Transducers For Instrumentation
Prof. Ankur Gupta
Centre for Applied Research in Electronics (CARE)
Indian Institute of Technology, Delhi
Lecture - 20
Acoustic Sensors: Introduction

Hello, welcome to the course Transducers for Instrumentation. Today we will discuss about acoustic sensors. These are special type of sensors where we use acoustic waves and acoustic sensitive materials to make a sensor. So acoustic sensors primarily use longitudinal waves or the mechanical waves as a media. We use the properties of these waves and make a acoustic sensor. So let us discuss first a little bit about what are these waves, the mechanical waves or the acoustic wave what we use in these sensors and what are their typical properties. So, we have acoustic waves, so today we are discussing acoustic sensors and in this we have something called mechanical waves or longitudinal mechanical waves. So in these type of waves the oscillations occur in the direction of wave propagation. The oscillations occur in the direction of wave propagation. So for example we have wave which is travelling in x direction and this is the media.

So let us say time t equal to 0, this wave is at the extreme corner where we can see that this spacing is different. So it is, this is because of this difference in the spacing compared to the normal condition we have a perturbation here and at t equal to let us say t0 this perturbation moves to x direction, so at time t equal to 0 this distance moves somewhere in the middle for example here is the this perturbation. So we have a medium or this media which is composed of atoms or so and when the wave hit from the x direction from the left then there is a oscillation of these atoms of the media. These oscillations or this disturbance this is in the direction of wave propagation. So wave is travelling in the x direction and the atoms of the media they are also oscillating in the x direction only.

So at t equal to 0 this oscillation is at the extreme left and then at after sometime t equal to t0 this movement actually shift in the x direction only. So the direction is same. So this is what we call longitudinal mechanical waves and our sound waves what we speak so these sound waves are type of mechanical waves only. So we have sound waves these are created by alternate compression and expansion of solids, liquids or even gases. So sound waves are created by alternate compression and expansion of solid, liquid or gases. And these sound waves are longitudinal mechanical waves. So between 20 hertz and 20 kilohertz. So here we have sound waves which are created by alternate compression and expansion within the solid, liquids and gases. So as we speak the sound actually travels from the transmitter to the receiver because we have air which is having full of atoms. When we speak this sound is created by us and then it moves through the movement of these atoms in the air. So air has these atoms and when we speak in this direction for example in towards the front so these atoms move these atoms which are present in the air these gases these atoms move in the direction of wave propagation. So we have sound waves and the typical frequency of sound wave is 20 hertz to 20 kilohertz which a human can can hear. So these are type of longitudinal mechanical waves. So now we have some properties of sound waves. The sound the speed of sound depends on the media to which the waves are passing sound is often a fundamental property of material. Hence the speed of sound changes with ambient temperature. So the speed of sound changes with ambient conditions. There are so many ambient conditions can have one of them is temperature. So the speed of sound changes with ambient conditions. For example speed of sound is around 343 meter per second in air.

This is 1482 meter per second in water and it is much higher 5960 meter per second in solid like steel. So here we have the speed of sound which is a property of sound this is often a property of material in which this wave is traveling. So when the speed when the sound is traveling in the air the speed is 343 meter per second. However when it is traveling in the steel when we hit the steel on one end through longitudinal waves the wave travel in the steel with the speed of 5960 meter per second which is much higher than the speed in air. So these are the fundamental properties of material itself what kind of material you choose based on that we have the speed of sound different in that material. So these are the materials we have these materials most of the time they are not linear they are not the response to this speed is not very linear is it most of most of the materials we have they are non-linear in nature and when the speed is sensitive to that non-linearity we generate some sort of harmonics in the in the waves. So we have something called non-linear mediums. And the speed of sound is also slightly sensitive to the sound amplitude. Which means that there are non-linear propagation effects. Such as the harmonics the production of harmonics. And tunes. So we have a non-linear medium if the sound is traveling in the non-linear medium the speed actually is not only dependent on the material property but it also depends on how much is the amplitude of the wave. If we have a very high magnitude then the speed is slightly different then the in that case we have a smaller amplitude. So smaller amplitude may have a different speed than compared to a higher amplitude signal and that is because of the non-linearity in the material. So because of these non-linearities we generate some sort of harmonics. The harmonic of a wave is a component frequency of the signal that is an integer multiple of fundamental frequency.

We apply a frequency which is fundamental frequency to this non-linear medium then because of the non-linearity in the material the harmonics will be generated. Harmonics are nothing but different frequencies which are integer multiple of the fundamental frequency. For example we apply a 10 kilohertz signal then the harmonics generated will be 10 kilohertz and then 20 kilohertz, 30 kilohertz it is an integer multiple of 10 kilohertz, 10 kilohertz multiplied by 1 multiplied by 2 multiplied by 3 and so on. So like that the harmonics will be generated which are integer multiple of fundamental frequency. So if let us say we apply a frequency to this non-linear medium and the fundamental frequency is let us say 440 hertz then the second harmonic will be 2F or we can call it 2 times F this is let us say 1 time F which is integer multiple of 440. So this is 440 multiplied by 2, 880 hertz this is called second harmonic or sometime we call it the first overtone and then we get a third harmonic which is 3 times F, 3 times of 440 means 1320 hertz. This is third harmonic and the second overtone and if we have the another frequency which is fourth harmonic or 4F that is 1760 or we call it the fourth harmonic.

