Design for Internet of Things
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Lecture - 14
Power Conditioning with Energy Harvesters - I

Let us begin now with this energy harvesting circuit and let us see what are the how should you go about. Let us take something that is very popular and we will as we go along let us look at other energy harvesting sources, but for to begin with let us start with the solar panel solar panel is the simplest thing that you can think of.

Now, solar panel we did mention to you about I did mention to you about the fact that the solar panel or any of these harvesting devices always have a point at which they provide you maximum power right.

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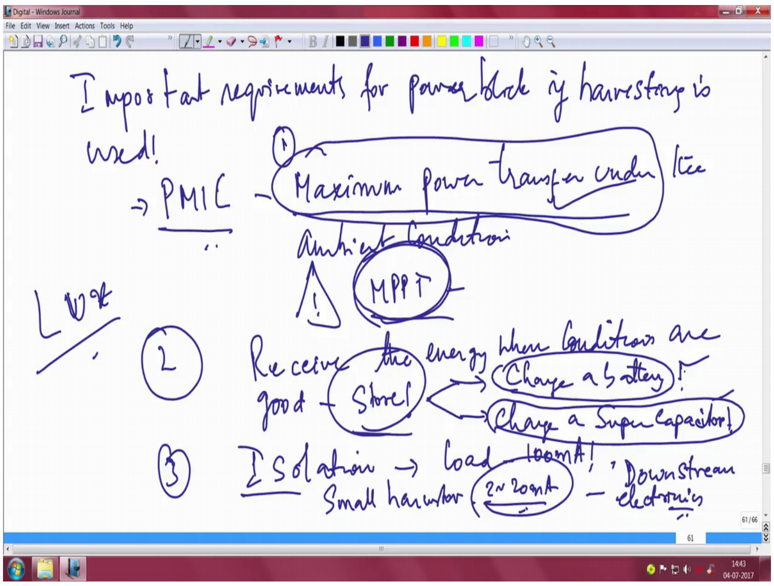

So, you recall this thing we did mention to about the maximum power transfer under ambient condition, which means you may have to look at maximum power point tracking systems and chips which essentially are components which essentially will be useful for energy harvesting applications.

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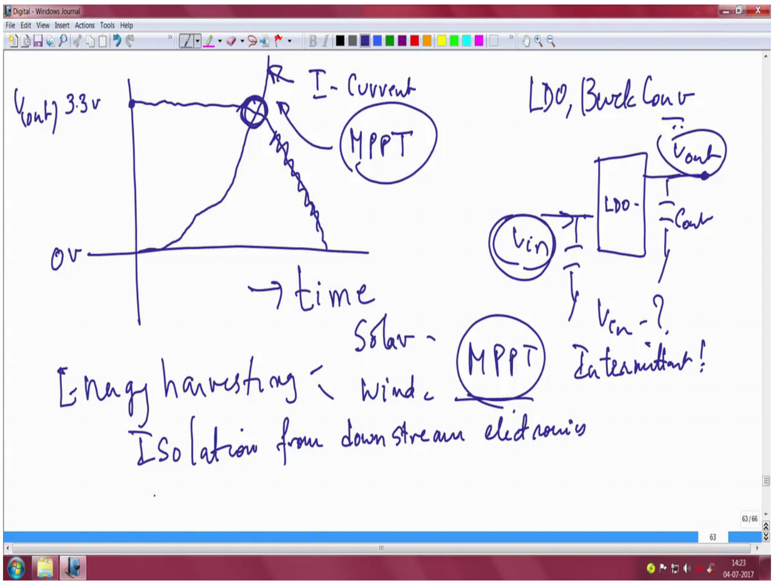

So, let us actually see why is that an important thing. What I will do is I will draw something very intuitive let us assume that this is time this is the time axis. So, let me write it a little more clean time, this is time axis. Now what I will do is the output of whatever power conditioning or whatever system that you have done let us say fixes the voltage to this point all right and let us say that this is some 3.3 volt some output point some voltage point.

Now, as the output load as the output load this is say let us say V out as you keep changing this load this is R load right, as you keep loading this R load by this potential meter essentially the voltage will keep dropping. So, you are here and as you keep loading the R value the voltage will keep dropping right this; obviously, is 0 volts. When does this voltage keep dropping here as and when the current start increasing, let us draw the increasing in current like this.

So, this is I, I am sure you all agree this is nothing, but current this is that I that is flowing and this is the V out that is what you are measuring this is V out, this is your V out, just look at this point. There is one point which essentially will intersect both this voltage and current curve which is a really good optimal point anything you do beyond this essentially will not give you any voltage, voltage will go to 0 and anything below you do you are not completely loading the system; that means, you are not drawing sufficient amount of current which is also an issue because loads do require sufficient amount of current and voltage sufficient power in order to work and that power requirements will not be met.

Therefore this is that my sweet spot which you have to keep worrying about and this is indeed the maximum power point tracking point or maximum power point right. So, any energy harvesting system, any harvesting system particularly if you are looking at solar or wind or any one of these variable input energy sources you will have to worry about the IC chip component which essentially will give you maximum power point because the input is all the time changing.

Clearly, it turns out let me rub this out, so that we have sufficient space to talk about other part clearly what this simply means is unlike the LDO and the buck converters we spoke of where we know that there is a certain V in and then we have a certain V out input capacitor output capacitors for stability purposes we discussed this earlier, this is a LDO.

This made an assumption that V in is always there this made an assumption that V out is with respect to V in being present, but in harvesting circuit you do not even know if your V in will actually be there, is it there, is it intermittent, is it not intermittent. So, that is a problem. So, unless there is sufficient amount of logic in silicon which makes things smart and assumes that the algorithm such as maximum power point tracking then assumptions related to very low grade very low grade, not low I would say low grade inputs is available input, very low grade assumptions related to very low grade input all of this will have to be made in order to bring out a component which is suitable for energy harvesting. This is the key point. So, all these things will have to be born in mind.

