**Advanced Measurement Techniques in Fluid Mechanics and Heat Transfer**
**Prof. Saptarshi Basu**
**Department of Mechanical Engineering**
**Indian Institute of Science, Bengaluru**
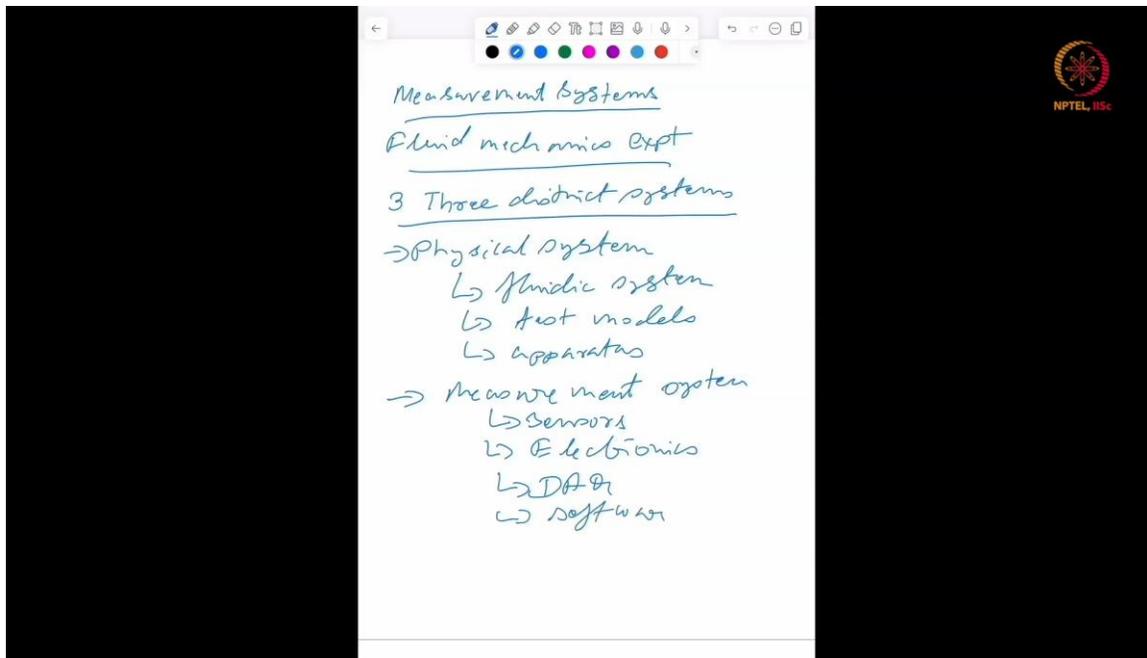**Week – 02**
**Lecture - 05**
**Overview of Measurements in Fluid Mechanics – 1**

In today's lecture, we are going to talk about measurement systems. Just a quick idea of what the different components of a measurement system are, because this is how we approach the measurements that we are going to discuss during the course of this particular course. So the measurement systems are basically, for example, since we are dealing with fluid mechanics, an experiment is performed. Basically, we want to measure the flow. Right? Thus, in any fluid mechanics experiment, one may identify three distinct systems. They are dealing with a fluid mechanics experiment, you know.

So you are dealing with three distinct systems. All right? Okay. So the first one is a physical system. All right, so this consists of the flowing fluids, the apparatus, the test models, and the related objects.

So it includes the fluidic system. You see the test models, for example. And of course, you have any other related apparatus. Then, of course, you have the measurement system. So that's what you are going to do: the measurement system.

Okay, these measurement systems basically consist of your sensors, your electronics, whatever the sensors may be, your data acquisition or DAQ, as we call it, the processing devices and software, software image analysis if you have analysis, etc.

Measurement Systems

Fluid mechanics expt

3 Three district systems

→ Physical System
  ↳ fluidic system
  ↳ test models
  ↳ apparatus
→ Measurement system
  ↳ Sensors
  ↳ Electronics
  ↳ DAQ
  ↳ Software

Okay, so of course then you have the experimenter element, which may be the person or persons whose job is to interpret the data and also execute the measurements. So this is a very, you know, detailed explanation; you can find more details about this in the measurement in fluid dynamics. This is a Cambridge University Press book that is highly recommended. So, let us look at the measurement system in particular.

 So the measurement system has one or more inputs and one or more outputs; okay, it can have one or more inputs and one or more outputs. All right, the output of each component may represent an input to another component. This can also happen. So each input or output corresponds to a physical property. For example, a displacement or voltage.

