Design for Internet of Things

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Lecture – 09
Introduction to switching regulators

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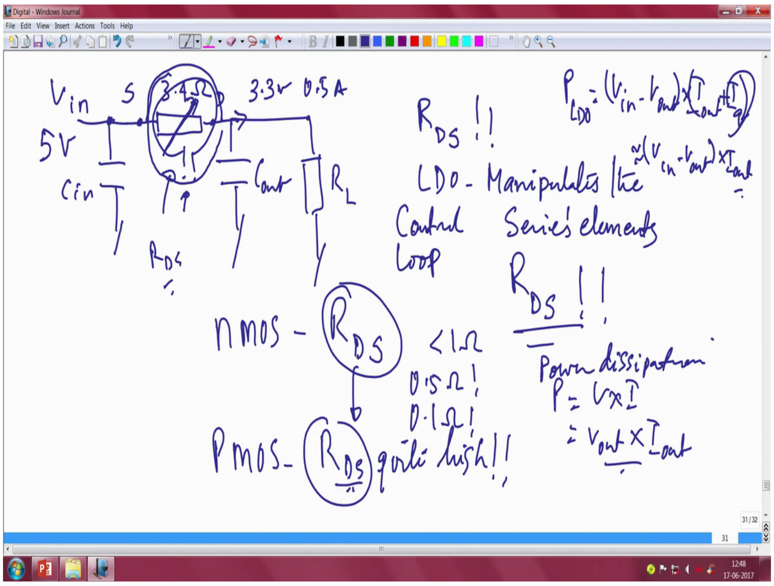

So, serious interesting thing in the circuit this is nothing but equivalent of a this particular part is nothing but like a series register, which is essentially the R DS, which I mention to you essentially in any voltage regulator it is like if you are able to have a variable resistor which now adjust itself to the output load current and the required output power then you have actually done the whole thing and building a nice voltage regulator right. So, this is the most important take away from this.

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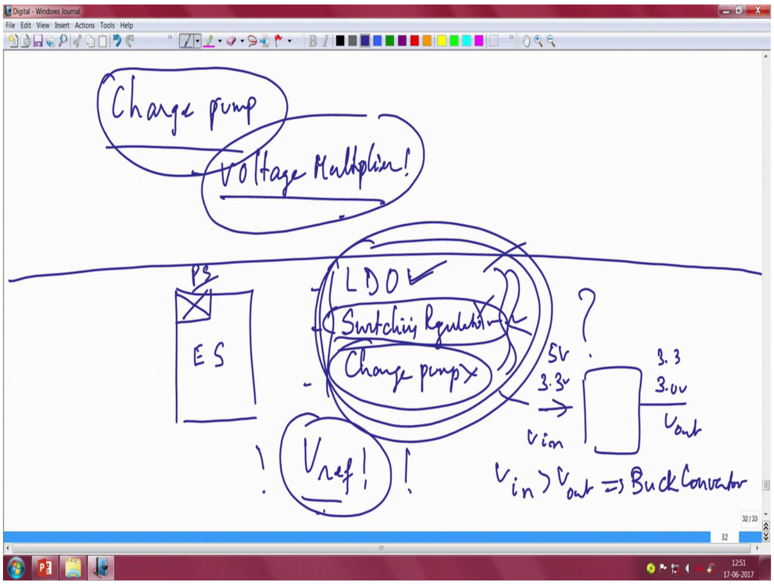

We also mentioned about the fact that there are what are known as charge pumps. Essentially charge pump will give you some configurations of a where you do voltage multiplication. All of this means if you go back to your original our original idea of an embedded system, which has several things and one of the important thing we said is the power supply.

You will see that one part is use of an LDO. The other part seems to be that of a switching regulator; switching regulator. And suddenly we have also introduced this term which is called a charge pump. Now question is we do not know much about this and this, but LDO is fine again you are confronted with the same problem, as I mentioned in the starting of this course, 3 options which one to choose right. It goes back to the same problem. So, we let us discover slowly what the switching regulator does and then subsequently move on to this charge pump. And then try and make comparisons between the 3 of them, and then come to a conclusion that yes for this application perhaps LDO is the right choice. And for another application it is switching regulator or a charge pump. So, that is the key point.

All of this has led to a very important thing that we mentioned soon little later a little earlier, and that was with respect to either, if you take LDO or switching regulator both of them mean a voltage reference. If you want to do if you want to have a stable V out consider this as a box V in, and you have V out for consistency let us assume that always

V in is greater than V out, that is in other words you are doing a voltage regulation by taking an higher input voltage and creating a lower generating a lower output voltage.

