Micro and Smart Systems
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Lecture - 05
Microsystems: Some Examples

So we had about 4 lectures already in this micro and smart systems. I had given my first lecture on the glimpses of Microsystems and after that you had lectures on smart materials, then some overview or some examples of sensors and one more lecture on examples of actuators. So this is the fifth one on Microsystems some examples. Again I am Professor K. N. Bhat from ECE Department once again.

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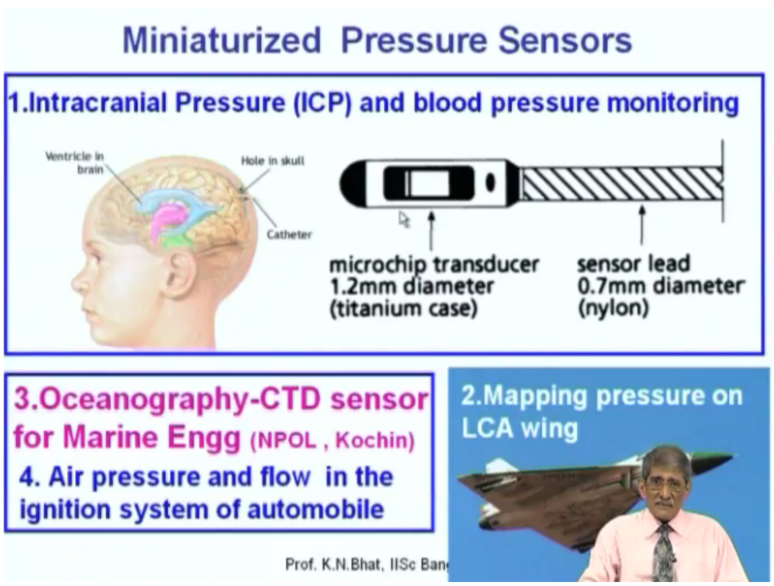

Last time, I touched upon these that is the miniaturized pressure sensors, which is useful for the intracranial pressure monitoring. So what I pointed out is you need to miniaturize this, so that what goes into the skull inside the brain is this particular thing, which is packaged and it has to be inserted. Several applications I had cited last time. Now today, what we will see is, what is inside this very quickly and how is the system and what is necessary for the system.

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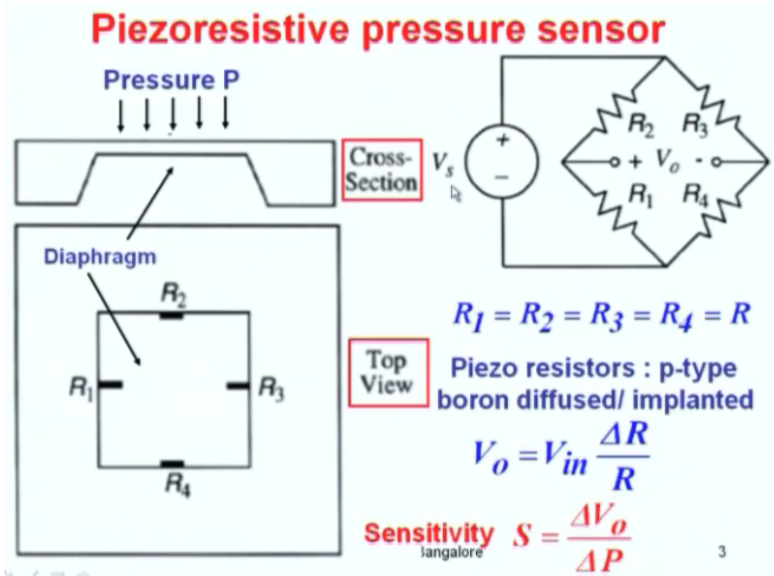

This is actually inside the package. What you will have will be a membrane as shown here, which in this case in a microfabricated pressure sensor, it will be a silicon membrane. The thickness of the membrane may be 10 microns, 15 microns, or 20 depending upon what pressure you are monitoring, lower the pressure, thinner should be the membrane, so that the sensitivity is better. So this pressure is experienced by this membrane and that stress actually gets amplified over the edges.

We will discuss the details of the pressure sensors in the case study when I talk to you at the end of this course, lecture number 39 or so. Now there are 4 resistors located here, R1, R2, R3, R4. They are connected by means of metallization in the form of a Wheatstone bridge. This I am sure all of us are aware even right from first year engineering or even sometimes high school today.

This Wheatstone bridge is balanced by choosing R1, R2, R3, R4 = R and when there is no stress on this membrane, the resistances are all equal and output is 0. Now when this membrane is subjected to stress by means of pressure from the top, 2 of the resistors, if they are P type, they will go up in value and the other 2 will go down in value by delta R. So these 2 will go up and other 2, the R1 and R3 will go up and R2 and R4 will go down.

The principle behind that we will not discuss today. So the output voltage of this here is such a change is there in R will be delta R by R into input voltage. That Vs is the input voltage. So you can see that how much delta R decides how much is sensitivity, how much is delta R Vr depends upon the strain experienced by the resistors and what is known as this factor of the resistors. Now if you take a look at the output versus pressure that is what you will get finally when you make the device.

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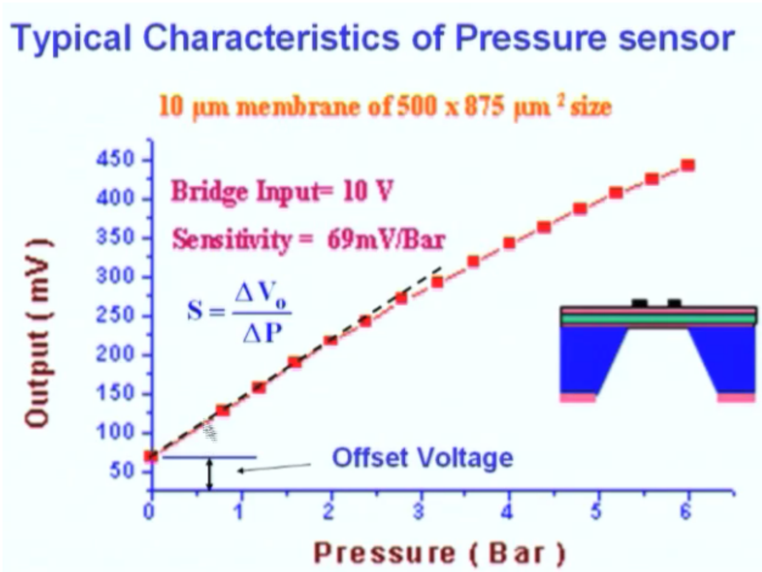

Here on the y axis here are the output in millivolts and on the x axis you have the pressure that the membrane is subjected to in the case of intracranial pressure monitoring, it is the intracranial pressure experienced inside the brain or on the brain. For a 10 micron membrane of this dimension, 500 micron by 875 micrometer square, you will get a voltages of several millivolts. Ideally, you do not need any electronics. You can as well use these output voltage.

For example, when there is 1 atmospheric pressure, you will get more than 100 millivolts, 59 millivolts per bar, but notice, we are in a certain point that there will be non-linearity. So this particular pressure sensor can be used totally up to about 2 atmospheres or 2 bar, one bar is one atmospheric pressure and other thing is, you notice also that when the pressure is 0, there is some output voltage. That is called offset voltage.

This is present in all the pressure sensors. So in any pressure sensor, you require to correct this and for that correction, you need electronics, otherwise you do not need an electronic for the Piezoresistive pressure sensor. So you can actually use electronics along with that to correct that and also these sensitivity is defined as delta V0 divided by delta P, slope of this particular curve, that is the sensitivity that will also become a function of temperature.

So you need to compensate for the temperature changes brought in output voltage, you need to compensate for this offset voltage, so for that what you do is:

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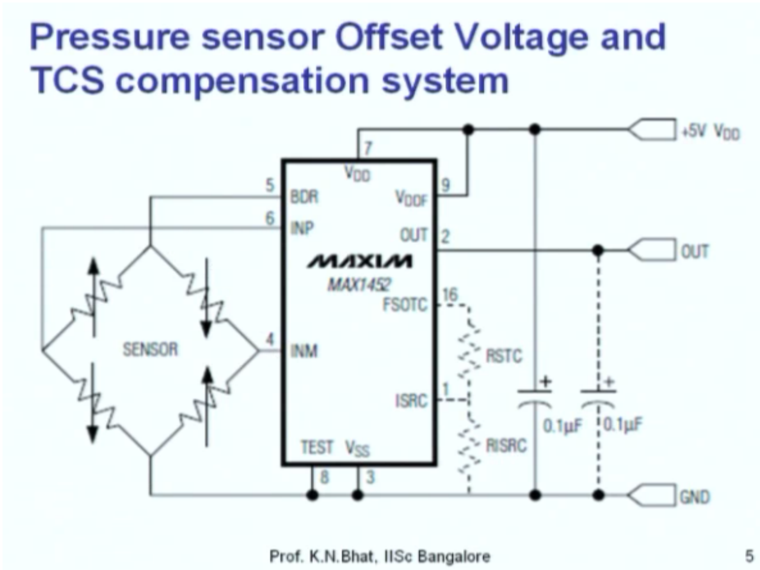

You use this bridge, the pressure sensor along with a chip, you can use for example Maxim, Max 1452 is a very popular chip that is used along with this. You can have it mounted along inside the package. You can have this pressure sensor as well as this chip that is put together in the package and that is the microsystem. Alternately, you can have the entire circuitry decided along with this particular resistor on the silicon itself. That is fully integrated.

