Control Engineering
Prof. Madan Gopal
Department of Electrical Engineering
Indian Institute of Technology, Delhi
Lecture - 10
Models of Industrial Control Devices and Systems

Having introduced to various plant models we frequently encounter we frequently come across in indusial situations now I think we are in a position to come to the complete feedback control system so that is why the subject which we are going to start from today concerns models of industrial controlled devices and complete systems which we are going to make using those devices.

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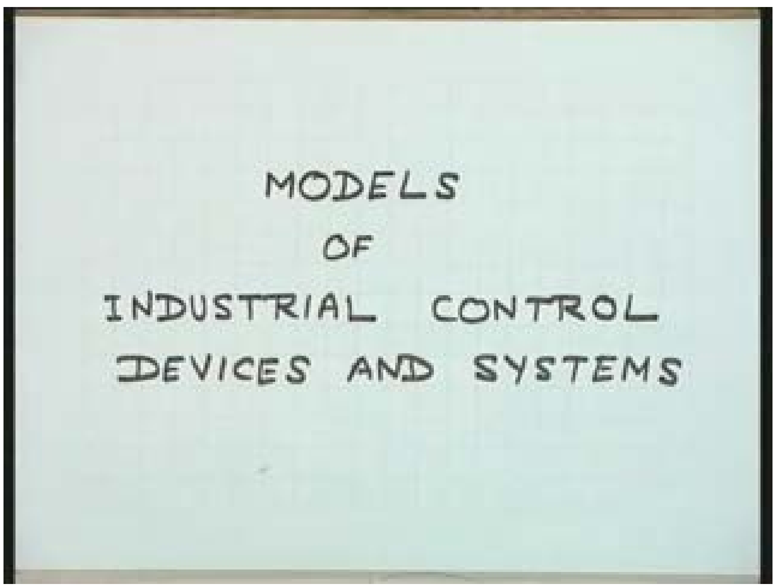

I will like to see the situation which we have seen; we revise the situation which we have seen with respect to the plant models. I will say that we have captured a model in a block diagram in this way that the dynamics of the plant is descried be a transfer function G(s), the input to the plant let me say is typically R(s) and the output is given by Y(s) the controlled variable of the system is given by Y(s). So you see that Y(s) the output will always be equal to the transfer function G(s) into the input to the plant or input to the block model R(s). So this becomes a mathematical model in the transform domain for the plant which is a system which is a subsystem in the overall control system we are going to encounter.

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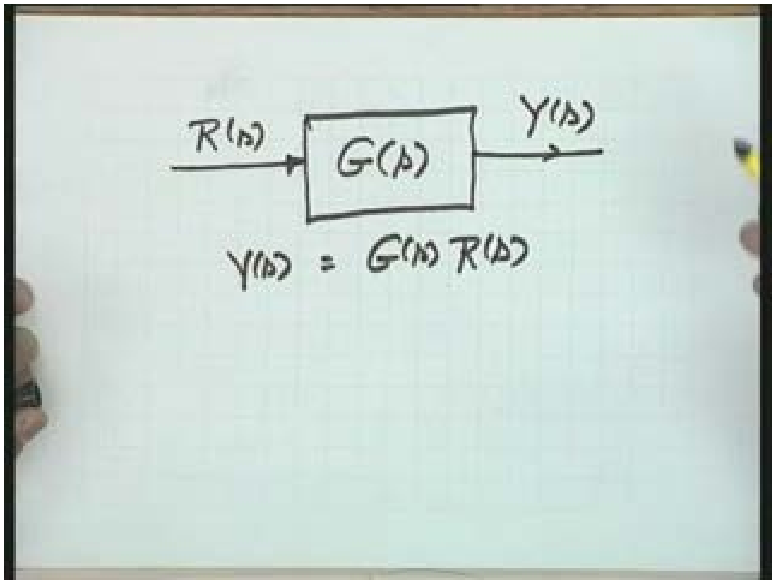

In addition to this, what else we have come across? Please see, we have come across these block diagrams also in our discussion. Let me assume that now I have two blocks G 1(s) and G 2(s), R(s) is the input to this particular block and Y(s) is the output here. These are the two blocks here. Please see, if I have a variable X(s) in between you know that Y(s) is equal to G 2(s) into X(s) and X(s) is equal to G 1(s) into R(s). So, that way if I couple these to equations I get Y(s) is equal to G 1(s) G 2(s) into R(s). So it means if two blocks are in cascade representing two subsystems of an overall system I can multiply the two transfer functions to get the input output relationship in this form that Y(s) is equal to the multiplication of the two transfer functions into R(s) the input of the system.

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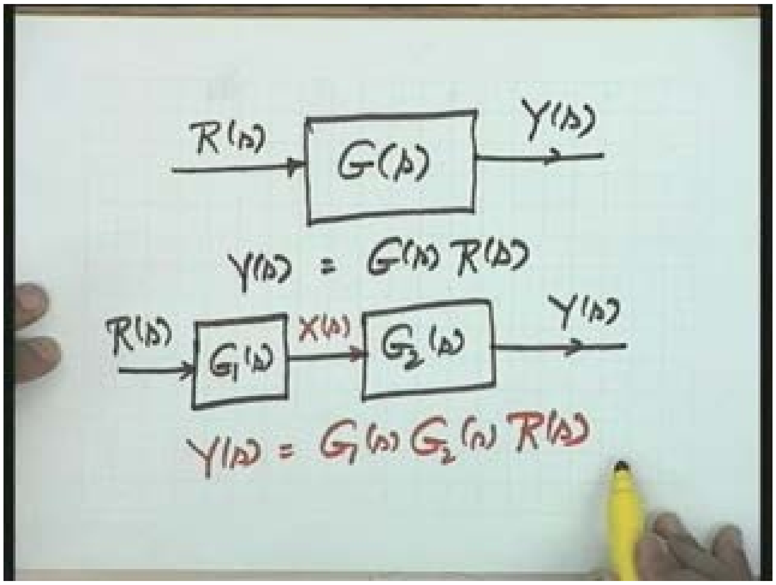

In addition to these two the other situation we have come across, many a times in my block diagram if you recall I have shown a circle in this form with these algebraic signs (Refer Slide Time: 3:45). I will be using this as an error detector or as a summing junction the terminology being R(s) is the signal here B(s) is the signal here, in that particular case E cap(s) the signal at this particular point will become R(s) minus B(s). Or let me say that if the signal is plus naturally at this particular point I have addition of the two signals.

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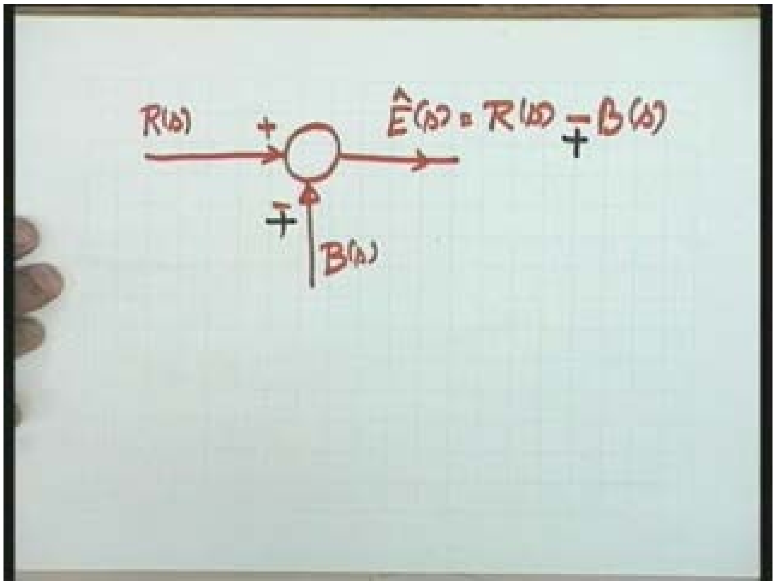

So this is the symbolic representation for me for an error detector or summing junction where algebraic manipulations of two or more than two signals is required. The last point, the last point is, let us say that this represents a flow of signal. So, in that particular case if I want to take off the signal for the purposes of feedback, please see, let me say that this signal is Y(s) the take off has been represented in the block diagrams so far this way that is the signal at this particular point is taken off so that the value of this signal which is being fed back to some suitable point in the overall system is also Y(s). So you will find that the total representation of the system will be a suitable set of these four basic elements of a block diagram. I repeat, a basic, block two blocks in cascade and a summing junction and a take off point the take off point or you can even call it a branch of point because from here the signal is being taken off for the purposes of feedback to other points.

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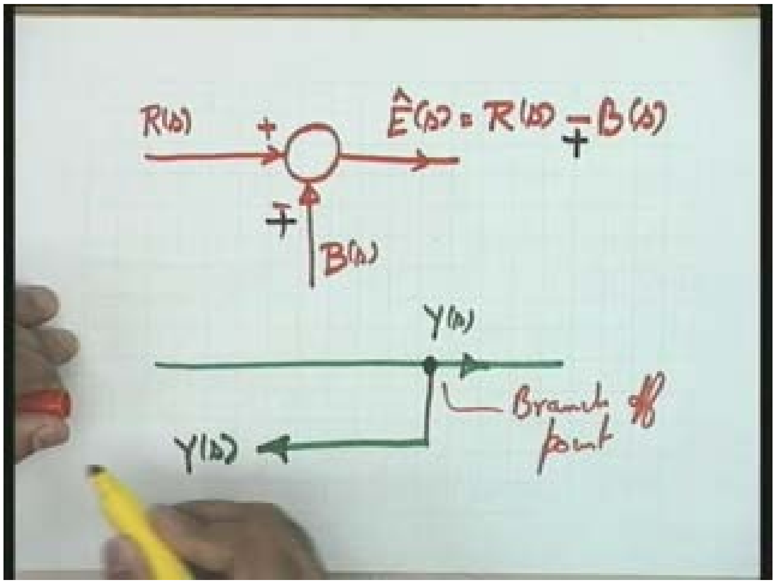

Now, before I go to a composite block diagram one point I like to mention I think it is quite important and that I take up with respect to a liquid level system. Only last time we have discussed this type of system where the purpose is to control the height of the liquid in the tank. So you see that that basic unit for me is this tank (Refer Slide Time: 5:58). You will recall my statement that if your modeling a tank you are going to get a model a first-order system the personality of the tank dynamics being represented by system gain and time constant; and this is our model this model we obtained last time only. That is the height and the input flow is represented by a transfer function of this form.

Consider another tank the input to this particular tank is coming from the output of the first tank. In this particular case same think again H 2(s) over Q 1(s) now the input is Q 1(s) it is represented by a transfer function given by this, this we have derived last time.

