Electronics for Analog Signal Processing - II
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Lecture - 1
Feed Back Theory

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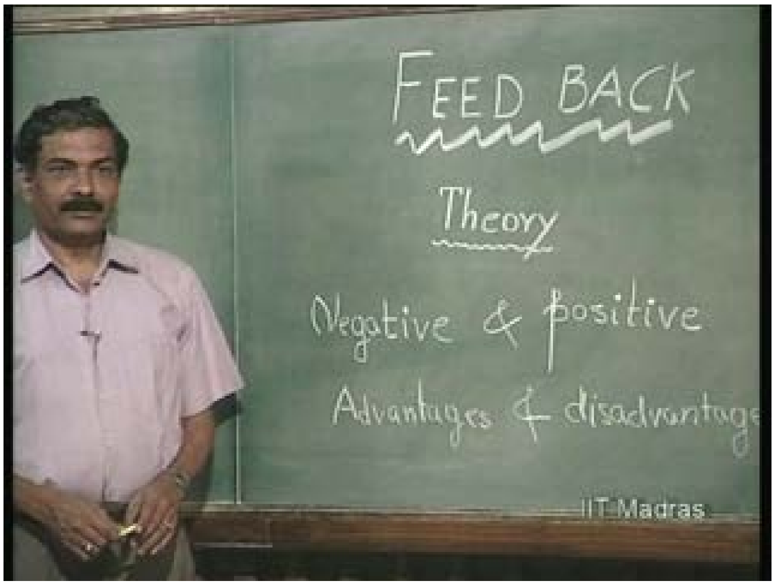

So, so far in the first part of our series of lectures on analog electronics, we had concentrated on amplifiers. Only feed forward amplifiers were considered. There was nothing like feedback from output to input. We were only concerned with devices, active devices, which are capable of transferring information from input to output. Nothing was fed back from output to input or feedback factor in all those cases, we had assumed to be zero.

Now, we will consider what is feedback. This is an important part of circuit design. Therefore, we have to learn something about feedback theory. What is negative feedback; what is positive feedback; what are the advantages and disadvantages of each one of these feedbacks; where do we adopt these; will be the topics which will be dealt with in this chapter on feedback theory.

Now, let us consider a block box kind of thing wherein... This is what is called a linear block where, if I give v i, it will give me a transfer function which is G times v i. I am adopting G because it is called a game block. This is the symbol adopted also by control systems people in discussing what is called feedback.

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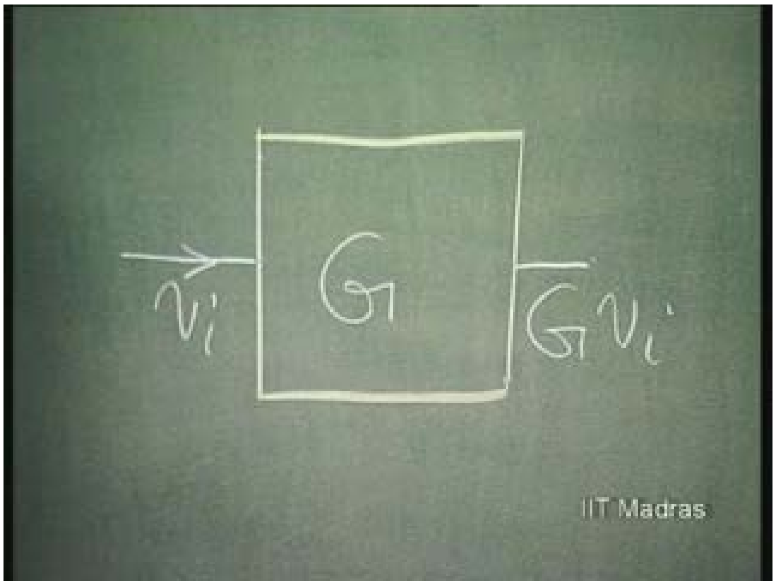

So, we have a system here where v i is the input and G times v i is the output. This is a feed forward kind of structure. For that matter, in controls, we will not bother about voltages. It is a parameter; X i input parameter and X naught is the output parameter. So, this is going to be X i times G equal to X naught.

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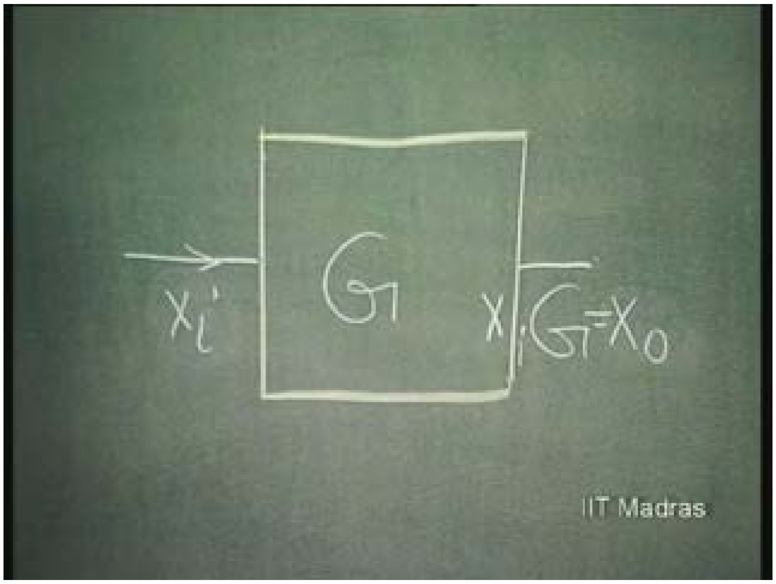

So, feedback - something of X naught is taken; and this is another block. This is a new block that we are discussing. H is the factor, transfer factor. If this is X naught, the output here is H times X naught. So, some part of output parameter is sampled and fed back to the input.

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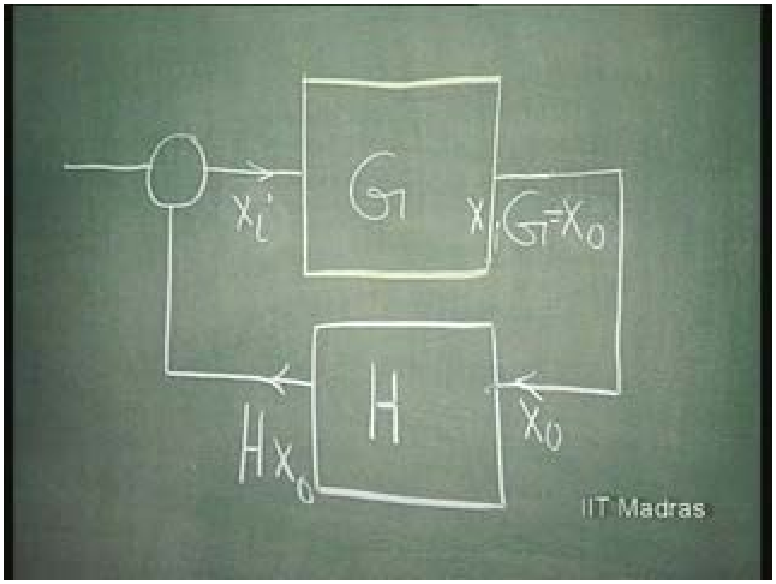

Now, this commonly...this is called, commonly called, error detector. What is the error that it is going to detect now? Instead of X i now being the input directly to the the block, what is going to be fed to the main block is going to be X i minus. Now, this plus minus indicates that this is finding out the error. This is transferred with plus; this is transferred with face error of 180 degree. So, this is really going to give you epsilon the error, which is nothing but X i, how much it is different from H times H naught.

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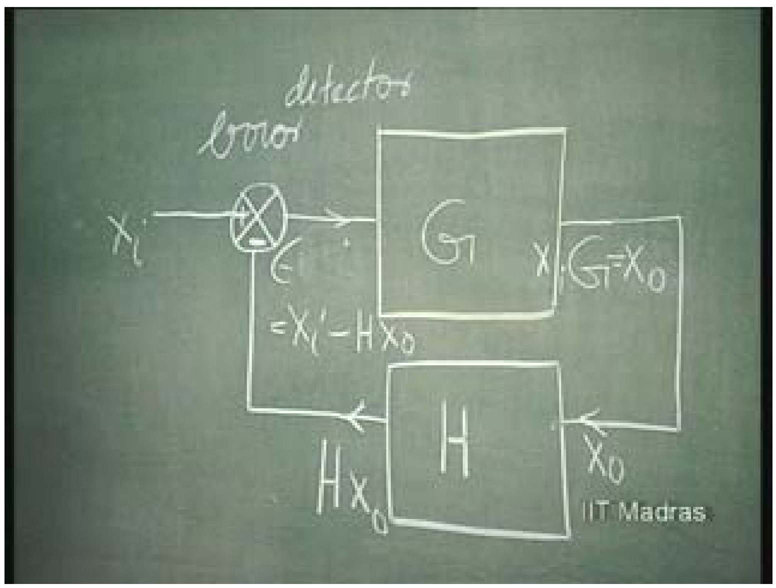

So, X i minus H times X naught is the error here which is the output of the error detector. That is now what is fed to the amplifier or the feed forward block, which has the transfer parameter of G. So, if this is done in a linear system like this, we have X i minus H times X naught into G because this is the error. Error is amplified as G. This is again equal to X naught. This is an important equation in control system engineering where X i and X naught could be any parameters; so variables. And G and H are transfer functions of these linear blocks. G is the feed forward block and H is the feedback block.

