Electronic Packaging and Manufacturing
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Lecture – 30
Thermal Management 9: Novel Cooling Technologies

Welcome back, today we will conclude our discussion on thermal solutions, Thermal Management and Cooling solutions ok. So, if you recall in the last class we talked about some of these regular or more commonly used cooling technologies starting right from heat sinks then, we looked at cold plates, we looked at thermoelectric, we looked at heat pipes. So, these are you know solutions may be with the exception of thermoelectric peltier coolers, but the others are pretty widely used. Even thermoelectric coolers are used though not though not as common as the others ok.

Now, but today what we will do is, we will do two things one is we will look into the aspect of what is called system level cooling.

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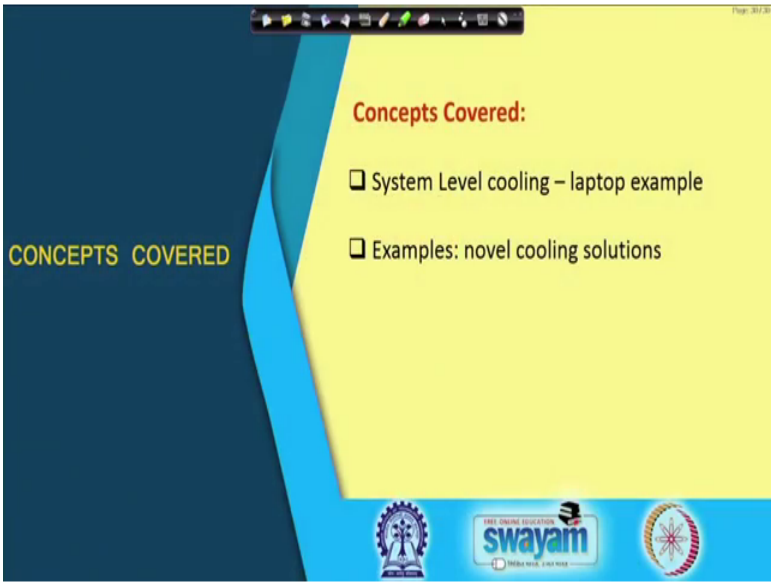

See so, far we were only talking about I need to cool a CPU or I need to cool a graphics chip. So, these were all certain component level cooling solutions ok. So, today we will see that what about system level because there are multiple components to be cooled. So, what are the different constraints what are the different limits that, we need to conform to or that we need to comply with as a thermal designer ok.

So, will take the example of a laptop computer its a generic case, but even though the example is that of a laptop many of the constraints that we are going to talk about are applicable to other computing platforms as well or for that matter any other electronic platforms many and we are also going to talk about a few examples of novel thermal technologies all right. So, with that first we will move on to as we said system level cooling.

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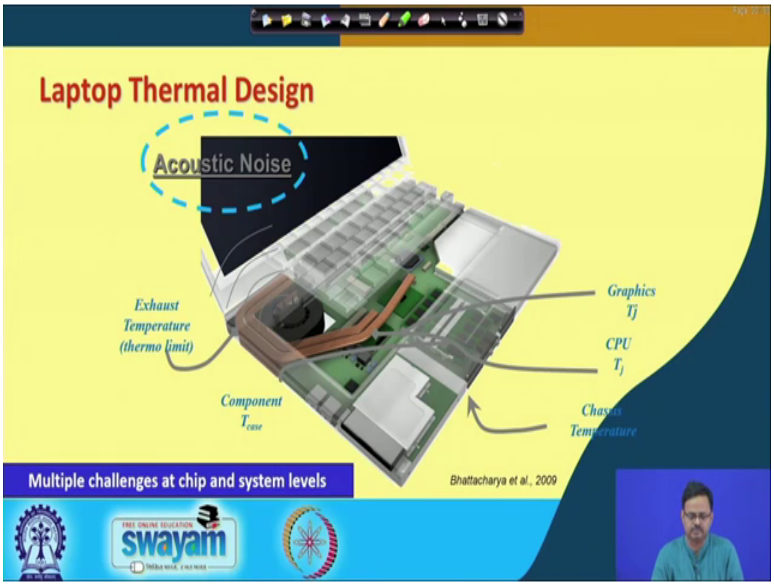

If you look at a laptop thermal design what all do we have. So, you see a bunch of stuff written here. So, if you look at this figure what we see is over here we see a heat pipe which is attached to the CPU there is another second heat pipe that is a to another heat generating device or component.

And then they are going to a fan right here is the fan and then you have these faint heat exchangers or heat sinks over here ok. So, how is this cool? Now laughs cut from laptop computer works on what we call the evacuative mode in the sense that it sucks air inside through the various vents and holes that we see in our laptops.

If you look if you turn your laptop upside down and look at the bottom chassis well be able to see these strategically placed vents ok. So, as this fan runs as its powered on and it runs it actually sucks in ambient air, that ambient air coming through the different you know openings and vents actually flows over the different heat generating components ok, it can be memory, it can be you know some of the lesser power dissipating components it can be the voltage regulators and as it flows over it picks up heat and then finally, it reaches this location of the fan where it is pressurized.

