Transducers For Instrumentation
Prof. Ankur Gupta
Centre for Applied Research in Electronics (CARE)
Indian Institute of Technology, Delhi
Lecture - 02
Introduction to Transducers, Sensors, and Actuators.

Hello, welcome to the course Transducers for Instrumentation. Today we are going to discuss some characteristics of sensors. These characteristics are some parameters for which we develop the sensors. So, for example, in a particular sensor we have this much of resolution, this much of linearity, range, what are all the parameters for which a sensor is need to be designed. So, these are some characteristic of a sensor which we are going to discuss. So, in normal environment the data comes in and this data is not a pure data it is full of noise and it keep changing.

So, these sensors what we are going to design these So, these sensors what we are going to design these are required to be appropriately characterized. So, because the data is noisy so, we need to take care of this noise and the sensor need to filter out the data from it. So, the term here is this characterization. So, this characterization is done in terms of certain parameters and characteristics of sensor.

So, there are certain parameters for which this sensor is need to be characterized. And these sensors are like measurement systems they have two types of characteristics one is the static and one is the dynamic. Before discussing these static and dynamic characteristics we have a term in hand which is characterization. So, what is a characterization? So, the device characterization is the process of quantifying the electrical behavior and performance of electronic device. , It may be another device but we are particular about electronic system.

So, we are discussing electronic devices. So, this characterization is the process of quantifying how we can quantify the behavior of a device such as transistors, diodes, sensors etcetera. So, this involves measuring the various electrical parameters such as gain of an amplifier, stability and various other terms this involves measurement of these electrical parameters and these frequency response repeated measurements it allows engineers to understand how the device operates under different operating conditions. Because the sensor is not going to work throughout its life at a particular fixed voltage or fixed parameter only. This parameter is going to be changed and because of that the output of the sensor is going to be changed.

So, we need to characterize this sensor so that we know upfront what is the input parameters and based on that what output is going to be there. This is also done to know any performance limitations or issues with the sensor upfront. So, if we have let us say sensor has a limited range so that can be quantified using characterization process. In characterization process what generally we do we apply a full range of input parameters and check the output of the sensor. So, this gives us the idea of how the sensor is going to perform in real world.

So, this is called characterization. So, what we do we characterize the sensors or transducers characterize the sensors or transducers in terms of certain parameters and these parameters or these characteristics are of two types one is the static one and one is the dynamic one. So, as the name says static characteristics we have the characteristic of sensor which does not evolve or does not change with time. So, these characteristics are like sensor the sensitivity, the sensitivity is something how much is the change in the output per unit change in the input so that is called sensitivity. Resolution for example, the smallest amount of change in the input that can be detected by the sensor so that is called resolution.

Linearity of the sensor for example, how much the sensor output deviates from a standard straight line output. Drift is one another property. So, there is a drift in the output does not evolve or does not change with time. So, these characteristics are like sensor the sensitivity, the sensitivity is something how much is the change in the output per unit change in the input so that is called sensitivity. Resolution for example, the smallest amount of change in the input that can be detected by the sensor so that is called resolution.

Linearity of the sensor for example, how much the sensor output deviates from a standard straight line output. Drift is one another property. So, there is a drift in the output of a sensor with the input it kind of drifts from a from its regular output by a certain amount so that is called drifting. And there are special cases in that there are some zero drift full scale drift there are other types of drift. Range we characterize the sensor for for range as well range is the upper limit minus the lower limit of the output or the input Repeatability this is also something does not change with time.

So, if we apply a repeated input at the sensor how much the output deviates from its previous input. So, we apply let us say a similar input 10 times all 10 times the output will not be same there will be a certain difference at the output for all the 10 inputs this is called the repeatability issue. So, the sensors has this repeatability issues. Reproducibility is another characteristic which is static characteristic repeatability over long time lapses between the measurements. So, these are some static characteristics which we are going to discuss in detail.

The other sensor characteristics are dynamic in nature dynamic means the output of the sensor actually drifts or it changes with time. So, these are called dynamic characteristics. So, these are first is rise time. So, for example, we have a sensor when we apply a step input for example, to this and the output changes like this graph it shoots up and then it goes down and it settles down to certain final value. So, there is a rise time involved rise time is how much time the output of a sensor takes in reaching from 10 percent of the final value to the 90 percent of the final value.

