Microelectronics: Devices to Circuits
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Lecture - 45
General Feedback Structure and Properties of Negative Feedback

Hello everybody and welcome to the NPTEL certification online course on Microelectronics Devices Circuits. In our previous modules we have discussed about amplifiers, what are the various types of topologies of amplifier? And we have also discussed single stage and differential amplifiers. We have seen the effect of various components, passive elements to the concept of gain and also cutoff of frequency rule of.

We have also looked into the Bode plot and then compared the Bode plot of each and every configuration of amplifier. What we will do now, we will just change our tracks a bit and start off, if not entirely a different but slightly different module and that module is basically negative feedback. So we will start with the concept of feedback. What is the meaning of negative feedback?

And the general properties of negative feedback. After we have learned that we will learn into various topologies of negative feedback and then take up a valid example. Since we have already dealt with amplifiers we will take up each one of the amplifiers and explain to you how negative feedback helps me to achieve certain important output parameters of the device. So with this in mind this module was developed or discussed.

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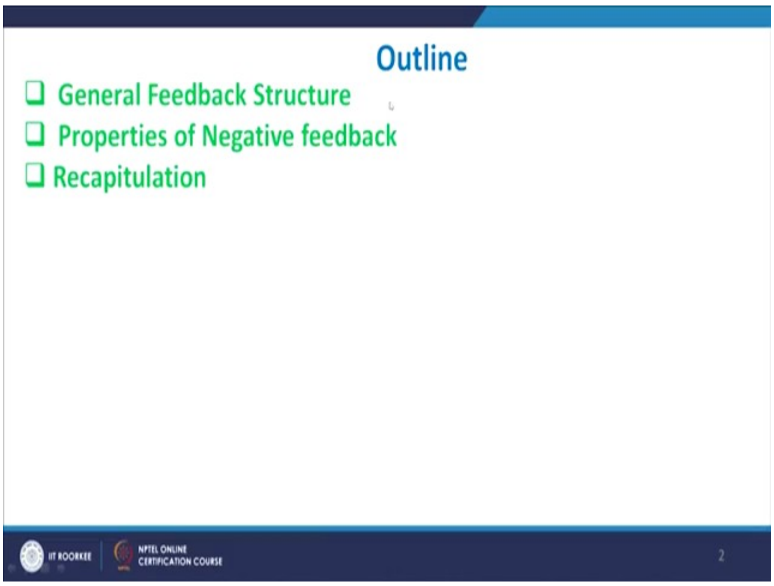

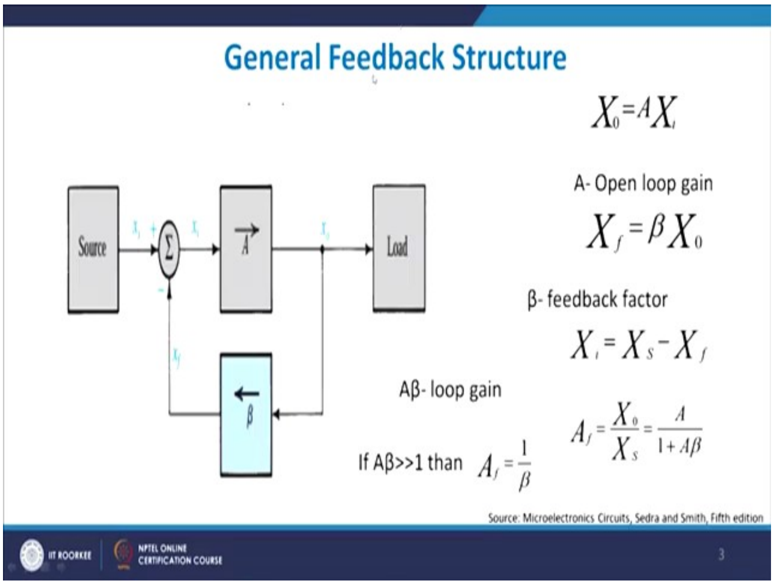

So the outline of at least this module there will be 4 or 5 modules related to negative feedback. For this module we will be restricting ourselves to what the general structure of the feedback, right?

So we will be looking into our general feedback concept which is basically the feedback structure which you will be seeing, right? And then we will look into the properties of negative feedbacks and we will be restricting at this stage only to negative feedback. They will not do anybody feedback. And of course we recapitulate what we have done till now, right?

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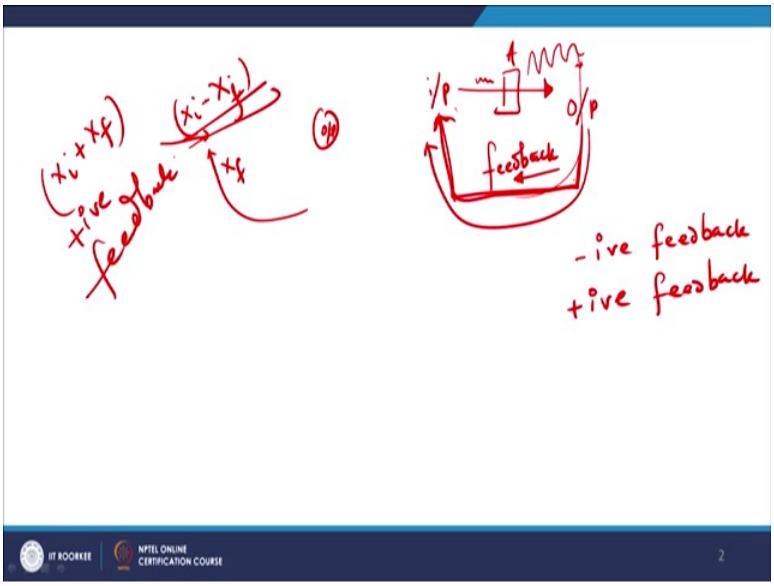

Now let me explain to you why feedback was an important essential part as such in the structure for any amplifier or for that matter any structure. See feedback primarily means that you take a portion of the output, so if I have got some output here I take a portion of that and then feed it back into the input once again, right? And as a result have feedback. I will give you basic examples.