Now I can put this total dynamics (Refer Slide Time: 6:36) into a block diagram. Please see, Q i(s) is the input yet this is the transfer function of the system so the output becomes H 1(s) of the first block corresponding to the first tank. Here the input is Q 1 but this Q 1 I hope I can put it here itself (Refer Slide Time: 7:04) this q 1 as you know is equal to p 1 divided by R 1 where p 1 is the pressure at this point the perturbation the total pressure being P 1 plus p 1 where P 1 plus P 1 bar is the steady state pressure. So this q 1 is equal to p 1 by R 1 this is equal to…. help me, I think you can write it this as: rho g h 1 by R 1.

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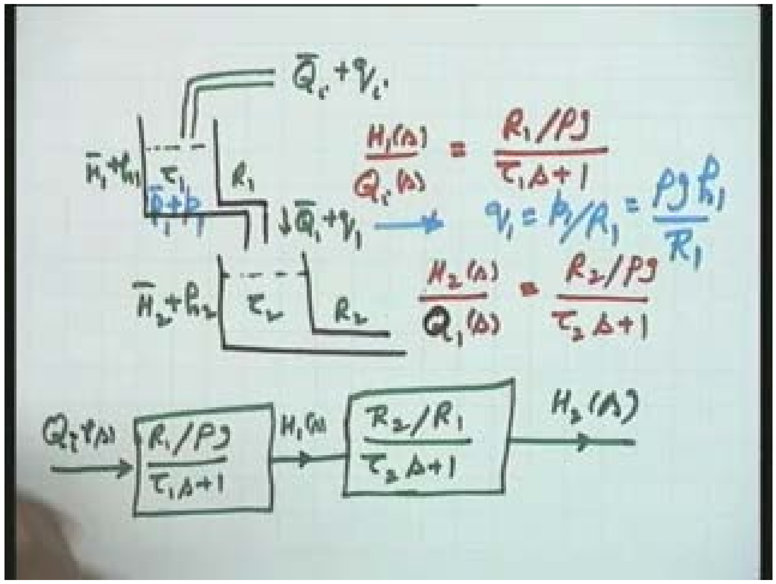

So since in this particular case H 1 is the output variable and not q 1. You see that the two are algebraically related by this equation. I can put this q 1 is equal to rho g h 1 by R 1 and if I multiply this with this I get this as the transfer function. I need your attention please, i hope this is okay. I am simply eliminating this Q 1 and writing this Q 1 in terms of h 1. You see that Q 1(s) is equal to rho g divided by R 1 into h 1(s). So substitute here so H 2(s) upon H 1(s) will become R 2 divided by R 1 and the denominator being tau 2 s plus 1 so that is why I have given this as the transfer function between H 2 and H 1 and these are the two blocks which represent the total dynamics of the system. I hope this is okay.

Now, if that is the case, please see, the point I want to mention is the following: The dynamics of this particular system Q 1 is the inflow and h 2 is the controlled variable it does not affect the dynamics of the first tank and therefore, well, electrical terms we already know, in terms of non-electrical systems I want to make it clear that it means that this particular subsystem does not load the system so it is a non-loading component. This system connected in cascade does not load the system and when the second subsystem does not load the first subsystem then and only then the two transfer functions can be multiplied, please see that. These two transfer functions can be multiplied together to get a single transfer function H 2(s) by Q i(s) provided this particular system does not load this particular system. I will make it clear with the help of another system where the two tanks are connected in cascade and then I will come back to you ask the questions if any.

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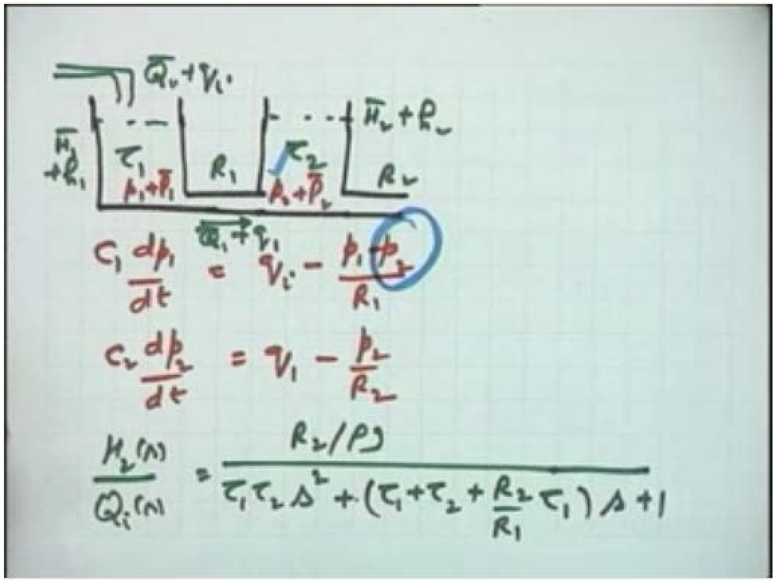

Now I take the same two tanks but these two are now connected this way (Refer Slide Time: 9:38). You find again that the flow out of the first tank is the inflow to the second, similar situation but with a difference and what is that difference; that difference will become clear from these mathematical equations.

Please see C 1, again very well known to you C 1 dp 1 by dt is the rate of storage in the tank one is equal to q i the input here minus P 1 minus P 2 divided by R 1. The second equation C 2 dp 2 by dt is equal to q 1 minus p 2 divided by R 2. Look at this point please: p 2 is the pressure of the second tank, however, this affects the flow or the dynamics of the first tank and hence there is a loading effect. the loading do to the second tank on the first is there because of this variable because this in the earlier situation, you recall the situation this particular pressure (Refer Slide Time: 10:39) was an atmospheric pressure at this particular point and the second tank was not affecting this pressure and hence the second tank was not affecting the flow out of the first tank.

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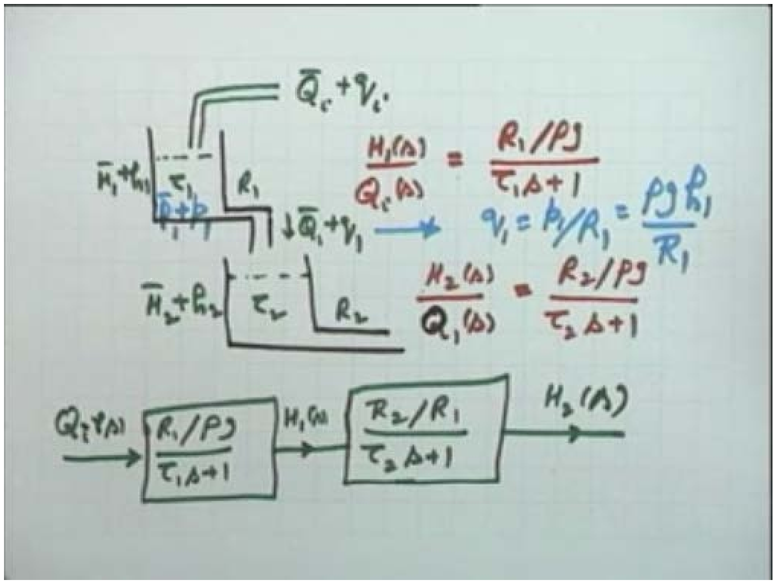

But in this particular case this particular pressure is now the pressure of the second tank and this affects the flow because the flow is given by p 1 minus p 2 divided by R 1 and hence in this particular case the second tank loads the first tank.

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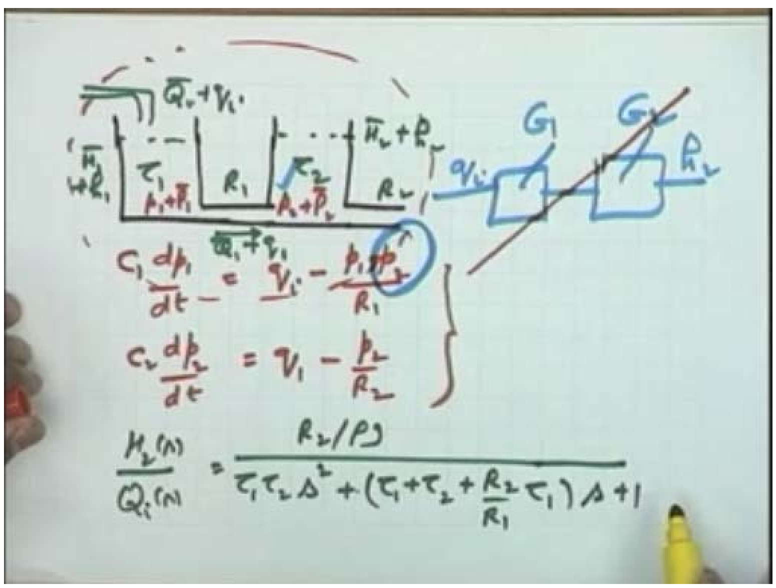

And therefore when there is a loading effect these two systems cannot be written in this form that is: This as q i, this as h 2, this as G 1, this as G 2, this particular thing is wrong this is not possible (Refer Slide Time: 11:26) the reason being that the two tanks or the two subsystems are not independent the second subsystem loads the first. So in that particular situation you will have to take this as a single unit you cannot break the system into two subsystems you will have to take this is as a single unit .a simple exercise for you: These two equations when suitably transformed into transform domain Laplace domain you get this as the mathematical equation you get this as the transfer function of the system (Refer Slide Time: 11:58). And you will please note, though I made a statement that in a liquid level as well as in a thermal system you will always get first-order system. But, however, in this particular case, we have got a second-order system with the where the characteristic equation is given by a second-order equation that is there is a quadratic lag and this quadratic lag where zeta and omega n are appearing is coming because of the loading effect.

As far as indusial tanks are concerned individual tanks are modeled by the time constant and the system gain. But if you put them in the non-loading fashion you have got two time constants. In the non-loading fashion the total transfer function is again is a second-order transfer function but is represented by two time constants.