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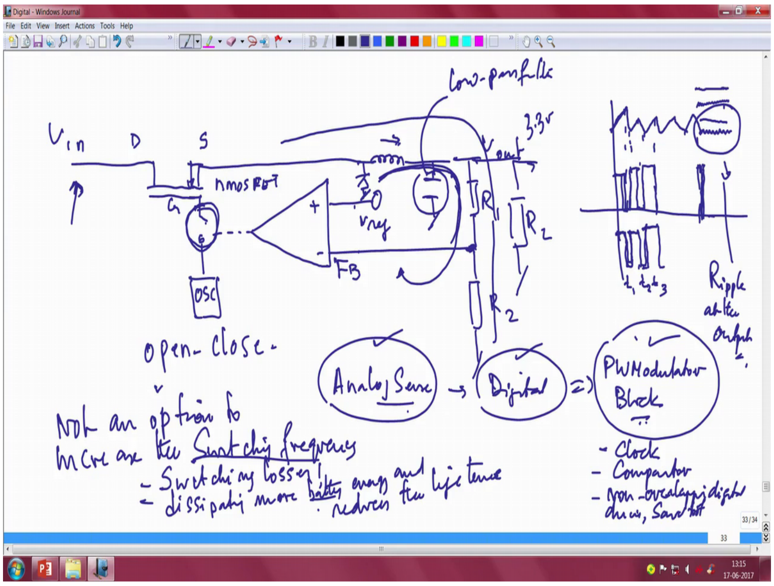

Typically 5 volts to 3.3 or 3.3 to 3.0 and things like that. So, voltages like that. So, you can to be consistent let us also consider a switching regulator which takes higher input voltage and gives you a lower output voltage such a regulator can also be called the buck converter right; buck converter. So, let us to be consistence let take examples of both LDO and buck convertor. And both of them need this voltage reference. In order to do any sort of regulation at the output, and why again let us go back to our basic let us go back to a very basic circuit, block diagram I would say I would not going to get details, but this time I will draw not the linear regulator, but I will draw the switching regulator.

Let us go back to our starting point where we have a plus and the minus our usual error amplifier. And to be put back what I mentioned just now we require a V reference, this V reference; obviously, will have to be used and each time you do a comparison there is a. So, essentially this is back to our error amplifier, which is V out here you have R 1 you have R 2 and usual comparison that happens between V ref and this feedback point which comes; obviously, this is a feedback. So, this is nothing but if you look at the block diagram of any switching regulator you will see that this is a feedback point and so now, this is a fine how does it going the input side. So, let me just you know remove this and put it here. Just for ensuring that we write a reasonably good circuit see the point really is basic you first go to the basic idea switching regulator basic idea.

What is a basic idea, basic idea is you energize and then deliver you energize and deliver keep energizing, what do you energize you energize, either a capacitor or an inductor remember both are possible? So, let us consider a case where we are going to energize an inductor, how do you energize an inductor that is a next question. So, let us put an inductor here which requires to be energized. Now if this inductor has to be energized, if this inductor has to be energized it has to be given a voltage right. It has to store a energized, the it has to store energy so; obviously, we will have to go back to our famous series pass circuit.

So, now you see we got back the series pass element here, and for as usual for you know for continuity I continue to use an n mass n MOSFET, n channel MOSFET. And so we will keep at the same thing here now what you need to do is something little bit different in this part, in this part it is a little bit different. What you actually have is an oscillator I will call it by the block diagram and this oscillator so, let me move it a little bit. So that let me just redraw for clarity purpose. So, just nothing but just redrawing it this is an oscillator I have done something like this oh this should go you can not have the line violating the basic way by which we draw a MOSFET.

So, let me continue to keep at this way this is a gate this is; obviously, the source and there is a drain because I have taken a n channel MOSFET for just for you know keeping things consistent across all our discussions. So, you can see now that unlike the lean the LDO, where the output of the error amplifier directly draw the gate, here the gate is actually switched on and off and on and off you can see that there is a switch here. This switch essentially connects and disconnects this connects and disconnects and therefore, applies gate voltage or removes gate voltage and that is about it that is all that actually happens, and that is why it is called as switching regulator every time the switch is closed assume that the switch is closed.

What will happen the inductor gets energized and there is storage. There is storage on this device how does it store it goes in this path delivers also power to the load in the process. I will call this R L and goes to ground. Now every time it opens now you see you need this. Every time it opens it circulates, here it circulates here, but when we say circulates and to be careful that it actually circulates like this again. In the one case it was doing an outside loop and in the other case it was doing an inner loop. And because we had this diode it was able to close the circuit and was able to circulate the energy here, deliver the load required power again back to this R l.

First time R L got like this from this loop, and the second time the R L got what was stored and this kept on this inductor into this load. And again moment this inductor dropped it is storage came down, it is current storage capability came down this switch opens this switch again closes and again delivers power to the load, and again in the process also charges this inductor. So, you see pretty straight forward. You store in the process of storing you also deliver a you know power to the load, you open when you open you basically draw all the current from the store stored current the current that is stored in the energy stored in the form of current in the inductor and deliver it to the load and then open close it back and open it back open close open close right. Open close and again open close and so and on. So, it goes on like this.

Remember this point here this point continues to be a analogue input sensing only it is an analogue point right. Analogue input analogue sense you have analogue sensing. This analogue sensing is nicely you know converted into a digital on-off, on-off, on-off, and so on. So, this transistor is switching like that right. So, essentially you are taking an analogue input here, and then converting it into a digital signal, whose duty cycle is being controlled. And such a block essentially is referred to as the pulse width modulator, pulse width modulator block.