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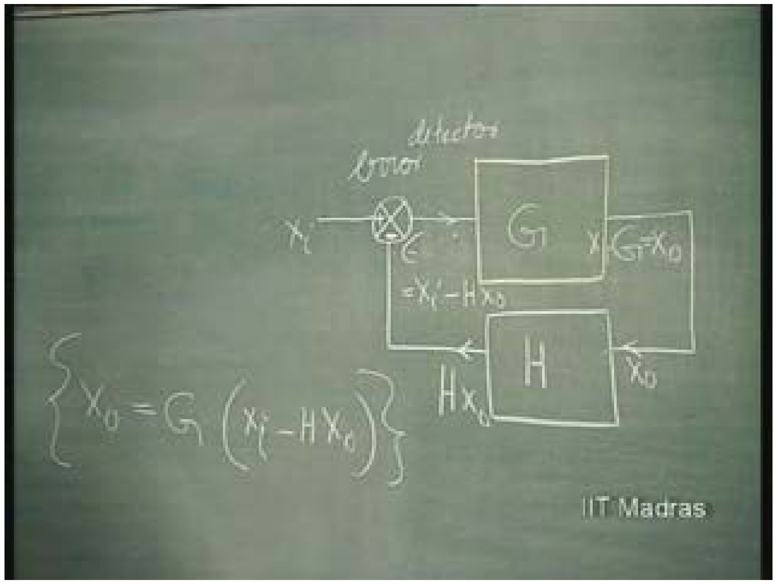

So, from this equation, X naught into 1 plus G H equals G times X i; or X naught by X i which is the important thing now, output divided by input in this basic feedback block, is always equal to G divided by one plus G H.

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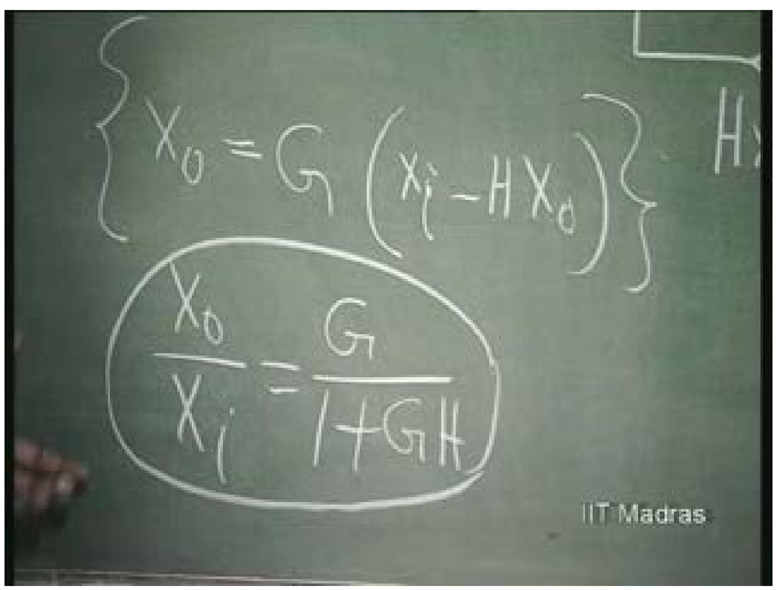

This, if you have done a control system engineering course, you would have been familiar with. Output parameter divided by input parameter is equal to G divided by 1 plus G H. This is negative feedback because you are now finding out the error here; X i and the feedback thing are such that you are comparing the difference between these two and the error is appearing here. So, this is negative feedback.

If this is plus and this is plus, then you are adding input and feedback thing; this is positive feedback. If this is plus and this is plus, there is nothing like error. You are simply adding this and that is called positive feedback. We will discuss that later.

It will merely change the sign. Here, instead of considering that this is X i minus H, you will have to consider it as X i plus H. So, wherever H is there, put minus H; it becomes what? Negative or from negative to positive feedback it becomes. So, G by 1 minus G H you get. So, that we will discuss later. Let us now consider what is important. That is negative feedback.

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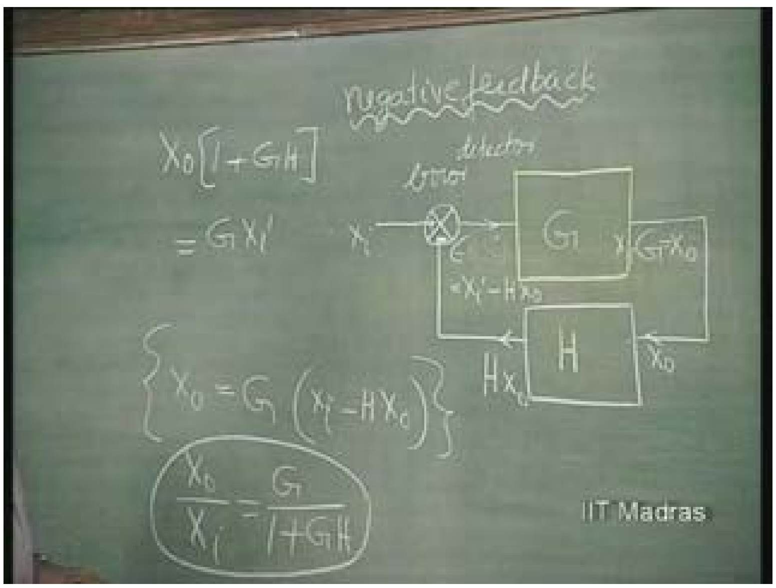

Now, this theory which was long ago proposed by one Black has become very important. It is a very simple theory. He was also worried about amplifier design and decrease of distortion. They were trying desperately to reduce the distortion and at that point of time suddenly, while he was crossing the riv...one river in a boat or something like that, this idea flashed on him. Why not try this. Immediately he went to the lab and tried it and found it working. So, this is an important theory; negative feedback theory, which was very well established and then, of course, lot of work went on on this.

Now basically, this negative feedback is not something that is not there in nature. It is not that we...it was only discovered by human beings. It was already existing. So, for example, the yogis go into a state of what is called meditation. Now, for a long time, the scientists were puzzled about how this was being achieved. What was happening was they monitored these yogis' brain waves, E E G, and found that they were predominantly generating what is called Alpha waves, which is occurring at a certain frequency, low frequency. We generate what is called Alpha, Beta, Gamma, Delta, kind of waves in our E E G; whereas these people were predominantly generating, when they went to a state of meditation, what are called Alpha waves.

Then it was found out that if you give what is called bio feedback; that is, if you tell an individual that this is the Alpha wave, I mean, you can have an electronic sort of a filter put after E E G and show him the Alpha wave and say that this is something that you have to increase in its amplitude, then there is a feedback because he is looking at his output and you have told him that his main responsibility is to increase the amplitude. So, he will look at the wave form or it can be put in the form of audio also. So, increase the strength of the audio. You can convert it into some audio equivalent frequency and increase the volume. So, you can...the moment you say that, suddenly he will go into a state of meditation. This is somebody who is not at all a trained yogi; an ordinary person, who is told this can go into a state of meditation.

Now, lots of such gadgets have been marketed in States just to put like a head gear. You just put it on and you will become a yogi like person going into a state of meditation. This is nothing but negative, that is, bio feedback. Basically, feedback technique is increased; used to improve the performance of the individual.

Now, it is also used for a lot of...let us say, increasing the Alpha wave is also good for the brain in certain illnesses called epilepsy. This is also being used to cure epilepsy, sort of. They can control the attack. That is, they get an aura that they are going to have an attack. At that time, if they are told that this is the way; you have to go into some kind of meditation, then they can possibly prevent the attack. Now, this kind of thing is also being tried.

Now, coming back to this feedback theory, we saw that X naught by X i is equal to G by 1 plus G H. So, what is the good of this kind of transfer? We just do not see what have we achieved really if you look at this expression; because earlier, it was G; now it has become G by 1 plus G H. In fact, if you strictly see, if G and H are positive quantities, G by 1 plus G H is definitely less than G. That can be clearly said. If G and H are positive quantities, then G by H, 1 plus G H is less than G, always.

