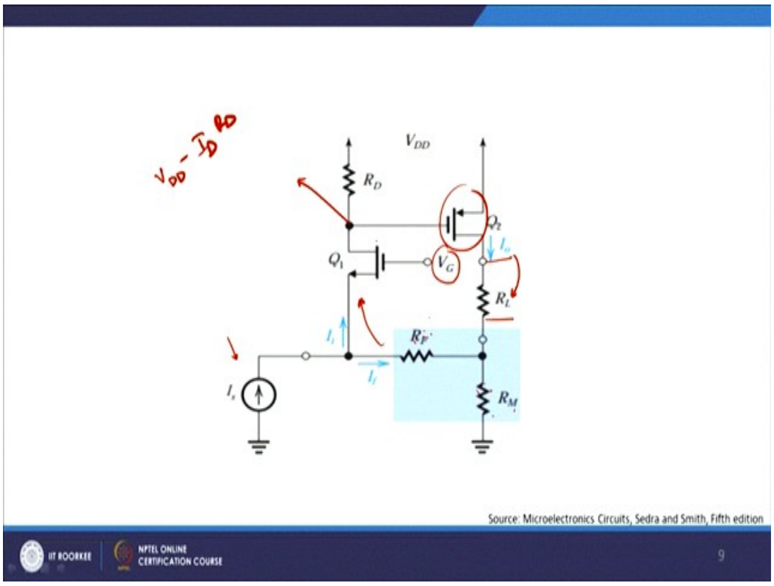

This is an example of your current series feedback network and as you can see here, I am feeding the through a current source here I_s and this is my gate voltage which is fixed, of course, this you as a discussed with you, you will be taking output in the parallel side, so the parallel is basically R_F and R_M are in parallel with respect to each other and therefore depending upon the voltage appearing across R_L, part of it will be divided between R_F and R_M and there will be a negative feedback to you Q_1 right.

As a result this Q_1 will be reversed biased with respect to each other, as I discussed with you earlier also the voltage here will be nothing but V_{DD} - $I_D R_D$ and therefore that voltage will be switching on my Q_2 and there will be current I_0 flowing through this point, $I_0 R_L$ will be the voltage, that voltage will be divided between R_F and R_M and a part of it will be feed into negative feedback of Q_1 and you will get a negative feedback amplifier available in this case.

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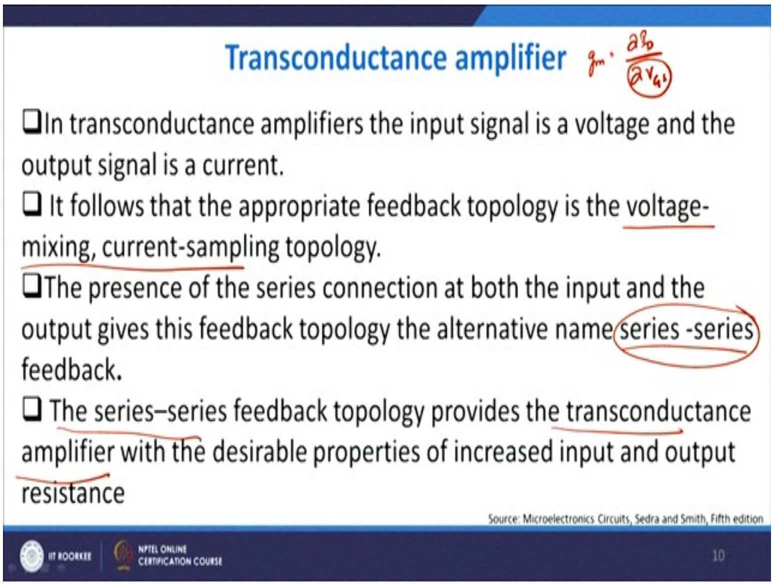

Let me come to the transconductance amplifier, a transconductance amplifier is that when you are, so the first one was voltage, so input was, voltage output was voltage, I used VCCS, which is voltage control current source, then we have a current control, current source, so it is a current amplifier second one, now we will have the first time where the input is basically a voltage and the output is basically a current, so my input, so I will have a voltage controlled current source right, so I have voltage controlled current source, so VCCS right, so the first one was voltage controlled voltage source, the second was current controlled current source, the third one is basically voltage controlled current source.