So, if you ask; what is the difference between a linear regulator and a switching regulator, the presence of the PWM block essentially holds the key into this particular way of working. Let me draw a nice picture here to show you how a everything happened. So, I will put it here. So, that you know it is in line with you keep observing what actually happens in the system by some simple waveforms.

Let us say the output voltage here that you require is 3.3; I like this example 3.3 volts as an example or some output voltage that you want. So, what actually happens is you will charge, you will discharge, you will charge, you will discharge, you will charge and so on, you can see this I am not. So, I am not being consistent. So, let me redraw with some practice you should get some stability, I will make it a little more steeper. So, that you actually see what actually happens right. And so on.

Now, every time this guy is charging this up line is like presence of the on here it is like a 1, and you see here again it goes down this is going down and again you will see that. So, this is going. So, let me just rub this out here and put it here. So, you see it goes down and again here it should switch on and again you switch off here. So, if you want to draw, it nicely I will draw it nicely here this width is like this then there is a very small width then there is a width here. And this is coming down and then this is a larger width here right. Like this look at this on time, if you see I will make it a little more narrower and make this a little more wider.

In other words what I am trying to show you is there is this t 1 time there is this t 2 and then there is this t 3. In other words, 3 different times you can observe on times each of varying length right. These 3 different are 3 different varying lengths. So, it is actually not like this anymore, it is not with the 50 percent duty cycle, but it is indeed with this kind of on times which are changing. Essentially this on times will change based on how this waveform will look right. If the output voltage remains very stable you can go back and re sketch, this you will almost see it is on like this and then very small time it is actually on.

So, more or less it will remain you know on for a very short time and off also for a extremely short time perhaps it will actually not even you know discharge and it still able to deliver the current directly from the from the inductor. And therefore, it is not going to be very significant. In fact, ultimately you want you do not want anything to happen right. You just want to remain you know in a sort of a straight line. So, you can see that this is nothing but what actually happens with a buck converter which has a significant amount of ripple at the output there is a ripple at the output.

So, depending on what your embedded system would require, you would either choose a linear LDO or linear regulator like an LDO or a buck converter like the switching regulator such as the buck converter. What is the big summary of all this? The big summary of all this is that this switching regulator is a hybrid of analogue and digital giving rise to a PWM block which is which is quite a interesting block, because it is a I have not gone in to the detail of this block, but indeed this block if you look at the inside of the block you will see that there will be a clock generator, then there will be a comparator, then a you will have non overlapping clocks digital driving circuits non overlapping digital drivers driving circuits.

Sawtooth generator, sawtooth generator you see this this is actually coming from the fact that you are getting a switched output is actually coming from a sawtooth, and triangular wave generator and all that. So, it is a fairly complex block which we will not go into detail, but the point is it is actually used as part of the part of the as a important block of a switching regulator so, all this brings us to what we discussed sometime back about the response time response time of the regulator.

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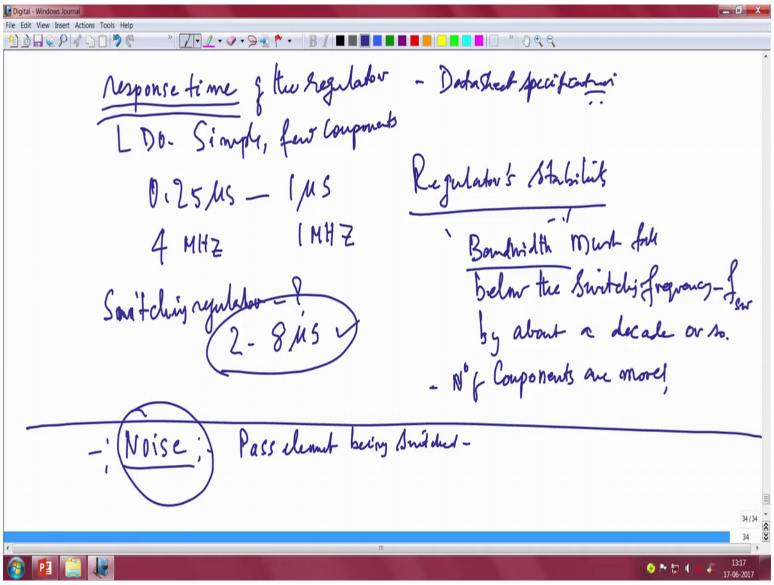

Now, you can see that if you take LDO simple few components few components, more storage of any energy kind of a thing oh by the way before, I go into that I must tell you that I have shown you the one output capacitor, this is a capacitor which is like a low it is for it is a low pass filter basically. So, it is a low pass filter we will elaborate that if time permits, but just a for the for the sake of completeness assume that this is indeed a low pass filter capacitor there capacitor for the purpose of a performing the function of a low pass filter.

Ah. So, coming back the response time of the regulator the LDO is simple with very few components and very few components and has response times of the order of 0.25 microseconds to roughly one microsecond it can be as. So, you can see that this is indeed

1 megahertz down to 8 mega hertz right. Sorry is it 8. So it is it is 0.5 is 2 megahertz and 2 megahertz, 4 megahertz sorry 4 megahertz. I am sorry it is switching at a quite a high and it is response time indeed is as high it can be as high as 4 megahertz, whereas the switching regulator in the switching regulator switching regulator what about it is indeed quite sluggish.