 The relationship between the values of the input and the output is called the response of that component concerning a particular input.
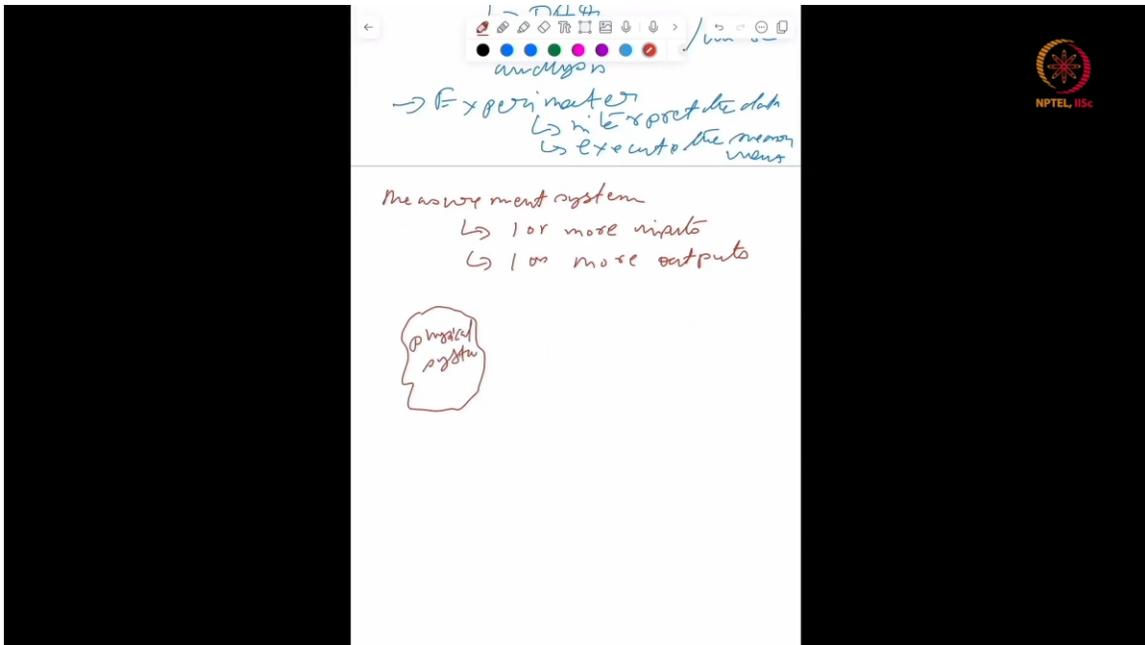
If this is a physical system, then this is a physical system. To look at it like that. So you see, here is our box. So this is basically our measurement system.

So the physical system, what it does, is just, let me finish drawing this. Just giving you some examples. All of these are available in the book. It's a very nice one. So these are your                                                                                                    outputs.

And these are basically your desired inputs. And these are basically the modified inputs. So this is a communication in which one component communicates with the other component. These are basically, you could say, interfering ones, interfering inputs.
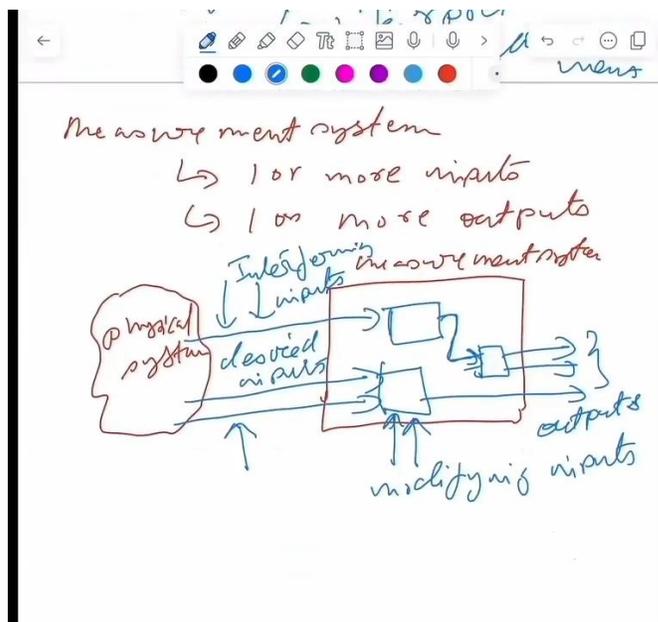
So, for example, if you consider an experiment that uses a velocity transducer, say you are using a hot wire anemometer.

To measure, we will see what a hot wire anemometer is later in the course, to measure, say, velocity. This is what you want to do. So this measures, once again, the local velocity. It is a nozzle from which a jet is coming out. This is the velocity of the jet, and you want to measure it at a particular point.