We will discuss some of these things much later.

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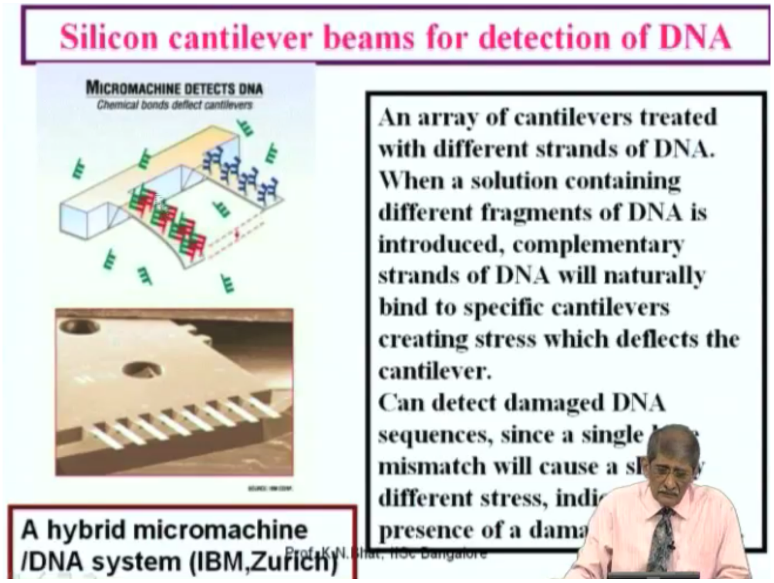

Now leaving the topic of pressure sensor and the system resisted that, just see that this is the silicon. We will take a look at this silicon cantilever beams for some DNA detection. Here, you have got an array of cantilever anchored here and this will get deflected whenever a molecule or DNA strand comes and rests on that. So here the trick is to dip this in a solution containing different fragments of DNA.

Then complimentary strands of DNA will naturally bind to specific cantilever creating stress that will deflect. You can identify whether the DNA is damaged or what is the DNA type, etc. you can identify by seeing the deflection there. There is just a bird's eye view of what is happening here. This is something, which we have realized. I think I pointed out about this last time. This particular beam can be made as small as possible even in nano scale.

So that even a molecule or smallest particles can be directed.

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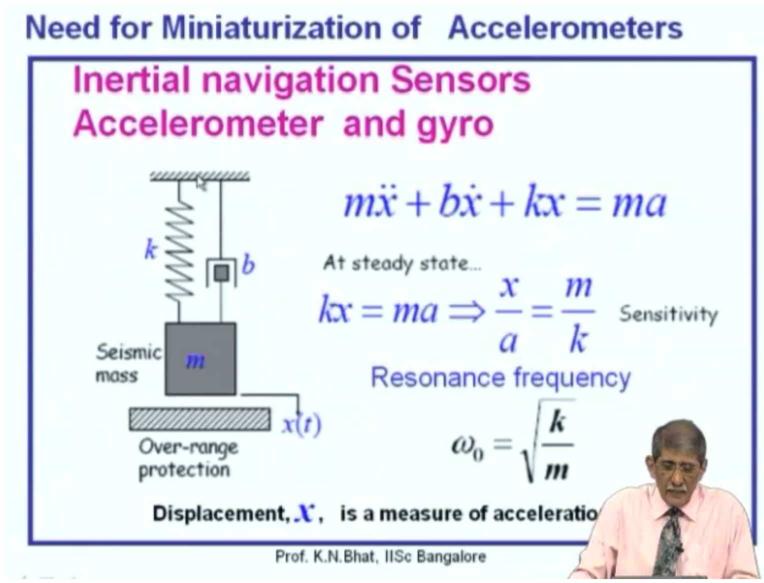

The next one, I am just touching upon these miniaturized accelerometers. A quick look at that, you would have discussed it already, but you know that this is an accelerometer system, is a combination of a spring and a mass and the mass is attached the spring. The spring is anchored to the body from air. So if the mass experiences a force, it will get elongated. It will be going down in that direction if you force in that direction.

The mass will get pulled in this direction till the force exerted by this acceleration, that is mass into acceleration is the force, is balanced by the spring with a force = K into x. So in equilibrium condition, K into x, x is the displacement, K into x will be the force, mass into acceleration. In dynamic conditions, you will have a second order differential equation. For steady state condition, you will have Kx into m into a.

So x is related to x by a, which is actually the sensitivity, displacement divided by acceleration will be related to mass and K. K is the spring constant, which depends up on the dimensions of the spring. How it is realized in the case of micromachine devices, we will see in the next slide. Now take a look at this. Here you see a diagram like this, which shows the damping. After all, if the mass is moving with respect to another plate with a gap, if the mass moves down in the direction, there will be air in between.

The air film will get squeezed. We are talking of gaps of micron between this mass and this plate, so the air film will get squeezed and that will prevent the force, which opposes the movement of this, that is called damping. It is like resistor in a resistance. RLC circuit, if you take, inductor is equivalent of mass, spring constant equivalent of capacitor and this is equivalent to resistor.

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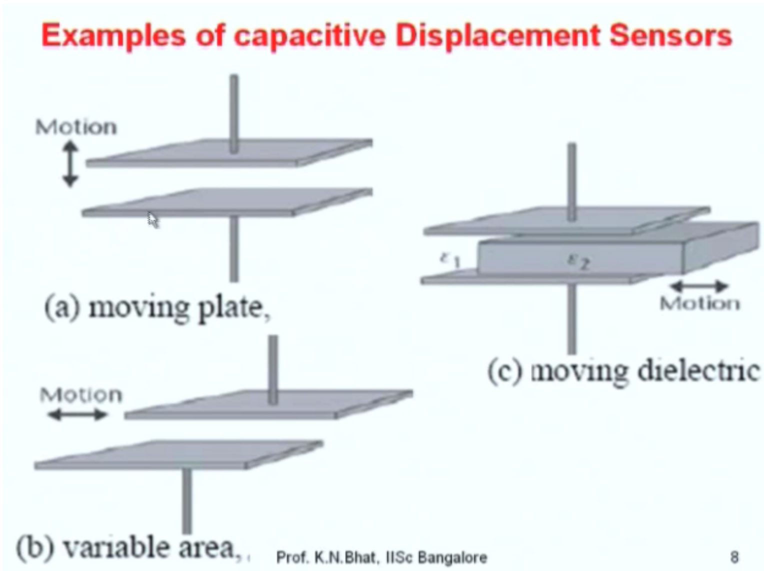

Now what you need to do is, you have to measure the displacement of the mass. Going back to previous slide, what you want to measure is how much is the displacement x for a given force. So if I measure the displacement x, knowing this mass and the spring constant, I can find out what is acceleration, what force is. So the entire theme of accelerometer is based on measuring the displacement. There are several ways of doing that.

One of the ways of doing this is, this is a movable plate. This is a fixed bottom plate. You see the movement of this plate by measuring the change in the capacitance between the 2 plates. Either vertical movement or if this plate is moving laterally, then you can see the area overlapping is changing, capacitance is changing.

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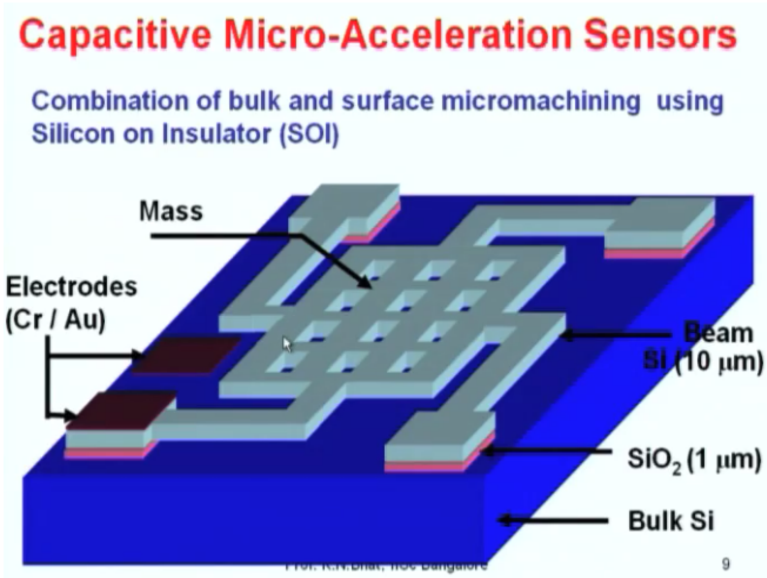

So find out the change in capacitance to determine the displacement and ultimately the force or the acceleration. Now, this is structure of a micromachined accelerometer. Here, this particular region, the central one with holes is the mass. The hole is provided to adjust the damping between the mass and this bottom plate. So when it moves, if there are a sufficient number of holes, the squeezed film damping can be adjusted by adjusting the number of holes.

