Design for Internet of Things
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Lecture - 21
LDO - 02

Okay folks. Welcome back. See LDO, you must know the specifications of the LDO. You should be able to read the datasheet carefully and use it for your application. Let me point you to TPS 717 which we started.

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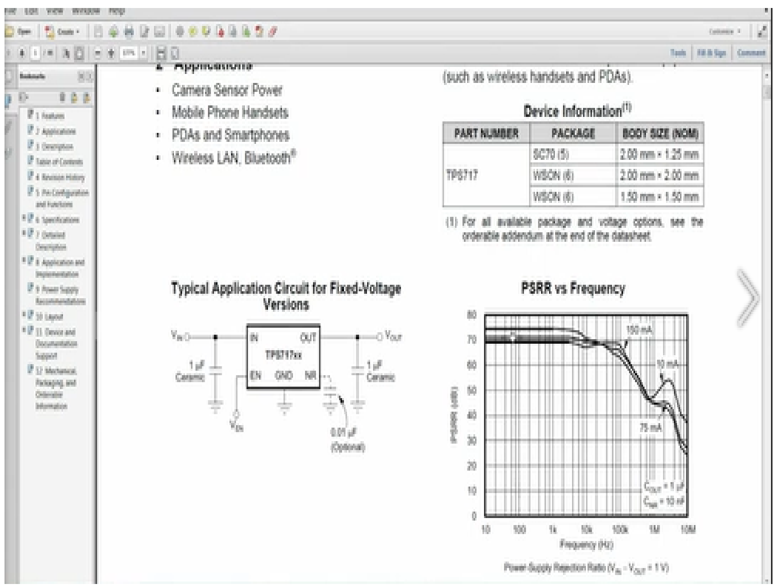

We went through some features of the LDO and very broadly we understood some features. So, we must spend a little more time trying to understand them in great detail. Then comes several parameters which are part of this datasheet, for example, the one that you see on the left side this is a nice picture already. You have input, you have a C input capacitor, you have an output capacitor, you have a ground, you have input V in and you have V out.

You know that V out is always less than V in, V drop out plus V out should give you V in. That is also an important thing. So, the dropout is the drop voltage that is dropped here across this LDO plus the output voltage should give you the input voltage. So, you could also interpret it that way right. Then there is the PSR versus frequency. And you can see that the output capacitor here, if you put one micro farad, you get some performance and he also talks about the CNR.

So, this is another capacitor which he is referring to as shown here in the dotted line here. If you put this value of some nature, you will get another characteristic which clearly indicates that the performance that you are looking for is available here. In order to get to that performance, you will have to look at what values he has chosen and accordingly populate your LDO with those values. This is why you need the datasheet.

Otherwise, you cannot design for an IoT system the power supply block. It is not just here. This result is beautifully written for not only different load currents as I mentioned PSRR influence of PSRR on the load current is one part also frequency component change in the frequency right. It is giving you some flat structure of different currents the one that is giving you the best must surely be for the lowest current.

So, if you trace this path, you will see that this is for the lowest current and we realize that as the current increases, the PSRR starts to dip, also it changes with the frequency. That is this result which is telling you. And they did this measurement for a power supply rejection ratio V in minus V out which is one volt.

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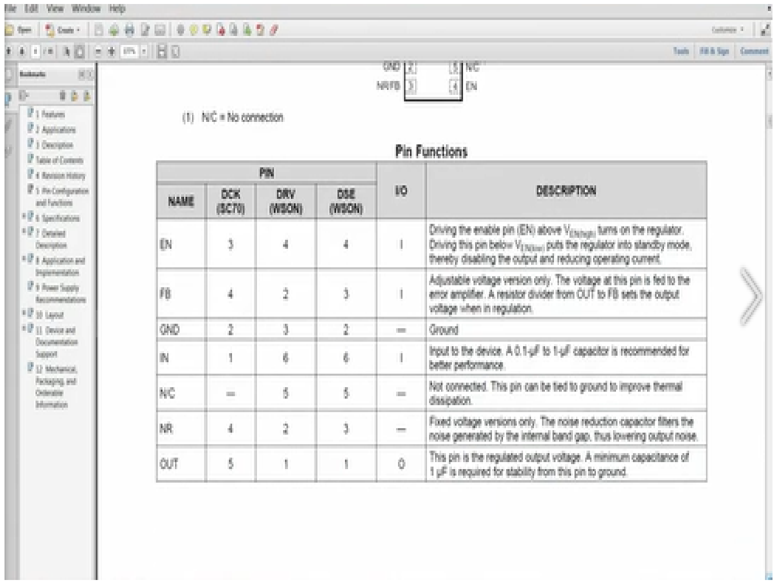

