Design for Internet of Things

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Lecture - 15
Power Conditioning with Energy Harvesters - II

So, let us just conclude on this Solar Energy Harvesting part. Let me give you some numbers which will help you to design systems.

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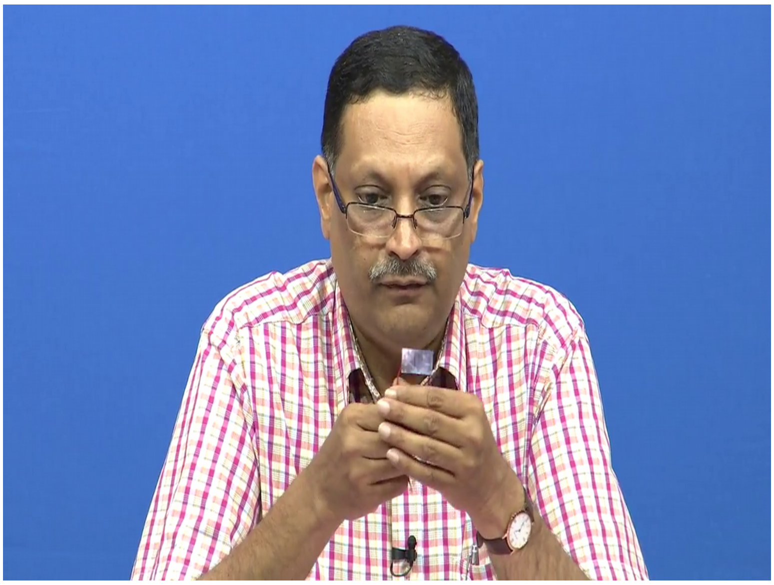

Do you recall that we were trying to play with this yesterday and we were trying to, I was trying to tell you that this is a small solar panel and I also showed you the kind of lux that you will get indoor as well as the lux that you will get outdoor, and all that from our understanding of this particular calculation that I showed you with respect to the area of the solar panel.

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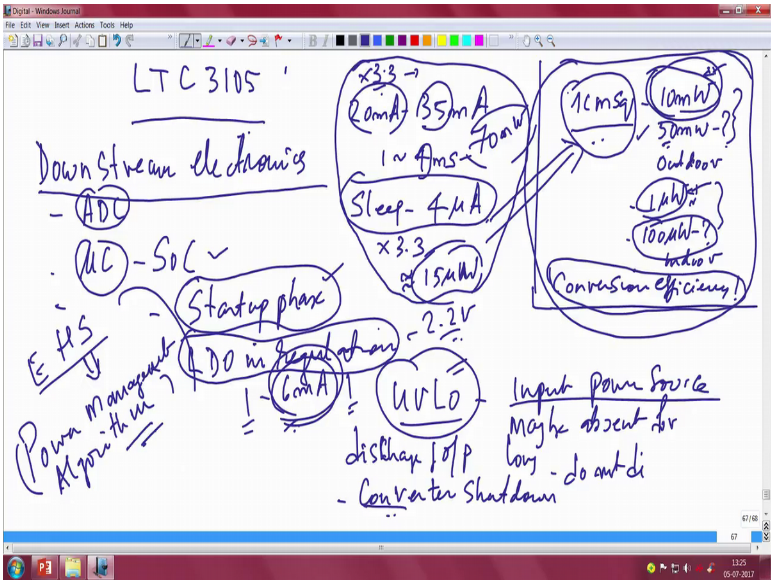

We said that if you have 1 centimeter square panel, you should get 10 milliwatts. So, it is clattered here. So, let me just shift back.

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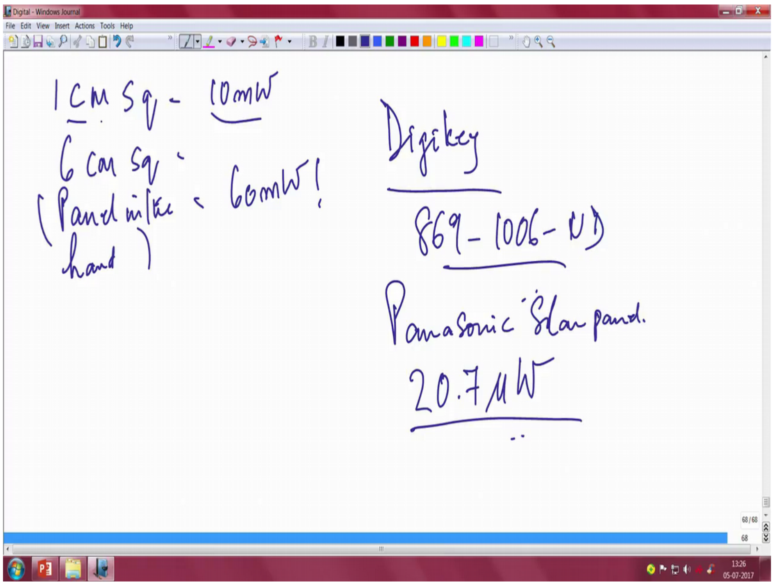

1 square centimeter should give you 10 milliwatt. This is actually 6 centimeter square. In the hand panel in the hand I have just put it here. This should give you 60 milliwatt of power. So, on paper it appears that this should give you 60 milliwatts of power, but I just looked at the manufacturer's specification. This is available in Digi-Key. You can bite from Digi-Key and it has a part number. I can give you 8691006 and this is from

Panasonic, this is from Panasonic solar panel and this base substrate is actually U class. The manufactures claims that this is only 20.7 microwatt panel. Clearly it is not matching to what we discussed about all this 1 centimeter square giving you 10 milliwatt and all that.

So, what is the big summary? Big summary is you have to take the specification of the manufacturer seriously and you have to do VI characterization of the panel. This is the truth. You have to do VI characterization. Once you characterize the VI use, that VI which you have made your own measurement in the lab and use it accordingly for your application. One simple thing that you can actually now go back because we discussed about LT spice simulation with an LT spice and so on.

