Analog Electronic Circuits
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Lecture 29
Introduction to Feedback Amplifiers

29th lecture we are going to introduce feedback amplifiers. Feedback as you must have known characterizes a system when part of the output is mixed with the input to influence the performance of the system. This is a feedback system. A feedback system is one, this class for example is a feedback system because at the end of the class I take your comments and I modify my teaching. So feedback system also is a kind of a self regulating system.

And the general definition is that a part of the output is mixed with the input to affect the performance of the system. That is what is a feedback system? We have already got several examples of feedback in the discussions we have held so far. For example in biasing of a transistor you recall that the emitter resistance R sub C, there is an R sub C and there is an R sub E. The emitter resistance is used for DC feedback for stabilizing the Q point of the transistor.

And what we need is that beta R E should be much greater than R B, okay. I am glad you remember this. This comes from DC feedback. In order to prevent AC feedback we had to bypass R E through a capacitor C sub E, okay. DC feedback stabilizes the Q point of the transistor.

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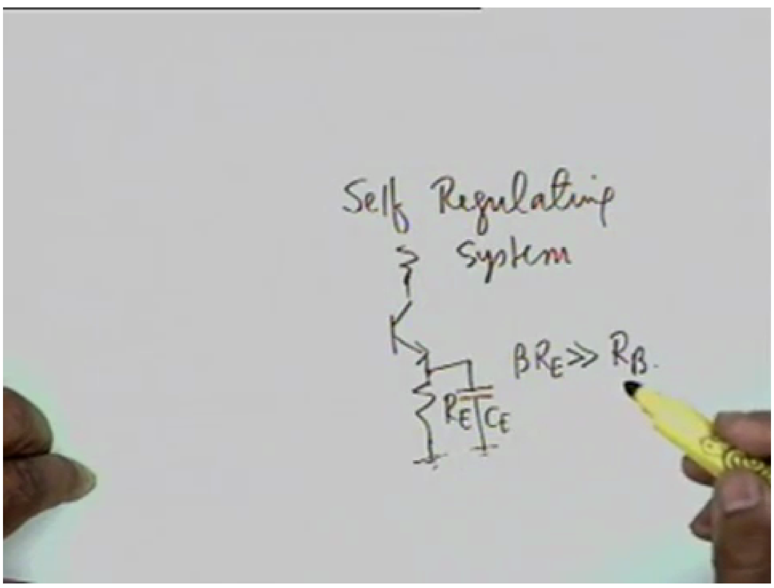

The other example of DC feedback in biasing that you had was in which the base was biased not by an R 1 R 2 but by a resistance from here to the base, okay, and the emitter could be connected to ground. This is also a case of DC feedback because normally I sub B is the input current and I sub C is the output current.

So a part of the output current or a quantity proportional to the output current is being used to feed the transistor and therefore this is a feedback system and you also recall that to prevent AC feedback we had split this resistance into 2 and in between we connected a bypass capacitor to ground.

So this prevents AC feedback. On the other hand we also saw an example of AC feedback in which there is a load at the collector and there was also a load at the emitter which was unbypassed and you saw that this provides DC as well as AC feedback and the gain of the stage was approximately equal to minus R C divided by R E.

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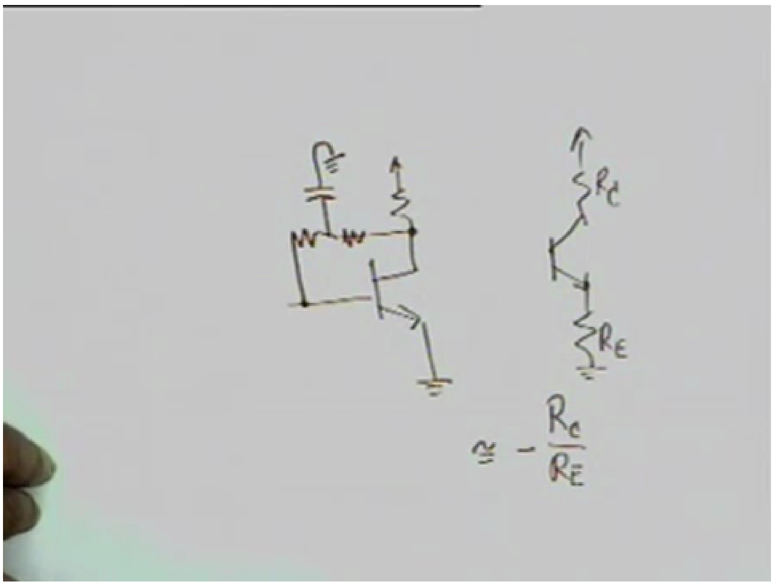

Student: Excuse me sir.

Yes.

Student: Sir how is this a feedback?

How is this feedback? Because, your input is here and what is developed across this is proportional to the load current. The collector current is approximately equal to the emitter current, the signal current. So the voltage developed across this is proportional to the output and the actual input to the transistor is this voltage minus the voltage across R E. So there is feedback.

That is the actual input V sub i to the transistor is a mixture of the input that you physically apply and a part of the output. So the part of the output is being mixed with the input signal in order to affect the performance of the device. Yes, you had a question? Yes?

Student: Sir you have taken V i as the input that is voltage between base and emitter.

What I provide is the signal source, okay. This is my t actual physical input. Could be a microphone. Now what is being applied to the transistor between the base and the emitter is the actual input to the transistor is being influenced by not only what you provide physically but what you provide as part of the output. So this is why it is a feedback, okay.

Now this also shows one of the good effects of feedback that the gain of this stage is approximately minus R C by R E so it is independent of the transistor parameters. And the technical term that is used is desensitizing the amplifier to the parameter of the active device, desensitize it. That is this gain will not be sensitive to the parameters if you replace the transistor by another in which the beta maybe half of the previous one, it is not going to affect the gain.

If the temperature rises by 20 degrees it is not going to affect this because temperature term V B E is not there in this, okay, or beta which is also temperature sensitive. So, one of the advantages of feedback and this feedback is negative feedback. The actual input applied between the base and the emitter would be less than what you have actually physically provided. It would be V s minus V R E, okay.

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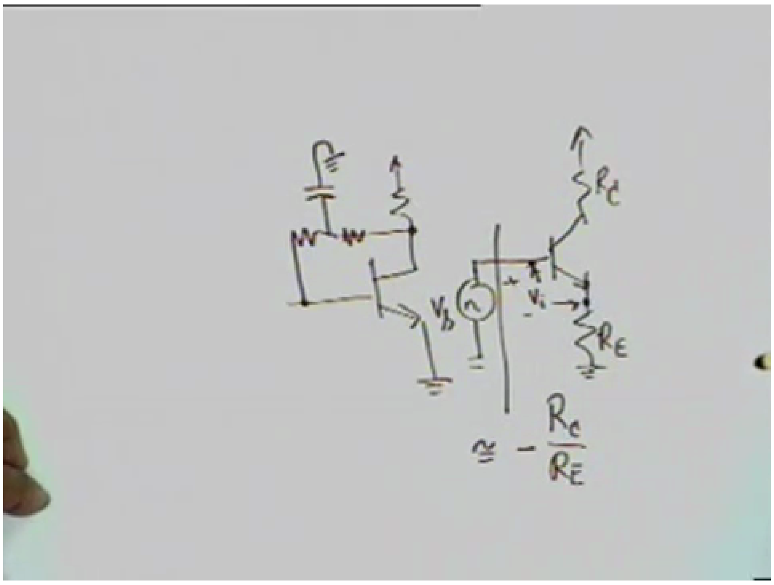

Negative feedback desensitizes the gain with respect to the parameters of the transistor or environmental conditions for example temperature, humidity and things like that. You have also got another example of feedback. The same mechanism that is a common emitter follower or a common collector stage in which you saw that the output is taken from here. You saw that the input impedance which if R E was bypassed would have been simply r pie its increased tremendously drastically from r pie to beta plus 1 R E, agreed?

Also the output impedance becomes very-very small. It is of the order of 1 by g m, alright. So these are two other effects of feedback. This is also negative feedback. Negative feedback increases the input impedance and decreases the output impedance, okay. So these are the examples of feedback that you have already been introduced to. What we shall do now is to treat this on a formal basis and see, what are the general rules of analysing and designing a feedback amplifier?

Feedback is a beneficial thing and basically the benefits of feedback are control of impedance levels. As we had seen in emitter follower the input impedance is increased that means you can apply a voltage source at the input and the output impedance is decreased and therefore you can take a voltage from the output. It is a truly a good voltage amplifier. Although amplification is less than 1 but an ideal voltage amplifier should have infinite input impedance and zero output impedance, okay.