(1) N/C = No connection

Pin Functions

PIN				I/O	DESCRIPTION
NAME	DCK (SC70)	DRV (WSON)	DSE (WSON)		
EN	3	4	4	I	Driving the enable pin (EN) above $V_{EN(high)}$ turns on the regulator. Driving this pin below $V_{EN(low)}$ puts the regulator into standby mode, thereby disabling the output and reducing operating current.
FB	4	2	3	I	Adjustable voltage version only. The voltage at this pin is fed to the error amplifier. A resistor divider from OUT to FB sets the output voltage when in regulation.
GND	2	3	2	—	Ground
IN	1	6	6	I	Input to the device. A 0.1-μF to 1-μF capacitor is recommended for better performance.
N/C	—	5	5	—	Not connected. This pin can be tied to ground to improve thermal dissipation.
NR	4	2	3	—	Fixed voltage versions only. The noise reduction capacitor filters the noise generated by the internal band gap, thus lowering output noise.
OUT	5	1	1	O	This pin is the regulated output voltage. A minimum capacitance of 1 μF is required for stability from this pin to ground.

Some LDO's; actually have an enable pin. So, that if you make that zero the LDO output will go low. Therefore, you may want to save energy there right. So, you do not want to maybe the output load does not require that voltage then you may want to shut it down.

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Then there is a wealth of information related to junction temperature, output value, output capacitor, the enable voltage, I out which is the load current and the output voltage, the input voltage and so on. And they are also telling you about the junction temperature it should not exceed this much. How do you get to all this? How do you do some basic understanding of back of the envelope is the question.

You can see here R theta J A junction to ambient thermal resistance, R theta J C junction to case top thermal resistance and so on. All these values are given for different packages which are shown here and everything expressed in terms of degrees Celsius per watt. Then you have electrical parameters. And very interesting parameters particularly you may want to look at the things that we sort of know. One of the things we know is the about the accuracy.

This is a very important aspect where he talks about nominal output accuracy then over V in V out temperature and over V in-out temperature, one in temperature two for two different temperatures.

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In the data sheet there was one more parameter and that was related to the accuracy. Your understand this very well, folks. It actually refers to I have written down this so that I can show you.

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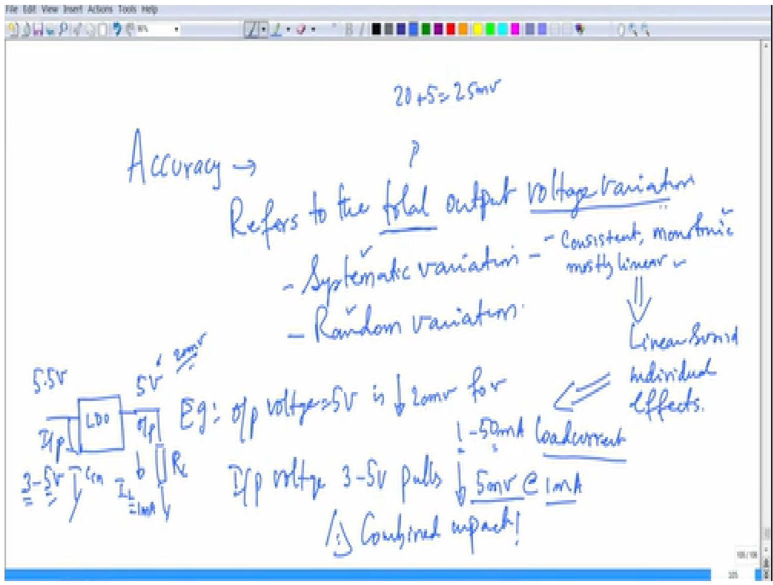

It refers to the total what I have marked here is very important. It underlined is very important, the total output voltage variation, it is the total one. What do you mean total? What are the component constituents of this total? One is systematic variation, the other is random variation. Both of them together will give you the total output voltage variation. Now, what are examples of systematic variation? And what exactly do you mean by systematic variation we have to learn.

