Analog Circuits
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Lecture-18
Feedback Theory

Okay, we start with the analysis of a feedback amplifier, general amplifiers. The basic amplifier is unilateral.

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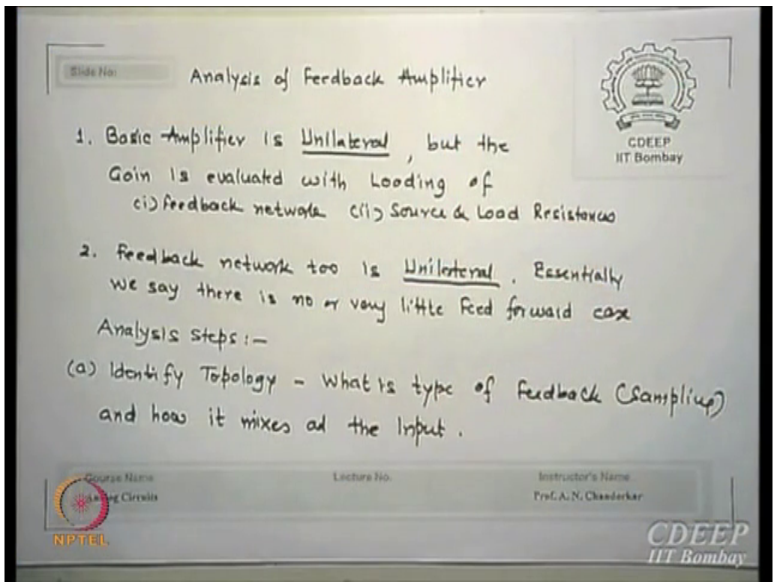

What does that mean that if you give an input you get an output okay? It does not mean if you give an input at the output you only see anything at the input. So, it is a unilateral device or circuit however please remember that when we evaluate for basic amplifier design even with feedback if I want to know what is the basic amplifier with feedback. So, the first thing I want open loop amplifier.

But in evaluation of gain for open loop amplifier please do not neglect the loadings of components which you are going to create there by feedback. So, what essentially we is saying that even if we are looking for open loop circuit the effect of feedback network and source and load resistances be taken care in your analysis for open loop. So, otherwise you will say you remove RF or whatever resistance or impedance you are putting and just do not solve for it.

So, use that impedance well in the circuit for open loops we will see how we will do it. We also assume in most cases that the feedback network is unilateral. Essentially we say there is no very low there is there is no or very little feed forward in this case. So, when I have again and again saying I am actually first trying to find the open loop gain, why? Because the closed loop gain with feedback is open loop gain divided by 1 + A beta okay.

So, I want to know what is AOL but in evaluation of AOL, I do not want to neglect that circuit parts or components which would have come after the feedback. So, that those I want to retain some way. So, I have given I am writing down here for you or I written down for you the steps which you can follow whenever such analysis has to be performed. So, the first thing in any feedback amplifier is to identify the topology.

What does that mean? Whether the, what kind of feedback is it is? What is the sampling kind? And how it mixes at the input whether it is series sample, shunt sample, series mixed or shunt mixed and if we know that then our analysis will become relatively simple. If you know which kind of amplifier we are considering okay. So, first thing is given a network on amplifier circuit first find which kind of feedback topology this amplifier has.

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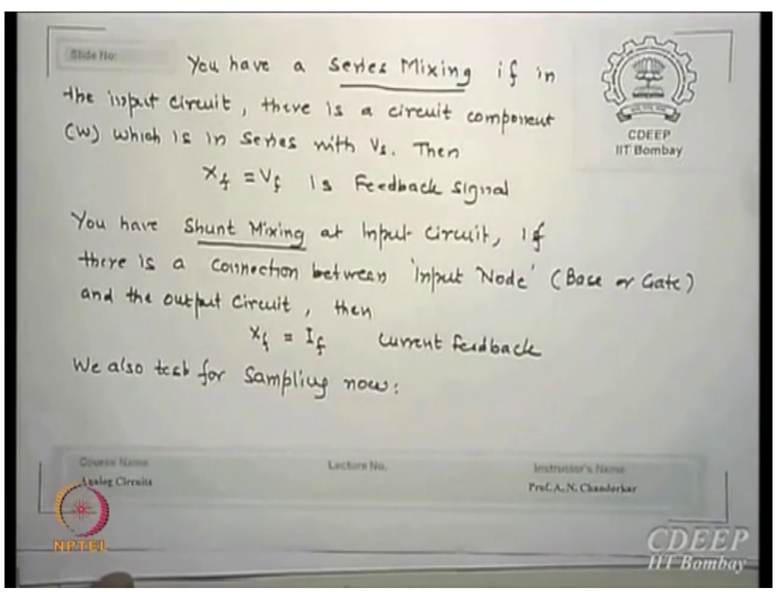

Then let us say for example if you have a series mixing and if they in the inputs are kept in the input circuit there is a circuit component say W which is in series with the signal source then the feedback signal is $X_f = V_f$ is the feedback signal okay. So, we will see how out of what does that mean? However if you have a that; please remember if it is a series connection it must be voltage in series to the source okay. Whenever it is series mixing it has to be a voltage source in series to the signal source that is what we described as series mixing. However if you have a shunt mixing the feedback must return the current okay.

Because at that time the current will only allow you to shunt across the input terminals and the source will be current source. So, depending on the kind of input you see whether you have a feedback which leads to shunt mixing or series mixing first you should find. If you know series it is the voltages in series in the feedback. If it is shunt then it must be the current which is shunted across. Those topologies which are given you four figures please be revisit them again and check what I am saying is that okay to you okay.

This is just whatever we did in nutshell I am not saying so that this is the method you should follow in any amplifier analysis and later on designs. Having seen whether it is which kind of mixing, we also will like to see which kind of sampling okay. I repeat if the sampling is I see is the mixing is series the feedback must be voltage. If the mixing is in shunt it must be a current which is in shunt to the input circuit is that okay.

Typically shunt circuit will occur when the current has to be brought there what kind where it will current can they mix with some other current, at a node, is that correct at a node. Voltage can be in series when it is in the mesh is that correct only then it can go into the series of this source. So, think of it whenever there is a node connection feedback it must be shunt kind, whenever it is in loop kind of input inside that loop it must be a series feedback which must be voltage is that okay.

Okay so, obviously in a mesh you cannot have current additions there okay. So, this is trivial but must be understood and must be solved correctly because otherwise there will be a mischief in actual solving.

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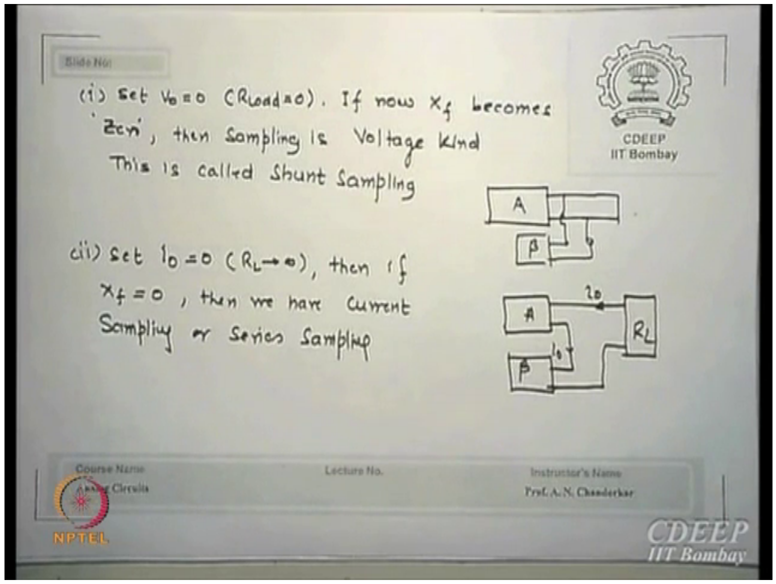

So, having said that this is how it will mix to get the sampling set the output 0 which is your output okay essentially you say short the load. If now Xf becomes 0 that is if output is V0 in your shorting and now in no feedback will go because part of V0 was to be fed and you are shorted addictive. So, a feedback goes to 0 then you must be obviously voltage kind of sampling which is essentially shunt sampling across the output, is that correct.

Across the output main shunt figure is shown here this is my I shorted the output and as soon as I shot the output the feedback goes okay. I said something by V0 and V0 is not there, there is no feedback there. So, once I noticed this kind of circuit I shot and I say I do not see any feedback then I say I must be having a voltage sampling which we define as shunt because it is shunt to the output there is a shunt sampled.

On the contrary if I make a, I0 0 which is I open circuit the resistor output load okay. Well if Xf becomes 0 and it must be in series to do this because then your open circuit in the loop and therefore no current can go and therefore we say you are series sampling and that is what the current sampling will be, is that correct. So, the conditions you should do first see at the input side whether your source is getting in the loop of this then it is the series.

If not it is shunting then it is a current, so slowly shunt some mixing we know by making V0 or I0 0 if your feedback goes to 0 we know which kind of sampling we are done okay. So, having now known whether it is series-series amplifier series-shunt amplifier shunt-series amplifier or a shunt-shunt amplifier I know which topology now I am at okay. So, given a circuit first thing you have to find by doing this simple this which topology we are; because you know in the circuit this kind of network will not be shown.

