Design for Internet of Things
Prof. T V Prabhakar
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore

Lecture - 19
Battery less power supply and battery life calculation for embedded devices III

So, we had a look at RF energy harvesting, right? We looked at some typical circuits for that, like voltage doubler circuits, then looked at the possibility of storing that RF energy, then looking at how you can use that RF energy, how you characterize that RF energy, I both in terms of efficiency the different kinds of input power that is required and so on and so forth. Let us now shift gears and try and see how you can also use vibration, right. Vibration is another potentially good source for energy harvesting because, vibrations are all over us, all around us. You have vibrations in you know, even in the bicycle that you move, the motor, the 2 wheelers that we use, the 4 wheelers, the cars, the buses and even the aero planes right.

So, all of them have vibrations around us. I agree that most of it is low grade sometime if it is not a very old model one, the vibration is not really something that you can really, you are actually you do not, you do not like vibration, right. If it is vibrating actually know that it is not very comfortable. So, you actually in also that is on the one side. On the other side there are vibrations. So, can you actually exploit vibrations and see use that for any sort of energy harvesting applications. This is something that people have been I mean exploring for a long time. Now one potential application which you will see lot of papers and lot of companies trying to do is in the area of tire pressure monitoring.

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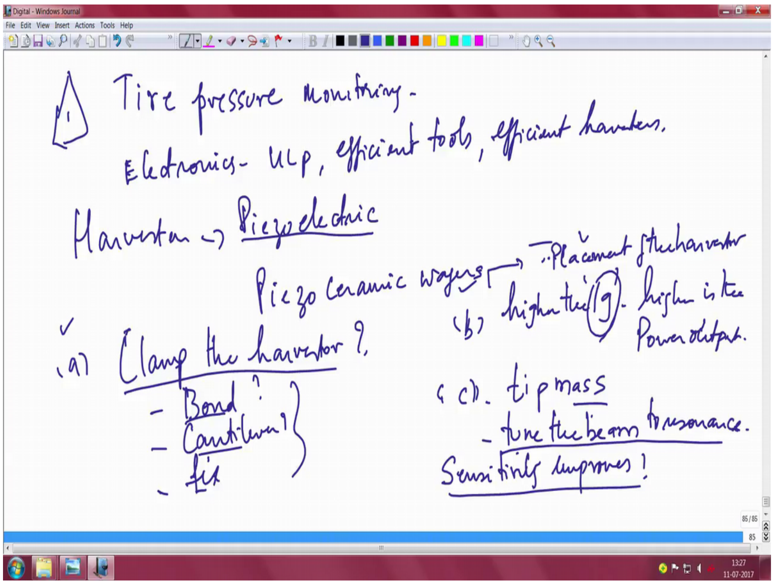

Tire, tire, tire pressure any example you take on vibration monitoring, vibration harvesting, monitoring you will actually come across this tire pressure monitoring. But that just one aspect of what people have been saying.

Really the fact that the power the electronics has gone, electronics has gone ultra low power and there are very efficient, efficient tools not just tools also a very efficient not only efficient tools, but also very efficient harvesters, this is become a reality. So, electronics is ultra low power efficient tool the efficient harvest tools all of it is made it very, very rich for vibration energy harvesting. So, let us not waste any time. Let us go directly and see a small demonstration of this particular aspect of energy harvesting. But before we go I must give you some background, right. Because you may not appreciate if you just see the demonstration. So, let me give you a little bit of a background the harvester of consideration that we are going to look at is piezoelectric.

So, the piezoelectric is base it is basically a piezoceramic wafer, so it is a piezoelectric or piezo material wise it is piezoceramic it is a wafer. There are multiple wafers which are essentially bonded together to form the basic energy harvesting; let us say a basically an energy harvester, right. And it uses the principle of piezoelectric effect. So, it is nothing but a very important thing I would not get into the detail of that. And we are using it for vibration harvesting. I am going to tell you a few things which we found it extremely I would say hard and also with lot of, I would say a lot of experimentation that you will have to really worry about many aspects of vibration harvesting before you can actually extract anything useful. First thing that occurred to us is, how do you clamp this, clamping the harvester. First question a, will you bond it? Bond it to the material or will you cantilever it, will you cantilever it? Will you bond it? Will you bond it on, let us say on both sides? Or will you just do or will you simply, will you simply fix it. Fixing which screws and all that or will you cantilever it or will you bond it.

Each one of them have their own advantages and each one of them each of these methods actually give you different performances from the same harvester, this is one thing. In fact, one of my project staff by name mister Abhishek, he tried to harvest from a 2 wheeler. He is trying different you know places where he can actually get energy from, he tried on the engine side then you put it on the mud guard.

And then he tried and just trying to characterize and say what gives me the best g value, right. That is that is the key behind the highest the g the better with the harvesting. So, essentially if you say you are having a 2G instead of 1G then you are much better off because 2G is a lot more power that you can extract with 2G. Basically it is the attitude right. So, this amplitude higher than amplitude more is the power that you can actually draw from the system.