First of all, what is the meaning of something being systematic? It simply means things are consistent, monotonic and mostly linear. Now that is what you termed it as systematic variation which means you can actually do a linear sum of individual effects. Whatever is that effect you can take and simply do a linear sum you will get it, you will get the total systematic variation. I will give you an example of this whole thing related to accuracy.

Now particularly with respect to systematic variation. Look at supposing you have an LDO, the LDO was output is 5 volts, input can be 5.5 volts as an example. And now 0.5 is getting dropped and this is an LDO, this is output and this is input. Now, the point is this. If let us say the output voltage is 5 volts and if you connect a load resistor and the load current flowing in this is anywhere between 1 and 50 milli amperes, the output voltage drops by 20 millivolts.

This is one parameter which you can consider straightaway. So, point is it is slightly lower than 5 volts, roughly 20 millivolts less than 5 volts for this is for a load current of anywhere between 1 to 50 milli amperes. Now this is on the output side. Now, look at the input side. Let us say the input varies quite randomly. It pulls let us say input goes somehow goes down from 5.5, it goes down to 3 and then moves to 5, it does not even go above 5.

So, for a very short duration anywhere it fluctuates between 3 and 5 volts. Now for that small fluctuation; because that fluctuation is not seen due to the input capacitance. So, I put an input capacitance. So, that the LDO does not shut off. For that small variation let us say the output is down to 5 millivolts for a very short duration under let us say load current of 1 milli ampere, just 1 milli ampere of load current. In this case now, it is 1 milli ampere.

And the output is down by 5 millivolts. Now, when you say total what will you do? You will add 20 plus 5 and then you will say 25 millivolt is what you have got as a number due to systematic variation. That is essentially what the accuracy, one of the terms related to accuracy is. But I will not defined what are those terms which come under systematic variation, I never even told you but I did mention to you about this fact that it is down by 20 millivolts if the load current varies anywhere between 1 and 50 milli amperes.

It simply means the output regulation is not, it the load regulation is a parameter which becomes important. So, let me show you now, some examples of what exactly we mean by that.

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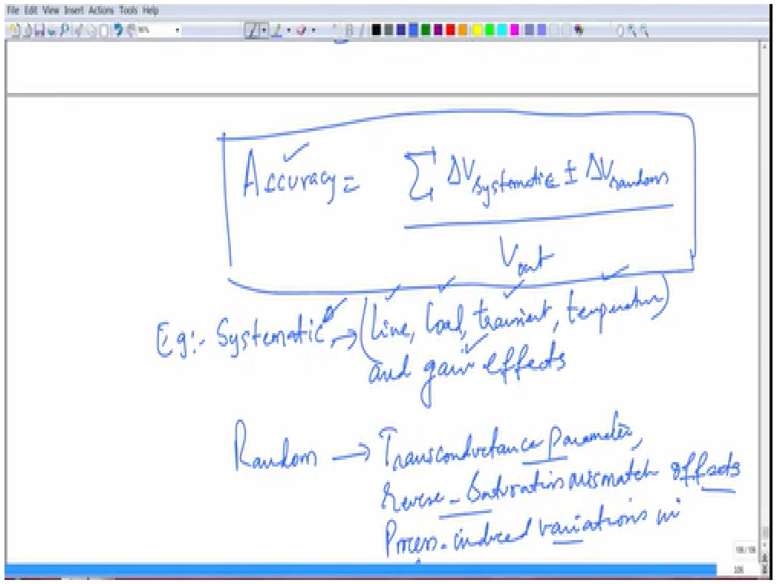

Now you have line regulation, load regulation, transient, temperature variation, gain effects, these all are come under systematic. Now what are random then? We did not even take the example of whatever is random in our 25 millivolt calculation, but here is what it is? Trans conductance parameters, reverse saturation mismatches, offsets, process induced variations, all of them come under in the manufacturing process.

All of them essentially are basically give you that combined effect of accuracy. So, in a very simple way, accuracy is just this parameter. It is sigma of all the more systematic variations, voltage changes due to systematic variations plus or minus because this is random all the variations due to randomness divided by the output voltage will give you the accuracy. Some of the manufacturers represent them in percentages, some of them represented in terms of actual numbers.

Either way you can use them and this is what the meaning of accuracy is in your data sheet respect to the LDO.