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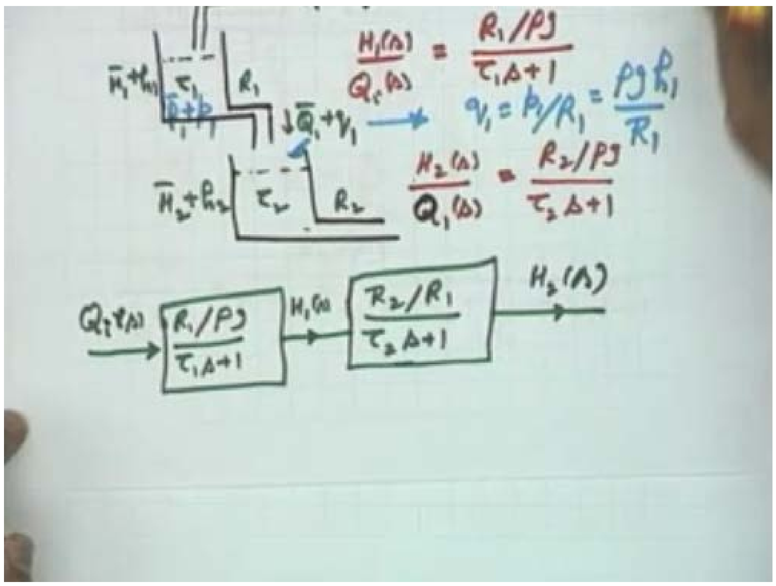

When you take it in a loading fashion, in that particular case please see, the transfer function is a single transfer function where it is represented by a quadratic lag that is a zeta and omega n will appear as far as the personality of this particular system is concerned and separating it out into subsystems will not be possible because of the loading effect.

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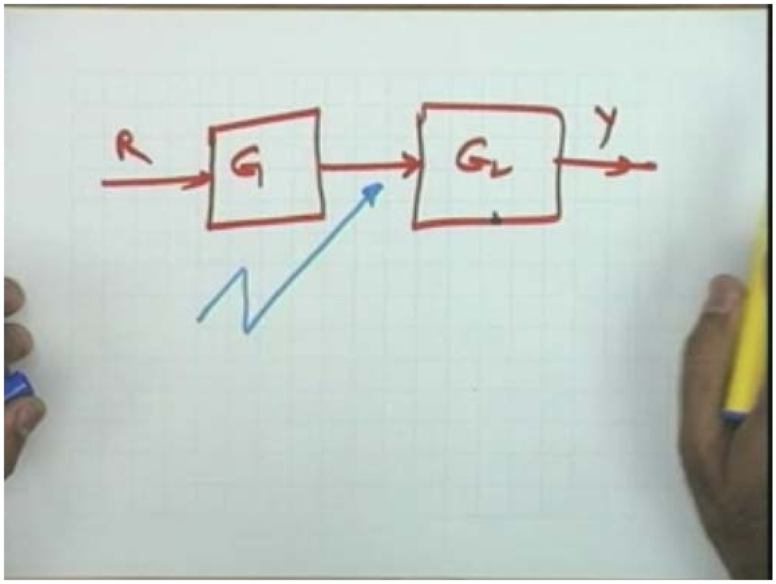

So, in my block diagram representation I now I mean it is just to make this statement: Whenever in my block diagram I come across the situation this is R, this is Y, this is G 1 this is G 2 it is implied, I may not explicitly say again and again it is implied that this G 2 does not affect or does not load G 1.

Please help me, if there is a loading how can you help out? You see, you can help out by putting a suitable buffer in between. Electrical buffers amplifiers Op-Amp circuits you already know; you can have a suitable pneumatic buffer as well, you can have a suitable hydraulic buffer as well depending upon the type of system we are working with. So I at the stage will not like to go to the hardware details as to how to install or how to interface a buffer amplifier a buffer in between the two units; I will simply like to make this statement that, in over all block diagram whenever I have two cascaded blocks it simply means that either the loading effect is not there, if there it is negligible, if not negligible then I have already put suitable buffering effect in between so that the two transfer functions can be independently taken. If it is not possible in that case the two subsystems have to be clubbed into a single system and they will be represented by a single transfer function only. This is a very important statement because as you will see when I come to the overall closed-loop block diagrams for feedback control systems you will have to take into account; when you take up various devices and interface them to make a total system you will have to take into account this loading effect to get an appropriate mathematical model for the system.

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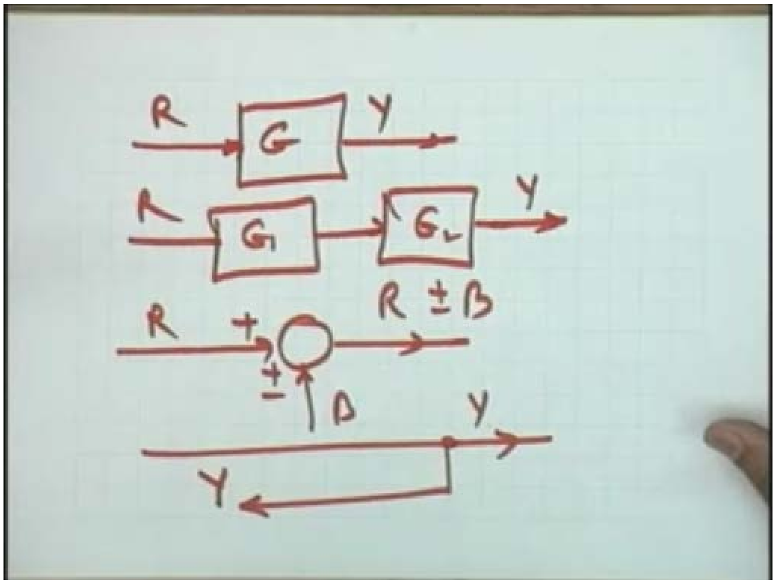

So I just now review revise this. The four points will be for me like this. In a single slide let me put it this way: a G transfer function, R and Y, two blocks in cascade. There will be hardly anything deferent than these four basic elements. This is R; this is Y with the assumption that there is no loading effect. There should be a summing point plus plus minus R B it is R plus minus B and last point let me take this Y signal and there is a take off; if there is a Y here there is a Y here.

I will say that when I give you block diagram representation of a total feedback control system you will hardly come across any element other than these four basic elements. With this introduction I can now probably go to the overall feedback control systems and I will first of all like you to review what we have done earlier. And wherever you find that you are not remembering anything please do raise an alarm, ask a question, I will revise that concept otherwise the total block diagram which I am going to give you we have already done.

So the very first element in this block diagram I put as y r the standard symbols. I have already given these symbols earlier y r is my command signal. This command signal can be suitably transformed to a reference signal r. By suitable transformation I mean making it compatible with the feedback signal and the elements in between I can say reference input elements and I call this as A(s) the transfer function. This is sort of revision coming to you. Now here let me say is an error detector or a summing junction (Refer Slide Time: 17:08). This is plus here and this is minus here let me say a negative feedback system a general basic structure I am taking. So let me say that the feedback signal coming is b. Now this r minus b is the net signal which I had symbolized as e cap and I had named this e cap as the actuating error signal.

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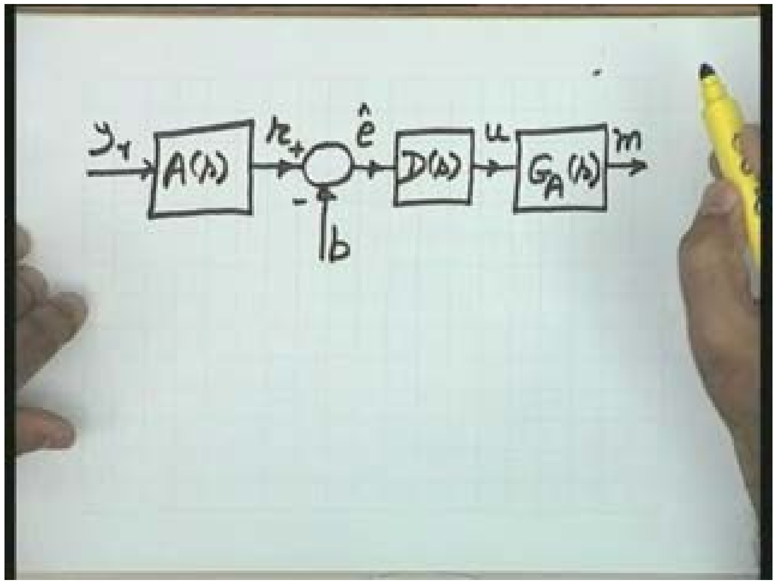

Now what is this actuating error signal doing?
This actuating error signal is going to D(s) the controller transfer function; the transfer function of this subsystem which is going to control the manipulated signal to the plant. The output of D(s) we had represented by u the control signal, after this u we had taken a transfer function and G A was the symbol reserved for this, let me now put (s) as the variable G A(s) is the actuator transfer function which is the power element of the system which is the muscle of the overall control system D(s) being the brain.

Now, this G A(s) after this I called I took the variable as m which is the manipulated variable which is the power signal given to the plant. Let me take it here. Now let us say, at this point (Refer Slide Time: 18:40) I symbolically, I said that let me assume that, at this point though it was made clear to you that disturbance can occur anywhere all through the block diagram but symbolically I had taken this way plus plus, w was reserved for the disturbance signal.

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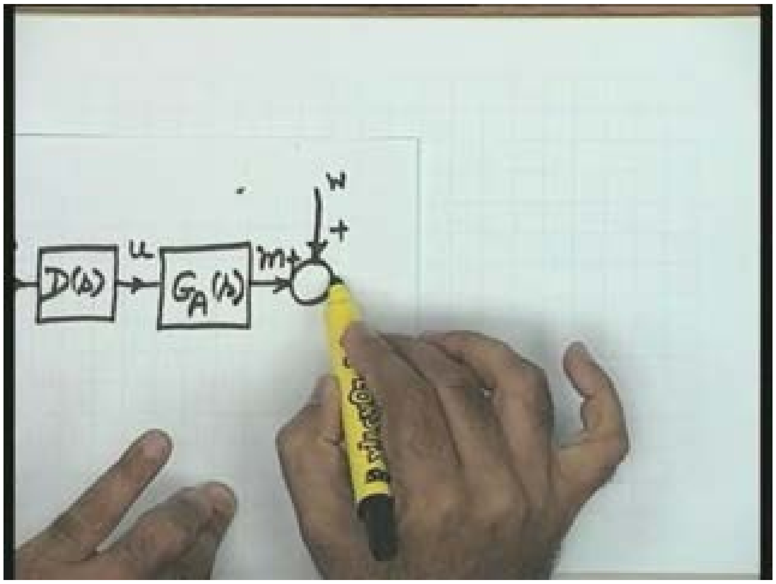

So the disturbance is acting into the is entering to the system through this particular at this particular point. And now after this I had taken the plant transfer function G p(s) was reserved for the plant model, the output of the plant is your controlled variable and this is being sensed through a suitable sensor signal H(s) suitable sensor signal H(s) this is being sensed this way. Did I miss anything please help me? In this particular case Y(s) I will like to project it this way: y is the output signal, this is the sensor signal (Refer Slide Time: 19:50). Now the thing which I have left is that there may be an indirectly controlled signal and it is being manipulated through indirectly controlled variable Z(s) and q was the symbol reserved for this.