Let's say this is the point where you are measuring the local velocity. You're basically parked. It's a hot-wire anemometer. It's like a wire that you are parking over there. So the desired input is, basically, the flow velocity.

In this case, the input is your flow velocity, correct? The draft of the air. Now this laboratory can have, you know, a ventilation system. There can be other types of air flows, which are probably coming from all possible directions because of the ventilation system in the lab. So this distorts, these things distort the jet velocity field. Okay, so this is like an interfering input.

If the ventilation or the cross flows is strong enough, it is going to do something to the jet velocity field. Now you can also have a change in room temperature, which can act as a $\Delta T$; the room can affect jet velocity. All right, so that can also affect the jet's velocity. Now, here the undesirable effect is that it modifies the response of the electronic circuit supplying the transducer and causes deviations from the transducer's calibrated response, right? So you see, you have all these things interfering with your local velocity. So you actually have electronics that basically supply the transducer; the response of the transducer and the response of the electronic circuit actually varies because it causes deviations from the transducer's calibrated response.
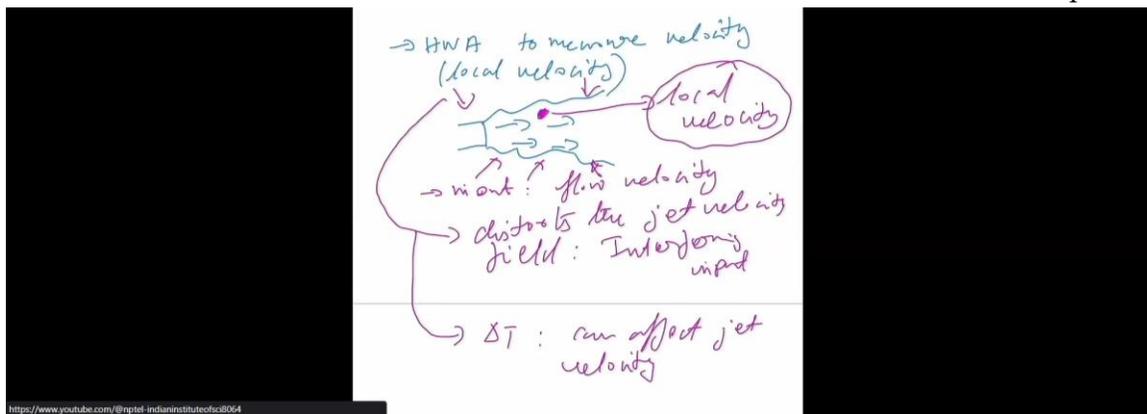
What people do is sometimes use something called filtering and compensation. How do you actually do it? Now, the undesirable inputs cause measurement errors and may produce an output even in the absence of the desired inputs. For example, when there is no velocity,

only the ventilations can actually produce an input. Whereas we want to measure the jet.

 The jet is not there. Even then, there is undesirable input. What the experimenter in this case should do is identify all these undesirable inputs and estimate their effects. So, for example, if this ventilation, say if this velocity is 100 meters per second, and this distortion, let's call it distortion, is of the order of 0.1 meters per second. So naturally this effect, now we     can     consider     it     to     be     insignificant.

 But if this U distortion produces a velocity of, say, 10 meters per second, which is roughly 10% of this, then it is significant. So this needs to be taken into consideration and applied as a correction. So you need to redesign a component that is sensitive to undesirable inputs in a way that it is insensitive to them. For example, using materials with a near zero thermal expansion coefficient may eliminate the temperature sensitivity of a mechanical flow meter or a hot wire anemometer that has been calibrated to measure the flow in terms of the displacement of some component. So you need to identify the components and design your experimental                                                                                                 setup.

 Either you know them a priori so that you can subtract them out, or you need to design your experimental setup in such a way that your components are basically insensitive to these     kinds     of     things,     like     the     example     that     I     just     gave.
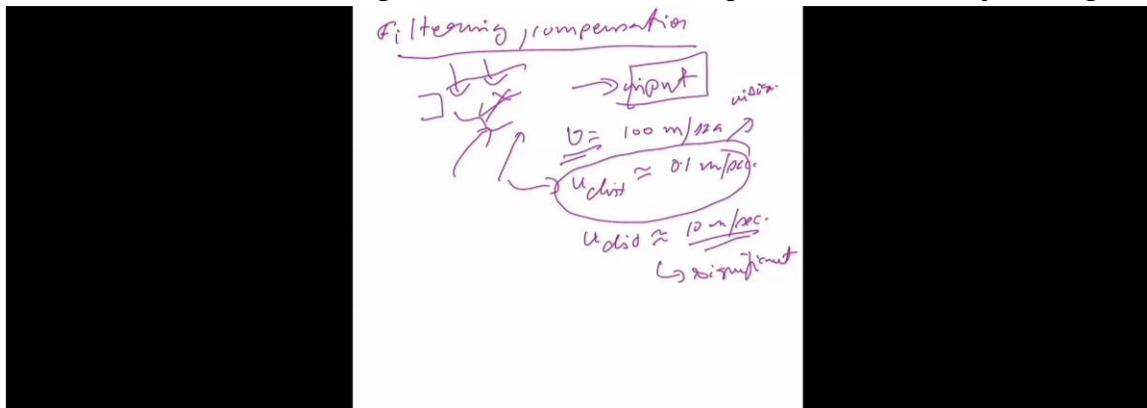