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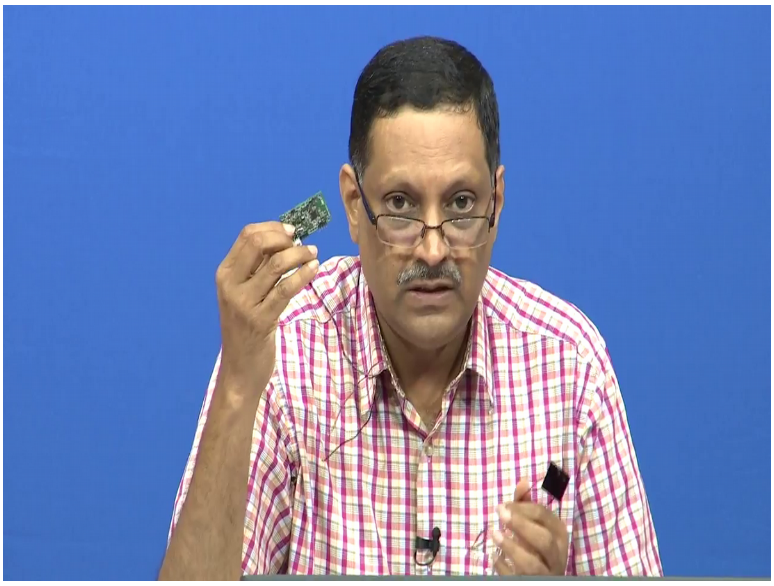

You can actually go back and use this board which actually has the LTC 3105 here and connected to this input here and see actually under practical conditions what is the voltage developed across the output because this has been program for giving you 3.3 and all of that should go into this capacitor, right. This is super capacitor here. Remember that condition monitoring of ball bearings example that we started with, essentially you are trying to harvest from the magnetic field all that.

So, essentially it is a same board. So, the idea is that you should be able to harvest and actually find out how long it takes to change this go back perhaps into your simulation model with the LT spice in LT spice and you know re design back and put back values for the LTC 3105 circuit and re-simulate it. You can either do from implementation, come back to simulation or ideally you should go from simulation to the actual implementation because when you really want to prototype the first step is to be even before you buy any component because these are little bit and the expensive site. You may actually want to try out from all the available free software tools, ok.

So, I can also tell you that this is a bigger panel which we got from another vendor and perhaps the right solution would be to interface this.

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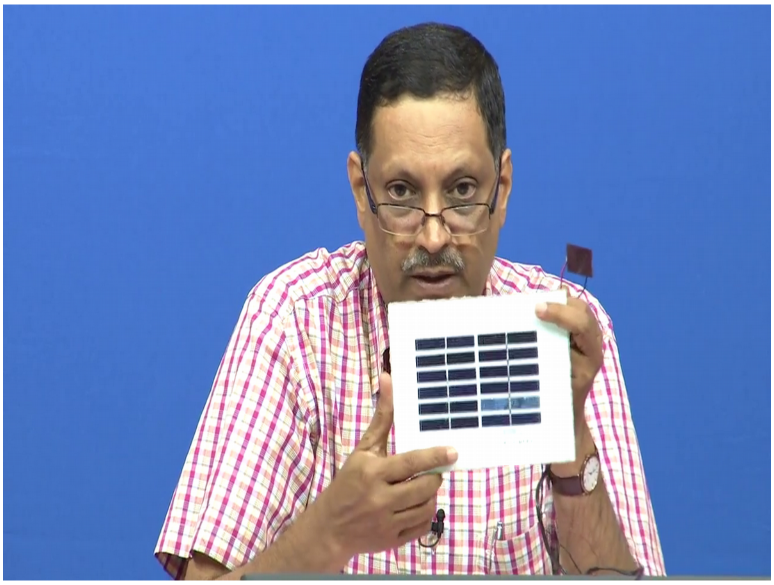

Panel with this LTC 3105, this is a bigger panel. This is 400 milliwatt panel. No I think it says 600 milliwatt panel. So, this is really a 600 milliwatt panel and perhaps they should be for your application, but you see now the size of this panel is uncomfortable to the size of the electronic and what application it will have. You have to really imagine before you try to deploy it for indoor applications. So, this is about the solar discussion solar panel LTC 3105, the way you have to configure LTC 3105.

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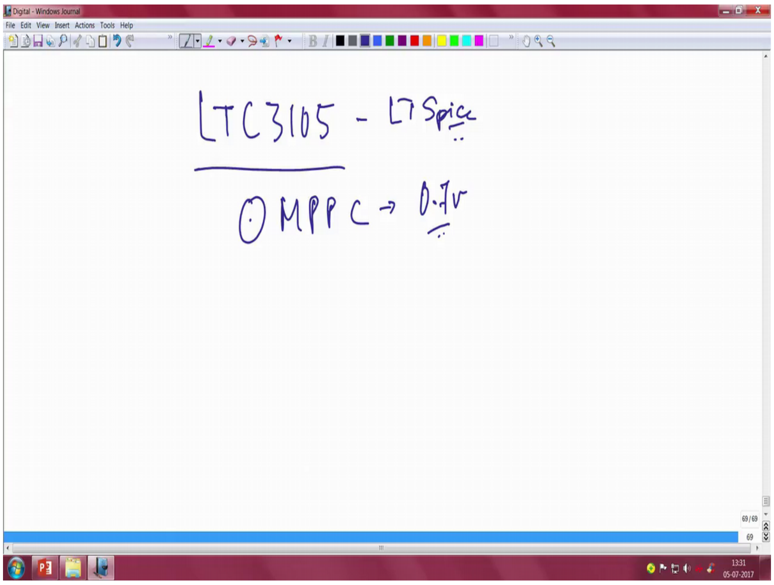

It is feature of using OMPPC, where you are setting this maximum power point control feature. If you have let us say two panels which are stacked in series, you may actually want to set it to 0.7 volts and ensure that the panel never collapses and yet you are able to extract energy power from the panel and store it into maybe a capacitor or trickle charge into a battery, ok.

So, all those possibilities exist. I will let you look up more detailing on LTC 3105. Particularly simulation with LT spice, you could download and then, try let shift gears. Now, let shift gears this is one way of harvesting power, right. Solar is so well known popular and all that, but is that the only way by which you can actually use this. I will take another example of measurement of human pulse. Human pulse is nothing, but heartbeat, right. We are talking about heartbeat and show you another way of harvesting power.

