Industrial Automation & Control
Prof. S. Mukhopadhyay
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 9
Signal Conditioning (continued)

Welcome to this lesson of industrial automation and control. Today, we are supposed to do lesson number 10, but because we could not complete 1 topic in lesson number 9, which is very important in instrumentation called phase sensitive demodulation. We will just take a few minutes to cover the topic first and then go into lesson number 10. So, we start with lesson number the 9, the next part of that. So, lesson number continued lesson number 9 was on signal conditioning.

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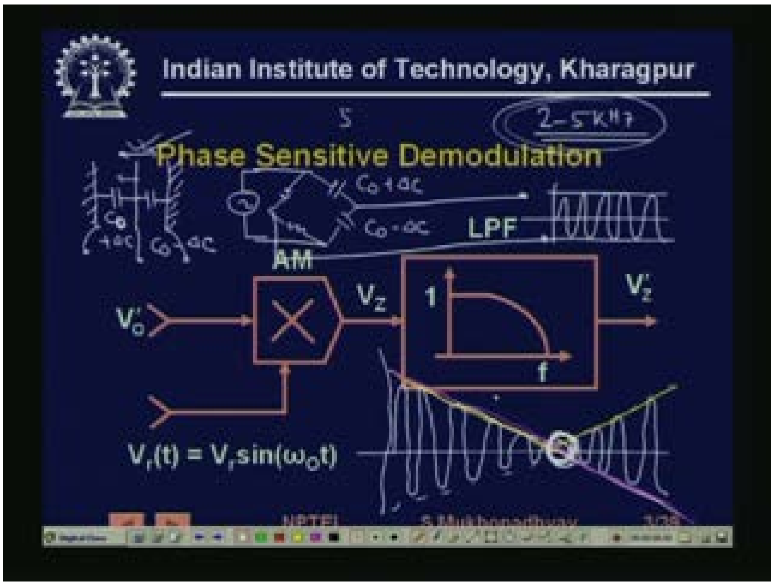

So, we straight away come to phase sensitive demodulation, and let me try to explain this because this arises in many different sensor applications. So, first of all let us see, let us realize that from many sensors. Let us say, we have a capacitance sensor, we have just seen in our last lecture that capacitance sensors are of10 the signal from capacitance sensors, which is in capacitance sensors. There are the capacitance gets modulated by the quantity, which is measured suppose motion right.

So, now this change in capacitance, which is I mean typically we have also seen that typically there are 2 capacitances, and if 1 capacitor becomes c naught plus delta c the configuration is made such that the other, the other capacitor becomes c naught minus delta c. So, that that we have seen that typically if you have 2 fixed plates, and if you have a parallel plate in the middle. So, then and you have terminals from here, and here and here. So, you actually form 2 capacitances and it turns out that these plates are fixed and this is the movable plate.

So, obviously, if as long as the displacement is small, we can say that if this c 1 both of them are actually equal because in the nominal position the separations are equal. So, if is c naught, if it becomes c naught plus delta c, if it moves to this side then this 1 will become c naught minus delta c right, and then these. So, these 2 capacitances are typically we have seen that they are formed as 2 ratio arms of a bridge. So, 1 capacitance is here and the other capacitance is here.

So, this becomes c naught plus delta c and this becomes c naught minus delta c, and these bridges are actually excited by A C sources, right? So, what happens is that? Now, we see that the output becomes modulated that is, so if you take a bridge and if you take the signals from here, what shall we see here? So, we obviously, this excitation is generally of high frequency typically of the order of, let us say 2 to 5 kilohertz or even sometimes little more.

On the other hand this motion is typically any you know, you know, you know any motion will be of the maximum. And let us say if you, if you it even if you take vibrations even if it even, if you take vibrations it will be, it will be the order of 10 of hertz or may be may be 100 hertz. So, what is going to happen, is that generally you have a output is actually, is actually a sinusoid of frequency 2 to 5 kilohertz, while the amplitude of this sinusoid is going to vary according to the motion.

So, what you get is actually an amplitude modulated signal. So, you get. So, if the suppose the plates are moving like this, then what you will the then the output that you will get is will be somewhat like this. Actually, I am the frequency; I am drawing because I cannot draw such a high frequency. So, therefore,

And here there will be actually a phase inversion because the modulated signal is negative here right this is this here the modulating signal is positive. The motion here, the motion is negative. So, therefore, there will be a phase inversion here, which will be very difficult to detect. These waves will actually look very similar if you see them in the in the C R O. So, it will be very difficult to detect whether the motion was.

Let me use a different color. So, whether the whether the motion was like this yellow line or whether this motion was like this would be like this pink line both waves will actually look similar in the output, while the motion is completely different.

So, therefore, one has to find the mechanism by which these motions can be separated and in. In fact, this that is the phase inversion here has to be captured. So, the demodulation mechanism, if you just put a rectifier, if you just put a simple rectifier, suppose you want to rectify this wave, then that that rectifier will not do because it will, it will rectify both of them in the same way. So, it is not phase sensitive.

So, therefore, we have to have a mean such that we have a phase sensitive demodulator, which will see, which will sense whether there was a phase inversion here or not. Then, we will be able to distinguish between this pink and this yellow kind of motion. So, this is the basic problem of phase sensitive demodulation. Now, suppose, let me use a different pen, now because we have got a different background.

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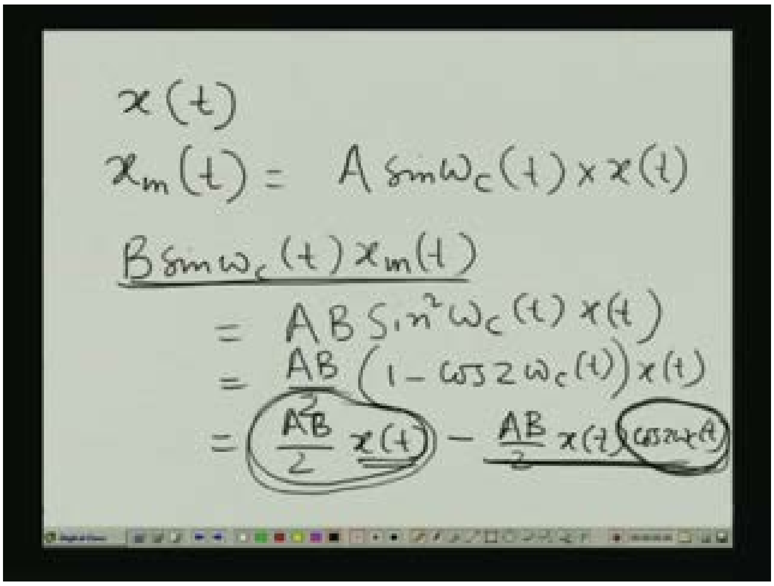

So, typically suppose the motion x t is the actual motion of the plates just giving you an example exactly similar thing will happens for L V D T, where which is an inductive sensor and where the core will move. So, the modulated wave the modulated wave. Let us say, the x m t, which you will get out of the bridge will be some A sin omega c t. This is the carrier wave. This is the excitation frequency into x t, right.

Now, from this x m t we need to get x t out, right. So, one of the strategy is there are there are actually various strategies. So, one of the strategies would be to multiple x m t, if you multiply x m t by again sin omega c. Then, suppose we multiply it by B sin omega c, then this will be A B sin square omega c into x t.

So, sin square omega c. So, it will be A B by 2 into 1 minus cos 2 omega c t, right x t. So, we will get 1 signal, which is A B by 2 x t, and another signal, which is A B by 2 x t cos 2 omega c t, right. Now, you see omega c itself. Suppose, x t is low frequency signal motion. So, about 5 to 10 hertz, and omega c is let us say 5 kilohertz. So, there is a 1000 time separation, and 2 omega c is 10000 times.

So, you naturally see that this signal will be, this will be a 5 to 10 kilohertz signal 5 to 10 hertz signal because it is just x t, while this it can be shown easily that this will be a signal, which will stay very close to whose components will stay very close to this cos twice omega c namely of the order of 10 kilohertz. So, we need to now separate. So, now the signal this is the signal is actually a sum of A 0 to 5 hertz signal and a 0 to 10, and a, and a signal, which is around 10 kilohertz very narrow.

So, it is very simple to separate these 2 any simple low pass filter will if there is. So, much separation will actually cut off this 10 kilohertz signal and will give you the 5 hertz signal, which is this x t. This is the basic principle of phase sensitive demodulation.

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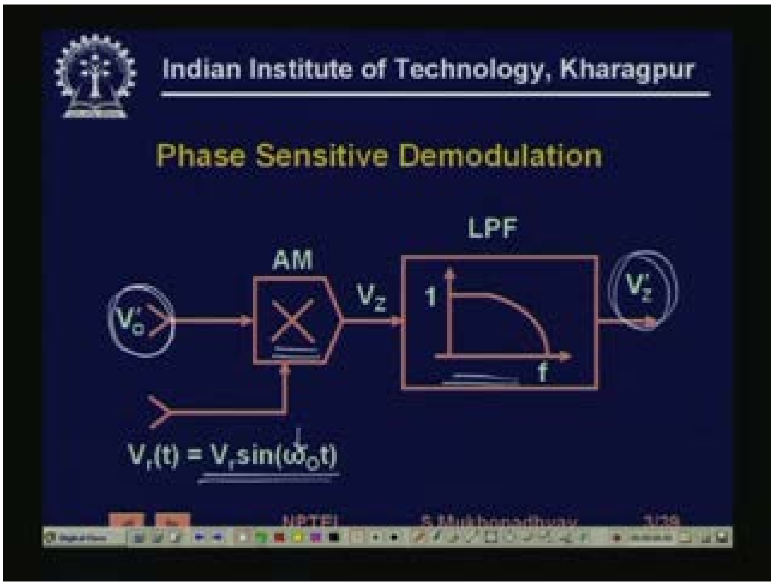

So, exactly this is what is being done here that is. So, you see that this is the signal, which is the modulated signal from the bridge. Let us say or from a L V D T and we are multiplying it by the same sin omega naught t, where sin omega naught t is either the primary excitation frequency of the L V D T or the excitation frequency of the bridge.

So, we are multiplying it this is a multiplier as I did, and then we are low pass filtering it. So, if we low pass filter it what we will get is the, is the signal, which is proportional to the original motion signal. This is 1 way of this is conceptually the simplest way of doing phase sensitive demodulation.

Now, this multiplication is not such a simple thing to realize. So, therefore, there are various you know other lower cost simpler circuit versions, which will also realize this they are also in a sense like multiplication, but not exactly. So, we will see some you know some realistic circuit. So, for example, let us see this one.