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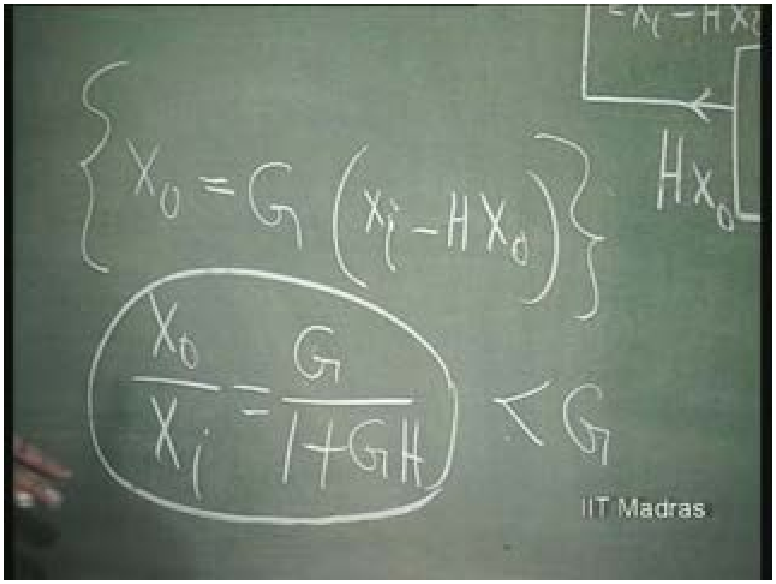

That means, if it is an amplifier, the negative feedback amplifier will always have a gain which is less than the open loop amplifier. So, this is an important fact; that negative feedback causes a transfer function which is less than the original transfer function ratio which you had. Earlier we had G as the transfer function parameter; now it is G by 1 plus

G H. Now, we are not saying what this is. This can be voltage gain, current gain, or transfer conductance or transfer resistance in the case of our amplifiers; but whatever it is, it is reduced. So, reduction in the transfer parameter.

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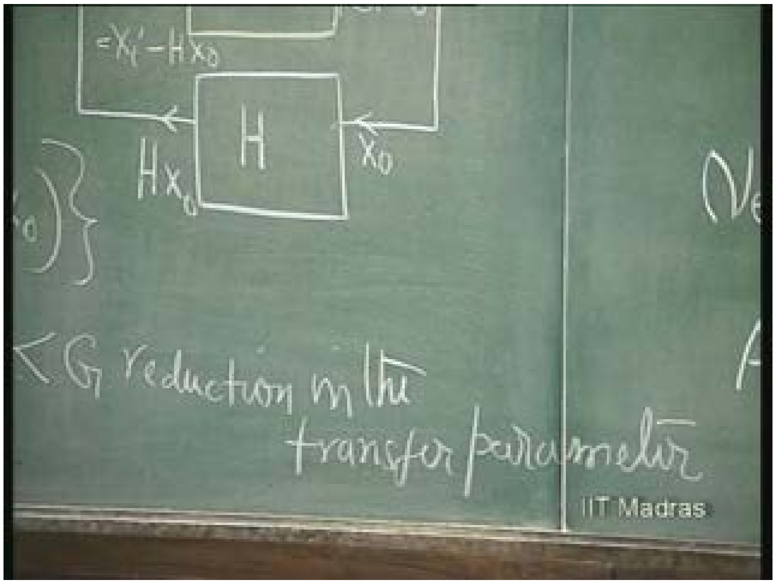

Now, it might look very funny. Earlier, our attempt was always to make this as high as possible. Now suddenly, we are confronted with a situation here where the the transfer function reduction occurs because of negative feedback. So what possible use could it be to you?

Now, let us consider the fact that G is something very high and G H is much greater than 1. We will see... G and H are positive quantities; we have started with that. G into H is much greater than 1. Then we can say that X naught by X i can be approximated to... G H is much greater than 1; so this 1 can be neglected. So, we get 1 over H. G... if... If G into H is much greater than...we get X naught over X i equal to 1 over H.

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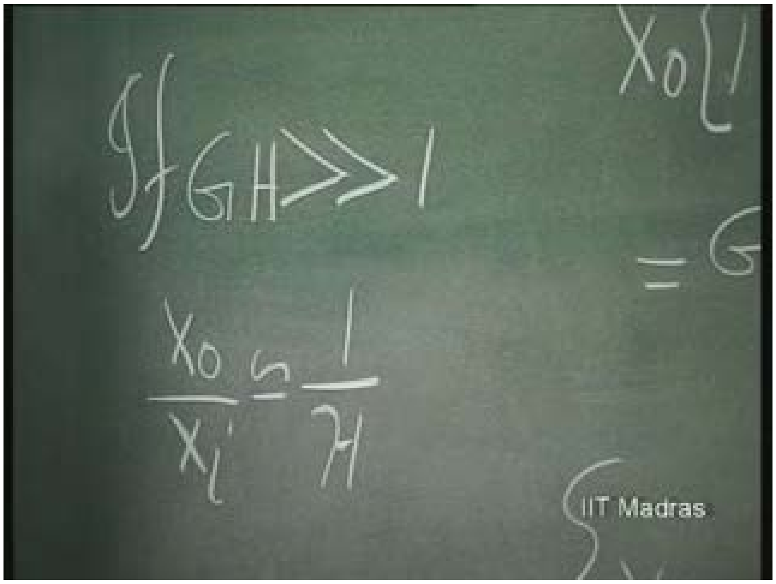

Now, this is something which is fantastic. It is independent of of G. Now, this is something that you have to understand; and H, if less than 1; if it is a ratio and it is less than 1, 1 over H is going to be greater than 1.

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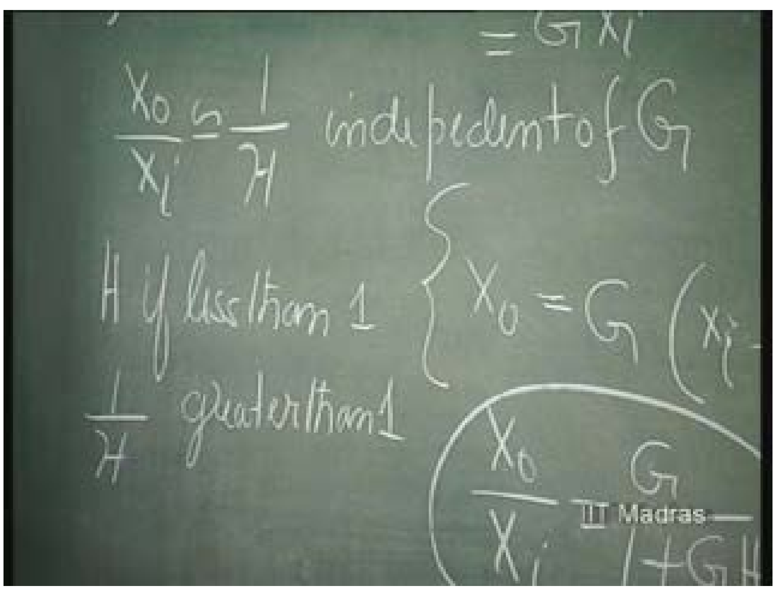

That means, you start with something, that is G is, let us say, 10 to power 6; H is 1 by 10. G is, let us say...say G is equal to 10 to power 6; H is 1 over 10. Now what happens in this case G H is still equal to... G H if you verify is still greater than... G H is equal to 10 to power 5, which is much greater than 1 anyway. So, this assumption is valid. So, this is equal to 10. So, this is fantastic.

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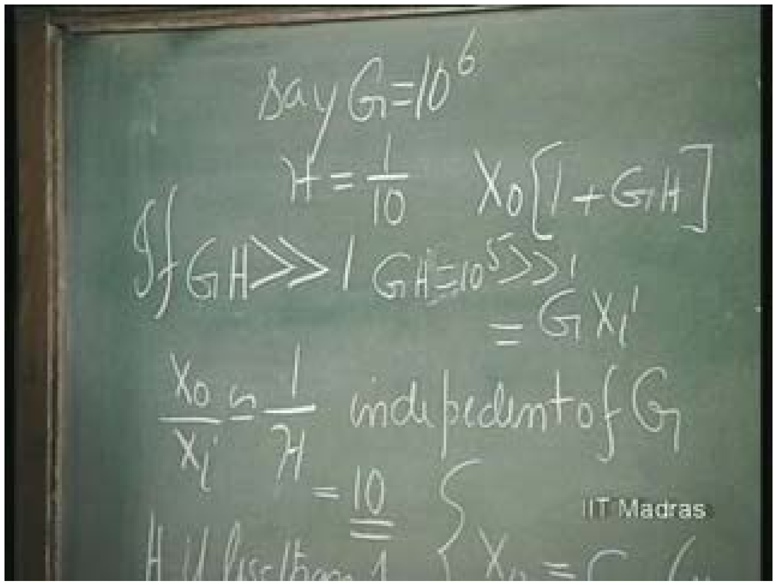

I design, for example an amplifier; we said op amp, whose gain can be made of the order of 10 to power 5 to 10 to power 6. Then, I connect in the feedback, an attenuator, a resistive attenuator, which attenuates signal and it is 1 over 10, the transfer. And then, the gain of this overall negative feedback amplifier is decided by only the attenuation factor. It is independent of the op amp open loop gain.

This is an important advantage of negative feedback. Have you understood this? That, if G is made very high and G H is maintained higher than, much greater than 1, then the amplifier, for example, gain becomes independent of the forward transfer parameter of the open loop amplifier. That means it is insensitive. We will use this: insensitive to G, because G, as long as it is high, such as to maintain G H very high compared to 1, G can vary. G, instead of being equal to 10 to power 6, let us say, has gone to 10 to power 7 or 10 to power 5, then also this is valid. Then also, this remains at 10.