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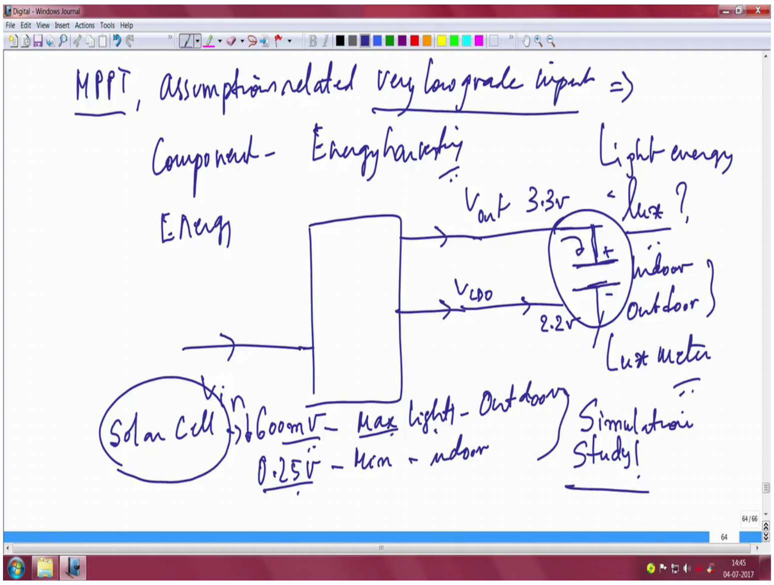

It is also possible that energy harvesting chips energy harvesting chips if you take and you apply V in here you basically get 2 types of outputs - one is called the normal V out the other is called the V LDO. This is typically around the 2.2 volt range and this could be typically what you connect to the output loads which is 3.3 volts. Input is low grade right if you take a solar panel as a possible input a single solar panel will measure under bright sunlight conditions it can give you a maximum of about 0.5 about 550 I would say let me write it as 550, 550 or 600 maximum millivolt and under very low this is maximum lighting condition outdoor right and it may give you an up to 250 millivolt just for completeness and I will say 2.5; 2.54, 0.25 volts as the under the minimum input lighting condition, minimum condition this would typically indoor.

How to know how much you will get? One is to use a multimeter the other is to know as an engineer some numbers essentially which will allow you to design your system your energy harvesting system essentially may be used or your embedded system or your IoT system, your IoT device for which you are planning this energy harvesting system could be applied in indoor or it could be outdoor right that is what we said. If it is Indoor you should know what kind of lighting conditions exist Indoor what is the amount of light energy, light energy is it not coming well let me rewrite it light energy, energy in the form of light and what is the kind of lux that is available indoor as well as outdoor you must know this before you plan anything.

For that you use a very cheap lux meter, lux meter and what is a lux meter? I will show you now, let us make a measurement let us see under writing condition what is the amount of lux that is being measured. For that I will pull out this lux meter and you will see that right now it is reading 0 then what I will do I will take this out this lid and I will place it against the indoor light that is there, how much is that reading it is about its reading about 1000 lux roughly close to nine hundred and so it is fluctuating between 900 and 930 lux.

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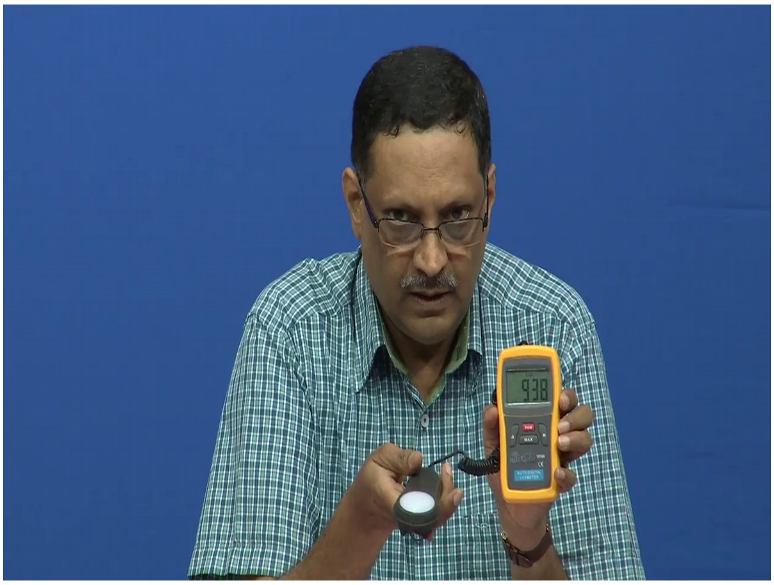

So, just to see whether everything is working well I will continue to point here, but I will simply reverse this, this is the element which is actually reading it. So, I just reversed it if I reverse it I should get low light you see you get 200 here, but then you get some other value something close to 200 right, it is about 185. So, if I close this it should go back to 0, yes it is I closed it and I open it back here and, so you see about 200 lux. If I open it like this and face it against the light bulbs I am getting 900 lux. So, you see this is telling you a big story, this is telling you a very big story.

Just do not keep the solar indoor solar panel it is some arbitrary position and say I will get 200 lux or I will get 400 lux and I will be happy that is not the way you must orient your panels in a manner your indoor solar panel, in a manner that you will be able to maximize the amount of light energy available such that your electronics will work. What kind of panels do you typically use in indoor? Right, that is your next question. So, I hope this demonstration was good for you simple lux meter is just available for a few hundred rupees you can buy this and make a measurement before you start your IoT device for indoor applications with energy harvesting right that is what you want to do at the end, very good.

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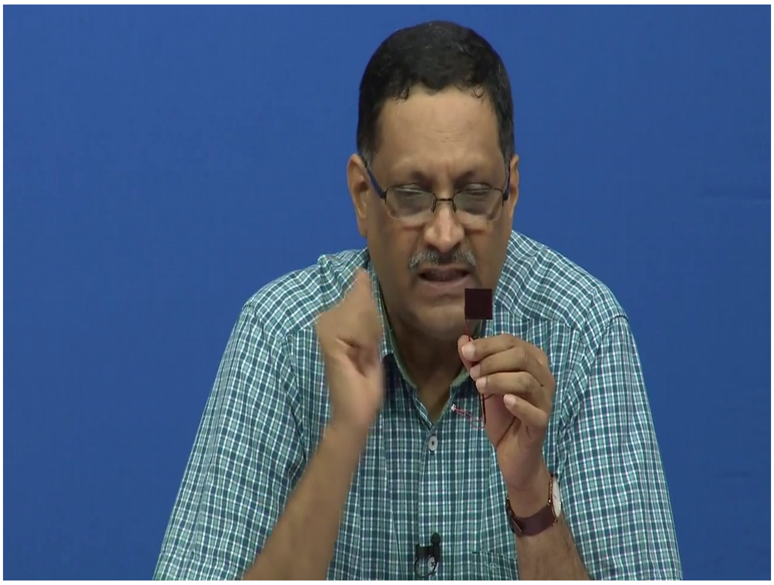

So, I will put this back and I will show you something more. What I like to show you is the kind of panels that you are likely to use are something this is a solar panel, you see this is roughly I would say 2 centimeter cross, 2 centimeter and your IoT device and electronics perhaps will also fit behind this and the let us say it is doing some monitoring of some parameter inside your building or inside your inside your house, it could be some typical some parameter that it is measuring. Clearly you are not talking of large panels which you might have seen in outdoor for traffic signals and all that where you are talking of a few hundreds of watts that would be required you are actually talking of milliwatts of power here.