So we apply a signal of 440 hertz here to this non-linear medium and we get the integer multiples of the applied frequency which is 880, 1320 and 760 hertz which is we call second harmonic, third harmonic and fourth harmonic and so on. We get multiple we get different harmonics even to a very high value as well. The generation of these harmonics depends on how non-linear the material is if the material is very highly non-linear then the amplitude of these harmonics are different it is much higher and if the material is very linear it does not have much of a non-linearity then the amplitude of these harmonics will be lesser. So we want a linear medium so that the amount of harmonic generation is less and we do not lose our energy of the wave in terms of the harmonic generation. Harmonics are something which is undesirable or some sort of noise we can we can see them as a noise. So these are the harmonics generated. Now there is one more term associated the pitch of the sound. So the pitch of a sound is determined by the frequency of the sound. For example a low pitch sound is thunder or gunshots like thunders. Medium is for example telephone bell and a for example high pitches like small bells. So the pitch of a sound which is another parameter for the sound waves the pitch of a sound is determined by how much it is for example the low pitch sound is a sound which is generated in the thunders or the gunshots. Medium pitch sound is telephone bell or something and the high pitch sound is like very metallic bells when they ring this is a high pitch sound which they produce. So these are the type of pitch we have in the sound waves. Now we make sensors using these acoustic waves the properties of acoustic waves and some of the applications of these acoustic waves are found very in very wide variety. So the typical applications for example in military we have multiple applications for example chemical substance detector. And bio substance detectors in automotive parts and engine performance control in industrial and environment. We have water quality, workplace monitoring. Some applications involve food industry as well where we use them in process control. And food freshness we can also check with them. And we use acoustic sensors even in the medical fields as well. For example in the emergency room diagnostics and drug discovery and deployment. So these are some typical applications where these acoustic sensors are used military, automotive industry and environment, food industry and medical. In military also these acoustic sensors are very much used because for example the underwater surveillance.

The RF waves they do not propagate into the ocean or into the water. These RF waves cannot be used within the under the sea or under the water. So for underwater typically we use the caustic waves and hence we use the caustic sensors for these underwater surveillance which is a field which is very much linked to the military for the defense applications. So these are some typical applications where we use acoustic sensors and let us see what are some typical advantages of acoustic sensors here. So the advantages of acoustic sensor is the first one is these acoustic wave sensors are very versatile devices. They are competitively priced. get damaged very early, they are quite sensitive, they are decently sensitive enough and inherently or intrinsically reliable for their operation. They can be used as passively and wirelessly. So these are the sensors which do not require a external bias circuitry to perform the function. So for example, a diaphragm based acoustic sensor when the wave hit on this diaphragm, this creates a pressure difference. So this is a passive device which does not need external bias or external source to power it up. The pressure will be generated by this diaphragm and this pressure how do we change that is the subsequent step, but this acoustic sensor does not need a voltage source or any external supply. So they can be used as passively and even they can be connected wirelessly. And some other application include these measuring force, acceleration and displacement and flow etc. So we have for example, we have two items for example, microphone which is acoustic sensor for air waves in the audible range. And second term we have hydrophone which is again a acoustic sensor, but for liquid and both of these are pressure sensors. So we have two terms one is microphone this is the acoustic sensor, but this is for the air waves in the audible range. And second we have a hydrophone which is used within the liquid in the underwater sensing or so. This hydrophone is the working principle is same, but it is used for the liquid or underwater. So this is also a caustic sensor and both of these sensors are pressure sensor they measure the pressure generated by these acoustic waves and this is converted to electrical signal.

These microphone and hydrophones they have a moving diaphragm. And a displacement transducer. That converts its motion into electrical signal. And these microphones and hydrophones they have some parameters on which they differ for example, the sensitivity, directional characteristics. Frequency bandwidth. And dynamic range. So these microphone and hydrophone they both have a moving diaphragm. So there is a diaphragm there in these acoustic sensors. When a wave hit this diaphragm this diaphragm actually moves or shake depending upon the waves what kind of wave it is. So this diaphragm responds to this wave and it moves and there is a transducer attached to it which measures how much this diaphragm is moved and based on that we can calculate how much what is the kind of amplitude and the frequency of the incoming acoustic wave. So this is how a caustic wave is detected by microphone or a hydrophone. So this signal is then converted to electrical signal and these microphone and hydrophones they differ in terms of their sensitivity, how much sensitive a hydrophone is. Some of the hydrophones or microphones they are directional. For example, we want to send the wave in this direction and we want to receive only we want to detect only from this direction than they have. Then we use directional hydrophones they are particular only in one or desired direction.