For example say you are going through these NPTEL lecture courses of various professors across India. And you have already seen or understood one lecture. But after about 5 to 10 days you seem to have forgotten it and therefore you want to re- consolidated it. So what you do? You can go back to the same set of modules of the lecture, go through the lecture once again and then sort of give a positive feedback to your mind which means that you are again adding to your memory. Once again the same whole thing. As a result now your memory becomes much more stronger and it is able to retain the data to a larger extent. So this is a very basic sort of a layman approach feedback.

So feedback primarily means that you in a sense are able to get or add on a particular data from the output once and for all. So this path is basically known as a feedback path this mechanism is known as a feedback and this path is known as a feedback path which was from output to the input, right? And of course there will be always an input to output to transition because you need an amplifier.

For example a small input you give you get a very large output here and from the output you take part of the output and you feedback into the input side, right? And we will see mathematically why it is important or why is it interesting to see, why it will be important at a later duration of time? But the general scheme is something like this.

Similarly, so let us, so there are 2 types of feedback which is basically one is known as a negative feedback, right? Another one is known as a positive feedback, right? As the name suggests negative feedback primarily means that you take voltage or current from the output and then feedback into the input such that you abstract it from the main input source. So I have an input current source here I will discuss with you just now.

So I have an input current source suppose X_i and I feedback certain from a path from the output, right? And such that suppose this is X_f the output will be X_i minus X_f then it is referred to as a negative feedback. So if this is 180 degree phase shift between your input and your feedback signal and then if you add or apply superposition principle you will automatically get a lower value of subsequent signals.

Whereas, if they are 0 degree or 360 degree out of phase and you add those 2 signals together what you will get is basically X_i plus X_f, so this is known as a positive feedback, right? So a negative feedback will lower the voltage or current and the positive feedback will increase or improve the gain, right? So with this basic knowledge of feedback or the concept of feedback let me explain to you the general structure of a feedback loop.

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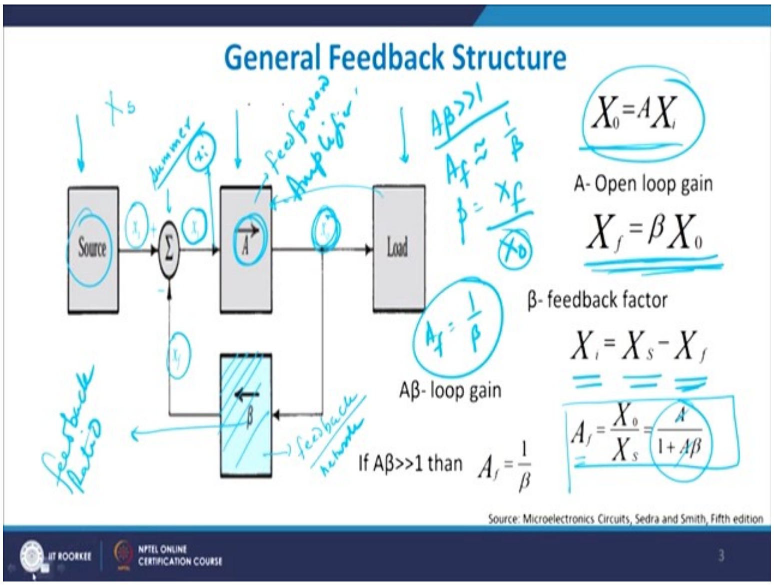

If you look very carefully it comprises of, of course source is there, right? Which will be responsible for giving a voltage or current and there will be of course a load. So for any electronic system you will always have a source and a load. The load might be a resistive load, a capacitive load but primary a load will be there across which you will be able to find out the voltage or current.

Then you will have the amplifier in the middle, so this A is referred to as a feedforward amplifier, right? And its job is to basically amplify signal which is available at this particular point, right? So let me start and go through across the loop, across this. So source gives me, see input signal X_s, right? That is X of s means the source signal, you will have a summer here which is basically summing 2 signals.

And then the output is given as X_i which is fed into A. So output of A will be, feedforward amplifier will be A times X_i. So X_0 if you see is A times X_i. X_i is the input signal, so X_i is nothing but the signal at this particular point or the input of an amplifier that if you multiply with A you automatically get X_0 as A into X_i, right? Now what you do is, your X_0 is here. Now you also have a loop here.

So this blue colored box which you see is basically my feedback gain or a feedback module. What it does? It takes a portion of this X_0 and it feedback's X_f is nothing but the portion of this X_0. So my X_f which is also referred to as the feedback voltage or current is given as β times X_0, so β is basically what? Is given as X_f by X_0, what does it mean? It means that β is a fraction, say β is 0.5, 0.5 primarily means now that my feedback or a feedback voltage will be approximately 0.5 times that of the output voltage, right?

So half of the output voltage is being fed back. So this β element is primarily referred to as a feedback network. So you have got a feedforward amplifier, I have got a feedback network here and we refer to X_f as β times X_0. This X_f gets added up with X_i, so now since X_f we are doing 180 degree phase shift here and adding it to the source signal. I get X_i to be equals to X of s minus X of f, right?

