Design for Internet of Things
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Lecture - 22
LDO - 03

Welcome back. We discussed PSRR in quite some detail for an LDO. It is good to see some small pictures are an expression that will sort of connect and give you some idea of how this PSRR is an important thing. I will not go into great detail, but you must know where to find material. So, that you know sort of locate it yourself and do some self read self study by yourself.

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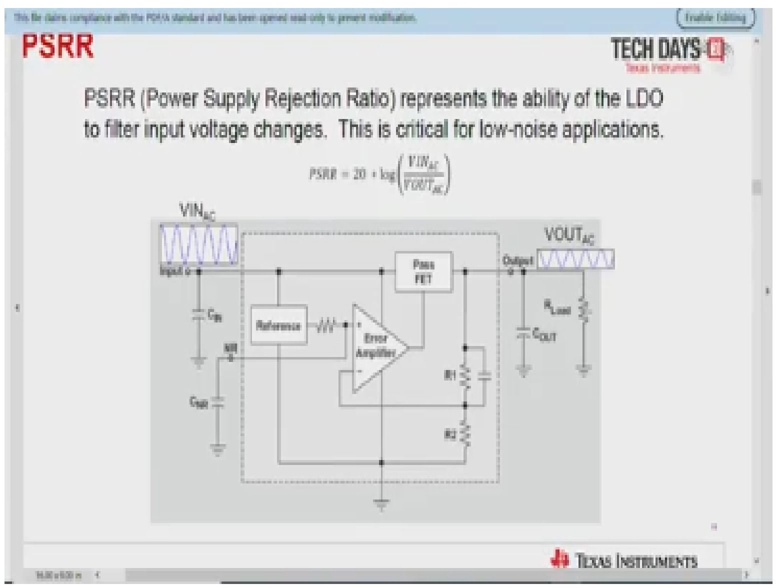

Let me point you, this is about a document which I got from Tech days. This is from Texas Instruments, I can share this document you can actually download this document. This picture is nice because it is telling you the expression for PSRR. This is 20 log of VIN AC divided by VOUT AC. It says VIN AC, this is not DC input this is more the fluctuations in the input that appear at the output of the regulator.

So, please note, this is not the DC component. We know that it has to be superbly DC output, low noise. But the noise is because of the AC component in the input signal. And that is what he is giving you, 20 log of VIN AC by VOUT AC. Okay if it was indeed a straight line at this point you would get a straight line here which is basically the VOUT will be less than the VIN and everything will be hunky dory right. But that is not the case.

Unfortunately, there is always some ripple at the input and that is the ripple that he is showing here. It is talking about how much you are able to eliminate this ripple at the output. This looks a good picture, you have huge variations in amplitude here at the input; you have a smaller variation at the output. So, what is the definition? Ability represents the ability of the LDO to filter out input voltage changes. This is critical for low noise applications.

Very critical, because this can affect if you give this output to a V ref of an ADC which is doing some sensing application then this will appear as a change in the reference voltage. Remember, we discussed that. So, be careful about the output of the LDO to what you are feeding the output of the LDO. You do not want to mess up with that because it can create a noise pulse noise at the reference of even an ADC here.

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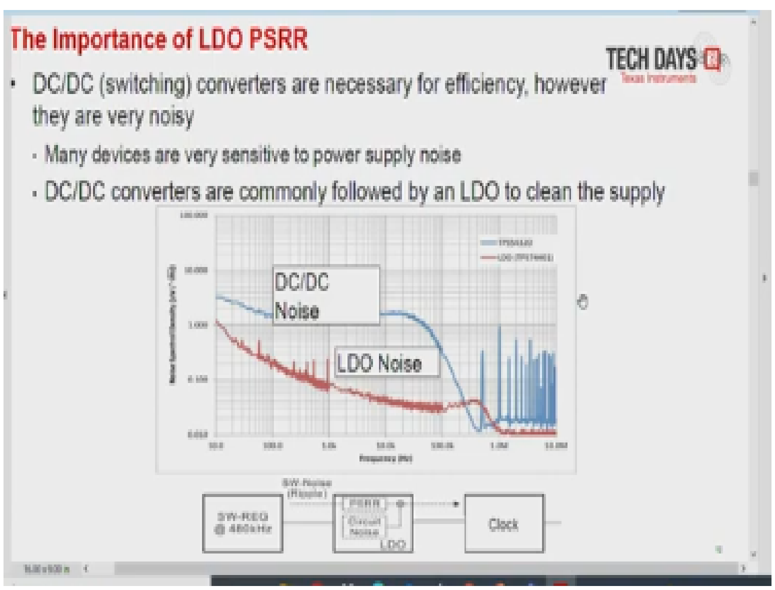

