Design for Internet of Things
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Lecture - 19
Introduction to System Design for Low Power

Alright folks, let us now begin with the new topic. And this is related to power management in embedded devices, IoT devices and particularly, we must know a little bit of hardware. You even if you are a software programmer and you are good in software, configuration of the hardware through your software mechanisms are very critical and unless you know how the hardware is behaving, he has no way by which you can configure them and its impact. Recall one picture I showed you and I want to point myself to this picture.

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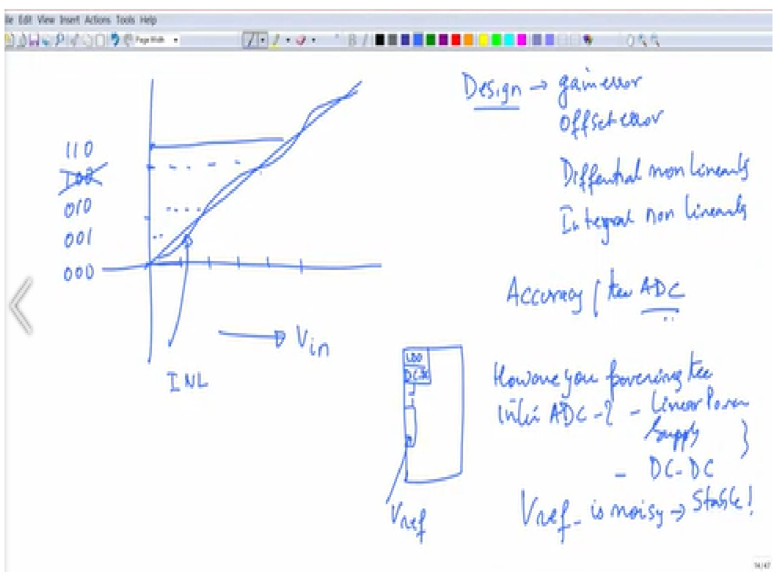

What is this picture saying? Here is a micro-controller and here is a block which is part of the SOC, micro-controller SOC. This is an SOC. This SOC has one important block which is the power block. Here we divided this block into two parts, we said one block can be in LDO, the other is a DC-DC converter. Today, we should discuss about both these blocks at least the LDO we should discuss in great detail and do spend some time in understanding the DC-DC converter as much detail as possible.

Question is why? Because of this full picture that you have in front of you. If the output of the power supply block is inconsistent, is not stable, it has a huge bearing on V ref. If it has a bearing on V ref, it will have a bearing on the output code word, because your expression is V in by V ref into 2 power n where n is the number of bits that bit resolution. So, the accuracy of the ADC has so, many parameters.

Apart from the problems that ADC itself has like gain error, offset error, differential non linearity, integral non linearity and so on. You will now end up with problems which you could have controlled. These are design error in the design of the ADC to that you are adding more complication by not keeping the V ref stable, which means sensing can be impacted. Therefore, and even the overall functioning of the SOC block itself will be an issue.

Now, normally ADCs should be noise free references should be noise free. They should be absolute clean DC signal, only then your input even if it is very, very small amount will be nicely digitized into some code word. But, if the V ref itself is noisy, you have no way of deciphering what the code word output is because each itself the basis of comparison itself is changing V ref itself is fluctuating.

Therefore, you need clean, superbly clean DC signal. The one that I can think of and you can think of as a good DC signal is coming from a battery. From a power source if you take AC signal moment you say AC you will use AC to DC, already you will have ripple. Then you will have harmonics associated with it you are removed the ripple you put a capacitor and then remove the ripple make it try to make a DC.

Still there will be a small bit of ripple then you have filtering which you may use a larger LC capacitance and combination of L and C and then remove LC filters basically, and then you will get back the DC. Huge amount of circuit, huge amount of paraphernalia, which we have all studied in the back. This is the one part of the story. The other part is, if you want let us say 3.3 volts at the output stable 3.3 volts at the output.