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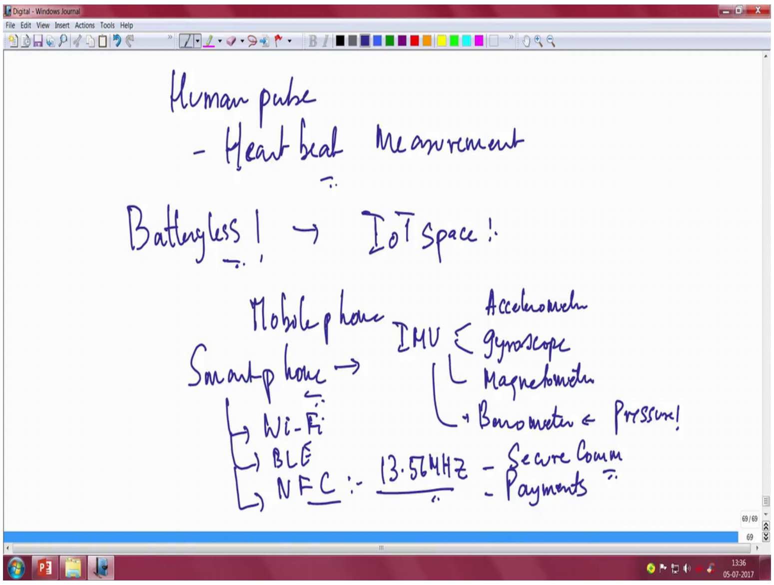

So, harvesting power difficult to use this word because I am not sure whether you are really harvesting in this case. I would say it is more power transfer. Transfer of power I would say power transfer from one device to another device more in that sense, ok.

It is harvesting because you can say it is battery less. I think I do not want to use this word harvesting in this case. So, it is really battery less. So, I would like to refine my answer heartbeat measurement battery less. Battery less that is the key. See one thing we mentioned already that in the IOT space if you consider gateway devices, I did mention to you about raspberry pi, beagle board beagle bone and all that. These are one set of embedded boards. Do not forget that the mobile phone is also a very powerful hardened commercially available easily deployable gateway device.

So, I would say mobile phone particularly if you talk about a smart phone as an example, you have a number of sensors on the smart phone. Each one, each sensor we will have one novel application or the other for example, there are what are known as inertial measurement units IMU sensors on the smart phone. This includes accelerometer gyroscope and of course, magnetometer right. You can also have a barometer. I will try and explain to you some nice things that you can do with this barometer basically measuring pressure. So, you can measure pressure using this barometer.

Also, if you look at communication interfaces on the smart phone, you of course have wi fi, you also have bluetooth low energy and some phones also have I think in fact, a large percentage of phones also have near field communication also called NFC, right. We will not get into detail of this NFC technology for the moment, but because it is an extension of what is well known RFID technology except that NFC works in 13.56 megahertz. These chips essentially work in 13.56 megahertz as compared to RFID which is in the sub 1 gigahertz RI frequency. As the name suggests, it is really near field.

So, you should be able to have let say very secure way of secure communication. It is a very secure way of communicating between two devices. A security comes for the simple reason that proximity itself is a form by which says it offers you a very secure communication. It is used for several things. We will not get into that detail at the moment, but in passing it is meant for payments. One thing is people talk about secure payments. You can have E-cash loaded on your phone and you can transfer e-cash from one phone to another phone or from one NFC device to another device using this NFC, ok.

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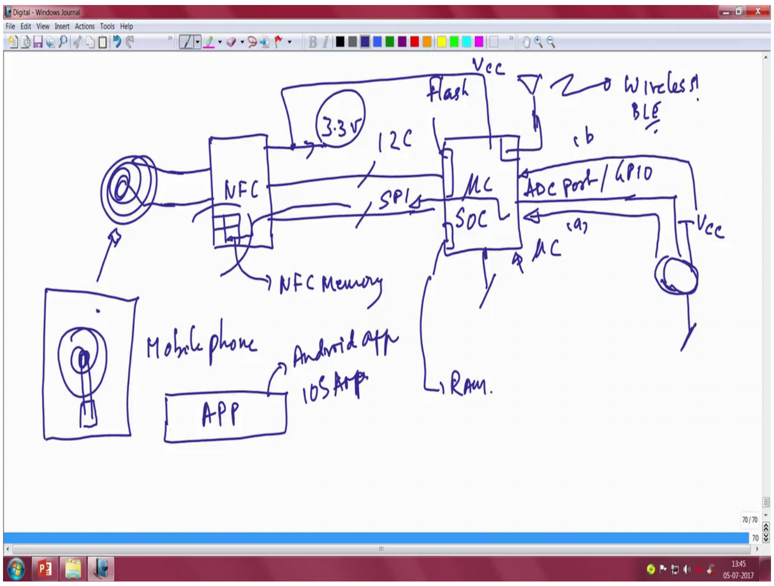

So, it is also used for secure access. It can also be used for payments, all kinds of applications one can find. What we try to do in this NFC is, NFC is well supported also by the fact that it can give you as a chip, it can give you an output voltage. Let me redraw this. I will just draw a picture of NFC chip here. It can give you an output voltage which can be 3 volts or 3.3 volts which is connected to coil and coil is interfaced. So, essentially if you have a mobile phone which also has a coil and also, has the NFC chip and there is a user, so I will simply call this mobile phone. If you bring this mobile phone closer to this NFC system, you essentially can access the NFC memory.

What it means is you can write content from the mobile phone app. Let us say some app, you have an app. When I say app, I mean an android app or it can also be IOS app. You could be downloading from any of the apple websites if it is an iPhone. So, it could be any one of them. So, I will just call it an app. So, this app actually you can program you know build a nice application with this app and then, get this phone closer to this coil. You should get nice access to this memory, you can write, you can read and you can also do interesting things like suppose you do not want to just read and write in the NFC memory, but you want to actually write and read to let us say a microcontroller memory.

So, what would you do is, the NFC would obviously support some sort of digital bus. It could either be I to C or it could be SPI. Typically I think it is typically I to C or I think it is typically NF’s SPI bus. It is an SPI, but never mind some chips, some components, some manufacturers we will give you I to C. It is a digital bus. You can interface it to a microcontroller typically an SOC. Let say then the SOC that we have been discussing deeply for a while, now things which are popular. SOC seems to be from nordic, the famous NRC 51822 is SOC which has BLE module in built into the SOC and NRF 51822 itself is a cortex M0, right. It is a cortex M0 processor and it say 32 bit processor and it is an arm cortex, actually arm cortex M0 processor.

So, now, what you can do as long as the phone is paired, call it as long as it is closely paired with this coil, you should be able to do several things by writing data reading data and so on into the NFC memory and you can also access through SPI and I2C, you can also access microcontroller and read write into that location as well.