So, higher g, so higher the g value higher is the power output, is the power output, power output. This is the, so this is another aspect. So, you clamping the harvest is one issue and how to get placement, then I will call this b is basically where do you place it, placement of the harvester. You have to look at where the vibrations are are good. And you must going place the energy harvester there, that is why after we have localized the spot where you want to place the harvester you will have to confront this problem of bonding, you should be bonded to the place should it be cantilevered or should you fix it. All this thing you have to node a and b very, very critical before you can actually extract anything from the from the system.

So, please note this 2 important steps before you go. There is a third step there is also a third important thing. And the third important thing is related to the tip mass, this is c. So, let me write it little better, I will remove this clatter on this. And I will put clamp is the clamp the harvester. So, these 3 things and I think this is fine c is tip mass. So, what about this tip mass? Basically, this tip mass is to tune, the beam, basically it is to tune the beam to resonance. This is why you have to put the tip mass. But there are all sides to this coin, what happen if you do not put the tip mass? What happens if you put the tip mass? Without getting into great detail of you know the mechanical equations and understanding the it complete detail because of full study by itself. From a harvesting perspective, from extracting energy perspective let us understand this problem of tip mass ok.

Now, if you put the tip mass essentially you are damping. You are tuning the beam to resonance, but you are actually in a way you are actually damping the system. In other words what actually happens is the sensitivity improves very, very good sensitivity you get. In other words this g value there is a good possibility that you will get a higher g if you put a tip mass there is a good possibility. But there is a other; obviously, there has to be some problem with putting this sense by improving sensitivity. Essentially if you put a tip mass while sensitivity improves it is ability to extract energy across a range of frequencies reduces, that is the problem. So, while sensitivity improves it is ability to. So, let me write on a fresh sheet of paper.

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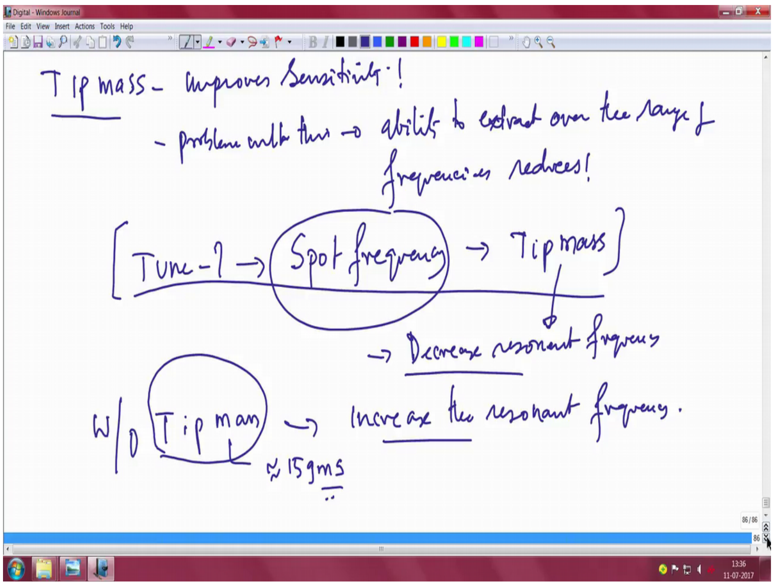

Tip mass, tip mass improves sensitivity, but has a problem of this is good, but the trouble is problem, problem with this is ability to extract, extract over the range of frequencies, frequencies reduces

So, this is the problem. So, you are now confronted with a problem. The problem is, how do I tune to a given tune to a given spot frequency? How do I tune to a given spot frequency by applying a tip mass? And how do I find out this spot frequency? How do I put the tip mass to bring the system to tune the beam to resonance? That is an issue. I think more and more from an energy harvesting perspective this make sense. Put a tip mass get it get improve it is sensitivity so that it works over a given small range of frequencies. In fact, it could even be a sport frequency and then you extract maximum g value you and use that g value for all the power in for basically power in the system. So, this is the key point. So decrease in, so just to summarize this means it is decrease the resonant frequency, decrease resonant frequency. If you put tip mass and without tip mass without you increase the resonant frequency.

This is the big summary of the system. So now, without wasting much time when having understood this basic you know story behind background, theory behind the vibration energy harvesting let us see a nice demonstration of the system.