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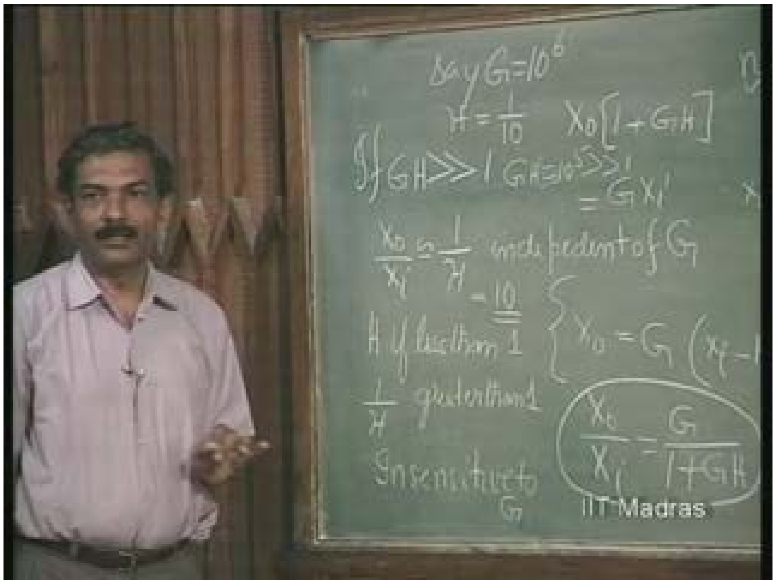

So, even if this G varies considerably with temperature and time, as long as it is kept high such that G H is much greater than 1, this gain remains unaltered; or it is insensitive to G or variations in G with respect to ((... Refer Slide Time: 20:21)).

This is an important contribution of so called negative feedback and most of these amplifiers that are designed, or for that matter feedback systems that are designed, use this to advantage.

Now, I am not concentrating only on amplifiers. This is... relationship is valid, whether X naught is a voltage, X naught is a current amplitude, please remember. I have not put X naught as any specific parameter. X naught can be a voltage variation, X naught can be...X naught and X i could be current variations. So, if X naught is V naught and X i is V i, that becomes a voltage feedback structure. If X naught is I naught and X i is I i, it becomes a current feedback structure; but the theory is equally well valid.

Let us therefore see. X naught is V naught and X i is V i, it becomes a voltage feedback structure. This is V i. This is, let us say, V naught. So, error detector simply becomes a differential amplifier; so that will take V i minus H times V naught. So, error detector is now going to be called a difference amplifier. This error detector will combine with G to form a differential amplifier.

If X i is I i in H times X naught, is nothing but H times I naught. Then the differencing is done simply by a node because if this is I i and this is H times I naught, you do not have to have any electronic device to take the difference. If you have a node, this node itself will generate I i minus what is that? It is this way...I i if you have it this way, let us say. Now here, it will add I i minus H times I naught.

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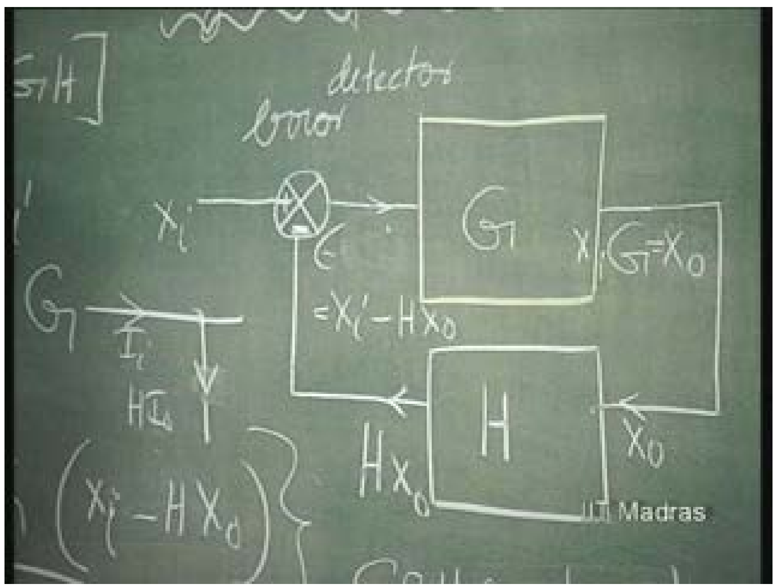

So, you just have a node and reverse the correct direction here and you have a current differencing structure. Voltage differencing is done by differential amplifier; current differencing is done by a node. Then, X naught can be phase; X i can be also a phase; phase difference. This is, in a given let us say, linear system, we are considering a voltage and phase of a sinusoidal wave form. Voltage, we have already discussed. Suppose it is phase; phi naught. This is phi i. phi naught by a phi i is again equal to G by 1 plus G H. This is a prelude to a discussion on what is called phase lock loop which is also nothing but a negative feedback system.

So there, phi naught is X naught; phi i is X i; so, X naught phi naught, X i phi i - ratio of the phase changes will be equal to G by 1 plus G H. So strictly speaking, if G were to become equal to 1, G becomes equal to 1, then we get this as 1 by 1 plus G; G by 1 plus G; or 1 by 1 plus 1 over G. And G being very high, this goes to 1. So, this is what is called a follower, input follower, in general. So, let us consider these various blocks.

If X naught is equal to V naught, X i...these are for sinusoidal things I am considering, V i, linear systems are always discussed with sinusoidal input...

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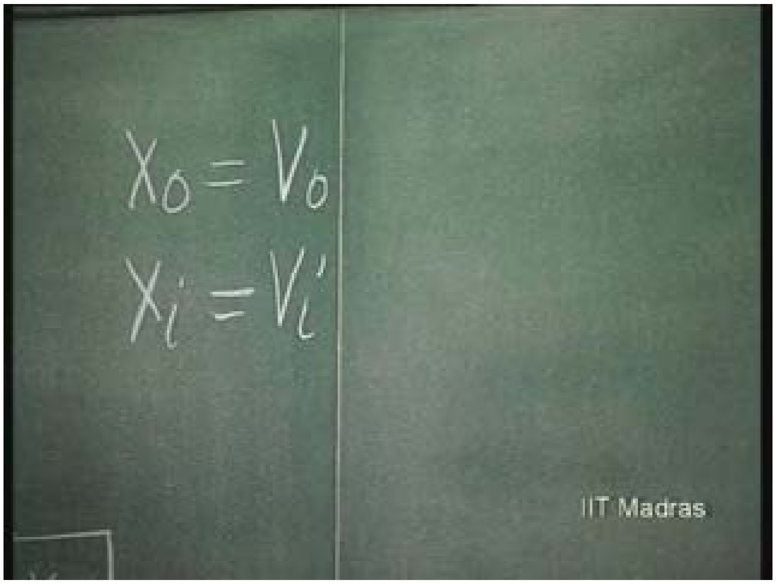

...then, this becomes V naught over V i equal to G by 1 plus G H, is approximately equal to 1 over H; and if H is equal to 1, this is called a voltage follower. Is this clear?

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If complete output voltage is fed back without any attenuation at this point, this particular structure with H is equal to 1 is called a voltage follower. Once again, as far as error detector in this case is concerned, that can be done by what? - differencing the voltage, voltages. That is, input voltage is subtracted from part of the output voltage.

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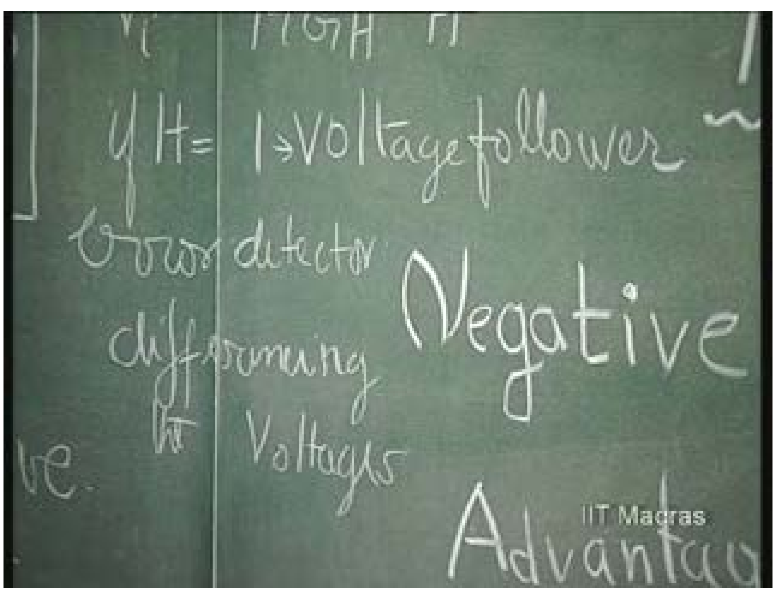

Now, if X naught is I naught, X i is I i, I naught over I i becomes equal to G by 1 plus G H. And this is approximately equal to 1 over H, if G H is much greater than 1. Then this is called a current follower. We will call it...we will name it...because on the same lines as the other one, output current is going to be same as input current. So, we will call it as a current follower.