So as I discussed with you, you will be sampling, you will be mixing voltage and sampling current in this topology, this is also referred to as a series-series, because both sides sampling and input side will be having both side will have series-series combinations with you and that is the reason you can have a, it is also known as series-series feedback topology, provides transconductance amplifier, which means that it takes voltages as the input, remember where transconductance term is coming is basically g_m, so it is $\partial I_D / \partial V_{GS}$ right.

So if you look at transconductance is refer to as g_m and refer to as $\partial I_D / \partial V_{GS}$, so which means that I give an input voltage a gate to source voltage which results in output current right, so voltage to current amplification is been shown in this case for all practical purposes.

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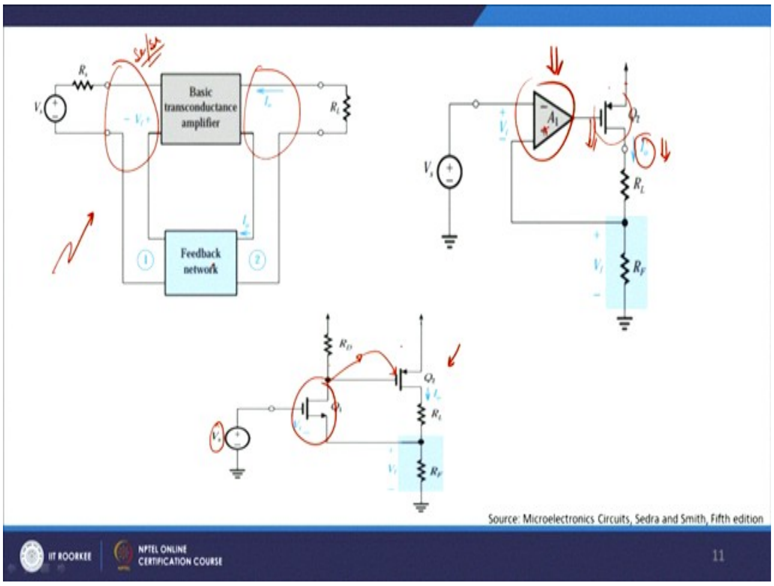

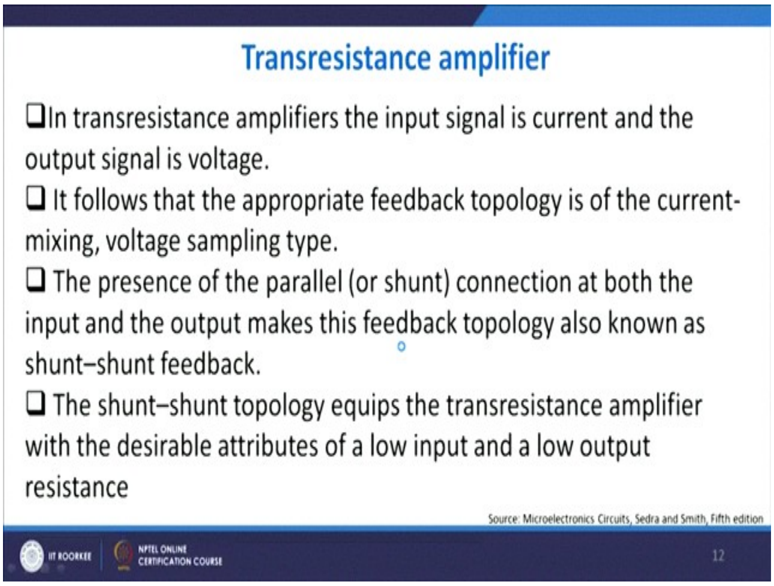

This is an example of a basic topology of your series-series network right, because both sides are series, so you have an sampling side as well as your in mix side, both side are basically a series-series combination here and you have a feedback network coming here right, if you want to do a analogy with respect to real circuits, well, you have an op-amp here and you do have a, this drives your Q_2 right, and as a result, you will see this is basically a P-MOS right.

So and you giving to the negative side here V_I and a positive side is connected to the feedback network, so when this voltage, when this current becomes larger and larger, the voltage drop across R_F increases, this feedbacks in a negative sense to A_I and as a result, the voltages starts to fall, the current starts to fall here right and therefore this is basically an example of a negative feedback network for all practical purposes.

The same example can be seen here as well, where we have replace this op-amp by this Q_1 network here, so this is basically a transconductance because we are giving a voltage source, V_S here, which converts this into a current and that converts into a voltage here which feeds this gate of Q_2 and the same conceptually this remains the same, so you have series-series network here right and then you do have a series-series network which comes into picture.