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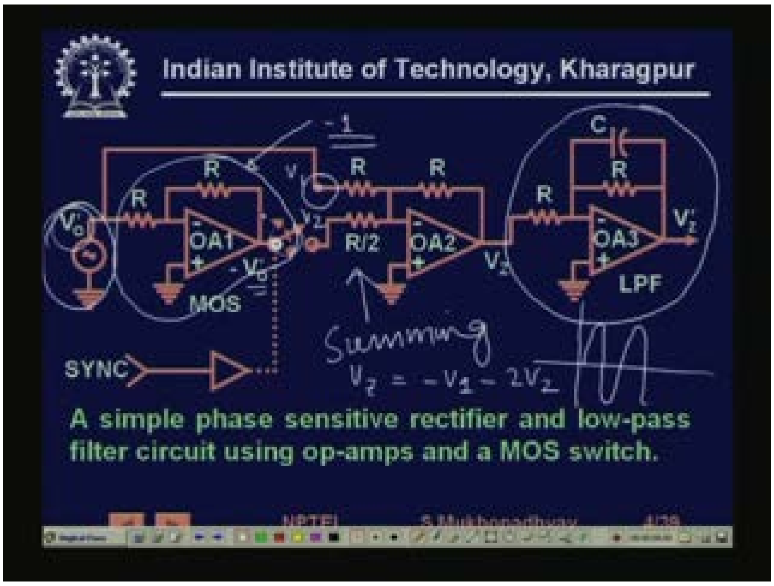

So, you see this is a simple phase sensitive rectifier. So, here we are using a rectifier, but it is a phase sensitive rectifier, how we? So, how does it work? So, you see what is happening here; first of all let us realize that this is the low pass filter that is something, what is this. This is a summing amplifier we yesterday we have seen summing amplifiers. For this part the gain is 1, it is R by R. For this part the gain is 2. So, it is actually if you call this as V 1, if you call this as V 2. Then, V z is equal to minus of V 1 minus of 2 V.

Now, you see that what is this is a simple unity gain inverting amplifier. So, the gain here is minus 1. So, here at this point of time this V 0 dashed is equal to minus V 0. This is the signal that we want to demodulate right.

Now, here is a switch and the switch is synchronized, how it is synchronized that suppose whenever this signal is going. So, here you have V 1 equal to V 0 dash is directly connected and here this minus V 0. So, this is V and this minus V is being switched on and off.

So, suppose we switch it in such a manner that when V is positive this switch is on. So, when, so when V is positive this is this is minus V or rather may be when V is negative, when V is negative. Suppose, when V is positive this is off and when V is negative this is on. So, V this V, so when V is positive first of all this is off. So, therefore, the signal is. So, now imagine that V is something like this. So, we have got a, we have got a picture of this. So, let us just imagine that the input here this input is let us, let us see that signal then we will able to understand better.

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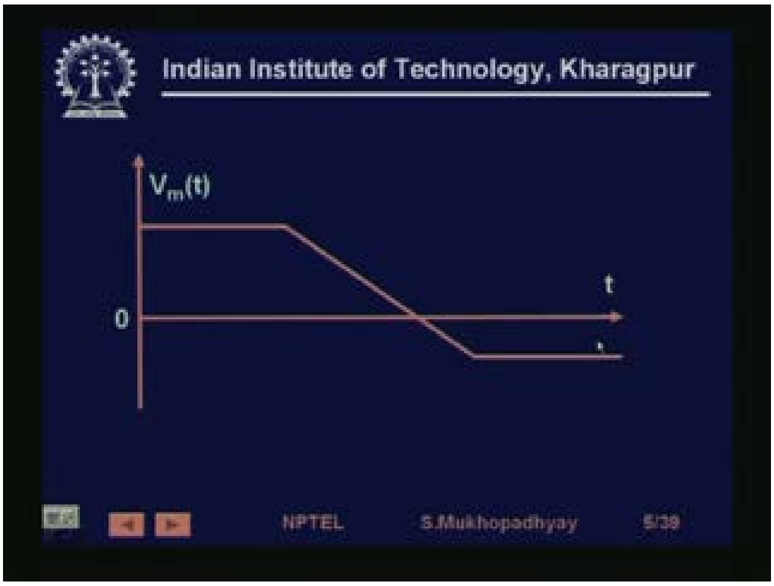

Suppose, the motion is like this, right. So, it stays positive then goes negative, then it goes positively, then it goes negative and stays negative.

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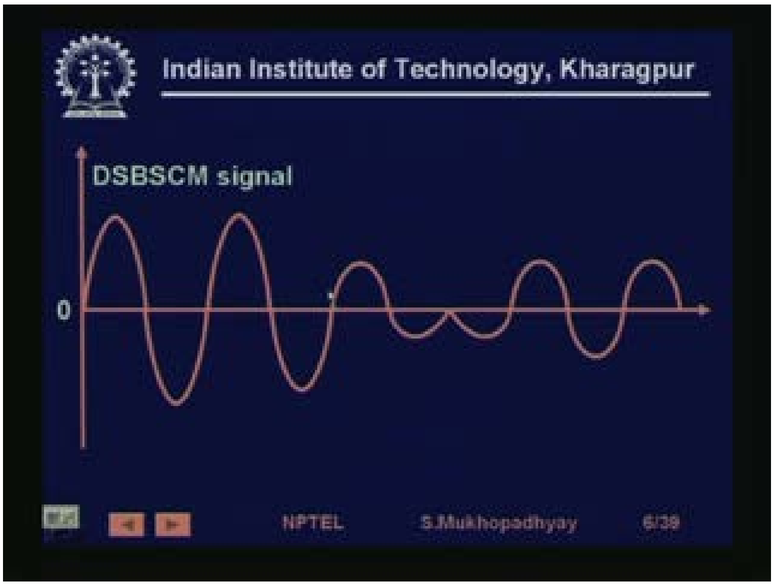

Now, what is the, this is a what is the phase what is the, what is the amplitude modulated signal. So, you see that for some time the amplitude is remaining constant then the amplitude is actually decreasing that is the linear part here, it is going negative. So, there is phase inversion, and then the amplitude is increasing negative, and then for sometime it is remaining constant.

So, this is the wave the carrier frequency is shown to be much smaller because it is then the picture will become clattered, but the we can imagine the actual the carrier frequency will be much higher than this, but the wave form will be the if you draw the peaks. Then, it will resemble the motion and since here there is a phase inversions. So, therefore, the motion will be negative. So, this is the modulated wave, which we have to demodulate. So, we go ahead.

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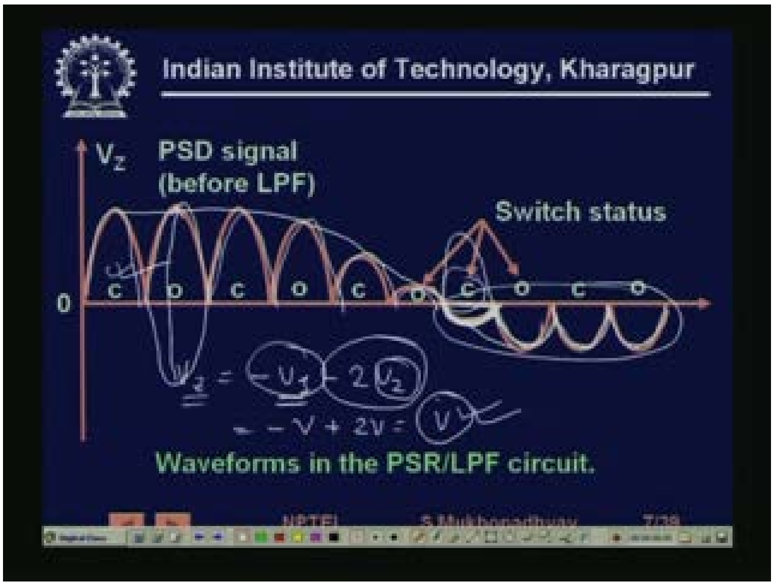

Now, you see what is happening to this circuit. So, you see suppose the switch is in this case they have assumed that when the switch is closed when positive. So, when it is closed when. So, first of all did you see, when it is open then V z equal to minus V 1 minus 2 V 2, and V 2 is 0 because it is because the switch is open.

So, therefore, this is just minus V 1 V z. So, therefore, the negative half actually the wave was like this if you recall. So, the negative half, so V z will go up it will be minus V 1. On the other hand when this is, when it is when the, when the switch is closed, then what will happen? So, when the switch is closed, then it is minus V 1 minus 2 V 2.

So, and V 2 is equal to minus V. So, it is actually it is going to be minus V plus 2 V is equal to V. So, when it is, when it is positive then it is plus V, when it is negative then it is minus V. So, negative minus of negative means positive. So, essentially the wave will be rectified.

So, now you see that is why you are getting this wave. So, it is a full wave rectified wave, but when this V will itself go negative then when the V will itself go negative. So, you can see that all the it is, it is always when it is closed, then also then it is V. So, now when V is going negative. So, actually this wave is being synchronized along with this along with a sin wave. So, the carrier sin wave.

So, when the carrier sin wave. So, now when it is, when it is, when it is, it is now closed during the when the wave is negative. So, the same thing is happening here it was closed, when the wave is positive here it is because there is a phase inversion, but the sin wave carrier is still positive here.

So, therefore, the switch becomes on. So, the switch gets on and off according to the carrier wave. So, then we will get a. So, you see that when there is phase inversion the signal goes negative its rectified, but it is rectified in a phase sensitive manner it is not an ordinary rectifier. Now, if we, if we send a send it through a low pass filter, then what will happen is that simply this these you will get the envelop of the wave. So, if you get the envelope of the wave then you see that you are getting back the motion. So, this is the basic principle of phase sensitive demodulation, and it is applied in various large types of you know inductive and capacitive sensors.

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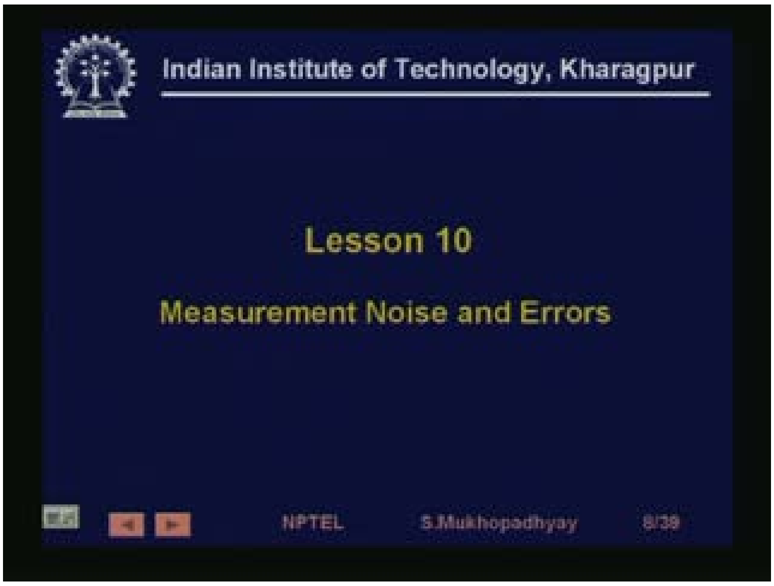

So, now having said this we can now get on with the measurement our lesson 10, which is on measurement noise and errors.