What should be your input in order to ensure that you get the table 3.3 volts, is another story. Input voltage, because if input changes output will change. So, you should be able to say I need a magic block. Irrespective of the changes in the input, to some extent, I will still give you a stable output at the output. Such a block which does this magic is one part, one important aspect, of the LDO is essentially taking care of that.

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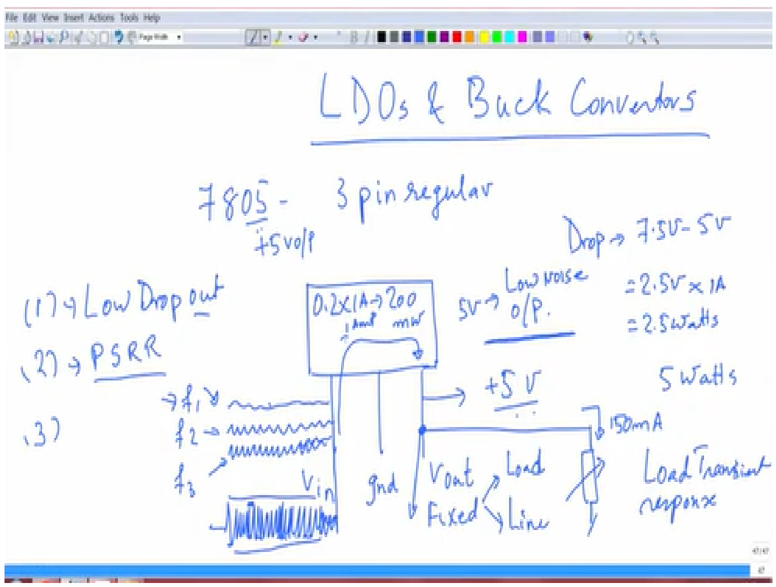

So, let us put down the LDO. And how does an LDO behave? And how does it give you clean linear output? Let us go back to some very basics if you look at the famous 7805, 3 pin regulator, you have all used it I am sure, one pin will be V in the other one may be ground and this will be the V out, correct? three pins are there. So, you have to supply let us say 7805 stands for +5 volt output. If it is 7806 it will be 6 volts output, 7809, 9 volt output ok?

So, 7805 is a very popular one it gives you +5 volts. If you read the data sheet ok? the data sheet of the 7805, you will realize that to get an output of 5 volts, you will have to feed anywhere between 7.5 volts up to 9 volts I think you can give. So, minimum you must supply at least 7.5

volts, if you want to get 5 volts at the output. Now, think about this problem ok. I am drawing let us say 1 amp, 1 amp load current. The power output of this 7805 is actually 1 amp.

So, you are dissipating 5 watts of power. This is dissipating 5 watts of power. 1 amp is flowing from input to output. Where is this 1 amp is coming from? It is coming from here. Output by magic is 5 volts, input is let us say 7.5, as an example. So, if you take the drop across the regulator, it will be dropped across the regulator, quite simple, -5 volts which is 2.5 volts. If it is 2.5 volts and 1 amp it is 2.5 watts. You definitely need a heat sink to keep this chip cool.

Maybe you can also boil coffee, water for drinking a hot coffee. So, this is the kind of system you have to put in place from legacy systems. But you will get clean DC at the output and also input, if it goes below this you have a problem. You won't get 5 volts at the output. But if input varies on the higher side between 7.5 and 9, there is no problem it will continue to give 5 volts on the higher side but not on the lower side.

It simply shuts down and it is not able to give you any regulated output here. So, you see now, your problem is pretty straightforward. If I can keep this voltage to let us say 5.2 volts, I did 5.2 -5, which is 0.2 into 1 amp, it will give you 200 milli watts, you do not need a heat sink. It will still give you clean 5 volts at the output. You can still draw 1 amp, but you do not need a heat sink here.

This is essentially what an LDO is. The dropout between the input and the output is maintained as small as possible. This is the theory of an LDO. To begin with this is at the block level, this is what LDO was supposed to do, he is supposed to take very low input and give you a very low drop across the system and he will give you a stable output here. The LDO has another fantastic feature. This is feature one. Low dropout is understood now.