It will be a formal circuit with some components connected left and right okay. So, from there you must be able to figure out which topology we are working at okay. Also we have seen depending on the topology input resistance and output resistance change in some cases it increase in some cases it decreases. So, the topology will also tell you how the input output will respond to the input side addition anything coming or output side when it is driving.

So, some idea of Ri, Ro also should be immediately known because you know now that what kind of amplifier I am working that is that okay. Now these issues a priori you do it because as soon as I put a network or circuit you should be able to find what I am. I will give an example do not worry that this is the end of it.

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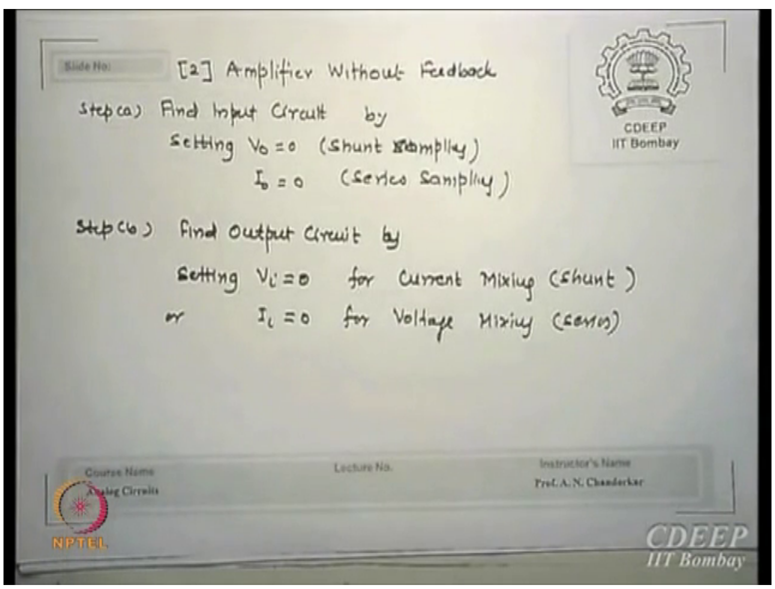

Now the next step having found the topology I want to find amplifier without feedback and I just said to start with what I am saying even if I am want the open loop circuit I do not say feedback network has been removed. is that point clear. Feedback network has been I am not saying it, I say I want feedback be broken but the effect of those components still be taken care okay. So, let us see what I am saying little later.

Step a in the input circuit if I am looking for what has happening because of the feedback in the input circuit. If you have a shunt sample make V0 0 and if it is shunt sample make I00. Essentially the feedback you want to remove ok. Then the step b first I figure out something where I will give an example to find an input circuit make V0 0 if it is shunt sampled make I00 if it is series sampled. Now to get an output circuit what do I do make V input 0 okay.

If it is current mixed and if it is voltage mix remove the input current. So, either of the case you all only find the topologies of which you know which ones have to be shorted or open as for the conditions we are done okay. Now these two conditions once we do (FL) people normally do analysis without knowing also its answers come correct nothing big about it. But methods why they are shown these methods because they are short they, will simplify your job.

That is the only reason we show all the methods otherwise what is the big method is put whole equivalent circuit and solve. It will always come fight the end of the day. So, to even do this can I small simplify a few things beforehand I do that ok that is the trick we want to use. So, what is that I am trying to say I want to find the closed loop gain with feedback by not directly calculating with all components present as normally should have been by Kirchhoff's law?

What I am going to use the expression for closed loop gain open loop gain divided by 1 + AOL beta that is the expression I had derived for feedback. So, I say okay I will calculate AOL, I just calculated beta I substitute ok and I am sure that calculation of AOL will be much simpler than calculate off to total ACL this is my belief if your; is not your beliefs finally all of it no one no one is saying you have to solve ACL by first getting AOL you actually can solve full network.

And once you write an equivalent circuit you can always find V0 by Vs, is that clear. So, there is that method stands anyway. These techniques are only trying to minimize the effect. So, if I get my AOL fair enough I know my beta then AOL upon 1 + a beta is my closed loop gain feedback gain. So, I just want to do the two steps now.

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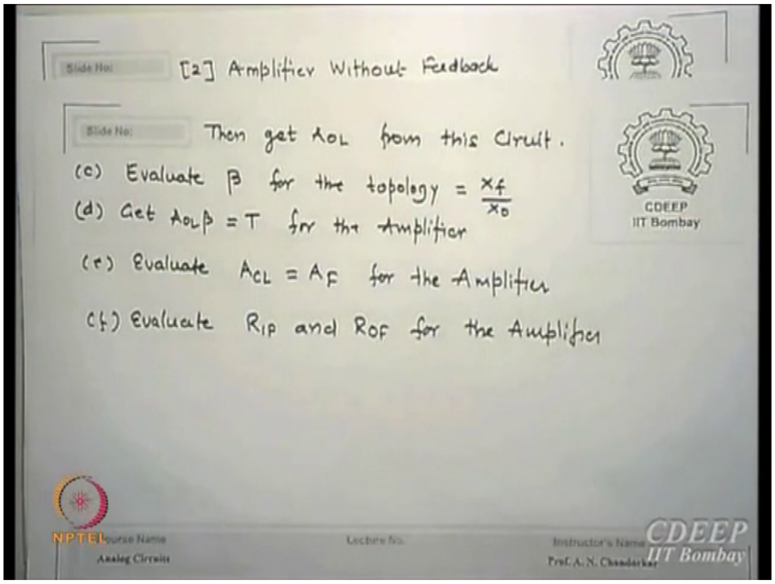

So, one of the step I should say once I know what is Xf because I just know sampling as well as mixing so I know what Xf I am talking then what X0 I am talking, is that correct. So, the ratio of Xf by X0 is your beta please remember Xf, Xs is the return part coming from V0 side or I0 side it can be resistor it can be conductance or it can be voltage ratio or rhythm or current ratio is that clear. 4 possibilities can exist.

I may return as the I, V may return as a V, V may return as I, I may written as V. So, in any case there are four possibilities of the beta value, is that clear. Because A beta should not have; A beta should have what in our units irrespective what is A? Whether it is current gain voltage gain transconductor what should be the A beta? Non dimensional or it should not have unity that means a beta must be opposite that of A in the units is that correct.

Therefore done only it becomes dimensionless this is essentially what we are saying okay. So, first find beta. Then get AOL beta if you already calculate AOL then you get AOL beta that is T function. Evaluate loop which is also in some books called AF for the amplifier by what function AOL upon 1 + AOL beta is the correct closed loop gain so evaluate that and then also evaluate as we did already earlier.

What is it is RI F and what it is’s always RO F. These are the three parameters of interest to us other than frequency response which we will see later. For normal after the first thing I want to know again what does our gain I got and what are the input output impedances I am going to get. So, is this method clear to you? So, what is first thing we will do? First thing we must find the topology, to give the topology we must find what is the kind of mixing and what is the kind of sampling.

From there we know what is the feedback going on okay, correspondingly you actually find your beta using the network available of feedback and that is what to get AOL will see with the example that will prove my point. Fins AOL you know the beta and therefore you know the closed loop gain. But by the same circuit you can always get your RIF as well as ROF let us do one example which will clarify what I am saying okay.

In normal cases unless said otherwise assume feed forward is nickname unless and otherwise. You can see the, it is like superposition we always solve for feedback okay and if there is a feed forward which turn will appear in gain function, 0 will appear. So, that means there is a partial feed forward path is going on is that clear to you. So, if there are 0’s this means there is some feed forward is going on anyway is that clear otherwise poles will always give you feedback is that correct. This is what the technique is to know what whether we are doing correctly or okay.

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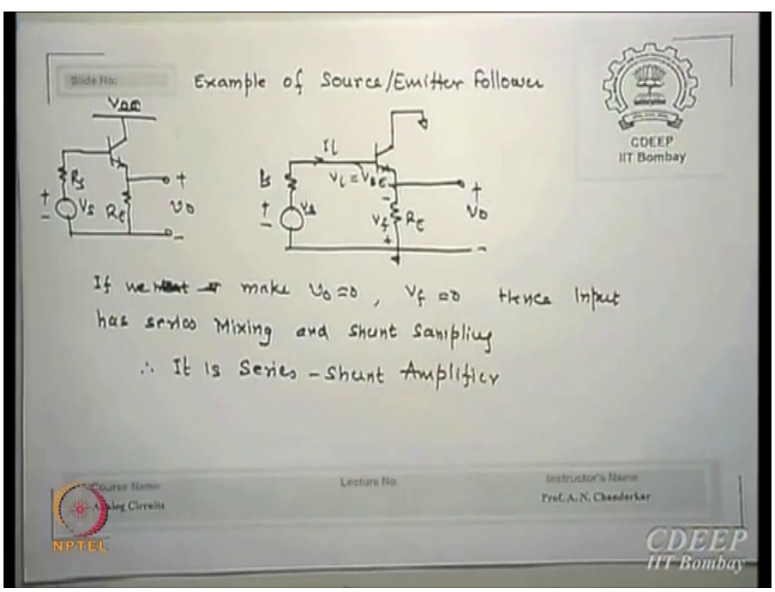

Here is an example which is very simple and very easy to understand. Let us say I have a source follower I saw the emitter follower which essentially called common collector circuit. Please remember the other name of emitter follower is common collector circuit okay collector is grounded at the VCC ground and means to go to VCC. There in the source VS there is a source resistance RS, there is a load which is RE.