Some hydrophones are omnidirectional they measure any waves coming from any direction. So some hydrophones are directional they have directional characteristics. Frequency bandwidth how much the frequency bandwidth they have and the dynamic rate based on these factors these hydrophones and microphones they differ. So now these hydrophones or microphones they generally have diaphragm one is moving and one is generally fixed. So for example, we have for example, let us take example of electrical system which is capacitor. So in capacitor we have two plates one is positively charged when we apply a bias across it and one is negatively charged. Now the area is A and we have applied a voltage which is V and the distance is D between these two plates. This is also we can use as a acoustic sensor or a hydrophone. For example, if the first plate of this positive plate of this capacitor actually moves then the capacitance of this capacitor changes because the capacitance of this is C equal to epsilon naught K A upon D. So this is the formula for the capacitance of this capacitor when a plate moves in x direction upon application of this acoustic wave this distance changes and based on that if the distance is decreasing the capacitance will increase.

So there is a change in the capacitance of this capacitor if this plate is moving and this plate we can assume it is a diaphragm which is moving with respect to a fixed diaphragm or fixed plate then if this diaphragm is moving based on that there is a capacitance change and this capacitance we can measure using electrical circuits when we apply a voltage across these two plates. So this is one example where we can use this as a hydrophone or a pressure sensor. Now a capacitor microphone entirely converts the capacitance between plates into an electrical voltage. So this capacitor actually converts the distance which is the distance moved by this diaphragm this converts linearly into the equivalent electrical voltage and there are some circuits which we can use to calculate how much is the capacitance change of this capacitor. So few circuit example a microphone for example we can use this kind of circuit where we have a resistance on the bottom we connect this capacitor and below there is a ground there this is our output and this is the supply voltage let us say positive V this is our capacitor which is actually moving diaphragm so the capacitor is actually a variable capacitor so this is our microphone and when the sound wave coming from the left so this is the sound wave which hits this capacitor from the left there is a change in the capacitor so when the capacitor is changing its voltage across it then this output voltage which is detected on top of this capacitor this voltage output also changes.

So if we assume the incoming wave is sinusoidal so at the output node V out we get a electrical signal which is sinusoid in nature. So this is a simple example of a circuit where this resistance is let us say R or we can have a more improved circuit which is using active devices for example we have a MOSFET and on top we have a resistor this is out and the capacitor is connected here this is a variable capacitor the voltage applies plus V as a bias this resistance is let us say R this is MOSFET M. So in this circuit if a acoustic wave hits from the left the voltage across this capacitor changes and this is this voltage change which is happening because of this diaphragm movement this voltage is applied at the gate of MOSFET. Now this work as a amplifier so here we have a MOSFET which is connected on to the resistance on top with a supply bias this active device act as a amplifier. So we have a small signal generated by the diaphragm which is now boosted by this MOSFET by this amplifier and at the output node V out we get a much amplified version of signal which is generated by diaphragm. So this is a active device or the amplified version of the input signal. So here we have a non amplified version and here we have a amplified signal. So these are some circuits which we can use pressure sensor working and how to detect the output of a pressure sensor. So now to discuss acoustic sensors how do we make these acoustic sensors we need to discuss first there is a special term which is called piezoelectricity or the piezoelectric effect. So there is a effect in some material that if we compress those material or expand those materials means we change the shape of those materials so they develop a electric potential across it.

So this is the fundamental properties of some materials not all the materials have this kind of property. If we have a piezoelectric material which shows this kind of property we take a crystal of this piezoelectric material and we compress it then it generates a voltage across it plus voltage on the top and minus let us say on the bottom and if we expand this material this polarity of this voltage reverses on the top it comes negative and on the top on the bottom it comes positive. So this effect this phenomena is called piezoelectricity. So acoustic devices or acoustic sensors use piezoelectric material to generate acoustic waves. And this piezoelectricity refers to the production of electrical charges by imposition of mechanical stress. So this piezoelectricity refers to the production of electrical charges in a material if we apply a mechanical stress on this material. We compress it or expand it means we are changing the structure of this material accordingly the voltage will be developed on the one side of on the one and on the top and the bottom side of this material. So this is called piezoelectricity and in a diagram if we show it we have let us say a piezoelectric material and we apply a force from top and bottom. So we apply a force this side then it develops electrical charges across it for example positive is coming this way and negative is this way. So we get a net potential difference which we can measure using some multimeter or so a measuring instrument if it has a if we connect this multimeter to this side. So we have a material which is piezoelectric. So here we have this piezoelectric material and we are applying a force from the top and the bottom. So this piezoelectric material is generating some charges positive on the right side and negative on the left side. So this charge we can measure using some measurement device for example multimeter or some high end equipment. So this piece this property is shown by certain materials only which are called piezoelectric material and this effect is called piezoelectricity. So this is the effect which is very important because this effect is used in acoustic sensors to generate acoustic waves.

So this is all for today.

Thank you.