And as we shall see it improves the bandwidth of the device. Normally your amplifier, R C coupled amplifier for example will have a gain curve like this. With feedback what happens is that we have to reduce the gain. The gain is reduced but the bandwidth improves. That is it goes over a larger band of frequency. This is with feedback.

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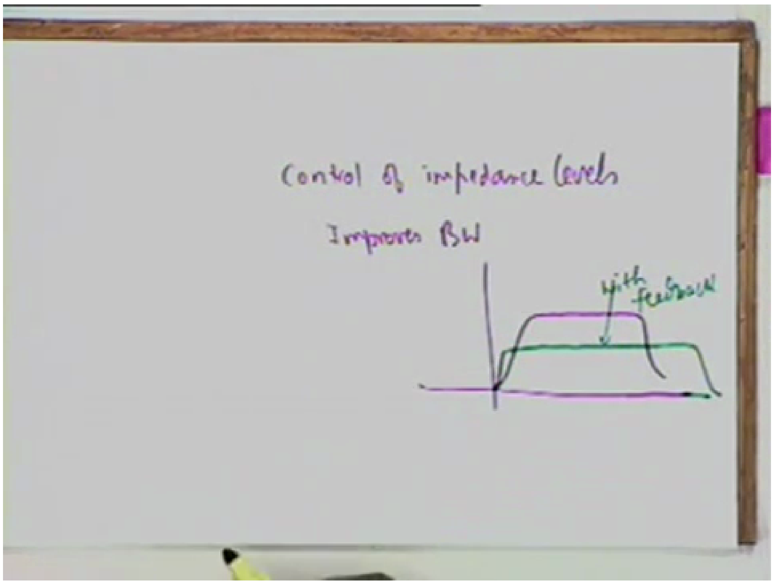

We shall see this by a simple analysis. Then as I said it desensitizes the circuit to manufacturing tolerances, the placement of devices or environmental conditions. Desensitization of circuit performance to device parameters and environmental conditions, okay. And one other advantage of feedback is if you use positive feedback then you can generate oscillations, okay.

In fact you cannot generate oscillations without positive feedback. Oscillations can be sinusoidal or relaxation oscillator. It could be a square wave or triangular wave but positive feedback is essential for generating oscillation. So the other use is generating oscillations.

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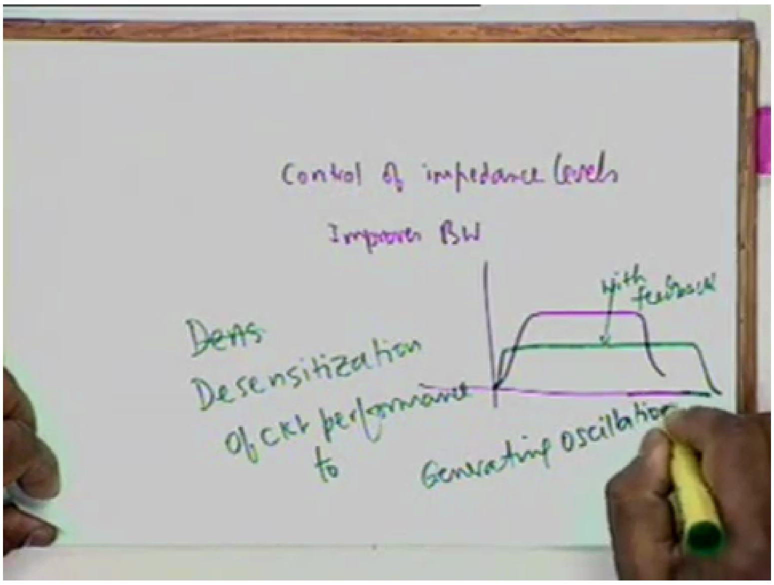

Student: Sir what is positive feedback?

Positive feedback is in which the effective input to the device increases, okay. And if it increases to the extent that the output can be maintained without an actual physical input then we get what are known as oscillations, okay. So these are the benefits. Well there are some bad effects of feedback also. One is that because of, yes?

Student: It reduces gain.

Reduces gain, okay, you have to pay a price for everything. So if you want stabilization of the gain you might have to reduce the gain, gain decreases. Due to unwanted feedback the bandwidth may decrease. Can you give an example of unwanted feedback? We do not want it but it is there. We cannot do anything about it. The miller effect, the C mu. That is an unwanted feedback but it is inherent in the device.

If C mu was not there, you recall that the high frequency 3 dB point of an ordinary common emitter transistor amplifier is approximately r pie multiplied by C T which is C pie plus C mu times 1 plus g m R L. Now if C mu was not there the high frequency 3 dB cut off would have been very high. It would be simply C pie. But because of miller effect you have to add C M.

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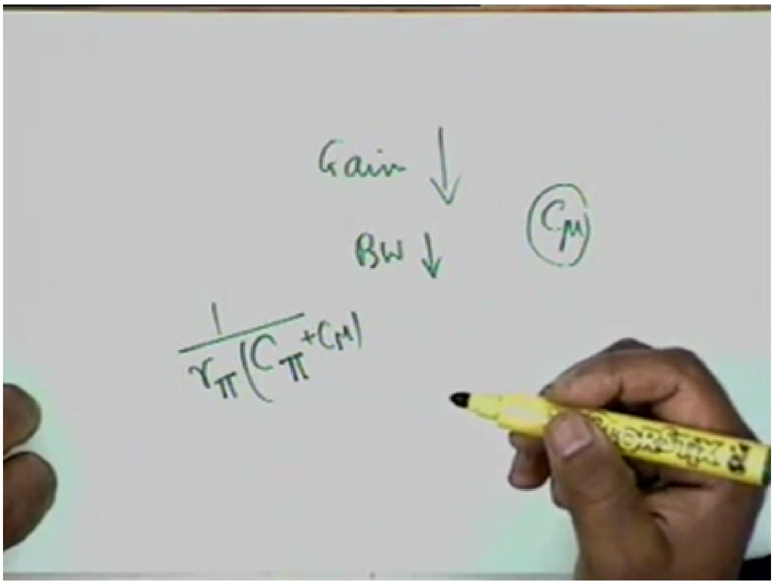

So, unwanted feedback causes deterioration in the frequency response of the device. Then if you want to take advantage of negative feedback you have to be careful that negative feedback at some frequency may become positive at some other frequency. And if it so happens that the feedback becomes positive at some frequency and becomes so positive that that particular frequency can be generated, that is the C device becomes absolutely unstable then obviously advantages are all lost.

So, one has to stabilize a feedback amplifier. Stability of feedback amplifier or any feedback system is a very important topic but we shall not discuss in great details how do stabilize a circuit and what are the stability criterions? This will be discussed in another course, principles of controlled engineering. Did you already have that course? No? You shall have it, okay. Now in order to discuss feedback amplifiers we model a basic amplifier, okay.

You see the usual amplifier is you have an amplifier, you have a source which is applied to the amplifier and then you have the load, okay. In feedback what you do is to make a feedback amplifier what you do is in between you use a network called a sampling network. This is not the sampling in the time domain. For example it is not an on-off switch. Sampling means you pick up with this network a quantity which is proportional to the output.

It could be proportional to the voltage or proportional to the current and the output of this sampling network is fed back to the input through a feedback network FBN and it is fed to another network at the input which is called a comparison network or a summing network. This is the basic block diagram of a feedback amplifier.

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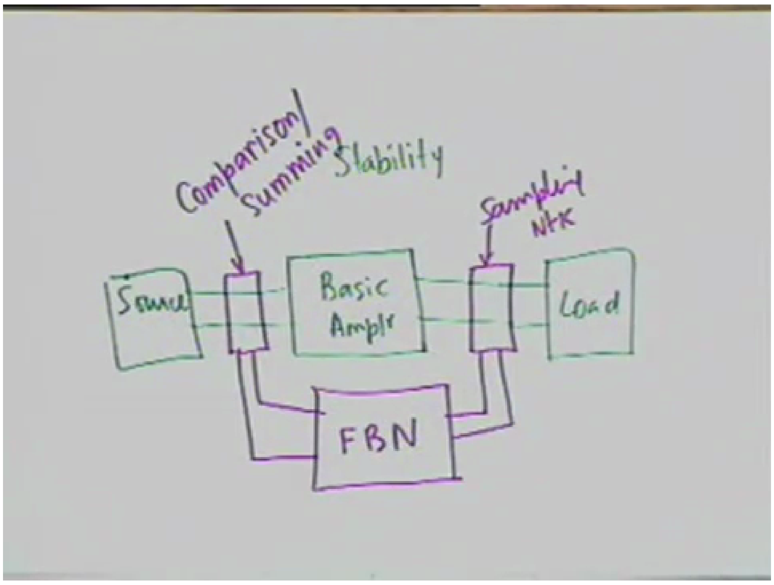

You have basic amplifier, you have the source and the load, a quantity proportional to the output, it could be either voltage or current, is sampled and processed through a feedback network to influence the actual input to the basic amplifier. And this is done by comparison or summing. If the feedback voltage for example helps the source voltage then we have positive feedback. If the feedback voltage is in opposition to the source voltage then we have negative feedback.