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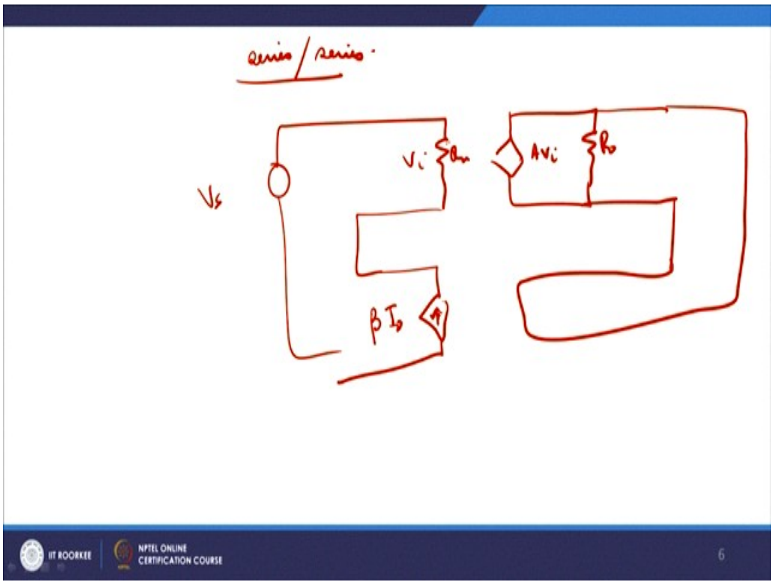

Now if you look at the series-series network, let me just right down for you, the, for the series-series network, if you write down series-series, you will see that I can write down in this format that you have got a currents, your voltage here and then of course you will have a current here and then you will have R_0 here right, this is R_i, this is V_i and the same thing goes on this side and then, alright and then this is shorted and then you have got β times I_0, because this will be a current, this will be a current and then this will be going like this and this is the voltage source V_s right.

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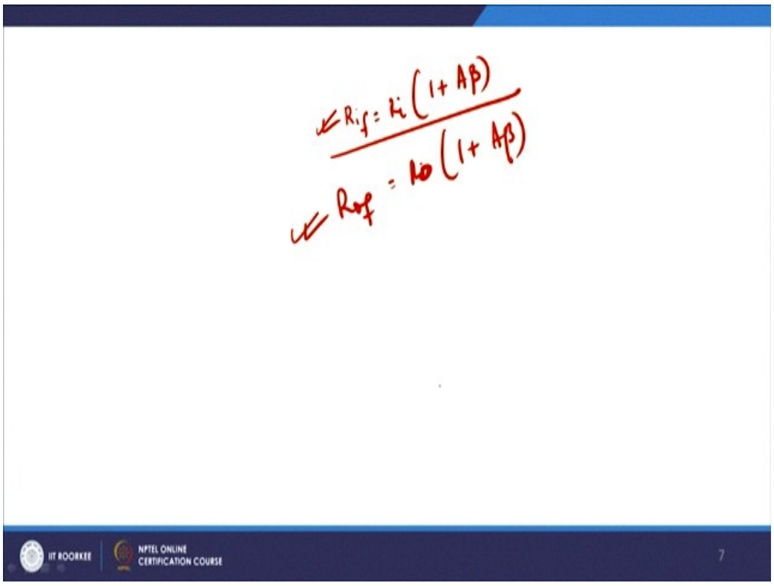

If you take into consideration and do the same formulation as we did earlier, I get R_{if} to be equals to $R_I(1 + A\ \beta)$, so your input impedance also rises and R_{of} is also equals to $R_o(1 + A\ \beta)$ in this case, so your input impedance as well as your output impedance both rise with respect to negative feedback in a series-series combination, so whenever, just you can, even if you do not understand the mathematics of it, whenever you have a series combination, the impedance rises, obviously.

And you have a parallel combination, the impedance falls, now when you have a both side, if you have both side shunt, then both the impedances will fall, both sides series, both the impedances will rise, one side series, one side shunt, the series side the impedance will rise and the shunt side the impedance will fall, with respect to feedback, so that general rule of thumb is most important for you to remember as far as feedback theory is concerned.