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Now, moving on you also see that line regulation is mentioned, load regulation is mentioned. Now, you look carefully he said delta V out in both cases, but delta V out delta V in delta V out open bracket delta I out. See, load regulation is always with respect to the current. The line regulation is always with respect to the voltage, this is the key difference. How do you measure this? It will be whatever V out minus 125 micro volts provided the input has dropped by one volt.

Similarly, as far as load regulation is concerned, for every one milli ampere change or increase in the load current, the voltage at the output will change by 70 micro volts 70 micro volts per milli ampere. And he has given the full range here you can see. This can be a significant number. So, you have to be careful about by how much the load will vary momentarily, it is all momentarily varying. So, these are this is what the load regulation is, the smaller the better in both the cases.

You do not want the set point V out to fluctuate under any condition. For any change in input voltage this will be the output voltage change. And for any current change, load current change I load this will be the change in the output voltage which will fall by 70 micro volts. Look at V LDO, LDO says look I can give you a minimum drop of 170, I am minimum going to drop and at the maximum current that is at 150 milli ampere which is the maximum current.

I will drop up to 300 millivolts. So, any current you are trying to draw will actually vary the VDO which is the dropout voltage accordingly. It can be swinging from 170 drop to a maximum of 300 millivolt drop. So, like this you can go on looking at different parameters. You can take eye ground for instance. The ground current actually depends on the current you draw at the output. If the output current is almost close to 0 which is I out of 0.1 milli ampere.

You will get anywhere between 45 to a maximum of 80 micro amps of ground current. But if you are drawing full 150 milli ampere it can go up to 100 micro amps, the ground current. Now, what about the shutdown current? Shutdown current also the values are given here. Then there is feedback current and then there is PSRR. So, it can vary from 45 to 70 dB depending on the frequency okay. This is a very important parameter.

So, please do look out for what is it that you want to attenuate. Then there is output noise voltage, then there is start up time and a certain amount of time for the system to come up then there is under voltage brownout condition. For some reason the input goes very low, you do not want the output to give you any garbage. So, you can just shut off the LDO which is essentially the UVLO and then that can be used.

I mentioned about operating junction temperature which is out there already. So, now from here you have to interpret so many results. So, to interpret these results means you should know a little more about the definition of all these terms. So, let us spend some time understanding them and then come back to look at this particular datasheet. Now, let us understand some of the technical parameters of the LDO from a data sheet perspective.

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We have been visiting this repeatedly. But step by step we will have to dig and find out more about these parameters and I will now take you to the next phase of getting into little more detail.

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This is the origin; you can actually download it, introduction to LDO regulators by these authors. So, you can easily Google you will find this document, I found it to be good because it gives you a clear understanding of several things. See, now if you start going into a little more detail remember, this is a completely closed loop system. And unless you understand that there are so many loop parameters, you will not be able to get a grip on how the LDO is actually functioning.

So, we must go a little more slowly. And for this reason, you must add the closed loop control system to ensure that the output voltage remains constant so, it is a beautiful closed loop system here as you can see. Now, under voltage detection and over voltage detection essentially under voltage is useful, because you want to avoid the brownout. For some reason the input goes very low you do not want the output to be remaining at some indeterminate voltage which will energize some part of a circuitry and create a problem.

So, you just shut it down. So, that it becomes output becomes zero and forcibly the load also will have no access to power. So, that is essentially trying to take care of the UVLO condition under voltage lockout condition okay. Now detecting the occurrence of these abnormal conditions is useful because you have to design your embedded system IoT node for failsafe elements in the overall system. It is good to shut down rather than give away some wrong garbage value.

So, use this UVLO in that sense to design a very good failsafe embedded node for IoT applications. So, this is one part. Then this document goes into the DC electrical characteristics of the system. Quiescent current, well, I think you know very well that. This is also something that very important when you are doing battery driven or energy harvesting systems. You have to take care of it. Here he is talking about 100 micro amps of quiescent current at full load.

Shutdown currents can be as low as 20 nano amperes. So, you can see quiescent current and shutdown currents are different. This is when the LDO is on running, it takes only 100 micro amperes to give you the required performance, input to output. Suppose to set the output to 3.3 with a certain input voltage and some dropout, it will continue to take only 100 micro amps at full load. Full voltage at the voltage and the output current and output voltage both that means full load means full power.

And you are not using the LDO and you want to shut it down, it will still take about 20 nanometres. That is what you should account for. Very important these numbers look very small at this moment, but just think about multiplying these 20 nano amperes into one day which is 24 hours. Then what will happen to the battery life? That can be a significant number.