So, this is one thing then this picture is telling you something a little more important than the LDO. We will come to that dope, but it is good to tell you this straightaway. And this picture is telling you DC/DC converter noise is way beyond that of LDO noise. So and you can see that

DC/DC behaves even more peculiar at a slightly higher frequency. So, first of all, remember this is a log plot.

The best way would be to take do all your buck conversion from higher voltages to almost what is required using DC/DC and feed the output of the DC/DC to a low noise to an LDO and get back this configuration essentially this configuration. So, you can say that this is coming from DC/DC converter and what you get output will be pretty smooth provided you pass it through the LDO which has a high PSRR.

So, essentially that is what this is actually telling you. You can see that switching regulator is the input and it goes connects to LDO which has quite a high PSRR and then you get the output out there. So, anytime you want to do some noise filtering, it may be good to pass it through an LDO, it is like a noise removal.

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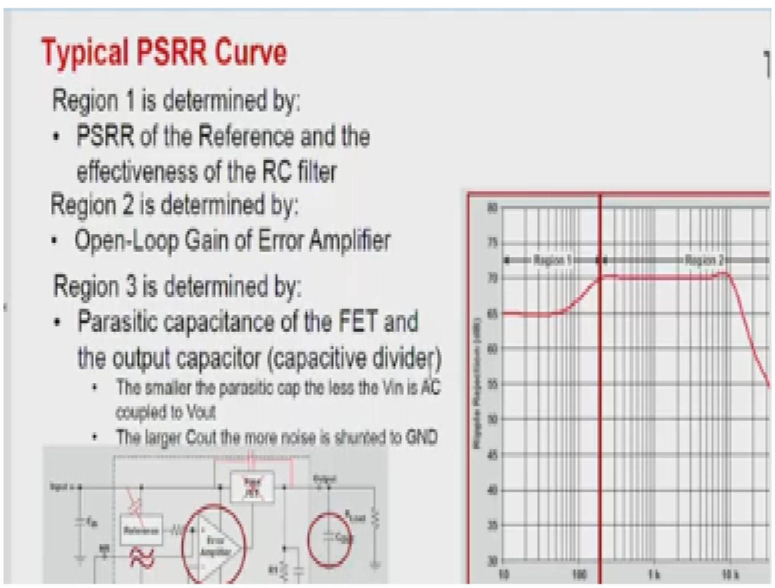

Then these are the regions of the PSRR which he talks about region 1, region 2 and region 3. How the region 2, the effectiveness of the open loop gain of this error amplifier which is so important in the ability its ability to keep the output voltage at the right point is also mentioned.

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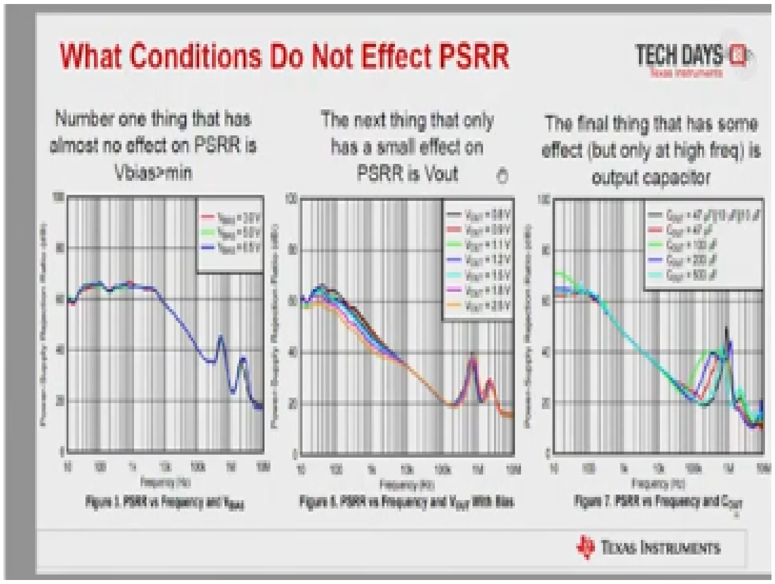

Then this picture goes on to talk about what are the conditions that affect PSRR. He talks about one then the next and the final thing, then what are the conditions that do not affect PSRR. Number 1, what is it? Number 2, what is it? And number 3 what is it? I encourage you to strongly read up on this document and which will tell you a lot more about hand at selecting your LDO of your choice for certain applications.