Second beautiful feature of LDO is another aspect I will show two pictures. It 5.2 volts DC, but it is coming like this. Another way is it comes like this, obviously this is also 5.2 this is also 5.2

this is low frequency and this is DC at a higher frequency, input voltage is at a higher frequency. DC, but when you start increasing the frequency it becomes like an AC. This LDO does magic, it even if you give signals like this, it will still give you beautiful one line 5 volt.

And that ability of the LDO is related to power supply rejection ratio. So, these two features can be exploited to the maximum and you can use them to give you a very good DC output voltage, because it will give you stable 5 volts, noise free or that is a noise free is a misnomer in electronics, they can never be noise free you can only say what can you say low noise. You cannot say noise free you can say low noise output, low noise output you will get.

Because of its feature called power supply rejection ratio which rejects the ripple and then gives you a very stable output. Then there are other terms which we will define as we go along and look up the parameters of interest to us. So, how do we connect all these things from a design perspective? How do we connect all these things? Means we must look up one important data sheet.

Something some LDO data sheet if we know, we can use data sheet as a centrepiece and build the understanding of LDO around the data sheet. So, let us do that as the next important step. Our focus is to use in this course, how to use an LDO? How to apply an LDO? Theory is there we should know the theory but we should also know how to apply it. Therefore, the best way to apply an LDO in a circuit is to understand its data sheet. So let us put our energy there. I took one data sheet in random. This data sheet is shown here.

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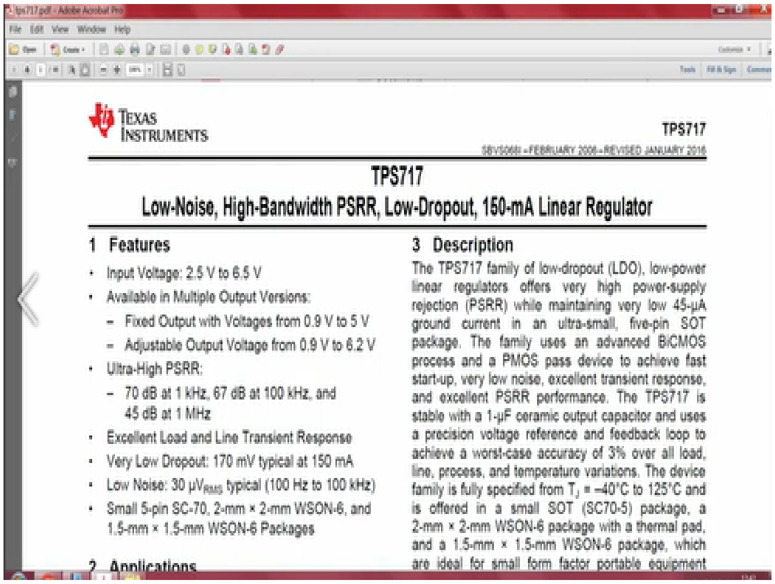

TPS717
SBVS068I – FEBRUARY 2006 – REVISED JANUARY 2016

TPS717

Low-Noise, High-Bandwidth PSRR, Low-Dropout, 150-mA Linear Regulator

1 Features

- Input Voltage: 2.5 V to 6.5 V
- Available in Multiple Output Versions:
  - Fixed Output with Voltages from 0.9 V to 5 V
  - Adjustable Output Voltage from 0.9 V to 6.2 V
- Ultra-High PSRR:
  - 70 dB at 1 kHz, 67 dB at 100 kHz, and 45 dB at 1 MHz
- Excellent Load and Line Transient Response
- Very Low Dropout: 170 mV typical at 150 mA
- Low Noise: 30 μV_{RMS} typical (100 Hz to 100 kHz)
- Small 5-pin SC-70, 2-mm × 2-mm WSON-6, and 1.5-mm × 1.5-mm WSON-6 Packages