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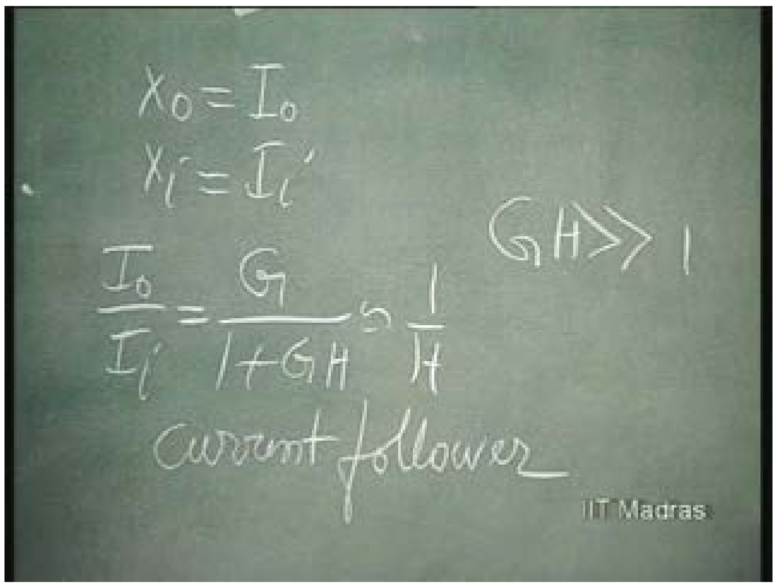

Again, if X naught is equal to phi naught and X i is equal to phi i, then phi naught over phi i, once again, is equal to G by 1 plus G H, approximately equal to 1 over H. So, what is this called now? This is called a phase follower; or, if it is phase follower, it is also called what? - frequency follower because, phi naught... and...phase and frequency, they are related by how? - Delta phi naught by Delta T. Or, D phi naught by D T is nothing but omega naught. D phi i by D T is nothing but omega i.

So, if you say that, this is also equal to omega naught by omega i.

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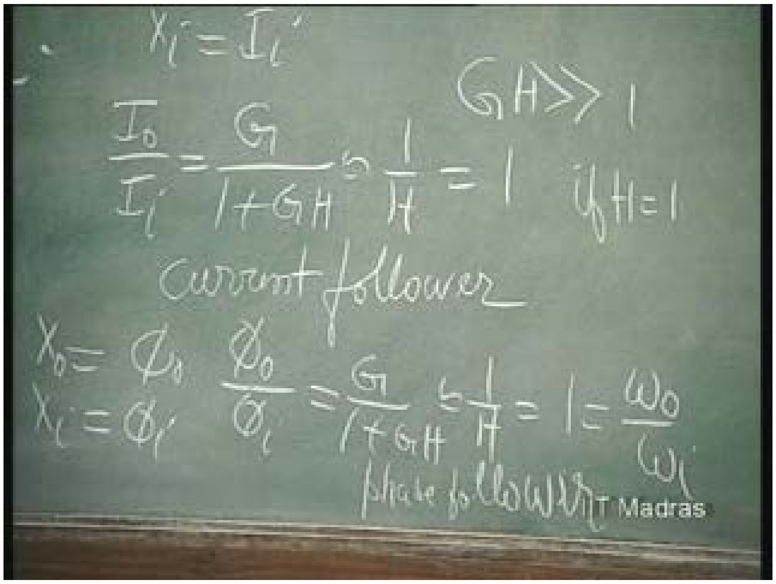

Laplace transformer is...phi naught is going to be equal to omega naught; D phi naught by D T is equal to omega naught. So, phi naught is going to be what? - s times omega naught. So, this is s times omega i. So, s gets cancelled, omega... So, it is called a what? - also called a frequency follower.

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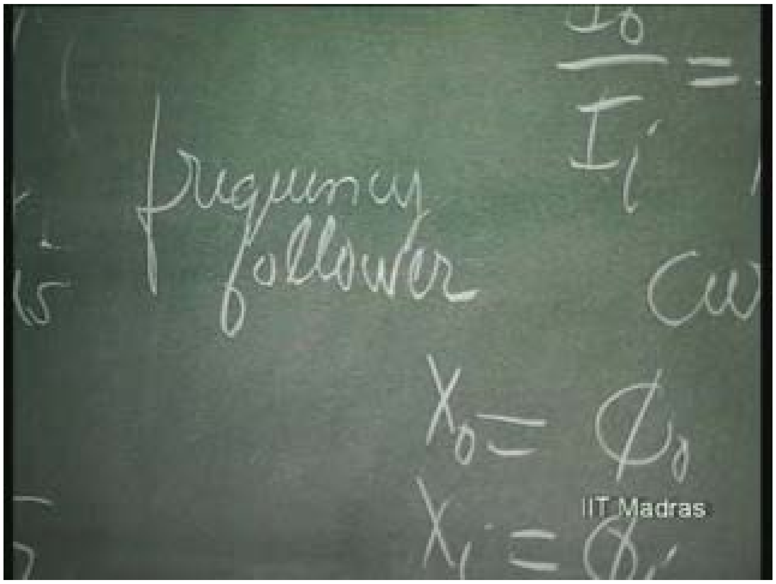

So, all these topics will be of discussion, as far as we are concerned, throughout this course. Fine. In fact, there will be a heavy dosage of negative feedback as well as positive feedback almost throughout this course.

And first, we will be concentrating on X naught being equal to V naught and X i being equal to Vi in discussing what is called voltage follower or voltage negative feedback. In fact, we had discussed this already; current follower, if you remember, when we discussed what is called current mirror. I will also show how current mirror...in a current mirror, we can design a circuit called current follower. Current mirror that we discussed in the last class was a feed forward structure; but even there, I can design a structure of current mirror with negative feedback with H is equal to 1 and make a good current mirror.

So, that circuit is called Wilson current mirror. We will discuss that later. Here, we had discussed the voltage amplifier and also discussed the differential voltage amplifier; and we can therefore feedback the total output voltage to the input and get a voltage follower. So, how we can design voltage followers, current followers and phase followers will be discussed later.

So, we just said something about negative feedback and its advantages.

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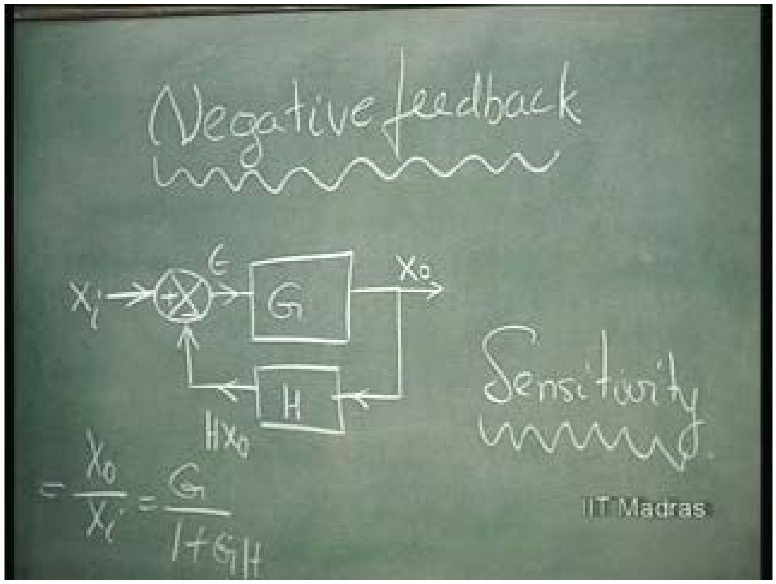

Negative feedback and its disadvantage was first mentioned in the form of reduction in forward transfer parameter. That is a disadvantage; but the advantage is the sensitivity improvement or reduction of active parameter sensitivity. This is called reduction of Active... What is it? Active parameter.

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We know that active device only can give give you an amplifier. A power amplifier, we said, can be obtained only by using devices like transistors, bipolar or MOSFETs and these are biased to operate in the active region so that the power gain is greater than 1. That, such an active device has an active parameter associated with it. If it is an amplifier, let us say voltage amplifier, it is the voltage gain and we were trying to make it as high as possible.

So, this active parameter however was found to be dependent upon the operating point. For example, in the case of a bipolar junction transistor, G M was the active parameter and G M was directly proportional to the operating current. So, it is sensitive to current and G M was equal to I E divided V T. V T was K T over Q; it was dependent on temperature as well. So, both on temperature and operating current it is dependent; and if these things vary because of bias current variation, etcetera or temperature variation, our performance will vary. If I design it for gain of 100, it might change over to 80 or 120; it keeps fluctuating.

So this... it is therefore in a feedback less situation or a feed forward situation, the active parameter, or, which is the gain we call, is dependent on temperature or the device that is used, operating point. Now, how to make the overall device become independent of this active parameter but still get an amplifier whose gain is greater than 1; this is the technique. That means, we make an amplifier whose gain is very high compared to 1 and then give feedback, negative feedback, so that H is the feedback factor which is less than 1, always, let us say, using passive devices like resistive attenuators, etcetera, we can easily make H very stable and less than 1. It is the ratio of resistor. So, it can be made to be independent of temperature and the type of resistor we use.

So, H will be perfectly stable in its value; in which case, this, when it is close to 1 over H, if G H is kept much greater than 1, is going to be insensitive to variation in G; and G is the active parameter here.