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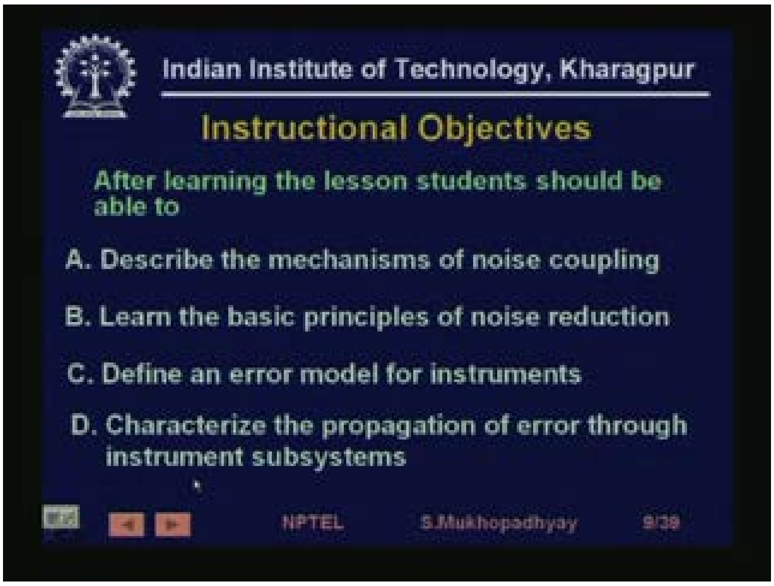

And first of all we will see the instruction objectives. So, the basic instruction objectives are that the student is able to describe the mechanisms on noise coupling is very important to understand that how noise is coming into this system. Then, learn the basic principles of noise reduction thumb rules.

Then, and one has to understand, what are the error models of instruments, how the instrument errors are mathematically characterized. If, you connect a number of instruments together, and if you have individual specifications for them, how do you know the characterization of the propagation of error through instrument subsystems? If, you typically it happens that your are connecting a number of individual components each of them have some specifications from manufacturers.

So, 1 needs to understand that what is the overall specification of the instrument because you know, one has to understand that this instrumentation is very much connected to product quality control, and it is a because it is, it is either directly it is used. I mean to a large e x 10 t in quality control product quality control sometimes in product process, and in, and in product process control.

So, if in both cases the instrument accuracy effects the quality of the product because if the process, where control is not well maintained. Then, also quality of product will survive will suffer, and on the other hand in during inspection you directly observe the quality of the product and you either accept or reject the product. So, it is very important to understand the kinds of errors that the instruments are likely to have and then accordingly decide with what kind of instruments to buy or what should be a good, what should be a good interval for calibration of the instruments, etcetera.

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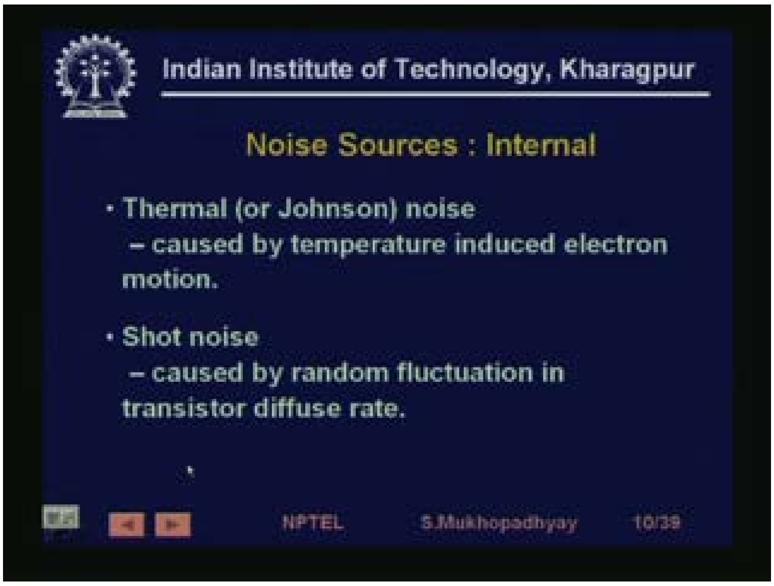

We first try to take at noise, the concept of noise can be you know noise in circuits can be generated in many ways sometimes it is internal sometimes it is external. Internal noise, there are various you know descriptions of noise, but they are actually arise because of various atomic and molecular phenomena.

For example, there is thermal noise, which is basically caused by the temperature induced electron motions. One can do nothing about it at I mean thermodynamically this noise will be there unless you probably check keep things very close to the absolute 0, but that is not possible obviously. So, then there are other kinds of noise for example, in transistors and semiconductor you have you can have short noise. So, we will not focus. So, much on these kinds of noises because. Firstly, they are can of inevitable, and secondly their levels are not that high. In fact, these noises are very important for very low level measurements.

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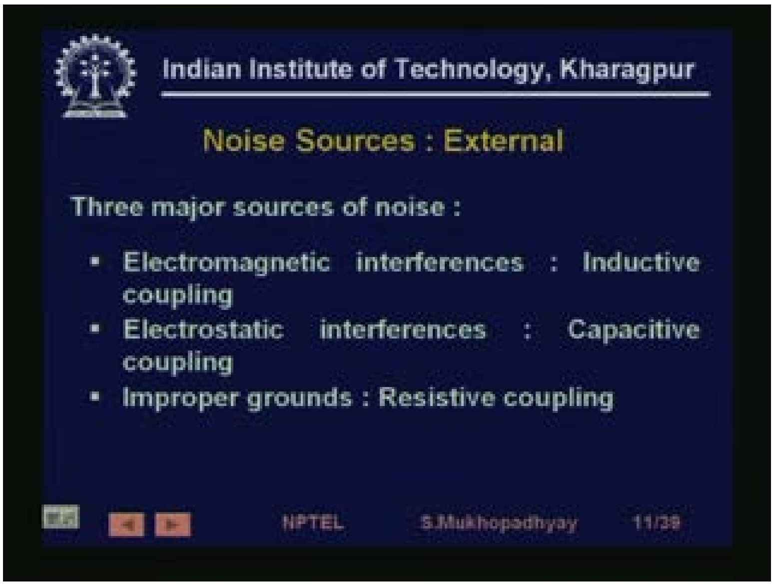

But much more important and much more strong noises can actually come in from various external sources, and they are also relatively easier to prevent. So, the 3 major sources of noise are actually noise that comes in from electronic magnetic interference by inductive coupling from a noise source, and or comes through a electrostatic basically electromagnetic interference are created by inductive coupling created by other devices, which are carrying heavy current, they are the is magnetic.

So, some flux has to be created. So, that purpose current must be flowing. On the other hand electrostatic interference are caused by capacitive coupling. So, they are essentially caused by voltages and electrostatic coupling between from other you know high voltage conductors, and you can also have resistive coupling by 1 of the main reasons is that you can have you know improper grounds connections in circuits, which will cause ground potentials. And since all signals are actually reference to ground potential. So, therefore, these signals will also become noisy. So, you have inductive capacity and resistive coupling and we will take quick look at these.

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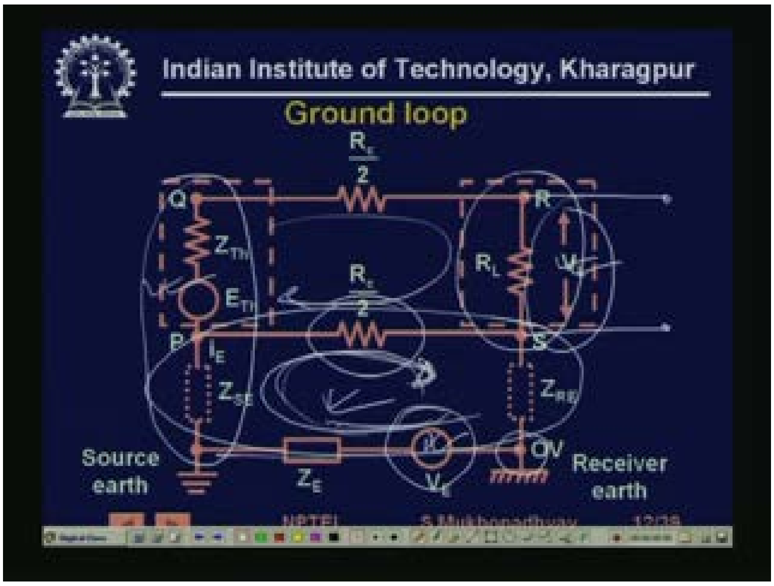

First, we take a look at ground loops. So, this happens when in a circuit you connect you have multiple grounds at multiple points, and not only you have, you have multiple grounds these grounds. So, if when whenever you have multiple grounds these, there are, there can be certain difference in potentials of this these grounds, and not only that these grounds may be connected may be conductively connected. That is the resistance between these grounds may not be very high. So, in which case you have an equivalent circuit, somewhat like this.

So, you have the same circuit this is this part is locally grounded at this point this part the source is locally grounded at this point. On the other hand these 2 potential there exists a certain amount of ground potential and they are connected by impedances. So, what happens is that you have ground loops. So, obviously currents will start flowing across these loops right and not just along this loop.

So, naturally there are going to be voltage drops because of this ground loop current, which is not related to the signal at all which is caused by this voltage source. So, this ground loop currents can cause potentials here, and if you are especially, if you are making single ended measurements, you know typically you will find that sometimes people will assume in a single end ended measurement. We assume whenever you talk of a voltage a voltage is actually between 2 points, but sometimes we assume that one of the voltages is actually some standard common reference voltage of the whole electronic circuit.

You know to reduce, when whenever this assumption is reasonably good. We can just take one of the wires and connect it to the circuit, and assume that the other is the common ground of the circuit such measurements are called single ended measurements. So, you can see that when you, when you make single ended measurements here, because of this ground loops you are going to get errors. So, that is why for more accurate measurements. We must make differential measurements, where we will, we are going to take both of these and then some of these effects will actually go away, but still some of the effect can also be there because there are going to be some current flowing through this part also.

So, but in general differential measurements, where you take 2 points and both wires are generally more accurate. So, in other words this is, this is, this is one of the problems, where you have multiple grounds, which are connected by not. So, high impedance paths and where there is, there is a difference between the ground potentials.

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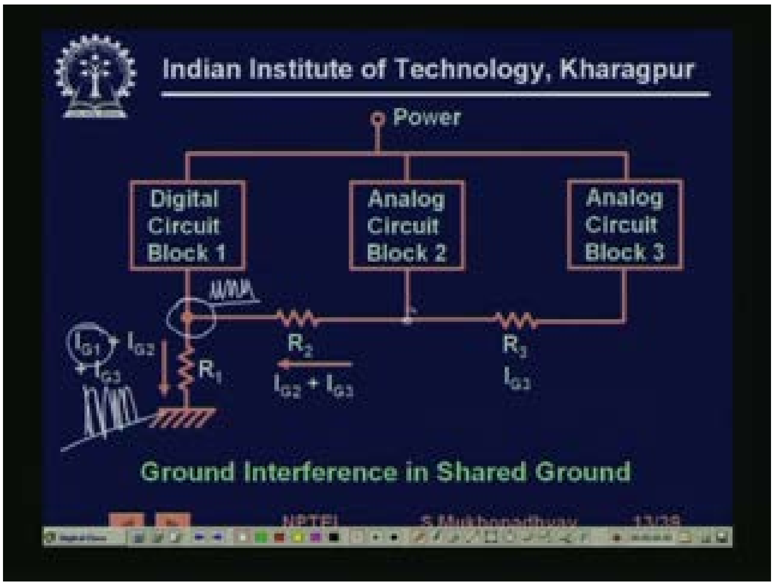

There is, there is another classic case of where you get you tends to get ground problems, and this happens in instrumentation a lot because. So, what happens here look at this? So, you have this is this a very typical scenario in instrumentation that you have some precision analog blocks followed by a digital block. So, this is, this is a common situation where you know on a, on a, on a normally we go for I mean high level of integration.

So, you can have some digital circuit switches, you can have some even some processor driven some small, you know digital circuits may be on the same board, and suppose for ease of you know a P C B layouts. You have connected the grounds these are this is the, this is the ground point of the analog circuit block. This is the ground point of the other analog circuit block, and this is the ground point of the digital block, and they are you know on a, on a, on a, on a, on a, P C B, there are different parts.