2 Applications

3 Description

The TPS717 family of low-dropout (LDO), low-power linear regulators offers very high power-supply rejection (PSRR) while maintaining very low 45-μA ground current in an ultra-small, five-pin SOT package. The family uses an advanced BiCMOS process and a PMOS pass device to achieve fast start-up, very low noise, excellent transient response, and excellent PSRR performance. The TPS717 is stable with a 1-μF ceramic output capacitor and uses a precision voltage reference and feedback loop to achieve a worst-case accuracy of 3% over all load, line, process, and temperature variations. The device family is fully specified from T_J = –40°C to 125°C and is offered in a small SOT (SC70-5) package, a 2-mm × 2-mm WSON-6 package with a thermal pad, and a 1.5-mm × 1.5-mm WSON-6 package, which are ideal for small form factor portable equipment

This is called TPS 717, just an example system here. So, let us see low noise already we know what it means high bandwidth PSRR we know that also. High bandwidth PSRR means we know it in this form. So let us go back to this picture. Can this LDO also take care of signals which are coming at even higher frequency? This is f 1, this is f 2. So, I will put it back. I will put it slow this is a slow low free this is f 1 this is f 2, this is f 3 okay? high bandwidth. What is your bandwidth?

Bandwidth will be f 3 - f 2 or f 2 - f 1. If you can do f 3 - f 2 you are much better off compared to doing f 2 - f 1. So, if your bandwidth of the regulator is good, that means it can handle higher and higher frequencies and it can still give you a stable this is important. It should still give you a straight line equivalently. Then you will say that it is an extremely good LDO. So, we are looking at the datasheet from that perspective.

So, what does he say? You can see that the definition says low noise, high bandwidth, PSRR low dropout, 150 milli ampere line a linear regulator. What is 150 milli ampere? Very simple folks this is not one amp this is 150 milli amperes. He says, look, I cannot give you a 1 amp I can only give you 150 milli ampere. For the simple reason that this is not a 7805, this is LDO. He says I cannot give you that kind of output current I can only give you a maximum of 150 milli ampere.

Now, what about output voltage all along we made the assumption it can give, the story was around 5 volts. Will it give 5 volts? Let us see that. Go back and look at the data sheet and see what it can give. Fixed output with voltages from 0.9 to 5 volt, yes folks, it can give you output voltages up to 5 volts without any problem. Adjustable output voltage from 0.9 volts to 6.2 volts that means our example we took is good.

5 volt is a possibility with this particular LDO you can adjust it to give you an output of 5 volts. So, now it is very simple for you folks. You can if you assume 5 volts at the output, then if you assume 150 milli amperes that total power dissipation it is 150 milli ampere into 5 volts. It is 750 milliwatts. So, for 750 milliwatts maybe you do not even need any kind of a heat sink on that chip. It will be a small chip, perhaps you can manage without a heat sink.

See also heat sink means more space that means your IoT device becomes big. You have to note that you may not be drawing all the time 150 you may be drawing sometimes only 50 milli amperes which means the power dissipation is much, much shallower it will be about 250 milliwatts or something like that. So, you may also not be configuring the LDO for 5 volt. You will be configuring it for only 3 volts or 3.3 volts.

In which case you will be able to manage in under 500 milli watts, in which case you perhaps do not need a heat sink or any other paraphernalia. Choose a package of the chip which is suitable for dissipating that power is very, very important. Do not choose flimsy packages, packages come in different types of packages are available. Alright, let us go back to this. Okay folks. Next parameter is ultra high PSRR 70 dB, at 1 kilo hertz 67 dB at 100 kilo hertz.

It is down by half, 70 dB to 67 dB is half right by 3 dB at 100 kilohertz, but frequency has gone up 100 times and 45 dB at 1 megahertz. It is even more lower at 1 megahertz. Very good high PSRR actually very good. Any input signal in the range of 1 kilo hertz, 200 kilo hertz, it can give you 67 dB rejection. It is essentially saying that 70 dB rejection of the input signal at 1 kilo hertz. 67 dB rejection at 100 and 45 dB rejection at 1 megahertz.

Maybe it is still unclear to you what these rejections mean? You will know that if you know the expression for PSRR. I never even told you what, how to define PSRR how is it written as a simple expression I never told you. That is the point where we have to go and discover these parameters all by ourselves as we go along. Excellent load and line transient response. Think about this problem. I will explain this bit this picture only.