Please remember this RE itself is a load for source amplifier. There is no additional load it may have also but right now far in this will just take RE and output is taken across this. Equivalent saying this is the VBE for the transistor. Please remember RE is common to the mesh of the voltage drop across RE is common in this mesh. Do you see this mesh? In this mesh the drop across RE is in series with VS.

So, what mixing I am doing series mixing okay. However if I shot V0 nothing goes inside the feedback. So, what sampling I am doing? Across I am sampling. So, what is this shunt sampling and series mixing, so what amplifier I have series shunt amplifier is that clear. If I shot V0 no feedback drop across RE becomes 0 so nothing changes in the input no feedback in the input. So, it is essentially voltage feedback which is shunt across the output okay. So, it is a shunt sampled at the input side.

If you see this mesh this drop across RE is in series with the source. So, you have a series mixing and shunt sampled. So, it is series shunt sample or it is essentially called voltage amplifier, it is called voltage amplifier. What is series we said then the feedback signal is in series with the source and that can only be voltages, not current cannot be in series with something ended. So, only voltage can mean series.

So, if you look at this input loop input circuit the drop across RE which is common which the feedback V0 is by this much is the drop across this VF that is in series with the signal, you can see this series. In this is actually twice 1 because of Ii and 1 because of this, but for the input side this color takes care of the drop across this. So, whatever voltage VF here is in series with the signal, whenever there is a mesh the two voltage sources can be in series.

They may be + or - depends on the signs but they will be in series if you are a node like this there is a current here, there is a current here something like this what is the mixing done here? I can I can or I brought let us say this is 1 I1, this is I2 and this is I3. So, I3 is I1 + I2 so it is no mixed that means current is getting mixed is that correct which is essentially shunt to the input circuit, current is always shunt, source is that correct.

So, we say whenever there is a current feedback going on at the series this it is the shunt feedback going on shunt mixing is going on. If the voltage across the feedback network is in series with the source then we say it is a series mixing is that correct that is the voltage mixing. Please remember series cannot be crunched it always will be sure voltage is so it is therefore voltage input voltage output.

So, what amplifier I am looking for if voltage amplifier V0 by VS is my A is that correct that is the way I have figured it out. So, it is a series shunt amplifier which we are already done earlier but let us do it again okay.

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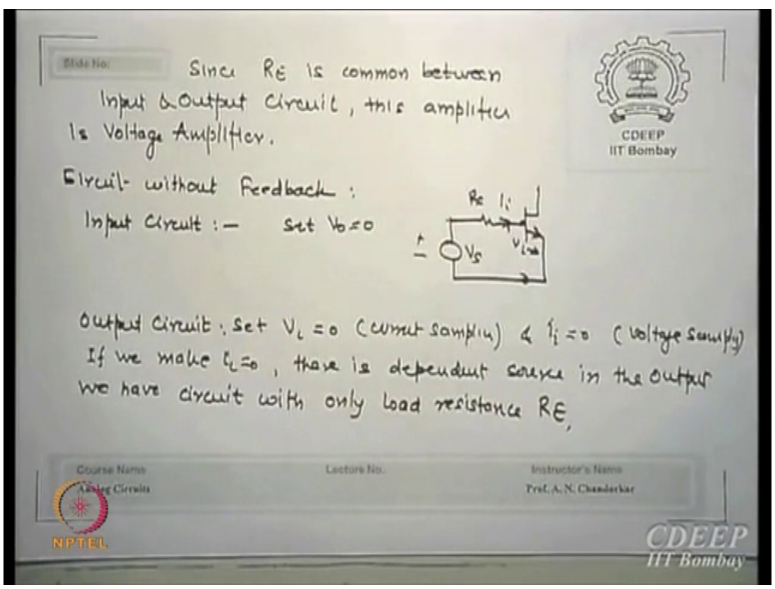

Just to show you again since RE is common between input and output this amplifier is the voltage amplifier circuit. Now we want to find circuit without feedback okay, I repeat, I want to find AOL which is I say circuit without feedback but what is the condition I am still forcing you do not let the feedback components. Because if you neglect them then the feedback part will all look a normal amplifier there is no question of feedback there.

So, if we say at the input what is the condition I said to get an input circuit short the output is that correct, short the output, so I set V0 is 0? So, what things get shorted at the input side the VF because if V0 is 0 Re does not exist it is a short circuit? Please look at the circuit again, if V0 is shorted here this is grounded. If V0 is grounded this is grounded okay. So, in the input side I have RE bypass now by short okay, this is my input circuit.

Now this is my input circuit now to get an output circuit what is the condition I told you? Short input, so, okay if I shot input Ii is 0 if you make Ii 0 there is dependent source on the output we have circuit only in the; what happens here.

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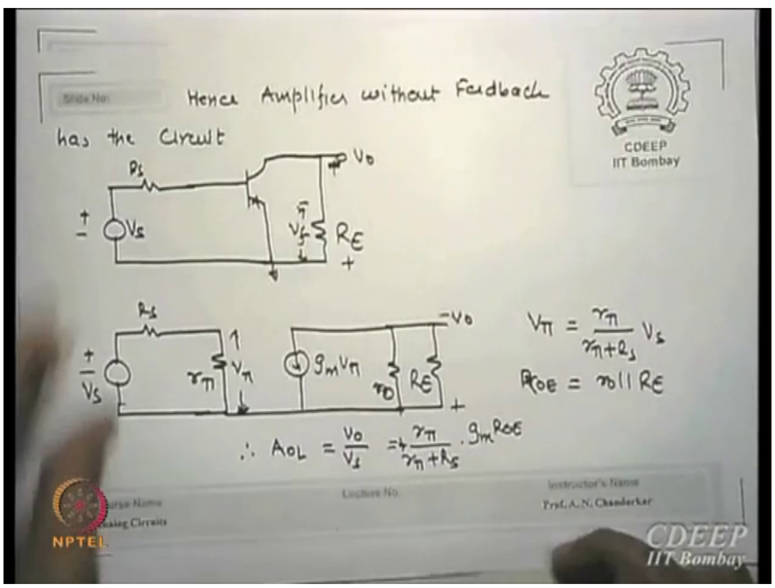

If I say this is going down the gm times that will also go away okay. So, what will remain at the output therefore only the RE factor gm times parallel RE but gm itself will be open circuited gm Vi current source is open circuited. So, what is the resistance seen there at the output RE. So, that is the circuit I put this is my input circuit this is my output circuit is that correct. So, this is which amplifier now I am calling this amplifier.

It is a open loop amplifier for the feedback circuit amplifier given to me taken, for the taken input circuit short V0 and then whatever you see in the inputs that is your input circuit. To get an output circuit short inputs but as soon as you shot input gm Vi will open up because there is no current source. Then the only resistance of course there is a RO but right now I say RO is infinite so the only resistant left is RE at the;

Please remember you see circuit again, again. So, if I see from here and this is this the only resistance I see that nothing else at the output is that correct. So, if that happens then the equivalent circuit of a transistor now is a common emitter amplifier with RE as a load drop across RE is the feedback voltage and then I write equivalent circuit of this, this is VS r PI okay bipolar Vs r PI, VV PI this is my emitter this is my base this is my collector.

gm V PI parallel R0 if you want to make R0 infinite you can make that parallel RE and then I can get the gain of this amplifier (FL) gm V PI times RO parallel RE is the output voltage. But V PI is how much are R PI upon R PI + s times signal is that okay potential divider (FL) this voltage divider this upon this + this into Vs is V PI. So, substitute V PI in the output so V0 by which is gm r PI by ROE, ROE is the parallel combination I make r PI + RS.

So, this is my open loop gain is that clear to you how did I get my open loop gain? I got my input circuit I got my output circuit then I made a new amplifier now for me and I got the gain for this amplifier which I say it is open loop amplifier gain. See normal it is a common emitter amplifier we are seen what is for common emitter amplifier what is the load resistance we are seeing output resistor which is RE.

So, it is a bit cross collector to emitter that is the equivalence that is what I keep saying it is not symmetric same as what we have it is a source amplifier common emitter amplifier sorry common collector amplifier that is emitter followers have an equivalence with a feedback of that RE is of this kind in open loop. This is something you have to appreciate this is the output resistance RE I got.