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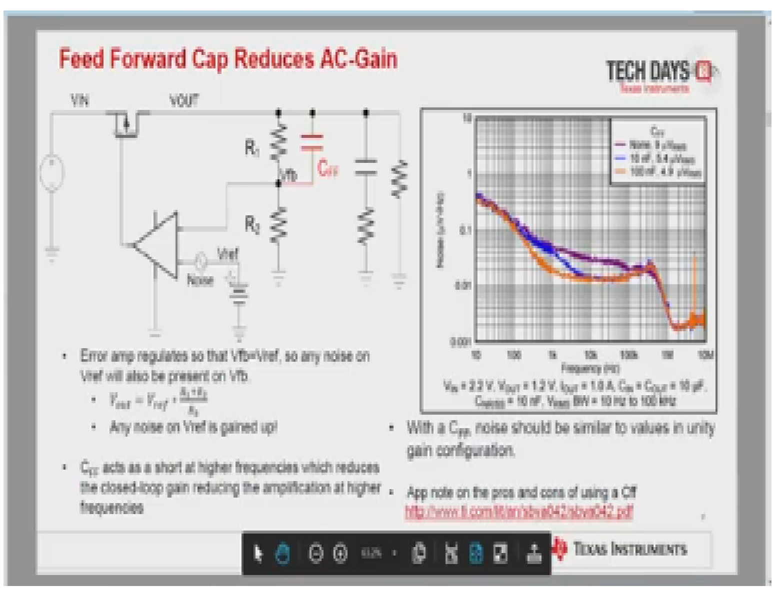

And well, this picture is also well known to you. Now, that this is the series pass of a LDO and this is the error amplifier, these are the sensing resistors and so on and so forth. And you can see that the V out is nothing but V ref multiplied by this term here which are the two sensing resistors. And that is what your; V out is usually held at. Any noise on V ref is gained up. So, if you mess up the V ref of an LDO, again you are going to have trouble.

So, your own V ref should be extremely stable. And the output if it is connected to a V ref of an ADC, even that is going to be troublesome. So, careful with output voltages extremely important to keep them under low noise condition. So, we will close the discussion there.

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But we will move on to other important aspects of an LDO and we will look at what is known as this transient responses okay. I want to point you to the understanding of this transient response.

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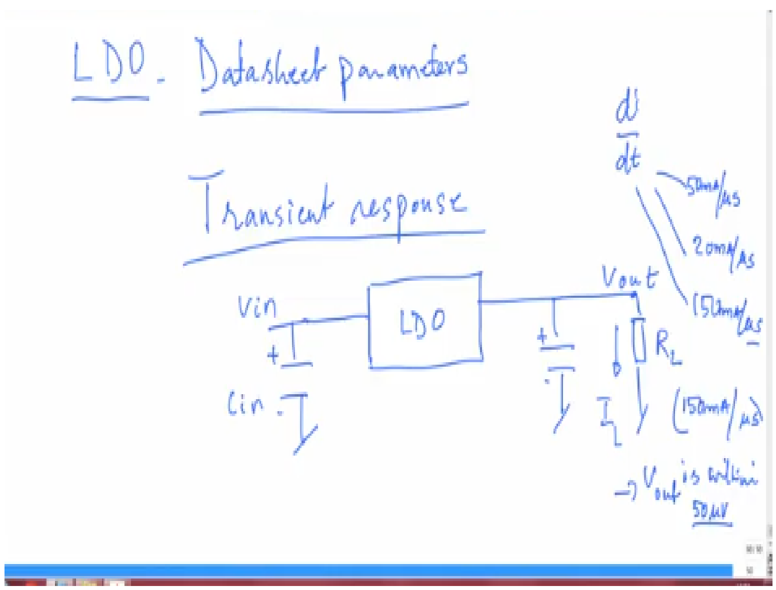

See transient response is, what is the effect of the LDOs output? This is your C in which is going to the LDO, this is your C out, this is V in and this is the load resistors, this is V out, this is your V out, like a block diagram. The trouble is you always want the V out to be held at a fixed point. But what actually happens is the load current keeps fluctuating depending on the state of the IoT node. Sometimes it may draw 50 milli amperes spike in 1 microsecond.