So, for example, we have 1 which is kind of normalized output. So, 0.1 to 0.9. So, this much and this much. So, this time difference what this sensor takes from reaching from 0.1 to 0.9 this is called the rise time of a sensor. Delay time is how much time the output takes from reaching from 0 to 50 percent of its final value or the steady state value. So, steady state value as we have seen this is 1.

So, how much time the output takes from 0 to 50 percent and here it is shown as TD this is the delay time or the time delay of the sensor. The peak time peak time is how much time the output takes starting from 0 to 50 percent starting from 0 and to reach the peak value of its output. So, peak value is this value which is MP here and how much time the sensor takes is 0 to TP. So, TP is the peak time this is the time it takes in reaching from 0 to the peak value. The settling time, settling time is the time taken by the output to reach its steady state value though this is the dynamic characteristic and it takes very long time in settling to exactly value of 1.

So, we define a criteria that when the output reaches 1 percent or 5 percent that depends on the application. So, when the time time taken by the sensor to settle down to within 1 percent of the steady state value. So, this steady state value is 1 percent and when the output reaches to 1 percent of this value then we say this is the settling time and typically we can see is plotted here T S which is typically 1 percent of the steady state value. The percentage overshoot is something how much the output overshoots above the steady state value. The steady state value is 1 and how much in percentage this output overshoots above this value of 1.

So, this is again MP the peak the this this is TP which is peak time and in peak time the output approaches the percentage overshoot. So, this is the percentage overshoot how much the output overshoots above the steady state value. Steady state error is deviation of the actual SSV from the desired value. So, how much the steady state value is different or is deviated from the desired value these are the some dynamic characteristics. So, let us discuss these static characteristics first in detail.

So, these are some of the static characteristics which does not change with time and these are depends these depends mostly on the sensor the quality of sensor the material of the sensor and these characteristics are these characteristics are inherent to the sensor. The first one is accuracy. So, the accuracy is specified by actually inaccuracy or usually error in the measurement and the formula for error is given like this epsilon A which is the error in percentage is equal to x m minus x t divided by x t into 100, where x m is the measured value of the sensor value and x t is the true value of the measurement. So, the error actually is how much is the difference between a actual value of a parameter and the measured value of a parameter. For example, we have a stick which is 1 meter in length this is the actual value of the true value of this object which is 1 meter, but when we measure it using a tape we measure out to be like this is 101 centimeter or 1.01 meter. The actual value of the object is x t which is 1 meter only, but x m the measured value is 1.01 and because of this measurement we have a error in measurement which is given by x m minus x t which is 1.01 minus 1. So, this is the error which we have in measurement and we multiply it by 100 so that it comes in percentage. So, this error is actually the difference between actual measurement and the measured value and which is normalized to the true value of the measurement.

So, this is called epsilon a sometime this error is often expressed for a full scale output as well. What we mean by this full scale output is we have a sensor or a meter this has a particular range let us say from 0 to 100. So, this sensor is going to measure only from 0 to 100 which is the full scale or the sensor. So, we define this error as a full scale output means how much is the error in percentage for a complete full scale reading. So, we define this by epsilon f s o is equal to x m minus x t which is the measured value and the true value, but this is now divided by the full scale x f s o which is the full scale output of the sensor and we multiply again with 100 so that it is in percentage.

So, this error is often expressed in terms of the full scale output. So, we have two ways of expressing this error which is one the accuracy as a percentage of full scale percentage f s or percentage of reading which is the first case where we normalize it with the true value of measurement. There are difference between these two expressions of error. Let us take it using an example if we have an instrument where the accuracy specified as percentage f s or the full scale if we specify the error as a full scale output then the error will have a fixed value no matter where the flow is in the flow range. So, here we are talking about a flow meter which is going to measure the flow of liquid let us say water.

So, this is the diagram of a flow meter that where the liquid goes in goes out and this has a particular range from let us say 0 to 100 or something. If we show the error we as a percentage of full scale then the error will have a fixed value. We calculate this value at a full scale and this error remains fixed no matter how much liquid is flowing into this flow meter. So, for an example this instrument calibrated for a flow of 100 litre per minute with a stated accuracy of 1 percent of full scale. It means when a flow of 100 litre is there through this sensor the error will be 1 percent of 100 litre which is 1 litre per minute.