So X of f is β times X_0 and X of s is already available with me. So I can write down A_f to be equals to, A_f means the gain with feedback to be equals to X_0 by X_f. X_0 is what? This by X_s which is basically this. So gain is basically output by input. Output here is X_0, input here is X_s and therefore X_0 by X_s happens to be A upon 1 plus A β. And therefore, if A β is much larger than 1, right?

Then I get A_f to be approximately equals to 1 by β, so why? Because A β plus 1 will be very large as compared to 1. AA gets cancelled out from here and I am left with 1 by β. So the feedback factor or the gain with feedback does not depend upon the gain of the feed forward amplifier it does not depend upon this gain here or the feed forward amplifier it only depends upon this feedback factor, so β is referred to as a feedback ratio or a feedback factor, right?

And as a result we always get that A_f will not depend upon the value of A, it only depends upon β and β is basically passive element which can be very accurately modelled and therefore my A_f which is the voltage gain or current gain with feedback is very stable and it does not depend upon any factor which is temperature dependent or something like this. It is almost fixed depending on the user value.

While designing these we have tacitly assumed to important points that this load actually does not load our amplifier. Quite interesting I will expand to you what does that mean?

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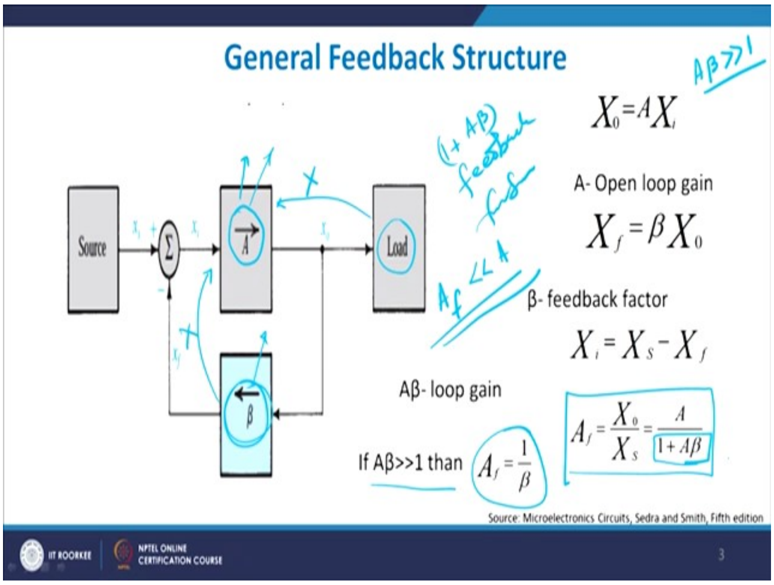

It means that, you have this load, right? We have this load, so this might be resistive load. Now I am assuming that resistive loading or for that matter this β does not load my amplifier in this manner or this does not load in this manner. There is no loading effect, right? So there is no loading, so I am assuming that. Then, second assumption is that my signal through my feedforward is always moving from input to output, so there is no reflection of signal within the amplifier itself.

Similarly, there is no reflection of signal within the feedback network also. So it is always going from input to output in the direction of the arrow here. So it is going in the direction of arrow here, this is going in the direction of the arrow here and that is what I have assumed here for all likely purposes. 1 plus A β is referred to as a feedback factor. Now you see that quite an interesting part here that A_f is given as A upon 1 plus A β and under this condition I get A_f to be equals to 1 by β, right? And β is basically as I discussed with you very small quantity.

Now, since A β let us assume it to be greater than 1, it primarily means that A_f will always be less than A, right? Which means that whenever you have A β greater than 1 you will have automatically this to be denominator will be large and therefore you will always have a negative feedback and as a result you will automatically get A_f less than A.

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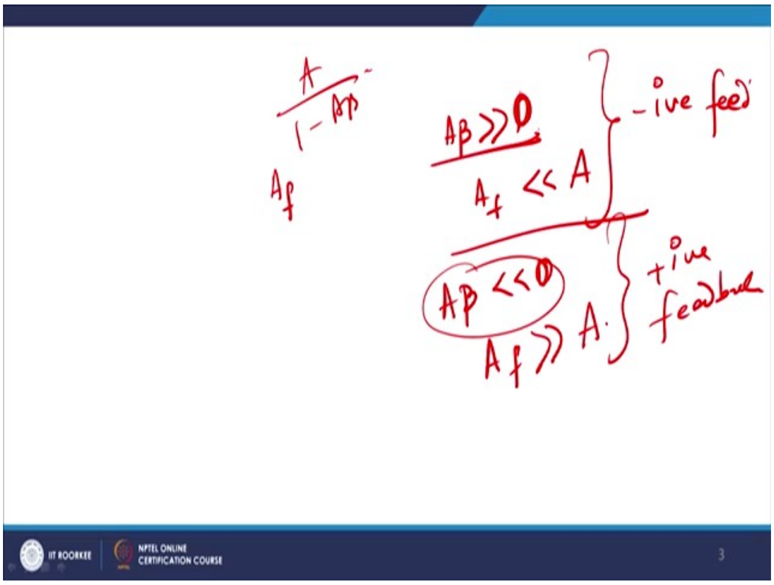

Whereas if A β, so let me write down for you explicitly that if A β is greater than 1 which is in most cases it is then I will get A_f to be equals to much smaller as compared to A, right? And therefore we refer to this as negative feedback. Whereas if A β is less than 1 then therefore A β is negative and therefore A upon 1 minus A β, A_f will be always larger than A. As a result this will be actually your positive feedback.