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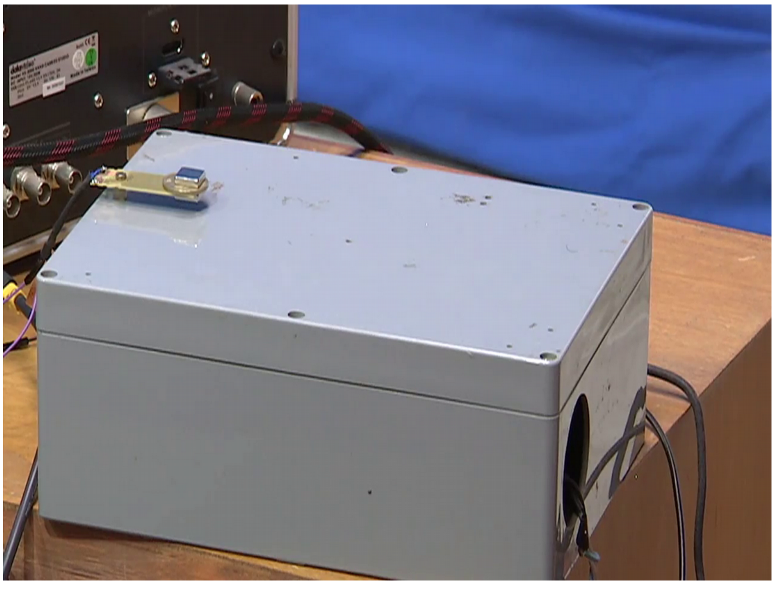

What I so show you here, is this platform is actually now switched on as you have seen Abhishek just switched it on. It is vibrating. This is the vibration energy harvester. It is basically not bounded, but it has a tipping mass here we can see, there is a tipping mass that has been applied. And it is fixed to this surface which is vibrating using this screw and we are trying to see what actually happens in terms of the output voltage.

So, before we go there let us zoom in a little bit this is the tip mass here. This is the vibration energy harvester this is the platform which is vibrating at the moment. And you can see that with a screw it has been fixed here, this is the output which we are taking here there is a very small PCB, right. And we will discuss this PCB in a moment. And there should be a reasonably good output, which we should get this is output or which you should be able to see on the oscilloscope. So, let us move on to the oscilloscope and see the output.

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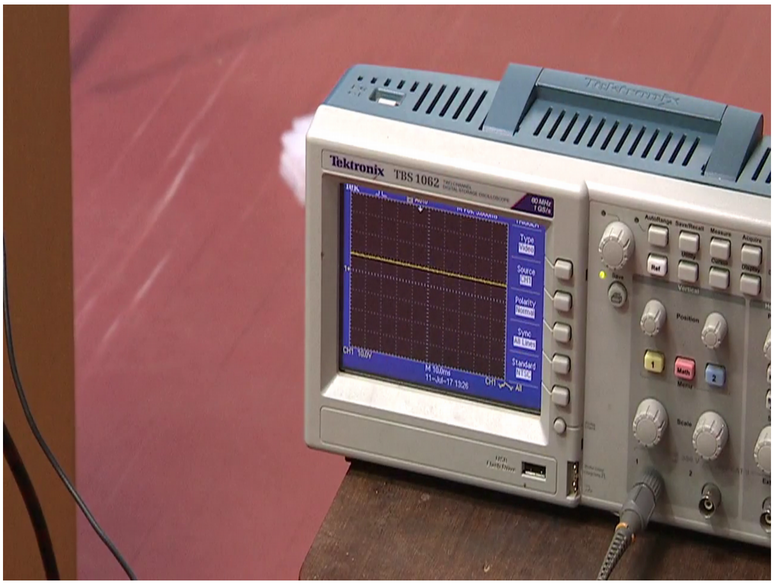

Yes you see now the oscilloscope output it moves to, so you are getting close to 10 volts DC ok.

So, that is the story behind this demonstration. You can see that this voltage is actually changing based on the placement I mean by just simply moving the harvester, the platform, see as we move the plus as we moved the platform the vibration freq the frequencies are different, just by moving this output there you can see that it has even gone up to 20 volts. Which is a clear indicator that what we discussed with respect to placement of the harvester it is position, exact position actually gives you the ability to extract lot more power from the harvester. Now what did what did we put? I showed you a demonstration, the tip mass that we have chosen is about 15 grams.

Roughly I would say is about 15 grams. And we have notengineered anything from this, I put 15 grams and we found that the system is giving you an output how do you find out at what frequency this is happening this whole system is vibrating and how do we tune the system what is we do not know anything more than just that it is just giving as a good output which is not the, right. Way, right. Obviously, you have to characterize the platform and then up accordingly you should be able to apply the tip mass.

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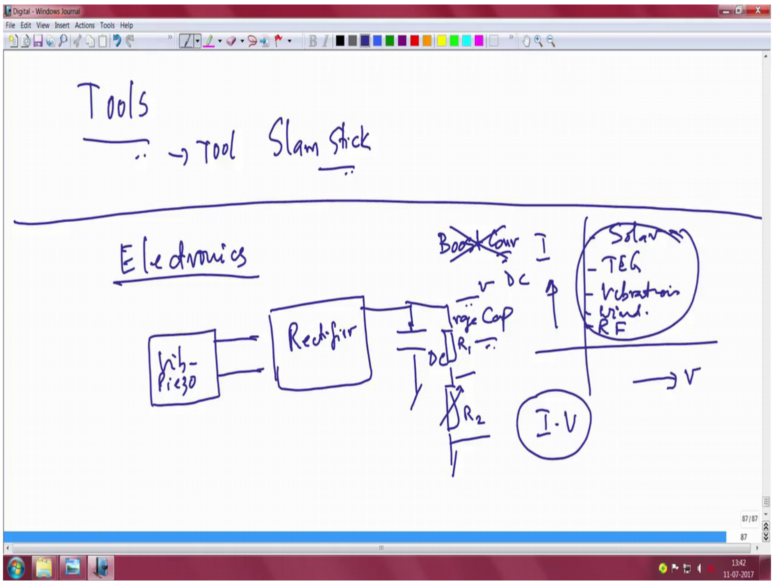