What is the output resistance will be across what, it will be always a cross collector to emitter okay that is the output resistance of an amplifier. Substitute there, then solve this once I get this then how I get the gain okay before the;

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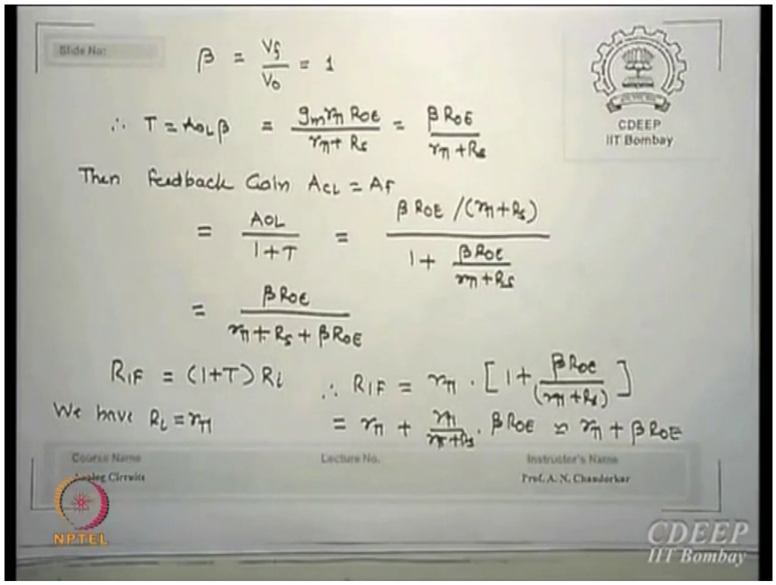

What is beta? Unity it is same voltage now (FL). So, beta is 1 so the return law or it a loop gain T is AOL beta which is this function and then the feedback gain on a closed loop gain is AOL upon 1 + T substitute these values here and you get beta Rho E upon r PI + Rs. Now I am now giving here, a case this already we have solved source amplifier is that clear. We already saw normal common source sorry source follower and emitter followers.

Do not use feedback theory what do I do, do not use any feedback thing. I actually solved equivalent circuit for this, is that as it is? Then evaluate this gain for that V0 by Vs and verify whether using this AOL upon 1 + T kind of function is this expression is same as what I would have got if I would not assume any fee I just solved the network okay. Verify yourself and it will be surprised it is exactly what we got otherwise.

And why positive sign is coming everywhere because source follower or emitter followers have the same phase outputs as inputs. By same logic we only have said what is ROF for such shunt series shunt amplifier Ri is 1 + T times Ri, what is Ri this is 1 + T what is Ri please look at our circuit equivalent circuit what is Ri is only r PI. Please look at the circuit what is Ri here r PI, r

PI times 1 + T is the RiF that is what we already said series shunt amplifier we are evaluated Ri Ri Ri a for in terms of RI and RO.

So, I substitute here and I get roughly if I solve it r PI + beta Rho E do you recollect this very well that we said if there is a source follower or emitter follower if input impedance actually increases by beta times the feedback whatever RE they help + r PI this may be very small actually this may be much larger value. So, the input resistance of a series shunt amplifier is very high, very high.

That is what essentially we want that is why it is called what; what is the other name version as a common name this source followers or repeated followers, buffers. The buffers have larger input resistance and smaller output resistance.

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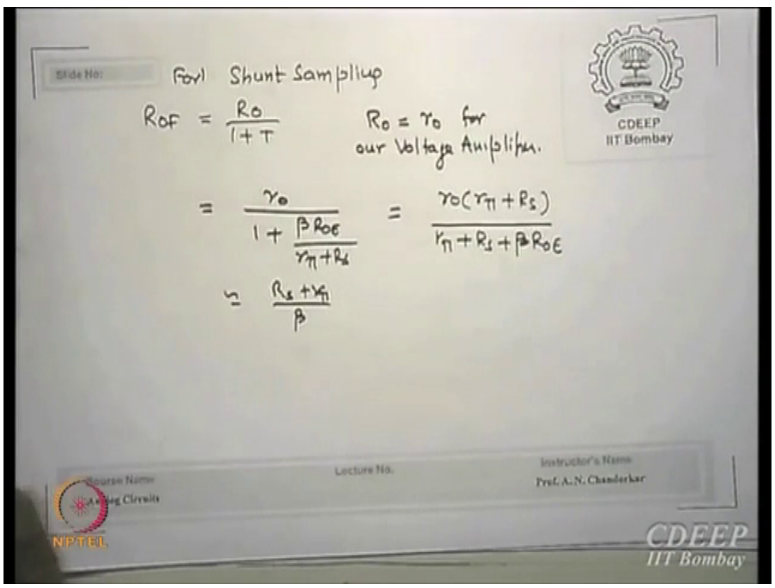

So, let us calculate output resistance you can do yourself that is not a big issue what did we calculate for this shunt sample Ro, Ro by 1 + T we had done all that what is essentially Ro for this small ro. Please remember Re is outside the load so the only resistance is Ro for this Ro upon 1 + T if I substitute these Rs + r PI by beta, beta being very high, RS is typically few hundred ohms, r PI is typically 1 or 2 kilo ohms.

So, it is a at best 2 kilo ohms by 100 so how much it will be 2 kilo ohms by 20 ohms is that correct. Let us say it is this whole becomes 2 K divided by 100 how much it is; so the output resistance of a emitter follower is very, very low typically of the order of for example I gave you say 20 ohm, 50 ohm kinds and how much is the input resistance will be; let us say RE is 1 kilo ohms, so how much is RI will be RiF beta times RE.

It is hundreds of K's is that correct hundreds of key is that what we did in not normal so source or emitter follower you can verify once again I repeat yes RE is what, RE shunting loaded let us say one key. So, in feedback with 100k in the input side beta time RE it will be reflected. So, input resistance will rise to 100's of K okay whereas output resistance will be how much 10 to 20 or 50 ohms.

So, buffer requirement that the unity gain with high input impedance and low output impedance is achievable by source follower or emitter followers and this problem can be solved by using feedback is that correct. wWhatever feedback without knowing also we solved at network or equivalent circuit (FL) our feedback, you are asking to verify, here is a verification okay you verify both value.

There will be some small change may occur because of some a provision we are making here there but if you do not make any approximation they will be identical in both case okay, is that okay. This is a technique which essentially we use in feedbacks okay. So, what is the method I repeat what is the method I suggested first find topology then find what is the mixing going on sampling hang on.

Once we know we know what is their Ri and ROF can be because either by 1 + T or multiplied by or divide whatever that topology I get. I also offer to get an open loop circuit first I say short input find the output, short output find the input make a new amplifier using this input output circuit with a transistor as usual solve the gain for that that is AOL. If you know the topology you know the beta whether current by voltage current by current voltage by whatever you are getting so you know the beta.

You know beta you know AOL, so you know AOL upon 1 + AOL beta is the closed loop gain, is that clear, with feedback. I told you that output resistance is defined for the transistors and not for the loads RE is the load yeah, but that is we will take all the ways as seen by the transistor Ro is the resistance as seen by the transistor. Any external component you do not add to it, is that correct. That is the definition we see.

The final Ri F, RoF will be shunted or by this and whatever the other side is that point clear. The actual someone asked you Ri F, so, you calculate that okay. Then you say them net are I have whatever you call them you are looking from the source side and you are looking from the actual output side. Then whatever parallel or series combinations they get you right for them. So, in this case whatever our RoF got shunted by RE.

Whatever I got here RiF in series to this is that clear. So, that method may; where to calculate (FL) first we always calculate at the input of that amplifier at the output of the amplifier and that actual outputs with nodes and actual voltage or current source (FL) but that is once you know this, this is only additional, is that clear. But the definition wise we always do this is that clear. This is nothing to say that why we do not want to use the other values.

Because the source things I do not know what is Rs value, what is our RE. So, I say intrinsically (FL) is that correct, that is why we do not want to use those values in our actual definitions, is that clear, but you are right but actual impedance phase will be somewhere at the out output side (FL) okay. If I am equivalent circuit or that gm V whatever V PI we are doing if his force is 0 and the gm V PI is 0 which means current source is in open circuit.

So, the only impedance seen by V was RE there (FL) is that okay. So, these techniques which I suggested we one more example on the mass will clarify some more doubts okay.

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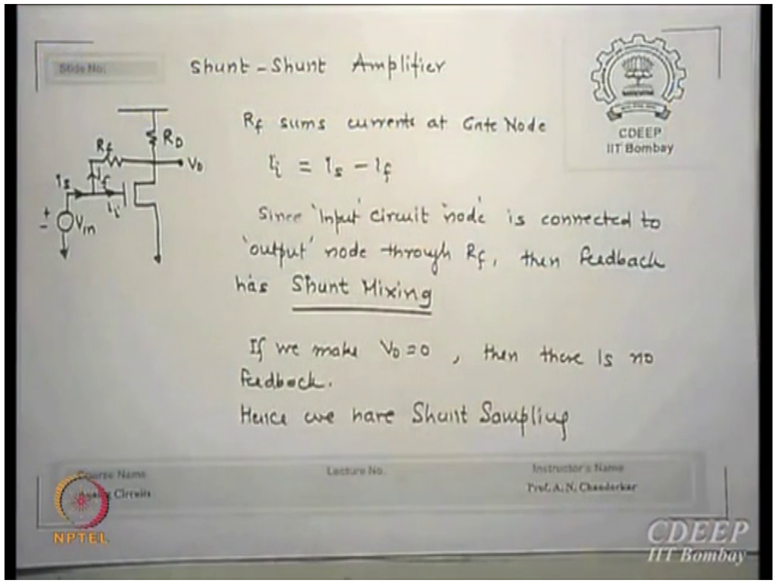

Shunt-shunt amplifier it available (FL) here is a current node as soon as I say current feedback (FL) so what we say as soon as I make V0 there is no current at the input is that correct. As soon that means its feedback is removed by me which essentially means this is a what sampling I am done a shunt sampling I did and when I say at this site at this node all three currents can meet so it can change at the node any current and therefore it is shunt mixing.