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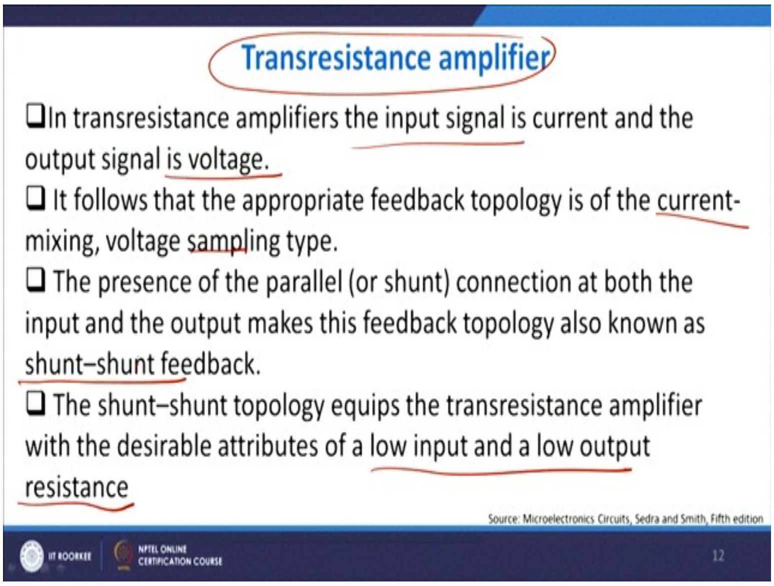

We come to the last part of the amplifier which is basically my transresistance amplifier, in this case, just it is just the reverse of the previous case, where my input is basically an input signal and the output is basically a voltage right, so I will have current mixing and voltage sampling here and it is also referred to as a shunt-shut because both sampling and mixture will have shunt-shunt regulation and so as I discussed with you, it will give you a low input as well as a low output resistance because it is a shunt-shunt feedback resistance.

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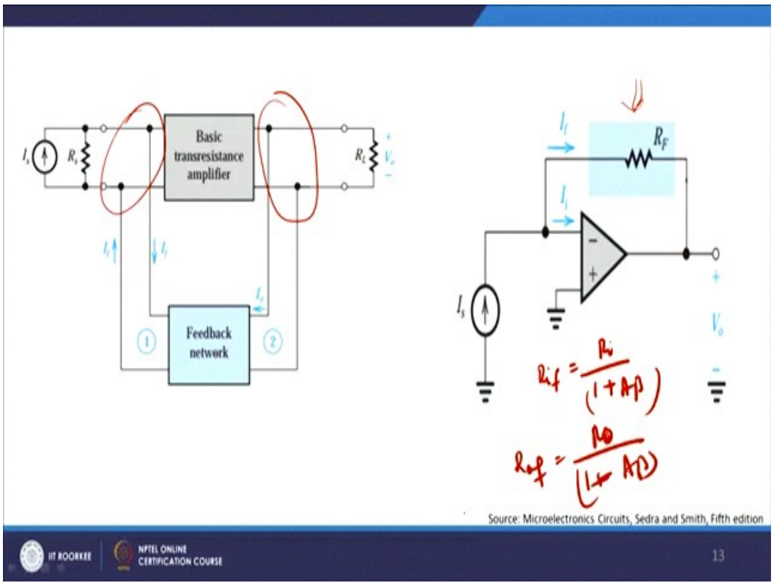

And you see that I am taking a shunt here, I am taking a shunt here and therefore this is my R_S source resistance, load resistance in the feedback network and one of the best examples is basically your operational amplifier design, wherein you will have R_F here which is basically, so you take a shunt here, because you are taking parallel, from here you are taking parallel output from here and therefore you are sampling in it parallel and you are mixing it in parallel in this case, so basically this is a shunt-shunt network.

Here in this case, you get R_{if} to be equals to R_i / (1 + A β) and therefore there is a drop and R_{of} is also equals to R_o/(1 + A β), so in both the cases R_i as well as R_f, your output impedance with feedback actually falls down drastically and therefore there is a decrease in the value of your shunt-shunt resistances in this case, so one thing you should always remember is that in presence of shunt-shunt the impedances fall down, series-series both the impedances rise up, shunt series and series shunt, series will rise up, shunt will fall down and in all the four cases your gain will always drop down, if you have a negative feedback.

So this is a common thread across all the amplifier which you see, you will ask me why this is important? Well, this is important because now you have an amplifier because you remember your maximum power transfer theorem from your basic network theory courses, wherein you need to make your output impedance of the driver equal to that of the load, input impedance of the load for a maximum power to be transferred, so when you have these type of amplifier sitting in between your load and your source, then you can change your output impedances in such a manner that it becomes almost equals to the input impedance of the external load and therefore the maximum power will be transferred from the chip or on the circuit to the load, external load right.