So, you can say that this is a theoretically this should give you 1 milliwatts to about about 1 milliwatts of power, I have taken 10 percent as the efficiency and I think that you will get about 2 milliwatts roughly 2 milliwatts if you are lucky and if it is a poor good quality panel our measurements do not even indicate that you will get 2 milliwatt you are actually getting much lower values. See the answer itself is very incomplete right, what do you mean by saying it you will give you 2 milliwatts? It means you will get 2 milliwatt under maximum lighting condition maximum, what do you mean maximum?

Let me go back here, this maximum simply means you are getting a number here right this number is something like 200 300 and all that, and if I face it, it is going up to 1000 right that is what we said a little more than it should go to 100000 it should go to a 150000 it should go to 200000 and when will you get that. You will not get it indoor you will get it outdoor under good bright sunlight you will get 150000 or 150000 lux or 200000 lux. If a cloud comes it will be down to 50000 it may be even down to 25000, may be down to 10000 lux that can happen, but you can you can imagine that that is all fine outdoor what about indoor you see that is what I was saying if you do this you get 1000 and if you do this you are down to 200.

Even here indoor you have this problem, unless you orient yourself panels properly indoor you are not likely to you know harvest in a more efficient manner. Therefore, the big take away is these panels are all fine no problem you may have to ensure that you orient them in a manner that you will be able to extract maximum power and energy from this system. Is this not a tough task, is this not going to be without any knowledge in energy harvesting what should be my panel what should be the output voltage that I should get, how do I design my electronic and all of that such that I will be able to get some reasonable output for measurement of my parameter of interest well that is indeed the hard problem, but as an engineer I did mention in one of my previous classes that you should not hesitate to use the free tools that are available on the net, you should never hesitate to do that you must simulate.

So, let us see before you actually buy anything can you actually simulate something like that and let us see that whole cycle of trying to do something using your laptop simulating something and then trying to see in practice whether you can actually achieve it right. So, let us connect all these bullet us together and I want you to actually do it during the course to make your own a little more practice to actually try out all these examples all by yourselves. Let me now switch to the computer, this is my computer and what I will do is I will start a stimulator note what I am doing I am starting a simulator called LT spice. Let me write it here for you LT, sorry where is it marked let us see.

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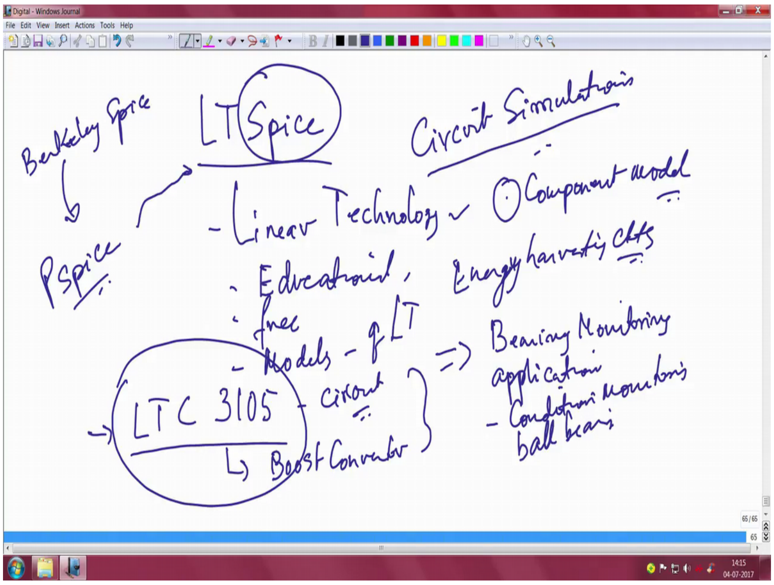

So, LT spice this is from a company called linear technologies technology they have adopted the Berkeley spice and have released an educational version this is an educational version free for learning educational obviously it is free. It has a number of models of there of LT of linear technologies and number of the component models are available essentially any component manufactured by linear technology you can simulate the circuit if it can do a circuit simulation basically this is called circuit simulation.

I will not go into detail because simulations are of different types and this is the most important thing you are actually doing the circuit simulation component that you use will have what is known as a component model very actually describing the components behavior captured well and that is indeed the component model. I will not get into the detail because I am sure all of you would have used spice, p spice for instance is also coming from the Berkeley spice, Berkeley spice and different people have adapted the p spice actually came from there and the same spice tool simulation tool is actually also appearing in LT spice, we call it LT spice because it is has a number of linear technologies components.

So, let us try and open up the technology spice and just try some energy harvesting energy, energy harvesting circuits right harvesting circuits in this LT spice let me show you a very popular energy harvesting chip called LTC 3105, LTC 3105 is from linear technologies and you should be able to build a circuit with this when I say build a circuit essentially populate the chip pins around the pins of the chip with several passive components. Remember LTC 3105 is a boost converter, boost converter why do you need the boost converter because in energy harvesting applications you get very low grade inputs and in order to ensure that the low grade input is being taken I am giving you a reasonable rail voltage of let us say 3.2 or 3.3 you should be able to drive the electronics.

Why did I choose this particular component? Well, it goes back to the basic bearing monitoring application right, bearing monitoring application which I took as an example where we were talking about condition monitoring condition monitoring of ball bearings right of ball bearings that use this LTC 3105 and therefore, let us see if you can simulate LTC 3105.

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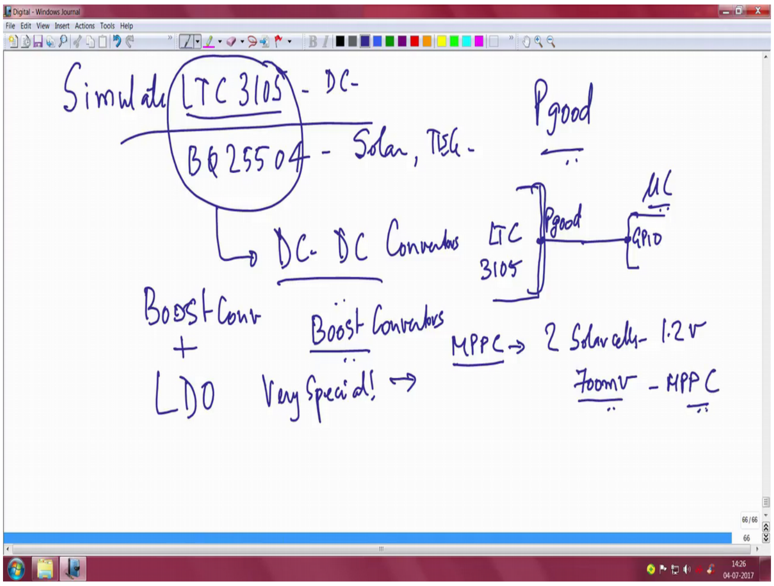

Again I have no bias for a particular company, but just that energy harvesting chips and components lot of work is actually done by linear technology and so much also with TI and magazine and vendors. In fact, TI has another chip called BQ 25504 which is also a very popular energy harvesting energy harvesting chip where the input is also solar as a possible, solar or even thermoelectric generation as an input and so is with LTC 3105. This is basically a DC-DC converter in fact, most of the energy harvesting chips that you know very well basically form some form of the other they are basically DC-DC converters right. They will have, they are they are nothing, but know a boost converters they are nothing, but boost convertors.