So, you tend to think that the ground point of the right most part and you have, you have, you have, you have some point where you have a ground connection. So, you have to bring the ground here and all the way. So, you tend to think that if you are connecting any way you are connecting one point any way you are connecting this point to ground. Then, it is easier to connect the ground of this to the ground, this other than all the way to the different ground.

That will help your will ease your P C B layout, but it will cause tremendous ground problems because of the, because of the fact that the digital circuits blocks are highly switching and when they are switching the power supply currents drawn, which return to the ground are suddenly rise, and they are very spiky and. So, you all the time you have this you know sharply varying power supply currents in these circuits.

Now, since these grounds are common. So, you see that here the current I g, three is flowing through this R 3. The same current I g 2 plus I g 3 is flowing here, and I g 1 I g 2 I g 3 is through R 1. So, if suppose I g 1 is actually a highly spiky current. So, then this potential is going to, going to the I am, I am, I am not able to bring this here. I got, I got it.

So, the potential here, so if you have a very spiky current in this because of this I g 1 then the potential here is also going to oscillate, and obviously, the potential here is going to oscillate, and the potential here is also going to oscillate. So, at all the analog circuit grounds you are going to have an oscillating ground potential. So, which will be if you, if you, if you are making a single ended measurement, then this is going to be, this is going to induce noises here. So, this is a, this is a, this is the basic problem of sharing a sharing a ground actually of more actually and the right way of doing it is the following.

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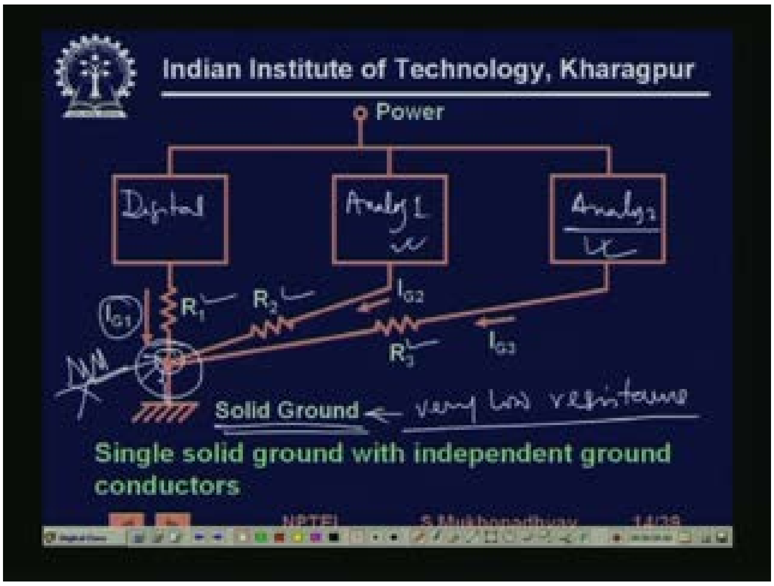

So, here you see this is the digital block, this is analog 1 and this is analog 2. So, the right way of doing it here is to draw separate wires, which do not share and then connect it to the ground using a solid very low resistance connection, only 1 of them and very low resistance connection. So, even if when you have, if you have a ideally if you have a short then even if this current is switching the this current is switching, this potential will not switch will not oscillate. So, therefore, you are going to have stable grounds at these points.

So, the whole basic idea is that first of all these ground resistances must be kept as small as possible, and secondly, they should be connected separately using and then connected to a solid ground. This is one of the reasons why you see all the time that the ground plains are use thick conductor on the PCB layout.

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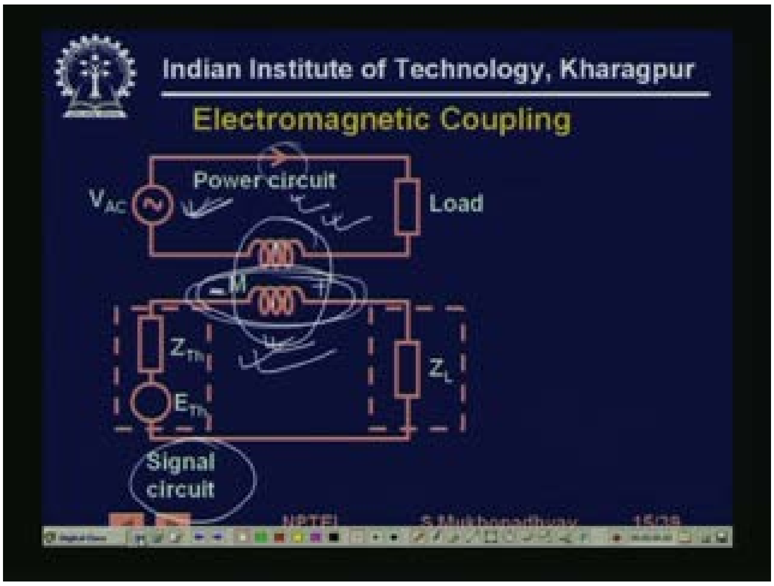

Next we talk about electromagnetic coupling. So, in electromagnetic coupling, what happens is that. So, here is a power circuit, where high current is flowing. So, this is creating flux, the same flux actually linking this loop, which is an, which is a signal circuit where may be we are trying to measure some voltage. So, because there are, there will exist this flux produced by this will be linked by this coil, which means that there will exist a mutual inductance between these 2 coils.

Therefore, some because of, because of M D I D T there will be some series mode voltages induced. So, when you especially, when you draw long wires and you know, you know I mean power supply wires are all the time running, and you are drawing lot of power from these. So, you high frequency high frequency means about 50 hertz high current circuits.

So, they will they can induce quite a lot of voltage into these coils. So, now apart from the. So, now we have there are, the there are various options for example, you can try to you know magnetically healed these circuits, but that that may be quite expensive. So, one of the way that is why one of the ways is to is that we whenever we transmit it is much more. If we transmit in terms of current, if we transmit our signal in terms of current and not in terms of voltage it becomes much more immune, right.

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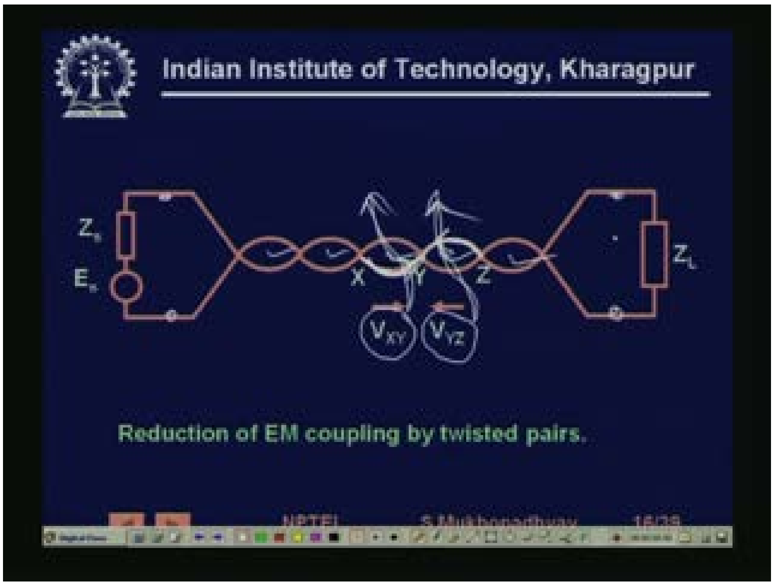

So, we see that. So, first of all if you want to do before we discuss that first of all the first thing that you have to do is that you have to see that very little flux is linked from other place from other sources. So, flux linkage, if you want to reduce you have to reduce the area of the loop, and not only that it turns out. So, you have to keep the coils close and not only that we know that if we, if we twist the coil. So, we have a twisted pair of wires then what happens is that.

For example, you see this is 1 leg x y and this is another leg y z of the same coil. Now, the e m f, which will be, if you, if you have flux you know going up from here going up from here, then you can apply electromagnetic laws, and can, and can, and can deduce that the e m f induced in V x y is suppose going to be positive. So, in this direction and the e m f induced in V y z is going to be in the opposite direction.

So, the effective e m f, which will be induced by these such that you know stray fluxes flowing, which will be linked by this coil between these 2 points will actually be canceled by in this successive loops. So, what happens is that net e m f, which is linked by interfering sources is much reduced. So, first of all your area itself is reduced because they are twisted, and secondly, a very little flux is linked and whatever is linked whatever effect it produces that also gets cancelled because of twisting. So, this is one of the tricks that you one can do.

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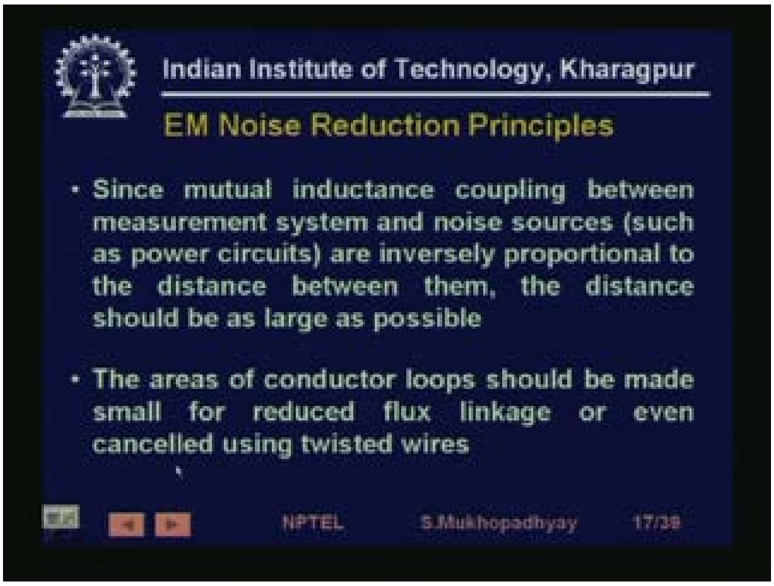

And the other one is that we can use current sources. So, you the other rule is that you must keep as much distance as possible from these sources of interference because the, because the coupling strength is going to reduce with the distance. So, the distance should be as large as possible and conduct areas of conductor loops should be made small and some and they can may be even get canceled.

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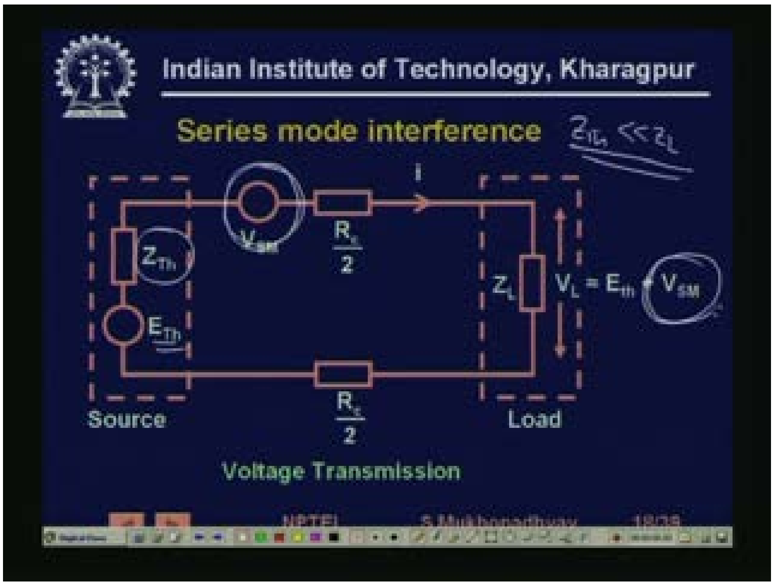

Now, this is a this is an example, which shows how for example, suppose this is a series mode voltage induced by let us say an inductive effect. So, if you have this E th of n is normally what happens is that the source impedance is a much smaller. That is this Z th in is much smaller than Z L.