So, this error is now fixed because we are expressing this in terms of full scale. No matter now how much liquid is flowing into this sensor the error is plus minus 1 litre per minute this is the error which is produced by this flow meter. Now, if instead of 100 litre per minute now my flow is only 50 litre per minute, but the error remains same 1 litre per minute. How much is the error in percentage now? 1 litre in 50 litre per minute which is 2 percent this is now higher than 1 percent what we have shown for a full scale reading. Going further if the flow reduce further to 10 litre per minute this error remains same 1 litre per minute then the error is 10 percent which is quite huge error.

So, if we express the error in terms of full scale reading then the magnitude of error remains same and if the input reduces or the output reduces then this error becomes significant compared to the full scale output. However, if we express this error in terms of percentage of reading then the error will this always remains percentage of what actually the flow is. So, for example, if we have if we express this error in terms of percentage R d then 100 litre per minute has a percentage of 1 percent it means 1 litre, but when the flow reduces to 10 litre the error is only 1 percent of 10 litre. So, this is the error which is given by the error which is quite less error compared to what we have shown in full scalar case. So, these are the two ways of expressing the error as in terms of full scale output or in terms of the actual magnitude. The next static characteristics is precision. So, the precision is how far the measured quantity is reproducible as also how close it to its true value. So, the next quantity is precision. So, the precision is up to how far the measured quantity is reproducible. So, we have output which is y as a percentage of full scale and the input is x which is in percentage.

Now, we sweep the input from 0 to x m which is the complete value. If we do this same measurement multiple times there is going to be the difference in the output. So, in one case when we sweep from 0 to x m the output traverse this curve let us say this is 1. If second time we apply the same input from 0 to x m the output is this second graph. So, there is a certain difference between these two output and this is called the repeatability.

It means that out the sensor is not perfectly repeatable and there is a there exist a certain change or the certain difference in the output for the same input. So, this term repeatability is close to precision which is the difference in output at a given value of input when obtained in two consecutive measurements. Next, we come to the difference between accuracy and precision. How what is the difference between an accuracy and a precision? Accuracy is the agreement between the measured value and the true value. It shows that what we measured how much it is close to the true value of the object true value of the parameter.

However, the precision is if we repeat the experiment multiple times how closely the output is confined all the output should be in a very close range that is called precision. In a graph if we plot we on the y axis we have this probability density function and on the x axis we have this value which is where we have this true value of output this is the true value or the reference value. But, when we apply multiple measurements and most of the time we end up at this value which is let us say our mean value of measurement and the difference between this actual value or the reference value and this measured value this is our accuracy. However, we are doing this measurement multiple times and let us say all these 100 for example, 100 measurements all these measurements are lying here follows a

Gaussian curve and the peak exists in between here. How confined these output are in a particular range this is specified by the precision.

So, this is the accuracy how much is the difference between actual and measured and how much output is confined to a narrow range that is called the precision. So, accuracy indicates proximity to the true value however, the precision to the repeatability or reproducibility of the measurement. This is the difference between the accuracy and precision. Accuracy is the degree to which the measured value is close to the correct value, measured value is close to the correct value. However, the precision is it describes how close the measured values are to each other in the data set it need not to be the accurate one or it need not to be close to the true value.

Usually accuracy involves single factor measurement you just apply one input and you can measure the accuracy of sensor. However, for to measure the precision you have to repeat the experiment multiple times and get multiple numbers of output and see how close they are confined. For a measurement to be accurate it should be precise. However, the measurement can be precise without being accurate means the accurate measurement is the measurement when it is precise and accurate. However, it measurement can be precise to certain other value which is different than the true value so, means it may not be accurate.

Let us take an example of some bullets we fire let us say we fire 5 bullets from a gun and one knows the exact number of bullets fired, but multiple attempts are made to obtain the precise result. The bullets hitting the bird's eye are precise and those hitting close to the bird's eye are accurate. So, this is the goal so, let us say we have this as a goal we want to hit on this which is the true value of measurement. We are hitting the bullets and bullets are not hitting true value but they are hitting somewhere here, here which is different than true value it means this is not accurate. However, if we see all these marks they are not even confined to very close to each other it means this is not even precise.