So we shall look at these structures of the comparison network and the sampling network. But in order to do that, in order to differentiate various kinds of networks feedback amplifiers we require a classification of the basic amplifier. And basically basic amplifiers of a feedback amplifier can be of four types. These are the so called V V T, I will explain this term, C C T, V C T and C V T. T is common, the other two are V for voltage, C for current. So it is voltage to voltage transducer. T for transducer.

We could have called it a voltage to voltage amplifier but this is the term that is used that is one voltage is used to create another voltage. Then a current to current transducer. This is basically a voltage amplifier that is input is a voltage, output is a voltage. A current to current transducer which basically is a current amplifier, okay, current amplifier. Then a voltage to current transducer. Your BJT basically is your voltage to current transducer, right? V pie is converted to a current source g m V pie, alright.

So V C T is a voltage to current transducer and the parameter that will determine its gain is the trans-conductance. So it is also called a trans-conductance amplifier. And finally C V T that is a current to voltage transducer and by analogy with V C T it should be called a transimpedance or resistance, okay. Here it should have been trans-admittance amplifier if the quantities are complex. So if it is called conductance we will call this a trans-resistance amplifier.

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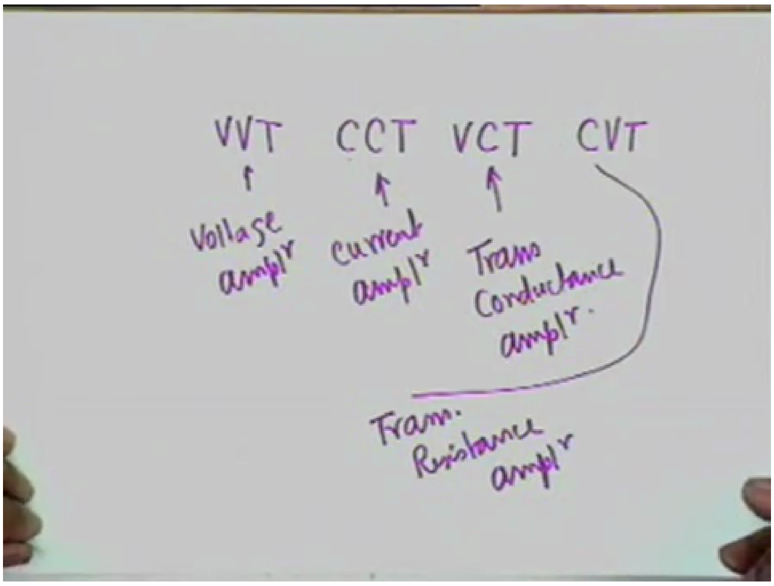

These are the four basic types of amplifiers and it is advantages when you discuss in general terms feedback amplifiers it is advantages to characterize them in terms of simple models. For example for V V T, a voltage to voltage transducer our simple model would be we have a V s and an R s, then we apply to the input of the amplifier R i and we have a voltage which is determined by this voltage V i and we call this as A times V i, okay.

And a practical amplifier will have an output impedance. Let us call it R 0 and this goes to the load R L, okay. Ideally this is our basic amplifier which is the V V T. This is the voltage to voltage transducer. This is the source, this is the load.

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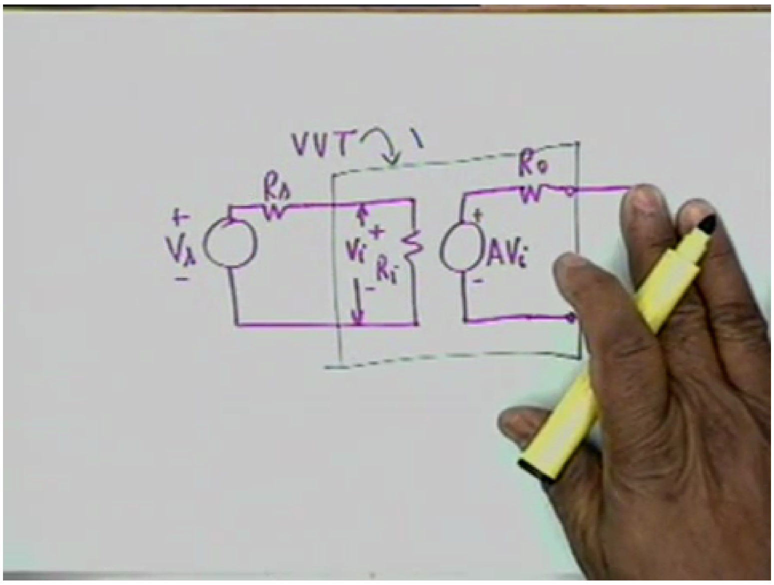

This is the basic amplifier. Ideally what we want is that R i should be infinity and R 0 should be 0. In practice we have to design such that R i is much greater than R s and R 0 should be must less than R L, okay. This is the practical. So we shall try to be as practical as possible.

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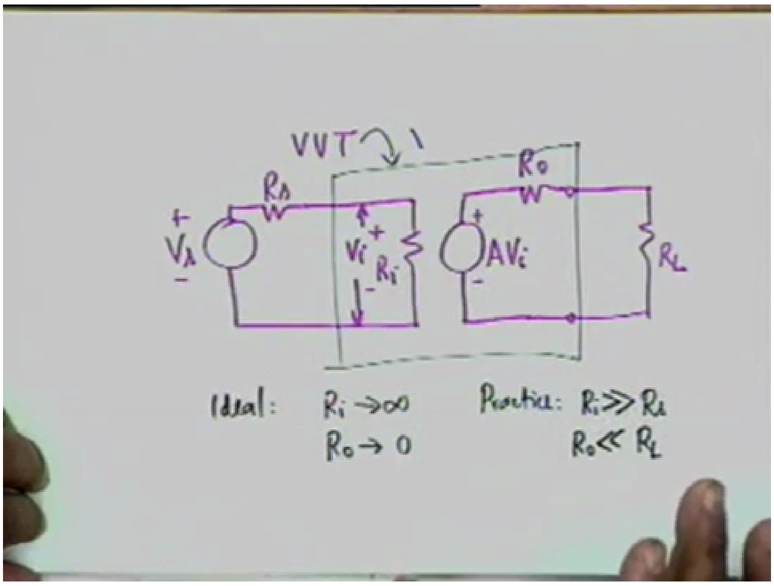

But sometimes we will assume an ideal amplifier and then look at the imperfection. So this is the model of a voltage to voltage transducer. For a current to current transducer, a current amplifier, we have I s, R s. Then we have the basic amplifier and this current is I sub i and in the output we have the current A I sub i, a current source, current to current. A is the gain of the current amplifier and the output impedance is now represented as a shunt resistance R 0 and this is my R L. The basic amplifier here is this block.

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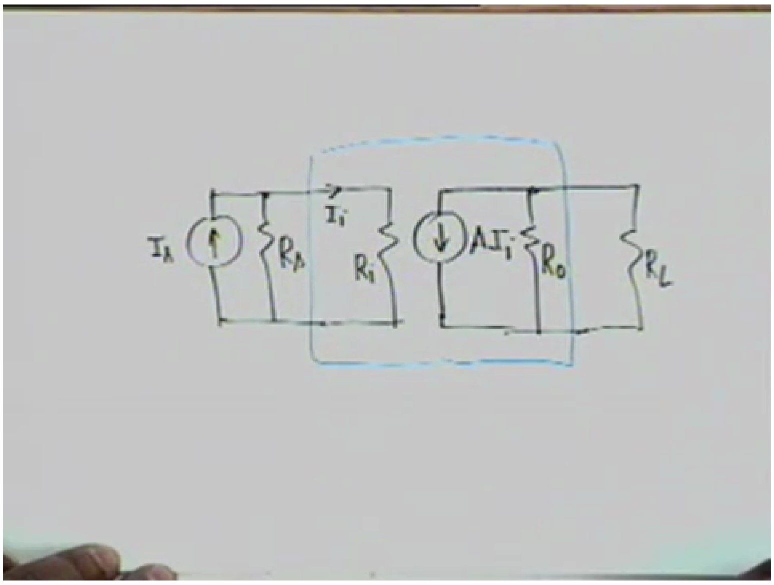

And to approach the ideal what we want is R i should be much less than R s in practice and R 0 should be much greater than R L. So this is a C C T, current to current transducer, also called a current amplifier. Now you notice that this A, can you give a name to this A?