So, you see that the e m f, which is, so if you have series mode voltage here then the, then the whole series mode voltage will come and appear at the load. So, whatever gets induced here gets transmitted to the output right. On the other hand, if you see a corresponding current source.

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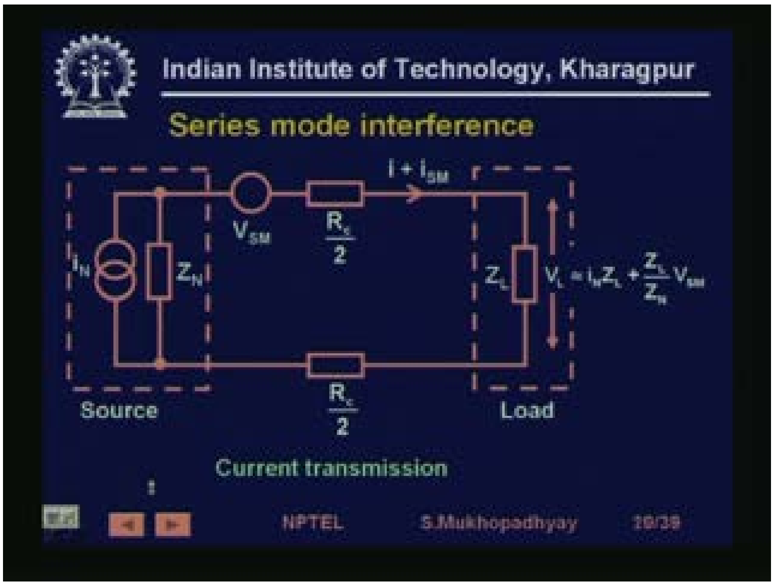

So, here we have a current source and for this current source as you always know Z n is going to be much larger than Z L right. So, it turns out eliminatory circuit analysis will tell you that the e m f, which is induced that is the, that is the output voltage is going to be in Z L, which is, which is supposed to be the in Z L is actually nothing, but e th.

So, that is the, that is the open circuit voltage, which is the ideal voltage, which should come and the effect of the series mode resistance will be multiplied by Z L by Z N. So, now since Z N is much greater than Z L. So, this effect is going to be negative. So, this is 1 of the reasons why this four to twenty milli ampere current standard has been so popular. So, you know it is, it makes a lot of sense to transmit instrument signals in a in the mode of a current.

However, although now a days because of our advent of electronics people are going 1 step ahead and transmitting these signals as voltage mode. But modulated and digital communication techniques has been used for this communication, which are also very robust to noise, which also offers you various other benefits such as a very high band width channel simultaneous transmission of several variables for a conductor etcetera. You will see these things some of these things towards the end of this course in the industrial, when we look at the industrial communication systems. So, this shows that current transmission is much more robust to series mode interference.

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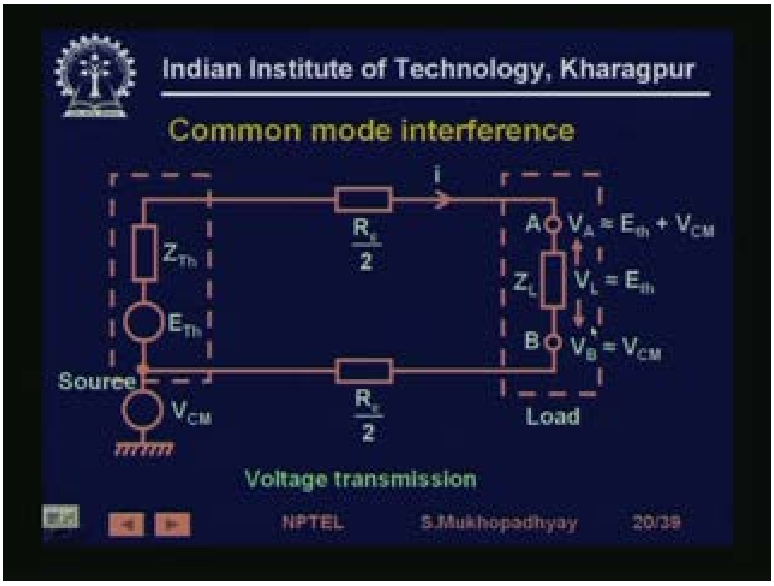

This again shows that one more interference appears as E th plus V C M and V B equal to V C M. So, as I was telling that if you take a take a differential measurement and feed then the, then the voltage across it is still, but if you make a single ended measurements from this point A. Then, the whole of common mode noise source, which is here will actually appear. So, this is the, this shows that why differential measurements are better.

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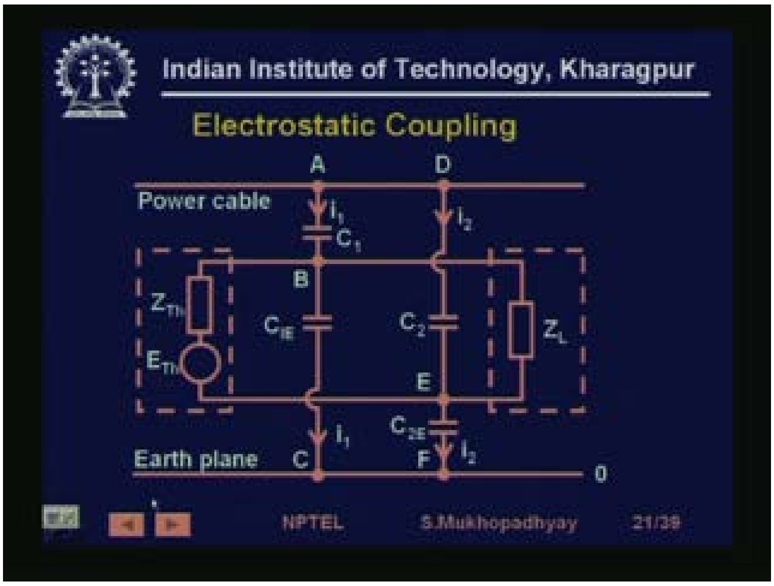

Now, we are coming to electrostatic coupling. So, in electrostatic coupling what happens is that there are always whenever we have conductors there always capacity of coupling between conductors. So, this is power cable which is, which is possible at a very high voltage and this power cable there is, there is a capacitance to the actual signal lines both signal lines there are capacities couplings to the earth.

So, now you can understand that the if especially, if this C 1 and this ratio that is this C 1 to C 1 E and C 2 C 2 E at are different. Then, you are going to have a good amount of voltage induced and especially if this voltage is if it is a, if it is an A C then current will tend to flow through this capacitances, and naturally at the capacitor divider point some voltage will be induced. So, this is the phenomenon of capacities coupling through, which a high voltage conductor can induce noise voltages into your circuit.

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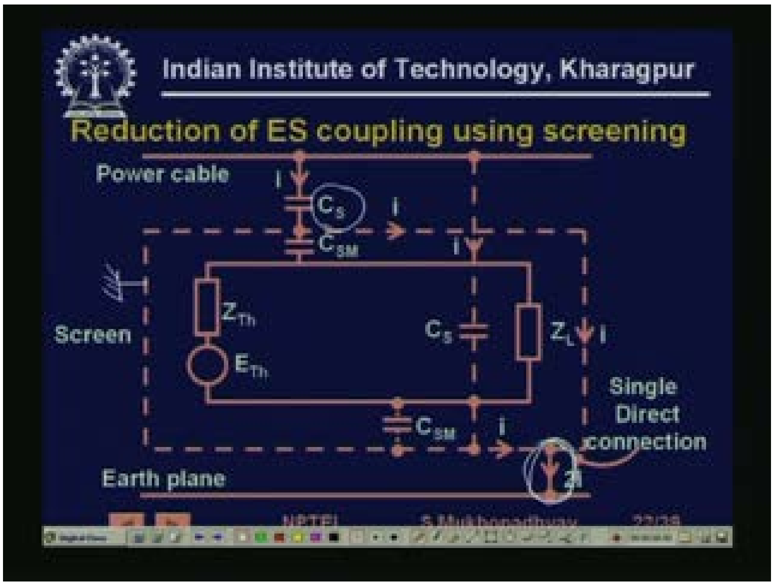

So, one of the ways of you know circumventing that or rather overcoming that is to make a screen. So, if you connect it by a conducting screen and then connect the conducting screen to earth by a solid connection, then what happens is that is that there is, there is now direct. There is now no direct coupling between because this whole screen is actually at ground potential.

So, this is actually connected to ground through this solid connection. So, what happens is that these capacitances are independently connected to ground. So, you have, now you have this disconnected to ground. You have disconnected to ground, you have this capacitance connecting to ground, and you have correspondingly, you also have these connected to ground.

So, these capacitances, so there is, so the voltage is here do not cause any voltage into these signal lines. This is the principle of screening similarly, you can have a similar principle where you have shielding, and sometimes in electronic circuits specially, when there are various you know high impedance very susceptible points. Typically you know the amplifier inputs, where if you have a small signal because of the very high gain of the a large noise component will arrive at the output. So, such sensitive points in the circuit like the o p amp inputs are sometimes connected by what is known as.

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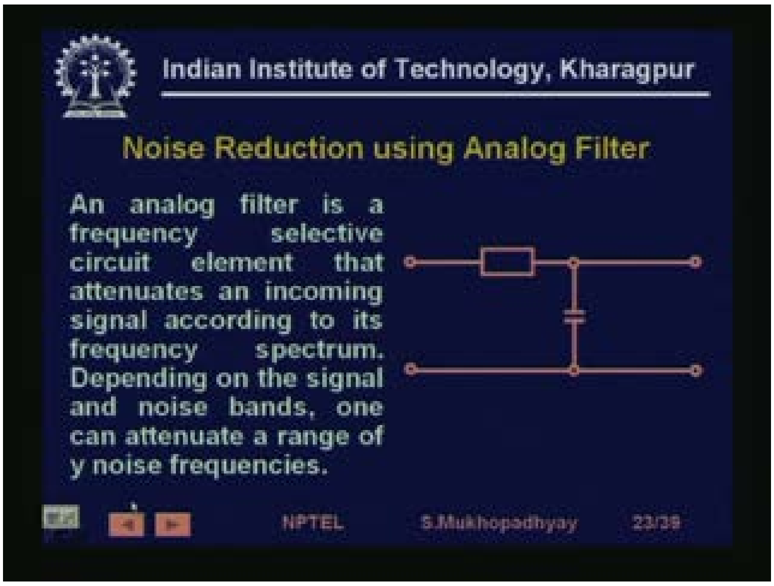

So, these are all to reduce electrostatic coupling with external sources such as power supply voltage or even other sources, and then these are in a way these are preventive mechanisms, which ensure that less noise gets into the system, but after but some noise nevertheless will get into the system, and after they get in the other way of removing noise is by using filters. So, filters as we have seen we have we have studied in the last lesson. So, filters are frequency selective networks and they will. So, if you can design them cleverly, and if you know in which frequency is noise is there and in which frequencies signal is there. Typically and typically if they are well separated then we can separate out the noise using filters quite well.