There are other purposes for the technology maybe when Professor Vinay discusses, it will come into picture. So this is the mass that we have been talking of and these 4, 1, 2, 3, 4, these beams are equivalent of the spring, which are holding the mass by means of the spring and the spring is anchored to this body by means of the red color, which is oxide. That is electrically the spring is isolated from the body, but mechanically that is connected through this oxide.

So you have this mass hanging by the means of spring attached to the body through this anchor. So this is the capacity accelerometer. So this mass is free to move up and down in the vertical direction, because below that there is a micron gap. 1 micron gap is there below that and the only portion where it is holding is this red portion, that is the anchor and you can measure the capacitance in the bottom electrode and this top electrode.

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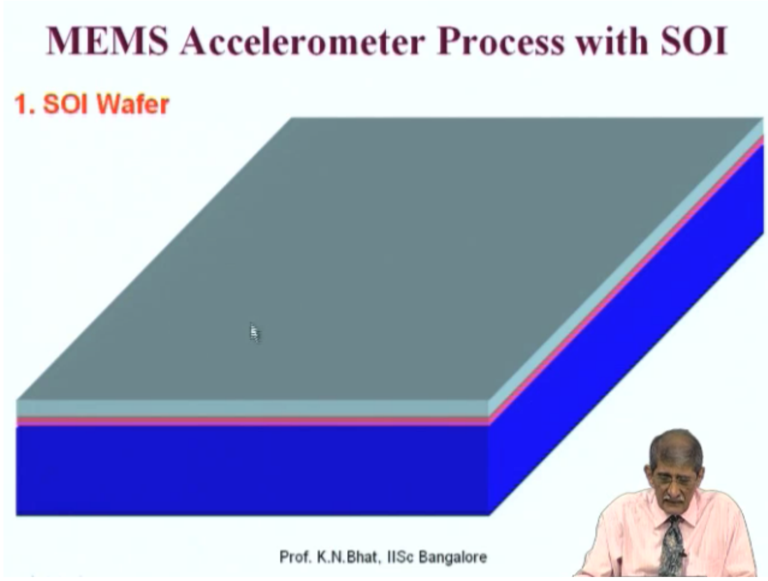

The way it is made you can just quickly see that this started this silicon, the entire thing is silicone, top is silicon, red is oxide, this is silicone. Now by means of a technique of photolithography, you can pattern this top layer, etch silicon from the regions where you do not want the silicon that. You can see that previous slide you had this color everywhere, now we have removed the silicon from everywhere else except in these portions.

Next, now what is happening is you have this mass and spring everything attached to the body. You dissolve this oxide by dipping in hydrochloric acid and retaining it below these anchor portions like that. You can see the red color retained here, all oxide from here is gone. This mass is free to move up and down that is accelerometer. So we can put metal contact here to make the capacitance measurement. Now this is a accelerometer. I will not go into details of that.

Now what I want to show is this accelerometer is based on capacitance sensing. The capacitance is a non-linear sensor, because as the deflection takes place on this particular plate and this plate gets deflected, the capacitance increases because the gap between this and bottom increases and this is inversely proportional to distance between the 2 D, as a result is non-linear. So if I go to higher and higher acceleration, the capacitance versus your acceleration will not be linear.

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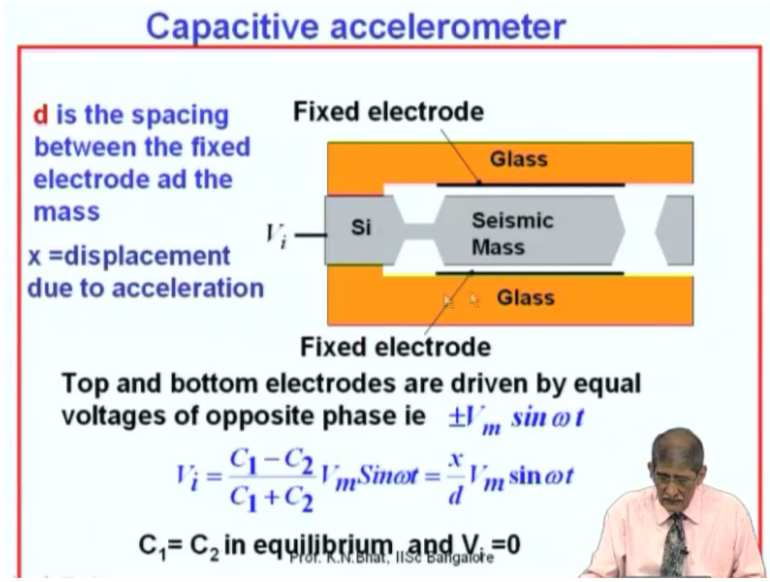

So what you do is, instead of using one plate like that use a mass, which is called as Seismic mass. Seismic is referring to earthquake. So these mass can be used in this type of accelerometer, can be used to sense even the very small low frequencies, which are seen or experienced during the earthquake. So this is the mass, which is anchored here. This is a glass. It is different from the previous accelerometer, which I showed. So this is the mass, which can move up and down.

So now you can make a microsystem because you need to convert this capacitance into voltage. So you need to have an accelerator and also you can have further electronics to ensure that for example when this mass moves, let us say up, due to an upward acceleration, it moves up. This is a metal electrode. The capacitance between this and the mass actually will increase because the gap is reduced. Capacitance is inversely proportional to the gap between the 2 electrodes.

So that is reduced, the capacitance will go up. Now, because this has moved up, the gap between this and the bottom electrode has gone up. Therefore, capacitance has gone down. So what you do is, by means in a microsystem, which I have discussed in detail when we discussed details of signal conditioning, I will bring in that. here, I will just give a flavor of that. So when it moves up, what you do is, do not worry about whatever I have written here, because we will bring that later.

What you do is, when these moves up, you sense that change in the capacitance and if you apply voltage between these 2 with phase difference Vm sin omega t and –Vm sin omega t, you will get a voltage here if the 2 capacitance are different. If they are same, the voltage will be 0. So you sense that voltage that have appeared here condition that converted into DC voltage, apply that to this middle electrode, so that if I apply voltage to these middle electrode with respect to these other 2 electrodes, this voltage between the 2 will decrease.

Therefore, this when the voltage between the 2 is decreased, what happens is the middle plate will move down, because after all the capacitor force or electrostatic force depends upon the voltage between the 2 electrodes. If I reduce the voltage between the 2 electrodes, already there is zero voltage here. If I increase this voltage here, the difference between the 2 voltages is reduced, therefore force of attraction is reduced. So the middle electrode will come down.

If the middle electrode will come down, ultimately what happens is if the feedback mechanism takes place till this middle electrode is pushed back to the neutral position. So then at that point, you would apply certain voltage to this middle electrode. You will find out what is the voltage that we applied to the middle electrode. How much voltage you applied to the middle electrode is the voltage that you applied to the middle electrode to bring the electrode back to the original position.

That voltage gives you the force that you once applied back to this middle electrode and this is exactly the force this has experienced in upward direction. The force upward direction was the acceleration force. The force downward is the applied voltage by a feedback circuit. So these 2 are balanced. So you measure the voltage that is applied half CB square by D, that is the force that is applied electrostatically that gives you an idea of the force and the voltage that you need to apply is the force you need to bring back into the neutral position.

So now you can see, you can use it for very small signals to large signals, without the capacitance changing too much by bring back to neutral position. So no non-linearity will be absent in this situation.

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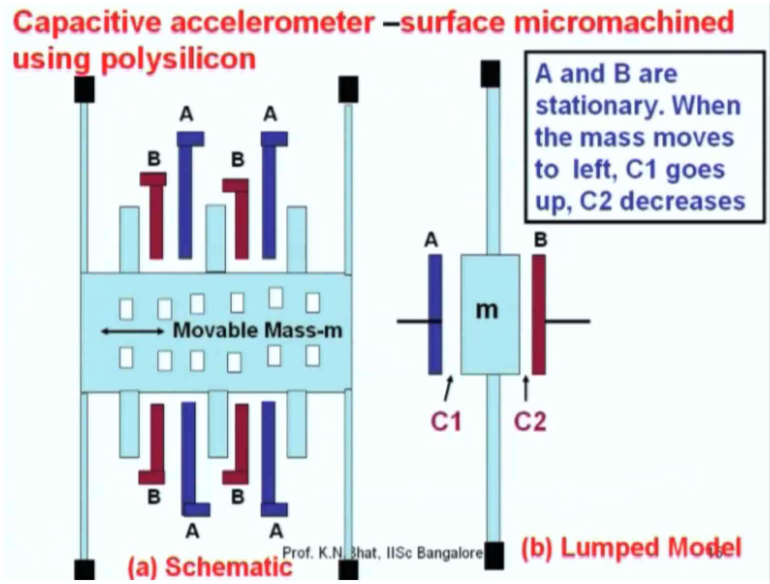

Now these are variations of that. I will have occasion to discuss this later. The previous one was the 2 electrodes, which are on both sides of the mass and the mass are moving only in the vertical direction. Now this is actually a mass, which is anchored in these 4 portions. The rest of the thing is able to move in this direction, in the horizontal direction, like that and these are the fixed electrodes and each electrode marked A is connected together to form one electrode.

