Transducers For Instrumentation
Prof. Ankur Gupta
Centre for Applied Research in Electronics (CARE)
Indian Institute of Technology, Delhi
Lecture - 23
Acoustic Sensors: Bulk Acoustic Wave (BAW) type

Hello, welcome to the course Transducers for Instrumentation. Last lecture we discussed about the acoustic sensors and we saw there are two types of acoustic sensors, one is the surface acoustic wave sensor where the acoustic wave travels on the surface of piezoelectric material and the second is the bulk acoustic wave sensor where the wave actually goes within the material, the piezoelectric material from one end to another end. And we discussed a configuration how do we fabricate a saw sensor, there are some photolithographic steps and then we saw there are two IDT structures which we pattern on a piezoelectric material, there is no junction formation, so we do not need any diffusion or ion implantation step. We just need to pattern two IDT structures on top of piezoelectric material. Now IDT structures are same, so these are reciprocal they can even convert a electrical signal to acoustic wave and acoustic wave back to electrical signal at far end or at the receiving end. So these IDT structures which are generating this signal from electrical to acoustic wave, this acoustic wave is generated perpendicular to the fringe of this com structure or IDT structure.

So we have IDT structure where pins are in perpendicular direction, so the acoustic wave will be generated in horizontal direction perpendicular to this fringe . So now this acoustic wave this will be generated at IDT structure and it will propagate in X plus X direction and in negative X direction as well. So this acoustic wave which is generated by this IDT structure this will propagate to the right and it will propagate to the left itself if there is a piezoelectric material there. So if we do not have a piezoelectric material on left side the wave will propagate to right side or the positive X direction.

Now earlier we saw we have a sensor where we have one IDT on the left and this is generating acoustic wave, acoustic wave is travelling to the right where it is converted back to electrical signal by same IDT structure. And in between we have a measurement zone, this measurement zone is there because of the piezoelectric material we have a certain velocity of acoustic wave. So this depends on what piezoelectric material we choose. Based on this material this velocity is fixed it means when we apply a electrical signal on the left we generate a electrical signal back from the right IDT and there is a phase difference because of the time delay between these two IDT structure. Sometime we call that delay line sensor the same saw acoustic wave sensor is sometime called delay line sensor because we are measuring the delay in the in the acoustic wave going from left to the right.

And this delay is fixed with the distance between IDT structure which is known to us and the material what we choose. So that material is also known to us. So while fabricating this sensor we know how much is going to be the delay of this delay line sensor or acoustic wave sensor. Now when we do sensing using this delay line sensor, so we have in between this delay this measurement zone if there is any impurity on on that surface because of that the velocity of a caustic wave will change because of that impurity. So if the velocity is changing the time taken from left to right is changing it means the delay will change according to the impurity present on the measurement zone.

So that actual delay which was let us say delta or let us say t earlier the delay with application of some impurity that time delay will change from t to t plus delta some delta error function will be there which is proportional to what impurity it is and what size of the impurity it is. So this is how this delay line sensor is used as a sensor as a caustic sensor that the delay of this caustic wave sensor is proportional to what is the measure and what is actually applied on the measurement zone. So that we discussed last time delay line sensor. Today we are going to discuss a little advanced version of that delay line sensor which is resonator or saw resonator we call it surface acoustic wave resonator. So we discuss this saw resonator or we call it one port saw resonator.

Only one IDT placed at the center of the substrate. Is used for both input and output transduction. So we have structure something like this. This is piezoelectric material. And in this we fabricate one IDT structure at the center.

So we have let us say this IDT structure. This is one terminal and this is second terminal. So these are the two terminals of IDT structure and we call it input and output IDT. So here we have this piezoelectric material. So we have this piezoelectric material. So we have this piezoelectric material. So we fabricate only one IDT structure. This will do both the function as input and output. So when we apply a electrical signal here it is going to generate a acoustic wave and if an acoustic wave hits it this that signal will be converted back into electrical signal and this input and output ID input and output electrical wave this we can do in time multiplexing manner for example for a fraction of second we just apply input and this IDT will generate acoustic wave. This acoustic wave generated by this IDT structure will travel in both the direction positive x axis and minus x axis because this IDT is same the symmetrical along this y axis.