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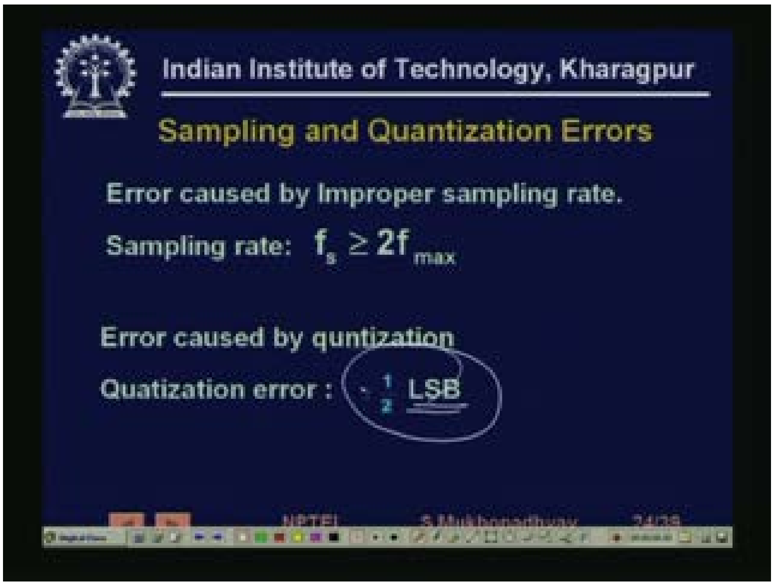

Another very common kind of noise, which arises in instrumentation, is due to sampling and quantization. You see typically finally, in modern instrumentation systems we tend to gets the signals into computers, and then use them in various kind of processing digital control etcetera. So, what happens is that sometimes sample and quantization errors can come in although these errors are gradually becoming more and more, and more small because of the fact that the speed of electronics is increasing many folds. So, you can easily obtain very high number of samples.

Secondly, because of the fact that the numbers of bits, which are used in processing are also becoming quite large. So, the quantization error, which is typically limited to you know to this plus minus half L S B kind of specification sometimes you see that is, that is because of quantization. Now, this the weight of the L S B becomes very small and so. Therefore, these errors become can be sometimes neglected. So, generally speaking these errors are gradually becoming more insignificant.

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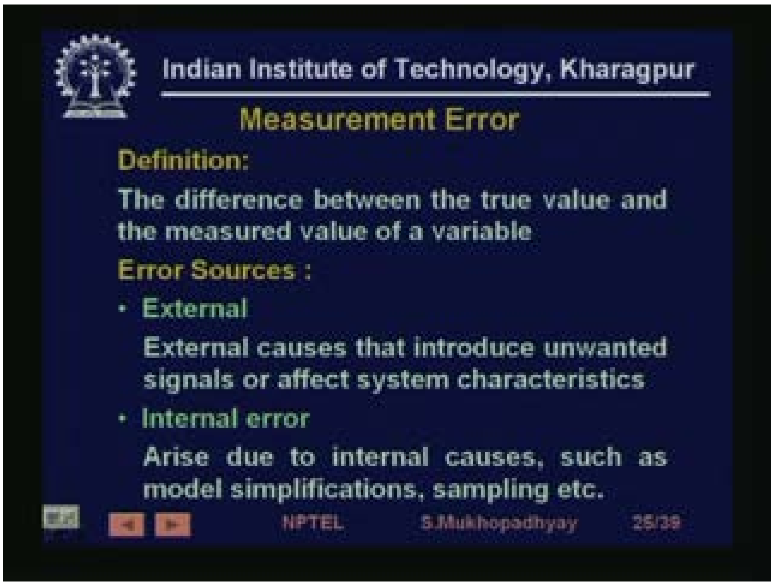

So, now, so this is, so now we have taken a look at noise and now all these now the all these finally, contribute to what is known as measurement error. So, measurement error can be contributed by various things. For example, measurement error can be contributed by noise sources measurement error can be contributed by external environmental changes like you know change in temperature like for example, in a strain gauge.

There are, there are there may be another input that is the, that is the transducer itself may be sensitive to not only the derived input it may be sensitive to other factors, which may change. It may arise due to you know improper measures of methods of measurement.

So, for example, if you measuring temperature using a thermocouple and if you not keeping the making the ambient error correction then you are you are going to get cold junction compensation, then you are going to get an error. So, such measures. So, errors can come from different sources they may be internal or they may be external right. Similarly, they may be external causes that introduce unwanted signals are affect system characteristics. Sometimes you know for example, if you especially if you have a, if you have a whetstone's bridge, if the supply voltage to that bridge changes then the whole gain of the bridge will change. That is if the output volts suppose, we are we are trying to sense resistance change.

So, the sensitivity between output and resistance change is dependent on the supply voltage as we have as we have seen in the earlier lesson. So, if the supply voltage power supply voltage of the bridge changes, then immediately they will be gain change in instrument. So, the system characteristic is changing. So, such things can happen or there may be you know sometimes they may arise due to, due to, due to internal causes like you know internal noise etcetera or sometimes they may arise due to due to model simplifications. That is we assume that something is linear for example, platinum R T D or nickel R T D more, if we, if we assume them to be linear, then because you have simplified the model.

Actually, they are not linear over some over the temperature ranges. So, if because you are, you are, you are using a simplified model. So, there you are getting to measurement errors that is the measured value that you are reading may not be equal to the temperature. So, but we have to be very careful as to we have to a clear understanding about these errors their and their bounds, and their nature because unless we do that we do not know the if we do not know the you know quality of these value, which you are using in control purposes. Then, our as we have said that among other things process I mean our product and process qualities will suffer.

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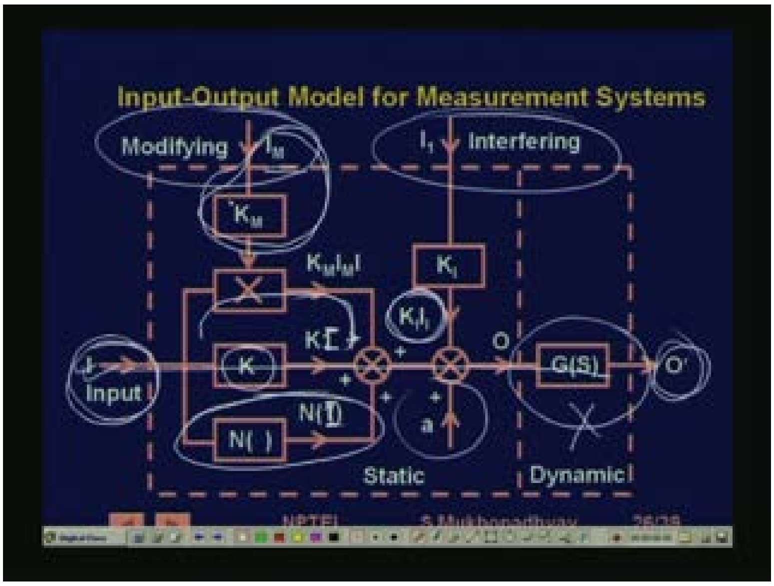

So, it is important to for example, this is a, this is a typical way that you know the input output effects in a measurement system are captured. So, you have in this case there are 2 kinds of three kinds of inputs this is the desirable input. So, you want the vary you want to see the variation of the effect of the variation of this on this output.

There are 2 kinds of other kinds of inputs, which come in for example, this modifying inputs, which change the characteristic of the instrument. So, for example, gain change that will be that will be a modifying input. So, the change in the supply voltage will be of will be a modifying input or let us say, the gauge factor of a strain gauge itself is dependent on temperature. So, that is a modifying input because it changes the relationship between strain and resistance.

Similarly, there are interfering inputs. So, for example, in a in a thermocouple the ambient temperature is going to be a interfering input, which gets added you know even the same temperature can be our interfering input like. For example, in the case of the strain gauge the temperature changes the changes the gauge factor. So, it works as a modifying input. It also causes a resistance change, which is thermally induced by the thermal coefficient of the resistance.

So, that is an additive error in which case the same ambient temperature is actually acting as an interfering input. So, in other words there are several modifying and interfering inputs. And for example, and we capture the output finally, as you know. So, this is the main path.

So, we say that in the, in the ideal case you can, you can, you can forget about this dynamics for the time being if you only consider steady state readings. Then, the output is actually K I, this is not 1, this is I. So, K I plus a. Now, along with that if you have interfering inputs then it is going to be K I plus a plus K 1 I 1. This is the effect of the interfering input along with that if this K itself gets modified by a modifying input. So, if K changes to K plus K M I M were the gain itself is getting changed.

Then, you will have another term, which will be K plus K M I M into I that is the other term. In other words then also there can be this is N I. So, in addition there can be some non-linearity effect. So, for example, if you are going to make a very accurate measurement then sometimes you put in those non-linearity effects and you can say that in this temperature range in that temperature range use such polynomials for temperature to resistance variations people use that.

So, this will probably give you a much more accurate behavior of the instrument and note that these are. So, when we use such a model we are actually trying to model the effects of this modifying, and interfering inputs, and if and thereby we are trying to compute the response in terms of these inputs, but even in even apart from them there are going to be some on modeled effects.

You know, ambient temperature variation may be may be measured if it is measured and if it is, if it is sensitivity is know then it becomes a modeled effect, and we can take it into account while we are interpreting the measurement interpreting the output. On the other hand if it is left as an un modeled effect you not measuring it, you do not know it then you can measure it as a random as a random signal, and you have to express in terms of only bounds. So, you can say that the instrument it will be plus minus 1 percent accurate, if it is used within this ambient temperatures. So, you are interested in quantifying the value.

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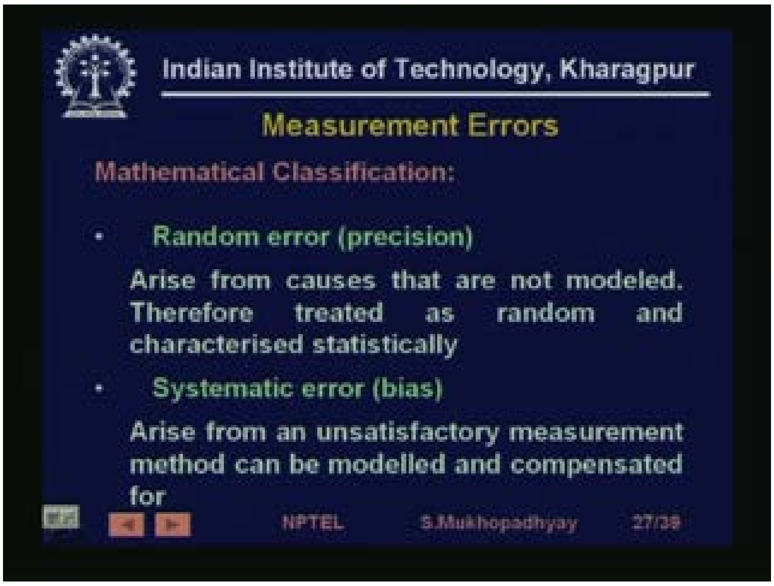

So, such measurements errors are classified accordingly in 2 ways: one is it is called a random error; the random error captures all the effects, which are not modeled. So, you know some signal is getting coupled through by some power line. You actually may not be able to model it because you if it is especially it is a, its portable instrument. You are moving it from here and there you do not know what is, what coupling exists, when you are making a measurement in such a case, it will be of random error. There on the other hand there may be some systematic errors, which are called sometimes called bias. So, which can also effect the measurements.