You will get 8 to 2 to 8 microseconds of a response time, this is indeed a very important parameter that you have to look out when you look at the data sheet remember we are trying to design. You are trying to do a design and in that you are looking at a regulator block, and you must look up your data sheet and what will you look out for. These are important the data sheet specification which you may actually want to look up. So, that before you choose it you actually understand the response time.

So, you see a it is said it is a little you will be very careful. So, that is the key point to what we are trying to say you have a power supply block, which gives you our standard which we like a lot 3.3 volts. And you have a load you have a load and the load requires 3.3 volts also for it is functioning. It is in sufficient if you just say that I have a 3.3 volt source, I have a 3.3 volt load requirement I just connect 2 of them and take care of the power requirement no, that is incorrect you can not be just connecting just because you have the required output voltage you have to ask questions, and you have to ask questions in a manner that makes you are embedded system for the IOT application the right one, the right choice the most optimal choice.

So, it can be an LDO it can be a switching regulator it can also be I am in when I say the switching I mean buck converter it can also be a charge pump we didnt forget that we will come back. So, which one again is a question. So, that is a point. So, really this is an important parameter which you have to look at you may want to consider the response time as one of the important requirements for a deciding the kind of regulation as the response time if the system requires.

Why is this really a problem that is the really the question. Well the point is that you know the trouble really is that the regulator stability becomes important when you talk about this response time regulators, because this is a closed loop system with negative feedback regulator stability is an important requirement. It has to be stable otherwise it would not do you any good by all these negative feedback and ensuring that you do sensing and all of that.

In other words, the regulators bandwidth see we are slowly introducing terms for a regulator the regulators bandwidth must fall bellow the switching frequency and that is important by a decade. Let us call give it this number FSW, let us say by about a decade or so. This is the most important thing it is bandwidth must fall below the switching frequency by I about a decade or so, plus a number of components right. Which you need to do you have to put an inductor at the output number of components are more number of components are more right. And say for that that is perhaps one of the reasons for this poor performance of the switching regulator.

Because the bandwidth it is a bandwidth it is bandwidth is actually quite limited and one thing that you might occur to you is that why do not we increase the switching frequency. So, why not I increase the switching frequency, what will happen if you increase the switching frequency, direct bearing is that this will smoothen out? It will smoothen out and give you a nice signal here at the output, let me draw it for better clarity oh sorry if it is really switching at high frequency, you will almost get a constant DC with a little bit jagging, but you will almost get a constant DC. Well you could write what is wrong if you switch at a very high frequency that is not an option that is not an option, not an option, not an option, not an option, to increase the switching frequency.

Why? Because you will have this is an important point right. Switching glasses switching glasses can be high. As a result, it dissipates more battery. It dissipates if you are if you are using it like a or with using battery here as an input source. It reduces the operational lifetime of the battery dissipating dissipates more battery energy and reduces the lifetime. So, you have to choose you have to check your switching regulator and find out what is the frequency of a switching frequency you have to find out. So, and as you know it is not a bad assumption to make you say talk about the battery at this stage because an IOT device; obviously, is going to be not be connected to the you know AC mains anymore it is going to be a battery driven system, and obviously you have to consider the lifetime of the battery.

The operational lifetime of the battery the amount of a time because, you know the cost of replacement is going to be very high we said this already. So, that is a very critical problem. So, you can not really go on increasing the switching frequency as and when you like as much as you like. So, keep that in your mind, now let us switch to you know every time, we talk about now you have a fairly good idea about the linear the linear regulator and the switching regulator more or less from a block diagram perspective it is easy to sort of you know think of several things several parameters, that you may have to consider when you start really looking at choice of these regulators.

One of them is indeed the noise. So critical again it is a data sheet parameter see what actually happens is if you go back and look at this this switching device. This switching device is the one that is delivering the power to the output right. Which means every time it is switching off and switching on it is indeed delivering quite a bit of it is creating noise, it is creating a certain amount of noise and that noise is perculating all through the silicon on which the regulator are actually is made. So, it is indeed noise creating the fact that you have a regulator a pass element, you have a pass element being switched, being switched creates all the more problem whereas with LDO there is that problem does not exist right. You have the series pass element always conducting all the time.

Here only you are trying to switch the a gate from the as from the output of the PWM signal. So, you will have to leave with more noise, it has it is going to be more noisy if it is the switching regulator and this is a cause for it.