Please note go back to what we will be discussing what we have already discussed with respect to boost converters there is a usual feedback that you do output sensing it is a complete close loop system, there is PWM generator and the PWM output basically drives the series pass element and the duty cycle of the PWM actually decides the output voltage right input output is determined by the PWM signal all these we spoke about, what is special about this boost converter with respect to energy harvesting is the question.

So, let us see a few simulations with the LTC 3105 and try and understand its pin layout and. So, on and also see how the output behaves with respect to the components that have been chosen all right. So, this is the background, let us now move to LT spice my screen here.

And I will open LT spice you can download LT spice from the web quite easily you can install it is a not heavy file, install it and then open the input the LTC 3105.

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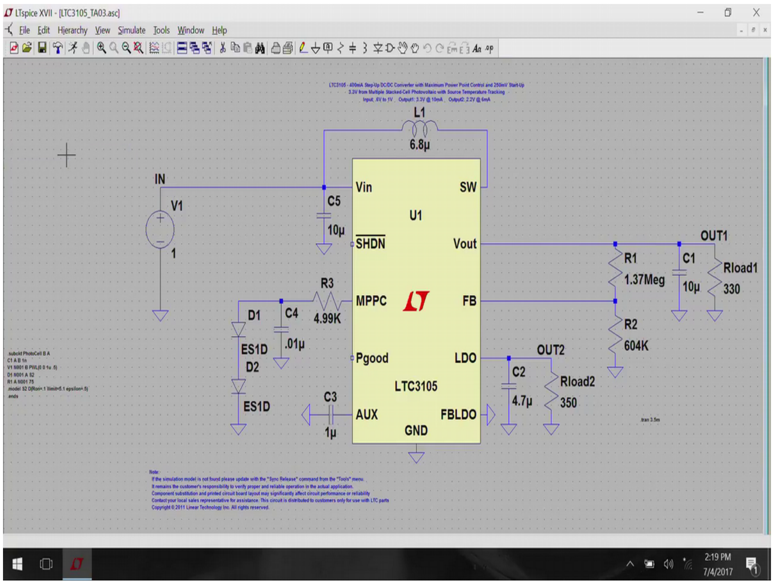

You see this, this is LTC 3105 basically I just went to linear technologies website and we downloaded the LTC 3105 and its associated circuit and we wanted because we think that before we build anything before we buy this chip, this chip and hook up all these components you may have to simulate and see whether it is suitable for our conditions.

Remember there is an input you can see this I replace the solar panel with this input voltage source which is going in here and then this is V out and this is programmed to give you 3.3 volts at the output. The feedback is available through from the V out from the back into the feedback pin here this is a resistor divider network and essentially it is providing you the required feedback in a manner that the output always remains at 3.3 right and it also has an LDO at the output you can see that there is an LDO.

So, it is a chip that not only has a boost converter boost converter, it also has an LDO at the output and you have out 2 which is essentially the LDO output and there is something called P good which is nothing, but the power good and this is a output pin which you can interface to a microcontroller this is the P good coming from the LTC 3105 and connected to the GPI open of a microcontroller and use this pin whenever it asserts to see to use additional operations. In fact, this is what we exploit in our bearing application as well I did talk to you about this pin in the context of condition monitoring of bearings. So, please look up those that discussion as well.

So, that is one thing and what is also special is this MPPC here which essentially is the maximum power point control pin which is doing something very special very special pin what is it doing as I mentioned to you major difference between a buck boost or a boost converter which is for which is a normal boost converter as against in energy harvesting boost converter is that the fact that the input sometimes can also go to 0 and the output electronics should not be loaded we said this in the previous classes in the previous discussions as well.

So, isolation right, you want to do an isolation so that there is no loading by the downstream electronics which is a clear indicator that you will need a handle for any loading effect which might happen and MPPC is essentially taking care of that aspect of ensuring that the output voltage never goes below. So, it never shuts down basically you should ensure that the LTC 3105 never shuts down and does not get thoroughly overloaded by the output.

So, it is in a way providing isolation, isolation from, isolation from downstream electronics in a way that is what it is trying to do which one this MPPC pin is essentially doing that what it actually does is if you take an energy harvesting source such that such as the solar panel and let us say I mention to you that a single panel can take single panel will give you under good lighting conditions something close to 600 millivolts and under very low single single panel single cell I should say single cell right. Single cell I think we wrote somewhere.

So, let us go back and we did not do that. So, I thought we had it is a single single oh. So, I should use the right the word see this is the mistake. So, let me rub this out it cannot be panel single cell, single cell gives maximum of 600 millivolt under temperature conditions of 25 degrees and as the temperature keeps increasing this voltage will keep falling down and that is under maximum lighting condition and you can get 250 millivolt under minimum indoor lighting condition. What this MPPC pin does is suppose if you put 2 cells, suppose you take so let me redraw it suppose you take very special as I said. So, if you take the discussion in MPPC what it simply says is suppose you take 2 solar cells right you get 1.2 volts maximum under good lighting condition you can set this to 700 millivolts MPPC.

In other words this pin that you see here with this registers that are here, with these this resisters this resisters here will actually set the MPPC point to 700 millivolts. I am just giving some examples for you to understand 700 millivolts. Now and this is essentially the solar panel which is supposed to give you under very good lighting condition 1.2 volts and under indoor conditions open circuits will give you significant output, but because the lux is poor you cannot draw too much power output whatever maybe the case this point this input will never fall below the set point of 700 millivolts that is the beauty.

That means, this V out might reach definitely 3.3, but this loading when there are different loads being connected when the output of the buck convertor is connected to the load which could include a micro controller or it could include the radio, it could include sensors all of that and there are other power guzzling power consuming components it will ensure the electronics there will have to work under the constraint that this input will never go below 700 millivolt, that is what it will do.

So, power management algorithm that is running on your micro controller will have to note that the energy for driving power consuming components, will have to come from the capacitor will have to be delivered through the capacitor after buffering, after storing and ensuring that once its stored it has the power and power to deliver for the power consuming component. This way, this input system does not collapse and with 0 output here you will never get that situation if you arrest it with this MPPC pin. So, that is the key understanding here.