So the inputs and outputs may be constant within a time interval or fluctuating because if you have a flow that, if you remember, has a fluctuating component, then there is a fluctuating component of the flow that means the fluctuating component depends on time. Then what we can do is say u is now a function of time. U is a function of the time set. So what we can do is that you can use this, so this is how the component probably varies.

 You see, this is the velocity profile with respect to time. What you can do here is convert this to the frequency domain by using something called a Fourier transform. Fourier transform, okay? So this converts the time domain, and you get the frequency domain, right? So you get it to the frequency domain now. You can also perform a surplus transform or a wavelet transform. Now, a common way to reduce undesirable inputs is basically the

use of filters, which may be directly applied to an input, an output, or one of the components.

To remove it, you can apply filters; it's very useful to apply filters in the time domain. And what the filters do is remove undesirable inputs.
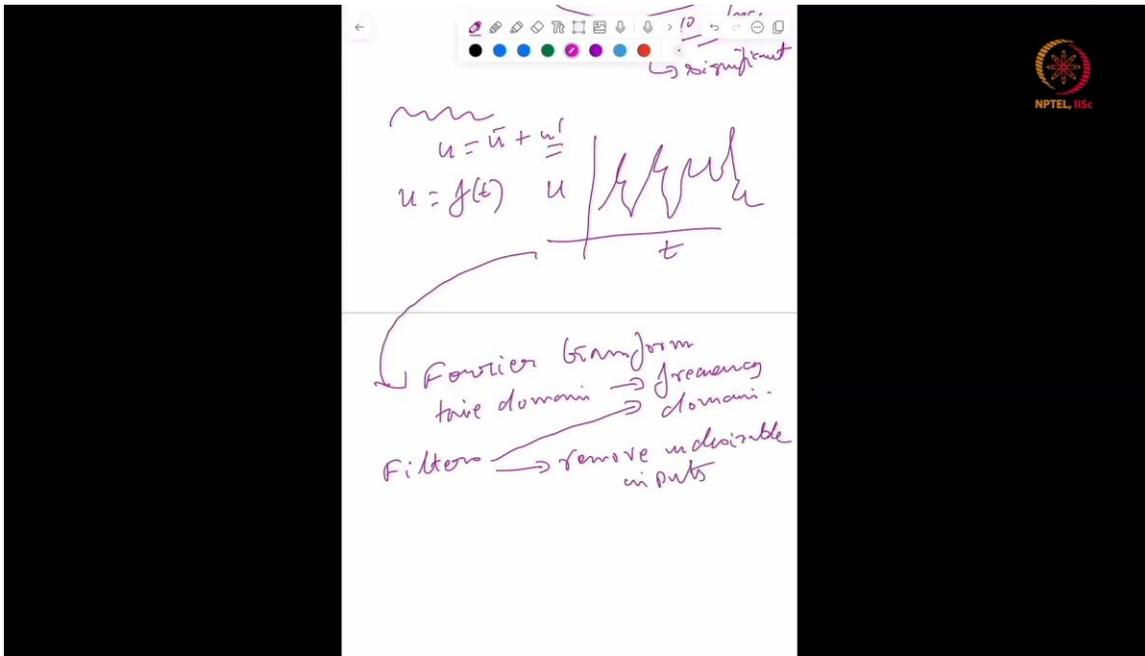