The electrode connected are marked B is connected together to form another electrode. So if the mass moves into the left, you can see this electrode A and the mass, this flange of this mass come closer together. Looking at this equivalent representation, if the mass moves to the left, it comes closer to A, this capacitance increases and what happens to the capacitance between this and this, B and this. If this moves to the left, the capacitance between A and M, mass increases.

The gap between B and M because it increases the capacitance falls. So exactly the same thing that we described for that previous slide happens between the 2, the capacitance increases between the 2 capacitance falls. So use electronics to bring this back to the neutral position and measure the voltage that we apply to bring it back to the neutral position, that voltage is measure of acceleration. I will have occasion to discuss in more detail when I talk about similar condition.

And the actual schematic diagram of the entire system is like this.

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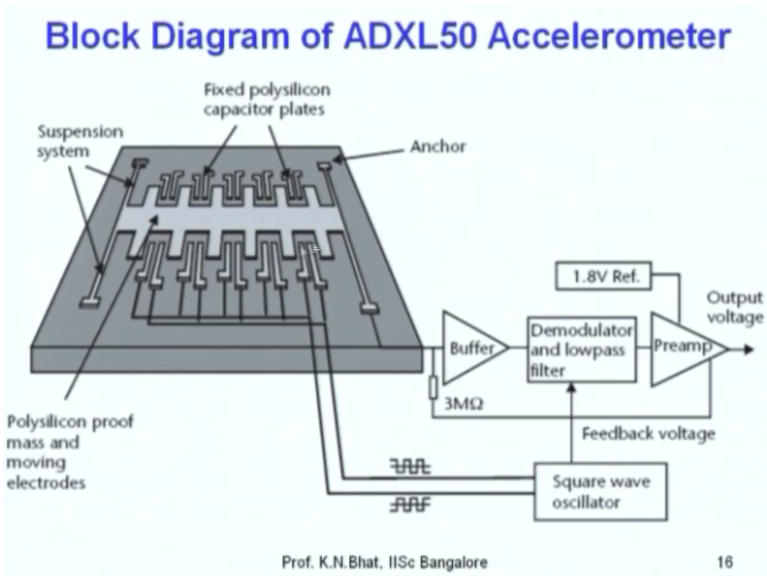

This is the block diagram of the ADXL50 accelerometer of analog devices, which is used for releasing or deploying the airbag in a car. You can see that this is the mass, which moves. These are the fixed electrodes and both are connected together to ensure that it can measure the capacitance between one electrode and the other, between the 2 you can do in this electronics. We will come back to this later.

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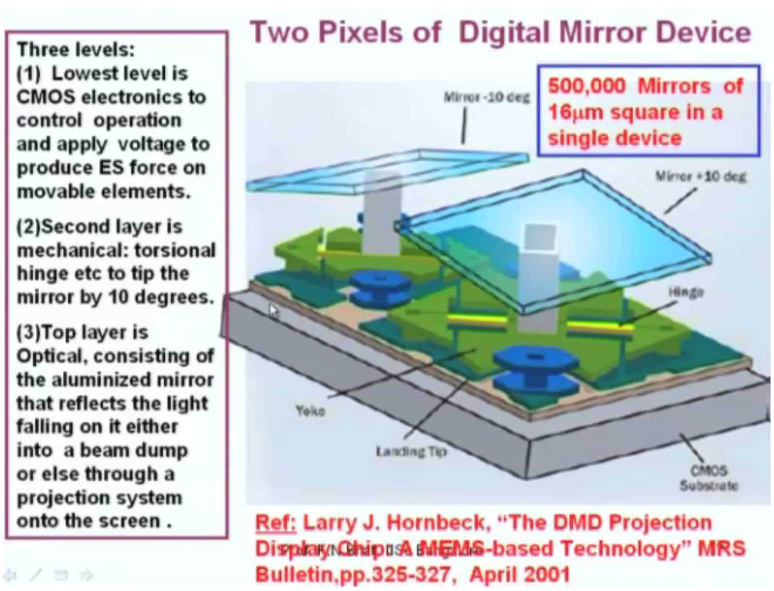

This is another system, digital micro mirror devices, which has, this is a very classical example of a micro system, which has lowest level. 3 levels are there. Lowest level is the CMOS electronics to control the operation and apply voltage to produce electrostatic force on the movable elements. This is a movable mirror. The top is the mirror. This is the CMOS circuit, which is present there. You do not see anything there. I am just showing the bottom level.

Then, you have all these second level is the hinges, etc, which can tip the mirrors, 10 degrees this way that way, so what happens is, there is a light source, which is split into red, green and blue, now depending upon the intensity that you require, these mirrors are tipped by means of electronics in this bottom circuit that tipped so that into the screen either you get red, green or blue or combination of the 2, to control the intensity.

This is actually the precision system, which we usually see and thousands of them are sold. These are available commercially in the market.

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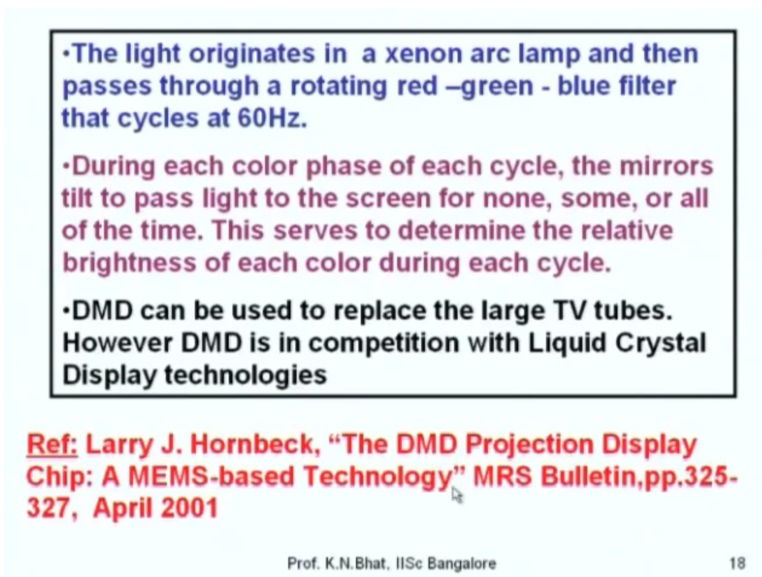

This has come in the journals as a DMD projection display chip, MRS Bulletin in 2001 April, it has appeared. You can take a look at that. Another system, which is very well known is the mirror for optical communication system. You must have heard of the fiber optics communication where the signal is transmitted through the lights and light is transmitted through the fiber through total internal reflection, it can be transmitted.

Now when you want to use it for telecommunication, you need switch to transfer a signal from one fiber to another fiber. Usually what you will have to do would be convert this optical signal into electrical signal. First what you have done is at the transmitting end, you have the electrical signal converted to optical signal. It goes through the fiber and when you want to transfer it from one fiber to another fiber, you need to have a switch.

One way of doing it is convert this optical signal to electrical, convert the electrical signal back to optical and transfer it to that, but it is all very difficult situation, you may lose some bandwidth. You may lose the speed. It is almost like traveling by train and when you see a river, you have to get down from the train and get into a ferry, which is slow, go to the other side of the river, get into the train, like optical to electrical, back electrical to optical.

So that is the example. So instead if I have a bridge over the ferry, I can go by train from one end to the other end very comfortably. So what you do is do not use the electrical switch, use an optical switch. What is an optical switch. It is a mirror. So you can see these are 256 mirrors, which are used and all these small ones are 0.5 mm diameter mirrors. The spacing between the mirrors is about 1 mm. What you show here is actually the needle, to show the size of the mirror.

The needle hole is here, size of the mirror is of that. This is to show the dimension. So several of these mirrors are mounted like this. It can be deflected by electrostatic activation. So optical signal coming here is bounced on this mirror into a reflector and it is bounced into another mirror, which goes into this fiber. So signal is transferred from this fiber to this fiber through optical switch. You do not lose any band width. You do not have loss of speed.