However, this case all these hit marks they are very much in a very close range though they are not at the true value it means this is precise, precise means the output is very much confined, but not accurate which is not equal to the true value of measurement. In this case if we see the third case when we have some hit marks are there on the true value it means the measurement is accurate, but it is not precise again because we see there is a distribution of these hitting marks. This case, case number 4 where we have all these marks are right at the true value which means the measurement is accurate and all the output or all the marks are very much confined to each other it means this is precise as well. So, this is precise and accurate. So, this is the desired property of a sensor or a transducer, it need to be accurate and it need to be precise.

So, this is a example of a case where the system is precise, but it is not accurate. Let us talk about a refrigerator which has a thermometer inside. So, this is it measures the temperature and displays out the reading and we have taken 10 readings which is 39.1, 39.4, 39.5 and so on 39.1 all these values we have taken from this sensor. However, the actual temperature inside the refrigerator is 37. So, we can see all the output readings these are all the output of a sensor these are all confined to 39.1, 39.4 they are very much close to each other it means this is precise the sensor which is used in the refrigerator is precise, but it is not very accurate because the difference between the actual and the measured value is 2 degree which is 39 let us say 39.0 minus 37. So, it around 2 degree centigrade is the error which is produced by the measurement of sensor. So, this case is we have precise sensor, but which is not accurate sensor. This is another example of accuracy and precision. So, there are let us say 2 sets of data from measurement on 2 different transducers let us say set A and set B. Set A measurement is 32.56, 32.55 and so on set B is 15.38, 15.37 and we need to find out which one is more precise. So, we subtract the lowest data point from the highest one. So, for set A we have 32.56 minus 32.48 which is 0.08 and for set B we have 15.38 minus 15.32 which is 0.6. So, this difference it shows the range of output from the highest one.

So, this is the maximum minus minimum. So, this shows the complete range of output how much the data has taken up The higher the range of output more less precise the sensor is. It means the sample B or the set B has the lowest range and so is the more precise. So, this transducer 2 or transducer B is more precise compared to A. next static characteristic is resolution. So, the resolution is defined as the smallest increment change in the output which can produce a detectable output of the sensor.

This is often expressed as percentage of measured range. So, the formula of resolution is R max as a percentage equal to 100 into delta x m divided by m R. How do we calculate is m R or the measured range is equal to x max minus x min which is the maximum value of x minus the minimum value of x and for a detectable output delta y if the minimum change required is delta x then R max is 100 into delta x m divided by m R. Let us take an example for this resolution measurement. We have a measurement system which can take measurement across a plus minus 10 volt range. It means that the range is plus minus 10 volt. This is 0, this is 10 volt and this is minus 10 volt. So, this is 0 and this measurement is being done using a 16 bit A to D converter, 16 bit analog to digital converter. So, the number of levels we will have in this A to D converter will be 2 to the power 16. These will be the number of levels produced by A to D converter. So, 2 to the power 6 equal to 65536. These will be the number of levels produced by A to D converter and how much this will correspond to in the voltage minus 10 to plus 10 means 20 volt. This full range is 20 volt minus 10 to 10. So, the resolution is given by the resolution of the system will be this 20 volt divided by 2 to the power 16 which comes out to be around 305 micro volt. So, the resolution of this complete system using this 16 bit A to D converter will be 305 micro volt. This much will be the output generated by this A to D converter. Next characteristic is the threshold. So, the threshold is at the 0 value condition of the measurement the input quantity is at it is 0 level. How much is how much the smallest input change that produces a detectable output is called the threshold. For example, we have a MOSFET transistor the input is 0 the gate voltage let us say is 0 how much gate voltage we need to apply so that the MOSFET turns on. So, that is called the threshold voltage of a MOSFET. Another parameter is sensitivity which is very important for sensors. The sensitivity is the ratio of incremental output to incremental input. So, we can write S equal to delta y which is the output divided by delta x which is the input. So, this is output divided by input.

Usually we express it in normalized form. So, we can write delta y upon delta x divided by y by x how much is the actual the the base value of output and input we normalize the sensitivity using their base values. In other words the sensitivity is for a unit change in the input how much output is being produced by the sensor. So, the sensitivity is the term which we want to have more and more for a unit input if the sensor can produce more output that will be good or the sensitivity will be very high. If sensitivity or the out level changes with time temperature and or other parameters without any change in the input level that is called drift in the system. Sometime the output of a sensor changes with other parameters as well for example, temperature and that is called a drift and which leads to most of the time which leads to the instability in the system. The example is let us consider a pressure sensor that has a measurement range of 0 to 100 psi and an output range of 0 to 5 volt. Its sensitivity is 0.05 volt per psi. The sensitivity of an instrument says nothing about the quality of an instrument.