So, that you will be able to extract maximum energy maybe it is not even optimal what we have done now. For that we need tools and what I am going to show you now is a tool called slapstick. So, this is what I have here with me in my hand.

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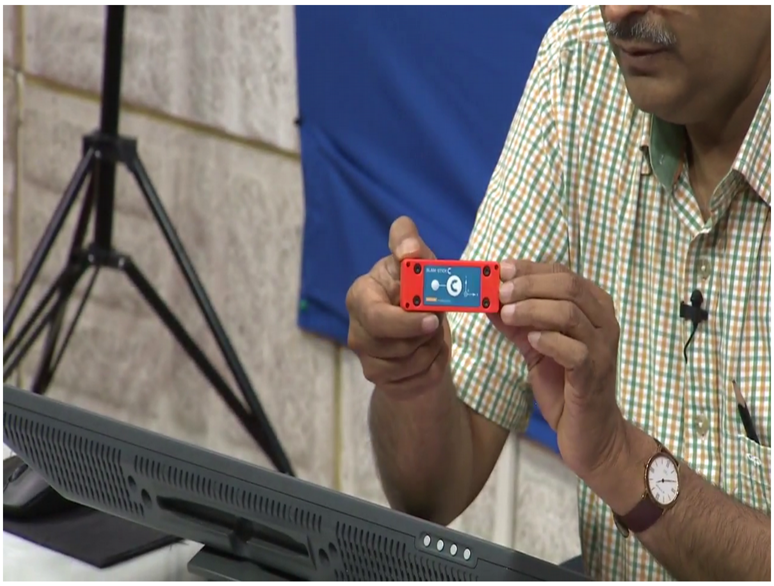

So, this is a slam stick basically this is a small embedded product which can be go little closer to this please, put this work yes little more closer to this yes absolutely. So, if I do this. So, this is a simple product which will allow you if placed on that platform, it should capture the vibration data and store it on some memory here after which you connected to a computer and extract the data and actually find out, what where all the range of frequencies over which the system is harvesting energy from.

So, we will do that as a next step and try and understand the frequency spectrum which will allow us to tune our complete system much better. So, that is one part which we will proceed, but before we do that we also have to find out what did we do in terms of electronics. The electronics is pretty much sorry; the electronics is pretty much straight forward the electronics is pretty straight forward.

Basically what it has is there is a harvester there is a vibration piezo element, piezo element which essentially gives you AC output. So, you have to pass it through a rectifier remember to use short key diodes So that you will get lower voltage drops across the diodes and your ability to extract power we will be much better. And put it into a capacitor, right. This is your storage capacitor, storage cap.

See the funny thing you do not need you do not need any further boost for sure, you do not need you do not need a boost converter for sure. Not required, why? Because already just after rectification you are able to get close to plus 20 volts. DC which is a clear indicator that you are a system gives you the vibration harvesters essentially give you a lot more voltage output. Power characterization is another story. What is the maximum power to extract from? We will again we will have to the based on the first principles of all that we know about energy harvesting. What is that? You have to do voltage versus current characterization VI characterization or IV characteristics as they call it. IV character some people say IV, some people say VI characteristics and so on and so forth.

Note that: you have to do this IV characterization for all types of harvesters such as solar, for thermoelectric generation, for vibration harvesters as well and any other form like even wind and so on and so forth. So, maximum power extraction of course, we also discussed a great deal about RF. Where we also you know took the example of a load resistor and be sure that for a given load resistor across the 2 frequencies it was giving the maximum, power output and therefore, efficiencies were very high. So, all of that was discussed.

So, if you want to do any of that with respect to even the vibration harvester, you will have to plot the IV characteristic of the system. It is a pretty straight forward thing you will have to take a potentiometer and basically, tune keep changing the value of the potentiometer. If time permit is we can do that, but anyway just the point is that the DC voltage that is available here we will have to be used across a potentiometer and keep measuring the current as well as the voltage drop. And a accordingly measure the keep measuring keep changing this register and keep measuring the voltage across this and the current flowing across this and therefore, plot V versus I quite effectively.

So, that is the thing that you will have to do even for vibration harvesting. So now, let us go back and try putting the slams take, to see how the vibration profile of the system looks like. So, we started with trying to see this is a nice piece of equipment, which is very handy for most of the energy harvesting applications that you may want to suppose you want to characterize the platform under which you want to harvest energy from. This is a nice little thing it is called slams tick it is also available in midday is the website where you can go and buy all these things. Including the energy harvester, the harvest is also from midday your experiment in this in the lap my project staff was looking at it.