So, the pressure goes up recall the fan pq curve. So, fans job is to pressurize the air and then it is thrown out through this heat exchanger and as it goes through the heat exchanger it also picks up the heat that is transported by the heat pipes from these components ok.

So, again for certain high heat dissipating components such as CPU such as graphics we have what we call a dedicated cooling solution in this case a heat pipe connected to a fan helix fan heatsink arrangement, but many of the others. For example, this memory this platform controller hub the wireless lan so, these depend on the air movement as the air gets into the inside this system and flows over that air is you know absorbing the heat and then bring to this location and then dissipating it and throwing. So, what comes out therefore, is hot air because the air that entered is ambient air, but it has picked up heat from all these components as well as from the CPU which was conducted to the heat sink or heat exchanger by the by this heat pipe.

And then it is thrown out all right, now what are the limits that we need to conform to. So, one is Tj recall that the junction temperatures every component will have its own junction temperature that needs to be conformed to. Some of the components which are plastic molded or which has a ceramic lid, you do not really find a lot of ceramic packages in your in your very in your laptops for example. But here the limit is on the case remember the case Tc that case temperature is on the lid or the heat spreader ok. So, these have their own limits for example, Tj can be 100 degrees or 105 degrees T case for a memory which is a plastic encapsulated device or component is going to be let say 85 degree centigrade ok.

And these have to be conformed to what else and now this is where the constraints of having a portable device like a laptop comes in see the hot air that comes out should not be. So, hot that it burns your skin ok. So, there is therefore, an exhaust temperature limit which is also known as the thermodynamic limit or thermal limit why is it called thermodynamic limit? Well come to that or we can say it right now actually. So, remember if you have remember the fan and system impedance curve and the operating point is a point of intersection.

So, what is the system impedance what is a system here whose impedance curve we need to consider that is flow through this entire laptop the bottom unit of the laptop computer and the fan curve of course, is what comes with this blower fan ok. So, now, the total amount of mass flow rate or volume flow rate of air and therefore, mass flow rate of air which is density times volume flow rate for a given volume flow rate.

What is the total amount of heat that I can dissipate? It is q equals to m dot Cp which is a specific heat times the exhaust temperature of their minus inlet temperature which is ambient exhausted. So, therefore, if I put an exhaust limit let us say 75 degrees in a 30 degrees ambient ok. So, 75 minus 30 is 45 times the mass flow rate times the specific heat of air that gives me the total amount of heat that I can pack inside this box, this laptop the sum total of the power dissipated by all components cannot exceed this thermodynamic limit that is set because of this exhaust temperature limit for a given mass flow rate.

So, therefore, now your next question is fine, but that is for a given mass flow rate. So, I can always run the fan at a higher RPM supply more voltage run it at a higher RPM and have more mass flow rate fair enough. But then what prevents you from doing that is acoustic noise because higher the rpm higher is going to be the acoustic noise and nobody wants to work close to a very noisy laptop right.

So, therefore, the maximum RPM of the fan and therefore, the maximum flow rate that I can get is limited by the acoustic noise ok, if that was not all there is a final temperature limit which is known as the chassis temperature. I should be able to put the laptop on my thigh I mean on my lap without burning it without the without the danger of burning my skin just like the exhaust temperature limit ok.

So, there is there multiple challenges at both the chip and the system levels and that is where we need to play a balancing game I can have a very good cooling solution I follow for therefore, the CPU and put in a lot of power in the CPU, but then my thermodynamic limit will become or will pose a constraint to the power that I can have on the other components ok. So, will have a very powerful CPU, but accompanied by a very low memory a very weak wireless lan not so, good graphics and so on ok. So, this is the balancing level this balancing game that we need to keep in mind ok.

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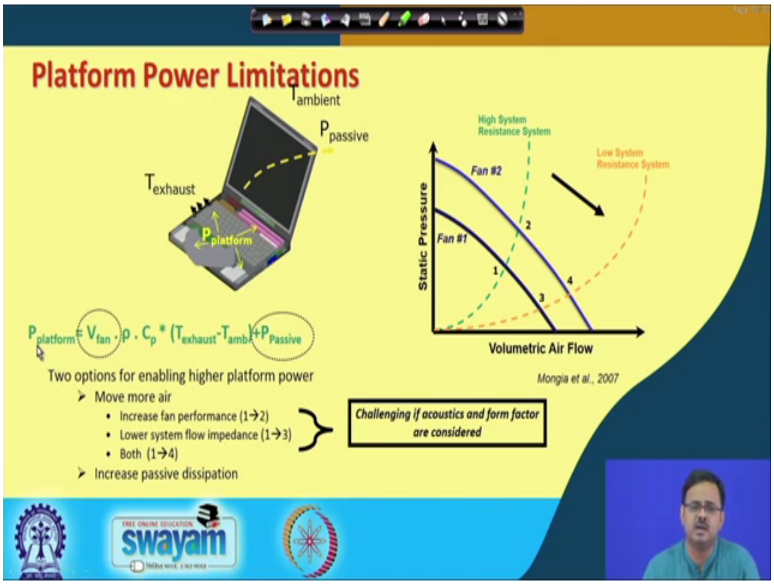

So, let us look at platform power limitations what our platform power limitations ok? So, what is the maximum total power that I can dissipate from this system ok. So, the platform power is going to be the mass flow rate times specific heat times the exhaust minus ambient plus a little bit of natural convection from the hot surfaces whether its the screen whether is the keyboard ok. Now what is this fan flow rate going to be that is going to be this intersection point of the fan and the system impedance curve.