So, if there is let us say a flash memory location, either a flash location, flash memory or if some RAM area, you can actually also do that, but look at what I am showing here. This chip also does something interesting, right. If you get this coil, mobile phone coil, NFC coil close to this, while you can do all of this by reading writing and all that. I also mentioned to you that it will give you an output voltage. Now, you see you can actually use this output voltage to power the microcontroller as well and essentially if you want to make a measurement using a sensor, let us say the sensor itself is connected to either DC port or GPIO port depending on whether it is a digital sensor or an analogue sensor, the whole chain is now up and running for you. As long as you have the mobile phone close to this coil, everything should work in practice.

This censor also requires power. So, let us say sensors rail also is required. So, I will just show it like this. This is a sensor rail, this is VCC for the microcontroller and of course, ground is here. So, let me re draw it, so that you will see it little better. This is the microcontroller; this is the sensor which also requires VCC and all that. So, look at this beautiful picture.

Bring a phone close to a piece of equipment which does not have a battery of itself, you power this, you pair it with this coil and somehow by magic NFC generators and output rail voltage connect this rail voltage to this microcontroller and with this microcontroller power, read this sensor. Now, you can do all kinds of nice things. You read this sensor value in this direction, write it into either flash or RAM and then, follow this arrow and then, either over SPI or I2C, you write it back into this location and get it back to the phone. You can do it this way.

We can also do it this way that I do not want to do this path. I want to sense. So, I will take this is route A, then I will take another route B. Route B is I will get the phone. So, let us start all over. Let the phone closer to this equipment. This is the device that we have built. Get it closer to this NFC. We will give you a rail voltage of 3.3 power micro control and therefore, also power the sensor, read the sensor value route B either through DC or GPLP. Put it to the RAM or flash depending on what you want to do and perhaps switch on this Bluetooth radio and then, do a communication over wireless. So, there are two roots. One is a route is back on NFC. Route B is back on wireless particularly on BLA. So, does it really work? Do we have a product? Is this reality? That is a question, right.

So, now what I will do, I will show you a demonstration and to demonstrate this Miss Madhuri will assist me. She is right here and we will do it together and I will actually show you that this really works. So, let us shift to the implementation demonstration of this complete system.

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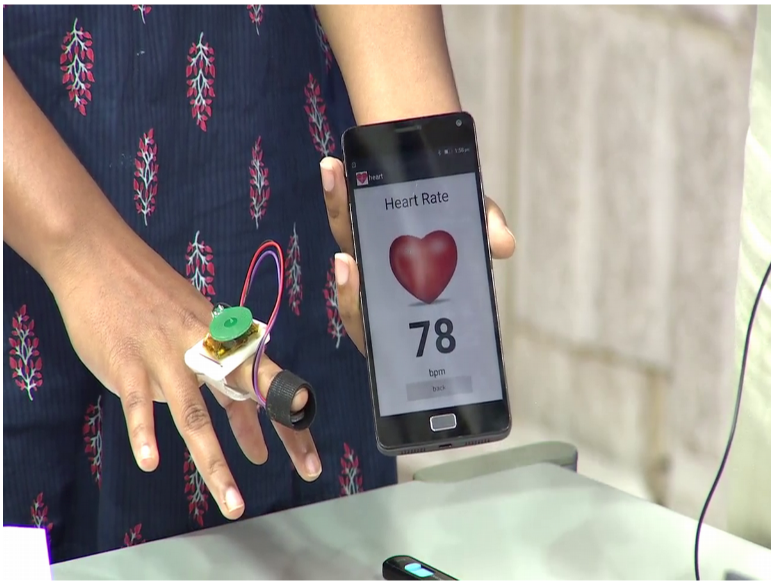

So, let us focus on this healthcare device. This healthcare device is strapped to her middle finger. So, it is trap to her middle finger, perfect. May be what you should do is, you should show like this to the camera. Does it make sense good? So, you can see let us see what all she has on her finger on her hand on this particular equipment that she has strapped to her fingers. She has a pulse sensor which she can show you. Perhaps you can see down here, this is a bought out sensor. I will give you the details as we go along. So, you can see this is the finger pulse that she wants that you want to measure up. Here she has a coil, right. This is that NFC coil I mentioned and her controller is sitting behind, ok.

You can see this is her controller here and what she will do is, she will get this phone NFC coil like this and she will pump energy, she will transfer energy, transfer power from this phone to this system on to a small capacitor and then, let us say what actually happens. So, let us try pairing it for a few seconds. So, now, it is charging the capacitor which is part of her equipment operator sitting strapped to her finger and the power which is transferred, the energy that is stored on the capacitor is used to power the microcontroller and after that this sensor is powered, the pulse sensor is powered and this pulse sensor is expected to be red and displayed back on the mobile device after charging the system. The equipment that she has on her finger here, she has paired it for about 20 seconds or so and then, you can see that it has red heart, it has red in it. So, basically it is a pulse sensors reading the pulse of the human and you can see that this whole system essentially has no battery, ok.

Let me just show you the hardware. This is the hardware and you can see that there is a small controller inside and essentially, the NRF board that I mentioned, NRF hardware that I mentioned, so this is essentially another way of building battery less devices. So, that is really the point. So, in this particular demonstration what we have shown is that it has taken route B. Route B is essentially the route that it goes from the port via the Bluetooth.

So, it has taken this route. So, you can try this if you wish. I try to build this if you wish and if time permits, we will also try to run through the software code which we will allow you to prototype this system completely. It isn't that this system has no challenges. I will flash you slides which will complete the story of this and that will help you understand the overview of building a battery less device in its completeness.

So, let me know shift to a set of slides which I prepared and here is the actual pulse battery less pulse meter that we showed you.

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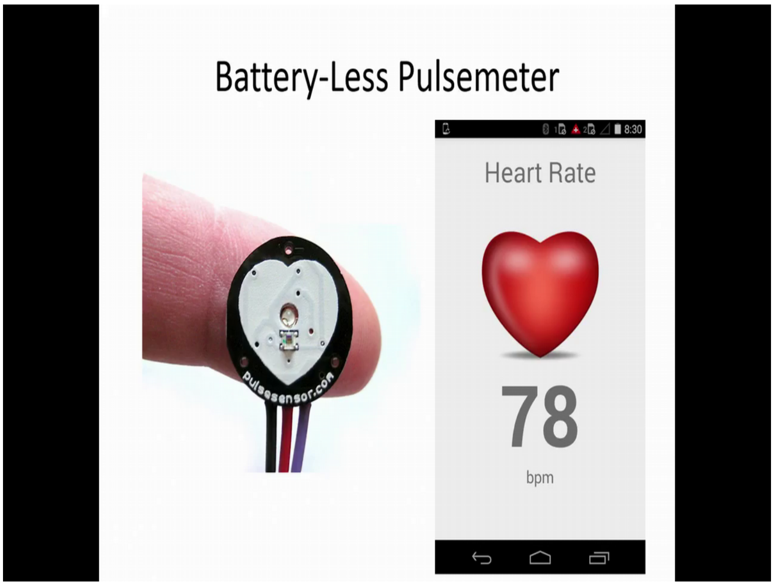

Now, you can see that the system essentially is strapped to either the index finger or the middle finger and you can make a measurement.