For example, if there is noise, like in the example I gave where there is ventilation creating an undesirable input, you know the frequency signature of that undesirable input.
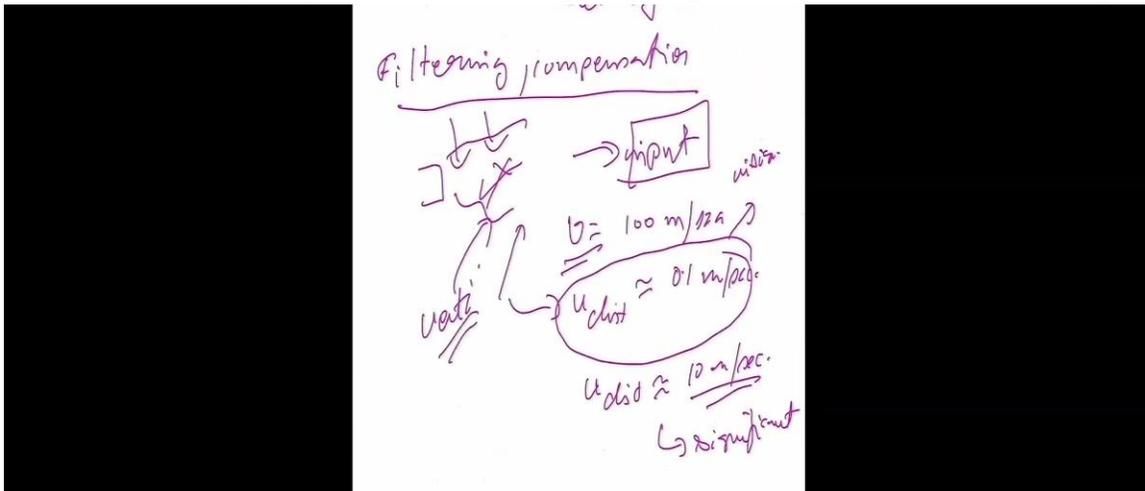


So what you can do next is apply a filter to remove that effect completely. There are filters that are called "no-pass filters.

" So what is a low-pass filter? It removes all fluctuations. So if you think that your flow is steady and it basically removes all transient fluctuations while retaining the steady state. So if you think that your flow is steady, then you can apply a no-pass filter because, in that
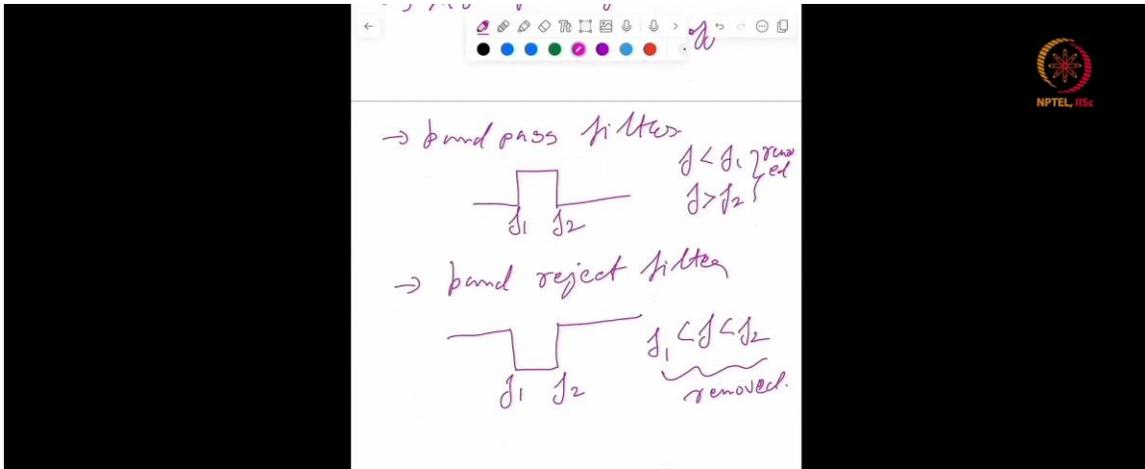
case, all other fluctuations are basically undesirable. Then you can have low-pass filters. And this will be important when you do PIV and things like that.