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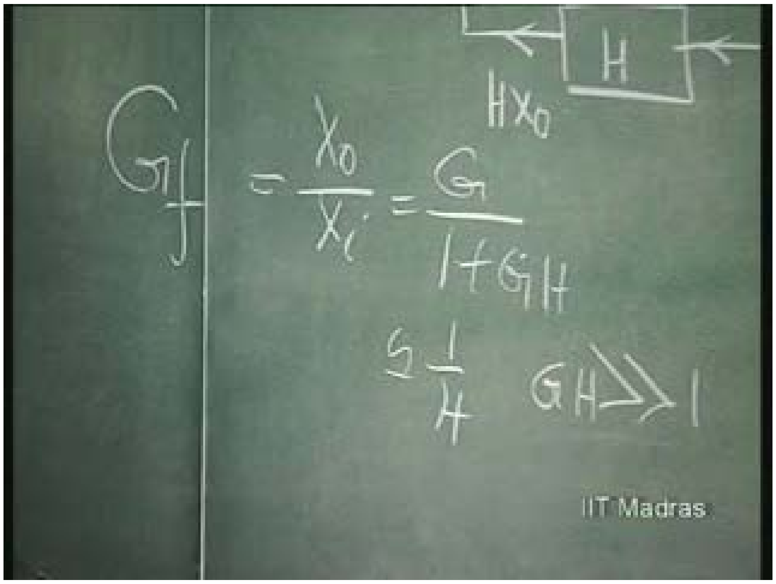

And, H is divided by...decided by passive devices like resistors and capacitors. It does not matter; as long as they are passive and linear, this is sufficient.

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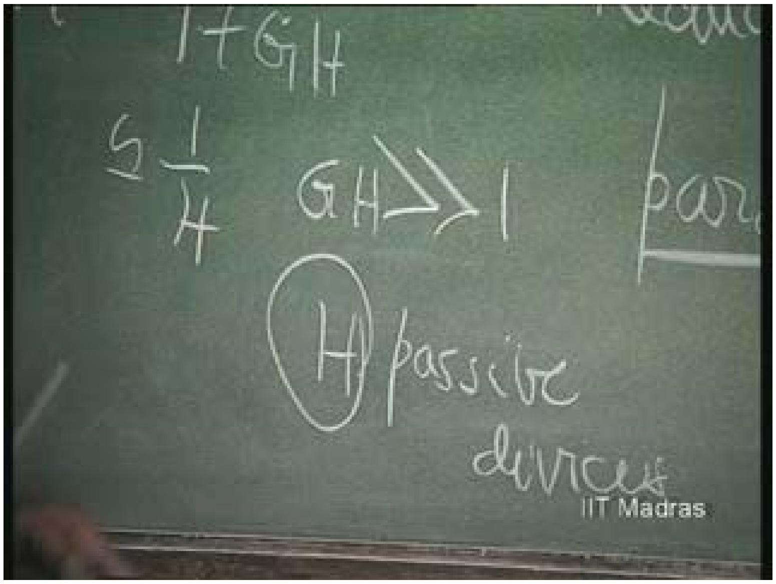

H is decided by passive devices and G corresponds to active device.

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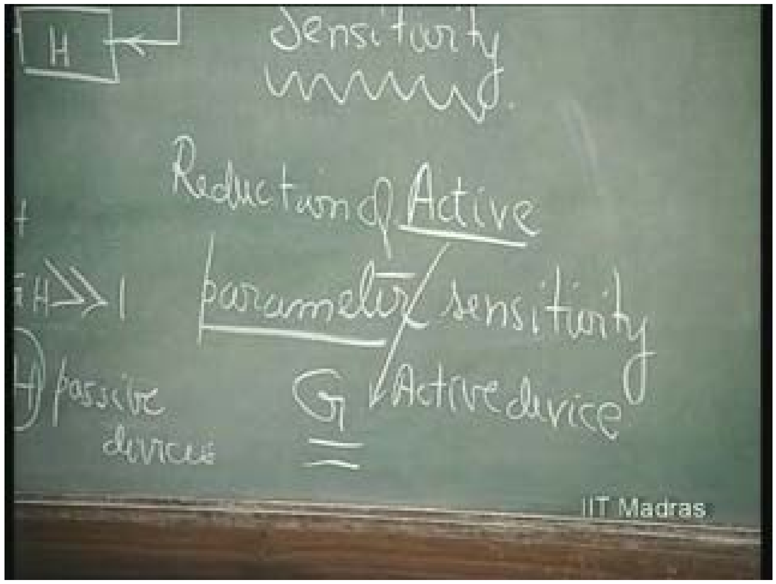

So, in such a situation, the resultant gain which is G with feedback, negative feedback... So, Delta G f divided by Delta G; this divided by G f, this divided by G, is called the sensitivity factor of G f with respect to G. This is the definition of sensitivity find the percentage variation in G f; compare it with percentage variation in G. That is what is called sensitivity of G f with respect to G.

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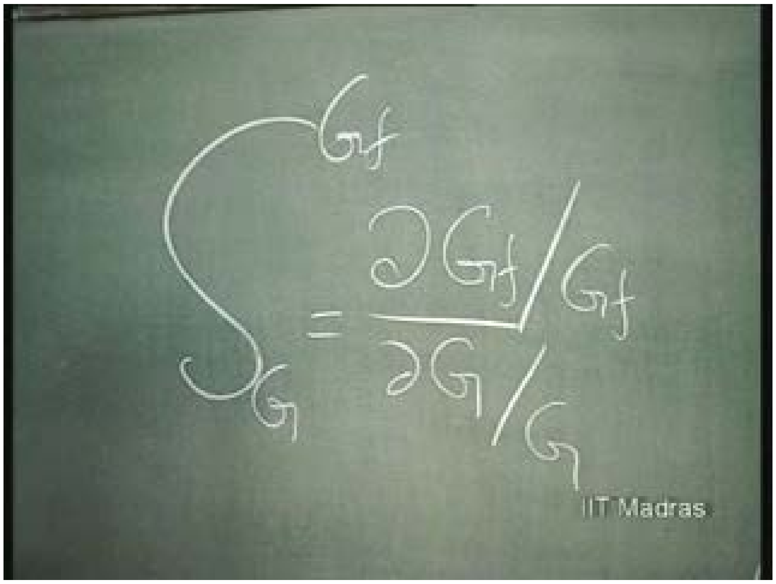

Now, that is equal to Delta G f divided by Del G into G by G f. Now, what is this Del G f by Delta G? Del G. That can be obtained by this expression. So, please differentiate this. How much is that? G f, differentiate this with respect to G.

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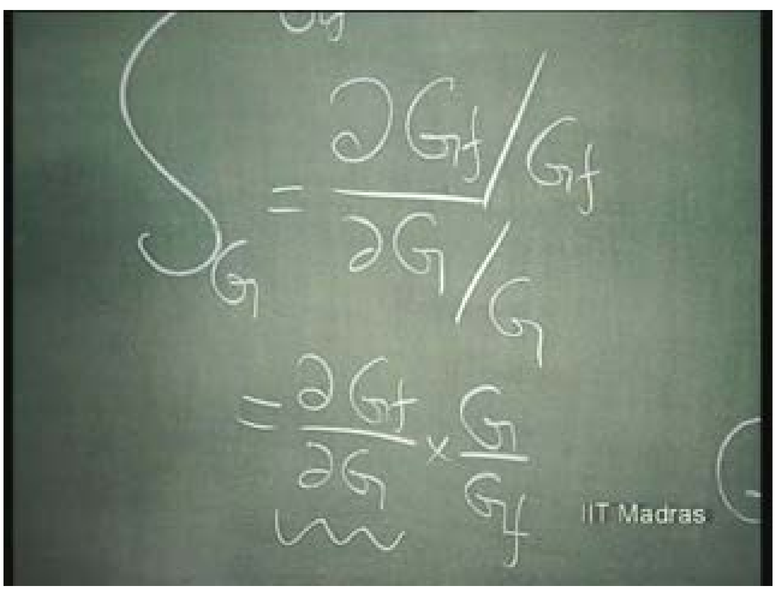

So, this will come out to be...if you again divide by G f and multiply by G, will come out to be 1 by 1 plus G H. Did you get this? This is an important equation for sensitivity.

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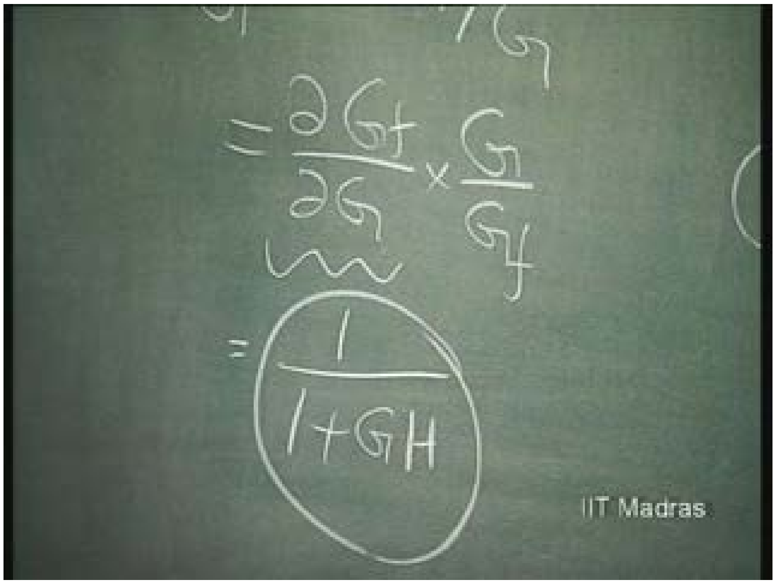

And let me tell you what it is. G into H, G into H. What is that? What is this that I am drawing? A loop. This is the feedback loop. G is the feed forward gain and H is the feedback factor. So G into H is called the loop gain.