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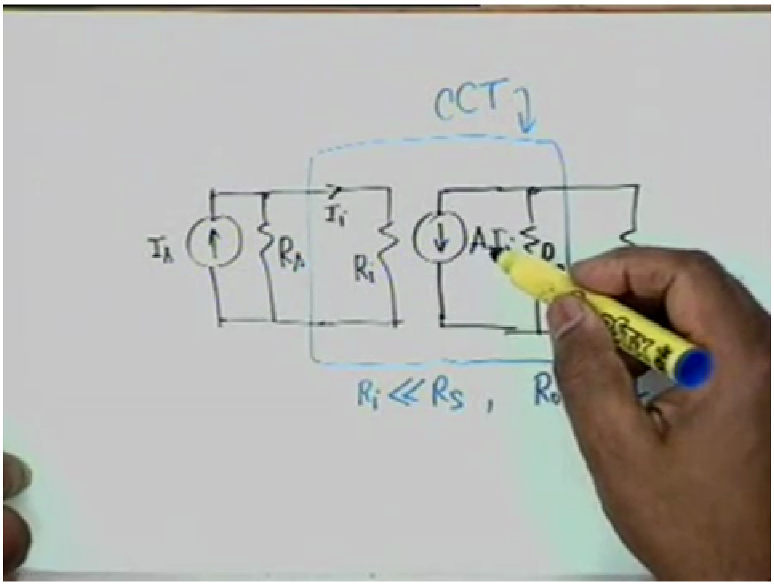

This is the current gain under what condition? Short circuit. If R L is short circuited then R 0 will carry no current. All the current will flow through this. So this is the short circuit current gain. In a similar manner this A open circuit voltage gain, wonderful. Let us look at V C T. For V C T our input is a voltage source and we have an R i. This voltage is V i, voltage to current and therefore we shall have A V i in parallel with a resistance R 0, voltage to current.

Then we have the R L. The basic amplifier is this and since A has to have the dimensions of a conductance, right, we call this capital G m to distinguish it from small g m of a device. So it is a trans-conductance amplifier. It is voltage to current V C T. And what we want in practice is that R i should be much greater than R s and R L must be much less as compared to R 0.

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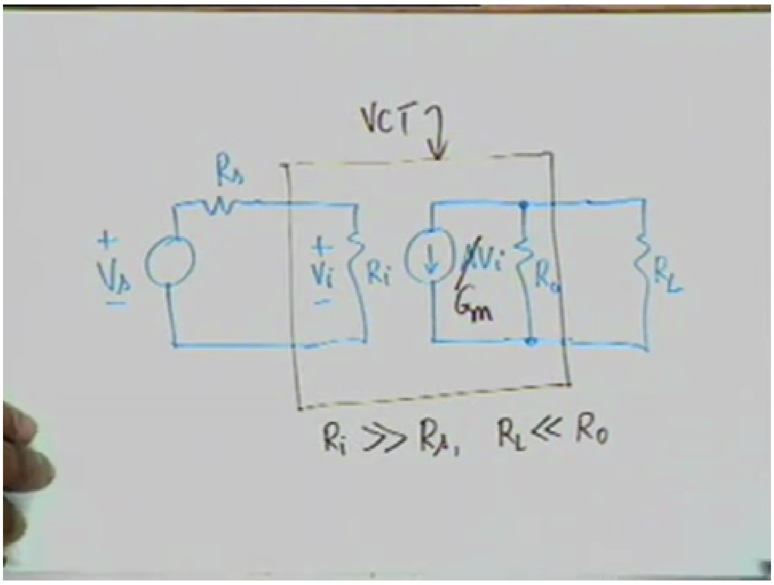

Finally the C V T that is current to voltage transducer. We have a current source I sub s in parallel with its source resistance R s. Then we have R i. This current is I sub i. Current to voltage so we have voltage source here and naturally the proportionality constant or the gain shall now have the dimension of resistance and we call this R m, mutual resistance or transfer resistance or trans-resistance, R m I i and this shall be in series with R 0 connected to load R L.

This basic amplifier is this and it is called a C V T current to voltage transducer. What we want in practice is that R i should be much less compared to R s, agreed, so that the I s is approximately equal to I i and on this side we require R 0 to be much less compared to R L. So these are the four kinds of amplifier models.

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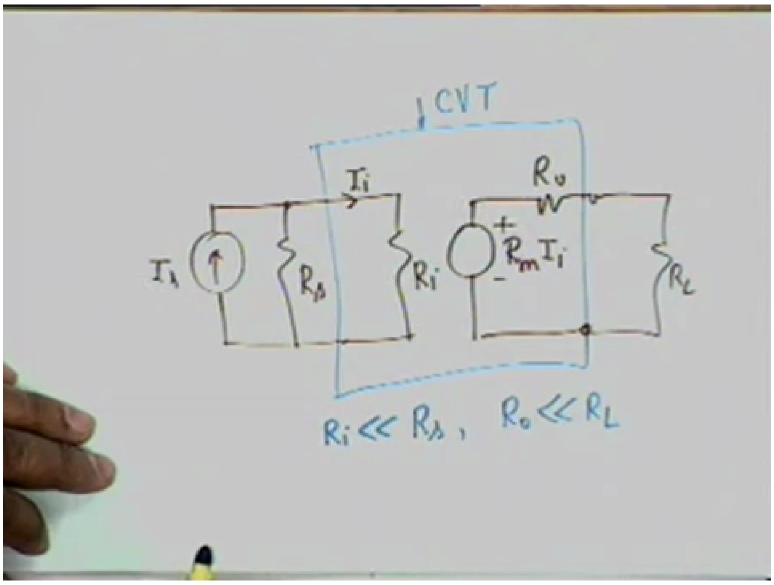

Almost any amplifier that you can think of because we know (())(24:26) theorems. Any amplifier can be modelled by any of them but these relationships may not be satisfied, okay. Wherever this relation is satisfied you will call this a C V T. You will not call it a V V T. Although as you see in principle any of these circuits could be converted to any other circuit. But these inequalities shall not be satisfied in all the circuits, okay. This is why we call them by different names. Yes?

Student: Sir, on all these amplifiers the input and output stages are decoupled?

Input and output stages yes. This is the model that we assume, yes. That is a good question. He says, input and output stages are they decoupled? Okay, this brings us to this question. If you recall we had a basic amplifier in the feedback and we had another network here called the feedback network, alright? These are two essential components and then we had a sampling network here and then mixing network or comparison network here to make it a feedback amplifier.

The question that he is asking is, are the input and output decoupled? Yes, we make this assumption that the basic amplifier transmits only in the forward direction. That is nothing gets transmitted from the output to the input. Output is coupled to the input. Obviously if it is an amplifier, say if it is to provide gain, output has to respond to the input. But the input should not respond to a change in the output, agreed, which means that it is a unilateral device. It transmits only in the forward direction.

This is an assumption and you know that this is not correct. This is only approximate because of that R mu and C mu even in a single stage amplifier this assumption is only an approximation. And we wanted to get rid of C mu through the miller effect but miller effect as you know is also an approximation. Well for that matter life itself is approximation as I have been saying many times.

On the other hand in the feedback network we want it to be unilateral but in the reverse direction. It should not transmit from input to output. From input to output only basic amplifier should take part. From output to input only the feedback network.

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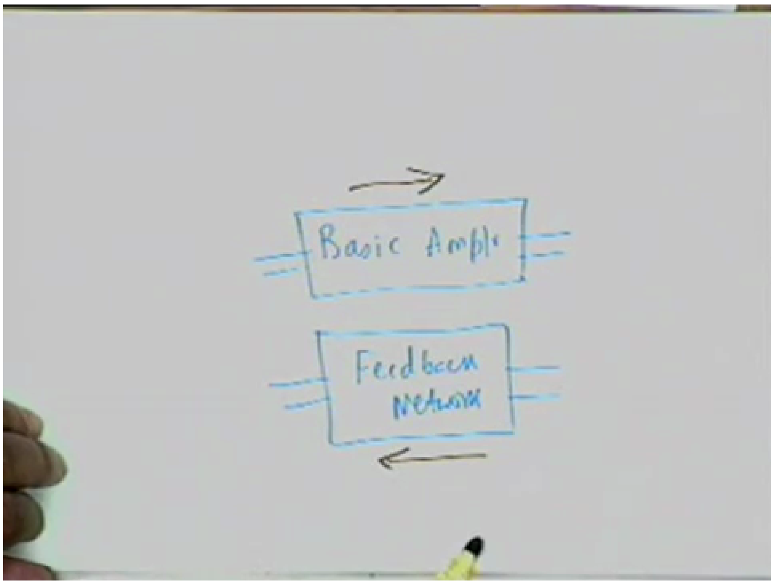

This is also an approximation because as you will see in most of the feedback amplifiers the feedback network is a passive network and a passive network is insensitive to directions, is not it right? If a network contains only resistors, capacitors and inductors, transformers, it is insensitive to direct. It transmits in both directions. So this will also be an approximation. We will revise the network in such a manner that the forward transmission is dominated by the basic amplifier and the reverse transmission is dominated by the feedback network, alright.