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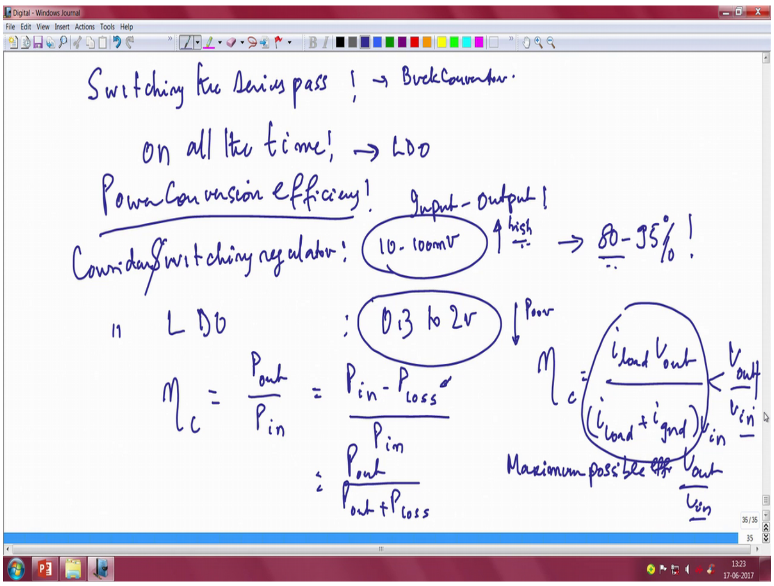

Now, this brings us to a very important thing that yes you are switching in one case, you are switching the series pass in one case and you keeping it on all the time on all the time. Only 2 cases exist; obviously, you know that you are associates with this to the node off of regulator and this to the buck converter brings us to a very important point about power conversion efficiency. So, look carefully at everything that we discuss now. If you take see essentially if you take the switching regulator you take the switching regulator, just consider this consider this it is a consider switching regulator.

What is actually happening you can be as close as 10 to 100 millivolts between input and output as close as this you compare this with consider now the LDO. You will have point 3, 3 100 millivolts even up to about 2 volts depending on the type of LDO, that you choose this differential can be high. Essentially the whole thing discussion about power conversion efficiency is about the input output differential. That is what ultimately voiced down to; because the drop across the regulator is high the efficiency also is poor, poor efficiency. And because the drop across the regulator is low the efficiency is high, in this case that is all the high level view.

Let us put down some simple expressions and see actually what it means. The efficiency can be indicated as follows right. You say p out by p in right. This is nothing but the power derivate at the output to the power available at the input this you can rewrite in simple terms, and you can easily show right. This is very trivial, quite trivial in this case. Now where is this term coming from this is the loss power loss power loss how much will it be power loss if it is switching regulator is going to be so small. That the efficiency for switching regulators is going to be as high as anywhere from 80 to 95 percent. This is the nice thing about the switching regulator; you can try by substituting input output values. Quite trivial you will see that efficiency indeed is can be as high as 80 to 95 percent. And if you take the case of the LDO, the efficiency can perhaps be again I will put back a very trivial expression. Load current I will this time I will express in terms of V i you have the reason is reason for that is, I want to bring in this ground current or the quiescent current which we mentioned last time.

And this term i load V out, i load plus I ground V in has and will always be less than V out by V in. This is the theoretical efficiency that you can achieve which one maximum I will say not theoretically I will say, maximum not theoretical I am sorry maximum possible efficiency is what V out by V in. Now this term indeed is always less than this maximum possibly maximum possible efficiency. So, what is it is all about it is easy to see that efficiency improves with the lower input output differential right. So, bit take away easy to see.

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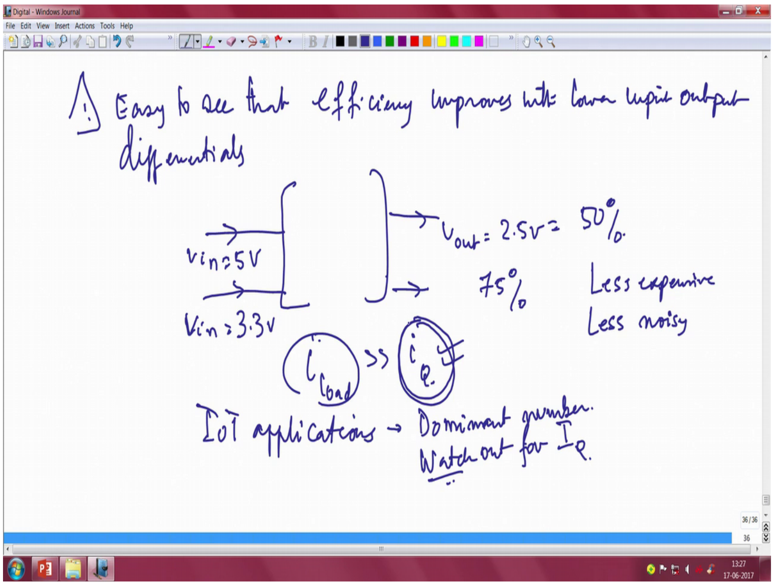

That efficiency improves with lower input output differentials. Many of the data sheet characteristics which are often publicly available everything revise round these kind of understanding. So, that is very critical.

So, now let us take a these are pretty trivial things right. Supposing you take input of 5 volts and for simplicity and quick computation, I will take V out as 2.5 volts. You can see that you will get some efficiency I am sure you know how to calculate that now consider that you take V in of 3.3 volts V in mind you for the same output right. You will see that if this differential is so what is this, let us put this down this is 50 percent right. And this is 75 percent efficiency, this is 75 percent.