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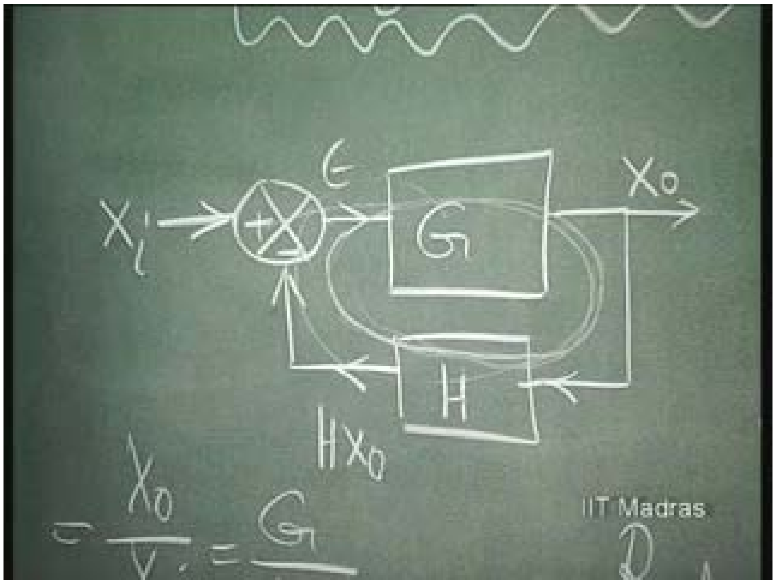

G into H is called the loop gain. This G into H...if the loop gain is very high, then obviously, 1 by 1 plus G H is going to be very very small. If loop gain is very high, then 1 by 1 plus this thing is going to be much less than 1.

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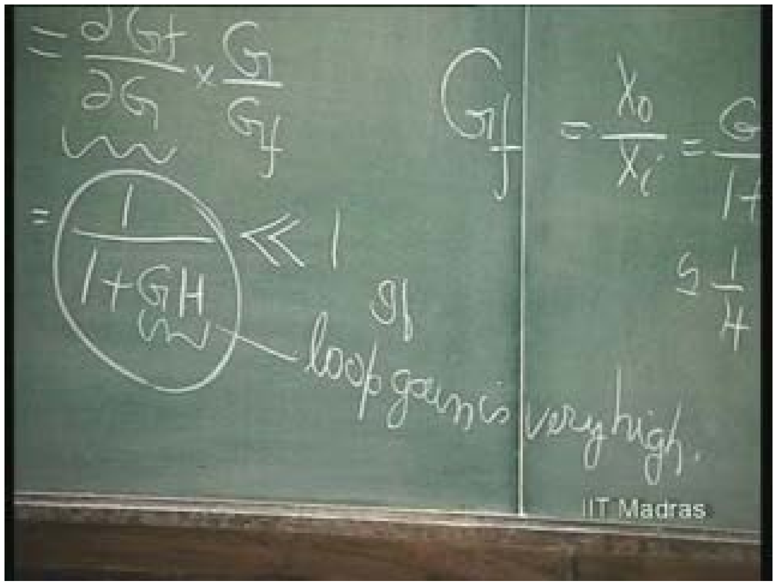

So, that means, sensitivity factor is going towards zero. That is what is established here. It is equal to 1 over H and it is almost independent of G. That means, sensitivity factor is going towards zero.

So, this is an important consideration for design of amplifiers using negative feedback. What is negative feedback? The input and the output should be opposing one another. They should not aid one another or there should be a difference of input voltage and output voltage or input current and output current. Then it is called negative feedback; or you can incorporate in this loop gain. The loop gain should be negative, G into H. That should be having a negative factor associated with it because when you go through the loop, there is a negative sign coming into picture here. So, G into H, actually the loop gain is minus G into H.

So, if the loop gain is negative, then it is negative feedback; if it is positive, then it is positive feedback. Is this clear? If this sign is positive, then the loop gain is going to be positive.

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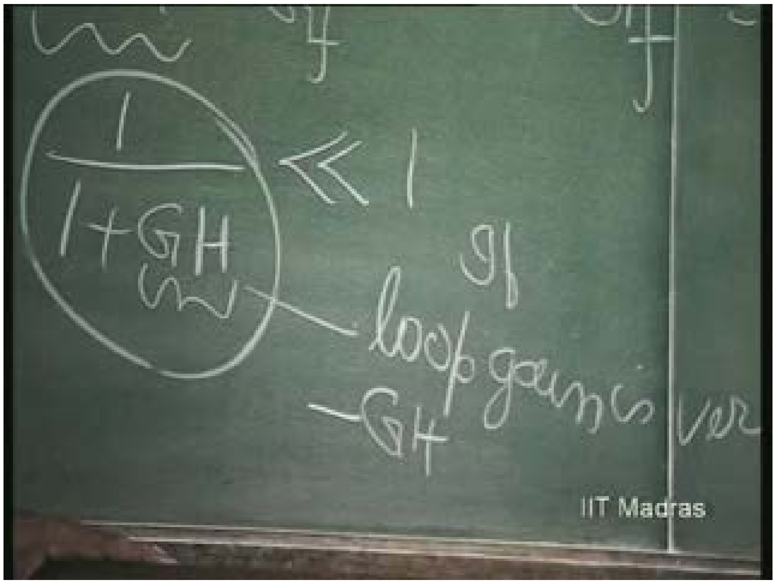

So, the loop gain, minus G into H...the negative sign indicates the type of feedback.

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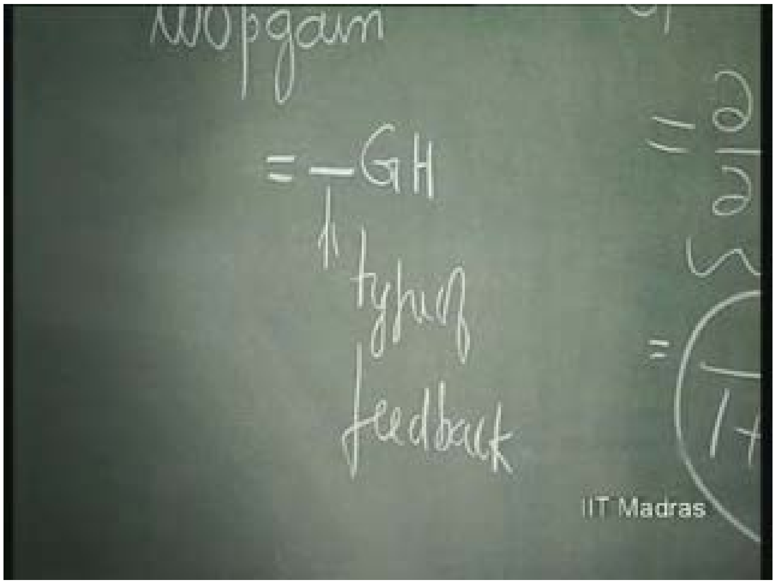

So, when it is negative, the loop gain is negative. It is called negative feedback. When it is positive, it is called positive feedback. And we are discussing a situation for negative feedback. We have not yet discussed anything for positive feedback.

In the case of positive feedback, let us see. This is going to be 1 minus G H. So here, if this is X i, the... here there is no error coming into picture. This is X i plus H times X naught. This is adding all to what already exists. So, X i plus H times X naught into G is equal to X naught.

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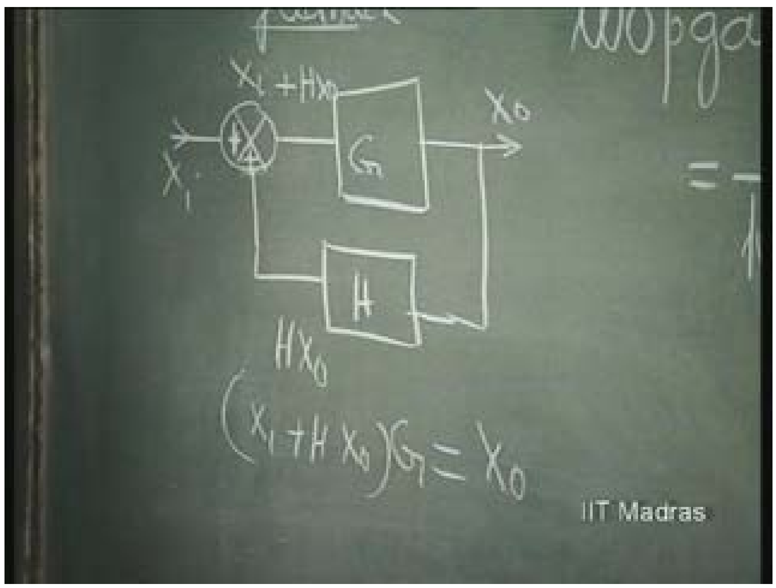

Or, X naught by X i is going to be, X naught by X i is going to be G divided by 1 minus G H.