We will have to make these approximations and this is where the complication in the analysis and design of feedback amplifiers comes in. You have to follow me very carefully. Now let us look at some of the sampling networks. One sampling network could be like this. We are looking at two different kinds of sampling networks. There are basically two different kinds of sampling networks. By B A we mean the basic amplifier and one sampling network could be like this. This goes to the load and there is a voltage V 0.

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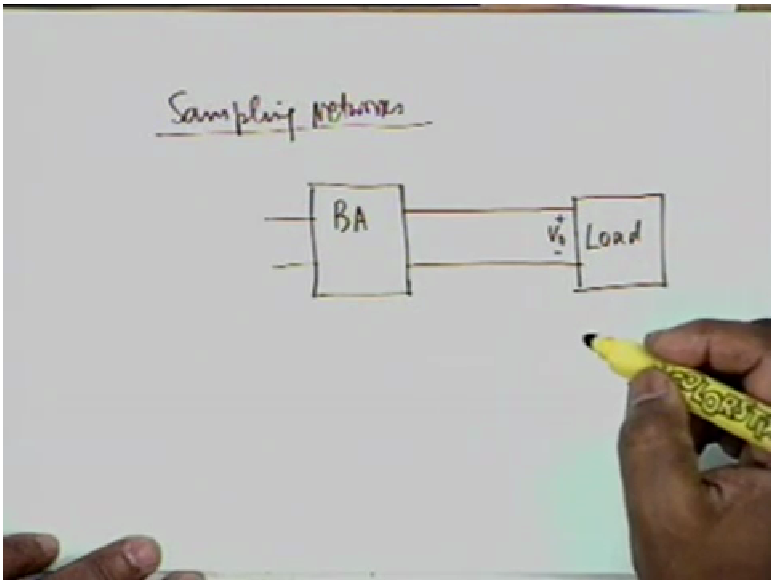

Suppose we want to sample the voltage then what we do is we take this to the feedback network, okay. So our sampling network becomes this. This is my sampling network where we have taken the total output voltage, fed back to the feedback network, okay. We have sampled the voltage. It is not necessary to take the whole voltage. We could have taken a potential divider, integral part of it, agreed? For simplicity I am showing the total voltage, okay. But here this is called voltage sampling.

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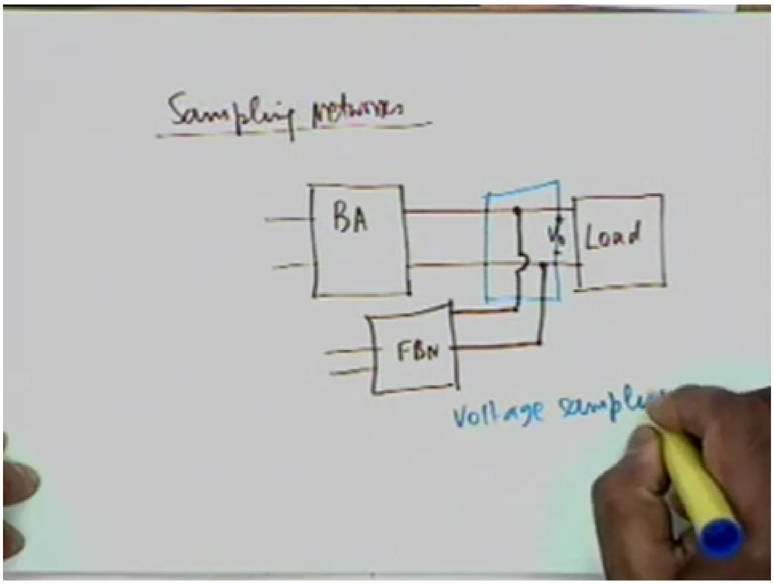

Student: Sir, I did not get your point.

You did not get my point, okay. To the feedback network the feedback is through a part of the output. The output could be voltage or a current. If I take in across the output obviously I am sampling the voltage, okay. It is not the load current which influences this. We are taking this voltage to produce a voltage here or a current here which is proportional to V 0, okay. So it is called voltage sampling.

And obviously for voltage sampling you have to take the connections to the feedback network in shunt, right, in parallel. Now what I was saying is you do not have to take the total voltage and feed it to the feedback network. You could have taken a part of this voltage. You could have taken the voltage from here.

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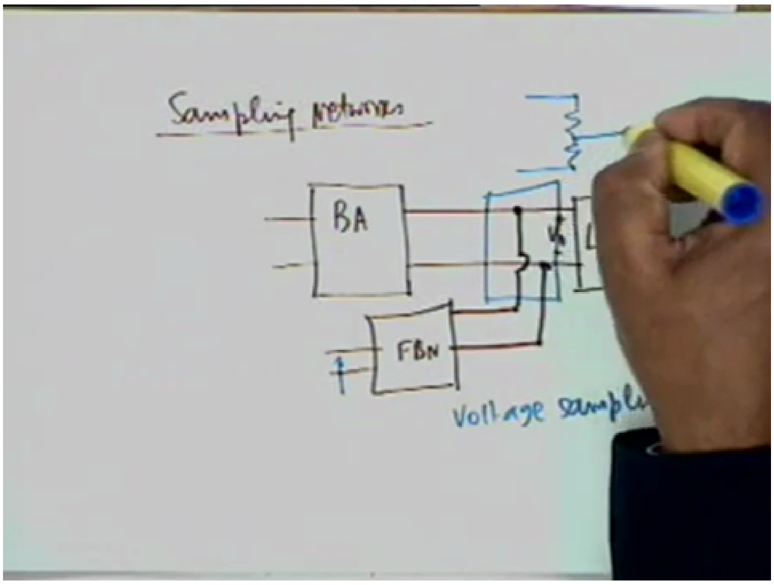

It could be a fraction of the output voltage. I have shown for simplicity the total voltage but it could be a fraction, okay. Yes?

Student: Sir what is the point in taking the fraction? What is the utility? What is the advantage?

I may not require the total voltage. I want to control the amount of feedback. Amount of feedback could be controlled either by the feedback network or by a network here, okay. It will depend on the convenience. Sometimes you will not take the load current or the load voltage. You will take the voltage at some other point. This is the convenience of design. This is the practical situation is quite different from the ideal situation. We are discussing an ideal situation, okay.

You will see how things differ in practice and that is where the complication arises. So this is called voltage sampling or a shunt connection. Sometimes we simply call a shunt sampling. Shunt sampling means we take the input to the feedback network is derived from across the load, okay. On the other hand we could also have something like this. The basic amplifier it goes to the load and suppose the load current is I 0. Then what we do is we break the connection here and take this to the feedback network, okay.

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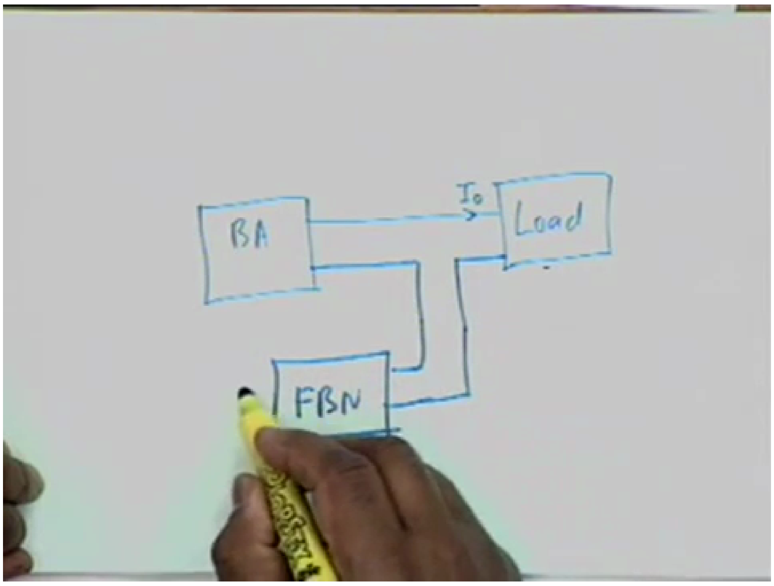

Obviously this will be current sampling because it is this load current which is coming to the feedback network and therefore the feedback signal that we derived from the feedback network would be proportional to the output current. So it is called a current sampling or what is the other name that you can give to it? Series sampling, okay. Either a current sampling or series sampling, agreed? In a similar manner there are two types of comparison or summing networks. Let us look at them.