This is typically established by the instrument's accuracy and precision. Next parameter is selectivity. The output of a sensor let us say we have a sensor which we design for a particular parameter. This sensor is not only sensitive to only that parameter, but it is sensitive to multiple other parameters for example, temperature. If the temperature changes the output of the sensor also going to be changed. So, the output of a sensor may change when afflicted by environmental parameters or even some other variables and this may appear as an unwanted signal. So, the sensor is then said to be non-selective. When the sensor starts sensing other parameters as well then the sensor is called a non-selective sensor and we can write this partial sensitivity to other parameters as Sjk where k is some other input and j is some other output and Sjk equal to delta yk divided by delta xj means change in input x produces a change in the output y where the output y may not be a desired output from delta x. And a selectivity matrix would be obtained Sjk and the jth entry and obviously, an ideally selective system will have only diagonal entries. So, this we will see in the next example. So, for example, we have a gas sensor and we make this gas sensor to detect oxygen, carbon dioxide, CO, NH3, VO and other VOCs. So, the input quantities are these 5 and based on based on that the output will be generated.

So, for example, if we flow the oxygen and the sensor oxygen output according to oxygen will be produced if we flow CO in the system the CO output corresponding to CO will be produced. However, the sensors they have partial sensitivity to others as well. For example, we have we flow oxygen in the system there will be a output generated by O2 according to O2, but there will be partial sensitivity to CO as well which should not be there. Similarly, if we let us say we flow NH3 in the system. So, NH3 should be detected, but along with this VOC is also be going to be detected. So, this is undesired which is because of the non-selectivity of the sensor. If a sensor is very selective then we will have only the diagonal element means oxygen will produce output according to oxygen here CO2 will produce output according to CO2 only CO will produce output to CO only and NH3 to NH3 and VOC to VOC to we we will have only these diagonal elements in the selectivity matrix for a selective sensor. Next parameter is non-linearity when the output of a system deviates from a perfectly linear output then it is called a non-linear system and this non-linearity can be specified in two different ways. First is let us say we have in this graph we have this output produced. So, we can fit a straight line in this output and the difference between this fitted line and the actual data this is the error produced by measurement.

So, this is one expression of non-linearity where we fit the data fit a line in the data and express the error. Second is we just join the first point and the last point using a straight line and we measure this error between the this fitted line and the actual data. So, this is based on joining the end points of the scale and the maximum non-linearity in the first method this is always lesser than the second method. So, this method will have lesser error compared to this method. A consequence of non-linearity is distortion. So, when the output of a sensor deviates from a straight line output then it produce distortion which is defined as the deviation from an expected output. So, let us understand what is non-linearity. So, consider a linear system where we have this this is a completely linear system and we apply two frequencies to input let us say frequency 1, f 1 and frequency 2 which is f 2. We are talking here in terms of frequency domain and we have this frequency system which is spectrum f 1 and f 2 these two frequency we apply at the input. This linear system will only produce output at these two frequencies means the output will be amplified that the level here will be different let us say at input it is A and the output it will be A 1, but the frequencies will be same f 1 and f 2 only.

So, no harmonic generation in linear system. However, if we have a non-linear system here we apply only two frequencies, but because of the non-linearity the system will generate harmonics. Harmonics are integer multiples of the input frequencies. So, at the output we get f 1 and f 2 and we get harmonic generation harmonics as well. So, we get f 1 and f 2 and the second order harmonics will be f 1 plus f 2 and f f 2 minus f 1 these are the second order where we have two terms added or subtracted together and this f 2 plus f 1 will be somewhere here and f 2 minus f 1 will be here and f 2 plus f 1 will be somewhere here. Third order harmonic will be where three terms are involved here two terms of f 1 minus one term of f 2 and two terms of f 2 minus one terms of f 1. So, this is third order harmonic which appears somewhere here. So, this is a non-linear system where the system generates harmonics of the input frequencies and these harmonics are generated due to the non-linearity of the system. These type of non-linearity or these harmonic generations these are y very important for high frequenc applications. Next characteristic is hysteresis. So, hysteresis is the difference in the output of the sensor for a given input x when x reaches its value in upscale and downscale direction means we have a input range let us say from x min to x max we when we apply from x min to x max the output follows this path, but when we come back from x max to x min the output follows a different path. The output does not go to the same path it follows a different path while coming back and for going up this is the path. So, these two paths are different ideally it should be same, but if the system has hysteresis or the memory effect we call it then these outputs are different and there is exist an area in between. So, this is called hysteresis in the system this is the case of analog where we have a in analog measurement hysteresis look like this. However, in the digital case it look like this when input is changed from low to high it follows this path, but when coming back from high to low value this follows different path. So, this is a digital case where a Schmitt trigger produce this kind of hysteresis loop.