So, I have a shunt mixing and shunt sampling so this is shunt-shunt amplifier (FL) this shunt-shunt amplifier ok. So, we first figure out what is the topology so I said it is shunt-shunt actually I knew it because I am actually seeing it (FL) yes if V0 is 0 no current from the output is going to the input side this is the 0 potential is that clear. So, we said some as soon as I get output 0 no feedback V0 0 (FL) that means I am sampling voltage no this sign (FL).

I just made for the do not see I have been below down if you wish you can always use + or - sign that is what I say we always write science as they actually appear as they actually appear at the node this will only + or - it will be. So, science will be correctly done whenever I just wanted to show you at a node if the three currents meet the sampling must be mixing must be how much be shunt mixing because currents are getting actually shunted to each other okay. So, this shunt-shunt amplifier of a mask I can now show you how do, I do it.

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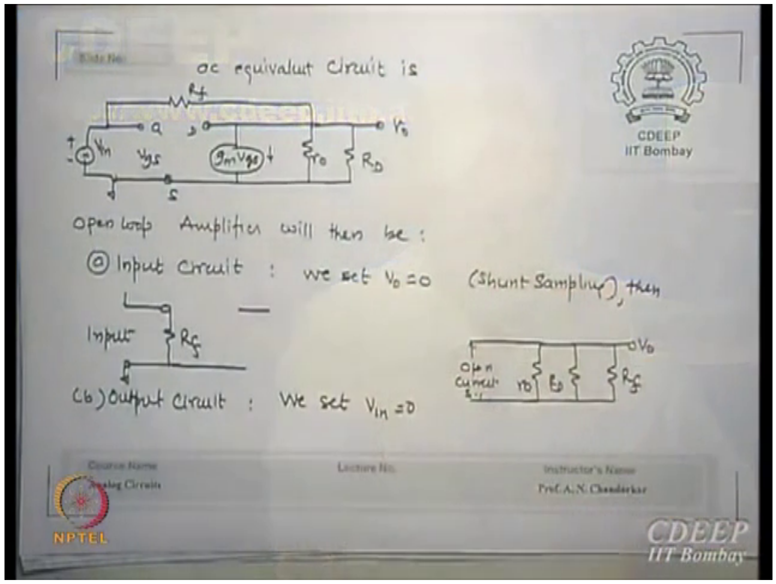

It here is the circuit equivalent your gm Vgs is your source this is gainf to source right now I assume source voltage is 0 and this is my RF is that correct. From drain to gain is my feedback resistor RF is that circuit clear, drain to gain is the feedback resistor RF this is gm Vgs r0 this is my RD and this is my source. Now to get an open loop okay I said V00 input circuit (FL) so what should I do short V0 as soon as I shot V0 this terminal goes to 0 whole this terminal is going to 0.

That means RF (FL) is that okay, as soon as I make V0 0 this terminal his ground so is source was ground. So, that means the RF is between gain and source RF resistance appears when the V0 goes to 0. So, the input circuit has a resistance shunting there as RF is that clear okay. To get in output circuit what should I do I say short the input okay. If thread V in = 0 even this goes to 0 so opens it so what is the output resistance see output same things I see RO, RD.

Now this is shorted please remember this other terminal is shorted now. So, where it will now come from this to the ground, so, now I see Ro, RD, RF in parallel at the output node is that correct. At the input what is there are a shunting gain and source. At the output I have three resistances in parallel shunting the output Ro, RD and RF (FL) open loop, is that correct. This is forgetting the AOL but remember I have not removed what does that mean without feedback.

So, what would I have done otherwise without feedback (FL) that is true but then these values would never have been seen my open loop list. So, the loading effect of the values cannot be neglected in evaluation of open loop gains though feedback is still broken by us. You can see now if I say equivalent circuit of this.

This is the input side RF this is the output side. Now there is no connection between input and output, so this is open loop.

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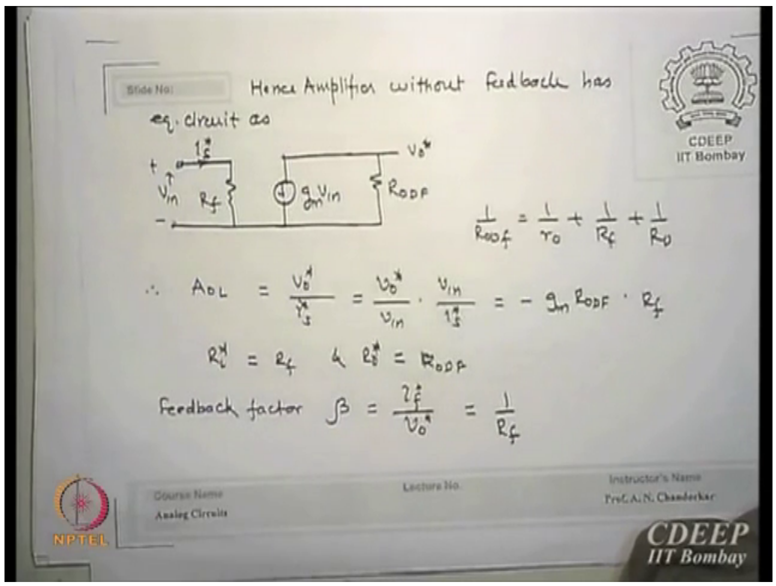

This is input this is output no connection from drain to gate so I have broken that so I have made it open loop but what is the criteria I chosen that the loading of RF I have not neglected loading of RF I have not neglected, though broken I have certainly broken the feedback okay. This is called open source, this is it point clear it is different from what we call without feedback word because without feedback means you would have just taken RF out is that current.

So, we are not taking RF out we are saying for feedback break it into so that as if there is no output input connections equivalently saying this is the circuit okay. Since it is the shunt mixing means it should have a current source so voltage by current is the amplifier. So, AOL is V0 by Is star, star I am making for open loop okay, star I am only trying to make it open loop. So, AOL is Vo star upon Is star which is Vo star by Vin, Vin by Is star.

This method do you know who do not write directly V0 by is essentially what do you do V0 by VL into Vin by Is star (FL) but this value I know by a normal amplifier how much is this V0 by Vin - gm times the load (FL) gm being times RODF, so Vo star Vo star by Vin its gm is gm RODF – sign. How much is V in by Is star, RF there is nothing else so into RF okay. So, I got now correspondingly RI if you see is only RF correspondingly RI if you see it is only RO (FL) what is the feedback factor here I should use.

Which kind of amplifier I said it is shunt-shunt input (FL) so IF star by V0 is 1 upon RF (FL) beta please take it verify I f times RF is V0 okay (FL) feedback factor is 1 upon RF (FL) we know our AOL we know our beta so what we can calculate closed-loop or feedback gain ok.

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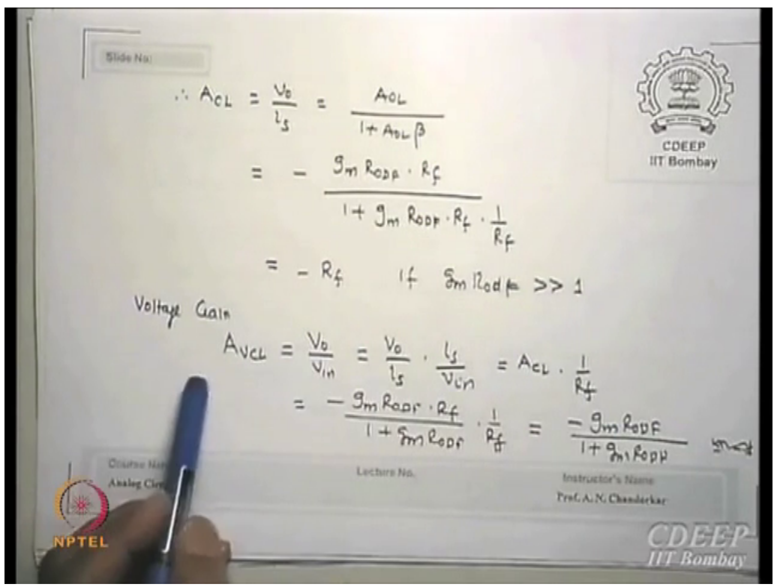

That I did (FL) closed group gain is Vo. Please remember it is still voltage by current. So, which amplifier I am talking in a real sense not voltage up which is this amplifier, trance resistance amplifier. This is transresistance amplifier okay. So, if I substitute all this (FL) what do you really need in normal amplifier it may be transresistance it may be transconductance it may (FL). So, V0 by V in can be written as V0 by Is into Is by (FL).