Sometimes it may draw only 20 milliamps in 1 microsecond. Sometimes it may draw 150 milli amperes in one microsecond. You can see this di by dt is the trouble created for you. The di by dt of course, di by dt is highest in this third case. So, in spite of a higher di by dt, you do not want the V out to move up and down at all. That is what you mean by transient response. And you may want to say that transient response of 150 milli amperes per microsecond keeps the V out is within 50 micro volts, it is a good thing.

So, you will have a spec like that. And this is what you should look out for in the datasheet, you do not want it to go more than that that means even under huge transient. Why is it transient? Because the time it takes to consume this, to draw this 150 milli ampere is quite short. In one microsecond you are drawing 150 milli amperes. After that it may settle down. That is another story.

But that should not pull the LDO out of regulation and that is essentially what you should look out for. Alright so, now we have to see how these things are defined and this datasheet, this little discussion I was trying to do is essentially talking to you about this particular transient thing.

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Transients can be improved by putting a suitable output capacitor okay. Many LDO's require a large external capacitor to be placed. So, that the loop stability transient response improvement and lowering the noise bandwidth. All these are possible, but then this becomes an additional component, your IoT node size may increase. So, that is one part then of course packaging then there is ESD related issues which you must read carefully.

And selecting the right LDO means you must look at mainly the datasheet parameters that we describe. Because essentially you are powering RF circuitry like as VCOs, mixers PLLs, ofcourse ADCs they all need very low noise in the frequency bands of interest. And so, you may need very good you know, noise rejection and also you must ensure that the low PSRR in higher frequency ranges can become an issue because they directly translate to channel jitter and intermodulation distortion. So, power supply is indeed a troublesome block even in an IoT node.

I just want to point you to this point of jitter you can see that load transients up to 150 milliamps per microseconds with less than 45 millivolt, just put a number I put some other number. In fact, I put microvolt he says I do not think you will get even 50 micro volts you will not get this, you will get 50 millivolt.

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So, that can be I mean the lower the better right. If you get 50 micro volts maybe it is magic. You may not get that, more practically it will be about one about 50 millivolts. So do lookout for 10 millivolt, 20 millivolts, 30 milli volt and so on, for this load currents, transient currents that is important. So, typically 150 milli ampere per microsecond is giving a number like 50 milli volts at the output. A change can relate to a 50 millivolt which you know will be quickly offset. But that may not again depends on your application.

So, what is very important to date may not impact so much. But it may also depend on your application. Now to ensure that this is the current transient will not matter too much for your output voltage, you have to choose the C out capacitor accordingly. So, that it is able to give you that deliver that power instantaneously. All of this has to be borne in mind. In summary, these are the parameters of great interest to you. So, let us run through them.

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We leave the reader with a summary of electrical performance numbers for Vidatronic's

PARAMETER	CONDITION	MIN	TYP	MAX	UNITS
Input Voltage		1.5		3.6	V
Output Voltage	Programmable	0.8		3.3	V
Output Voltage Accuracy	Variation from nominal VOUT		±1		%
Dropout Voltage	VIN – VOUT dropout at 100 mA output current		40		mV
	VIN – VOUT dropout at 300 mA output current		90		
Output Load Current				300	mA
Output Load Capacitance		0		4.7	µF
Load Regulation	1 mA to 300 mA, COUT = 0 µF			2	mV/A
Line Regulation	VIN = VOUT + 500 mV to 3.6 V			5	mV/V
Shutdown Current (ISD)	VEN = 0 V		20		nA

And this is the same that you saw in the other data sheet as well. Input minimum, typical maximum, output voltage programmable from 0.8 to 3.3 volts, output voltage accuracy plus minus 1%, dropout voltage 40 milli volt at 100 milli amperes. If you are drawing a load current of 100 milli amperes you will have a minimum drop of 40 millivolts, all you need is 40 millivolts drop. But if you drop 300 milli amperes the dropout voltage you have to maintain is 90 millivolts between the input and the output.

This particular LDO which has been shown as an output load current of both 300 milliamps. Output load capacitance 4.7 micro farads, load regulation units see carefully it is millivolts per amp, 2 milli volts per ampere just changes by two milli volts per ampere. Remember load regulation is different from the transient response there. It was so much of current in a given microsecond, huge spike in current drawn.