So, we are just trying to understand whole end to end of how to harvest energy from. So, you need this otherwise it is hard for you to characterize and find out. So, let us see that nice end to end system. Before you before we can really you know use energy vibration energy harvesting for any applications. So, take this midday and put it on top of this box that we were discussing. So, put it on this box it is as simple as that. There is a piece of you know tape that you see here you can put some tape and then stick it to this surface here. And then what you do there is a button here.

So, you just press the button this button if you press it will gather data right. So, you can see that the light there is a small LED which is glowing here it is actually acquiring data. And then you switch off it stops and then take it off and then get it into another nice tool. So, this is exactly what we will do now that there is data on this as you can see there is a nice a USB port here which you can use or not only for charging the battery, because this is a self contained unit, not only for charging the battery, but for also taking the data out for and for processing the data very useful, right.

How will you do any characterization? Now what is interesting after you do this and all that?

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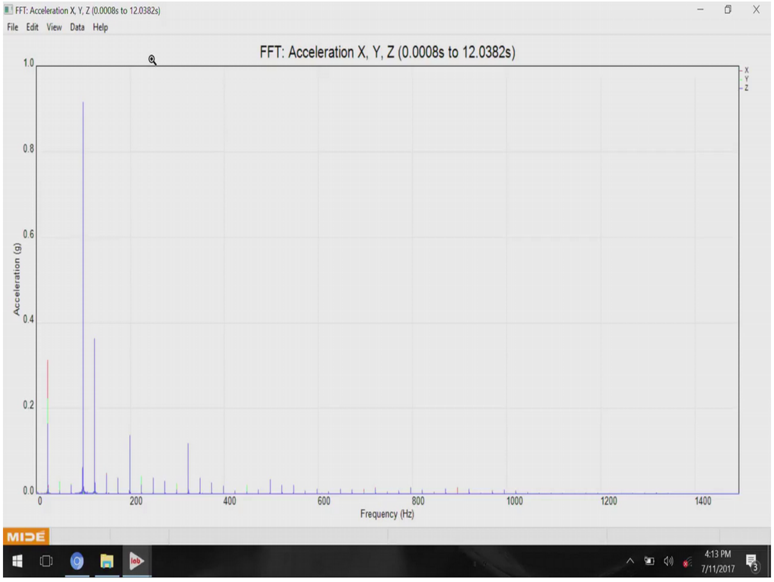

Let me show you the tool, the output from the tool. You see this nice picture here on the x axis is the frequency 0 to 1400 it has put the frequency. And it has done the he has it has found out the acceleration. Essentially, this is the fast FFT of the accelerometer which is on, which is in this inside this device essentially just that. Basically this device is has a MEMS accelerometer inside. And this data that you see here is actually captured at 1000, 3200 kilobit is per second it is sampled at 3.2 kilohertz. And essentially it tells you several frequencies over which this system can harvest energy from. You can see that there is one small peak which is around the 0.3g, there is a nice beautiful and at that what frequencies that that is roughly 30 kilohertz 30 hertz are so.

And then about around hundred hertz there is another one which is close to 0.9g. Then again at around 120 hertz or so, there is a little bit of g value which you can also exploit anywhere after 0.3 to about 0.9 about 1G if you are able to get some decent harvesting is actually possible. And you tune it for a given particular spot frequency now by putting a tip mass. Then you will essentially as long as the system is vibrating and as long as these frequency components exist, it will go on harvesting at that particular frequency. So, that is really the key here. And you can you should essentially exploit these kind of to so, you can do lot of interesting things with this little tool you can, for instance let us see we can also get what is known as. So, essentially what I did was I went to so, this is a view of that.

So, this is essentially this not only contains the 3 axis accelerometer inside, it also contains the pressure information.

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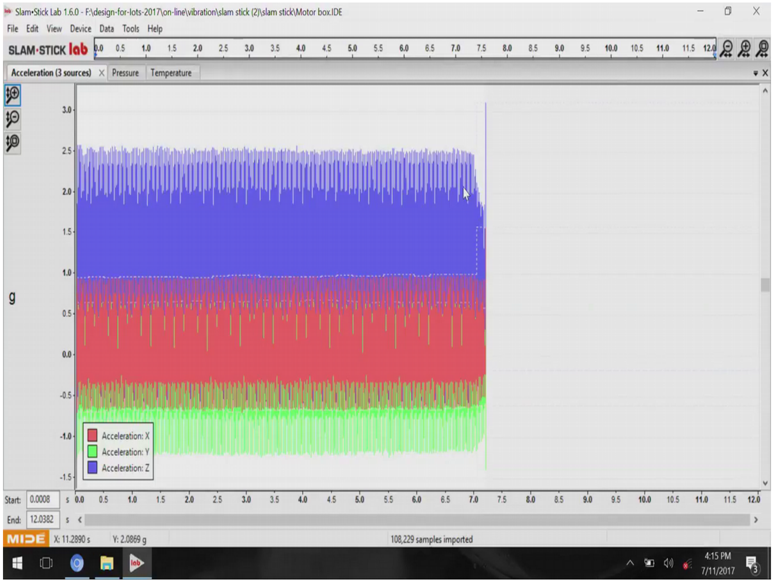