So we have this acoustic wave which is going to be generated and will travel in positive x direction as well as in negative x direction. So these are the acoustic wave generated. Now both the side acoustic wave will travel if we put somehow a reflector on both the edges for example we have a reflector present. The reflector is nothing but this strip of metals only they are out of phase of this frequency so that they start reflecting this wave. So these are the reflectors. So when we place these reflectors on both the sides these acoustic wave will travel from IDT to the reflector and at the reflector they will bounce back convert their direction will change they will come back to IDT and the time taken by the acoustic wave will be the distance which is 2 times the distance from IDT to reflector because there is a complete cycle IDT to reflector and then reflector back to IDT. So 2 times the distance between IDT to reflector divide by the velocity of acoustic wave and that acoustic wave velocity is known to us because of the material what we choose. So in this way this reflector actually bounce back these acoustic wave which comes again to the same IDT structure we generated it and at this time these acoustic wave will be converted to electrical signal. So the same IDT structure now will convert this acoustic to electrical and give us as a output. When we see these two applied signal these two signals will be delayed in the time and that time what we just discussed it will be twice the distance between IDT and reflector divided by the velocity. So these two signals will be displaced by that time delay and this is called the SAW resonator this is kind of a resonator where this acoustic wave is bouncing back to the same IDT. So this kind of structure is used for making of sensor and there are two types of these SAW resonator depending on the application the one is the direct and one is the indirect. Direct SAW resonator is something where we apply the electrical signal directly on this structure. Indirect is something we transmit the signal and it receives the signal and applied to this device. So we have two types of these surface acoustic wave sensors.

There are two types of wave sensors of surface acoustic wave sensor. The one is the direct and second one is indirect. So let's discuss them in brief the direct source sensor. In this type of direct source sensor the measure end affects the propagation of SAW in the sensor. The measure end for example temperature, pressure, strain etc, affects the propagation of SAW. SAW in the sensor in attenuation and delay. So the example for this is the torque sensor. So in torque sensor we have a shaft on which we are applying a torque. So this is a shaft and we are applying a torque on this let's say like this and we want to measure how much is the torque is being applied on this shaft. So we can place a SAW sensor and we can kind of paste it on the shaft itself. So we have these IDT structures which we place on the shaft itself one let's say in this direction and one is perpendicular to the z-axis this direction. So we can paste these SAW sensors right on the shaft itself. Now when we apply a torque on this shaft because of this application of this torque there is a deformation in the shaft and because the SAW sensor is sticking to this shaft there will be a deformation in the SAW sensor itself. Now think of it as a delay line sensor let's say we have pasted a delay line sensor on the shaft in case of no torque applied in the normal neutral condition this delay line sensor has a time delay of T.

When we apply the torque now because of the deformation let's say there is a compression in the SAW sensor because the SAW sensor is pasted on this shaft because of this compression the distance from the left IDT to the right IDT this distance is reduced. So accordingly the time taken from first from the source from the source to the receiver that time delay will reduce now because of the because the distance is now lesser because of the compression. So this we will detect it by a change in the time delay earlier let's say the time delay was T now the new time delay will be T minus delta T. So this delta T which is the now the difference between the delays this is proportional to how much torque is applied. If we apply a high torque it means there will be a very high compression and the size of this SAW sensor will reduce means the distance from source to destination will further reduce and accordingly there will be this time delay the difference in the time delay will be proportional to how much torque is being applied on the shaft.

So this is how we can use these SAW sensors as a torque sensor and we see here we pasted one SAW sensor on the shaft. If we want to have like perpendicular in which direction the torque is being applied that we can measure by placing two SAW sensor one in the let's say one direction and one is the in the perpendicular direction. So we by analyzing both the signals we can know in which direction the torque is up is being applied. So this is what the direct SAW sensor is where the measure end which is torque here this measure end is directly influencing the speed of SAW the surface acoustic wave it is directly influenced by the measure end. So when we apply this torque there is a direct change in the velocity or the how much time it takes from source to the destination. So we call it the direct SAW sensor and this SAW device is rigidly mounted to this shaft. So this is the shaft and SAW device is rigidly mounted on a flat spot of shaft. The torque applied will stress the sensor. If we use let's say both the sensors we use two sensors for practical applications. Two SAW sensors are used such that their central line are at right angle.