So, now, if that is constrained how can I increase this platform power, I can either move more air and how can I do that if I want to move more air I have to either increase the fan performance that is go from fan 1 to fan 2 or I have to lower the system impedance that is go from this system in this green system impedance curve to this orange system into the impedance curve or do both right.

So, if I change the fan I go from point 1 to point 2 which has corresponds to a higher volumetric flow rate or if I change the system impedance curve I go from 1 to 3 or if I do both I go from 1 to 4, but if you think of it practically going from fan 1 to fan 2 is challenging if acoustics are concerned ok. If acoustics are considered then probably I cannot go to fan 2 or basically or shift the fan curve from 1 to 2. On the other hand if I want to lower their system resistance curve what do I have to do? I have to reduce the flow resistance through my laptop, but if you look at the trend where we want to go for thinner laptops actually the trend is the opposite, the thinner you go and the lesser internal clearance we have higher will with my system resistance for flow.

So, the system impedance curve actually is shifting to the left not to the right. So, therefore, moving from either fan 1 to fan 2 or system resistance curve green to orange is challenging acoustics and form factor are considered. So, what is my other option, the other option is to increase my passive dissipation. So, let us complete that if you want to do passive dissipation then you have to think of some other ways how can I increase the passive dissipation from the keyboard from the screen.

But there also you have limits because if the keyboard is very hot the palm rest where you put your rest to your palm when you are working on the laptop and you cannot even operate on the keyboard then that does not help or they the screen becomes too hot let us say I am able to get some of the power back on the backside of the screen and dissipate it.

But if that gets too hot then your you know the visual effect the screen display we under certain temperature is going to be going to get affected, but this is what I am trying to say what are the what are the mean ways I can increase or I can have a more powerful system these are the ways how we are going to do that, that is the challenge ok.

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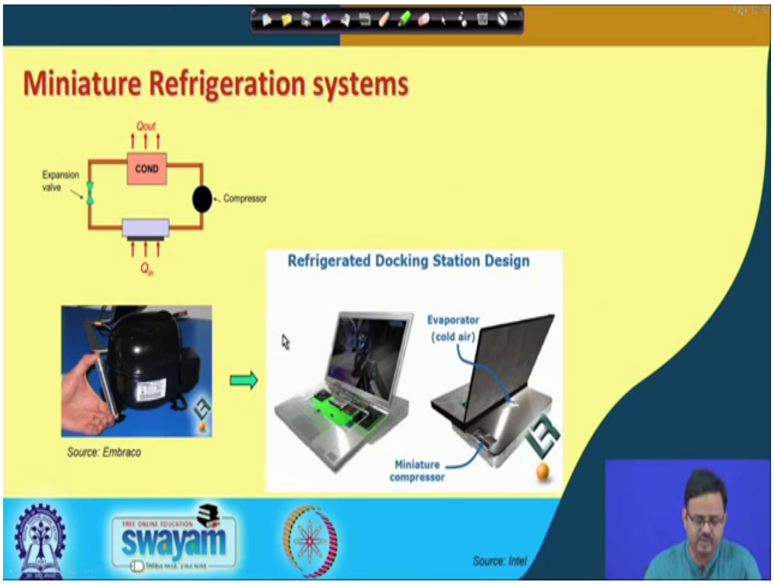

Now, what we will do is well shift gears. So, that was just to give you an overview of what is the system level thermal design what it involves ok. Now let us look at some of the shift gears and look at some normal cooling solutions refrigeration we talked about that, but this one is actually a pretty unique refrigeration system you want to put it inside a laptop and this was done at Intel if you want to do this then think about it if you think of a refrigerator household refrigerator.

The prime component in a refrigeration cycle is the compressor now the compressor if you look at it it is probably you know this big about a foot in height about 8 inches in diameter extremely heavy ok. How do you put that inside a laptop? So, that was the challenge and here this was again a collaborative or Intel work with a manufacturer called embraco who designed a miniature compressor.

So, it was co designed by Intel and embraco it is probably the size of a you know double a cell battery cell that we use in torches ok. And what they did was they put it inside the there are two options one is to put it inside the laptop that was possible and that was also demonstrated by Intel, but the problem is that there were some reservations about you know having a refrigerant inside this portable computer what if it leaks what if what if it is not fully sealed so on and so forth ok.