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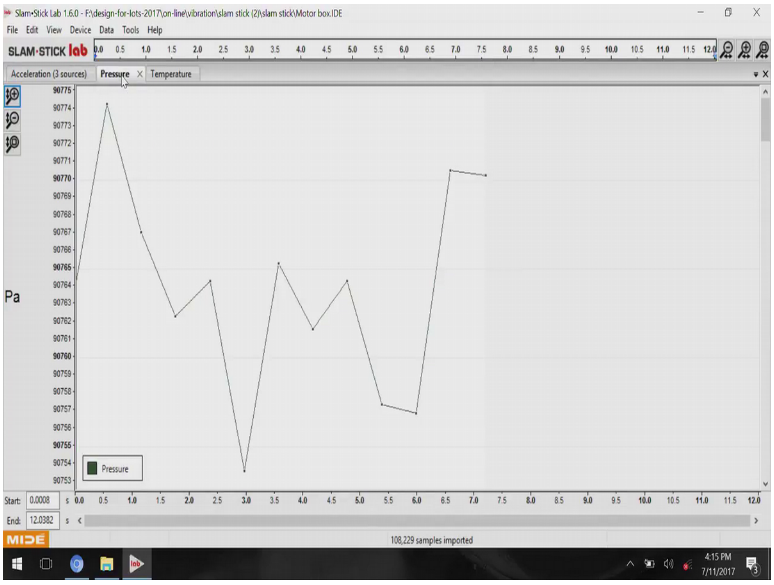

You can see that x axis this is time and y axis is the pressure and which it is measuring. And it also measures the temperature ok.

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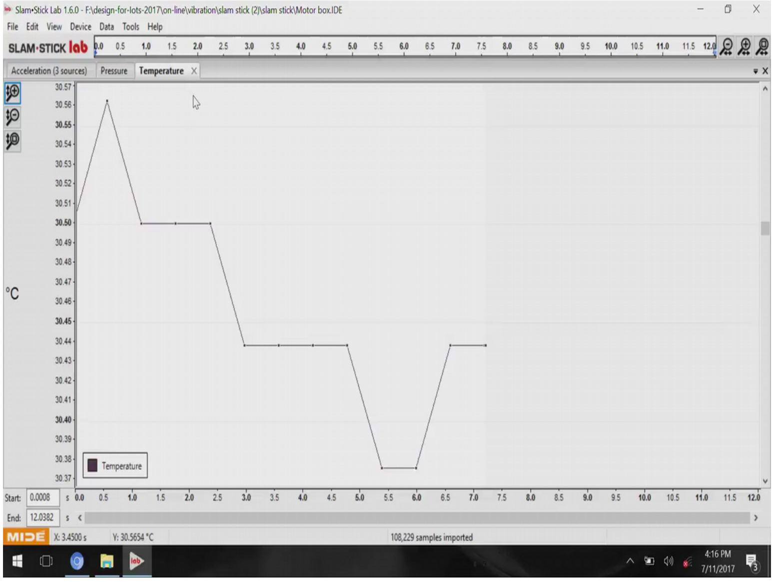

So, all the parameters are there these 3 critical parameters which are available, temperature pressure as well as the accelerometer. So, essentially this is telling you giving you the time series, right. It is just giving you the 3 axis accelerometer value time series. The 3 colors are indicated it is the 3 axis one so, it is giving you that. You just go and then do render and then you say FFT and used in fact you do not have to do anything, you just press it will just give you this nice little FFT plot. So, you can see that it has taken the data and his processed and give made available this information.

You can do several other interesting things as well. For instance you can also get, you can also get the spectrogram, render spectrogram you can see that. So, this is the spectrogram so, let us see.

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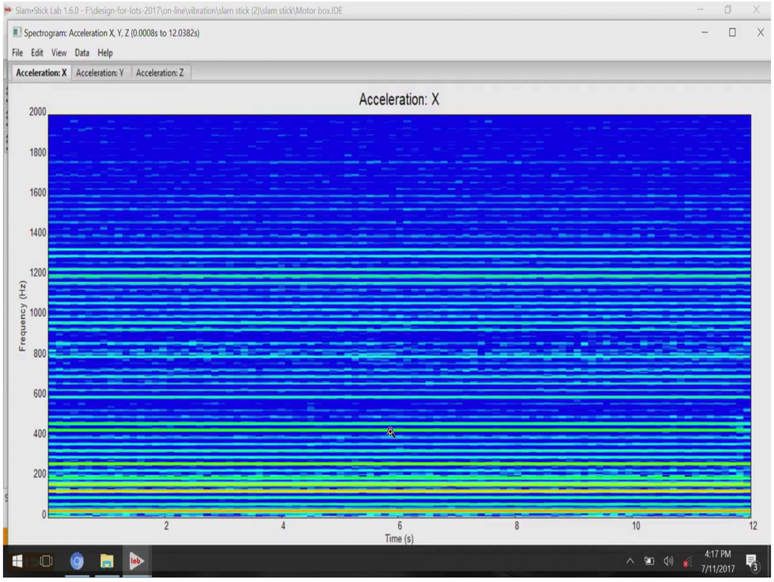