So whenever you want a positive feedback you have to ensure A β is to be less than 0, so it will be negative quality. Whereas if it is greater than 0 A β that we refer to this as a negative feedback. So any A β product of A β if it is positive, you have negative feedback. If product of A into β is negative you will always have a positive feedback, right? And so this is how it works out in a real sense.

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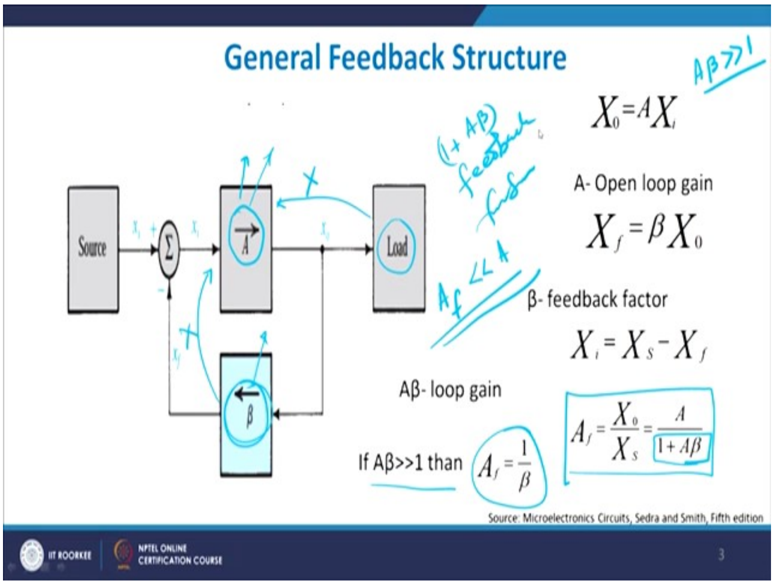

So, now what you see here is that your X_s is almost equals to, so what I see is X_i is basically referred to as the error signal. Now, what will typically happen is that X_s and X_f will be very close to each other, right? This is the source signal and a feedback signal they will be very close to each other and therefore your error signal will be relatively small. And the error signal will go on reducing with more and more feedback loop available and X_s will be very close to X_f, right? And therefore we say that the input signal will track each other. So X_s and X_f they track each other. So there is a tracking phenomenon which takes place between the 2, fine and there is a tracking which takes place between these.

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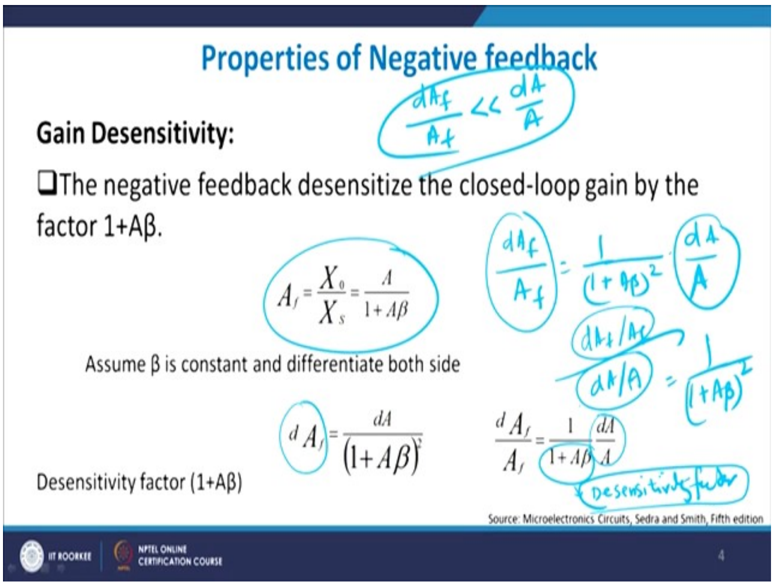

With this general property let me come to the properties of negative feedback. The first property of negative feedback is, the gain is desensitized which means that though our gain reduces in case of negative feedback, but the gain itself is desensitized which means that the gain is now more stable independent of frequency, independent of any of the systems available to us, any of the device parameters or circuit parameters independent of that.

Now, how can you do that? How can you show it? You can just simply A_f is equal to X_0 by X_s which is A by A β. And if β is constant and then if you differentiate both side with respect to A_f, so I get dA_f equals to dA upon 1 plus A β whole square. If you divide this by A_f then this becomes divided by A and I get dA_f therefore by A_f equals to 1 by 1 plus A β whole square into dA by A.

So you see dA by A is nothing but change of the gain of the amplifier, right? With respect to the amplification itself, whereas dA_f by A_f is the change when you have got feedback into consideration. Now therefore, if you find out dA_f by A_f divided by dA by A if you do it. It comes out to be 1 upon 1 plus A β whole square. Now, since 1 plus A β whole square is a very large quantity I get obviously this to be smaller as compared to this.

Which means that, it effectively means that dA_f by A_f will be much smaller as compared to dA by A which means again that you are able to control the gain with feedback in a much stricter sense as compared to without feedback, right? So I refer 1 plus A β, this quantity, in this case to be as desensitivity factor, so this is basically your desensitivity factor and this comes out from 1 upon 1 plus A β and A is referred to as dA by A, right?