The low pass filter removes all fluctuations with frequencies above a cutoff value. So, therefore, it removes fluctuations with frequencies greater than some cutoff. Okay, then of course you can go to high-pass filters. The high-pass filters remove fluctuations with frequencies below a certain cutoff. So if your frequency is below a certain cutoff, it will remove those frequencies.
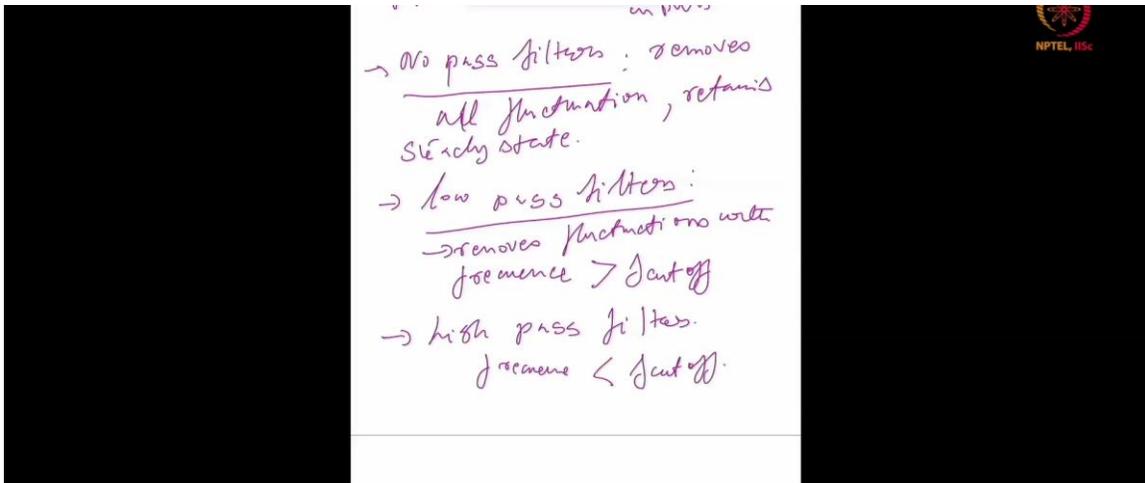


Then, of course, you have the bandpass filters. What does a bandpass filter do? It removes all fluctuations except those with frequencies within a certain band. So, it's something like this: it keeps frequencies, say, within $f_1$ and $f_2$, and anything that is less than $f_1$ and greater than $f_2$ is actually removed. Okay, so frequencies less than f1 and frequencies greater than $f_2$ are removed, so it retains only. Remove so it removes all frequencies except now the other part of this is a band reject filter, which is basically the opposite, so you basically have this.
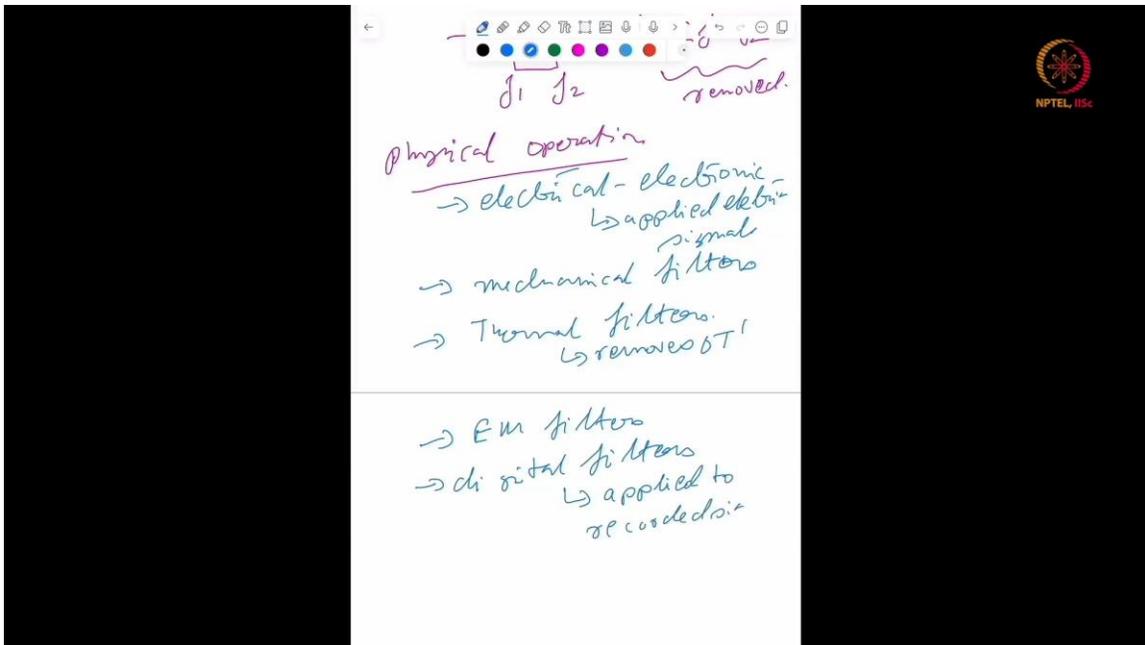
Okay, so this is $f_1$ and $f_2$. If your frequency is less than $f_2$ and less than $f_1$, this is removed. So, these are the different types of filters. What it allows is that if your undesirable input shows up at different frequencies, then you can use a filter to decimate that component.

$\rightarrow$ band pass filter

$f < f_1$ ⎤ removed

$f > f_2$ ⎦

$f_1 \quad f_2$

$\rightarrow$ band reject filter

$f_1 < f < f_2$

removed.