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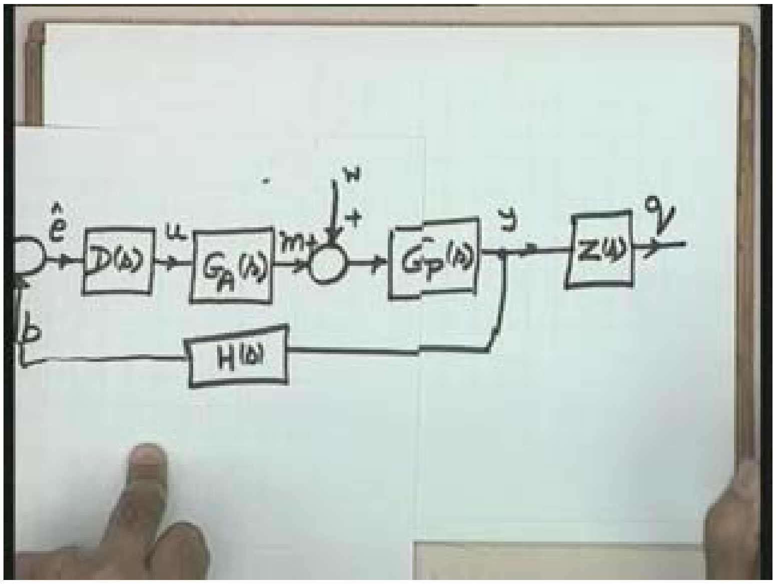

This is the overall block diagram and what is the exercise now we are going to take up?

We are going to take up the physical subsystems corresponding to all these block diagrams getting the mathematical models of those subsystems and then giving you a feel as to what type of industrial control systems are in use. This is the overall situation we are going to take up now.

Now, I think at this point if you agree with me, the total design will depend upon the feedback loop. You will not mind, if in my discussion, I do not include this indirectly controlled variable (Refer Slide Time: 20:39) because after all the indirectly controlled variable is just a hardware component in the overall system, it does not enter into the design of feedback control system this being outside the feedback loop. So I can take y the controlled variable as the signal of the interest to me, if q is the signal you are in you are interested in that particular case you will design a suitable hardware so that from y a suitable a variable q can be suitably controlled. So, as far as the feedback control system is concerned there is no problem you can simply forget about q and you can concentrate about the controlled variable y. This is one point I like to make.

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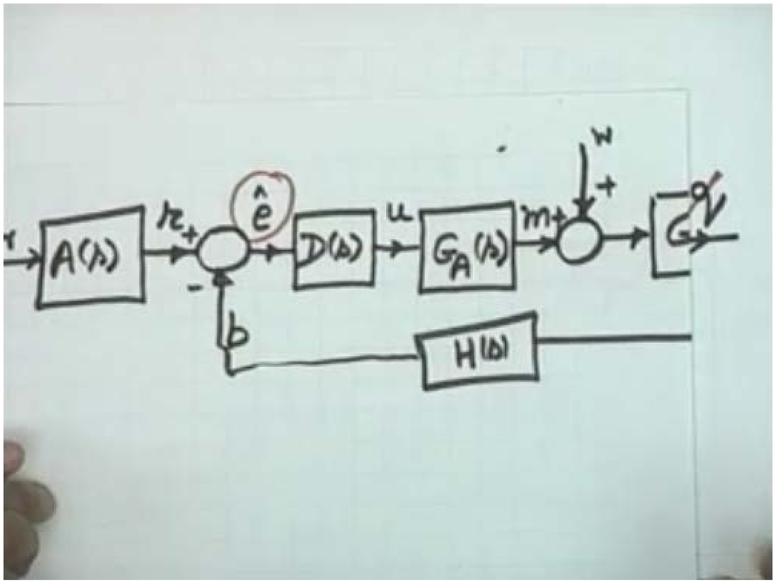

Another point I like to make is the following: You will please note that e cap the cap is to be explained, why did I use the cap why not the e signal; the reason being this that as far as this e this signal is concerned it is the comparison of the reference signal with the feedback signal.

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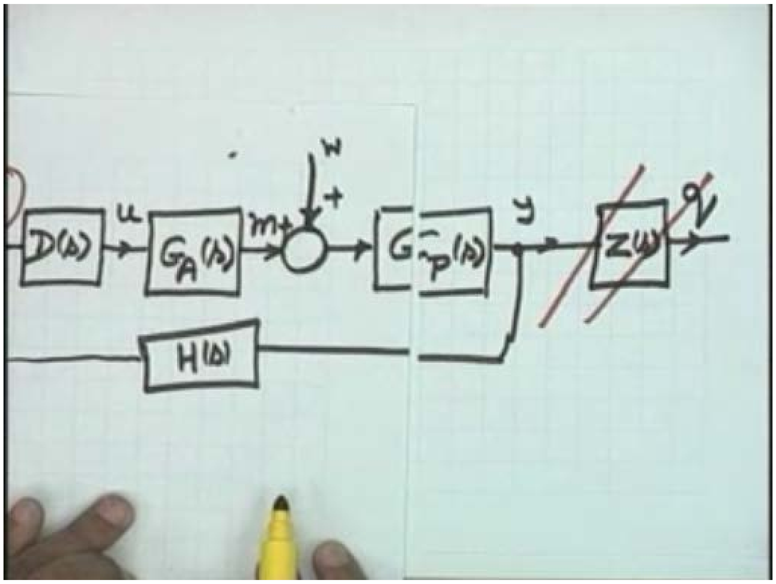

The feedback signal is coming after sensing of the controlled variable y. This is the controlled variable, this is the sensor so it means this b is not equal to y; I will call the error signal e is equal to y minus y r see the difference between e cap and e.

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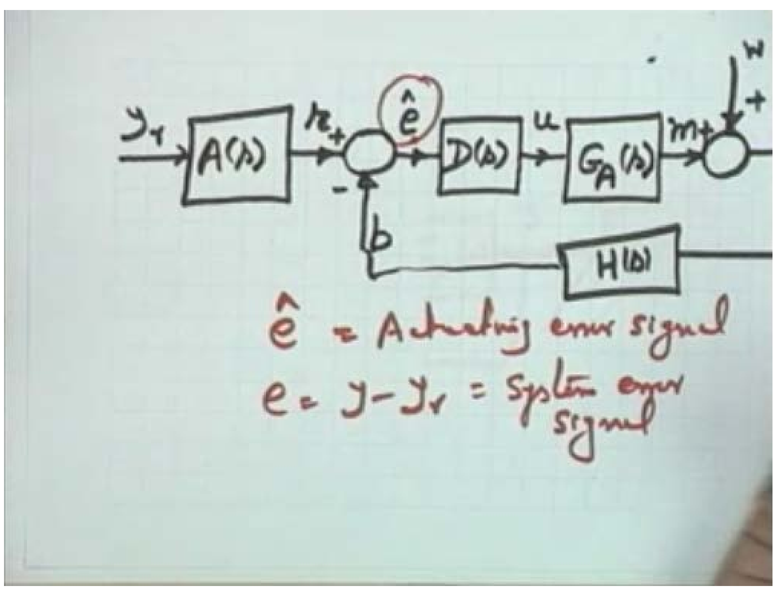

This e I call as the system error signal and e cap I name it as the actuating error signal. Why do I call it the actuating error signal because this is effectively the signal which is entering the loop, which is the input to your controller which is exiting the brain of the control system. You will please note e cap is the signal which is exciting the brain of the system. Well, what is e? e is the signal really you want to make it zero because e is the error between the controlled variable y and the commanded signal y r. This error signal has to be reduced to zero. So there is an e and e cap may be different signals it depends upon the transfer functions A(s) and H(s) which I am going to use in a particular control situation. So this difference between the two symbols e cap and e should be clear please. If this is okay in that particular case now I will say that the standard diagram of interest to me will be the following:

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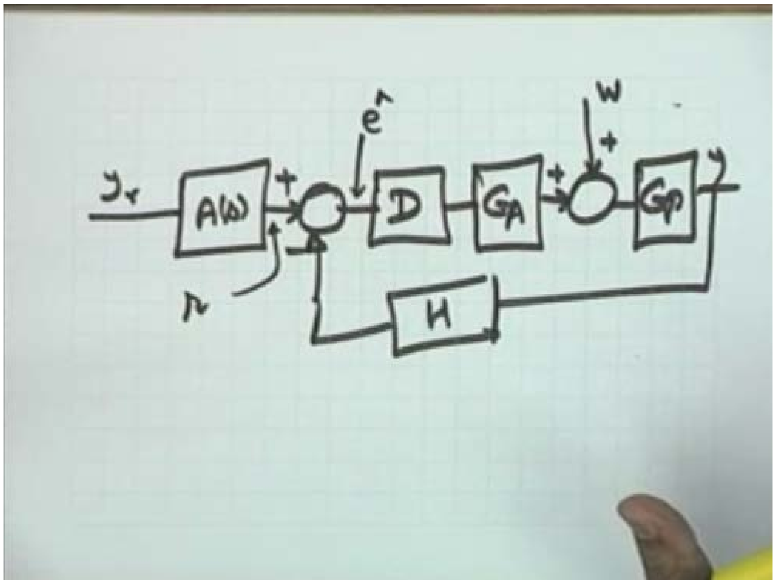

I can skip (s) if you do not mind to save space but surely all these are in the Laplace domain. This becomes the standard diagram for me please. This is the command this let me name it again because I will be interested in the signal, this signal is e cap and this is y (Refer Slide Time: 24:05). For the feedback design purposes I am going to work this type of block diagram. This is the feedback loop which has got the controller transfer function, the actuator transfer function, the plant transfer function and the sensor transfer function in the loop.

Now for the convenience of analysis and design, well, it may be possible to; please see that it may be it may be required to manipulate this particular block diagram into more convenient form. I need your help here, in this particular case I simply want to get this particular transfer function in this form and help me whether you accept this.