So, what I did was I replaced the solar panel equivalent component with a voltage source and why I did that because I actually wanted to show you what I have done in terms of actual implementation. So, let me first run this and you will see what actually happens, this is the output the input is said to let me see what the input is set to the input you can see is set to 1 volt. So, input is 1 volt, the output here is set to point three it is boosting there is a load of course, and it is supposed to give you 3.3 at the output. So, let us see.

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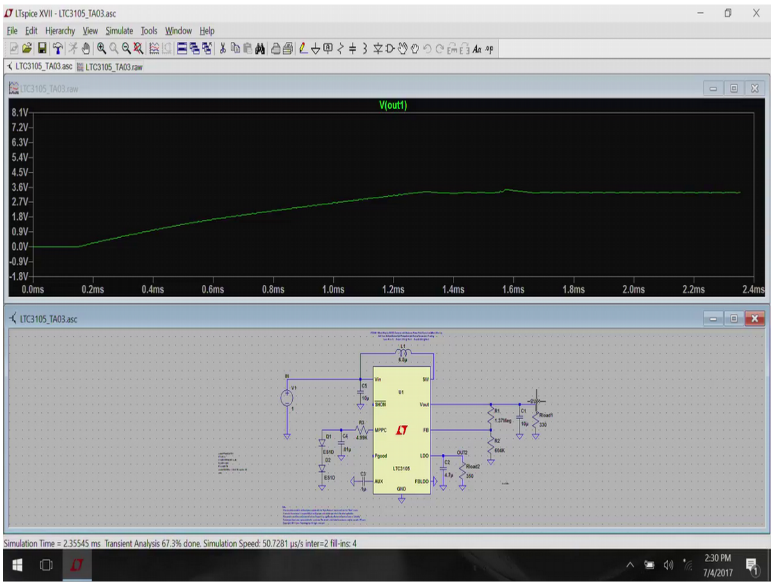

Supposing you want to simulate just go and press run right. So, there you are it has started the simulation the simulation output is here I want to see let us say this output I want to see output there you are. So, you can see slowly it is building and you will see that it has stabilized to some voltage at the output and what is that voltage, look carefully this output is 3.3, it has actually built to 3.3. So, you can see that the input is 1 volt and the output is 3.3. There you are, this line indicates that the input is one volt and the output is 3.3 very good.

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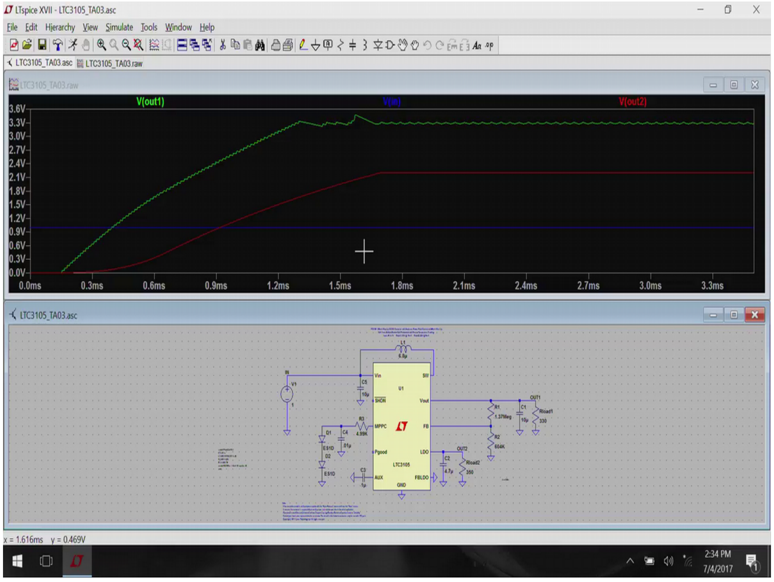

Let me also show you the outputs from the LDO. So, let me click here there you are, what is this? This is giving you 2.2 and interesting right initially what will come out will be this 2.2 volts which is much lower than the 3.3 as you are harvesting the energy here, let me close this I will actually keep this together only then you will appreciate this. This is the solar panel once you connect equivalent of a solar panel I have just connected the voltage now you will get 2.2 straight away that is this line, this 2.2 you can take and power the micro controller open start running the micro controller acquire the temperature of the bearing, ball bearing and store that value.

Once you get 3.3 how do you know you are going to get 3.3 because this power good signal is going to tell you that the output will go to 3.3 very soon after this ramping up period it will go to 3.3 and stabilize you will see that you can then switch on other power consuming components and also those components which require this higher (Refer Time: 39:50) field (Refer Time: 39:50) voltage and complete the operation of sensing and communication as well.

All along the input is assumed here that you are getting about 1 volt. So, that you can see is here. Now let us see having understood this simple tool how you can actually get the required output what I have done in order to achieve it in terms of practice for that I will show you the output of the LTC circuit which I had incorporated into the bearing monitoring part here.

So, let me turn my attention to you here where the output voltage which should give you 3.2, can you see, this can you see this output here very good.

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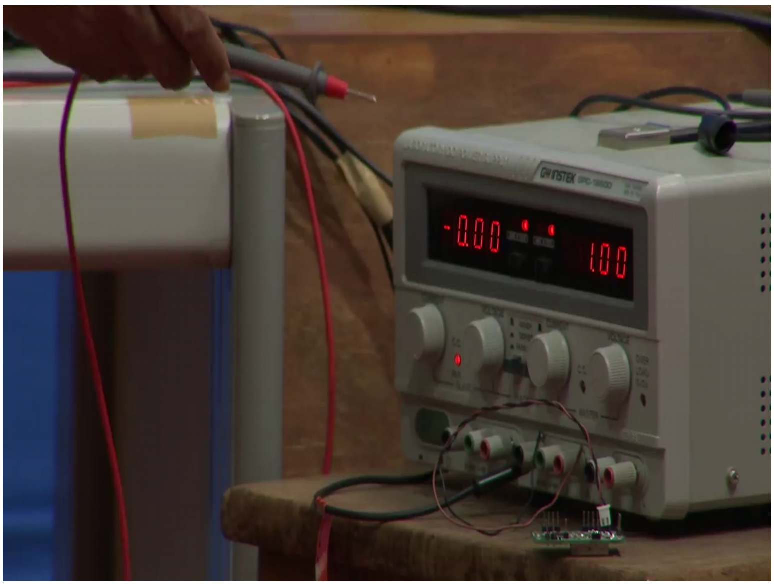

So, first let us see look at this, this is input of 1 volt, recall the simulator. We gave ADC input of 1 volt and we are supposed to get 2.2 volts from the V LDO and we are supposed to get 3.3 volts from the V out correct. So, let us see those 2 outputs for that let us look at this multimeter.