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So, it is not about this number just not this number, but also the duration over which the LDO is sleeping. So, please note that again this should be lower the better.

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So, that is an important thing. Now, coming to output accuracy and load regulation, we discussed enough. But again, I want to point you to an important thing here. Output accuracies, essentially most LDO's offer accuracies in the range of some percentage and load regulation in the range of 10 to 50 millivolt per amps. Let me draw your attention to what is shown here in this other sheet. This other sheet is telling you that it is roughly about 3%.

So, these are rough numbers, but you can already see that he is talking about a 3% in one case and he is talking about plus or minus 2.5 okay. Here he is talking about a unit which is in millivolt. But rarely you express it is in millivolt it can be of course, you can convert this to plus minus 2.5 millivolt back into percentages depending on what your output voltage is and what is the percentage of accuracy that is maintained for given that output voltage, you can convert that anyway.

So, the range is mentioned here again. Now, look at thermal concentration. Please note I mentioned to you about the different packages. Now how do you get to thermal packaging? Thermal packaging means you have a chip it is working in the ambient. It has a certain junction temperature. Now how much hot it is becoming depends on how much current is actually being drawn from the chip. For the current being drawn it will heat up and that is captured very well here by this power dissipation.

V in - V out is the voltage across the LDO into the output current which is flowing through the LDO plus its own current which it is consuming which is the quiescent current into the input voltage. This is the total power dissipation that you see on the chip. Now, this power dissipation means it will rise the temperature by something. Now, what is the rise in temperature that is governed by this equation?

T J is the ambient, ambient is in some temperature maybe it is at 25 degrees or whatever because this current is flowing through the LDO and because the LDO is getting heated up, it will again start increasing the temperature of the surrounding given by this equation, this additional part here P diss times theta J ambient. So, this equation now, you actually know that junction temperature T J, you now know because it is ambient plus this number.

Then they will talk about the transient line response and that line response is essentially coming because of the output voltage of a high performance of LDO, sorry, the output performance is mostly independent of the line input. So, input whatever it is it should not matter as far as the output is concerned. But that is incorrect because there are some practical limitations. The gain is finite gain loop gain and finite loop bandwidth.

Both gains as well as bandwidth of the LDO are finite. Therefore, there will be some sort of leakage between the input and the output there are leakages between the two. And therefore, the output voltage will have a component that is dependent on the input line. See, these are things which you are, it is not obvious.

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You have to read it between the lines to actually say that how can the output be influenced by the input? Yes indeed. Loop gain, loop bandwidth all of them parasites leaking from the input to the output can have an influence. So, the input voltage will definitely have a performance hit at the output. So, the output can vary because of the transient line responses.

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So, now he is talking about that particular component and that case quantified by millivolt per volt, the DC component is usually expressed as milli volts per volt. So, read this carefully because the output voltage will have a component that is dependent on the input line, albeit attenuated in magnitude and shifted in phase that is true. But it will still have an influence. Now, you can talk about just the output which is the transient load response.

Here the units of that is typically a milli volts per amp. Now, ideally, you know the output of the LDO should never change for any load current. But that is again incorrect because you have a finite closed loop output impedance of the regulator. It is not that, it is a finite output impedance. No, it is closed loop output impedance, it is a finite number. It is not that it can source infinite amount of current for any change that is not going to work.

The output voltage will vary a little due to load changes. Therefore, what will happen is the DC component is just the load line measured at the output while the transient part is a function of the output capacitance. So, the output capacitance comes into picture. The C out which I was mentioning actually comes into picture here now to take care of the load transient load response and it is measured in terms of these units I mentioned this already.

Then you have output noise. Remember, this noise is coming because of several reasons. The noise is coming because you have a full fledged electronic closed loop gain of the regulator and the noise is coming from the amplifier. It can come from the reference, remember all these are issues which can bother you continuously and then you have to battle them in an appropriate manner okay. The reference noise can be banned limited by placing an appropriate filter function before the regulator.

And the amplifiers input stage noise will be amplified by the closed loop gain and it will appear at the output. So, depending on the type of components and the architecture used at the input stage, the main components are essentially these three things. One is, it is short noise, flicker noise and also thermal noise. You need to factor output noise as well into the system.

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Now we will continue with the discussions on PSRR as we go along and then look at the other important parameters of the LDO and then see how we can use them in data sheets. Thank you very much.