Let us say this is your R L. This is your load resister. Never in your IoT device, the load equivalent is going to be fixed. If you have a micro-controller SOC system which has its radio on then it will consume some current. But if you put the SOC to deep sleep then it will be consuming in micro and nano amps. So, what is your fluctuation load fluctuation? It can be from micro-amps to several hundreds of milli amps. That means, equivalently this load is all the time going to vary.

Now, any time this load varies, this output voltage should always remain at whatever point you have configured, the point should never change, if it is 5 volts it should remain at 5 volts, if it is configured for 3.3 it should always remain it in 3.3. Then you say very good load transient response. This is 1 parameter; another parameter is line transient response. Line transient response means, and look at f 1, f 2 and f 3.

Supposing you have, this is the input frequency at which the input is coming V in is coming. I made an assumption here that Vin in is fluctuating all right, very high frequency these peaks down peaks will switch the LDO off because it will go below the Vin record below the Vin sometimes. At very high frequency it will keep pushing the V in down. Before it can recover, it will come back, because this peak will come back and let the V in come back higher.

That means, you can have very small instances where Vin goes below and that will keep happening at very high frequency. So, you can see this signal is a representation. In spite of this kind of fluctuating Vin going down very small instant in time very, very small instances in time.

The LDO should continue to give this point fixed load as well as line. That is why they say load and line. Load comes from because of transient in the load conditions changing.

Line regulation comes because of input conditions changing. These two things will have to be borne in mind. And this data sheet is telling you exactly that. It is telling you excellent load and line transient response. Very low dropout 170 milli volts, typical at 150 milli amperes. Folks, this is interesting. And it can get even more interesting if you have to understand this. So, I am going to show you at a high level view what this means, 170 millivolts at 150 milli amperes. So, let us go back to our drawing boards. And let me take a fresh sheet.

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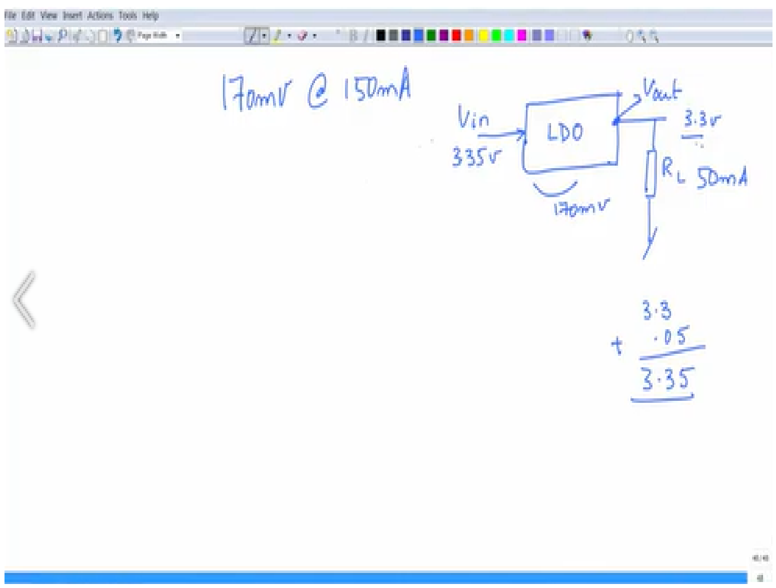

It says 170 millivolt at 150 milliamps. So, folks, this is interesting right? If my load current I will put back the LDO and output is Vout here is your input which is Vin, this Vout is let us say 3.3 volts. The load connected to this is, I have shown with the resistive load, is drawing 150 milli amperes 3.3 is the output I now add 3.3 volts plus 0.17 at the input. This will be 3.47. If I give 3.47, 170 will drop and I will get 3.3.

That is all folks, it just needs 3.47 volts at the input to give you 3.3 at the output. Go back and look at all the circuits we used to do with 7805 minimum 7 volts maximum some number right go back and look at the datasheet you will know the maximum. So, you to get 5 volts you are giving minimum 7 volts that means or 7 or whatever 7.5 or you just look up the datasheet you will know you are giving that.

