Power Management Integrated Circuits
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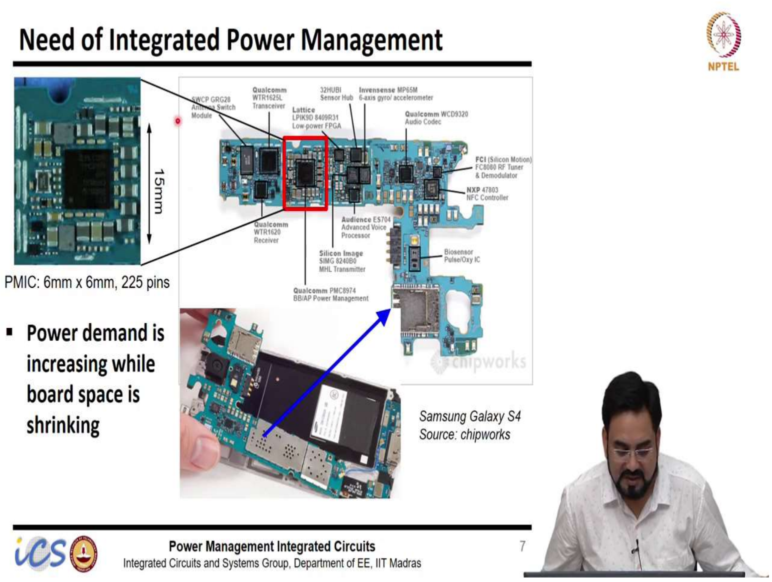
Lecture - 02
Introduction to PMIC - Part 2

Power management deals with the chip level. In a single chip we have a lot of regulators integrated along with a lot of other modules which are mainly relevant to power management.

Power demand of a cell phone:

If we talk about cell phone which we had 10 years back, it was a mostly the feature phone. And the power requirement was less, I mean your phone used to last like 2 to 3 days once you charge and the battery was also not that big. Those batteries were like a few 100s of mAh.

Now we have like a few 1000s of mAh. So, huge difference actually I mean almost 10 times difference in the mAh or the capacity of the battery. So, the power demand is increasing because now we have smartphones which integrate a lot of features in it. If you look at the display size of smartphone, it is huge compared to what we used to have earlier. And now it is a color display, so again power consumption is more. And if you look at the size of the cell phone, it is more or less same and it is not scaled with the same proportion as your battery.

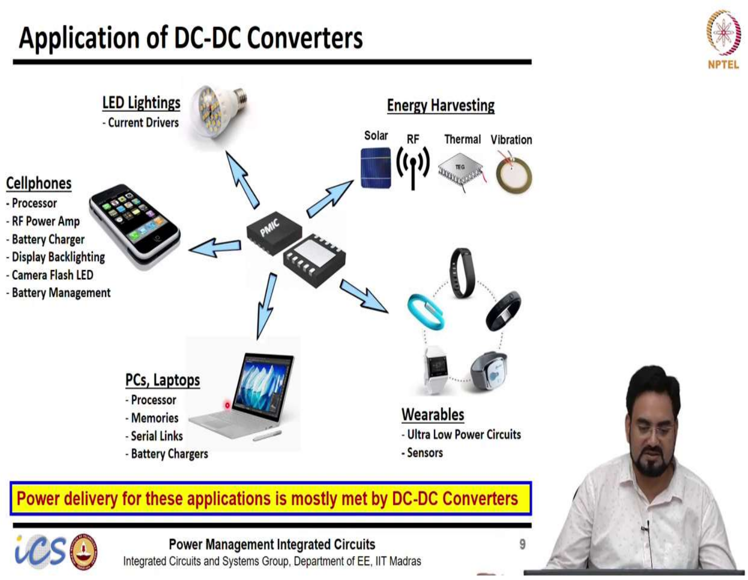


So, battery capacity is increased by 10 times that does not mean your phone size is also increased by 10 times. It is maybe like 2x larger than what we used to have earlier if you look at the feature phones, so not that big. Which means, now we have to integrate a lot of features and each of these features requires their own power supplies. So, now we have to integrate everything in a smaller space. Which means we have to deliver more power in a lesser space and that is why we have integrated power management.

When we integrate all the power supplies on a single chip which you can see in the above figure and the whole module is like 15 mm x 15 mm which is 1.5 cm x 1.5 cm and the chip size is only 6 mm x 6 mm. And the rest of the area is occupied by your passive components. This is the advantage of integrating your regulators or power management modules on a single chip.