The comparison network is at the input to the basic amplifier so if this is the basic amplifier and let us say this is the source V s, for simplicity we will ignore R s. Suppose we connect this like this. This is what comes to the feedback network. Suppose we make a series connection then this will be the fed back voltage, okay. I will be showing polarity, let us say the polarity is this, agreed?

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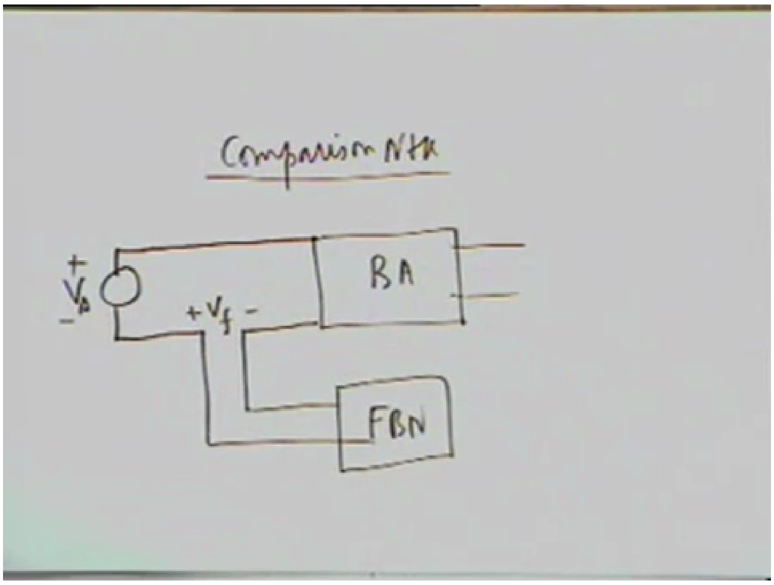

So the actual input voltage is being affected by the signal that is applied and also the feedback voltage. Now what would you call this? This is called a series connection at the input. Obviously this is the series, the two voltage sources, one is the actual source and other is the fed back voltage, these are in series and therefore this is called series comparison network, okay, series comparison network. On the other hand you can have a shunt comparison network in which the current shall be affected, the actual input current.

And for that we will show as a current source, ignore its impedance and then you have the basic amplifier and the feedback network is connected in shunt. So the actual current that is fed to the basic amplifier is affected by the feedback current. Do not pay attention to the direction. I have assumed an arbitrary direction, okay. I i obviously is I s minus I f. And if I s and I f are in phase then it is, what kind of feedback? Negative feedback.

If I s and I f are out of phase then it would be positive feedback, okay. So the direction of I f is arbitrary. It depends on the phase difference, phase relationship between the two. This is called obviously a shunt connection at the input, alright?

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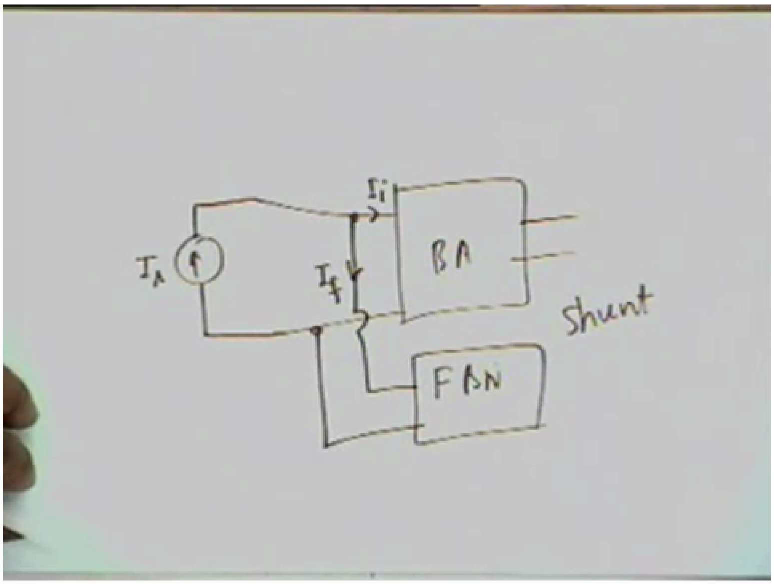

And depending on the connection at the input and the connection at the output obviously we can have four different kinds of feedback amplifiers and these are, the first one indicates the input. We can have a shunt-shunt. Now shunt-shunt means what kind of sampling?

Student: Voltage to current.

No , sampling.

Student: Voltage.

Sampling refers only to the output.

Student: Voltage sampling.

Voltage sampling, okay, voltage sampling and shunt connection at the input, okay. Pardon me. Current is being affected, very good. This is current feedback and voltage sampling, okay. It should be understood. Then we can have shunt series which means current sampling and current feedback, okay, shunt series. Then we can have series-shunt which means voltage feedback and voltage sampling or series-series. We shall use this terminology. This is a popularly adapted terminology for feedback amplifiers.

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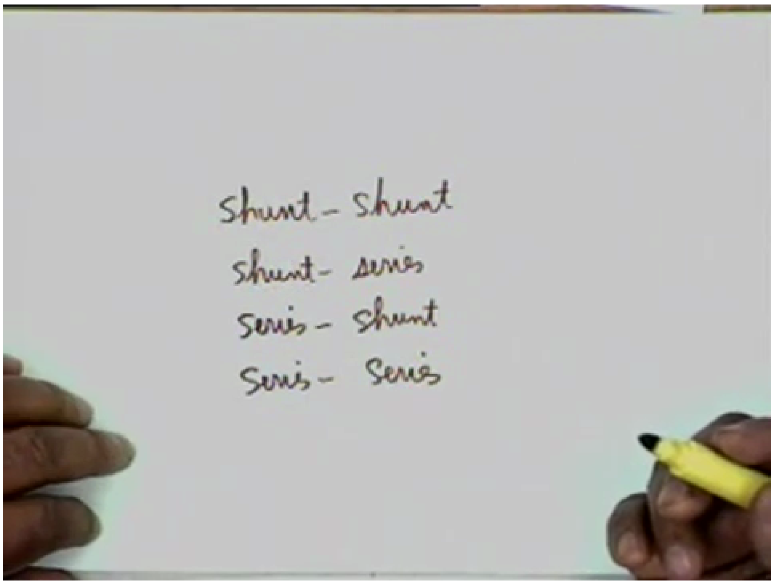

What is series-series? Series-series means voltage feedback and current sampling, okay. There is another type of terminology which you should not be baffled with if you encounter this, in which phrases like current-shunt are used. Current-shunt, current-series, voltage-shunt, voltage-series. But let me explain. I do not want to confuse you with two types of terminology. Let me explain because this is also used.

In this type of terminology the first one refers to the output where as this type of terminology first one is input, second one is output. In the other type of terminology first one is output, the second one is input. Your current-shunt means current sampling and shunt connection at the input. What does this correspond to in this?

Student: Shunt-shunt.

Shunt?

Student: Series.

Shunt-series, that is correct. Current shunt corresponds to shunt-series, alright?

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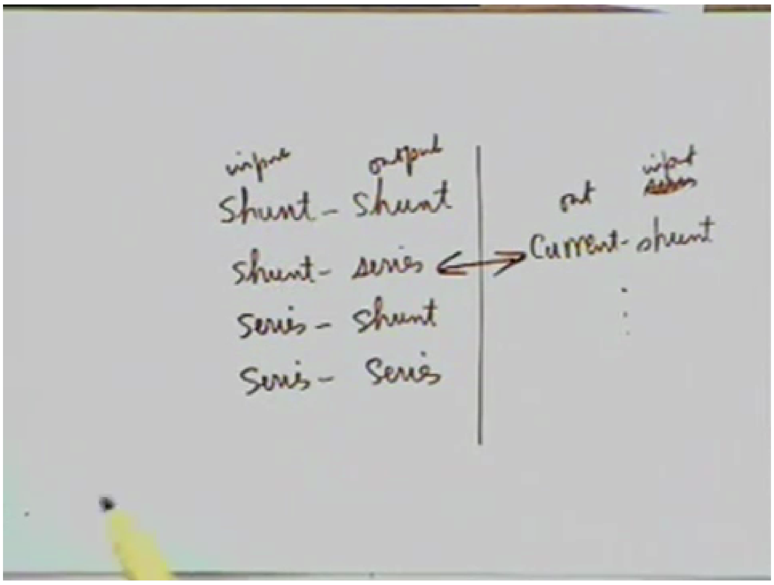

Similarly you can have voltage-series, voltage-shunt, current-series, current-shunt and each of them is identical to one of this. We shall divorce this terminology in order not to be confused. We will either call shunt-shunt, shunt-series, series-shunt and series-series. We will maintain this uniformly throughout our discussion of feedback amplifiers. If in future you encounter an instructional manual for example in which it is said this is the voltage series feedback you should be able to decode and find out what it actually means.