And what about vibrations because you have a reciprocating compressor inside so, then what the said was you know the other option was to put it in the docking station you have a docking station where I mean especially people who work in the corporate world we use docking stations pretty often right and where the computer docking station is a port replicator you go and put your laptop there and then to the docking station you can attach a keyboard, a wireless, a display in a bigger screen.

And its just a port replicator and you also have a feature of keying in or the locking the computer and take the key away. So, that it is also secured then what was thought of is you know many a times when we run these high end gaming or high end computations we are mostly at our desk and where the laptop can be in the docked mode can be on the docking station I am not really mobile at that point you know I do not do a high level computation sitting in a cafeteria there I primarily do some web surfing check my emails maybe do a power point presentation ok.

So, any high level workload is typically done when there is high probability that you will be in a dock condition. So, therefore, the idea was move this refrigerate refrigeration based cooling solution to the docking station ok. So, what happens? So, that is what you see this is the docking station on the right hand side this is the docking station and you have miniature compressor inside and you also have the refrigeration loop the evaporator and condenser ok. Inside the refrigerator inside this docking station sorry the entire refrigeration system is inside the docking station and what it does is it acts as an air conditioner. So, the air which was coming inside the laptop which was which is otherwise at ambient temperature is now pre chilled.

So, therefore, instead of coming in a 25 degrees it can be chilled to let us say 5 degrees or 10 degrees and so, it is already chilled. So, think about it platform power m dot Cp T exhaust minus T ambient is what we wrote now it is with tm sauce minus T inlet which is 15 degrees less than ambient ok. So, if the exhaust temperature was 75 degrees in a 30 degree ambient you had a delta T of 45 degrees to play with.

So, that time some mass flow rate times the specific heat was your platform power limitation and plus a little bit of passive dissipation, now if I am able to pre chill the air down to 10 degrees. So, I get additional two. So, the limit is 75 minus 10 instead of 75 minus 30. So, instead of 45, I was 65 degrees delta T to play with 65 degrees temperature gradient to play with from 45. So, do the math you see it is almost about 45 percent increase in the platform power right.

So, that is what is possible. So, refrigerated docking station design all right very very not just of course, our technology challenge of having a refrigeration loop of this size and now even a larger one and even now a very clever or innovative one where they move this refrigeration based cooling into the docking station ok. So, for large gaming systems etcetera this is the perfect solution.

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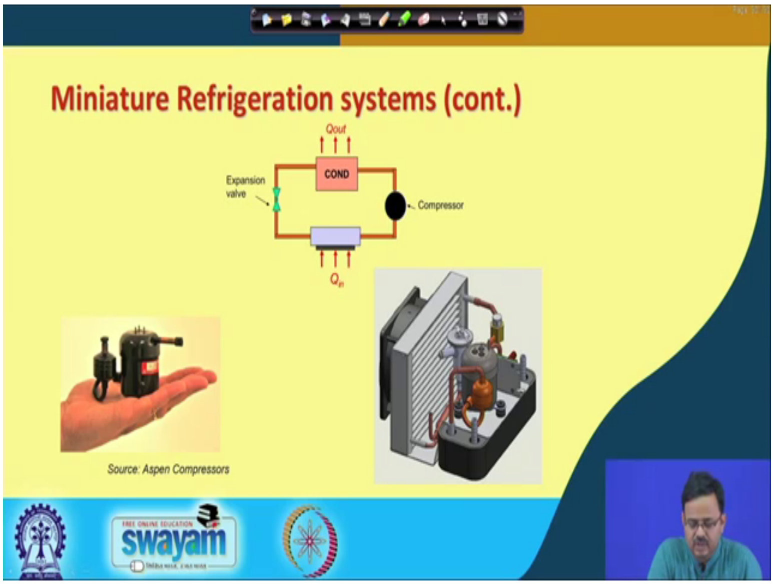

This is another one the previous one was you know a battery shape it compressor this is a regular compressor except that it is so, many its so, miniaturized. So, this aspen compressors make these and you can see you can you can use this in a variety of applications Intel large telecom installations refrigeration based designs in various electrical appliances is short in maybe in small refrigerators in medicine cabinets so on and so forth.

So, lots of lots of such applications was it maybe even battery pack force for stationary ones not for hybrid electric vehicles probably I do not know because, this compressor will not hybrid electric is still electric vehicles this compressor is going to consume power which is going to come from the battery. So, you are trying to cool down the battery to increase this efficiency, but in the process you are also using the energy from the battery to run this processor.