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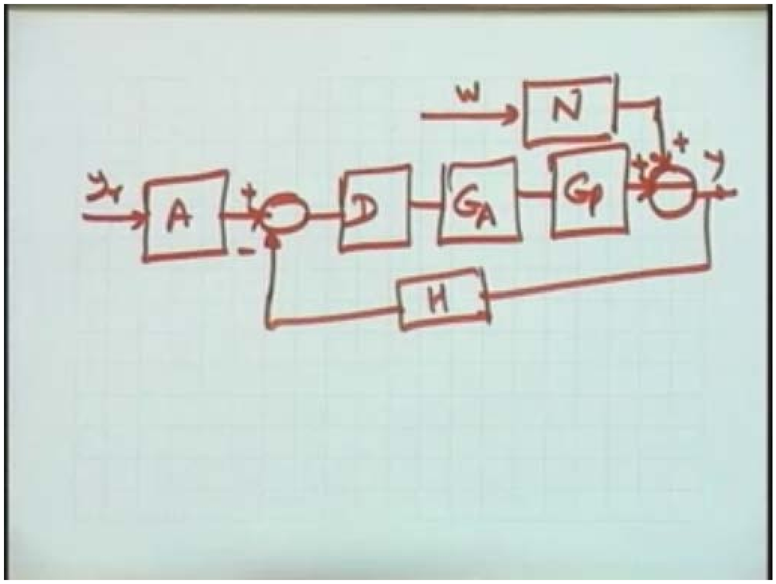

A, see the question, my point is this that the block diagram may be manipulated to write it in some more convenient form the convenience to be studied with respect to the requirements of analysis and design of control systems. This is your D here, this is G A here, I am removing this particular block, this is G P here, I put a summing block here plus plus and a transfer function N here a w here and y and this is the H, you see an interesting point (Refer Slide Time: 25:26). I make this change. The claim is this or I feel that this will turn out to be more convenient than the block diagram I have already drawn. The block diagram I have already drawn is just in front of you.

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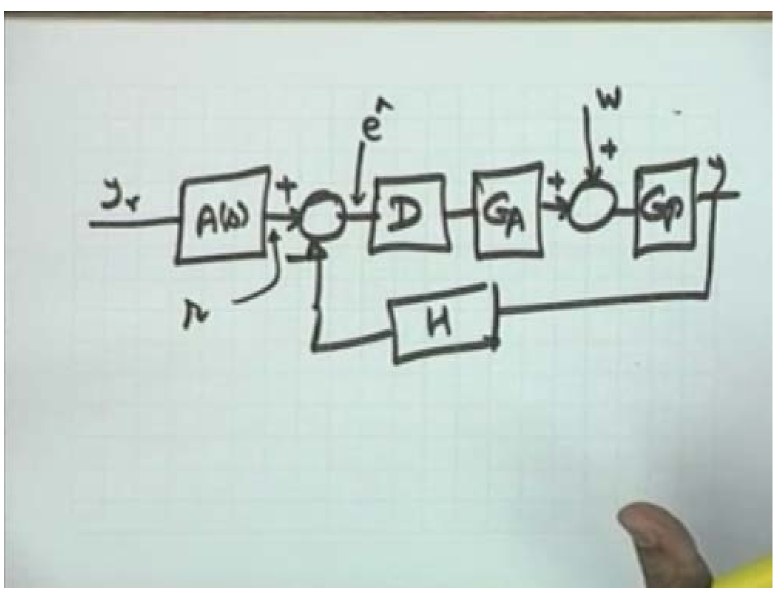

What is there?

In this particular case you will note that the transfer function between w and y is G P. In this case the transfer function between w and y is G P and the transfer function between u and y is G A into G P. Look at this block diagram please.

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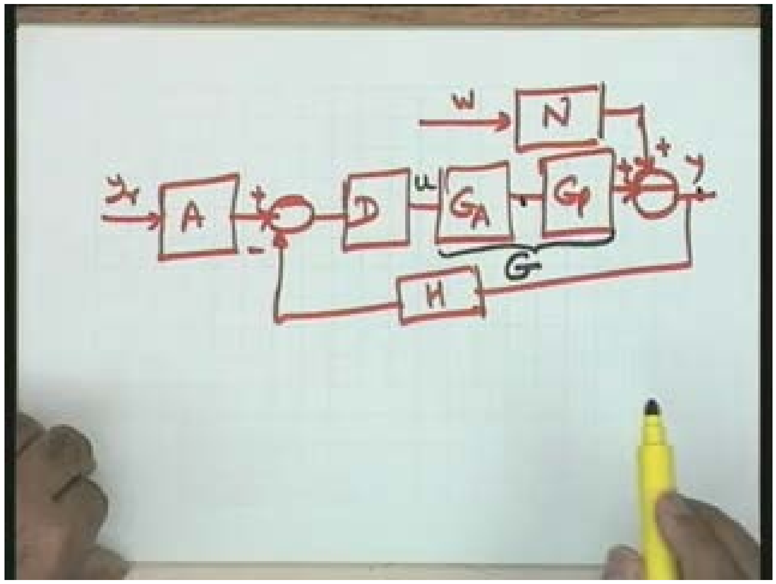

The u is here (Refer Slide Time: 26:02) the transfer function between u and y is G A into G P and if I make this N appropriately equal to G P in that particular case there is no harm in taking this N separately because I know that the transfer function between y and w in this particular case should remain as the case in the earlier slide. I hope you are getting my point. So you see that if in the two cases I can make the transfer function between y and w the same it really does not matter whether the summing junction is shown at this point are at this point; whether the summing junction is shown at this point or at this point it is one and the same thing and what I do now that this G A and G P can be clubbed together and I call it as a plant transfer function G.

So a more convenient block diagram now I am going to write is the following:
A plus minus D a single block G plus plus y and let me put a block N and this is your w and here is H. Definitely you see your okay is required to understand this manipulation. What I have simply done is this that if u is the signal over here the two block diagrams will definitely be equivalent if between y and u you have the same transfer function as in the original diagram. In this case it is G which is equal to G A into G P and as far as the transfer function between y and w is concerned in this case it is N which is same as G P and therefore this particular block diagram is equivalent to the block diagram I have drawn over here. This point must be very well understood. Block diagram is nothing but a symbolic way of manipulating the system equations. And as you will find in controlled system setting it becomes more convenient to work with block diagram than to work with, basically, the system equations. So this manipulation you will really be tune tuned to these manipulations because it is nothing but writing the rewriting the block diagrams with this particular point in mind that the system equations in the two cases should be identical. This is what I have done.

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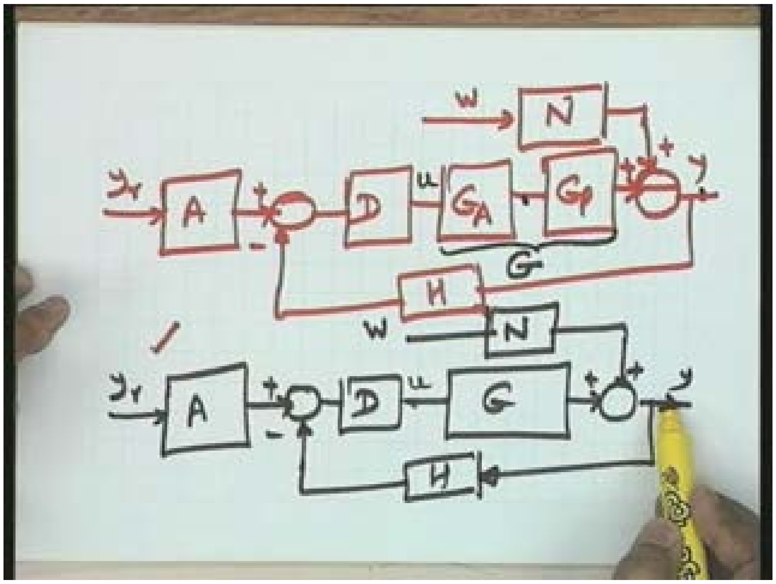

I claim that the transfer function between y and u and the transfer function between y and w in this block diagram is identical to the one I have given you earlier and hence the two block diagrams are similar or same. I hope this is okay. Now if this is okay then a question comes to you. So, in this case now you manipulate the block diagram for me so that this A block does not appear in the forward path. I want you to solve this question. This A block need not appear in the forward path. Just to give you a trick to give you a clue I may say that this point (Refer Slide Time: 29:18) e cap should have this same value in the present case and in the case you are going to change.

Now, in this particular case e cap, please help me, you get from here is Ay r minus H y this is your e cap. If your e cap, rather from here I can write even u is equal to DAy r minus DHy this is your u signal the controlled signal in this particular block diagram. Please see this now. I take this plus minus A into D, I put over here, this is G (Refer Slide Time: 30:07) a block here and an N here, w, this is y and H by A here, please see whether it is equivalent; you just look at u whether it is equivalent or not; u equal to…. this is your y r, u equal to ADy r minus H by A into ADy you find that it is equivalent; H by A block is being multi is cascaded as I told that the two blocks in cascade their transfer functions will be multiplied. The only thing is (s) variable I am not writing to save space. So if I go from y to u you find that it is this particular loop H by A into AD gives you H into D into y and your earlier u variable was DAy r minus DHy now you have the same u variable and hence this block diagram and this block diagram are equivalent.

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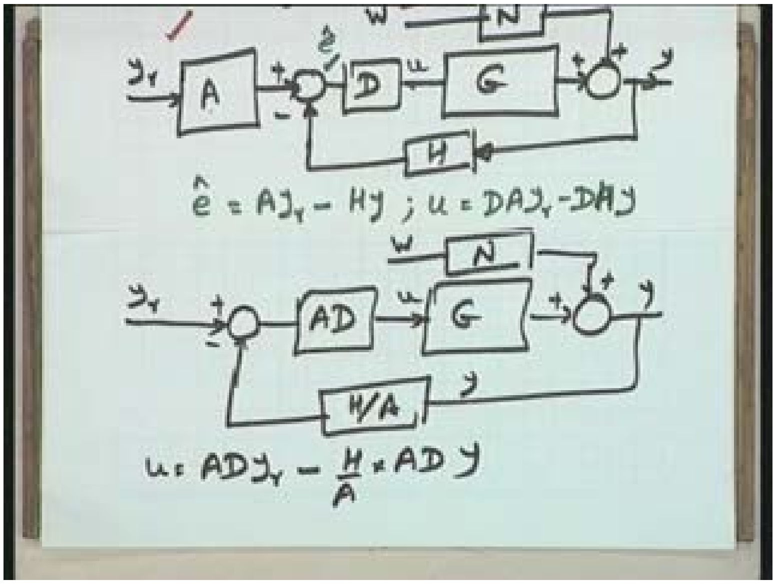

In this particular case you find that the input does not have the reference. Now you see, I at this juncture I will not tell you as to what convenience are we drawing from this particular manipulation but it should be clear that manipulating the block diagram may be required in control system analysis and design for the purpose of convenience and manipulating a block diagram is nothing but manipulating the corresponding system equations.

You find that the two blocks are equivalent where in this particular case y r has turned out to be an input signal to this which you can say in this particular case is a reference input are if there are no reference elements. It means the reference element block has been taken inside the loop now and this becomes the total loop where A also appears.