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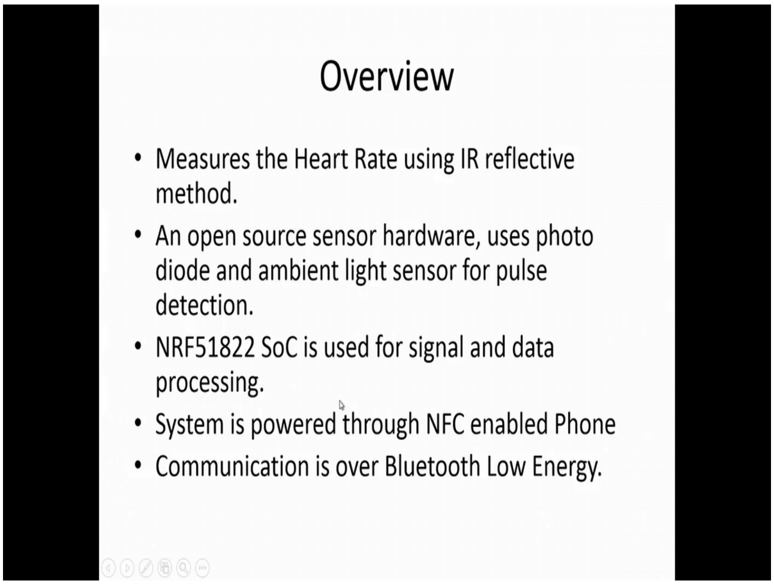

So, what is the overview? It basically measures the heart rate using IR reflective method. It is an open source hardware and it uses a photodiode and ambient light sensor for pulsar detection. I already mentioned to you that we use this NRF 51822 SoC for signal and data processing and system is powered through NFC enabled phone and the communication is true that route B which is essentially the Bluetooth low energy system.

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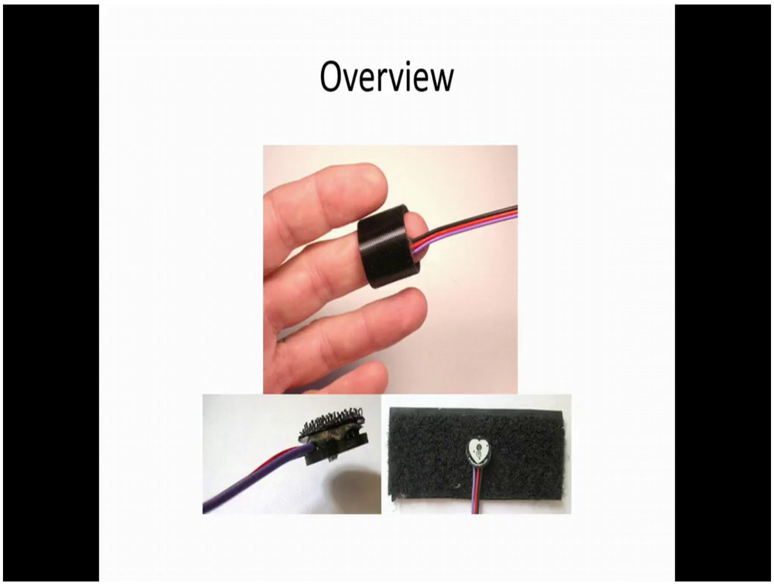

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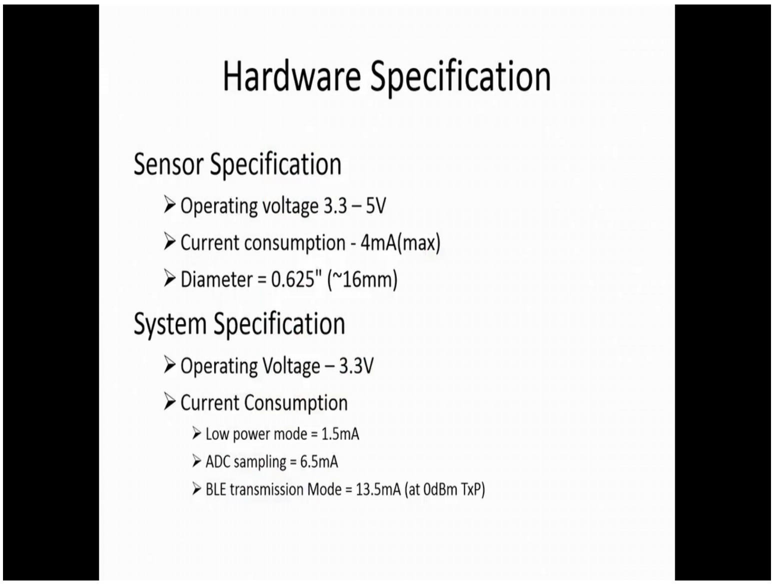

This is how you would attach and this is how you would actually use it for measurement. The hardware specification, this is again from what the sensor manufacturer has mentioned. The sensor operates between 3.3 and 5 volts. The current consumption is roughly 4 milliamperes. Maximum diameter of this is also mentioned. The system specification, the overall system that we have built operates at 3.3 volts and current consumption is low. Power mode is 1.5 milliamperes, DC sampling requires 6.5 milliamperes and BLE transmission mode requires 13.5 milliamperes at 0 dbm transmission power.

Look at that specification and look at the kind of power that you will require, right and unit this kind of power, but it is doable. You can do it with the devices that we have around as you can transfer power from one to the other and perform these kind of power guzzling because in the low power space, really this is quite a power consuming electronics, right. For example, 13.5 milliamperes at 0 dBm is a big number and so is DC sampling and so on.