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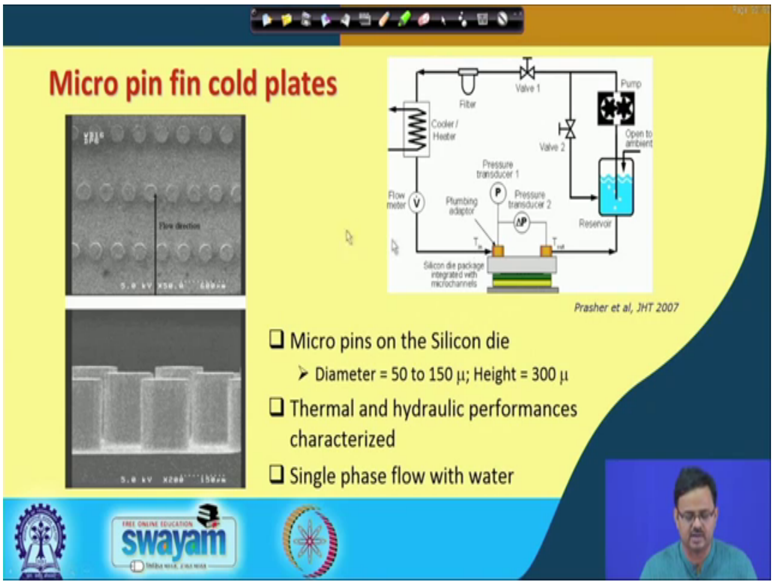

So, I do not know we have to do some trade off, but for static installations where batteries are required this is possible all right. Micro pin fin cold plates we talked about cold plate and now you see this cold plate is directly in the form of micro pillars edged on the backside of the silicon. So, instead of a cold plate sitting on you can have this right away on the silicon now just put a lid and have this water flow through these you know this micro micro pins as in the directions shown here ok.

So, that is possible it is also possible as I said that in the previous one that it is also possible that as the water or whatever there is a cooling liquid flows through these micro pin heatsink it may start to boil if the heat flux is high enough ok. And boiling heat transfer the heat transfer coefficient is very very high.

So, it can be single phase it can be 2 phase. So, the 1 that was that I am taking this figure from Ravi pressure right now in Lawrence Berkeley lab in USA we used to walk away. In fact, he was my technical mentor when I first joined Intel in USA right after my PhD. So, Robbie was Ravi has been a you know he is one of me one of my great mentors in my career so far. So, this is one paper that was he where he was a lead author on micro pin heat sinks force for cooling of microprocessors ok.

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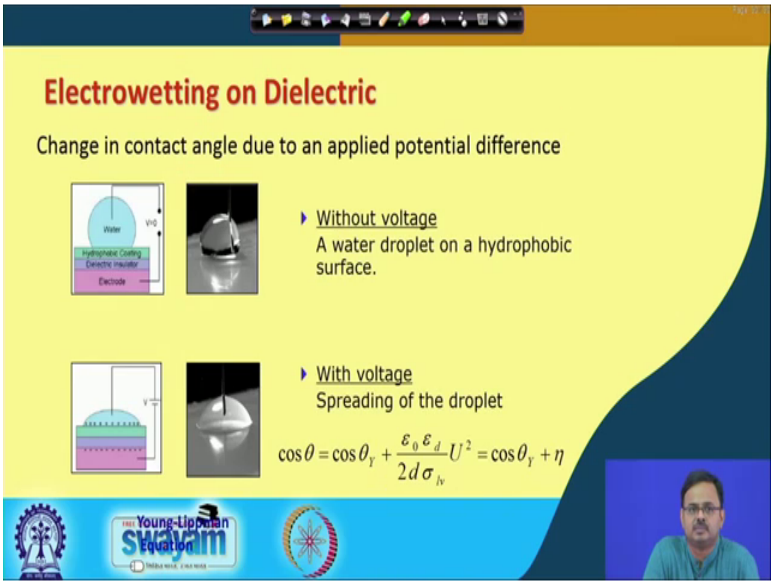

Electro wetting on dielectric, very interesting this is where we are trying to make a water droplet move ok. So, the basic principle of electro wetting is see when you put a water droplet on a surface and if it is hydrophobic then the droplet is going to stand and there is something called a wetting angle ok, this angle is a wetting angle alright. And if the wetting angle is high then it is called hydrophobic and if the wetting is better the angle is low like an acute angle here then and you see here then it is hydrophilic, it is a wetting surface.

Now what is shown is on the same surface if we are able to create a potential difference just in this manner then it is possible that under the influence of this externally applied potential or voltage the droplet the contact angle or the wetting angle can change and therefore, a hydrophobic surface can be converted to a hydrophilic surface ok.

It is governed by this equation as is shown here the original wetting angle theta y and the modified wetting angle theta as you can see cos theta is greater than cos theta y which means theta is less than cos is theta y sorry theta is less than theta y. So, the wetting angle has reduced ok.

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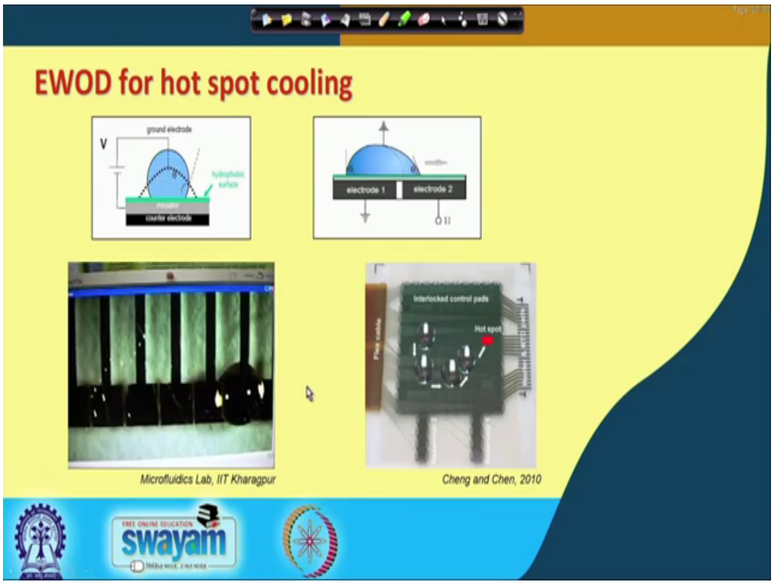