Now, if by design or by chance H happens to be equal to A please help me what will be the situation, it may be by design that is your sensor transfer function can be equal to the transfer function of the feedback elements. If H happens to be equal to A in that particular case the block diagram appears like this y r equal to r A into D G plus plus N w y…… just see very important diagram it has a meaning because many a system many a times you are able to transform your system into this block diagram and the statement which I make here an important statement that this block diagram is quite convenient from the point of view of design.

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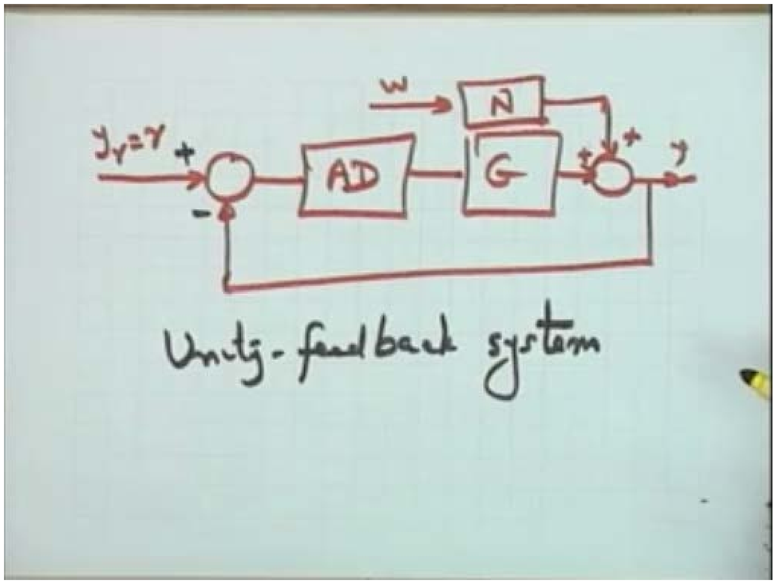

This block diagram as is visible from the structure is referred to as unity feedback system. I really need your attention on this statement. Many a times this causes confusion that if you are working with this type of block diagram one gets the feeling as if in this particular case y is directly coming here and going to the summing junction (Refer Slide Time: 33:42) without a sensor in between or necessarily the sensor transfer function is equal to 1 because it appears that way. If I give you this block diagram it appears as if this corresponds to a system with sensor transfer function is equal to 1. Please see, it is not the case, it need not be the case; your transfer for sensor transfer function need not be equal to 1. You have already seen that this particular block diagram (Refer Slide Time: 34:11) has been obtained by a sensor transfer function H is equal to the transfer function of the reference elements still your transfer the overall block diagram has turned out to be into what is called a unity-feedback system.

So a unity-feedback block diagram will come very often in our discussion and you will always keep this in mind that the result or this diagram has been obtained by manipulating the original block diagram. this particular block diagram necessarily does not mean that the sensor transfer function is equal to 1 though it does not rule out that possibility; your sensor transfer function can be 1, what I mean to say is that it is not necessarily equal to 1. So this type of manipulation also may be required. Yes please, some people have A, D and G also.

[Conversation between Student and Professor – Not audible ((00:34:58 min))]
Okay this is what I was going to do in the next slide. Yes, I definitely agree with you. I now say that with all these manipulations as has been suggested by him I can come to now this diagram which represents this system equations and this diagram is r the reference input, this now becomes the diagram which I am going to extensively use for design, please see, plus a minus sign here I am putting minus sign decidedly because mostly our structure is going to be a negative feedback structure.
Here now (Refer Slide Time: 35:42) as has been suggested by him let me call this as the transfer function D. Again please see, now this D is the block for the transfer functions in the forward path which have come after manipulation. These need not be the transfer function of only the controller. This need not be the transfer function of only the controller, however, in my block

diagram there is no there is should not be any confusion if I put a controller as the major contributor to this particular block. But like A was multiplied in the earlier block this may be the result of suitable manipulation of the block diagram as well.

But to give you a general configuration of the diagram on which I am going to base my analysis and design methods I will take this D as a controller transfer function. With the statement which I have over emphasized that all these blocks should not have one to one tie up with the physical elements. All these blocks have resulted because of the manipulations of the basic equations of the system.

Similarly, now I put another block over here and I call this as G(s) and let me call this as plant. the total thing I am clubbing: the actuator, the power element of the system has also being clubbed into this G(s) and this total I call it as G and this I reserve as the terminology for this. And here is the controlled variable y this variable let me call as u. This y is being taken from here, this is the block let me use H(s) for this, this I say is the sensor transfer function. now or let me call it a feedback path element because I am again repeating, this need not be the transfer function of only the sensor it may be the result of manipulation, some elements, the reference elements may also be coming into this particular block. Sensor I am using but again it could be at H block which may be coming as a result of the overall manipulation of the system equations.

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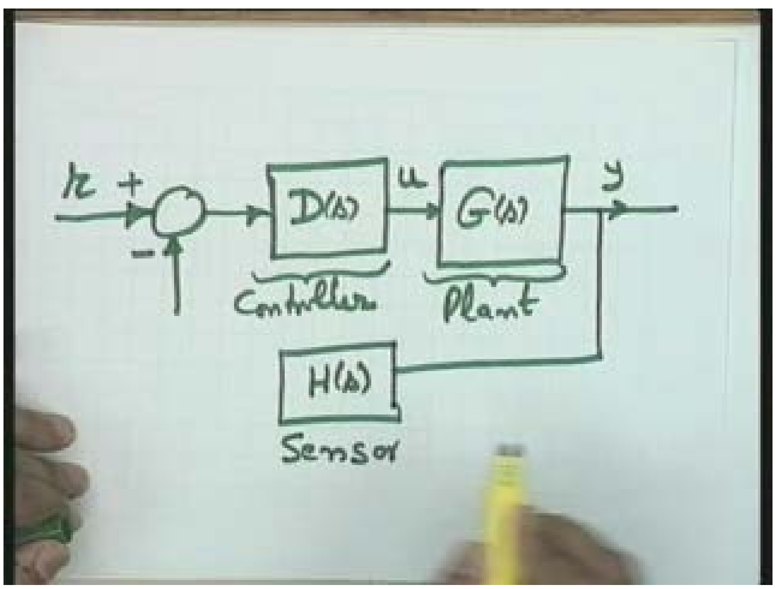

This (Refer Slide Time: 37:57) let me say is your feedback path elements, the feedback signal and this, help me please, should I take e here or e cap here in this particular block diagram. If I am taking this block diagram as per my terminology what signal should I take e here or e cap? I think it is clear, it should be e cap because e by definition is the difference is the system error is the difference between the actual signal and the commanded signal, it is between y and y r.

You will please note, the y r is not even shown in this particular block diagram. It is r the reference signal. It means r has been generated from y r. Since the feedback loop does not directly involve y r I need not include in my basic feedback loop transfer function model. But it should be very clear to you when you are analyzing the total performance of the system you should calculate the error e between y and y r which is not visible in this particular block diagram. The error e cap is simply an actuating error signal which is going into this particular controller. y r specifically we need not show in our design diagram in our feedback loop because this particular point or that particular block it is not entering into the loop which is the basic design element as far as our total effort is concerned.

Yes, please….
[Conversation between Student and Professor – Not audible ((00:39:28 min))]
Yes I have not completed, I am sorry, yes I should have shown a block over here, I had in mind I had to complete it. this you considered, disturbance is a very important component, without disturbance a control system block diagram has no sense at all because you will recall I have made a statement: If there were no disturbance in the system there would have been no course called feedback control theory because the open-loop control system could have taken care of all other requirements very well. So, disturbance I am definitely taking care of by this plus and plus I am adding a plus sign over here again this could be minus the disturbance can have an additive effect or the opposite effect but symbolically let me represent it as plus and here I am going to put a transfer function N(s) and here is my disturbance variable w this becomes the overall block diagram I will be working with.

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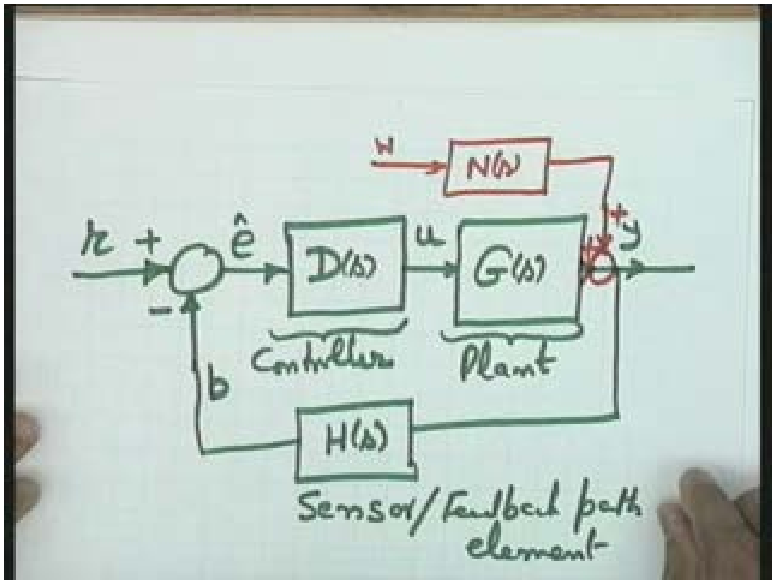

[Conversation between Student and Professor – Not audible ((00:40:28 min))]
Yes, please……is it this Ds the reference element into the actual controller D D into A)) ((00:40:30 min)) this b D(s) D(s) is the actuating error signal into D is the controller signal u. What is your question, please repeat your question? Is it the D(s) D into A? Yes, this is what I said; I think it should have been clear.

D(s) is the total transfer function between u and e cap. These are the variables. And controller, I am just putting over here just because this will represent that any action which generates a control signal u from the actuating error signal e cap is represented by D(s). Now do not related to A, yes, in a particular transfer function if a block diagram has been manipulated that way that A has been taken inside the loop, yes, this D(s) includes that as well. Now I am giving you the overall block diagram, that is all those elements between u and e cap will be clubbed into a single transfer function called D(s). This block diagram is now not a carryover of the earlier block diagram please. I am just summarizing the overall discussion that all those elements which contribute to a relationship between the control variable u and the actuating error signal e cap will be clubbed into a single block and that single block I am naming as D(s). Yes, if you refer to the original diagram, this D(s) with respect to the original diagram is A into D you are very right in that sense. Is it okay please?