Here is saying something nice. You give me only this much for your full current load current 150 milliampere I will give you 3.3 stable. This brings you to another story. The other part of the story is also true. If I give 3.47 at the input, you got 3.3 you can now find out supposing I will never draw 150 milli amperes I will draw only 50 milli amperes I will draw only 50 milli ampere, I will draw only 50 milli ampere. For 50 milli ampere he may only drop 50 millivolts not 170.

So, how much will it be 3.3 + 0.05 correct 3.35. If you give 3.35 volts you will get 53.3 at the output, but your current should not exceed 50 milliampere. Look at the beauty. The input to the output is shrunk based on the load current. And how do I know what should be the input minimum to give data sheet will tell you. So, we should go back to the datasheet. So, let us go back and look at the datasheet. So, you at least understood till here what the parameters are.

Let us look at the low noise it is a really low noise input system 30 micro volts RMS typical in the range 100 hertz to 100 kilo hertz. That means, it can it really it is a good LDO and it is able to generate or manage to give you an output voltage not more noisier than 30 milli volt RMS. That is the point at the output.

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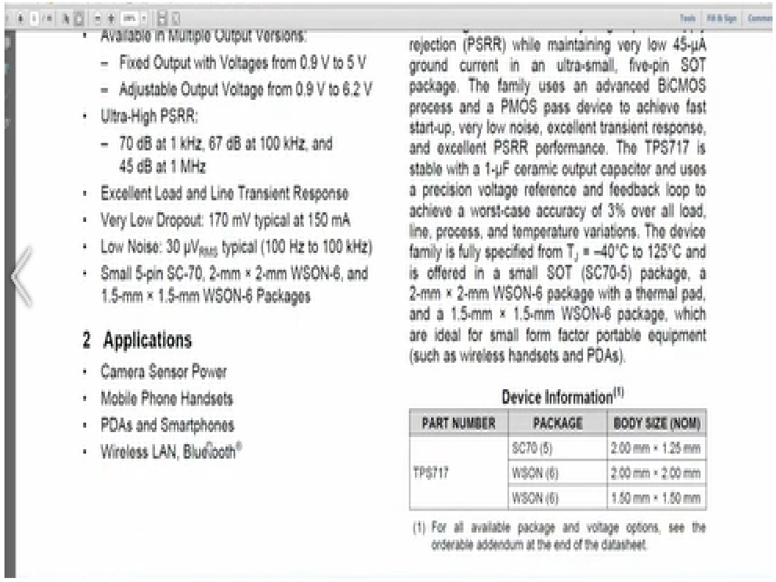

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2 Applications

- Camera Sensor Power
- Mobile Phone Handsets
- PDAs and Smartphones
- Wireless LAN, Bluetooth®

rejection (PSRR) while maintaining very low 45-μA ground current in an ultra-small, five-pin SOT package. The family uses an advanced BiCMOS process and a PMOS pass device to achieve fast start-up, very low noise, excellent transient response, and excellent PSRR performance. The TPS717 is stable with a 1-μF ceramic output capacitor and uses a precision voltage reference and feedback loop to achieve a worst-case accuracy of 3% over all load, line, process, and temperature variations. The device family is fully specified from T_J = –40°C to 125°C and is offered in a small SOT (SC70-5) package, a 2-mm × 2-mm WSON-6 package with a thermal pad, and a 1.5-mm × 1.5-mm WSON-6 package, which are ideal for small form factor portable equipment (such as wireless handsets and PDAs).

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TPS717	SC70 (5)	2.00 mm × 1.25 mm
	WSON (6)	2.00 mm × 2.00 mm
	WSON (6)	1.50 mm × 1.50 mm

(1) For all available package and voltage options, see the orderable addendum at the end of the datasheet.

And what are its applications? These 4 are these applications. Now, we have to understand further details about the theory of this regulator and then start looking up the datasheet the parameters. We will continue that discussion as we go along. Thank you very much.