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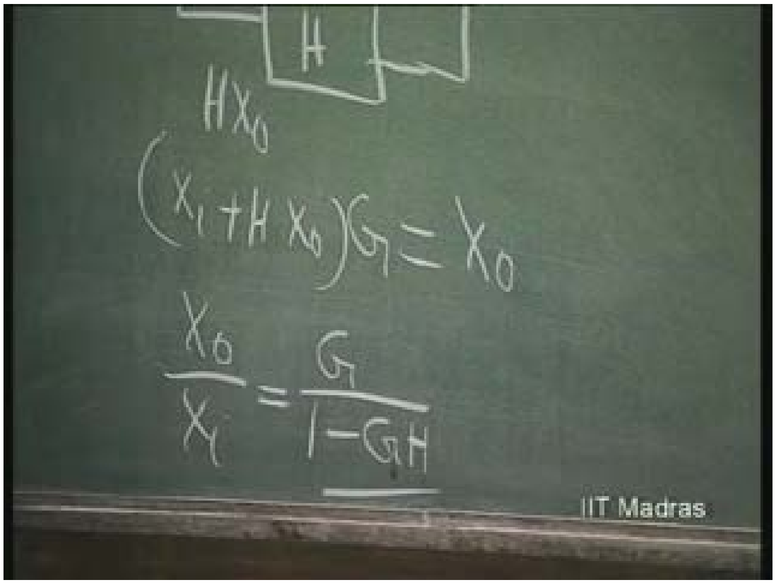

We are considering situations where G and H are both positive quantities. In such a situation, we can see that you have here G by 1 minus G H and the loop gain is...loop gain in this case is positive and is equal to G into H. So, this is for the negative feedback.

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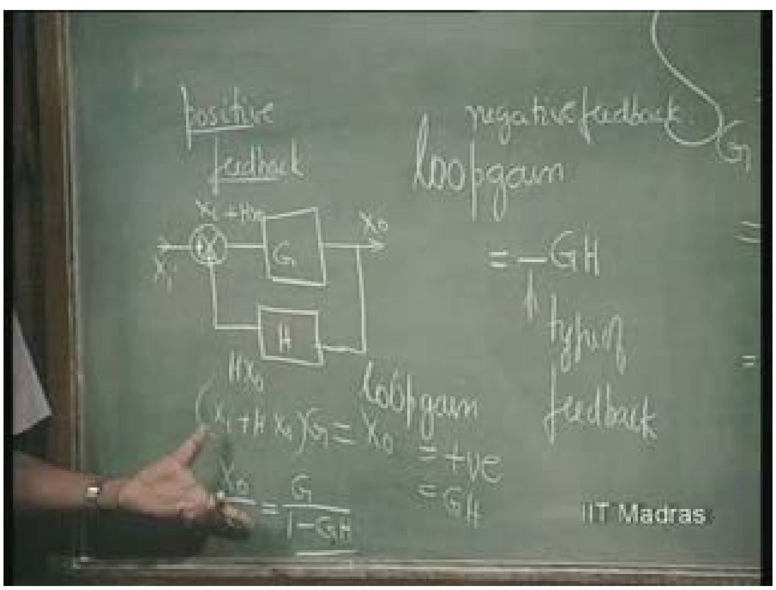

What is happening for the positive feedback? Unlike the negative feedback where the gain was always less than G, here the gain is what? - going to be greater than G. If G and

H are positive and less than 1, if G into H is less than 1, then G is always greater than...G by 1 minus G H is always greater than G.

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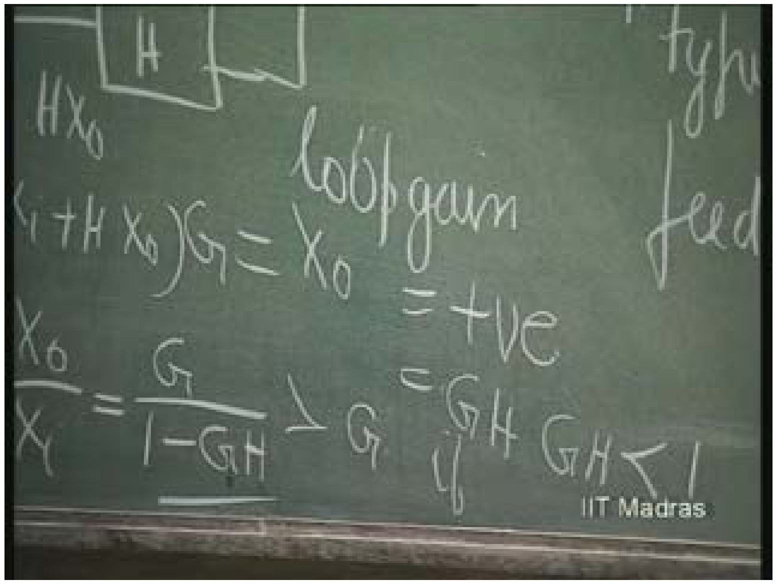

Let us consider G as 10. 1 minus, let us say, point 9. G is 10. G H is point 9. So, 10 by 1 minus point 9 is 100. So, if this is 10, this is 1 minus point 9. It becomes 100.

So, using an amplifier whose gain is only 10; by giving positive feedback such that G H factor becomes very nearly equal to point 9, you can obtain an amplifier with gain of 100.

So, you can therefore use positive feedback to improve the gain. But then, you can see the sensitivity factor in such a situation is going to be 1 by 1 minus G H. Just as that; put wherever H is there, minus H.

So, sensitivity factor of such gain after positive feedback is 1 by 1 minus G H. What is it? For the same example of gain equal to 10; G equal to 10; G H equal to point 9; G f is equal to 100; but sensitivity is now equal to 1 by 1 minus point 9. That is 10. Compare this, therefore, with that.

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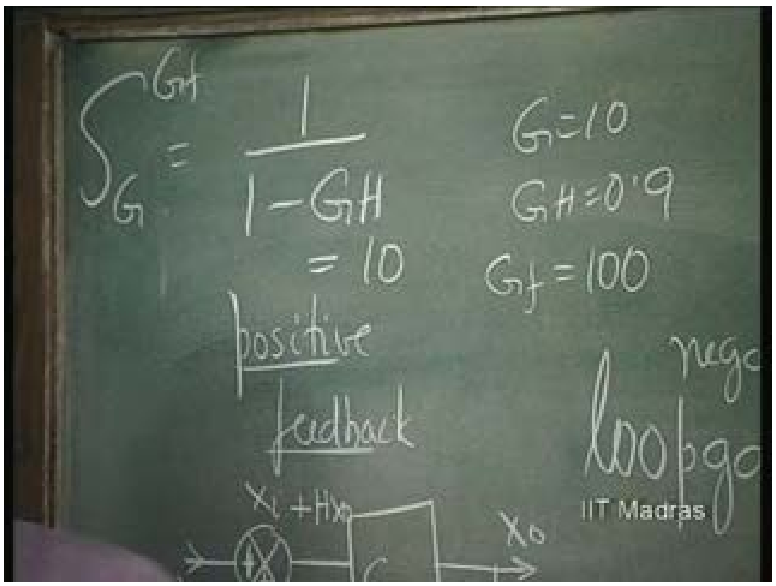

Sensitivity factor, or, to the active parameter in the case of positive feedback, is always greater than the sensitivity factor in the negative feedback. We can make G H much greater than 1 and make the sensitivity factor here go to zero. Here, we cannot do that. We will see. When you make G H equal to 1, you get G f equal to infinity. If you apply a finite input, you get an infinite output. So, finite input, infinite output.

So normally, any practical amplifier is going to have limitations of supply voltage. So, when you give finite input to such a structure with infinite gain, when you make G H equal to 1, the amplifier is said to go to saturation because it will...just it is...it has to give infinite output; it will give the maximum and remain there. So, the amplifier goes to saturation. Now, if you make G H much greater than 1 in this case, we will discuss this later; that is called positive feedback, but with what is called regeneration. So, regenerative positive feedback, it is called.

It is an unstable situation for amplifiers. No longer will the output be related to input linearly and output and input relationship now becomes non-linear. Output is odd, either always at one saturation level or at the other saturation level. This is an unstable state. That means, G H less than or equal to 1, it is perfectly stable, this positive feedback. But it gives you an amplifier which is not useful practically because of the fact that the sensitivity is very poor. It has high sensitivity to active parameter variation. So we reject positive feedback with G H less than 1 and loop gain positive. This is rejected because of the large sensitivity factor.

In certain places where you do not use the amplifier for amplification purposes, but use it for what is called voltage comparison, where it is used as what is called comparator, where actually output is going to indicate whether it has crossed a certain voltage or not. So, amplifier can be always in one of the two saturation states. In such situations, positive feedback is purposely introduced. It does not really matter if it is sensitive.

So, in such situations, positive feedback is used; but in most of the amplifier designs, it is only negative feedback that is practically used for this reason. This is not the only reason. We have other reasons for favoring negative feedback which we will discuss in the next class.

So, summarizing what we discussed today, I have told you the distinction between negative feedback and positive feedback with loop gain less than 1. Positive feedback with loop gain greater than 1 results in instability, I have mentioned; greater than or equal to 1. And that part of it, what is called regenerative positive feedback, is an important aspect of another circuit design which will be discussed later.

We will concentrate now on negative feedback with loop gain much greater than 1 in our future applications.