So, efficiency improves with the drop is low. This is actually we made one important assumption here. This we made an assumption that i load is much greater than the quiescent current that is the most important thing. But if you take IOT applications, if you take IOT applications, if you take IOT applications, where p o R periodically sensing it, I know sensing at some time and sleeping for most of the time, where duty cycles are typically 1 percent and so on, at that time when you shut down the regulator this i q starts becoming a dominant, dominant number.

It becomes a dominant number to worry about therefore, if you are looking at designs designing your power supply do watch out for, watch out for, watch out for, this quiescent current as well. It will be know it will not be in any great comparison to i load it would not be, but the fact is you are not going to use i load for longer time right. It is the IOT device often is in sleep mode, and as I mentioned the duty cycles are less than 1 percent. So, then this becomes start becoming a dominant number.

So, please watch out in your choice of regulators for this quiescent current system, in LDO which has the least amount of quiescent current. At that same time you still want to use these regulators because they are less expensive they are less noisy; so less expensive, less expensive, less noisy. These are all some of the major advantages. See you mentioned we mentioned about this i load and this i q, this load current. So, one way what people actually try to do is they use multiple LDOs.

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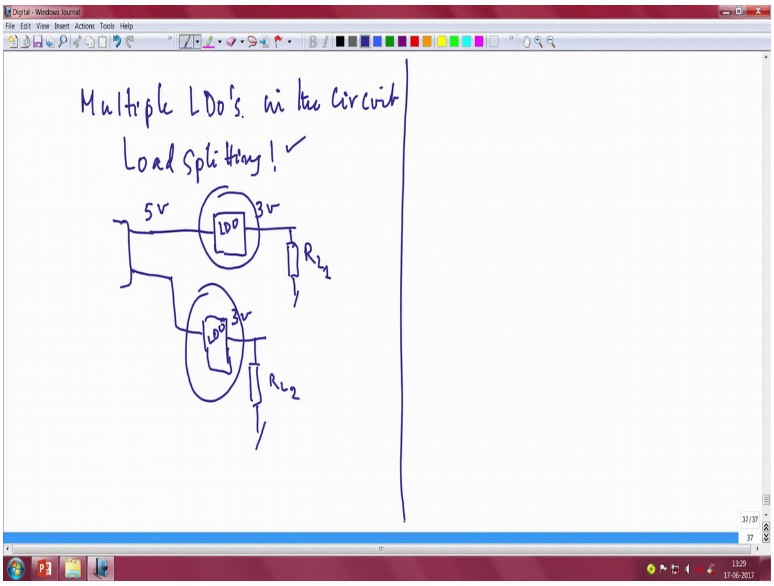

In their circuit in the circuit you can do that also because an LDO is a very small device. So, you do what is known as loads splitting, loads splitting you do. So, that you get you continue to get a very good efficiency from your LDO, that you have used. What it simply means is you have one power source, you have one power source and you want to let us say this is 5 volts. And what you do is you use one LDO and connect a few loads.

And you take the same 5 volts which is available here and use another LDO and connect other loads to that this way let us say this is 3 volts, this is also 3 volts right. So, together would have perhaps brought down the efficiency of the LDO. This is also an LDO. So, I will say LDO an LDO together they would have brought the efficiency down, but splitting them with you know, splitting the loads across load splitting, when you try you may end up with better, you know end up with much better efficiency and also it may be optimal for the design.

So, do consider not just by one, but may be the times may be you want to choose, multiple of them. So, this is important aspect of the as a choice of the component.

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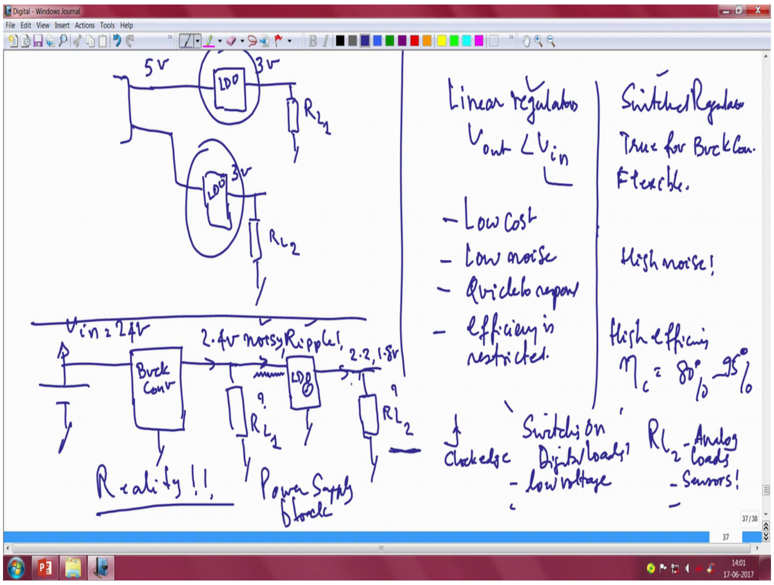

So, let us sort of you know some times it is useful to you know make a nice comparison between linear regulators and switching regulators switch regulators. So, let us see linear regulators, you must have V out less than V in. This is true only for buck converters. That is important very simple stuff right. So; that means, in other words you can say it is flexible in this case. You can have V v out greater than V in if it is a buck converter. So, really that is another thing this is really low cost.