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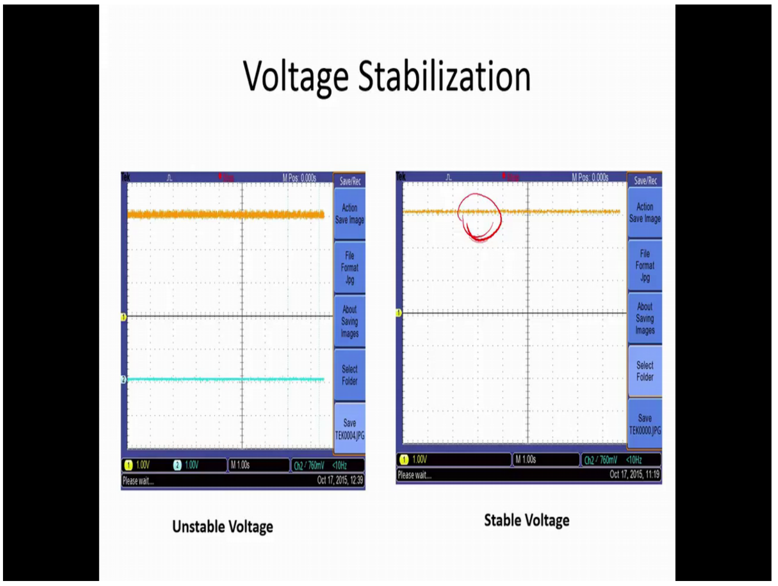

So, you could build that. The system is very stable when we were actually making a measurement. You can see that the voltage that developed across the microcontroller in the first picture that you see on the left side here, actually was quite a lot of voltage was really unstable and we had to do lot of nice tweaks in order to get back a nice good way form here which will allow us to use and power the pulse sensor effectively.

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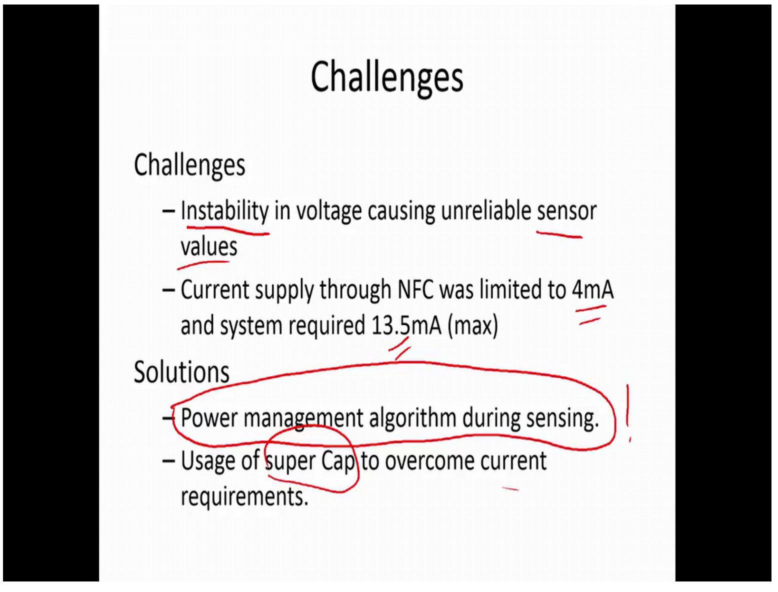

So, that correction was required. So, challenges were there was instability in the voltage causing unreliable sensor values. Current supply through the NFC was limited to 4 milliamperes and the system requires 3.5 milliamperes. Look at what I have written here, the power management algorithm.

So, if you really want to pull this half usage of super capacitor to overcome some of the current requirements, we used a super capacitor and it is indeed a challenging project, mini project that you can think of when you want to build battery less devices particularly if you want to do measurement of you know some critical body parameter. See this is from I would say it is a very nice thing from an academic perspective, but I do not think you should use this particular pulse sensor for any professional purposes. In fact, these are not FDA approved sensors.

So, if you are using it for some of your own personal requirement, this is a nice device that you can. It gives you the first cut, right. It is OT going to give you a very accurate pulse, right. It is not going to give you the heartbeat accurately, but maybe you know the range in which the measurement is MEC, you know the range or such a measurement has happened. So, I would say that this is purely from an academic perspective and also from a hobby perspective, actually this sensor it is available an open source and all the required hardware, required software drivers for this sensor is available for arduino.

So, pulse sensor dot com, if you go to pulse sensor dot com, you can buy this at roughly 25 dollars. Buy it if have the arduino with. You can interface it and you will start getting heartbeat quite actually. Apply it either to the finger or sometimes people also apply to the ear tip here. You can actually apply on finger pulse or also ear tip, you can use and these are good places to measure the heartbeat quite effectively.

So, in other words, this is a nice exercise and lot of software hacks, whole lot of power management algorithm which is required to ensure that the system is working successfully and you are able to read that value. So, that is really an interesting way of doing things. So, now I showed you solar, I showed you power transfer. I want to call it battery less power transfer using NFC. So, let me shift back. Let me go into another mode of harvesting.

How can you try something and can you do something around the humans, can you harvest something from human energy and so on and so forth. What I want to show you is harvesting from body heat that is another interesting thing that you can think off. So, let me now turn my attention to another demonstration whereby you should see whether you can actually get anything useful by exploiting the temperature differentials that exist around us. For example, if you are in AC room, the AC is particularly perhaps maintained at 19 to 22 depending on one's comfort level degrees celsius and the body temperature is typically at around 36.

So, you can have roughly anywhere between 12 to 14 delta t temperature differential and whether the differential temperature can be used for harvesting using devices, such as which are based on the physics principle and see Beck effect. Particularly see Beck effect because if you apply a temperature differential, you will get a voltage output, right. So, whether we can do that, how do they look, what kind of delta t exist, can we actually pull of anything from body heat, why do you want to do this, well there are many applications particularly if you are looking at any variable space.

You want to power the variables which you are using either for fitness or for normal monitoring. These systems typically are associated with a battery right because you want continuous monitoring, but energy harvesting has the ability to not just power those devices which is a dream really, but has the ability to charge a rechargeable battery which means you do not have to take it out put it into a charging pod or whatever and then, you do not need to do that. It can be on your body and all the time you can be charging the system, such that it gives you 20 bar 7 kind of powered always power device which can help you to use it for many long number of years.

Remember, I keep saying this that any design that you do if you are looking at battery based designs, any design should last for 10 years. Battery should last for 10 years, right otherwise it does not make sense. So, you should be able to charge and keep it always in a good condition, such that the device works for 10 years without replacing any battery.