Here it is for every one amp change in current, the load regulation is about 2 millivolts per amp provided you are talking about 1 milli ampere to 300 milli ampere and a C out value which is about some capacitance value okay. Now, look at line regulation. Line regulation is mentioned in 5 milli volt per volt it is not amps, it is millivolt per volt and this is about 5 millivolt. And the conditions under which line regulation is offered at 5 milli volt is that V in should be whatever you draw at the output plus 0.5 volts that is 500 millivolts.

You must maintain that. If you do that you will get 5 milli volts per volt in line regulation then shut down current is mentioned. Then power supply rejection is mentioned. These numbers are just about 40 at 10 megahertz, 40 dB. Remember 10 megahertz and current drawn is only 100 milli amperes. For a 10 megahertz, but if the current changes to 100 milli amperes, but the output capacitance that you have some other value then you will get up to 55 dB.

So, these values that you choose have a huge impact on the power supply rejection and this is very important to be borne in mind. Okay folks so, then you have you know other parameters which you may want to effectively use for your design parts. Let me now point you to this datasheet load regulation under light loads.

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When you say light loads, you are talking of 0 to 5 milli amperes here, you can see. This is 0 to 150 milli ampere then you have line regulation which is shown here. This is delta V out which is shown on the y axis and you have V in which is shown on the x axis. So, we can look at line regulation when the current drawn is 5 milli ampere in this case and when the current drawn in this case is 150 milli amperes, that is what is mentioned here.

Let us look at this load regulation under full load condition. You see now, the load variation if you draw 150 milli amperes and you are at sufficiently high temperatures, let us say you are kept the LDO is part of a circuitry placed in outdoor. And under that outdoor condition, the temperature has gone up surrounding temperatures that 125 degrees. The output voltage will drop by minus that means it is dropping down. Is not it? It is dropping down to anywhere between 35 millivolts to 40 millivolts that is what it says here.

Whereas, if your temperature is at 85 it is not dropping so much, it is dropping to minus 20 millivolts. Suppose you have 5 volts at the output, you will be 5 volts minus 20 millivolts that is what it means will be your output. Similarly, this picture, so, you always can substitute these numbers with whatever is your output voltage that is why it gives you the delta V out that means you have some fixed output voltage.

Now, what has happened is it has come down, the difference is plotting here that is what is plotting here; this is the important thing. So, difference will be so much. Same way if you go and understand this picture, you will see that at room temperatures 25 degrees and so on drop is only about around the minus 10 even less than minus 10. And it is a little bit negligible if the temperature is at minus 40.

Supposing you place the LDO, part of an airplane and it is exposed to outside ambient your embedded node is collecting data from an airplane at minus 40 of cruising altitude so you get minus 50 minus in that range. Then there is hardly any drop in the output voltage even under high excursion of current being drawn in some sort of very short duration. So, it will be telling you that under full load as well negligible change at minus 40 which is extremely good as a load regulation system.

You can interpret similarly for light loads and you can interpret similarly for the line regulation as well. We can see these pictures. There is a significant problem with the line regulation at high currents you see 150 milli amperes there is a drop, whereas under light load conditions you do not see any problem. Line regulation is very good in the order of minus 0.2 and so on. That means it is down not up minus is simply indicating that the output voltage is going down and that is very small insignificant at very high temperatures.

Whereas, if the output current drawn is in the range of 150, you will see some real drop up to about minus 2. Here it was 0.2, here this range is from my minus it was in the 0.2 range and here it is in the minus 2 range. So, please note the y axis here and the y axis here they are different in terms of the markings. You can go on like this read about this data sheet interpret several interesting things.

Now, you can also look at the dropout voltage versus output current. You can see that it can be as high as 220 milli volts, okay the dropout voltage. If you are operating the LDO at 125 degrees at full load current that is important. So, that this picture is saying that. So, you could go on interpreting these view graphs and use them in your applications. If you are to design something, you are to use them.

So, please I encourage you to read these view graphs and understand them better. Similarly, PSRR versus frequency are interesting plots. You can see that higher frequencies the PSRR drops and you have to somehow find a solution. If your input indeed has input; high frequency inputs, and you want to circumvent this problem okay. There is also pictures related to junction temperature, these are very important.