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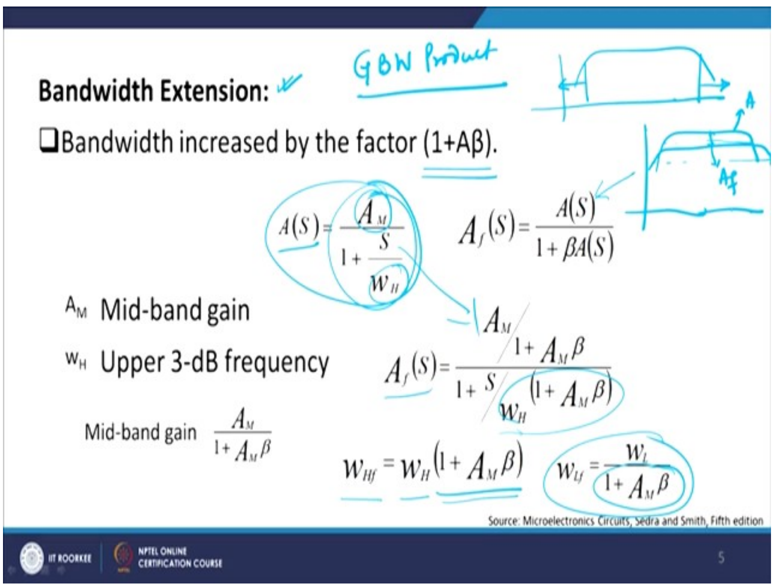

So, just let me explain to you therefore the next issue which is prevalent and that is known as bandwidth extension, right? What happens is that, what we have seen is that the bandwidth increases with A β. So your gain decreases by 1 plus A β but your bandwidth increases by 1 plus A β that I am just doing it to you here. So I already know that gain is basically given by mid-frequency gain upon 1 plus S upon omega H.

If you have with feedback, so this is given by AS upon 1 plus β AS, as we have discussed, right? And therefore A_fS will be nothing but I will just place this whole thing here, right? And I get 1 plus S upon this whole thing here and therefore I get omega of Hf is equals to omega of H 1 plus A β times f and omega L of f is equals to omega L upon 1 A_{ML} which means that my high frequency cut-off point increases by a factor of 1 plus A β and my low frequency decreases by factor of 1 plus A β.

Which means that if you are actually plotting again, so this is my low frequency, this is my high frequency cut-off, this shifts to right by 1 plus A β and this shifts to the left by 1 plus A β. So your effective bandwidth becomes, so what happens is that your, so, say this is your without feedback, right? And then with feedback the gain will drop down, right? But your bandwidth will become larger. So this is A_f with feedback and this is A.

So gain has come down but your bandwidth has become larger as compared to your with of course with the (())(18:37), right? So this is one thing such that and therefore your Gain Bandwidth Product is always constant. So the gain falls down but the bandwidth increases by certain factor such that the product of them is always constant with respect to each other.

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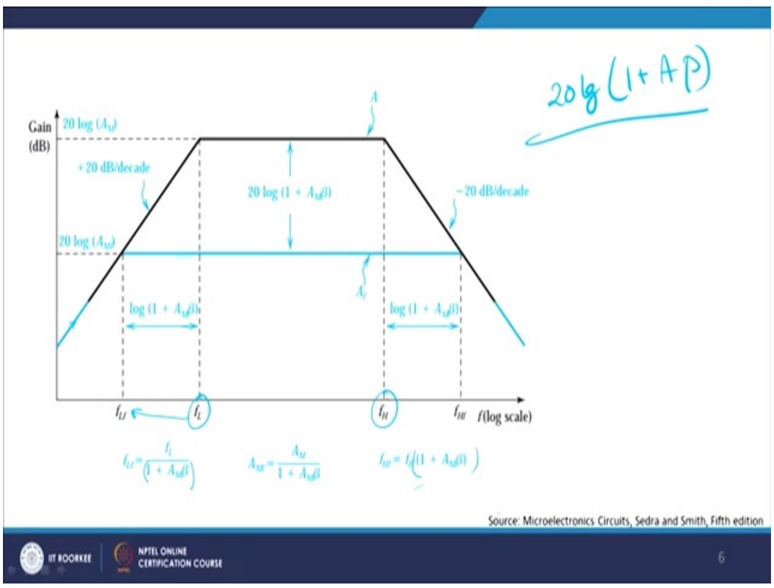

And that is what you see here, this is without feedback, right? And as you apply feedback this shifts to the left by virtue of the fact that you divide it by 1 plus A_M times β whereas this case shifts to the right by a factor of 1 plus A_M times β. So you see that with feedback the blue color with feedback is actually having a much lower drop. So your gain drops by about 20 log of 1 plus A times β, right? And you have what? 20 db gain here and 20db drop here. So that makes my life difficult in the sense that it makes the game fall down drastically.