For simplicity this shunt-shunt connection is sometimes simply referred to as shunt feedback. And series-series sometimes simply referred to as series. So if there is only one term then this applies to both input and output. On the other hand if the two input output connections are different then you shall have the complete designation, shunt-series and series-shunt.

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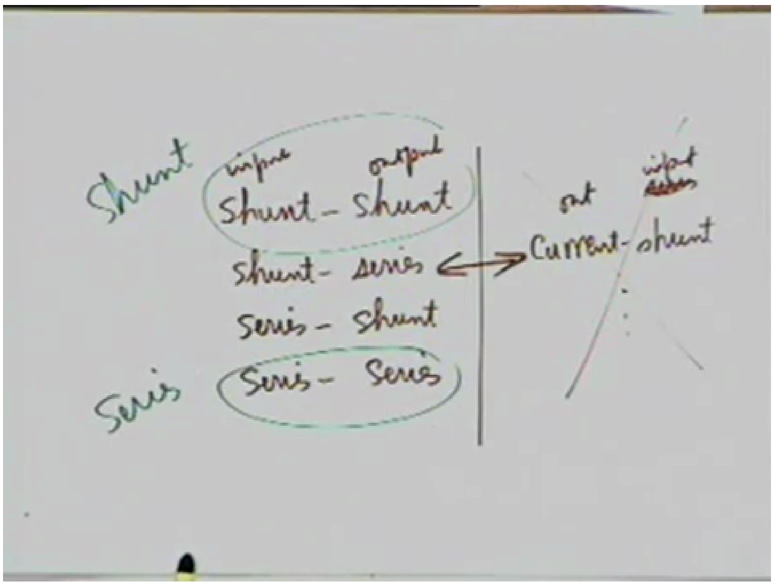

Let us consider a typical feedback amplifier . Draw with me. Again in terms of its model, okay, we have I s, R s, then we have the basic amplifier R i, this is I sub i and the basic amplifier is a current amplifier or a current to current transducer. So it is A i times I i current gain in parallel with its output resistance R 0. Then this post goes to the load. And let us say our sampling is a current sampling that is it is like this. Let us say the current is like this I 0 in the load.

Then this comes to the feedback network and we have shunt connection here, okay. The basic amplifier is this. Have you drawn? Have you been able to draw? Let me put some boxes. This is the basic amplifier. Obviously this is a C C T, current to current transducer. This is the sampling network S N and this is the comparison network C N, okay. And let us say this current is I f.

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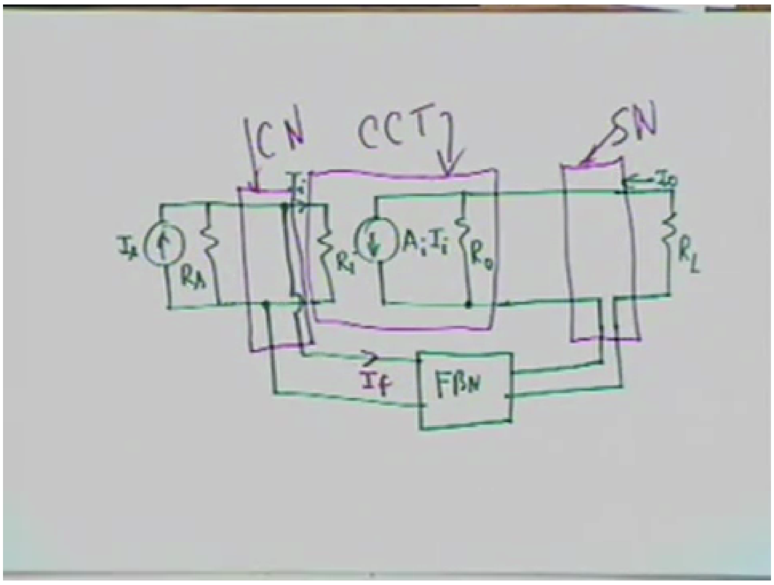

Is this negative feedback or positive feedback? We do not know unless we know the phases of I s and I f, okay. So these two phases determine whether it is a positive feedback or negative feedback. Now practical circuit we shall draw later. I thought I would illustrate at least one such configuration with idealized models. Now let us look at the general feedback amplifier circuit. The general feedback amplifier circuit usually analyse in terms of a block diagram.

That is a single line represents the signal and a block represents either a gain or the feedback network. And for historical reasons blame it to Nyquist or Bode, if you have to blame someone. The feedback factor is denoted by beta. Not to be confused with beta of a transistor, okay. We could have used some other symbol but then with due respect to the two gentlemen both of whom are dead now. Bode died at the age of 94 only a few years ago. He was still active at the time of just prior to death, not after death of course. We do not know.

And Nyquist died long ago but in paying respect to these two gentlemen we shall retain this terminology of beta. So what we have is the basic amplifier we shall denote by a block A and we shall assume that it is unilateral that is it only transmits in the forward direction. And the feedback network with call this beta network and we assume that it transmits only in the reverse direction, okay. The output whether it is a voltage or current we denote it by X 0.

The output is sampled and passed through the beta network. By these arrows we do not show current. It is the direction of flow of the signal. The signal can be either a current or a voltage, alright? Let us see and we have the comparison network we will show by means of a sum up. This is the usual thing that one does. You sum up the input signal to the fed back signal so we have an arrow here and an arrow here. This is X s.

That is the signal that is actually applied, the source signal and what goes in is X i. What goes in is X i and what comes here is X f and for simplicity we show both of them as addition, okay.

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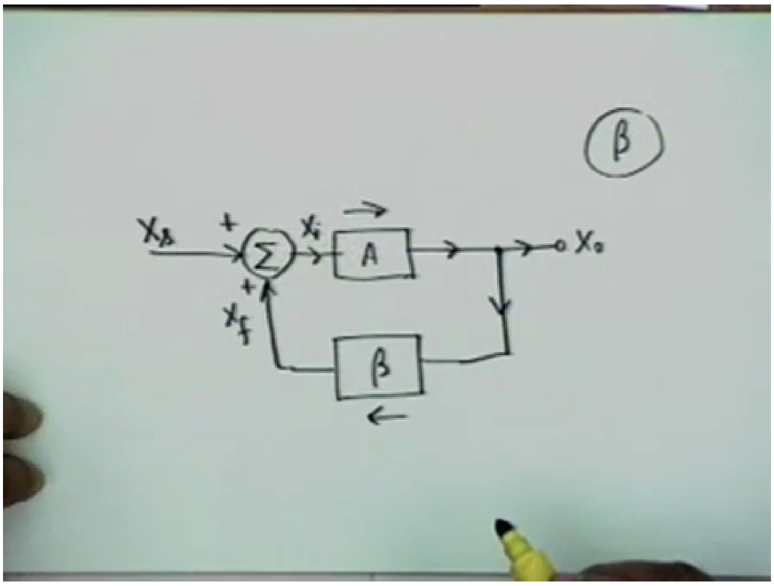

Then it is very easy to see. Is this block diagram clear? It is very easy to see that X i is X s plus X f and this is equal to X s plus, X f is nothing but beta times X 0, plus beta times X 0 and therefore X 0 is equal to A times X i, so it is A times X s plus beta X 0, agreed?

And therefore the feedback gain or the gain of the overall feedback system which is equal to let us call it A f, gain with feedback is equal to X 0 by X s. Obviously this is equal to A divided by 1 minus A beta . This is the basic formula for a feedback amplifier.

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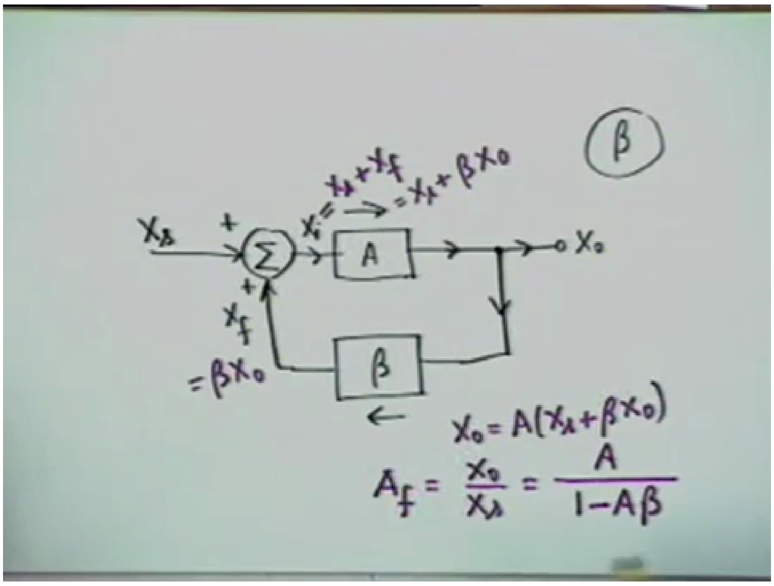

Yes?