It is straight transfer, only this particular, there is electronics to control this particular mirror. These are made up of usually aluminium. It can also be made up of silicon. This is an optical communication. This is a system, you know, which was realized by set of instruments.

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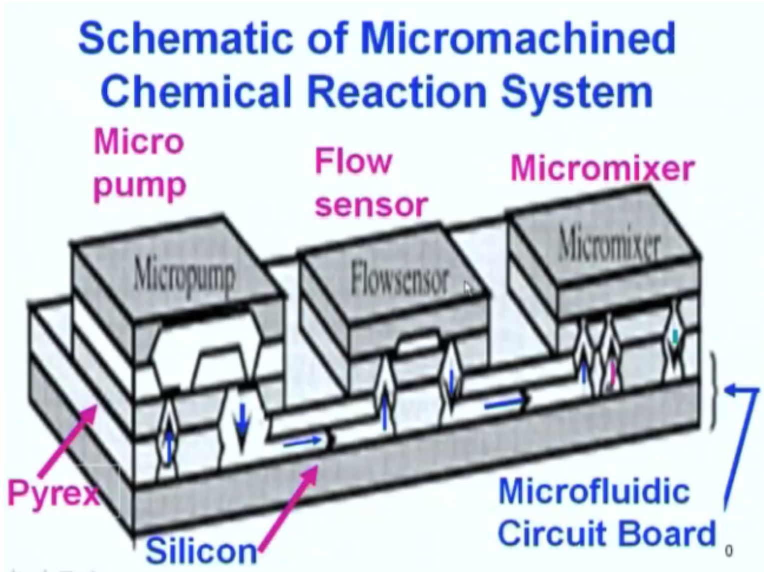

Another microsystem, I am just giving you some examples of microsystem. This is actually a chemical reaction system where you want to initiate a reaction. Normally when you want to initiate a chemical reaction or make a chemical reaction, you need large quantities of chemicals, mix them and then bring in the reaction. Now, you can do that in very small quantities by using a micropump and you can monitor the flow of individual.

I am showing one fluid line where one micropump pumps the one fluid and the flow is measured by means of a flow sensor and a mixer into which several such lines are coming in and mixing. So you can initiate a chemical reaction using this system. You can also synthesize chemicals in small quantities. Now let us see what each one of them.

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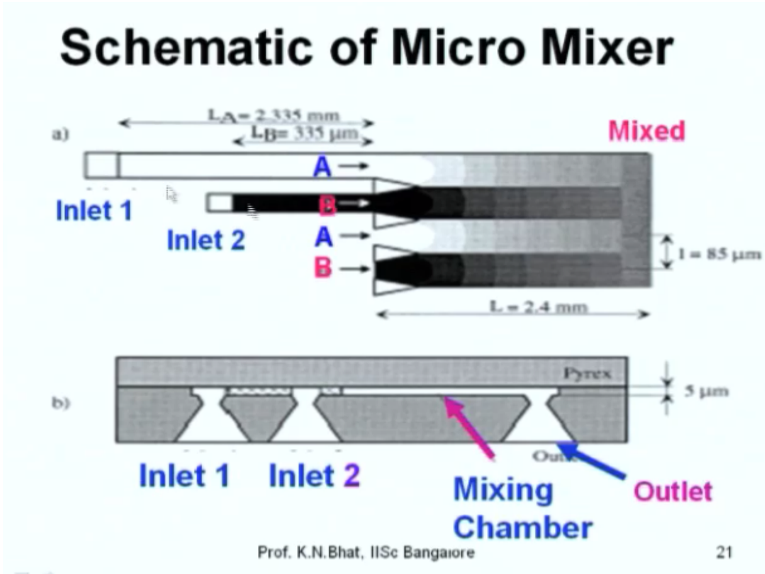

I just went in to show you the mixer. That is where all the chemicals come. So this is actually, there are different channels, which may be on glass. These different channel A and channel B are there. There one type of chemical comes in and another chemical comes in through another channel, this is the cross section where it flows in and comes in and mixing is done in this chamber. Both inlets are here. This is a mixing chamber.

It is not very clear, but what you realize is that 2 channels on the glass or silicon come and merge here in this chamber and they mix there. The reaction is initiated either for analyzing or synthesizing the compound. This is where the synthesizing compound comes here, that is the mixture and these can be done in micro scale. The dimensions can be few microns width, microns depth, very small quantities of fluids will flow and the flow will be really laminar flow in this case.

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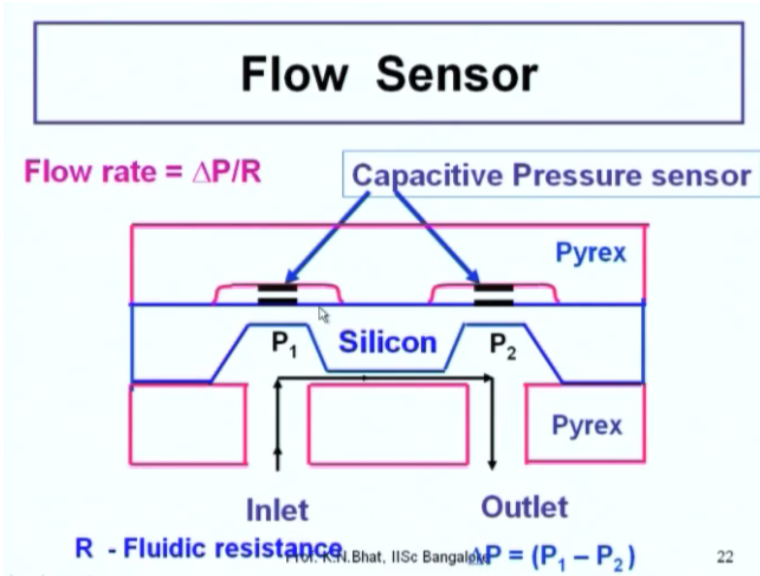

Now the other one, there are 3 components, I mentioned. One is the mixture where different channels will come and merge. The other one is flow sensor in each of those channels. You can just understand this flow sensor from the principle of flows like a current in electric circuit. If you know, if you have a resistor, if I apply voltage across the resistor, the current through the resistor will be voltage by resistance.

So here in fluidics, the flow rate is equivalent of current and equivalent of voltage is the pressure. This is the channel a gap through which the fluid flows and this is where one of the pressure sensors is located at the inlet and at the outlet you have another pressure sensor. In between you have a channel equivalent of resistor. So you monitor the pressure P1 and the pressure P2, P1-P2 equivalent of voltage difference, pressure difference.

The flow rate is known by P1-P2 divided by the channel resistance. In the case of electrical resistance, it is rho L by A, rho is the resistivity of the material, L is the length of the resistor, A is the area of cross section. Here rho will be the viscosity or the fluid in the channel, L is the length of the channel, A is the area of cross section of the channel. There may be a multiplying factor, correction factor will be there, exact equivalent of resistor is there.

So you can measure the pressure difference knowing the channel resistance by calibrating, we can estimate the flow rate, which are in micro-liters, otherwise there is no way of measuring that.

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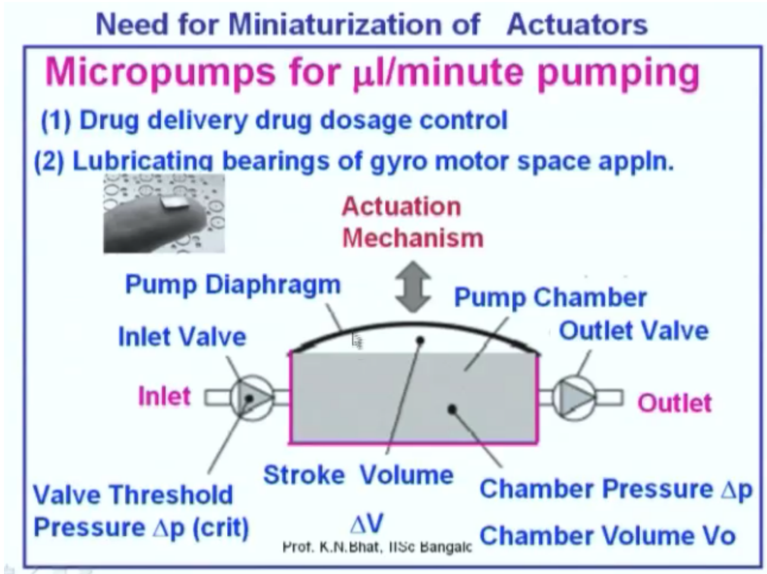

This is a micro pump. So you will have several micro pumps going through the channel, and the flow sensor and through the mixture and the principle of that is a chamber and a membrane, which can deflect and moved up and down and a inlet valve and a outlet valve. The valve will open only in this direction, inlet. This valve will open only in that direction, outlet. This is the size of the pump on a thumb, that is what we are talking of, for bio-medical application, space applications.