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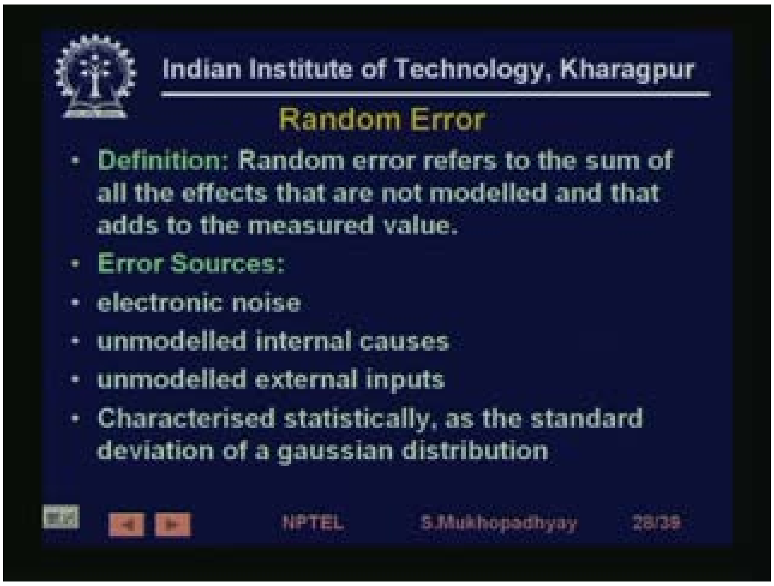

Random errors are typically specified by specifies. So, the errors sources can be, can be electronic or as I said unmodeled internal causes unmodeled external inputs like temperature. If, you do not model it and they are generally characterized statistically. So, you say that the unmodeled error is has this kind of a mean. So, the, so the error has this kind of a mean. Normally the mean of the error you try to characterize as a systematic error, which may be in terms of variations of temperature etcetera, and the random part of it you typically characterize by a 0 mean statistical distribution, which is of 10 assumed to be Gaussian. These are random errors are reflected in the precision or repeatability specifications.

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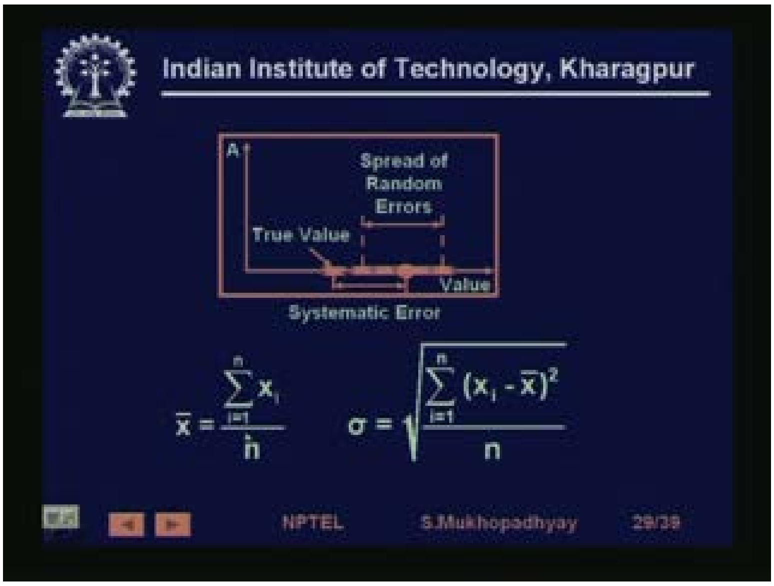

So, you see that this will probably clarify the picture that the true value is here the measurement that you are getting is around this point. So, every time. So, every time you are going to make a measurement most probably you are going to get a measurement between these 2 values. So, the mean of this. So, this is, this part is your systematic error, and this is your variance or spread of the random error, which is which you typically express in terms of a standard deviation value.

So, one has to understand these specifications. So, this is the systematic errors are of 10 classified of 10 even quoted by manufacturers in terms of you know quantities like gain error. So, this is the mean. So, this is the mean and this is the variance standard statistical distributions definitions.

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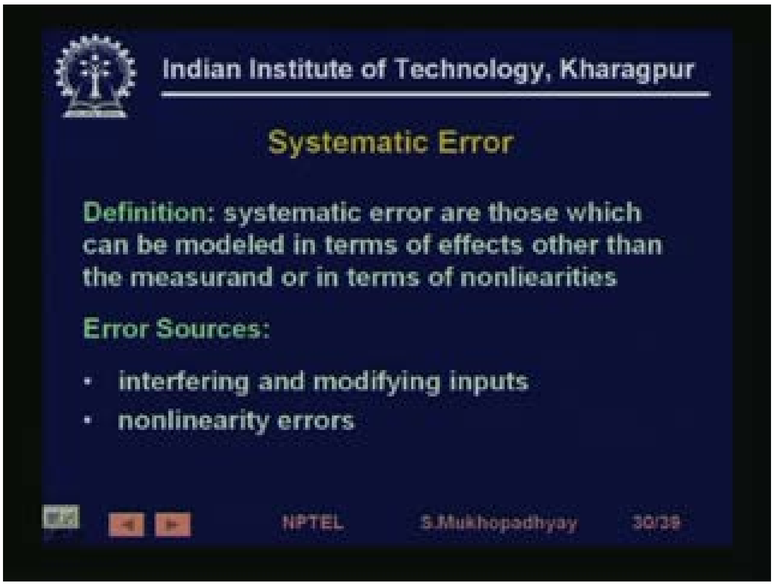

So, systematic errors are those which can be modeled in terms of effects other than the measured. So, effects are other than measured. So, modifying and interfering inputs measured or in terms of non-linearity. Sometimes you know non-linear sometimes you want to simplify your model. We want to, we want to use the instrument simply. So, even if we know that the instrument has is non-linear we sometimes say that it is going to be linear with this much kind of error within this accuracy level that is sometimes as simpler specification to use rather than going through non-linear functions. So, error sources are interfering and modifying inputs or non-linearity errors.

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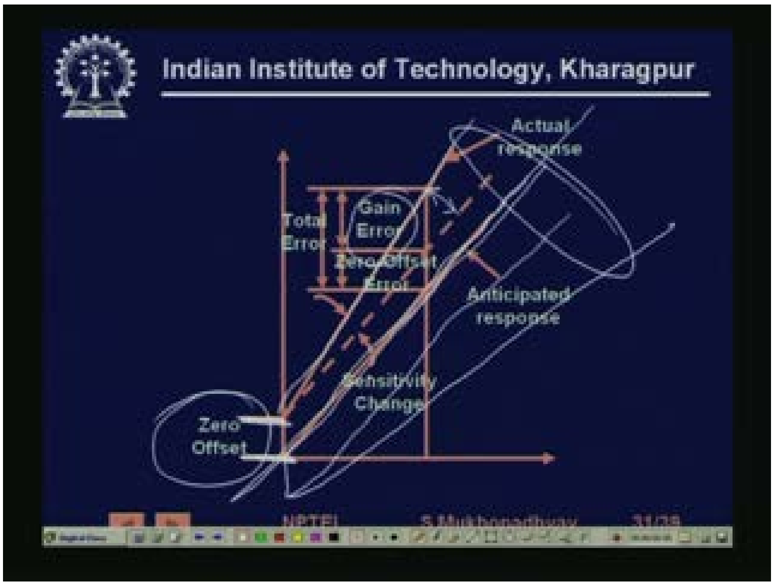

So, in such a case such error such systematic error sometimes you try to characterize as very of 10, you try to characterize in terms of a 0 offset and a gain error. So, you know this is the. So, suppose this is the anticipated response that is the instrument is supposed to be you know have a nicely go through 0 and have a sensitivity, but actually what you observe is this. So, this error you actually classify in terms of a 0 offset and a sensitivity change.

So, you say that it is going to be within. So, much plus minus 0 offset and within so much. So, this signal is going to be within, while you while you are actually assuming that the ideal response is this signal is going to be like this. So, in this way some times the systematic effects are coated in instruments and they are, they are interpreted.

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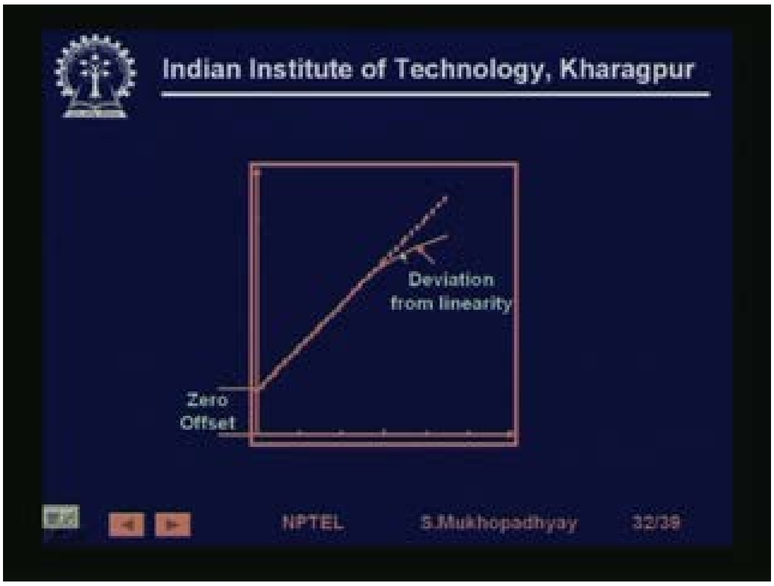

Lastly, this deviation from non-linearity, while it is a systematic effect sometimes we do not we, if we put it as a systematic, if sometimes we do not put it as systematic effect. But rather put it in the error and then try to quantify it that what is the, what is going to be the maximum deviation from non-linearity because we do not want to because we want avoid the complexity of the non-linearity in the regular usage.

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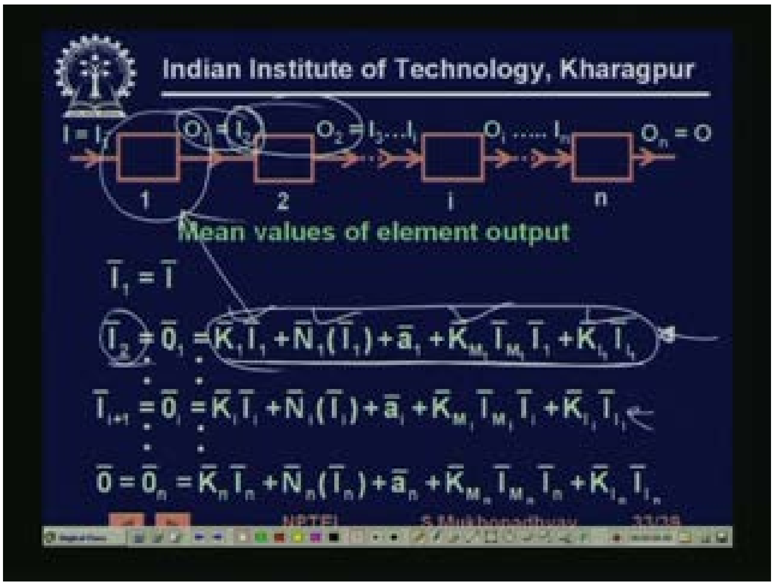

So, now we are what we are going to see is that normally as we have seen that measurement systems are one after the other. There are several blocks each of these blocks can have various kinds of characteristics error characteristics. So, if there are connected in series, then what is the overall error characteristic of the instrument.