Next parameter is the impedance. input output impedance of the sensor or a transducer is the characteristic which need to be considered when we start connecting more than one systems in cascade. Let us say we have one system and we want to connect it to the other system that time we need to take care of the how much is the input impedance and output impedance of these systems and these causes significant restrictions in interfacing these blocks. For example, here in this case we have this voltage source which is 100 milli volt in magnitude and it has a let us say internal impedance of 1 ohm and we want to connect it to an amplifier which is shown here this is amplifier. This amplifier has an input impedance of let us say 100 ohm. In isolation condition this voltage source will produce a 100 milli volt output here when it is in isolation it is not connected to any other block. But as soon as we connect this voltage source to an amplifier which is 100 ohm in input impedance the voltage at the input will not be 100 milli volt this will be distributed between this ZS and Z1. The net voltage will not be 100 milli volt now it will be approximately 100 divided by 100 plus 1 into 100 milli volt. This is your Z in divided by Z in plus ZS into 100 milli volt. This is your Z in divided by Z in plus ZS into 100. So this 100 milli volt will be divided using resistor divider across this path and this voltage is now lesser than 100 milli volt because this quantity is lesser than 1. That will be typically some 99 milli volt or so. So because of the interconnection of these two blocks now the output produced by this voltage source is reduced as soon as we connect these blocks together. So this input and output impedance need to be taken care of if we have a very less impedance at the input of this amplifier this voltage is further going to be reduced and accordingly your system gain will be limited. So these input and output impedances are some static characteristic which need to be considered. Next is isolation and grounding. So isolation is necessary to eliminate or at least reduce undesired electrical magnetic or electromagnetic and mechanical coupling.

So when we have these sensors and we connect it to some electronics then that electronics may be working at different voltage and the sensor may be working at different voltage for example, 5 volt, but the processing unit which is let us say computer or some electronics which is working at 12 volt. So this sensor should not be exposed to this 12 volt because sensor is at 5 volt if 12 volt comes in the sensor can be damaged. So there should be an isolation between the sensor and electronics however, the data should flow from sensor to electronics it means the AC signal the data should flow, but the DC voltage should be blocked. So we use some kind of decoupling capacitors between these two blocks so that the DC voltage are isolated however, the AC signal can flow. Similarly grounding is also necessary to establish a common node between these different parts of the system with respect to which the potential of any point in the system remains constant.

We need to have a common ground with reference to that we define all the voltages of other nodes. So these are some static characteristics of the sensors which we use for characterization of these sensors. These are some other examples for example, the length of a rectangular box is 1.2 meter, but if it was measured with a tape and the length was measured at 1.22 what is the accuracy of the system. So similar kind of experiment similar kind of example we considered earlier as well. This is the actual value or the true value Xt and 1.22 this is the Xm and so we know the formula error equal to Xm minus Xt divided by Xt into 100. So we put the values and we get the results around 1.67 percent is the error in this measurement hence the accuracy is 100 minus 1.67 which is 98.33 percent. Another example is let us say we have a measuring tape and it can measure with an accuracy of 99.8 percent only. What is the possible range of length which can be obtained by using this measurement tape to measure a cloth of length 2 meter. So this 2 meter length is the value of Xt and we are given accuracy which is 99.8 percent so the error will be 99.8 percent 100 minus 99.8 percent which is 0.2 percent. Now the new measurement or the measured value using this measuring tape will be actual value 2 meter plus minus the error which is 2 plus minus 0.004. So the maximum value of measurement will be 2.004 and the minimum value will be 2 meter minus 0.004 which is 1.996.

So this is all we have for today.

Thank you.