So this is how this direct SAW sensor works we apply the torque which causes a compression in the SAW device and because of this compression there is a change in the delay of this acoustic wave from source to destination. This is direct SAW sensor now the indirect SAW sensor is let's say we have a SAW sensor which is far away which transmits a signal which is detected by some antenna and applied on this SAW sensor and there will be a reflected acoustic wave which is according to what that sensor is. So the application of this kind of SAW sensor is for example in identification or let's say we have a spacecraft flying there and we want to check whether this spacecraft is ours or it's from someone else. So we make a SAW sensor place it on the aircraft with the antenna when we send a signal the reflected wave will be as per that SAW device what we have placed already. This SAW device may have multiple reflectors so accordingly how many reflectors we used in that SAW device reflected wave will have the signature of those reflectors and we can know by those signatures whether it is our own aircraft or someone else. So let's discuss what it indirect SAW sensor is and what is the use of this in terms of identification of the objects. So number two is indirect SAW sensors. The information in this case about the measurement is gathered by another sensor. So what happens in indirect SAW sensor let's say we have a base station. On this we have a radar or something which sends the signal.

So this is our base station and this sends the signal outside and we have a object. This is an unknown object for example which has this SAW sensor. This is our SAW sensor with antennas and in this we have some reflectors for example these are reflectors. So these are the reflectors for example here we have one reflector, here we have three reflectors, here we have two reflectors and this is our antenna and this base station is actually transmitting a pulse towards this unknown object. So the reflected wave now will be having the signature of these reflectors and the reflected wave will be having one peak because of this one reflector then it will have three peaks and then it will have two peaks. So this will be our reflected wave and this is our transmitted wave. So here we see we have a base station which is trying to read what object it is whether it is our own object or whether it is someone else object. So one dedicated SAW sensor is allotted to each and every device when the base station sends this transmitted wave towards this object. This wave this is a single frequency which will be detected by these antennas and this electric this will be generated to electrical signal and applied to the SAW sensor. Now this electrical wave will travel as a acoustic wave in SAW device based on the number of reflectors there will be a reflected wave.

So if we have one reflector it means it will be reflected there once some part will be reflected some part will be reflected in the same direction. Then we have three reflectors it means it will be reflected at three instances. So it will generate three peaks in the reflected signal and further we have two reflectors there those two reflector will give rise to two peaks. So the reflected wave we receive that one peak three peak and two peak that is according to how many reflectors we have put. So we can we can kind of put the coding in terms of number of reflectors and the readout signal when we get this reflected wave at back at the base station by the counting the number of peaks we can know what is the code of this SAW sensor and this code can be unique to each and every object. So this is how these indirect SAW sensor works and if we see the actual working of SAW here we have a SAW sensor there. This is piezoelectric material and on top of this we have antennas. These are antennas and these antennas convert the signal to electrical signal which is applied to these IDT structures. These are the IDT structures. So when we send the signal this signal is going towards this SAW device.

This will be picked up by antennas and will be converted to here into a SAW of the surface acoustic wave. Then in the same line we have some reflectors placed. This is one reflector. Then we have three reflectors and then we have two reflectors. So the reflected SAW wave which will again be converted to the electrical signal will come out like this. One peak because of the first reflector, then three peaks because of three reflectors and then two peaks because of these two reflectors. So this will be the wave coming out of the SAW sensor or we can say the RF response. And this we can call it ID tag using SAW.

This is the sample ID tag using SAW device. And this is the process of ID tag identification.

So this is the second type of SAW sensor which is an indirect SAW sensor. We apply the signal and the signal will be read out by a separate sensor which is here in this case this radar is this will gather that information and will decode the information. SAW sensor is used as a media to gather that information. So here it is acting as an indirect SAW sensor. Now we discussed SAW sensor which is the surface acoustic wave sensor. In all these cases the wave is actually traveling on the surface of piezoelectric material. Let us discuss something called BAW sensor or the bulk acoustic wave sensor where the wave will actually penetrate into the material into it pass through the material not on the surface but into the bulk. That is why we call it the bulk acoustic wave sensor. In these sensors a piezoelectric film is sandwiched So in BAW sensor we have a piezoelectric material. This is a sheet of piezoelectric material. On both the side we put metal film which will act like an electrode. So this is the first metal sheet on top and the second metal sheet is on the bottom. This will act as a second electrode. When we apply a electrical signal across these terminals let us say this I apply a signal then there will be an acoustic wave generated in between these two electrodes and it will be propagating within this piezoelectric material something like this. So this is the acoustic wave and this is now propagating within the material this is piezoelectric material and the equivalent circuit model of this consists of a fixed structure capacitance in parallel with frequency dependent electromechanical resonance circuit.