And it is low noise the series pass is on all the time quick to respond, limited efficiency is poor right. Efficiency is I would say yeah I think the right. Word indeed is efficiency is restricted. I would say quick to respond efficiency and so on. You can put here noise is a important thing, high noise, not quick to respond we know these numbers efficiency is fantastic very good efficiency is not really restricted, very efficient high efficiency.

Generally it can be even as high as 95 percent, it cannot be less than 85 percent, definitely greater than 95 percent so nice overview of linear versus switching regulator.

See the if you look practically, from a from a systems from a IOT systems perspective, there is no choice, there is absolutely no choice, that you can have a system which has only LDOs or only switching buck converters or buss converters whatever may be the case. You have to coexists the system; the IOT is board the embedded system board for your IOT application has to coexists with both types of regulators.

Now the most logical thing, that you can actually think of in this situation is, what can I do what is that and how do I sort of mix match this you know lead liner regulators with switching regulators, often your embedded system make take it from me it is going to be battery driven. If it is a slightly larger embedded system like the kind of gate way board that we mentioned, you will have as power coming from even a led horsy battery, multiple led horsy batteries let us say. So, let us take a case and I will show you an example of how you can mix match this things, in a manner that will actually come to our advantage. So, let us go back to the drawing board.

Take a battery case, and let us say this is a battery which gives you 24 volts all right. Now let us say I am interested in generating 2.4 volts. So, I will draw in simpler terms so that in much easier way. I will what I will do is now here is my V in, which is equal to 24 volts. So, I will rub this out this is the battery source, what I will do, I will feed this to a buck converter. And I will get 2.4 volts noisy, lot of ripple, lot of ripple out here. And I will connect it to what our loads that can tolerate this noisy and ripple, but then I will take this 2.4 and connect it now, to an LDO. And I will generate may be I will generate if it is 2.4, I will generate 2.2 or I will even generate 1.8 volts for some loads.

Now what is R L 1 and R L 2 is the question right. What kind of loads to I connect them, it is easy to say that anything in the digital domain which are essentially if you have on a clock rise, on the rise of, I clock edge the rise of a clock edge several parts of a digital circuit are switching on, switching on then I think you could connect R L 1 could be all these digital loads. Laptops then handhelds all of them which do not mind essentially which have a lot of ripple, they do not mind because they can tolerate, they are only looking for logic level right.

So, essentially and they all they are they are basically working in low voltage they work in low voltage and they are switching at quite a high speed that they do not they have no problem about taking a noisy ripple input, but if you now take an LDO, R L 2 is typical that you choose analogue loads. It could be sensors for instance right or mainly sensors analogue sensors for instance. These have the problem that they cannot tolerate any noisy signal the supply has indeed got to be extremely clean in terms of a the output. So, I will say accurate clean signal clean output clean output this is that 1.8 volts.

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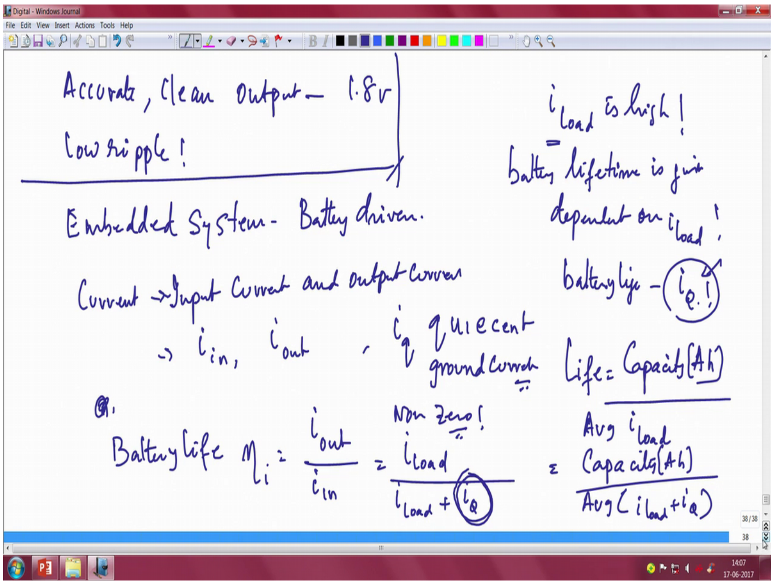

Low ripple you can also add this low ripple as well right. So, clearly the advantage is that you will be able to mix match the whole system with. So, let me just go a little low here yeah. So, you can see that this is what would actually happen in reality, this is reality. Take this as a very important point in the design of your power supply block.

Note one thing what is coming in here inside the LDO is very noisy lot of ripples, and by magic you get a nice clean signal here, clean DC output here whereas, here perhaps it is stills bringing right. So, let us see how this is actually achieve and what parameters you should look for to get to a nice looking DC signal at the output of this LDO; that means, there are parameters of choice that you have to look at which will actually give you this benefit of taking ripple, input noisy and ripple input and generates a nice DC at the output of the system. This is a very important point.