So, now the question is that if you have 2 such electrodes next to each other and I power up one of them by applying a voltage and the other one is not it is at ground. Then on one side there will be an imbalance that the contact angle theta 1 and the contact angle theta 2 are not going to be equal its not going to be a symmetric droplet anymore because one end is resting on a powered electrode the other a trend is restricted on a grounded electrode is is resting on a grounded electrode.

So, therefore, as a result it can be shown by force balance that this creates a propelling for in the forward direction as shown here. So, as a result what happens is there is a movement of this droplet, if you now think of an array of electrodes and you switch them sequentially one after the other the droplet is going to move from one to the next and so on ok. So, there is a this crawling movement of the droplet which is possible as is shown here this is on the right hand side cheng and chen you see a droplet which is mu which is being driven towards the hotspot through this strategic patterning of electrodes ok.

And this one is a video from the micro fluidics lab and let me see if I can play it. So, you have a series of electrodes as you can see one after the other and the droplet is sitting on the first electrode and what we will see is it is going to move you saw that right, it moved from one electrode to the other and it is moving continuously. As the electrodes are sequentially turned on one after the other so, the camera is now again repositioned and you see how the droplet is moved.

So, think about it if I have a hot spot as I shown here and I move this droplet on top. So, as the droplet moves over it will absorb the heat and then you take it somewhere else where it rejects it and again comes back. So, in a closed loop I can move these droplets there are also ways to generate droplets break droplets into smaller drops etcetera all right.

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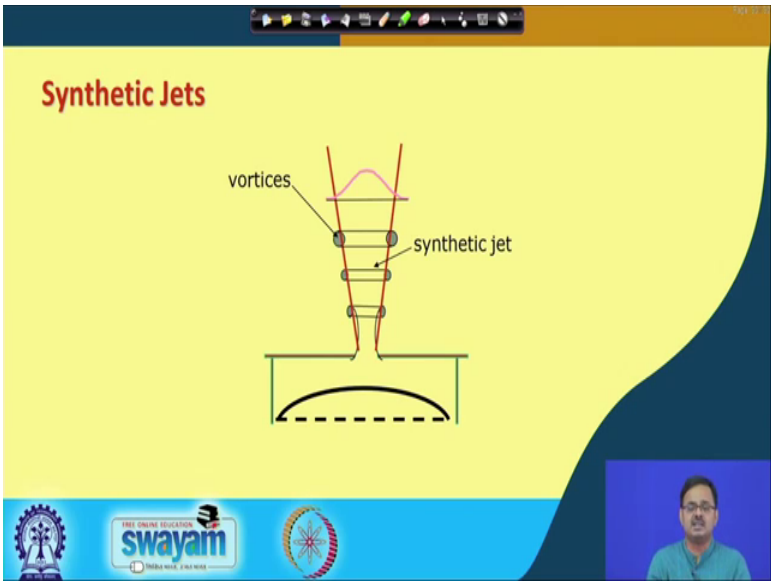

Next one synthetic jets. So, synthetic jets you can think of it as a diaphragm and if you the diaphragm can be made to move up and down and typically the way one of the ways we do that is by attaching a piezo crystal on the diaphragm and then you know putting an ac voltage across it. So, as a result what happens is during one half of the AC cycle when the pseudo of crystal contracts or exertion it expands it basically moves the diaphragm either downwards or upwards. As it moves downwards it entrains air from the surroundings through this aperture and as it moves upwards it throws it out in the form of a jet.

So, think about it this happening repeatedly. So, you get this pops of air coming out and if you can now direct it at the place where you want to cool then you get enhanced cooling at that spot ok. So, this is a principle of synthetic jets.