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So, I will show you this output first which is 2.2 you see that its 2.16 volts and this is 3.22 volts this is the close to 3.3 volts. So, what is the big takeaway? The big takeaway indeed is that use in energy harvesting, when you are trying to use energy harvesting technologies for building the power block of your of your IoT device do not rush and buy components and start trying do not do that, go structured identify what you want to do for your indoor application you want to try with the solar panel or you want to try with a thermo electric generator for instance temperature differentiates. Let us also try and see if I can show you a demonstration of that as well in the coming times.

So, that is your first thing you want to know what you want to do input indoor or outdoor and after that do not rush into things look up several of these energy harvesting chips components ICs which are available and look at the conditions under which they are supposed to work, is it 200 lux, is it going to be 1000 lux, what is the input condition input energy availability that you have to understand first. And after that you may have to put those parameters that you understood into this nice simulator let us turn our attention back here and complete the story right. You will have to go back and put this values into this simulator I put 1 volt here you can see and which is shown here by this line which is a 1 volt line maybe, it may be useful to expand for instance, but it is ok, this is still fine you can see that this is maybe, I can expand this part very well yes.

So, this is what we get at the input and you are getting something close to close to 1 volt at the input. Why does it show something else here?

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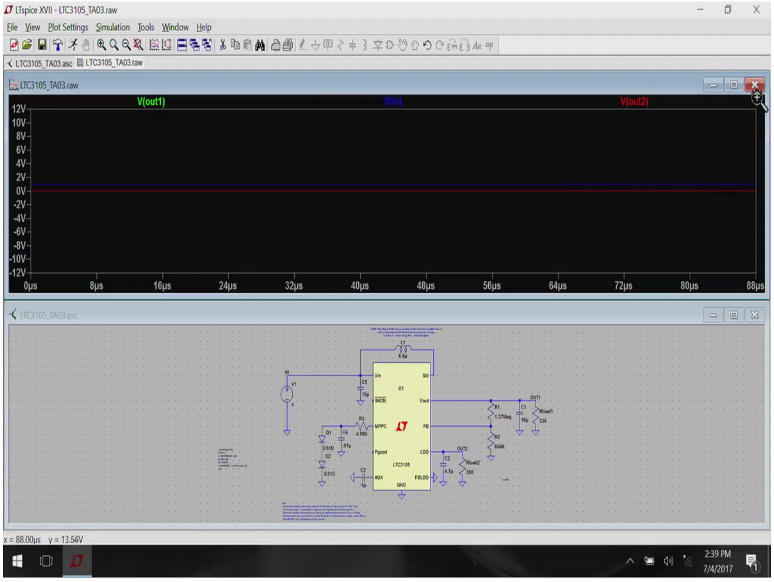

So, that is this is 1 volt at the input and 1 volt at the input and you basically have. So, let me go back its looks like we can try, let me do one more thing close this, and re-simulate it its much simpler. So, run this simulation and see one by one input. Input will be here, oops sorry about that.

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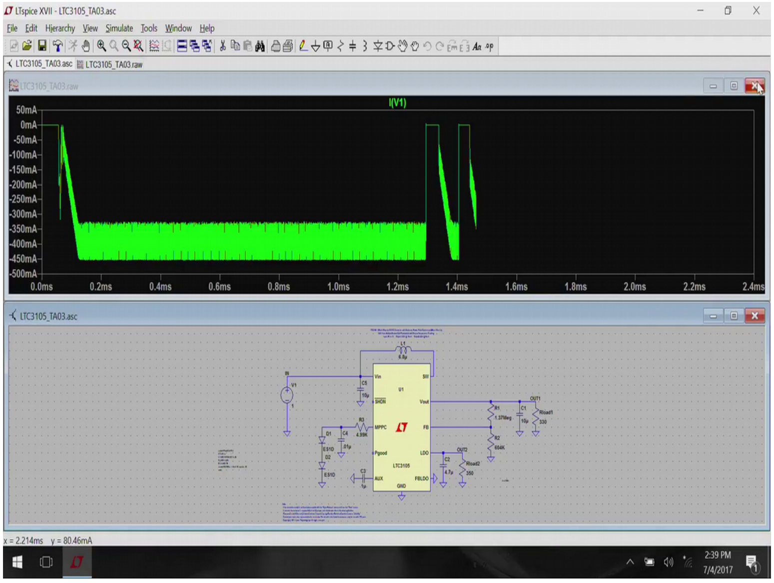

So, simulate we can do something went wrong. So, yes oh something went wrong in this simulation here sorry about that.

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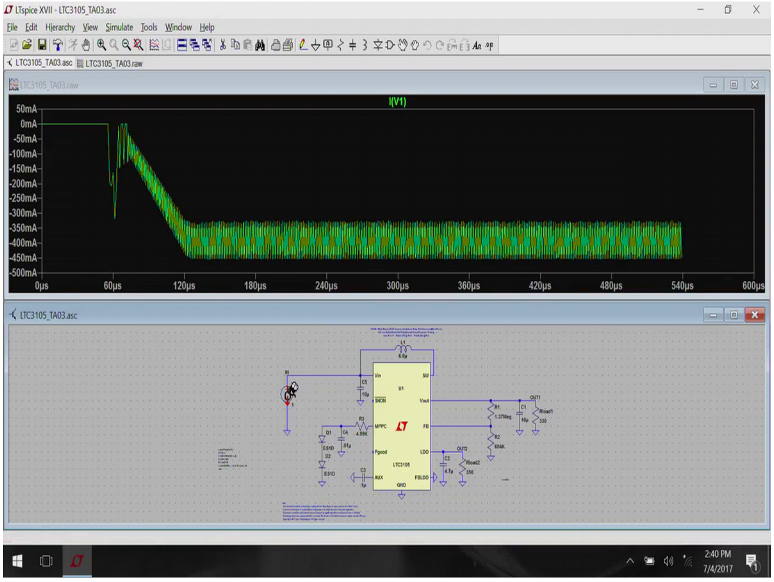

So, let me close this, I mean restart file open LTC and write simulate, first is to try the output let us see what happens with the output its slowly building to it should build to 3.3 yes it does you can see that this is 3 volts here and it is stabilizing till 3.3 at the output then we have yes it has stabilized to 3.3, right and let us see what happens to V LDO.