So, spectrogram essentially we will tell you, this is for the x axis, this is for the y axis and this is for the z axis, they are the this spectrogram essentially we will tell you how the frequency and the amplitude changes with time of course, essentially it is another way of representing the, so essentially it is after doing and FFT. So, how it basically where is you can see that, how this particular frequency where is over time.

So, x axis is the time and frequency is along the y axis. Essentially, it is telling you that time series of the frequency, how the how the frequencies actually varying are the same with and x and y and z alright. So, this is another thing that you can actually find so very useful tool free to download actually. Anyone can download this tool and actually play with this tool and get oneself very familiar with this tool. So, this is very interesting thing for you. For some people if there are also interested in let us say, from an energy perspective. For example, if there is a vehicle and the amount of energy vibration energy should not exceed a given threshold, is someone wants to characterize something like that then it may also be useful to go and do what is known as a power spectral density right.

So, here is another way of getting the power spectral density, you will get basically everything we will come in terms of g squared by hertz, as you can see.

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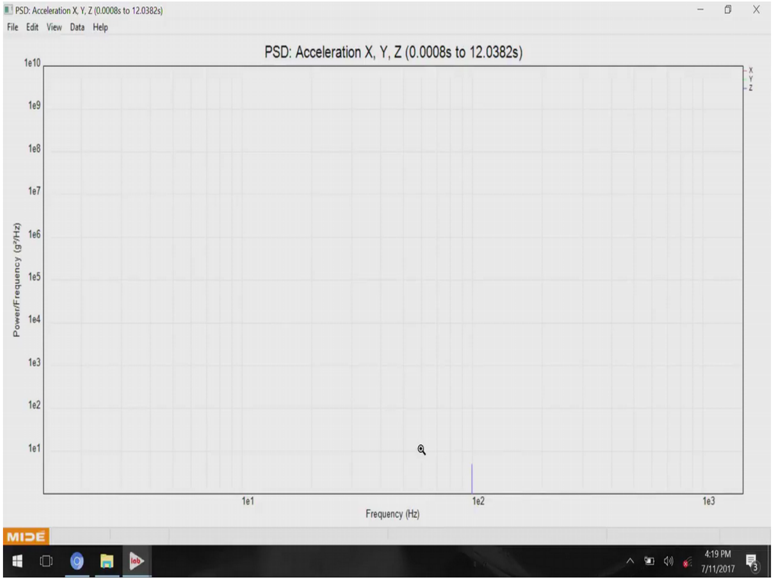

This is the frequency component and this is the, power frequency g squared by hertz it will tell you the basic power spectral density of the vibration energy which is available. So, this is the basic way by which if you have a vibration harvester with you and you are interested in trying and to find out at what frequency should you put your tipping mass. What should be the tipping mass? And what exactly you would like to let say, harvest energy at what at what frequency you want to harvest energy? For all that study this 2 tools, this particular tool in combination with the harvester that you have of interest we will together help you to basically narrow down on the possibility of using vibration energy harvesting.

So, further detailing is essentially this, that you know one thing is the one thing is this is basically a DC response MEMS sensor.

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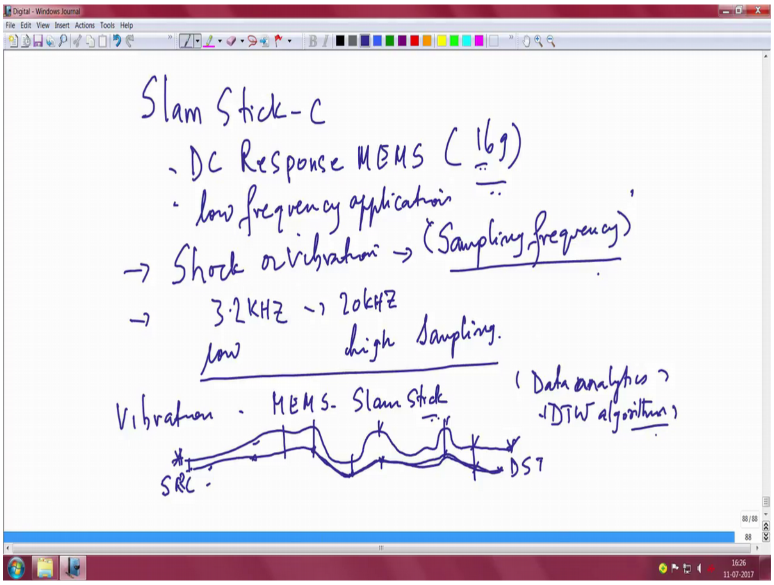

What it these slam sticks that we have it is called slam stick slam stick-c and this is essentially a DC response MEMS equipment, shock and, and vibration is that you must be careful about the sampling frequency. If you do not sample that enough at a higher at the a the required frequency you will end up losing, because if you are points are very spars then you may actually end up losing the required, you may end up losing the catching the right g value.