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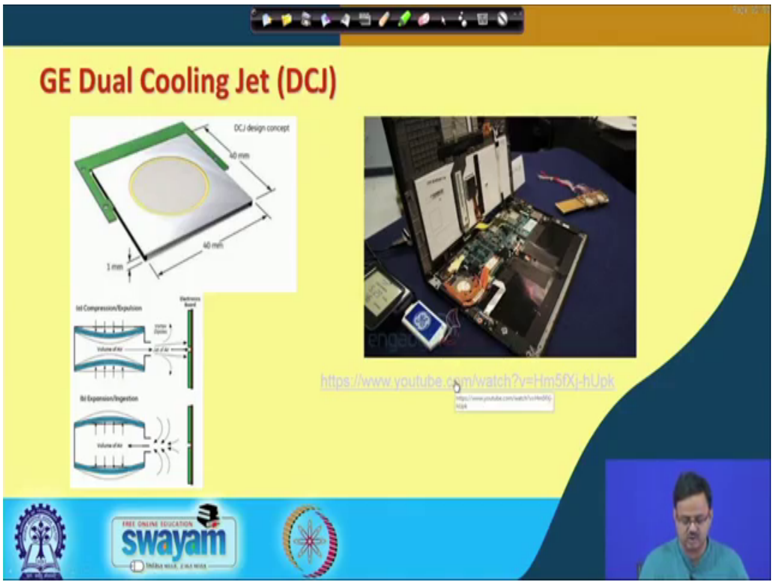

So, here you see this is there I was showing a diaphragm with a with a hole or opening, here you see a plainer synthetic jet it is a slit and you have diaphragms on both sides you see this piezo crystal on top this is actually a concept from GE, GE global research DCJ they call it dual cooling jets because you have 2 diaphragms one at the top one at the bottom and the cavities inside.

So, on one half it kind of the diaphragm caves in oh sorry diaphragm bulges out and it entrance here and then when it caves in it gives it out in the form of a chat and if you direct the jet on an electronic board then you will have cooling right. So, here you see they try to replace the fan inside a laptop you see that you see this heat pipe over here and the fan is replaced by a DC dual cooling jet ok. So, I will show you a video over here from GE.

Well its exciting is that we have developed a new kind of method to move air, but the dual peer school and yet.

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Its an arm over it does not require bearings or does not require a DC motor.

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So, we are enabling the next generation of teen products with this new technology that comes out of our labs.

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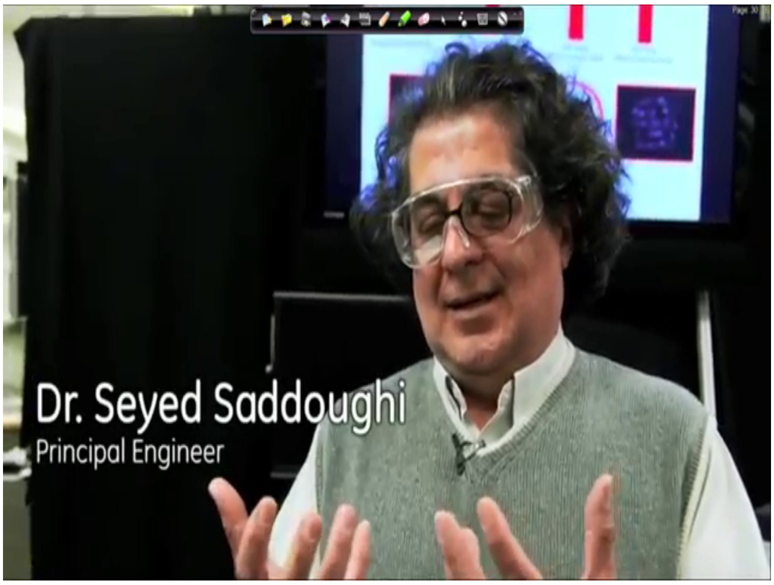

We basically copied nature you will cool jets are really based on the idea of your lungs they basically contract and expand as that happens the air is sucked in through your nose and out through your mouth. So, we copied that to create a synthetic jet.

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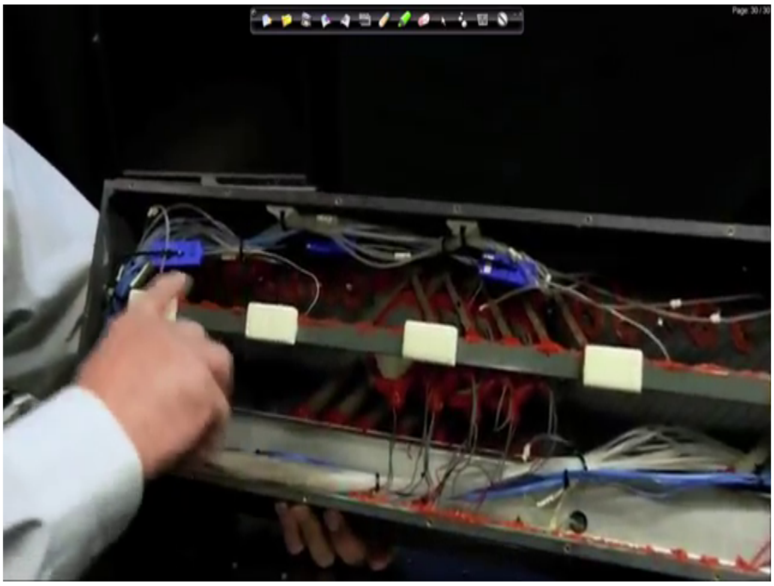

We thought about is there any way that we can actually create these jets in situ to them mainly was active low control for air of milestone for different parts of the aircraft and engine. The dual piece of cooling death is to metal discs with these elements on either side of it by activating the piezo with an AC signal the device can actually pump like a bellows pump, we do that at a very high rate say couple hundred hertz you get a very nice net air flow produced by this device by pulling.