So the membrane goes up the pressure drops and this is atmospheric pressure and this pressure is reduced because the volume increases by this amount. So this valve will open, fluid will enter, then if the membrane is pushed down deflected down, then the pressure increases, the fluid will flow out.

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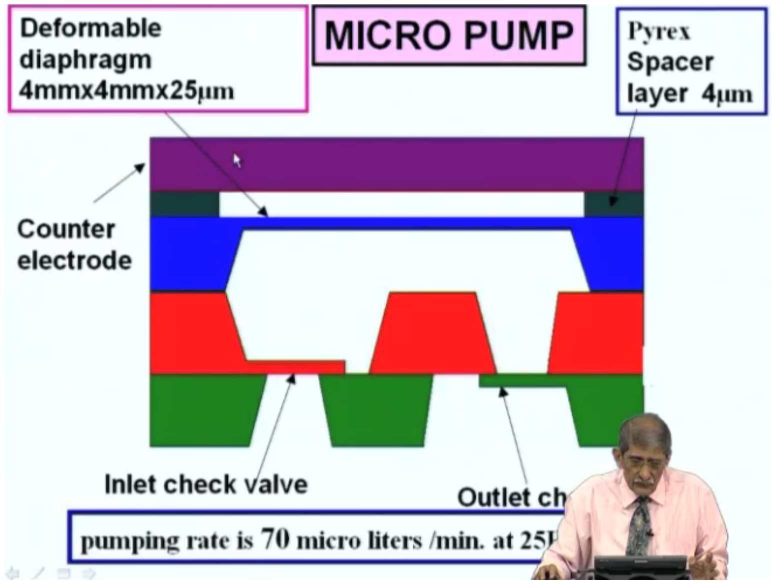

Now let us not look at this diagram alone. You can take a look at the actual micro pump. This is the micro machine micro pump, there are 4 different colours, 1, 2, 3, 4. In between there is a dark colour. 1, 2, 3, 4 they are silicon wafers. The entire size of this micro pump is 4 millimetre by 4 millimetre and this entire thickness will be each of them will be 200, 200, 200 microns thick about maximum it is 1 millimetre thickness, 4 millimetre by 4 millimetre by size and very small, on the thumb you can have it.

This is the membrane which can deflect up and down, the centre one, and if I apply voltage between these 2, this is thick, top one counter electrode, it is resist. This is about 25 micron. So there is a force of attraction between the 2, which I can introduce by applying an voltage between these 2, then this membrane will deflect up, because it is thin and there is insulating between the 2 that is pyrex or SIO2.

So there is no electrical contact between the 2, so the voltage. This is the air gap. This can deflect. In fact it is well understood by taking a look at animation. So this is the chamber and this is the inlet check valve and this is outlet valve. This valve cannot move down. It cannot move down because this is blocking it. This cannot move up because this is blocking it. These are silicon wafers in which there is a flat membrane, thin layer of silicon there and there is a hole in that and these 2 are bonded together by a technique known as wafer bonding.

And these portions are created by etching the silicon. Those details, I sure, Professor Vinay will bring in. So each wafer is taken and micro machine to create the structure. This is machined to create this structure and these are bonded together. That is called wafer bonding technique. Now let us go into the operation of this. Please remember apply voltage between the 2, this will deflect up. It will increase the volume inside the chamber and the pressure will drop then this will open up.

Now you can see the animation. This is the valve which can move up, this can move down. The membrane can get deflected when I apply voltage. I applied voltage. Now you can see, just watch, this particular membrane gets deflected up, because of the applied voltage between this and this, the insulating layer. The volume inside this chamber has increased, and the volume inside has changed, increased the pressure has dropped.

This is atmospheric pressure outside and this is kept in contact in the channel where there is fluid. So because of this pressure difference, this will open now up. Once it opens up, because this is in contact with the fluid, the fluid will enter, you can see the light colour there as the fluid has entered. And once that has entered, you remove the voltage the membrane will deflect down, because there is no more electro static force.

Once the force is removed the pressure has increased, because the chamber there is fluid now, the pressure is more, therefore this is closing and when pressure is more, because this moves down that moves down now, so the fluid goes out from that. So with one stroke what has happened is, this valve is opened, let the fluid in, then is come out. I will show you the entire thing, the one stroke where the membrane has moved up, allowed the fluid flow, moved down, allowed the fluid to flow outside into the channel, through this like that.

That I will show with one single animation. You can see now, just keep watching the entire one cycle of operational door. That is gone through the whole thing and a volume corresponding to the deflection of this membrane has flown in and flown out.

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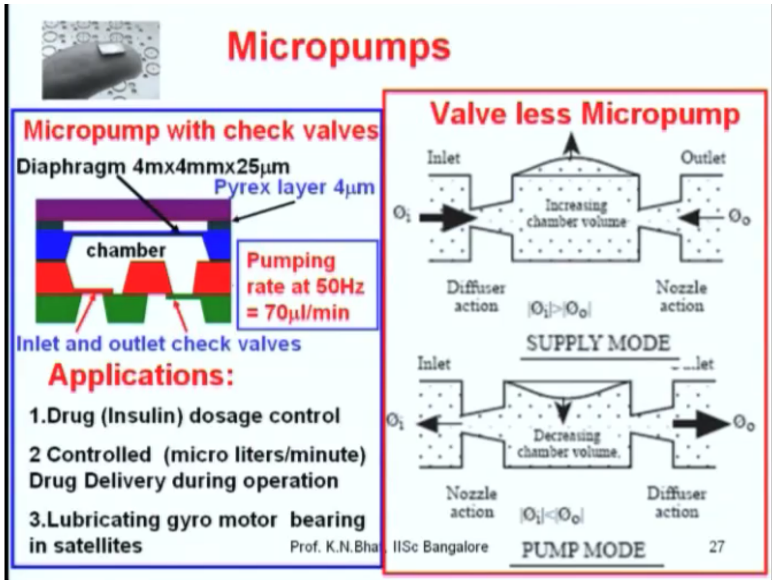

Now, this is the micro pump which we have discussed just now, and in that particular system that I have shown the flow rate is, pumping rate is 70 micro litres per minute for that dimension. How much is the flow rate would depend upon, what is the frequency of the voltage that we are applying. One stroke you will have small quantity of flowing. In one minute, how many cycles are there, it is 50 hertz, 50 cycles, you have 70 micro litres flowing.

So what you get is the fluid flow, more the frequency, more number of times this membrane move up and down, and more will be fluid flow. But you cannot keep on increasing the flow rate here, because there is a limitation of these valves, they will not synchronize, they will move slowly, therefore you will be able to operate it at 50 hertz or 100 hertz, depending upon the dimensions of these phalanges or these switches.

This is used for drug dosage control, or drug delivery during operation, very minute quantities of drug to be delivered during some cancer operation, etc. or lubricating gyro motor bearing in satellites. That is the micro pump with valve. You can have micro pump. You do not like this valve is moving up and down, in that case you can use valveless micro pump. What you see there on the right hand side is the valveless micro pump.

Here is a dynamic valve, for example, the membrane is here. This is a chamber, you can take a look at it what I am showing here, membrane moves up, the fluid will flow this, and there is no valve. There is no check valve. So fluid will flow from both the valves, the only difference is, this is a diffuser the duct size keeps on widening. The fluid flow will be more in this direction compared to fluid flow in this direction.

So both are in contact with the channel. So fluid will be flown in both directions, but because this is flowing more here, less here there will net flow into the chamber. Now if I bring the membrane down by electrostatic force or by Piezo-electric actuation, the pressure increases fluid will flow both outward from the chamber. You can see now, this is widening in that direction so fluid will be flowing more in that direction compared to fluid flow inside.

So what happens is, there is a net fluid flow from this end to that end, when you finish one stroke, it will go up, net flow in that direction and it goes down more flow in that direction, net flow is from left to right depending upon how much that stroke volume of this membrane. This is the dynamic micro pump or valveless micro pump, which is very popular in ECE department, some of us are working on and a couple of students are working with us, myself and professor (()) (40:45), but on this micro pump.

If you want to use this micro pump for biomedical applications, for drug delivery or for some other applications, you would like to make it biocompatibly if you really want to make it inverse you, then you want to use that biocompatible, so this material can be some polymer type of material.