[Conversation between Student and Professor – Not audible ((00:42:10 min))]

Sir it should be D then instead of e cap it should be e because the input is y r then. Okay let me take this particular diagram. Just look at this particular block diagram.

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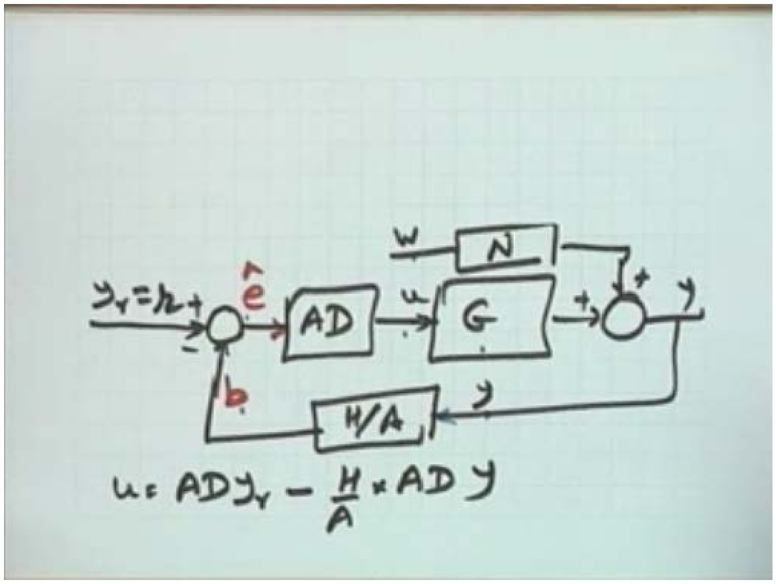

It is not e cap here, it will become e only when H is equal to A, only when H is equal to A it will become e. Consider this particular block diagram this is e cap because in this particular case y through H by A when A the reference elements have been taken in this particular sense y multiplied by H by A is your b signal and r minus b is the actuating error signal which is going into A into D and hence it is u over here.

So now you see this point that if you give reference to this block diagram, I need your attention because I like to answer your question so there should not the any confusion. Though D is used here and D is used in my final block diagram also but now what I am doing the following. All those elements which contribute to a relationship between u and e cap is clubbed into a single block and I am naming it as controller transfer function D(s). any transfer function which is representing the relationship between output this y and b I am taking it as the transfer function H(s) and the relationship between the control signal u and y as the transfer function G(s) relationship between w and y as the transfer function N(s).

Now the physical elements or how did we manipulate this equation the original transfer function that should not confuse us now. This from now onwards will become our standard terminology. The original diagram was given to you to convey to you that these blocks should not need not represent the basic physical elements of the system they simply represent the mathematical relationship or dynamical relationships in the system. So here D G N and H we should not try to relate to the physical elements immediately. Still I have given the names because many a times it is possible to relate and secondly if we have some names it becomes more easier to visualize the total working of the system. So these D G H and N are the basic blocks which represent the dynamical relationships.

Whatever systems are coming into the picture all the systems should be taken into consideration to get these dynamical relationships and hence the corresponding transfer functions (Refer Slide Time: 44:47). Is it okay please? Now, in this particular case itself if I make if I have a diagram in which H(s) equal to 1 in that particular case I will refer to that system as a unity feedback system. Yes, in that case, let me redraw it since you have raised a question. I will redraw this.

For a unity-feedback system I think I can give you this diagram now: Plus minus this is your D(s) this is G(s) here now let me put N(s) and here it is w this is y; you are very right if you say that now you put an e because in this particular case now (Refer Slide Time: 45:35) whatever be the manipulation in this particular case the feedback y as per this equation model, now again I said do not think that H is necessarily equal to 1 but finally D G N an all these blocks have been obtained by manipulation of the system equations in such a way that this becomes the mathematical representation in the block diagram form.

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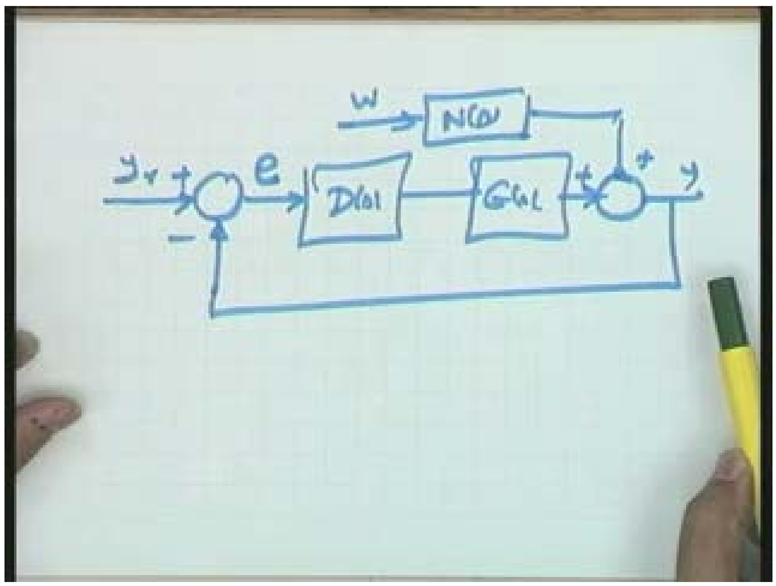

In this case y is going; your y r will be equal to r the reference input. Since y is being compared with y r this particular signal is system error signal so in this case the actuating error e cap is equal to system error itself which is equal to y r minus y. So, in a unity feedback structure the system error e explicitly shows up in the block diagram. But if it is a non-unity feedback structure that is if you have H in the feedback path in that particular case e cannot explicitly appear it is going to be e cap the actuating error signal which will appear in the diagram. And one thing I can assure you that, even if there is a gap……. at this particular stage to understand these diagrams when we come to the physical systems you will find that, well, a suitable interconnection of various elements of a physical system you will be able to translate into one of these two basic block diagrams and from there even if there are some gaps now I am sure those gaps will be filled up when we come to modeling of physical systems and transforming their block diagrams into one of these standard block diagrams. This is sure, for my design purposes I will pick up these two standard block diagrams only always. I hope this is okay.
[Conversation between Student and Professor]

Why this yr equal to r? y r equal to r okay, for that I will like you to go to this particular block diagram.

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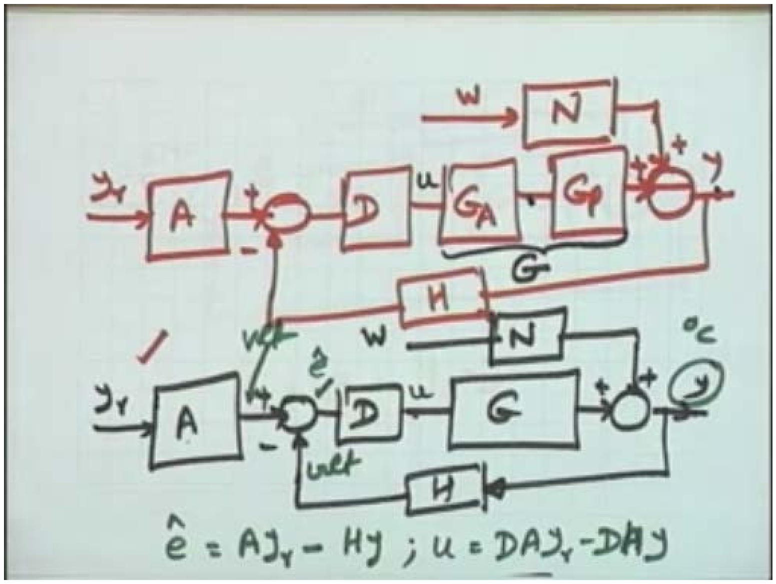

What is y r?
y r is the command signal. Let us say your command signal is temperature physically. A, it is converting it into a voltage so r in this particular case is a voltage signal. So, as far as the physical variables are concerned if all these blocks represent physical quantities and variables in that particular case y r is temperature, A is a block here and r is the voltage. Now if I transform this particular block diagram. that is, there may be a situation that in this particular case your y the variable here is also a temperature this temperature is also getting transformed into voltage so volt here volt here. Now if this A is taken inside in that particular case, as far as mathematical representation is concerned, the mathematical representation of the two will be equivalent if I make y r equal to r. You can just write the equation.

I said the two mathematical equations will be equivalent. That is the system equations obtained from here now physically it will not make any sense that is why I said that neither the variables nor the blocks after manipulations should be given a physical inter-relationship. So, physically it will not make any sense but you write the mathematical equations from this block diagram or you write your mathematical equations from let us say this block diagram we have written you will find that the two equations are exactly identical and hence in this particular case we can mathematically represent and draw block diagram this way.

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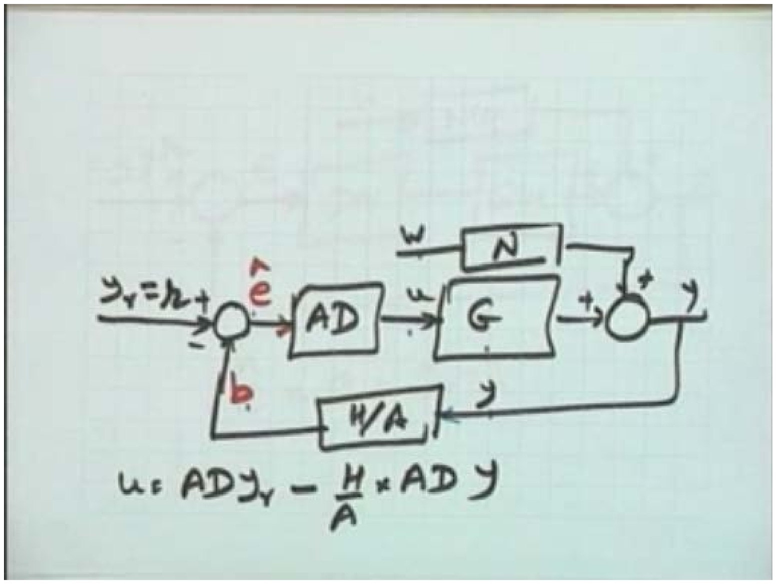

And it is this way only that the final situation has been taken to one of these two block diagrams: one is a non-unity feedback system and the other is the unity feedback system. Is it okay please? Before I can clue this discussion I will like you to get this basic block here. Let us say r plus minus I have taken e cap D G plus plus N w y H. If you know through any other course can you tell me directly what is Y(s) over R(s) is equal to? Y(s) over R(s) the closed-loop transfer function of the system what is this equal to if i a get if I am interested in the overall transfer function.