$f_1 \quad f_2$

So in terms of physical operations, now the filters, so if you go into, this is a very important tool. In terms of physical operation, the filters can be of different types.

It can be electrical or electronic. applied to electric signals. Many of the inputs that you will see, if you try to measure the flow—for example, a hot wire—will give you a voltage or a current as your output, as a component that is coming out of it. But most of the signals these days are electronic in nature. Then you can have mechanical filters designed to filter motion or forces. For example, shock absorbers are used to reduce vibrations.

So that is also like a filter. And then you can have thermal filters. Now, the thermal filters are designed to remove thermal fluctuations. It removes thermal fluctuations. and then of course you have electromagnetic filters the electromagnetic filters are designed to remove the interfering effects of electric and magnetic field okay then you can have digital filters which applies to recorded signal and you can have multi-pass filters and this is something that we can we will use a lot actually do your piv it's applied to recorded signal so you have a signal which is recorded then you can apply this digital filters to do this .

$J_1$ $J_2$                     removed.

physical operation
→ electrical – electronic –
          ↳ applied electric
                    signal
→ mechanical filters
→ Thermal filters.
          ↳ removes $\delta T'$

→ EM filters
→ digital filters
          ↳ applied to
     recorded.sig

So another approach to reducing undesirable effects is compensation. By this, we understand the deliberate introduction of additional interference in modifying the inputs, which will partly or entirely cancel the undesirable effects.

For example, if you use compensation, I'll give you an example, which is the case of a strain gauge. The strain gauge works on the principle of the Wheatstone bridge. So, in the case of a strain gauge, the output is sensitive to ambient temperature fluctuations. So what we do is put the strain gauge as one of the arms of a Wheatstone bridge.

So, this is your strain gauge. Because of its sensitivity to ambient temperature fluctuations, you attach it to a leg of a whetstone bridge. String gauge is routinely used in many applications, and connecting an identical string gauge in the other leg, so if this is string gauge one, you apply another string gauge into the other leg of the width switch. So this actually acts as a compensation. So you eliminate this effect by using compensation, by using the strain gauge.

This makes the circuit balanced. From that, you can know what the fluctuation is. So besides this compensation and filtering, analytical corrections could be also used to remove undesirable errors for such systems. This is routinely used.
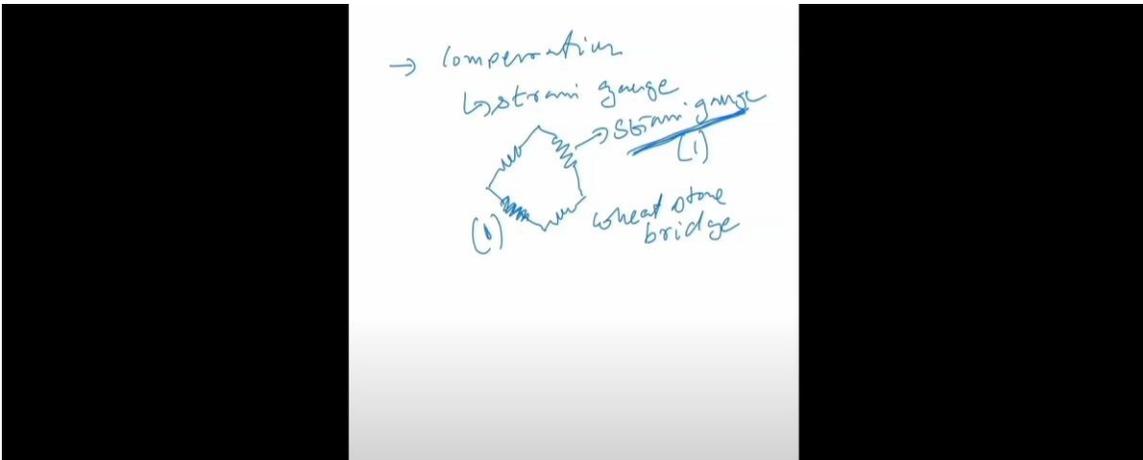
So the modes and functions of measurement systems look at it carefully; each component of a measurement system may operate in an analog mode, or it can operate in a binary mode, or in a hybrid mode. It may be passive or it may be active sensors, each class of the measurement system.