So, which might indeed be an issue and it may be sub optimal. Therefore, you must be able to set these sampling frequency sufficiently well So that you are able to capture and reproduce the vibration waveform as accurately as possible right. So, this is something I do not want to elaborate, but I am sure as engineers you actually know that sampling frequency is a very, very critical thing. The results that we have shown you that I showed you were with 3.2 kilohertz sampling. You can typically even go up to 20 kilohertz sampling and so, this is low value the low sampling and this is high sampling. And this is something that you can actually basically you can set. And pretty accurate one I would say therefore, please do consider for all energy harvesting applications, this particular try and see if you can invest in obtaining a tool like this for better understanding.

Finally I wanted to summarize the vibration energy harvesting and this thing about these this application of this MEMS slam stake. It can be used in the many different ways. For instance, it can also give you a pressure information, right. It can also give you pleasure information it can also give you temperature information. So, you can see that not only acceleration values, but pressure and temperature together we will act with so many with this kind of data, you can actually do some very interesting studies. For instance, in one of the applications that the midday people seem to propose the war vendor seem to propose, is that if there is a let us say, a source and a source at some at point source at and then there is a destination point. And there is a let us say a courier or a parcel service system whose route is fixed from source to the destination. Essentially, passing through some route where ultimately to reach the destination.

Now, if that truck carrying the parcel actually is equip with this MEMS sensor, the accelerometer data along with the pressure information you should be able to get some sort of correlation of these values, right. And with this correlation you should be able to say a few things about the route taken by the a parcel service system. Essentially, there propose algorithms for data analytics algorithms to find out to verify the fixed route from the source to the destination, whether the truck actually took that route by just analyzing the data from the accelerometer the pressure sensor and the temperature sensor, all the 3 put together. And they actually proposed a algorithm called DTW it is called dynamic time warping.

So, please do look up the DTW algorithm and try out a few exercises. So, that you are familiar with just not gathering data, but also trying to analyze the data and provide information from that data that you have. So, this is a nice thing, right. The source to destination is fixed and the route of the parcel service is fixed and we just equipping this slams take you can actually gather data. And run this nice DTW dynamic time warping algorithm to match at different points in time and actually say something about the route that was actually traced, actually taken sorry not traced that the route taken by the parcel service system.

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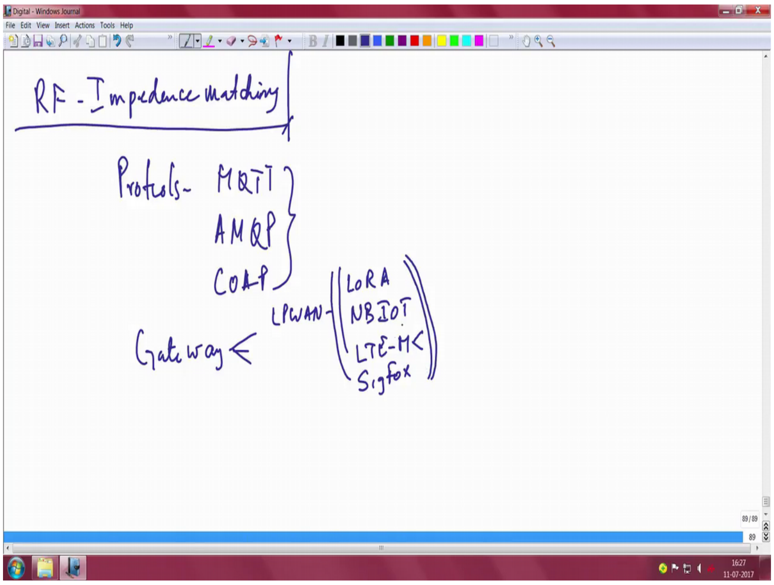

With this we sort of summarize several aspects of energy harvesting. And then we will move on if time permit is we will try and do something related to impedance matching. Because this is critical impedance matching if time permit is of course, I am not sure if we will find time impedance matching for RF circuits.

So, we will do RF impedance matching and then we will then take up other related systems such as the protocols, IoT protocols such as MQTT and MQTT, AMQP and COAP which are useful for which can run on the sensor nodes. And communicate to a central gateway. Gateway can run any of the LPWAN protocols which we spoke off such as LORA, NBIOT, right. LTE-M there is a cat and there are two actually in this so anyway broadly or SigFox, right. SigFox is also another LPWAN technology.

So, let us understand little bit of this protocols and move on from there.