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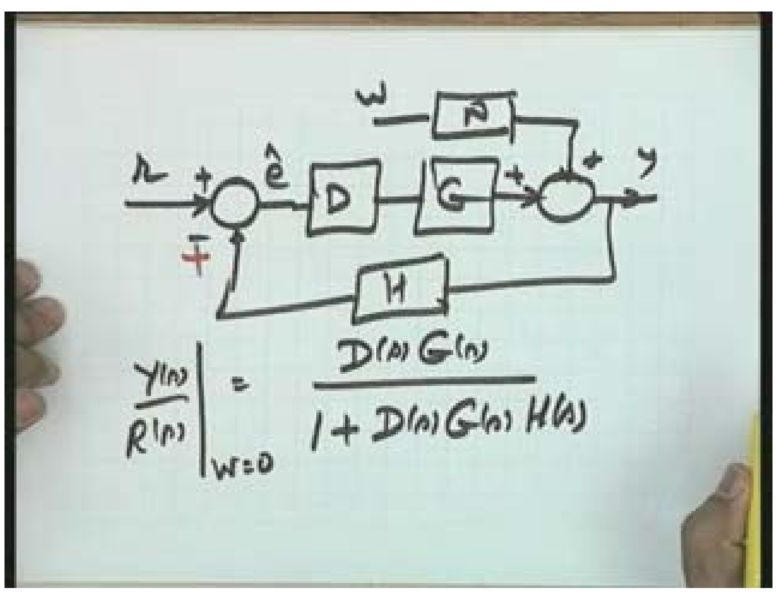

First of all please see, it is a two input one output system. In a two input one output system if you are interested in a transfer function naturally superposition will have to be applied you will have to take one input at a time. So I consider the situation where w is taken equal to 0 and I am interested in the transfer function between y and r. Please help me if you recall: D(s) G(s) over 1 plus D(s) G(s) H(s); I hope I can assume it I need not go for the derivation. Is it okay please? And please see that if this is a plus sign here that is, if you have a positive feedback loop in that particular case this will become a minus sign here. This is a basic loop and I may call this transfer function as a reference transfer function because this relates the output variable y to the reference variable R. I call this as a reference transfer function. You have rightly given this transfer function to me. Now please help me if you can manipulate the transfer function between y and w; between y and w, now you set R equal to 0.

So I am interested in this particular situation now; setting R equal to 0 so this is a minus sign, here I have a signal D this signal e cap this is D here G here a summing point N w y H. Yes please, I want you to give me transfer function between y and w. so it is Y(s) over W(s) setting R(s) equal to.

[Conversation between Student and Professor – Not audible ((00:52:13 min))]
N minus N s if you say then I think making an error. 1 plus
[Conversation between Student and Professor – Not audible ((00:52:23 min))]

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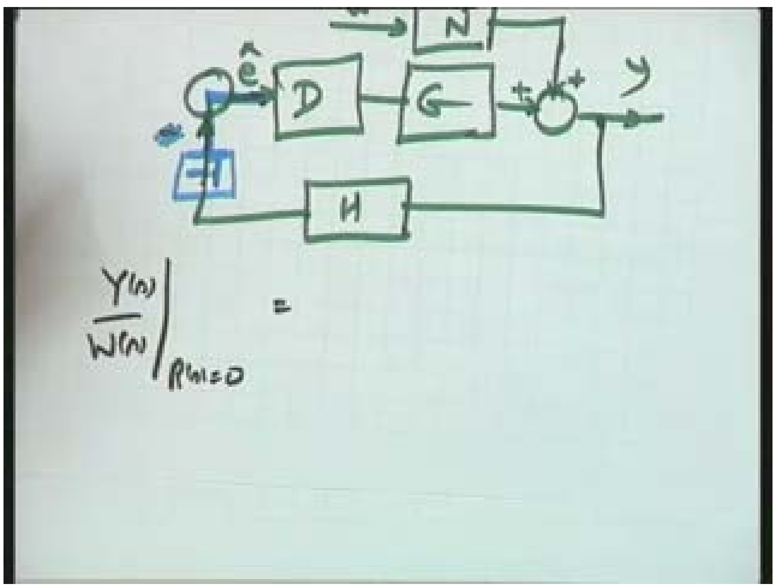

I think there are some errors in all the answers so we can have a quick look at this particular diagram and derive. This minus I take it into this a single minus one and let me complete the loop this way that is the error detector I am removing and putting it as minus 1 here so it means the transfer function now becomes D the block diagram now becomes D G plus plus N w e cap let me put a minus 1 here and this is your H.

The basic equations E cap s equal to minus Hs into Y(s). The other equation let me write between y and E cap; between y and E cap I write Y(s) equal to D(s) G(s) E cap s plus N(s) W(s) these are the two equations, eliminate your E cap.

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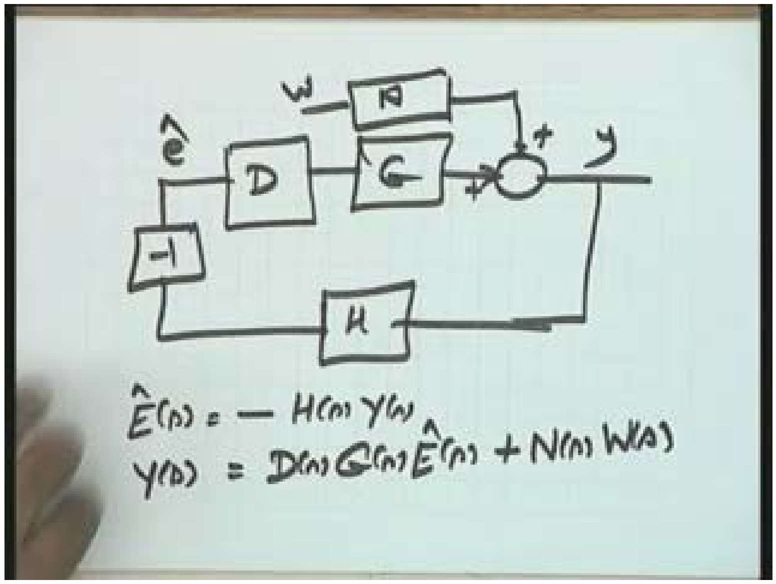

From these two equations if you eliminate your e cap, now you can see some of you might have given the right answer I do not know. If you eliminate your e cap now it becomes Y(s) is equal to minus D(s) G(s) H(s) Y(s) plus N(s) W(s) and therefore your Y(s) over W(s) with R equal to 0 becomes equal to N(s) divided by 1 plus D(s) G(s) H(s). Numerator is N(s), denominator is 1 plus D(s) G(s) H(s).

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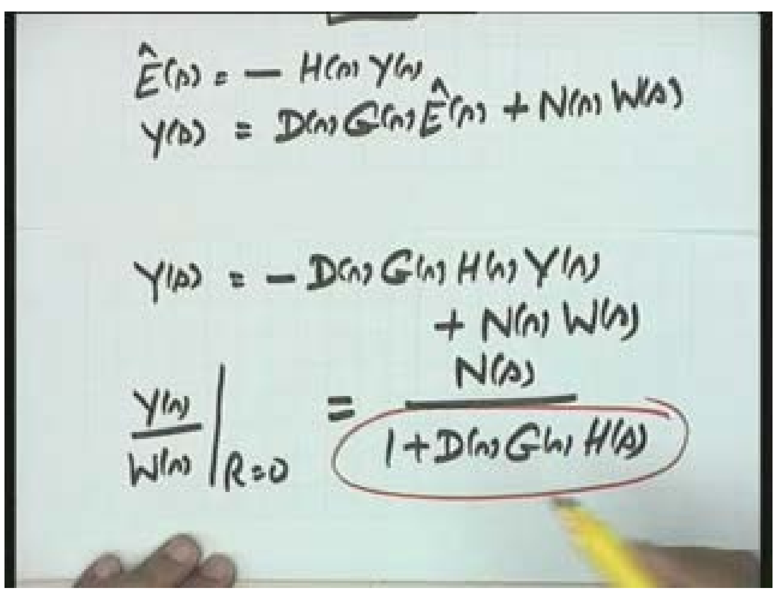

You will note one point that in the two transfer functions one you call it reference transfer function and the other one you call it disturbance transfer function the denominator is the same; it is 1 plus D(s) G(s) H(s) this is as you can easily visualize is the loop transfer function because it is the multiplication or cascading of the transfer functions in the loop. D(s) G(s) H(s) is the loop transfer function and in this particular case I can just in this particular case a symbol I will give you or in the disturbance transfer function now onwards I will represent by M W(s) (Refer Slide Time: 55:08) and the earlier transfer function which you had given to me this transfer function let me reserve M(s) for you. So it means M(s) is my reference transfer function, M W(s) is the disturbance transfer function, in terms of these to transfer functions I conclude my discussion with this particular block diagram that your input is R(s).

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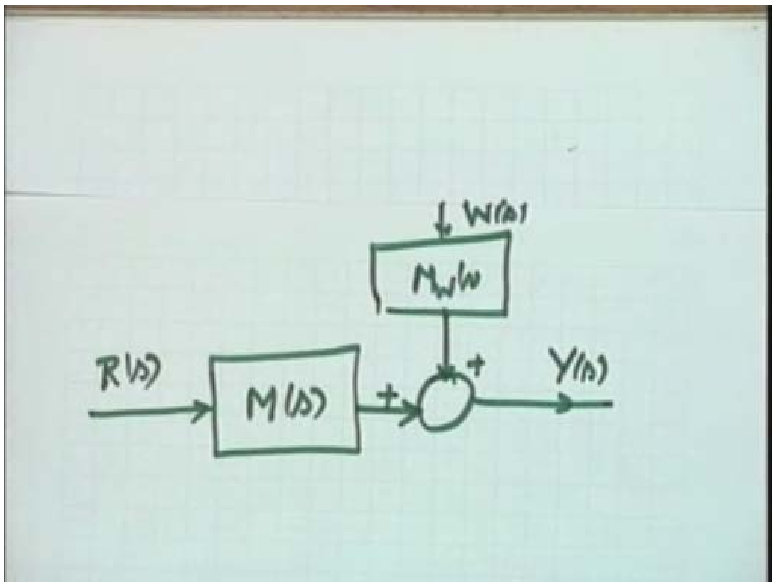

This is the M(s) transfer function and here let me put a disturbance transfer function M W(s), here is my disturbance variable W(s) and this is Y. This is the equivalent block diagram I have got. For the purpose of analysis, I will require this particular block diagram because this block diagram gives you a direct relationship but when the output and the reference element and between the output and the disturbance element. So this is the equivalent block diagram of the the standard block diagram we have reserved for design. Thank you very much.