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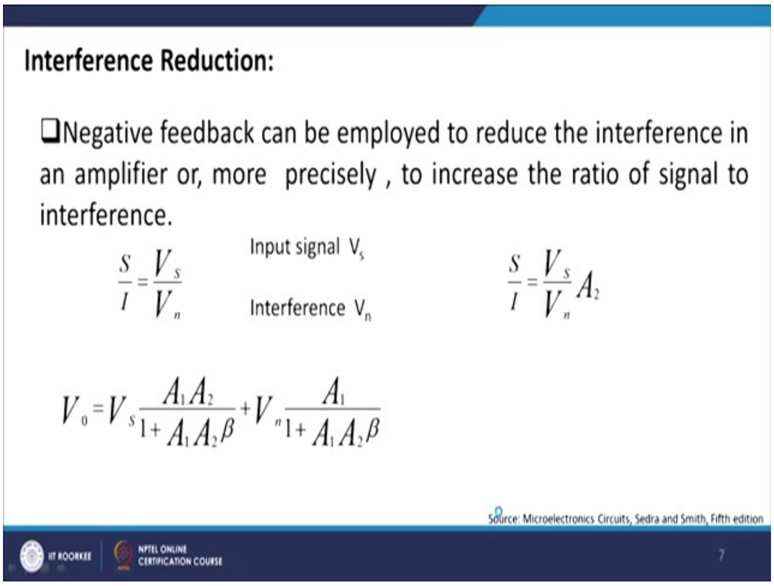

We come to the negative feedback concept and show to you that this also helps you to reduce noise reduction. So noise reduction is also there whenever you do have a negative feedback. How do you do that? Let me just explain to you how do you do that. It will not be visible here but let me show it to you.

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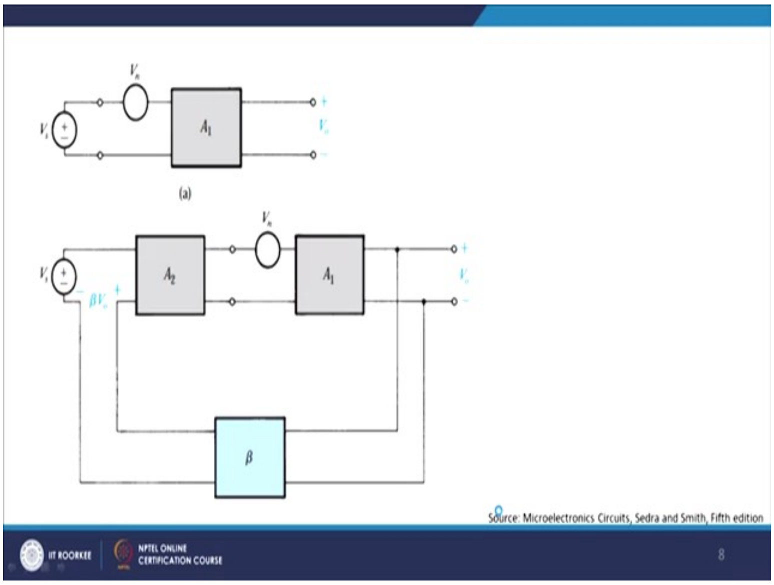

So I have got amplifier A_1 which is basically a noisy amplifier and I have a source signal here and at the input referred noise of this A_1 is basically V_n. Now what I claim is, that if I had this A_1, right? It should be preloaded by an amplifier A_2 whose noise source is almost 0, right? If this is the case then I automatically get a much better profile as far as designing is concerned.

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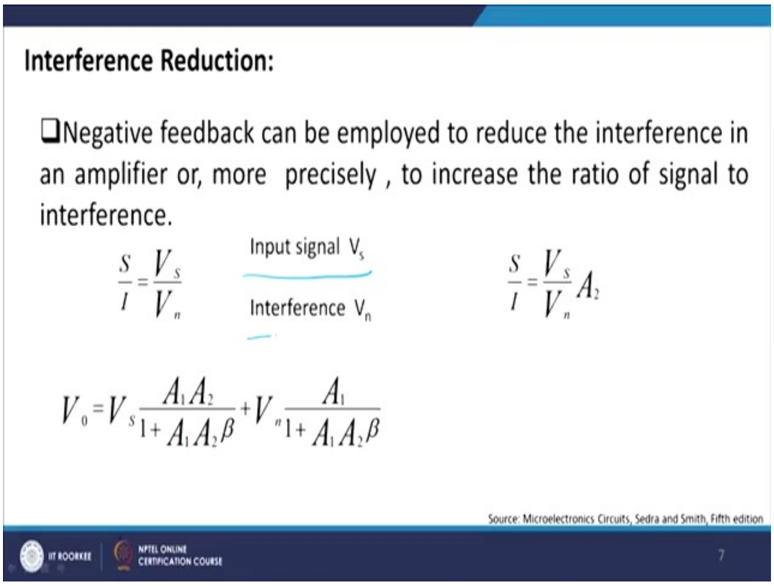

So, I will just show you what I am trying to tell you here that I have an input signal which is Vs, I have an interference which is V_n, so this is my noise voltage, input referred noise voltage. So I have Vs by V_N which I get and therefore I signal by interference S by I is Vs by V_n into A_2 because A_2 is nothing but this signal where am getting it.

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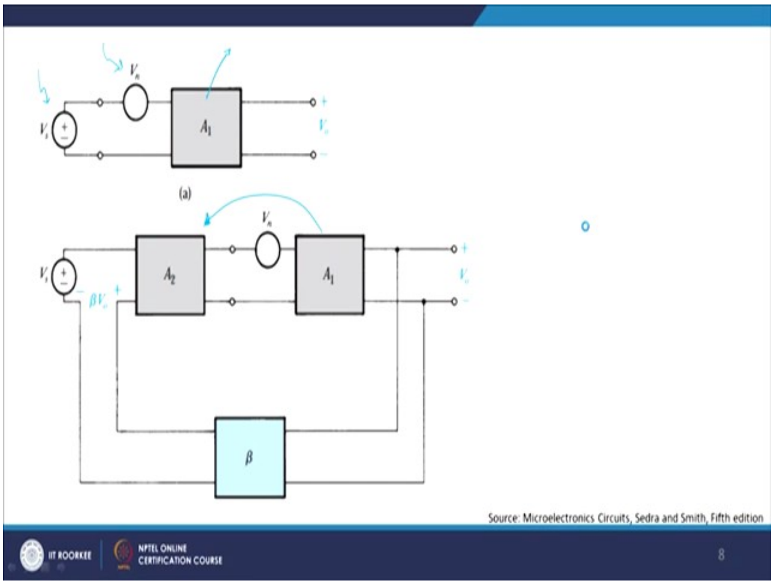