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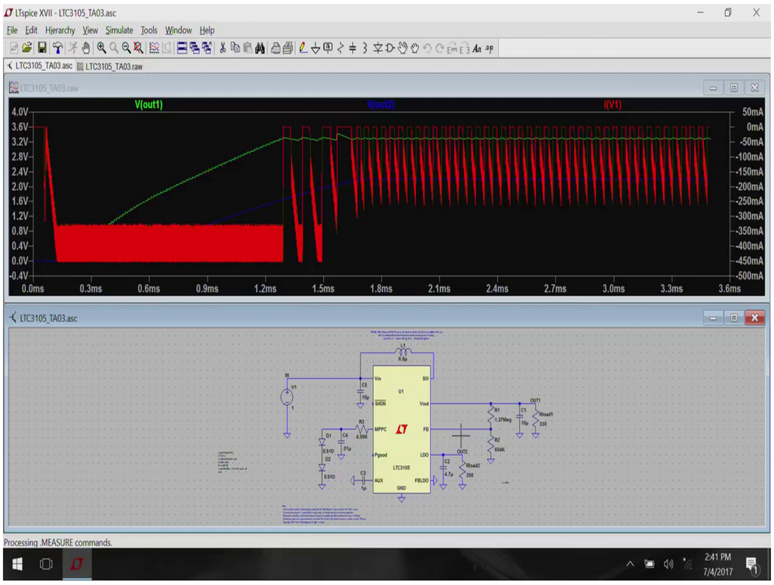

V LDO is at 2.2 that is what we measured and input is bit noisy for some reason is noisy for some reason it should give you 1 volt at the input. So, I think I should click it at the right point otherwise it would give you wrong output. So, this is the input right. So, you should actually click it here and I was clicking it somewhere else and it was showing you all the current and noise that was going to ground. So, that is not the right point. So, you can see that the 1 volt is the input and output is gone to 3.3 and LDO output indeed goes to 2 volts, 2.2 volts.

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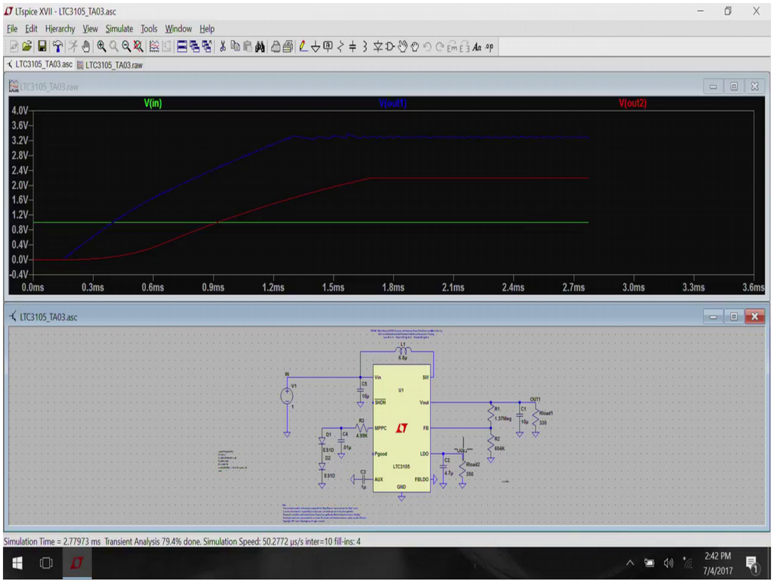

There you are, what this basically conveys is that you have to do all of this in if you are trying to build the power supply block for your IoT device. While I showed you a demonstration of everything that we did this is true even for non energy harvesting blocks, if you are trying to use a battery based system also you should do all these work. In fact, this simulation is so powerful that you can actually look forward to do the following, and what is that? You can try this by yourself, but you have to connect the bullet us that we spoke off in the previous class. Let me draw your attention to this thing that I spoke. Charge a battery, charge a super capacitor right this is the energy when conditions are good, store the energy and the storage can be in terms of charging a battery and charge a super capacitor.

What prevents you now from trying this little LT spice simulation by putting a battery at the output or putting a capacitor at the output of suitable dimension and seeing under input conditions, under input conditions of using a solar cell under input conditions of lux which is about 200 300 400 lux what is the output that you might get use that as an input here. Look at how you can connect a battery source right to such that it can charge this battery or connect a super capacitor and see how much time it takes to fully charge this super capacitor. All of this whether a battery at the output or a super capacitor at the output all of this can be very well studied by this simulation work, simulation study. And for me this is a very important thing that you have to do when you are constructing the power supply block of your system, IoT system that you are trying to build. So, let us move on with these demonstrations to complete the discussion of this chip that we started this LTC 3105.

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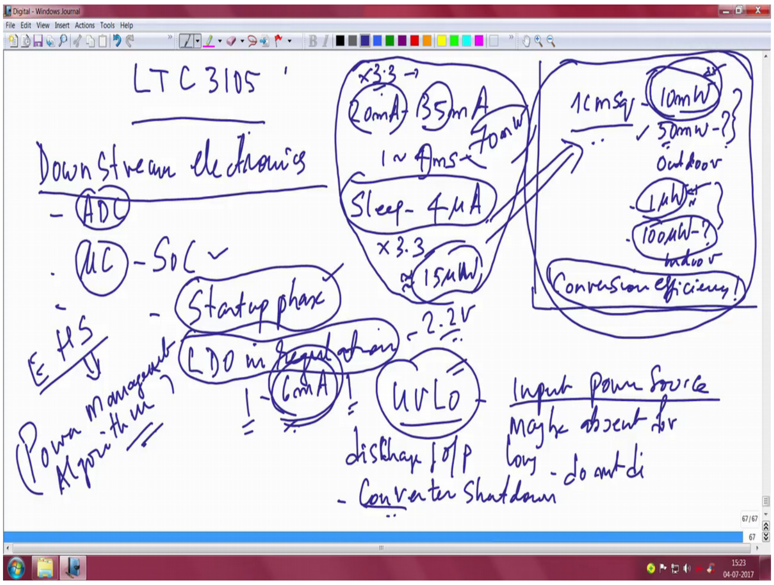

We took this chip and we have to complete basic understanding of energy harvesting parts which become critical for when you build the power supply using energy harvesting blocks what are all the things that you have to keep a note on. So, we should complete this discussion on LTC 3105 and close the story on energy harvesting with respect to this chip. See I started by saying that LTC 3105 can use a small solar cell and a single solar cell will gives you will give you something like 600 millivolts at 0.5 to 0.6 millivolt at a particular temp room temperature about 25 degrees or so right and it keeps falling as the temperature increases this is all fine, but you know the thing is that is maximum that is what we said right.

See different manufacturers give you different type of solar cells with different fill factors and so many other related efficiency is an important point that is the real story behind solar panel. My own experience is from whatever little bit I have been you know looking at how to interface solar cells and solar panels, I normally I am a little more conservative in taking the output from a solar panel. Let me draw your attention to what I have written here.

In my opinion you see this particular thing I have written, it is not always true, but you can go by this. If you take a one centimeter square solar panel I think under outdoor condition you should get about 10 milliwatt the claim by many manufacturers is that you should get even 50 milliwatt it may be true and it may be often true that you may get this actually you know you may get this output, but for all your calculation purposes for your dimensioning of the solar paneling and so on you can take this as roughly as what would be suitable for outdoor applications.