So, if no I do not write this, this you right, now do not throw anything, now this V0 by Is is gm RODF RF (FL) now how much Is Is by V in (FL). This is your essentially the voltage gain closed loop voltage gain of feedback amplified. What kind of feedback amplifier we started with, shunt-shunt okay. This is a shunt-shunt amplifier (FL) please look at your circuit and tell me your tables in case of shunt-shunt amplifier does RI increases or RO increases or I should decrease current if it subtracting out of it.

So, it is a negative feedback (FL) so it is opposite of what we did in the case of source follower or emitter follower their input impedance goes output impedance went down by making a transresistance amplifier I can now make opposite of that I decreased RI and increase RO. So, this is that clear to you what is the feedback is trying to do. Feedback is trying to play whatever specs you are looking for by choice of proper feedback topology I can achieve RI, RO and gains of my choice is that clear, is that point clear.

Why feedback because feedback allows me to tailor my input resistance output resistance and the gain and that is something which normal amplifier does not allow me is that if I take a source amplifier I cannot do much of that it will always be one kind okay. Feedback allows me to play that is why feedback amplifiers and what is the most important thing in feedback we were getting it gain becomes constant very close to a convoy.

Why it becomes constant in the negative feedback if there is a change of signal due to noise at the input and let us say it is + then what will be come to the output additional voltage will appear at the output so during feedback what it will do, it will start that answer will be higher now corresponding beta times V0. So, the input will further rise now as it will oppose it will live but you will subtract so in net input will go down so the output will go down.

Since output went down feedback reduces so it will start again till it balances to the normal value. So, feedback stabilizes the gain and it also allows me to make different RI, different RO and different ACL's, is that correct, that is why feedback amplifiers are always utilized. Please remember instead of RF what is normally will be present in the case of all amplifiers.

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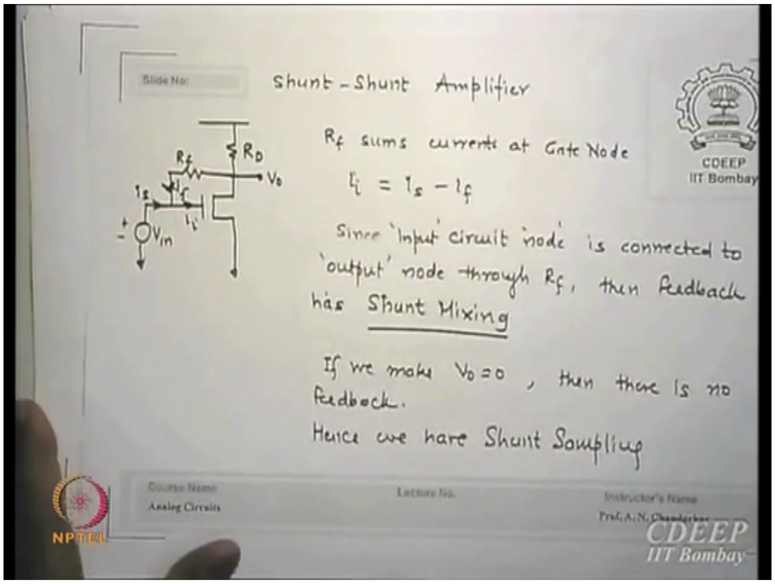

This I did not put RF there but what component will be always there in a MOS transistor which capacitor CGD. So, please remember CGD is there shunting actually between output to the input and it will give you shunt mix is that correct. So, it will also try to stabilize you okay with that impedance of that that frequency. The only problem why this was different from this because it is a frequency dependent impedance R is constant but Omega C different Omega will have different this.

At certain frequency it may have something different phenomena at other frequency it may have other phenomena but that is what we want frequency response to be modified okay that is what CGD series CGS and others will actually help us to achieve that is that point clear. This is an issue which you should always understand that feedback is a generalized network and sometimes in builtly present sometimes you may actually put it okay.

When I say I put RF in reality what do I put in such circuit RF parallel CGD, so it is impedance which I am putting there is that clear. So, there is some kind of a pull function starts appearing because of this RC network which I am going to put is that clear. So, the if the pole changes and what changes, bandwidth. So, you have to see that what kind of amplifiers will improve the bandwidth or decrease the bandwidth is that correct.

These are the techniques of controlling the bandwidth, the gain and the RI, RO okay that is why a feedback is very, very important phenomena. I am not going to do a great part of stability because why I thought I was thinking to teach a lot of things on that (FL) then you know I will go to the control side bit too much.

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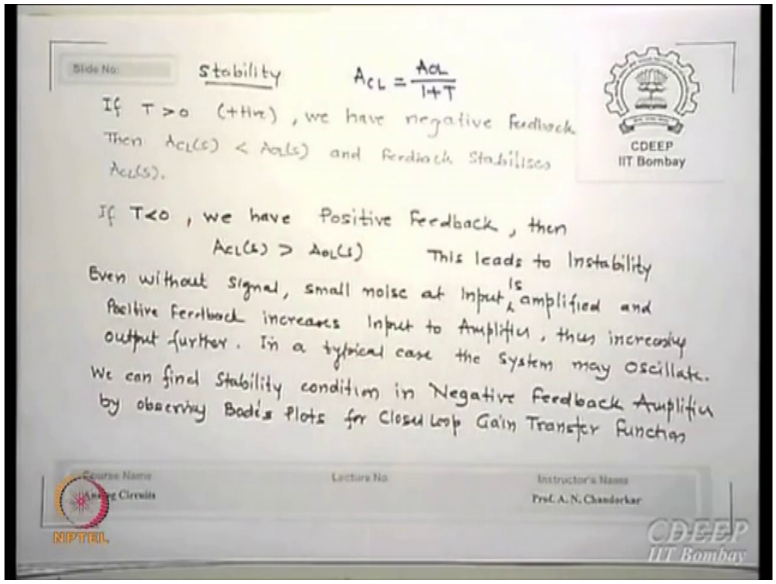

Let us take that expression in closed loop AOL upon 1 + T, I have I am looking for stability with feedback. If T is positive what have what does that mean if T is positive means 1 + T is higher means closed loop gain will be smaller than open loop gain is that denominator will be larger so obviously you will get smaller gains okay. What is the feedback essentially we say when this can occur only when negative feedback is present?

However if T is less than 0 then the denominator will actually enhance divided by smaller value it will actually enhance the ACL and if it enhances the ACL if it is negative then it will enhance and if that enhances what is the kind of thing will happen if the feedback signal is always in same sense as the input, what will increase? The net input if the net input increases what will increase? The net output the feedback will bring back additional input now which is in series which is in + 2 the input itself.

So, further increase of input further increase of output what is it going to do? So, at a given instant of time I do not know what is V0 because V0 is constantly increasing, increasing,

increasing is that correct. V0 return to the series of that increases V0 further (FL) amplifier does not have any known gain is that because every instant of time V0 is not known to me okay? So, we say such amplifiers are unstable or they show instead ability.

Would you like such things to happen for your amplifier why did we do feedback all this for this purpose can he gain constant whenever (FL) we want that fixed is that correct with nothing changing this gain should not change. Everything changing but this gain change (FL) growth patterns rose. So, such will not be an amplifier is that correct, it will not be a amplifier for a known gains. So, anytime positive feedback appears we say we have instability is that correct.

So, (FL) what should you lover guarantee that it should always be negative feedback (FL) V0 is a function of frequency, if the input is a function of frequency so if the output will be a function of frequency. So, there are two factors of any translate this return, return fact, this T factor which is loop gain. If you see a loop gain will it have a real quantity or imaginary quantity or a complex quantity, A is a complex, so is A beta will be a complex quantity, T will be a complex quantity is that correct.