So I am a negative feedback concept here. I have a β here, I have got 2 transistors A_1 and A_2 and therefore you see V0 will be nothing but Vs times A_1 A_2 upon 1 plus A_1 A_2 into β, why? Because now you see your overall gain in the feed forward part will be A_1 into A_2. So wherever you had A you will be replacing it by A_1 and A_2, right? So that is what you are doing here.

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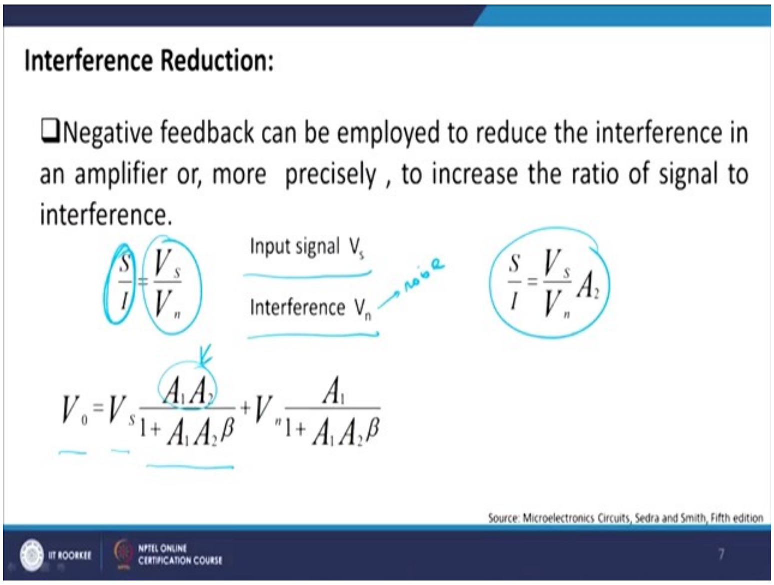

You are replacing A by A_1 A_2, here also replacing A by A_1 A_2. So what is happening is, your source signal is getting multiplied by this thing where is your noisy signal is only getting multiplied by A_1 upon 1 plus A_1 A_2, why? Because noisy signal is coming between A_1 and A_2. So only A_1 is responsible for increasing the noisy signal and A_2 is responsible for increasing the source signal and as a result your signal to noise ratios will be improved provided you are able to sustain this into consideration.

Now, if you look carefully here, so this if you take Vs into A_1 A_2 upon, if you take this plus V_n into A_1, if you take this as common factor and then 1 upon 1 plus A_1 A_2 by β, right? So you see if your noise voltage increases this factor will become larger, right? But if you are able to make your A_1 small than the noise voltage effect on the overall output voltage will be bear minimum provided you are able to reduce the value of A_1, right?

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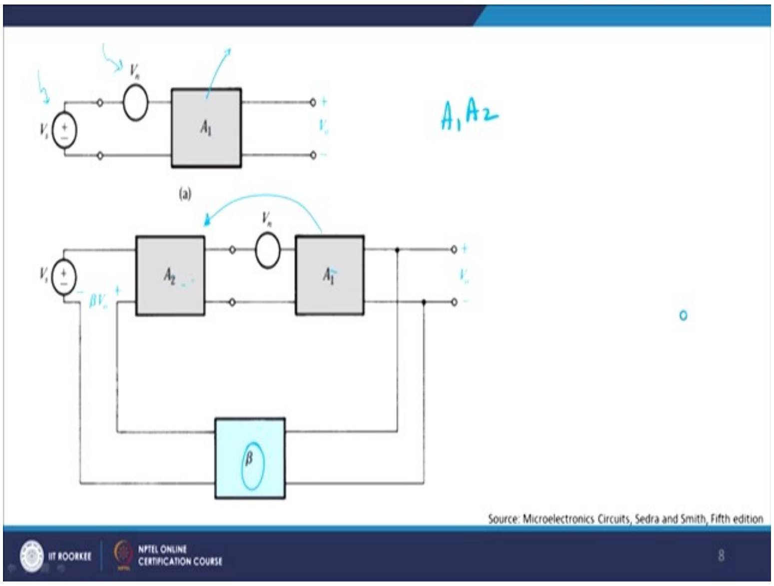

So what you do is that you make this amplifier a very low gain amplifier almost near to unity if possible and make this which is noise free amplifier a large amplification. Once you are able to do that you are able to sustain a much larger voltage in the output side. So also this helps you to do a non-linear reduction in non-linear distortion properties what happens is that, for example if you look at A it has got (()) (23:04) non-linear at this particular regions, right?