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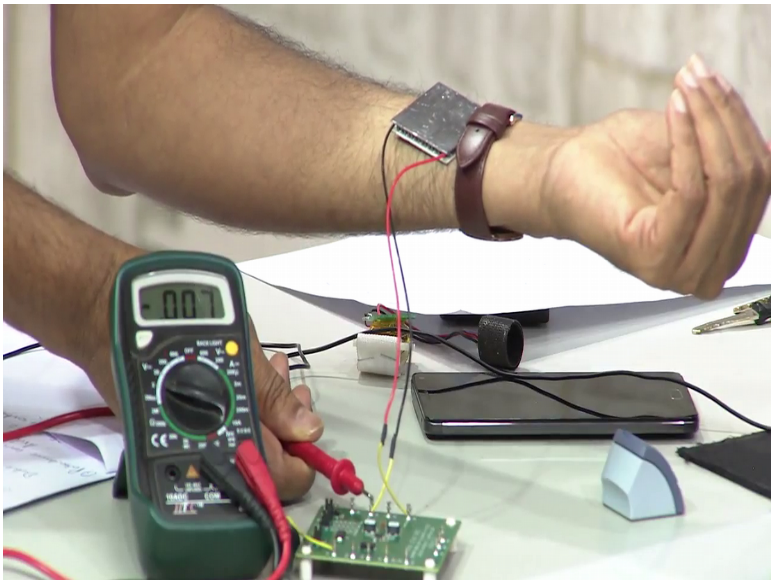

For this let me show you demonstration of another kind of device which essentially is called the thermoelectric generator. So, you can see this is TEG. What I have here is a Thermoelectric Generator and there is obviously it is not very thick. There is a hot side and then, there is a cold side and I will show you. So, what I have done is, I have connected it to a PCB which is right here.

So, this PCB is right here. You can see that this is PCB and I should be able to show you what kind of voltage develops across this system. So, just follow my instruction. I will connect the hot side here to my body and I will make a measurement. So, let me put back the meter and let us see what actually happens when I will connect TEG here. Just use it as a support and see what actually happens at V out. You can see I am measuring 1.6 volts. It is giving me 1.6.

So, the output I am getting is 1.3. So, if I start hinting a little bit and see what actually happens, see I get 1.8 and what I will do is, I will continue to rub, so that I heat this side and let see another measurement. You can see it is gone a little over range. You see it is developed up to 4 volts which is a clear indicator that if the temperature differential exists, you can actually harvest from this device. Now, it is down to 3.4 and I should be able to show the output. Yes, there you are. Now, it is coming down. So, this is another way of harvesting from body heat. What is this sensor, what are its detailing, how do we do this? Can you go back to this same standard paradigm of simulation study, first application simulation study and then, trying to see if this system is a viable option for powering our variable. That is the important thing that you want to study next.

Let us focus on the sensor of interest. The sensor that you have seen here, the one that you see here essentially is a thermoelectric generator. You can see it is not very thick and I repeatedly say that because you have to note there is a serious issue with respect to that if there is and it has two sides. There is a hot side and then, there is a cold side. This is the side which is the hot side and its written here hot and this is the cold side.

So, if you maintain the differential delta t, you should be able to harvest from this thermoelectric generator to which I have connected a piece of electronics here and then, I have shown you the output voltage across the multi meter. Let us move on to understanding thermoelectric generators straight away.

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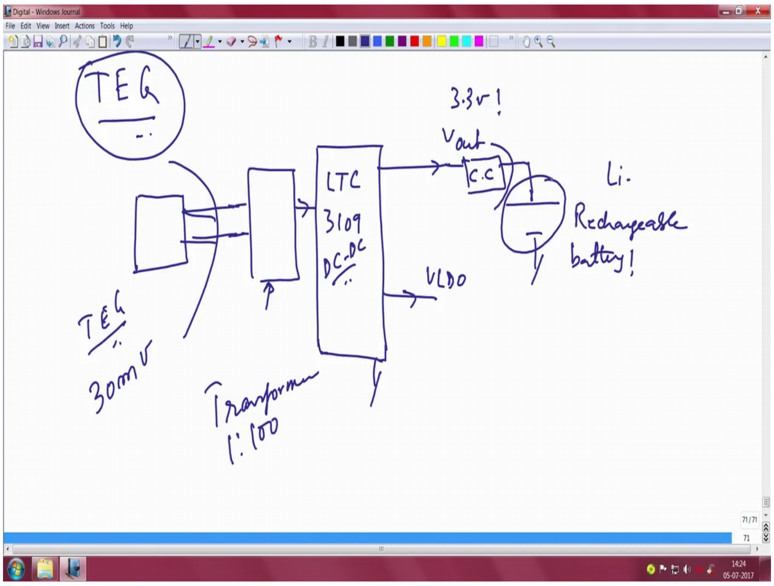

Let us now focus back on the other energy harvester I mention to you is the thermoelectric generator and that is what we had also seen. This is another form of energy harvesting. We will get into the detail later, but you may want to actually understand how did I actually you know use this energy for interfacing with the electronics that I showed you on the PCB here. Essentially what I have done is taken TEG which is sort of squarish and connected to sorry. I essentially connect it to IC also from linear technologies. This is called LTC 3109. I passed through a very important block before I connected it to the LTC 3109 and I got the V out here. This is essentially something which gives you this is TEG.

So, this is TEG and this TEG was applied to my body, connected to my body. I did not show you that, but I will show you very soon that the input which I get from the body is roughly 30 millivolts. I think it is better I shift to show you this before I move on to any other measurement.

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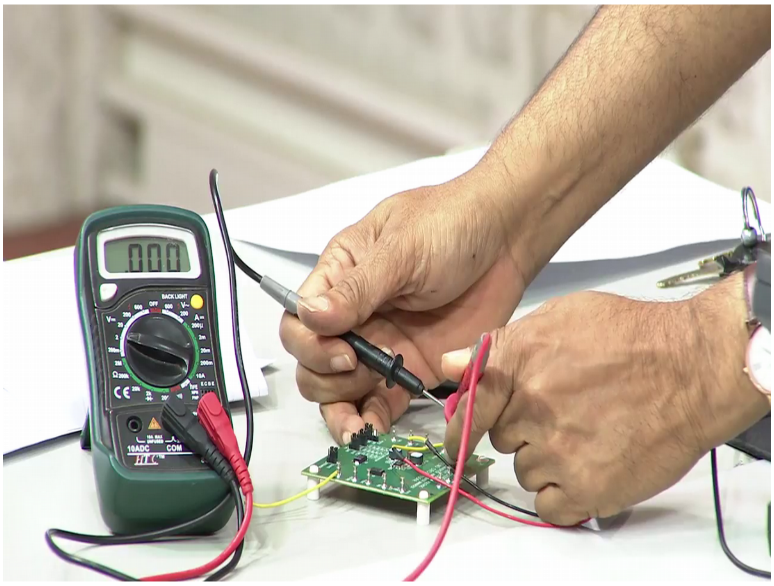