So, if it is a complex quantity however how do we represent any complex number A + JB is equal to magnitude of this value into e to the power J Omega or J Phi which is the phase part for that is that correct. Any complex function can be represented like this, is that correct. Tan inverse imaginary barrier is the phase for that. So, you have not only amplitude but also you have a phase. So, now look at a situation which is very interesting this (FL)

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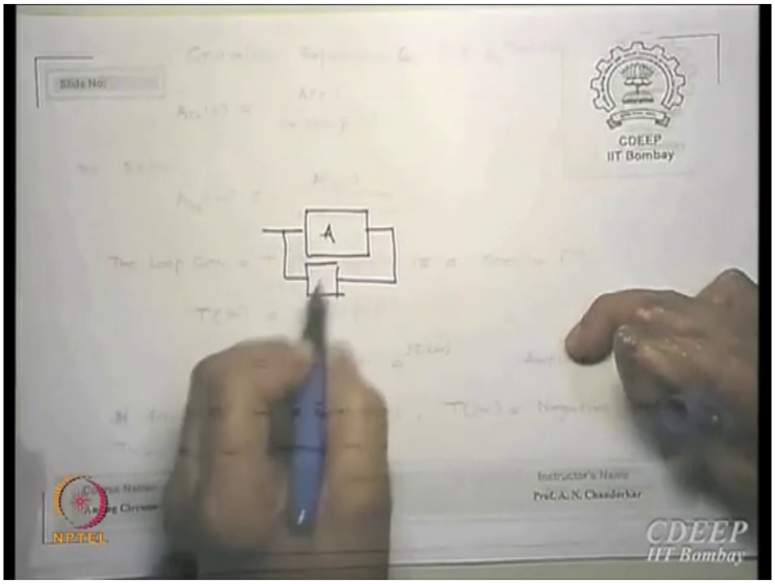

This is much easier to explain

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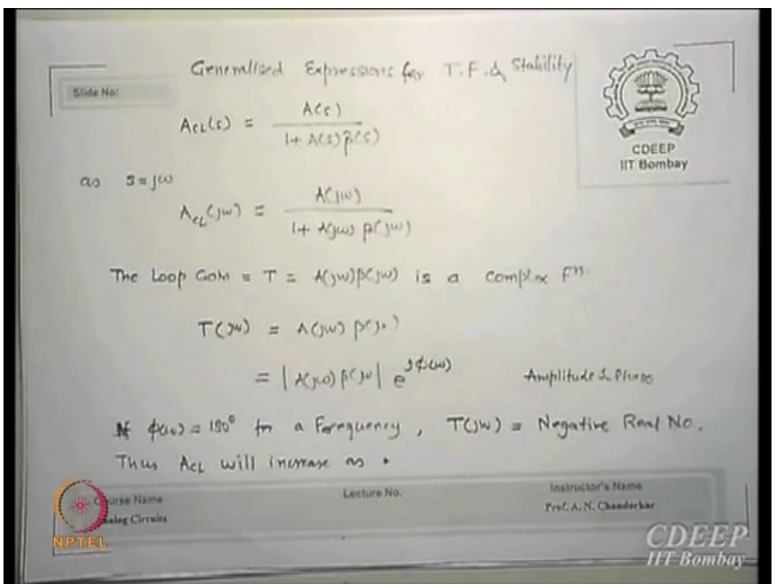

Then the closed loop gain is AS upon 1 + AS beta instead of a well I am just removing AS upon 1 + AS beta S, now my general I am using little generalized what does what is generalization I did, from the earlier one, what is beta I am showing you? That may be also a function of frequency. Right now normally what is the kind of beta's we are used so far? They are real values and there is no complex term with them okay.

But let us say it is also a function of (FL) so we write at for a frequency AC L and J Omega is A J Omega 1 + A J Omega B J Omega the loop gain T is a AJ Omega into V J Omega is certainly a complex function okay. How do I write complex function? The magnitude of A Omega J Omega this e to the power J Phi which is a function of Omega Phi is the phase what is the phase? By definition of complex number tan inverse imaginary by real value so that is I and that is how we represent any complex value.

Now look at the situation little carefully in that figure let us say feedback is coming okay. So, it has some magnitude, what is being returned, return has some value which has magnitude and also has a phase. If even if let us say the gain magnitude is higher than 5, 10 and 20 okay. But the phase is such that the return signal opposes the input signal. So, what it which kind of feedback it will give me? Negative, it is that correct.

There is on the AOL itself yes it said there is a phase shift what is the phase shift between input and output for the AS how much degrees? 180 degree amplifier shows phase out. So, there is a 180 degree in the normal input output on the return path because the complex function there is a phase going on. If this phase is also 180 degree how much is the net phase it will give you 180 there and 180 here. So, how much is the phase now 360 degree or 0 right.

So, what now they say the amplitude is positive then what will it will do? If the phase becomes 0 means in phase to the input which kind of feedback essentially I have gone into? Positive feedback, the gain is not less than 1, gain is higher than 1 okay but the phase was such that is 180 degree from the feedback and 180 degree from the amplifier. So, the return signal to the input is in phase with input which is higher now because your A beta is higher you are chosen 10 let us see okay.

So, now what is happening that your input has increased, output will increase and input will so which system, system has become stable or unstable? Unstable, so it is not just the magnitude but also the phase, is that correct. So, can you think from this very simple calculations which we do if we say at the frequencies of operations which we are looking if the gain that become; where is the gain will become 0 degree and the Omega T term that is the unity gain point.

So, if we see for the loop gain itself alone when it will become when it becomes 1 TJ Omega is 1 magnitude wise, we said at that frequency, if the phase of this function is how much less than 180 degree, I repeat less than 180 degrees which feedback I am still talking? Negative feedback, but if the gain is positive and feedback this has already crossed 180 degree phase then what will happen? The feedback will become positive.

I repeat the gain is positive it has not for 0 degree loop gain for example. How much phase has crossed? 180 okay are reached at 180. So, now what will happen there is a positive return positive value which is in phase returned to the input is that clear. So, which feedback I am now getting into positive feedback system will become unstable. So, the two terms we define one we call phase margin and the other will call gain margin.

If the phase margin is positive we will see that then we say system will remain stable. If the phase margin becomes negative then phase system will become unstable. So, all feedback amplifiers people try to see what the phase margin they are getting is, is that correct. If the phase margin is positive be assured that what does that essentially mean the phase margin is negative means? When the gain becomes less than 0 DB less than 1, your phase is still negative is that correct.

So, it has not returning signal and again has a little cross 1, so it is partially is only returning now much lower is returning and you are always opposing that value is that correct. So, what does that mean that if the Bode's plot think of it something on the Bode's plot, if your 0 DB point crossed by the magnitude at which point the big phase is still not 180 degree or 0 essentially 180 + 180 then what do we say then the negative feedback exist.

If that passed before after this then we say today positive feedback and we have an instability, so is that point clear. So, in amplifiers it is not only the amplitude which is also there is a problem of phase and that is what essentially the stability is all about okay. Just even to give you a basic idea any generalized transfer function in a feedback can be written as square you expand (FL)

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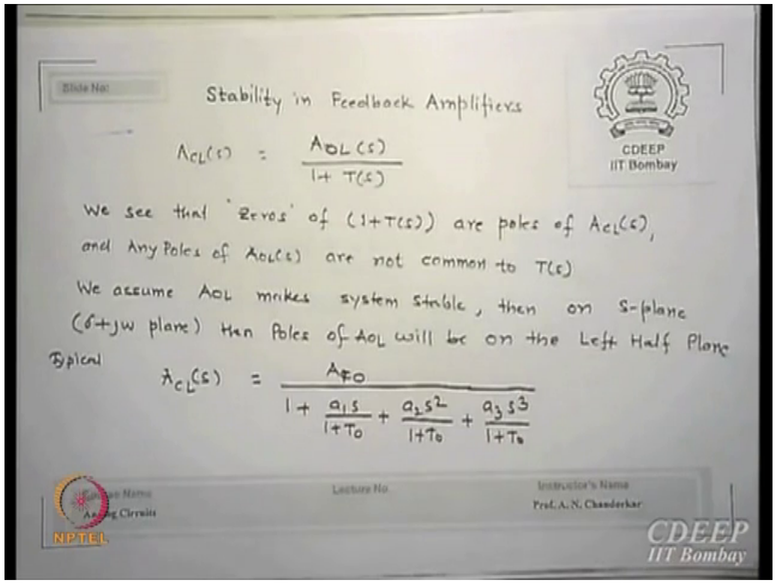

AF0 is 1 upon there will be large number of poles A1S by 1 + with feet this is always feedback this transfer function (FL) generalized form A1 + A2 + A3 A square, S cube, S4, Sn (FL) what does this essentially means if there is a S cube term how many poles are there? 3 poles, if only first this term present there, single pole. So, depending on your transfer function of closed loop amplifier system first find how many poles are there.

Then draw its Bode diagram what do we draw then Bode diagram, so what I do is the following: Here is some my definition I will come back to it again. As I say we can dwell on this detail theory or feedback it is a huge gain, interesting gain rather much more interesting than many things I thought but I like it that is what it is good locus technique. It is a very funny thing we scratch there are how many times you circle the very nice thing to learn. (FL)

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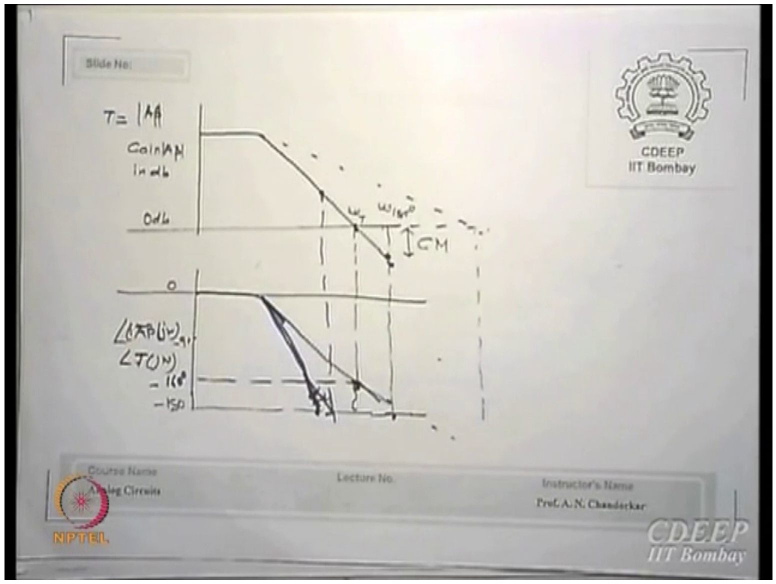

I have plotted for the transfer function and I saw the loop gain a single pole theory a single pole as I plot for the amplitude and this is this phase. At this point what is the gain? Loop gain is how much? 1, less than 0 or positive (FL) at this frequency if I plot my phase correspondingly 45 degrees per decay and it intersects at point let us say from 160 degree point. How many now, what is the phase there, -160 degree.