So, how to calculate that? So, you see that let us first characterize the mean characteristic. So, you see this is a block, which has an I 1 O 1 characteristic, which may be given by this one. This is the I 1 O 1 characteristic of the first block. Now, O 1 is acting as I 2 of the second block, and there is an I 2 O 2 characteristic of the second block, which is this.

So, in this second block I 2 you are going to put I 2 is equal to O 1. So, O 1 is this. Now, when you will calculate I 3 that will be equal to O 2 and O 2 in O 2, you will have a characteristic of I 2 O 2, where for, where for I 2 you will put this one. So, in this way if you, if you put the mean values of the non-linearity's, and if you ,if you know this if you know these effects. Then, you can calculate, what is the mean value of the element output? So, in this way the mean value can be combined, if we have the characteristic mean characteristic of the various instruments. On the other hand the randomness of the whole.

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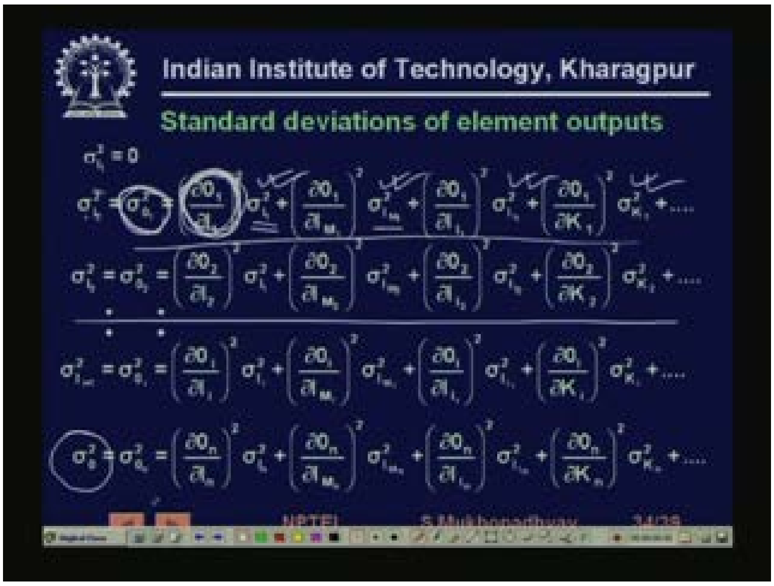

So, on the other hand if you can, you can also combine the standard deviations of the, of the various individual blocks to calculate the overall standard deviation of the, of the output of the whole instrument. So, which is, which is very similar and which assumes at the randomness effect, which actual occur in the various components are actually uncorrelated. That is an assumption, which may or may not be always valid.

So, if we do that then this is a very standard rule of statistics that if you have the gains, you actually multiply the individual standard deviations by their, by their corresponding gains, and then you get the standard deviation of the output. So, you here, you are expecting the standard deviation of the output in terms of the standard deviation of the various inputs, which affect their input output block.

Then, you are using that as the input standard deviation and again putting in the second block in this way you are going on substituting. And finally, you will get the standard deviation of the output. So, this is the way one can find the random specifications of an overall instrument.

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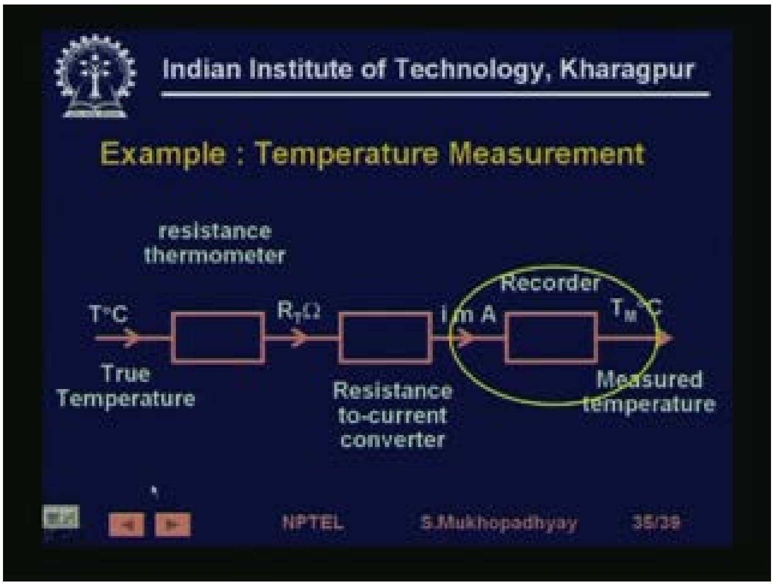

So, he here is the small example. So, you have a temperature measurement system in which we are only looking at the recorder. So, you see the recorder.

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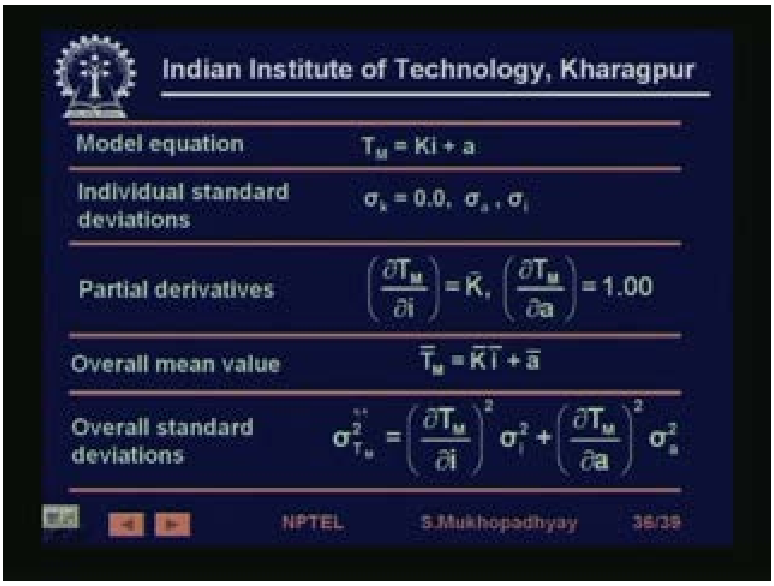

So, you see the recorder is has a model equation like this. So, we say suppose we say that an individual that is the K does not vary, it is very well know, while A and sigma I actually can vary. The partial derivatives are easily calculated, this is the mean value of the gain this is the here it is 1. So, the overall mean value you can easily calculate this is K bar I bar into a bar and the overall standard deviation also you can calculate.

So, you can you can find out that, if the, if the manufacturer gives the specifications for these if you can calculate then you can calculate the overall specification overall random oh the standard deviation of the output.

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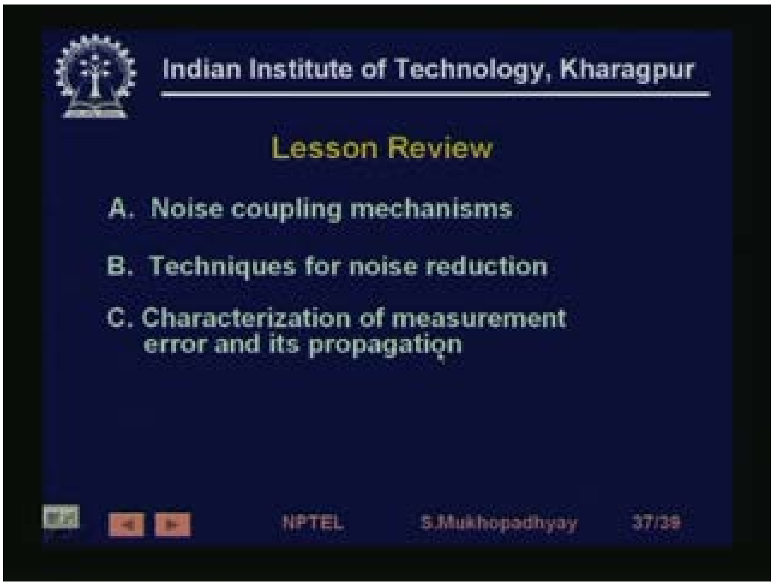

So, we have we have come to the end of the of this lesson. We have studied basically we have studied noise coupling mechanisms, and we have studied the basic some basic thumb rules of noise reduction. Then, we have studied the characterization of measurement error and its propagation.

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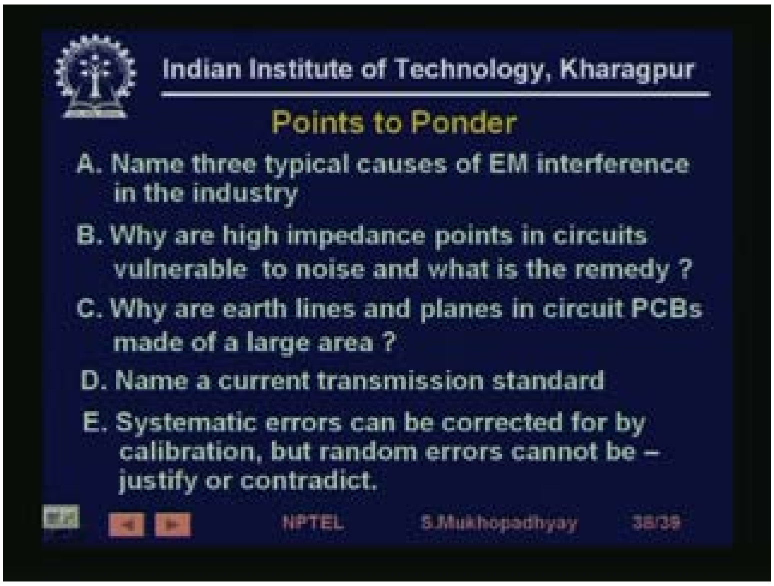

So, in points to ponder we have there are for example, you can try to figure out 3 typical causes of electromagnetic interference in the industry. I can tell you that one of them can be you know brushes of D C motors. There are all sorts of you know D C motors, D C motor drives and industries. So, if the brushes are loose and there is no of sparking. So, these that is one of them, you can think of other causes of such electromagnetic interference in the industry, which can occur. Then, why are high impedance points in circuits vulnerable to noise, and what is the remedy? So, why they are, why they are vulnerable to noise? You can understand if you can find the impedance from the noise source to the ground through the coupling paths.

So, if that point has a high impedance to ground, then you can see that what amount of voltage will be coupled compared to if it is low impedance point. The remedy we have already discussed in the lecture, why are earth lines and planes in circuit P C B is made of large areas. We have we have also discussed, you will, you will, you will typically find this name a current transmission standard, which is very well know all right.

So, you can you can try to also to figure out that why it is a it is called like that, and finally, you can try to ponder over this idea that systematic errors can be corrected for by calibration, but, random errors cannot justify your contradiction. So, we come to end of this lesson. Thank you very much, this is also the end of module on instrumentation from the next module we will start on process control.

Thank you very much.