So, let me shift this back. I will connect to the input. So, let me put back this hot side to my body and I make a measurement across this, so that we know what the input is. So, it is 20. So, let me move it. So, it measured 20 anyway. So, you see it is measuring. So, roughly it went up to 26. So, it is a little uncomfortable for me to make this measurement as a single person, but I will still try. So, it gives as an input of about 30 millivolts from the body. This is about 30 milli volts which comes from the body and what we normally do is, we pass it through a transformer, we feed this input to a transformer which is typically 1 is to 100 and magnify the voltage, feed it to this LTC and then, trigger LTC. This is basically DC converter and that in turn gives you an output.

So, we could get 3.3 from typically these kind of circuits with the body heat and all that which we are actually that is what we have been which I showed you as demonstration that we were actually getting 3 volts 3.3 at the output. In fact, it went even higher, right. It can go up with the setting is such that it could even go up to 5 volts, but if you want to restrict it, there is a way by which this circuit we will allow you to this chip. We will allow you to restrict the output voltage to 3.3.

This particular aspect is interesting because you will be able to charge, put energy into a rechargeable battery. That is the key here. You should be able to put it into a rechargeable battery. Of course, you cannot do this directly, right. You must have a charging circuit. I will simply call it nothing, but a charging circuit because over voltage protection, under voltage protection, all that we will have to be taken care. Protection we will have to come in because if you are talking about a rechargeable battery, you are looking at lithium battery.

So, lithium batteries are very sensitive. The charging characteristics have to be such that you do not overcharge it as there is a chance of explosion and so on. So, you have to be really careful about have a good charging circuit and you can actually use this body heat to charge the battery and the battery in turn is powering the wearable device. All this is actually possible. So, we will get into the detail of this as what this transformer is actually doing and all that, but let me quickly tell you that the idea here is that you could either you know put energy into this rechargeable battery or you may actually make another decision that I will use. I will use this energy to always power a microcontroller only and no other part, but only to just power a microcontroller which requires a very small amount of power.

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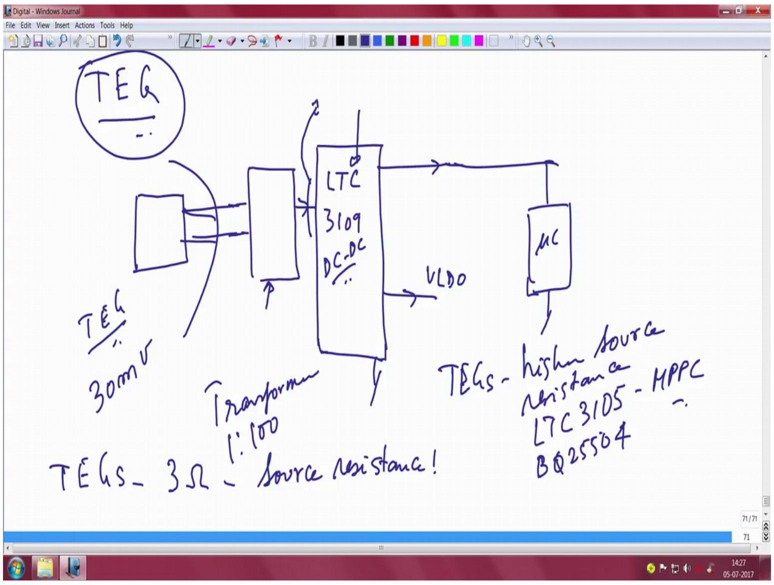

That is one thing that you can do. So, the TEG that we are talking here is which is essentially something that has very low resistance. I will just show you that we take the resistance is something in the order of 25, sorry as about 2.52.5 ohms takes typically have you should look for TEG which typically have about 3 ohms. So, 3 ohms of source resistance you will get them. You have to look out and actually purchase something that you will get in that range.

So, LTC 3109 resistance input resistance match quite well with TEG source resistance. If you end up buying TEG which have higher source resistance, then LTC 3109 perhaps is not a good IC. You may want to try the standard LTC 3105 or any other IC which should have MPPC part for you, right or you can also try TL BQ 25504 whereby you can adjust IC as you know IC resistance, input resistance.

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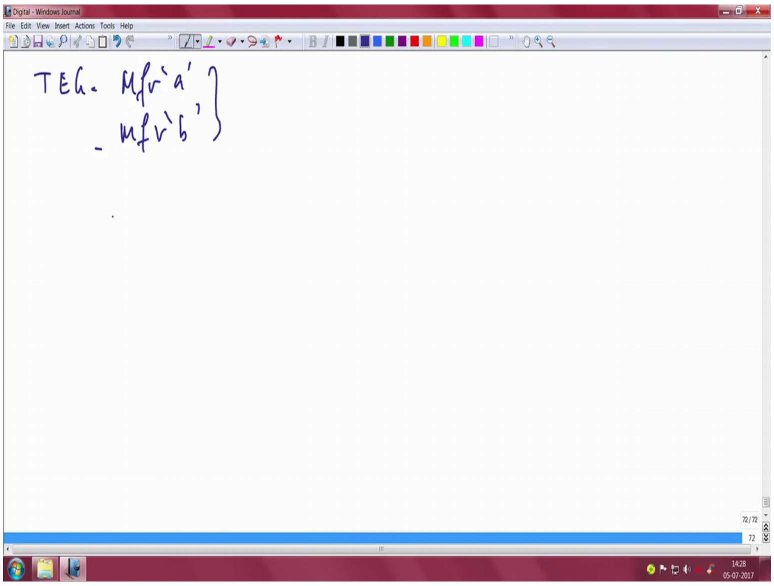

So, that is another important point to be noted that if you byte TEG from manufacturer a, manufacturer a also note that power conditioning from another manufacturer. Manufacturer b you have to take care that the source resistances and IC resistance, the input resistance of IC, both of them are matched in a manner that you will be able to extract the output voltage.

Now, it is not necessary that you are always getting only 30. So, it is possible that you will get typically 30 millivolts. If you maintain a good temperature differential, you will actually get sufficiently good power output. So, TEG that we have with us is essentially.