So the electrical equivalent model of this will look something like a capacitor which is fixed capacitor because of this material and a electromechanical resonance circuit which is in parallel to this. It has its own capacitance, resistance and small amount of inductance. Let us say I call it C0 and this is C1, R1 and L1. So here we have this piezoelectric material on top and bottom of this material we place these electrodes these are metal sheets and we apply our electrical signal across these two metal sheets. So when we apply this time varying signal on these on this film a wave will be generated within the material this piezoelectric material and this will will propagate from top to bottom let us say from one electrode to another electrode this is within the bulk. If we make a electrical equivalent model of this structure we have a C0 capacitance which is because of the fixed capacitance structure this assembly is going to now store certain amount of charge because this is a kind of a capacitor we have two plates and we have some dielectric in between. So we get a C0 because of this and in parallel to this we have a electromechanical resonant circuit because this is kind of resonating circuit which give rise to a C1, R1 and L1. So this is a resonant circuit. So when we get a resonant circuit it means this is going to store some amount of energy within itself and we have to talk about something called quality factor of this structure. So we need to discuss now the these resonators has certain Q or the quality factor.

So these barysonators stores the maximum acoustic energy within the structure achieving a high electrical quality factor. We represent it with Q. So this going to store some energy and the material is going to be chosen for this BOS sensors must optimize both electrical and electrical systems. And mechanical properties. So we have this resonator in fact, and this resonant circuit. whenever we have a resonant circuit we have an associated quality factor with this how much energy is stored within the structure that defines how much is the quality factor is and the material we use for fabrication of these BOS sensor that must be carefully chosen because it involves electrical as well as the mechanical properties of the material. So we have a quality factor associated with these devices. Now let us see these bulk acoustic waves are again of two types the one we call it the film bulk acoustic wave and the other one is this solidly mounted acoustic wave. So in the film bulk acoustic wave we have a thin film which is containing all the energy stored in the solidly mounted bulk acoustic wave this film is actually resting on different materials and the some amount of energy is actually lost to those materials itself. So that will change the quality factor to a degraded this mechanical energy to go to the substrate.

However this is shielding. This shielding is not as effective as we have in FBAS sensor where this material is actually hanging in the air. So there is no effectively transfer of mechanical energy through the air. But here we have reflector stack which can little bit prevent this loss of energy but still there is some amount of energy which will be transferred from piezo material to the substrate. So if we think about this structure, this structure is easy to fabricate because we need not to have that etching from the underneath of this structure. We just need to deposit multiple layers. Deposition of these layers is very easy in fabrication process. We can just put one metal on top of another metal. So the fabrication of this structure is easy but the quality factor of this structure is not as good as the FBAS sensor. So we have the pros and cons of this structure is the low quality factor but it is easy to fabricate.

The low quality factor but it is easy to fabricate. So, these are some pros and cons of the solidly mounted structure and this film bulk acoustic and solidly mounted bulk acoustic these are all types of BAW sensor and today we discussed SAW sensor where we have delay line sensors. There are again two types one is direct and one is indirect based upon the application and here we discussed the BAW devices or the BAW sensor where acoustic wave is travelling within the bulk and we saw again two types of BAW sensor. One is the film bulk acoustic wave the quality factor we get is very good but the fabrication of these structures are difficult. On the other hand these solidly mounted structures these are easy to fabricate we do not need to go for these under etching kind of techniques but the quality factor here is not that good as compared to the film bulk acoustic. So this is all for today. Thank you. this mechanical energy to go to the substrate. However this is shielding. This shielding is not as effective as we have in FBAS sensor where this material is actually hanging in the air. So there is no effectively transfer of

mechanical energy through the air. But here we have reflector stack which can little bit prevent this loss of energy but still there is some amount of energy which will be transferred from piezo material to the substrate. So if we think about this structure, this structure is easy to fabricate because we need not to have that etching from the underneath of this structure. We just need to deposit multiple layers. Deposition of these layers is very easy in fabrication process. We can just put one metal on top of another metal. So the fabrication of this structure is easy but the quality factor of this structure is not as good as the FBAS sensor.

So we have the pros and cons of this structure is the low quality factor but it is easy to fabricate. The low quality factor but it is easy to fabricate. So, these are some pros and cons of the solidly mounted structure and this film bulk acoustic and solidly mounted bulk acoustic these are all types of BAW sensor and today we discussed SAW sensor where we have delay line sensors. There are again two types one is direct and one is indirect based upon the application and here we discussed the BAW devices or the BAW sensor where acoustic wave is travelling within the bulk and we saw again two types of BAW sensor. One is the film bulk acoustic wave the quality factor we get is very good but the fabrication of these structures are difficult. On the other hand these solidly mounted structures these are easy to fabricate we do not need to go for these under etching kind of techniques but the quality factor here is not that good as compared to the film bulk acoustic.

So, this is all for today.

Thank you.