The junction temperature comes directly from the fact that the current consumed if it increases. The heating of the IC also increases and it adds to the rise in the ambient temperature and also rise in the junction temperature that in turn has an impact on the stability of the LDO itself. This voltage the LDO can start having issues with respect to the temperature if you do not choose the right kind of package for your application.

So, this is one part of the story. I will also take you to another part which is perhaps the last item under the LDO.

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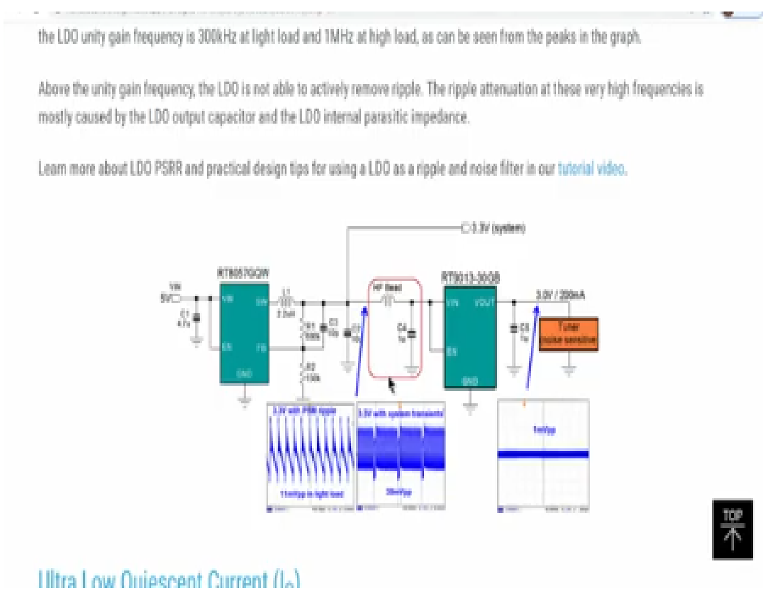

Let us just do one small bit and concentrate on this picture which is so important folks, so important. And this is how you must design your IoT node; this is a must kind of thing. This picture is powerful for a different reason. Forget about the company the ICs that are shown here the layout is really good. Look what is expected. You are interested in you have a high voltage in our case we are talking in IoT parlance high is already 5 volts.

You are interested in stable 3.3, 3 volt output and the current run is going to be about 200 milli ampere. This is your input. This is what you want to step it down to okay. Now if you want to get

3 volts at 200 milli ampere, you do not want to go very high. You want to be very very close to 3 volt to be as here. So, the dissipation across this can be reduced. So, what does he do? He brings 5 volts down to 3.3.

And that is what he takes as a tap out. This tap out 3.3 volt system is to some extent does have a ripple. But there is no doubt about it, it has a ripple. But then by magic he feeds this ripple input to this LDO, but before he does that he passes it through this block. This block does all the magic and what does it have? It has an inductor which you can buy in the market as high frequency beads, that are available.

Look up data sheets on high frequency beats. In essence it is an inductor and a capacitor essentially like a filter. You filter out the high frequency components and then feed it to this LDO. Now you get 3.3 noise free, ripple free as an input and then you will get 3 volt, 20 milli ampere maximum, load current which can be directly connected to highly noise sensitive systems like tuners and so on.

This paradigm you should never ever forget folks, never ever forget. I must tell you that you must sleep with this picture in your mind that LDO was typically you must have a difference in input to output which is not more than 0.3 or 0.2 volts. Of course that will depend on your load current on the right side. But typically the difference is very low. So, that power dissipation of the LDO itself is low. And if you have a higher voltage source the best is to come down to as close to the output of the LDO with the difference of whatever that the datasheet tells you.

Come down with a buck converter. This is a buck converter folks, you see this left side picture. This left side is a buck converter it has brought it down from 5 to 3.3 and from 3.3. After this filter action, you are getting 3 volts. So this is very important. This picture is actually capturing everything and it is self explanatory. You get 3.3 volts with a lot of ripple, 11 milli volt peak to peak in light load, 30 milli volt peak to peak with the transients it is really bad.

Look at what happens at the output one milli volt peak to peak. How did you do this? Exactly by this trick by removing it with a high frequency bead. So, this is a very important design requirement in this course, please remember this picture. Read this as much as you can and understand the LDOs to the best possible extent. Thank you very much.