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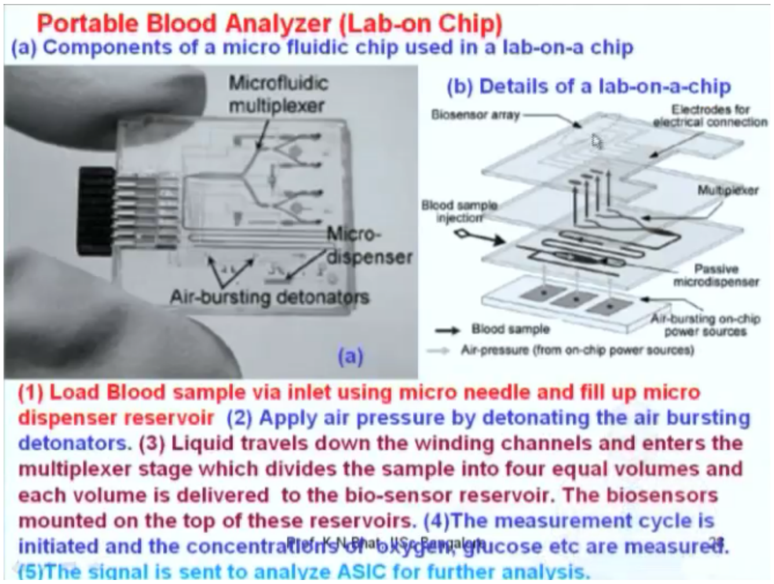

Now the other one that I want to mention here is the blood analyzer. This is a very classical example of a microsystem, which is also called as the lab on chip. The lab on chip here is not very clear there are multiple things. One is if you break it up in to subsections, you can see there is a region where you can inject blood sample via this inlet using microneedle and fill up the micro distance here, the reservoir. So how do fill up these small quantities of blood.

The whole idea is you must be able to test the blood, complete analysis of the blood. You must be able to do wherever the patient is, even in a remote place, you can take a small quantity of blood, put it into use this lab on chip, to analyse that blood and see how much sugar is there, how much oxygen is there, etc., etc., concentration of glucose, oxygen, etc. some people measure that is called lab-on chip. The entire chip can ease the lab itself.

Whatever you have in a big lab, is brought on to this small chip. So here you can understand this is better by splitting this into this reservoir where you inject blood maybe a couple of drops, air pressure is applied by detonating the air bursting detonators. You have some air pocket, which is put into this just right below, you need an actuator for that. So that will be contained in this. So you do that, once the air pressure is applied on to this blood stream, the liquid travels down the winding channels and enters the multiplexer stage.

This is the multiplexer stage, which divides the sample into 4 equal volumes and each volume is delivered into a reservoir. So that entering here, flowing through this channel, entering into a multiplexor, which divides into 4 equal volumes, deliver into 4 reservoirs, over which you have got this bio sensors and the measurement cycle is initiated and the concentration of oxygen, glucose, etc, are measure using an ASIC circuit, which is connected outside.

So you can see, you have got actuator, you have got a bio-sensor, you have got electronics here and you have got a channel there to see the lab-on chip. It is a very good example of a microsystem.

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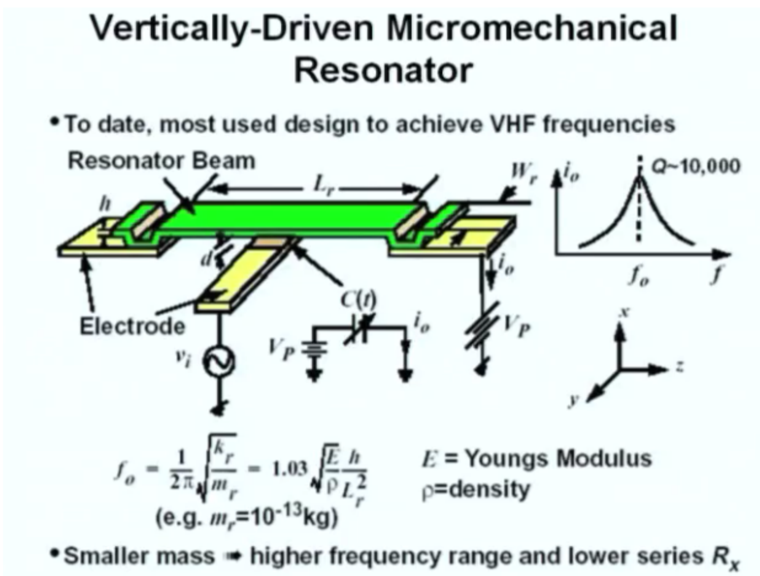

Now the last of the thing I want to discuss today is the filter. When you say filter, it is an electrical filter. If you see a signal passing circuit like the transreceiver. If you take your mobile, it is able to transmit signal, it is able to receive the signal and they are all at high frequencies, modulated signals. You must get from that high frequency, the voice signal. So you need to filter out some of the high frequencies, you need to convert that entire signal back into voice.

So that is present in your mobile system. Now, when you go to those high frequencies, you will have the oscillators, filters, etc. Filters will allow certain frequencies to be transmitted. For example, this shows filter characteristics. If I have different frequencies, the output of the filter is

0 for almost all the frequencies except around the frequency f0, that is the response frequency. A very good example or very popularly used filters are the LC circuits, inductor and capacitor.

Now if you want to use a filter, one of the characteristics that is required for the filter is that this should be sharp. It should selectively pick up the signal. It should cut off all our frequencies. So you will use inductors and capacitors, these sharpness goes off as you go to high frequencies because of the resistance of the inductor. When I say resistance, more peculiarly talking, you talk of a term called quality factor of the inductor or a capacitor.

Quality factor implies energy stored divided by energy dissipated. So it stores energy at the corresponded frequency and energy should not be dissipated. If the inductor becomes smaller and smaller, it will act like an antenna. You know that the transmitters are short antennas then you go to high frequency, short waves. If you have medium wave, you have got mass antennas, which are very long. So shorter antenna behaves like antennas at high frequencies.

Or to put in other words, if a small length of wire, it will behave like an inductor if I go to high frequencies. The frequencies that we talk of are in the gigahertz range or close to that. So very small wire will act like antenna and when wire acts like an antenna, what does it mean. It is losing energy instead of storing energy, it is giving out energy in the form of power, radiating energy.

So it is no longer able to store, that means that quality factor, which is ratio of energy stored divided by energy dissipated goes down. So the selectivity of the filter goes down. That means what I imply is apart from this frequency, many other frequencies also will go through that filter. So to overcome this problem, today one resorts to cantilever beams. It is a mechanical structure. Instead of using inductors and capacitors, electrical components, use mechanical components.

This is a mechanical component, which is a beam supported at these 2 ends and there is a gap between this beam and the other beam, which is going below that. There are 2 beams, one is horizontal like this, other one is perpendicular to that. Below that there is a gap of maybe about a micron between the 2. The property is like that. You apply DC bias between the 2. Now between this top and bottom there is a gap. There is a capacitor.

So when you apply DC, there is a charge stored between the 2. Charge stored is Q = C into V, capacity into voltage. Capacitance depends upon area and the gap between the 2. Now, if once I apply, keep the voltage constant here, there will not be any current flowing through that. There will be a charging current. The current has remained constant. Now if I vary their capacitance, Q = C into V. I keep the DC constant.

If you vary their capacitance by moving that membrane, by moving this top one, which is movable because of the gap. This is the bottom one. With respect to that, I can move it up and down. If I move it, C can change as DC/DT. Q = C into V. If C varies at DC/DT, Q varies as DC/DT into V. So Q is DQ/DT. So there is a current flow through this path, if that beam is moving. How much current flow depends upon the rate at which it is moving and the amount of amplitude of this movement of this beam.

We can call it a membrane, if we like. It is a beam whose dimensions are small. Now what you do is, along with the DC, this is the loop, through which the current flows. I can put my load here, but wherever I want to sense the signal, this is the incoming signal. If I keep on varying this signal, there will be movement of this mass or this beam with respect to bottom electrode. As you vary the frequency, there will be certain movement.

But as I keep on increasing the frequency at a particular frequency, which matches with the mechanical response frequency of this beam, the movement will be maximum. That is called resonance. So when the electrical frequency resonates with the mechanical resonance frequency of the structure, the movement of the beam will be maximum. Amplitude will be large and at that frequency, if it moves, DC/DT changes quiet large because the movement is very large.

Therefore, DC/DT into V, DQ/DT there will be current flow through that and because at response frequency, which is governed by the size of this beam that spring constant and the mass decide the size, decide the frequency. At that frequency, you get resonance and that resonance, you will have the current peaking up. So the principle is that. You have DC voltage and you make the membrane move, or make the mass move with respect to the frequency that you are sensing.

And when the applied frequency resonates with the mechanical resonance frequency of this beam, the movement is maximum. Therefore, DC/DT is maximum. Therefore, this current through this portion is maximum. So you get corresponding to that current flow that can flow through your circuit. So you have selected the frequency corresponding to the resonance frequency here. That is called the resonator. This is the one which people are working out.