So that is one of the major advantages of having feedback that you can control the impedances in the input and output form by simply choosing the type of configurations which you want to do right and that is the important part which you will see here.

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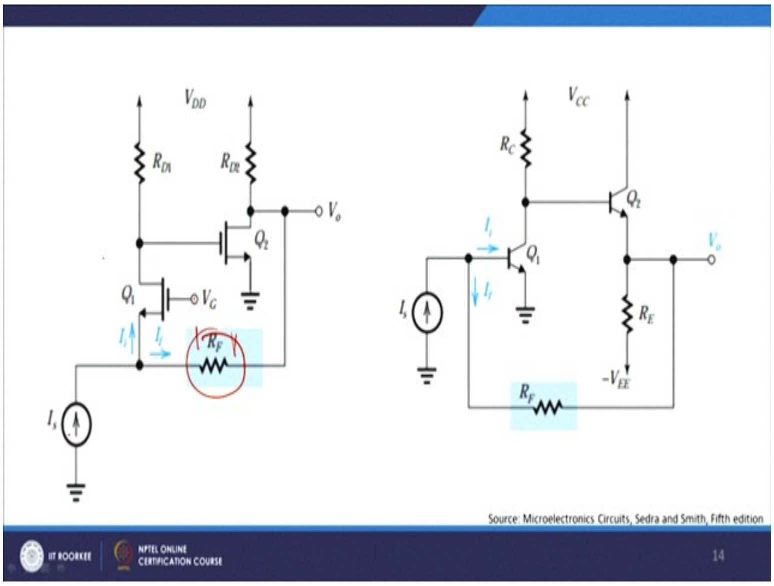

There is another example, I will not talk about the BJT maybe, maybe MOS device you can see here, this is basically shunt-shunt again, so you see here, I am giving you V_G, I am giving I_S as in the previous case, this R_F is basically in series to this one, as a result this voltage across this will be feeding back this in reverse direction and you are automatically get a negative feedback concept in this case right, for a shunt-shunt case right.

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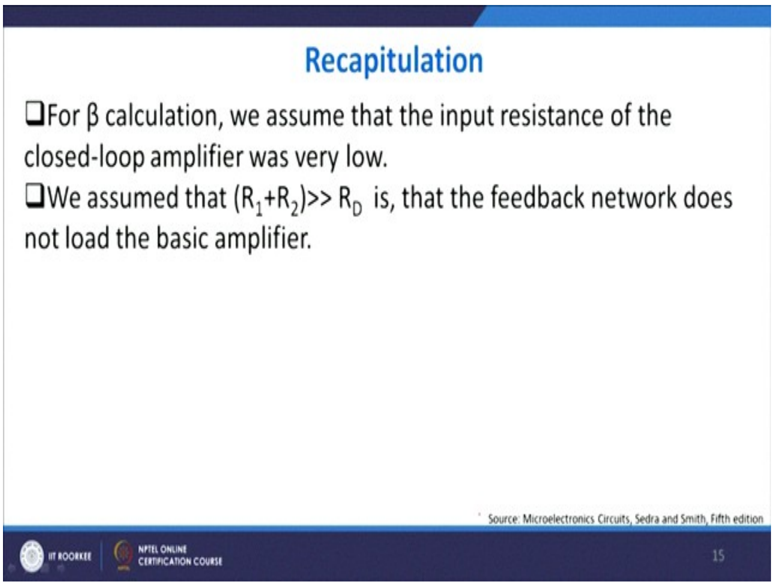

So let me recapitulate what we did. What we did was that two important assumptions, we have taken that there is no loading of the amplifier or the feedback network, in reality not true, you will always have a loading, howsoever the loading is low is still there, the second thing is we have taken them to be almost independent of frequencies, but therefore our definition of understanding here stands very well within the domain of mid-frequency band, where your gain is almost stable with respect to frequency right and at higher and lower frequencies, if you remember, the gain starts to fall down and therefore there these things might not be very valid in the sense.

We have also assumed that the feedback network does not load your basic amplifier, well, that is very important that it does not load and this gives me a proper feedback, advantage of such a network, also studying such topologies is, that you have a methodology with you by which you can vary the impedance levels and input and output of an amplifier and therefore you can have a good driver available with you while driving an input signal to an external load, right, so with this, let me thank you for your patient hearing and we will talk about other topologies in the next module. Thank you very much.