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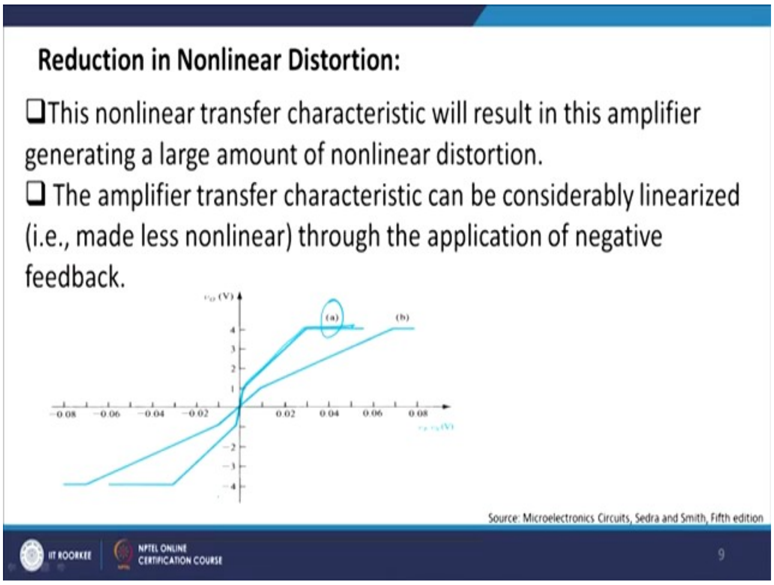

So when you do a negative feedback your non-linear distortions get reduced drastically, right? This is feedback and this is without feedback. With feedback it is almost linear in dimensions and nature whereas here you will have peace wise linear approximation because of, so when you apply a negative feedback distortion also reduces, right? The non-linear distortion also reduces drastically.

So this is one of the advantages of negative feedback as far as this is concerned. So with this let me wrap up this module and explain to you the other factors that while we have understood what is negative feedback, we have understood the topology of a basic signal flow, just to give you an idea this is also referred to as a signal flow diagram.

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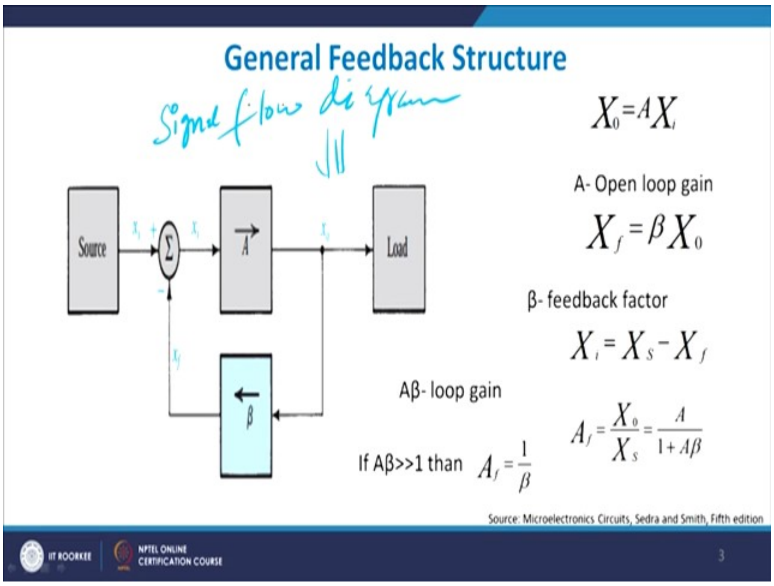

This is referred to as a signal flow diagram. So from signal flow diagram we were able to look at the general feedback structure.

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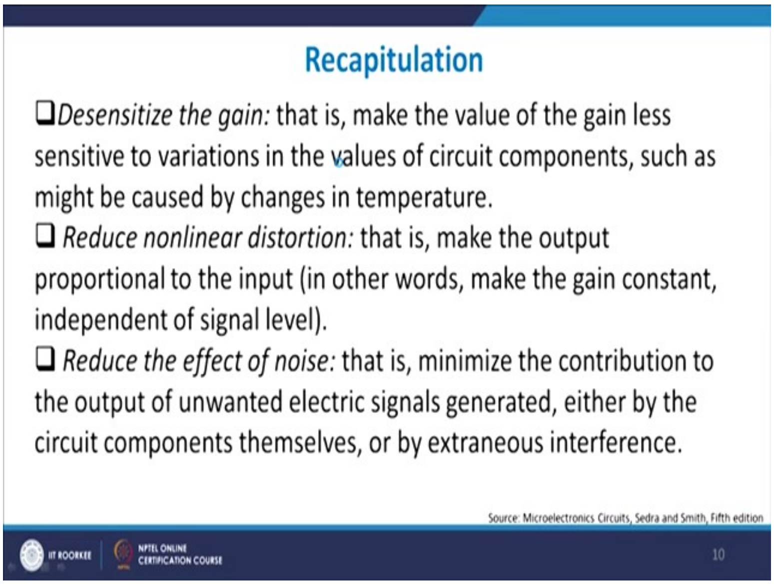

We were also able to see what are the advantages for example my again reduces but my again becomes less sensitive. So desensitization of gain is one of the important point and it becomes less sensitive to variations in temperature and so on and so forth. There is also a reduction in the non-linear distortion, but it also makes my bandwidth increase at the cost of a lower gains such that game into bandwidth is always constant.

And also if we reduce the effect of noise, but that is not so straightforward in that you have to reduce the gain of the noisy amplifier and improve the amplification of the preamplifier. So A_2 is referred to as a preamplifier, please understand this point also, that A_2 is basically referred to as a preamplifier. So preamplifier should be actually less noisy, but its gain should be very high and A_1 should have a much smaller gain as compared to 1 and your noise signals will be suppressed if you do a this thing.

So we have been able to see the advantages of negative feedback when we come next time, when we join next time we will be able to handle the other products of the system also and see the advantage in real life in real amplifier design, right? Thank you for your patients hearing.