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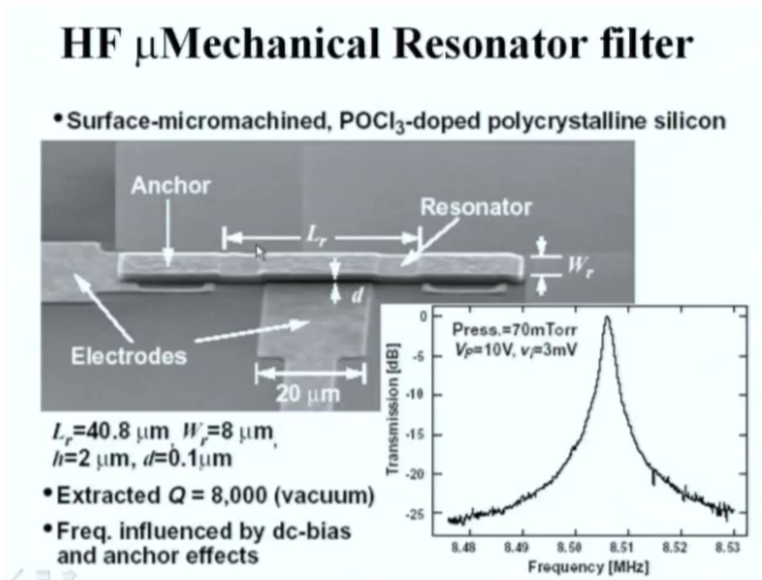

And this is the actual structure, which has reported literature that is beam, which is having gap between the 2. See dimensions are some 40 microns length, width 8 microns, thickness 2 microns, very small and the gap is about 0.1 microns. The resonance frequency of this particular structure is about 8.5 megahertz. Now you would like to have certain frequencies, which over a band width if you want to pass, that is called band pass filter.

This will allow only one frequency. What you do is, use 2 of those structures connect them mechanically like this.

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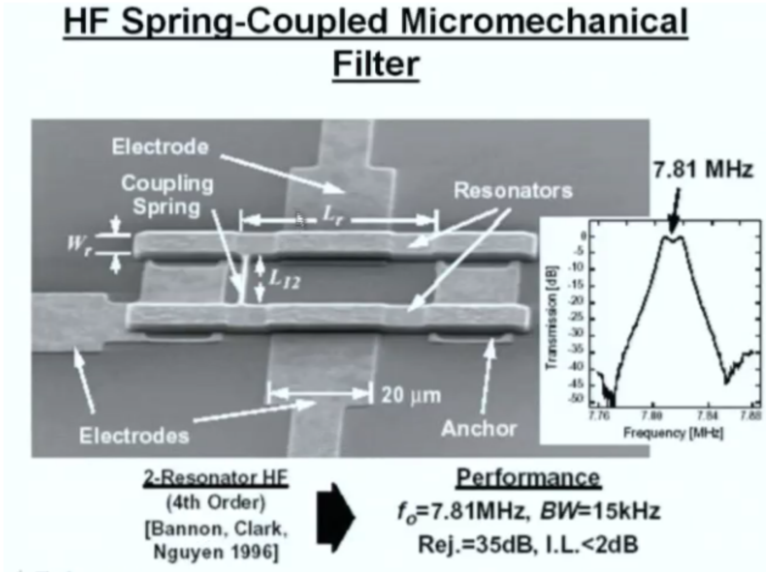

One beam, another beam, there is a mechanical connection between the 2. They will be moving, trying to move together. Each one will be pulling together with respect to other frequency, so which is the one frequency, you will get a band of frequencies that is called band pass filter. So use this band pass filters in all your trans receivers.

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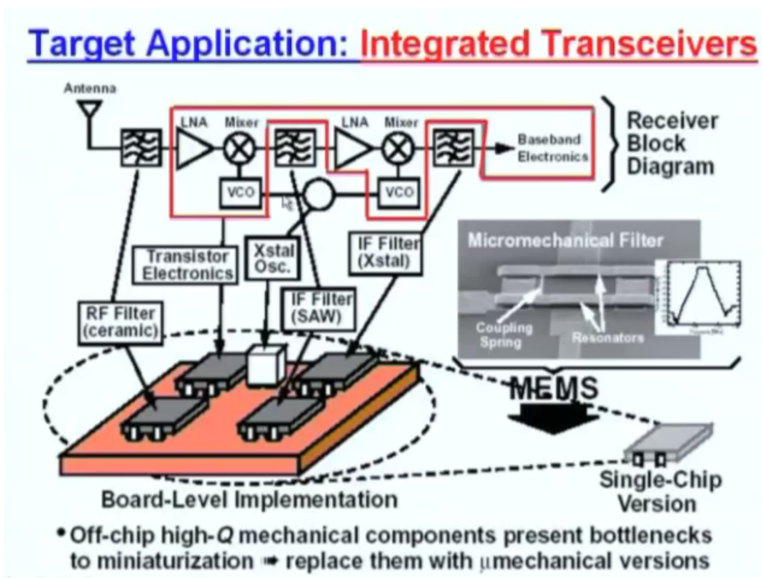

Now do not get frightened, this is actually the trans receiver in your mobile. All these within that is electronics and in addition to electronics, all these are filters, ceramic filter, then voltage control oscillators, saw filters. These all take a lot of space. So the goal is to change these filters with small size mechanical resonator so that the entire thing can be made. Where this entire electronics can be put in a single package. It is very small.

If you open up your mobile, you will see that a lot of space taken up by this circuit because of these mechanical filters. In fact, the saw filter will take a lot of volume like this 1 cm by 1 cm will be the space taken by that.

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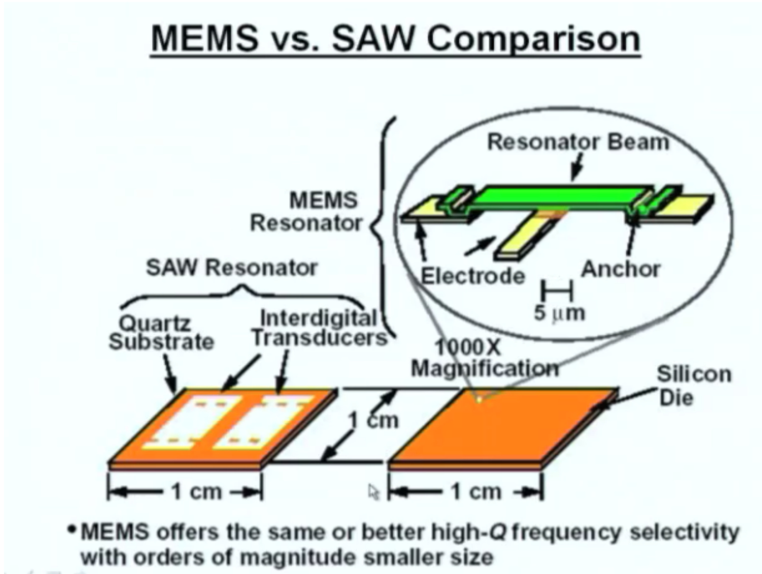

But the entire thing can be taken care of by one beam like that, which is like that. So what is 1 cm by 1 cm can go in by a few micron size here. So going back to the previous slide, this entire thing, the goal is to replace the entire thing by means of one such structure like this. you can have many more of them to represent different frequencies that are size can be reduced and quality factor will be excellent provided the whole thing is put inside a vacuum.

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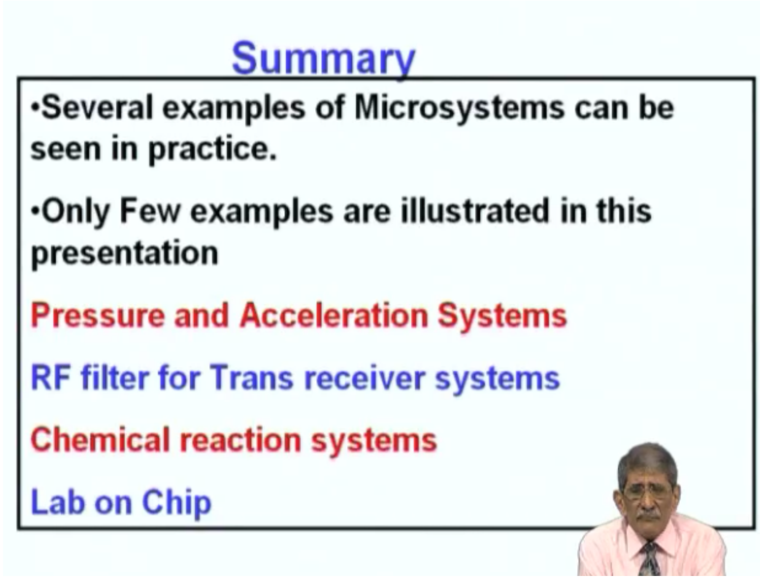

So in summary, I have given you several examples of micro systems, one few examples are illustrated in this presentation. I have illustrated pressure sensor along with electronics as one of the systems and acceleration system along with electronics for air bag actuation etc. I also illustrated the RF filter, resonator or trans receiver systems, chemical reaction system where you have got a pump, channel and mixer, lab-on chip, the classical example of a micro system, where you can actually use this for testing the blood of a patient far away from the civilized realization.

Even in war front or even in remote village, you can take this and make use of it for testing the blood. The components of the blood in the blood of the patient right there. Thank you very much. I think we will continue on some of these things in subsequent lectures.