In the air from the surroundings expelling it at high velocity to the center and there are different tricks you can do to make a smaller larger, but the particular concept can be skilled or modified to whatever your application aids are here. Can we have an aviation chassis with 6 tool cooled jets mounted to the frame we have now switched to a thermal infrared image were hitting the chassis to atc and were going to drop that temperature down to around forty c when each dual cool jet is turned on air flows from the orifice.

And will blow up through the fins to the surrounding air thus cooling the internal electronics of the chassis as engineers we like to try new things. So, we actually bought a state of the art ultimate laptop, open it up and replace the fan inside this device with the dual psu pull again. Actually it was a perfect fit there was in the xy dimension a lot of space available to put the jet in in the z dimension we actually had a lot of space left over because the dual quad jet is such a thin solution there is a lot of space left over that allows this laptop to become thinner if necessary or that space could be taken up with other electronics.

This is the first laptop in the world that is cooled by dual ps a coolant yet. Thin is the new fast increasingly today manufacturers are looking to differentiate their products based on the form factor and how their customers are using the computing versus how much computing power is built into the product its a theme towards more power in smaller spaces.

We can put these dual piezo cooling jets into a lot of very hard to reach places. So, its a very localized and very efficient way to cool electronics at the source of the heat generation for people who have a laptop computer in their hands or on their lap they do not want to deal with annoying noises or buzzing.

So, the acoustic profile of this technology its something that we can do based on the cooling that is required its one of the roles that we play in GE licensing is finding synergies between these technologies that initially are developed or invented to satisfy some GE business need, but we can translate those to similar demands and other markets outside of GE that is where GE licensing steps in make those connections ok.

So, I think that was a pretty nice and illustrative video and I also saw some of my ex colleagues Peter, Peter was did a lot of work on this dual cooling jets Brian helped him ably and we also saw side, side was looking more from the aviation and flow control point of view not so, much from thermal cooling all of them very brilliant engineers alright.

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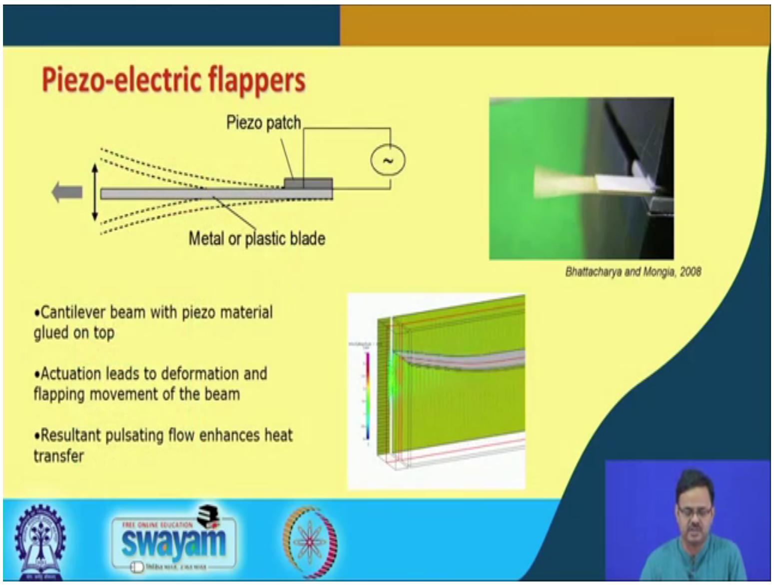

We will end with the last technology which is called very similar to synthetic jets is called piezoelectric flappers. So, think about it its a metal or plastic blade with a pairs of crystal at one end and you put an AC signal. So, what happens just like a bimetallic strip, but; however, what happens is during one half when the pairs of contracts it pushes the, it pulls it upwards pulls the blade upwards in the second one it pulls it downwards. So, think about it when we feel hot what do we do, we take a piece of maybe you know this Japanese fans definitely running otherwise if that is not possible to take a newspaper or or an exercise book and start doing this right. So, its exactly the same thing can I take a piece of flapper take it next to a hot component and blow air.

And if I do that then I will get localized cooling the resultant pulsating flow will enhance heat transfer locally and that is exactly what we see this is a high speed image of one other piece of fence and this is a CFD simulation of the same.

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So, thank you very much I think that just wanted to give you a flavor of really what the GE tagline imagination at work ok. You can really see cooling that that problem has existed since mankind [Laughter] existed, but since the advent of mankind, but then there are always. So, much of scope of innovations and many a times the constraints that we work in the environment the constraints of the application forces us to come up with these new solutions. And some of the examples is what we show there are lots more maybe later if I ever take a course just on thermal design I will be able to show many more of these examples.

But this was just to give you a flavor and tickle your brains and make you think there is so, much of scope for innovation all right. So, thank you very much with that we come to the end of thermal management and cooling solutions and from the next lecture we will go on to a different topic.

Thank you very much.