Now which means there is going to be integration. Now let us also look at as I said a embedded the embedded system the embedded system you have no choice, but to drive it to be with a battery, battery driver right. It is going to be battery driver and if you look at the let us say currents, input current, input current and output current. Let us just look at that why am I doing, this I am driving an important point here input current is i in and output current is i out very simple right. If you look at the linear regulator we did mentioned about the i q, which is the quiescent current q u i c q i e sorry q u i e c e n t. Let me re write it q u i e c e n t. Unfortunately, this c and the e look same. So, let me rite it again q u i e c e n t, quiescent, quiescent current is also an important thing also called the ground current. Some people use quiescent current and some people talk about ground current. This is a non0 one this is a indeed non 0 right. This is indeed non 0 and that is very important thing. So, you have to look at this as I mentioned earlier as an important parameter.

Now, if you look at battery life battery life because we took the example of that battery if you really look at the battery life. So, current efficiency is i out divided by i in. This is i load current right. Which is nothing but and in the denominator is indeed i load plus i q, and some people even say I ground. So, that is important, but you see the main point we are trying to drive at in this equation, is number one is this is non 0. You should be careful about how you interpret this i q that is the point we have to let us see what that actually means essentially it means if you are load currents are high that is if i load is high temporary high number, that is the output load current is pretty high then life time is just dependently.

I mean battery life time is just dependent on the load current all right. So, it is just based on the load current, but if you are not really loading it all the time and the loads are off all the time, and the dominant thing is indeed the fact that the duty cycle is very small less than 1 percent then the ground current becomes important then the battery life then the battery life time is dependent. So, here in this case it is just dependent on i load and in this time it will dependent on i q. So, here is where you should very careful if you are having loads which are switching at you have several events.

Several events where i q dominates then do not worry about i q at all. And if you have events where i load is very small the number of times i load is actually coming up as compared to the time the node is sleeping i q is high, then you will be driven by you have to take this i q into account. So, you can calculate the life time of the battery as simply the ampere hour battery which is nothing but the capacity of the battery which is indicated in ampere hour divided by the load current right. The total current it could be i load essentially. And it can also be actually you should take the average of the i load or it can also be capacity of the battery being ampere hours divided by average of i load plus i q or nothing but the I quiescent current. So, keep all this in mind when you chose the load drop out regulator and make a choice between the buck converter and the LDO with the factors that we discussed being quite crucial.

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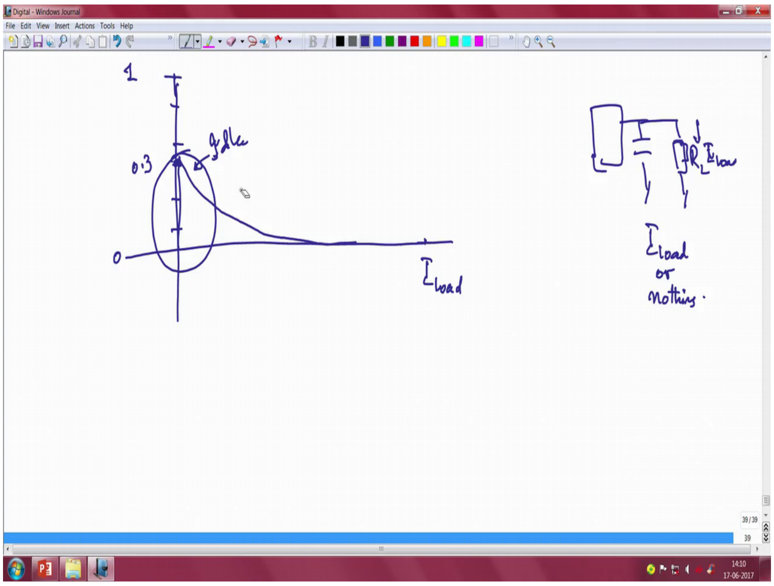

You can actually perhaps imagine a nice little picture of let us say i load that is nothing but i load this is the maximum current that is that is the just assume a situation where the output of the LDO or the so I should re write this it is always not to be good to be casual you have an output capacitor for stability. And you have the i load which is R L which is drawing I L right. Drawing I L it is drawing I L of current assume that it is either drawing I L or it is not drawing anything i load or nothing.

You will find that if you now take the probability this is along the x axis now if you take the probability of the system. So, I start with 0, and I will perhaps go up to 1. You will find that the time amount of time that the system actually spends drawing let us say a small amount of current is the highest. And that will drops like this all right. This clearly indicates that many devices actually do not take the maximum load current at all. They seem to be spending a significant amount of time and in the idle condition. This is where i q becomes important the ground current becomes important this also true in several things that we might have done in our daily life right.

That is what we do also in our daily life you keep the phone most of the time you do not get calls, but you charge your phone by the time, it is evening you will find that your phone even though it has received one or 2 calls, has actually drained from a fully charge phone to let say 30 percent or 40 percent depending on the numbers of time battery was charged and number of charge cycles the battery has undergone.

So, this is a story which is something that you can really relate to your daily life clearly indicating that the quiescent current are nothing but the ground currents have to be considered very carefully of the when you choose the low dropout regulator.

Thank you very much.