Then I say I put another value where the phase becomes 180 and I get the value of frequency at which that has happened. So, this one is that correct at this point this is the gain at this gain this is the phase. At this frequency this is the phase, at this phase this is the beam that clear. So, we say at this for the loop gain from this value where the T has become 1 or 0 dB you add 180 degree to it okay or subtract (FL) add 180 degree to it.

If that quantity is positive that is this number is called phase margin what is phase margin this value failed at this point where the T is 1 - of - when it image + 180. So, 180 - this phase value if you do and if this value remains positive then what is the phase margin will be called positive phase margin. You have just now said if it is less than 180 degree the output signal will never be in phase by feedback to the input.

So, which feedback it will retain negative feedback because the signal is not returning to same phase 180 from the amplifier 180 from here. So, 360 degree (FL) so as long as this is less than

180 degree system will remain always stable is that correct. So, what is the criteria I am saying if the phase margin is positive the system is always stable. When you should have occurred? Let us say at this value or this when the gain has become (FL);

But you have reach 180 degree but the gain is still positive is that correct so which feedback it would have given you get a positive feedback. So, if the phase gap margin becomes 0 negative the system will become unstable as long as the phase.

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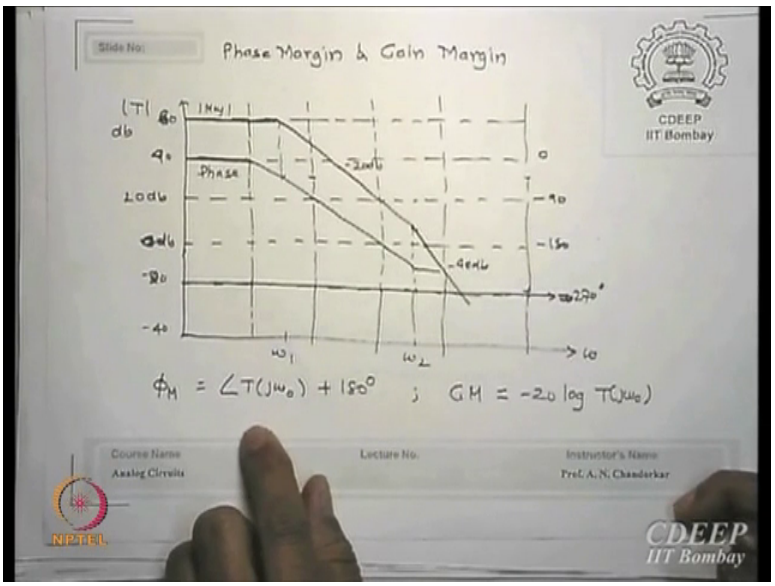

And what is the definition of phase margin there should be the phase of T + 180 why it is + I wrote - of - 180 is + 180. So, 180 and this will be -. So, if the net value is positive then we say feedback is always negative otherwise feedback is positive and system will become unstable our instability starts, is that point clear, is the definition clear to you I repeat if the returned signal is in phase as is more than unity which means it will add to the signal and output will grow, is that correct.

If it is not in opposite the input it will always reduce the V0 and therefore it will never grow is that clear. So, for stability negative feedback is essential and to do this phase margin must be written to less than or greater than 0 degree or rather prefer what is typical amplifier phase margin should be for normal good this remember 45 degrees per decay a capacitor with the head okay (FL) normally we have phase margin for normal amplifier should be kept between 45 to 60

(FL) so you do not want to reduce the gain too much at the same time you want it to be stable (FL) not that 60 if I will not stabilize but what cause the gain actually will go down okay.

So a typical (FL) we say system is amplifier is always stable is that correct otherwise even if you are thought it is stable initially at some frequency will find certainly unstable and that is why I say amplified design is very interesting if you have a feedback, is that correct.

Please remember what is the phase margin I keep saying you 180 + and this will be - quantity is that correct because this is going down so -1 then at 180 degree whatever is the gain from 0, (FL) 180 per year gain, is that clear (FL) is that clear. This is something interesting which feedback amplifiers please do this before we quit on this last X (FL) that is what I said is not it. I should day one I said 1 + A beta times the original bandwidth (FL) this kind of example (FL).

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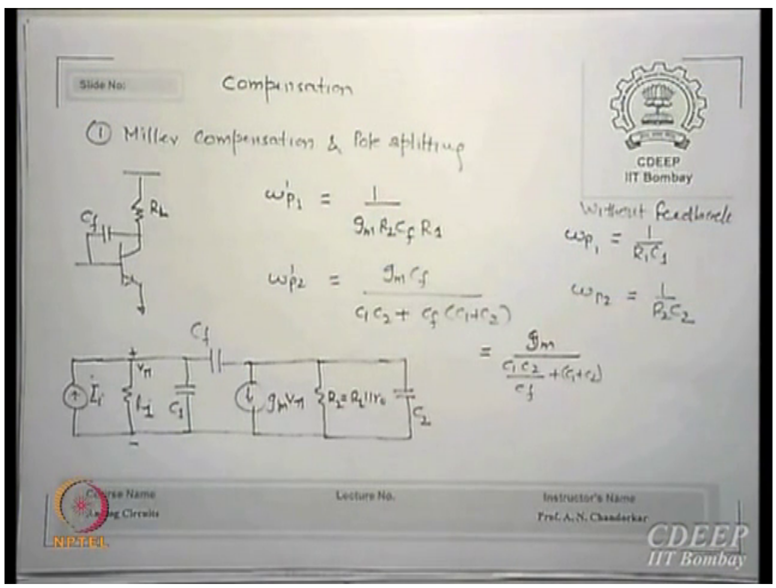

Okay, it is shunt-shunt amplifier, is that correct, shunt-shunt amplifier whenever I connect a capacitance between output and input we can separate them by which method input side output side Miller's theorem (FL). So, will their phase will reach 180 faster if the two poles are very close (FL) gain would not have probably gone to 0 but your phase might might reach to 180. So, what system will become? Unstable.(FL)

Phase will never reach 180 by then, is that correct. Before the gain crosses 0 in that case what will happen then system will remain stable but at what cost bandwidth will (FL) Ii is my current source this is my V0 or I0 velocity (FL). So, what are the two poles we say without feedback no CF it is not AOL kind it is just that there is no CF then R1 C1 will be 1 Pole and R2 C2 will be other pole.

So, Omega P1 is 1 upon R1 C1, Omega P2 is 1 upon R2 C2 these are the 2 poles available for you okay. If I use this now new circuit I evaluated the transfer function V0 by that and I evaluated the 2 poles (FL) this is the poles without feedback no CF. These are the two poles with CF. Its function with the Omega P1 (FL). If I increase here what will happen Omega P1 (FL) gm upon C1 C2 by CF + C1 + C2. So, CL (FL);

So, do you see by choice of a CF I am separating two poles p1 and p2 split (FL). So, I now figure out by choice of CF value I can move the second pole to my right and one pole to my left. So, this is called split, splitting. So, the post pole (FL) phase will never reach 180 degree before crossing off this value, is that correct. (FL) crossing of 0DB will be earlier before the phase becomes 180, so what does that mean system will become stable.

So, by splitting the poles I can make even an unstable system close to stable system what is the method I suggested it is called splitting of poles by adding a shunt feedback capacitor all that I did one of the poles I took left other pole I shifted right separation (FL) is that correct. So, they may never reach 180 degree -180 degree before the gain goes to 0 degree. If that happens what is the phase margin I will get positive which means system will become stable is that clear.

So, any system which is unstable can also be stabilized using feedback is that point clear to you. So, that is the trick which we are saying even if the system is unstable I have way to actually stabilize it. What things I will reduce I will reduce the gain I may reduce some bandwidth otherwise to some extent but I will make system stable for you is that correct, this is what the feedback is all about. (FL)

System should not remain in growth path it should remain stable gains. So, a feedback allows you to achieve any stable (FL). In nature the input signals which you receive from any of the like noise coming or any transducer you put to pick up temperatures variations all these are in nano volts to micro volts (FL). Now I want to do some processing so I must first amplify them is that right. Once I start amplifying what is my problem. (FL)

Is that correct, so in all instrumentations signal processing or any kind the first stage is called low noise amplifier which is essentially a feedback amplifier with a low gains is that correct. Why it is necessary because I want signal to be slightly larger than what I; even in antenna (FL) is that clear to you. This is the take why we are so worried about particularly for all signal processing applications including communication in networks and everywhere this will be the first stage of any input part, is that correct.

So, you need to understand why feedback is so much relevant is that clear this finishes our feedback part.