Student: (())(45:32)

Oh! If the output is X 0 then its output of the beta network is beta X 0 that is it. You see beta is the reversed transmission coefficient , okay.

Student: Sir, it need not be a dimensionless (())(45:52)

I need not be dimensionless. In fact since A beta subtracts from 1 it must be dimensionless. A beta must be dimensionless. So if this amplifier for example a V C T voltage to current then beta must have a dimension of what? Resistance, because if it is V C T then A is g m, a conductance, so beta must be a resistance. On the other hand if A is the voltage amplifier then beta would be dimensionless constant.

If it is a current amplifier beta is a dimensionless constant but not otherwise. Is the point clear? You can only make horses with horses not otherwise, okay. You cannot add a dimension quantity to a dimensionless quantity. This must be dimensionless, alright? There are various names that you will learn in your controlled course to this quantity 1 minus A beta. It is sometimes called a return difference and denoted by F. It is called a return difference and the quantity minus A beta is sometimes called a return ratio or loop gain.

These are various terms which have significance in the context of control and most of our textbooks unnecessarily go in to the definition of these quantities. We should avoid these terminologies as far as our analog electronics circuit course is concerned. But they will be brought back in the control course so we need not worry about them now. You notice that A f, this is the general formula, 1 minus A beta. And if the feedback is negative then 1 minus A beta magnitude has to be greater than 1.

So negative feedback will mean 1 minus A beta magnitude greater than 1 which means that the magnitude of A f shall be less than the magnitude of A. On the other hand for positive feedback, well if everything is resistive there are no reactances then obviously for negative feedback A beta quantity has to be negative, agreed, okay. And whereas for positive feedback you want A f to be greater than A which means that A beta, if it is totally resistive, A beta has to be positive.

You also notice that if A beta is a complex quantity and at some frequency if A beta is a complex quantity obviously it shall depend on frequency. If at some frequency the value of A beta magnitude is 1 and the phase is zero degree or 360 degree or 720, that is a multiple of 2 pie then the gain becomes infinitely large, is not it right? Okay.

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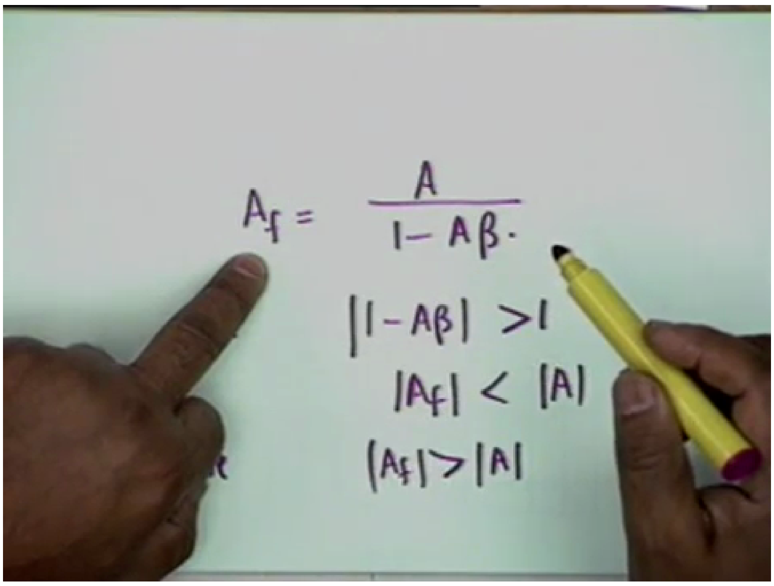

If our A f is A by 1 minus A beta, if A beta is a complex quantity that is if it is a function of frequency and if there is a frequency at which A beta magnitude equal to 1 and the angle of A beta is equal to multiple of 2 pie where n is an integer then obviously A beta becomes equal to 1. And 1 minus 1 is 0, A by 0 is infinity so the gain becomes infinity.

If the gain is infinity it means that the output can be sustained without applying an input which is the circuit for an oscillator, okay. It is an unstable circuit but it produces oscillation. Oscillations at what frequency? At that particular frequency at which A beta is equal to 1, 0 degree, okay. So oscillation. Yes?

Student: Sir, 1 minus A beta was in numerator. It was brought down and we could not have brought it down if 1 minus A beta was A.

Okay, that is correct which means that there are oscillations. You see it is the same thing. What we are doing is we are first assuming that A and beta are general quantities. Then we are investigating the state of this when 1 minus A beta is equal to 0, okay. We will not be able to write this equation because infinity we do not know what it is.

So we will not write gain. In fact they term gain loses its significance if 1 minus A beta is 0. But what I was trying to do is to tell you that oscillation will be at that frequency at which this is equal to 1 angle 0 degree or 360 or whatever it is.

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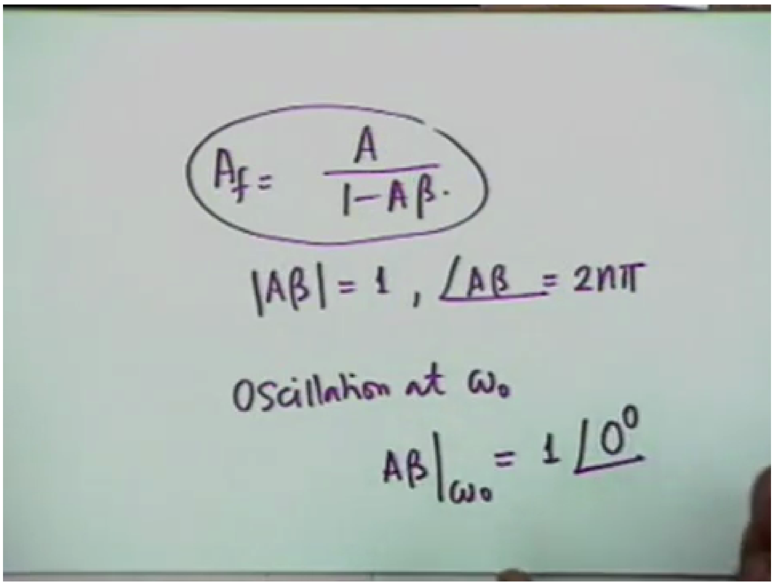

Now it may so turn out that this relationship is satisfied only at one frequency then you have a sinusoidal oscillator. Any oscillation at one particular frequency, okay, is a sinusoidal oscillation, right? On the other hand if this is satisfied over a band of frequencies, okay, then you will not have sinusoidal oscillation, you will have a sum of signs. That is a number of sinusoidal oscillations superimposed on each other and that would be a non sinusoidal waveform. For example you can generate square waves with an oscillator, okay.

You can generate square wave and you know square wave consist of the fundamental and a number of harmonics which means that the circuit that you use for square wave generation must satisfy this criterion at a number of frequencies. And this criterion is associated with the name of a man who as far as I remember was a mechanical engineer. His name is Berkhausen and this criterion is called Berkhausen criterion.

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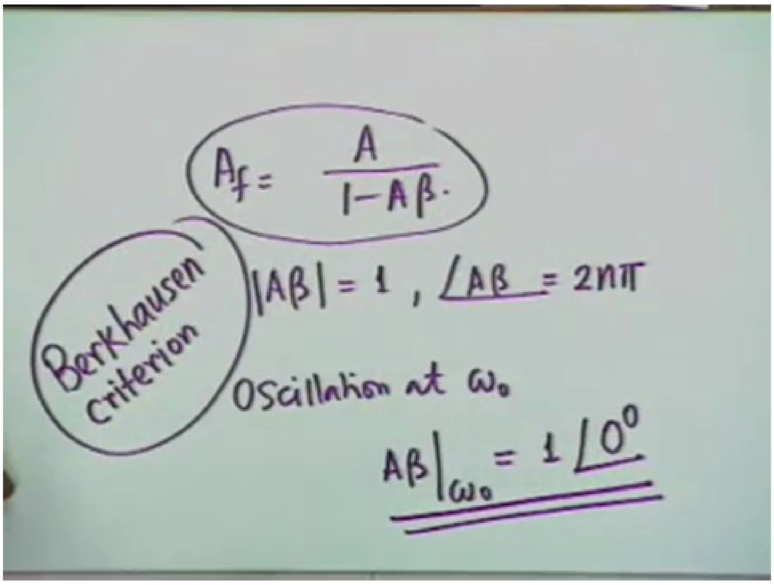

We shall come back to this when we discuss oscillators. Tomorrow we will go into more details of feedback amplifiers and see how to analyse them.