So the main function is like this. If you look at a sensor, the first part of the measurement system, rather, is the sensing. The sensing is a step in which the measured property excites a sensor. Excites the sensor all right, and the output depends on the magnitude of that property, so this gives rise to an output that is proportional or may not be linearly proportional. So let's put the term that depends on the magnitude of the input of this property, basically.
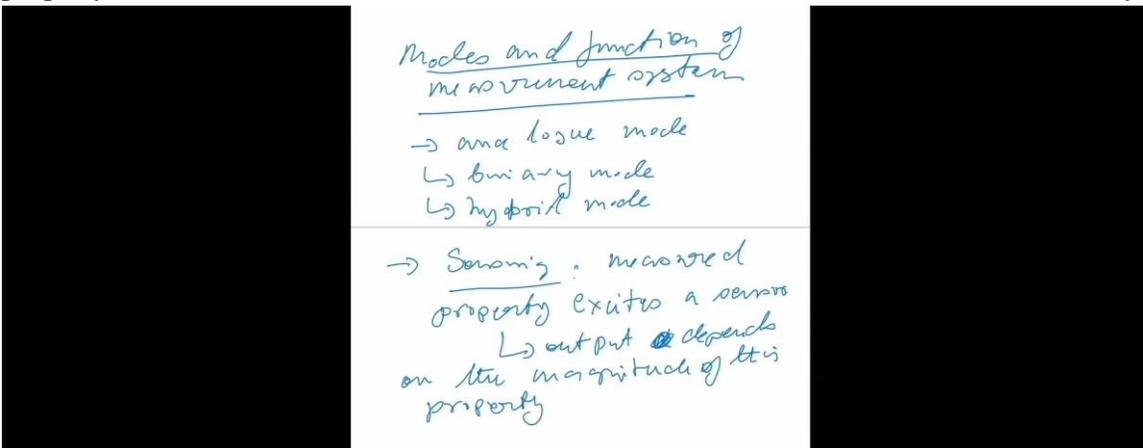


One example is if you put a thermometer in a bucket, and you put a thermometer over here, what happens is that it's an expansion of the liquid, and it goes up to a certain value.

The higher the temperature, the greater the rise. As a result of that, you can calculate. You can do the same thing by using a thermocouple. Okay, so this is a thermocouple; this is a thermometer. Okay, so the thermocouple also responds and generates a voltage.

Okay. So this is what happens: it excites a sensor; the measured property, in this case

temperature, excites a sensor, and the output depends on the magnitude of this property. Whatever the temperature e is, that much is the voltage or that much is the rise in height, depending on what you are actually dealing with. So, the first part is sensing.
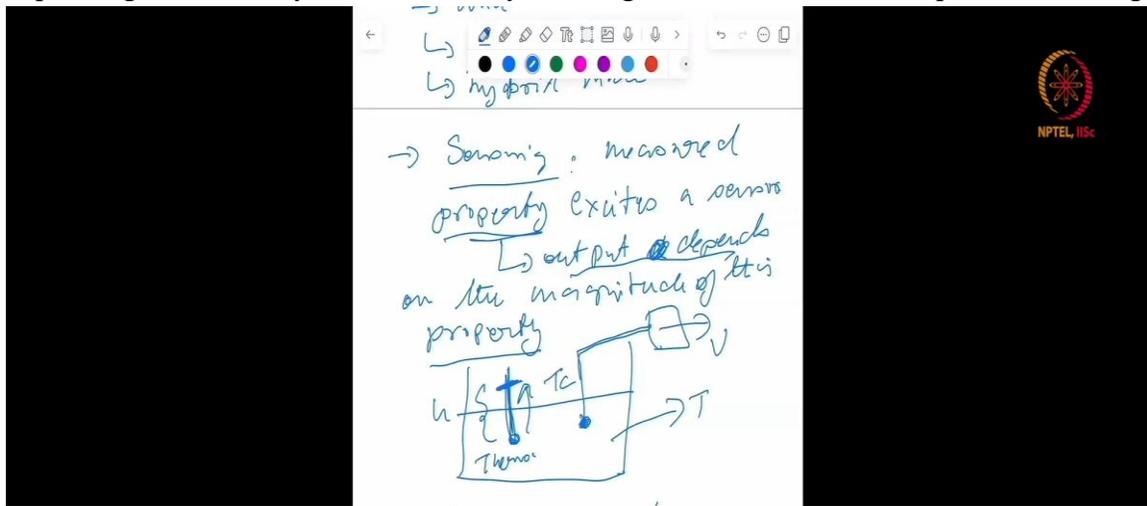


So the second part is what we call conversion and conditioning. Okay, so in this process, what we'll do is transform the sensor's output to a form or amplitude that is more suitable for observations or processing.

So we basically condition the signal that comes out of the components that compose the sensor. And we make it into something that is more suitable for processing. Then you have the transmission. Transmission is for transferring signals from one component to another.

One component connects to another component. So this is the transfer that happens. And then you actually present and storage. So this act in which the output is displayed, stored, and it can be also used for further analysis.