Come to indoor for any conservative approach I would say you must go away with something like 1 to 10 microwatts of this size panel, but the claim again is that you should get up to 100 microwatt indoor. All of this essentially means these manufacturers talk about this conversion efficiency and I have in my calculations I have only taken 10 percent which is very conservative. So, I would say this discussion on what is the power output from a 1 centimeter square panel is often going to be dispute whatever I say you will find something better. Obviously, you will not find anything worse than what I am saying.

So, kindly take this a little more carefully in all your calculations and do not go by what I am saying as the final truth my experience and my estimations have not gone wrong because I have considered only something like 10 milliwatt for a 1 centimeter square panel for outdoor and 1 microwatt to about 10 microwatts I would say even could gone up to about 10 microwatt for all the indoor applications. All right, this is one part.

The other part is when I say downstream electronics you must also note that when I say downstream this means that there is an ADC, the micro controller itself is the another load the ADC means it has sensors which are connected to the ADC their consuming components as well. And you may want to do a few tricks before you actually start doing any communications with typical micro controller cum radio the low power radio like a BLE radio for any communicational purpose you want to do any sensing operation like what we said about the conditioning monitoring, but all of that means, that the LTC 3105 itself when an input is given like what we show, like what we had discussed is 1 volt input goes through several phases before you can actually start drawing the power output either to the LDO output for certain operations or actually doing a communication of the sensor value.

The first phase that the LTC 3105 it is a HS chip energy harvesting systems chip does is it passes through what is known as the start up phase. Then the LDO will go into regulation and will provide you the LDO output directly. Let me switch to what I mean by this in this picture which essentially is here right this will connect well. So, you can see that this LDO here that you see essentially where I am pointing to is the LDO output which is essentially 2.2 volts right that is the 2.2 volt point which is here.

This one from the chip specification you cannot draw too much power, what you can draw is only about current of about 66 million amperes, again this is what the data sheet says. So, you can at best switch on the micro controller and perhaps do some basic sensing that is all you can do with the LDO output.

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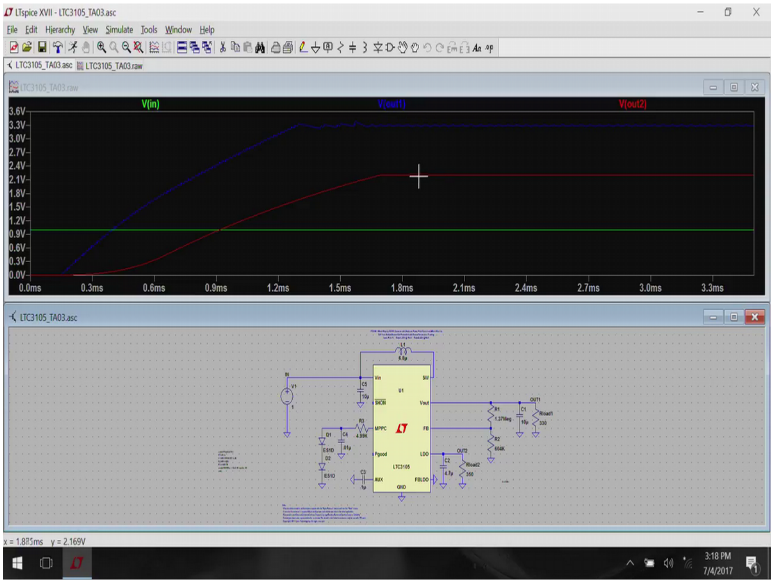

The point really is; why is this coming out first look carefully here, this LDO. So, this LDO has taken a little more time because the circuit here I have put the components I have put here is giving you a feeling that the LDO output is settling down faster as slower compared to that of the actual V out which is actually in reality not true. I will leave it to you to actually show that LDO output settles down faster compared to this actual V out you should actually get that. So, try it, I want you to try and come back and ask me questions related to reversing the role of the V out and this LDO output which should come you know much faster.

Now, going by what you have seen here I we can still argue that the output has not really stabilized because you can see that the stability point has come somewhere here. In fact, it is still giving you this little jagged output. I am sure you appreciate why this jagged output comes and if you go back to what we discussed in the last class it is purely because of the inductor current right, this is the inductor which you have seen here and this is the actual inductor of the boost convertor and the current flowing through the inductor is actually giving you this wave wavy nature. And you wanted to stabilize therefore you wait until it is stabilizes to a good value therefore, start using the output of the output of the regulator. In fact, you can do many interesting things before you essentially conclude on these actual results.

For instance you change this input ok. You change this input to because it can event start even 250 milli volt put it to lower voltage see what actually happens V out, V out actually comes to stability much much later. In fact, in some of my experiment which I apposition later the one point, the 3.3 get here actually comes much later what you will see 1.6 volts slowly rising to 3.3 the output this can be demonstrated. Mean while the LDO output which you see here will already come and it will give you 2.2, so that is the nice thing which you can already start using it for switching on the micro controller and doing other things, this is one thing.

Another feature which the LTC 3105 into half this energy harvesting chips normally have is that under voltage lock out, why is this important? Because input power source may be absent for extended periods when input power like the one set you saw here this input power in this simulation picture that I had here, if the input power is this one this particular one if it is not there for a extended period we do not want this output to vanish just because this LTC can now accept power in this direction in the ground it, right.

We do not want power float to happen this way and reduce the power output here. So, you want put this into a complete shutdowns state such that the output remains whatever it is, we do not want LTC to draw power in the reverse reduction and bring down the output voltage this is essentially what under voltage lock out actually is. The converter this converter chip, actually has to complete do a complete shutdown as I have written here in order to ensure that the chip is indeed a stable.

Finally, I want to draw your attention to this little story that many of the embedded systems electronics that we will be working on will actually be drawing. If you take the LTC output at we have seen as 3.3 volts and if you do sort of a communication you do some sensing compute and then do a communication, you will need any where between 20 to 35 milli amperes, for a very short duration 1 to 4 milli seconds which gives you a power consumption of about power requirement not consumption power requirement of above in fact, it is indeed consumption right about 70 milli watts or something like that you would might need.

If we put the microcontroller to sleep, your sleep currents ha typically 4 micro amperes you may need anywhere between 12 to 15 micro watts of a power right. So, this power requirement of, peak power requirement of a 70, sleep power requirement of 15 milli watt all of this leads to deciding what should be the size of your panel right.

So, that is what I wanted to derive home that your sizing of the panel will large depends on how you design your power management algorithm. Energy harvesting systems means sensors means this is the very important requirement you must design your power management algorithm and indeed the bearing condition monitoring of ball bearing essentially was doing that. I had discussed the flow chart with you, which you can now see is a very important, it really fills up all the gaps and what we discussed.

Thank you very much.