Basically, PMIC is nothing but it integrates multiple regulators on a single chip and that is why whenever you hear about power management IC, we know that we are talking about voltage regulators which are integrated in PMIC.

If you look at applications of DC-DC converters which are mostly integrated in your PMIC or power management IC. You will find these power management IC or DC-DC converters in your PCs or laptops, tablets, memories, serial links, battery chargers and cell phones. So, all of these modules require power supply.



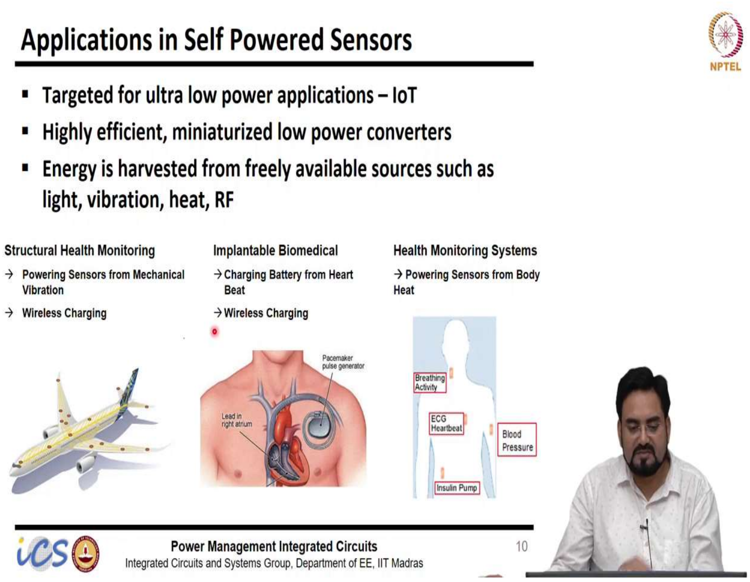
In cell phones there are even more modules compared to your laptops or PCs. You have processor, you have RF power amplifiers, battery charger, display backlight, camera flash LED, battery management everything is there actually. It integrates your multimedia application like your computer, your gaming everything in a cell phone. So, it has a lot of modules and all of these require power supplies.

LEDs mostly requires a constant current. So, we use current regulators there. And LED lighting is also driven by DC-DC converters.

Then energy harvesting where we harvest the energy from the environment which could be a solar, RF, thermal or vibration. And then convert that thermal, vibration, RF or solar into electrical energy and power your system with that.

Then wearables, which require ultra-low power circuits and sensors integrated on it and they require a very efficient power management because the battery size used here is very small. And if you want your smart watch battery has to last for a whole day, then we cannot have a DC-DC converter which has a very poor efficiency. Which means it is delivering a very low power but at the same time at very high efficiency. Because the battery capacity is very small and we want that battery to last for longer. So, the power management here manages everything to make sure that high efficiency is achieved so that your battery can last for longer.

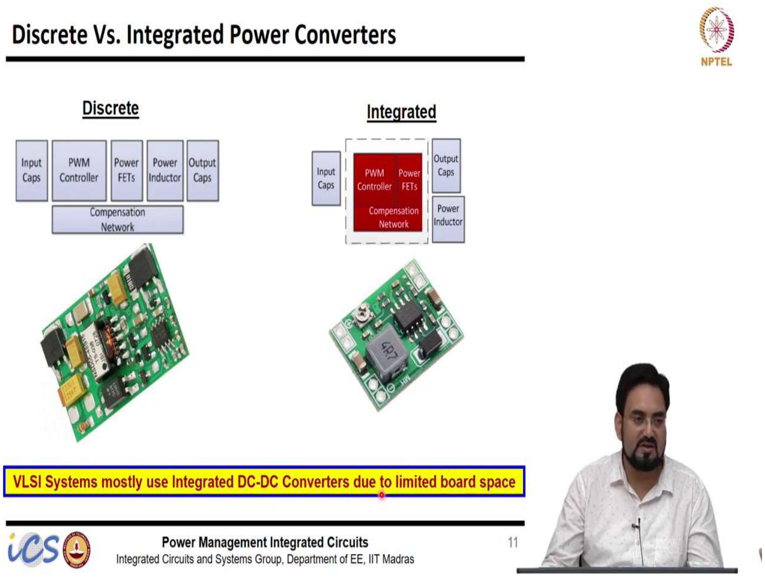
All these power delivery applications are mostly met by your DC-DC converters and that's why when we talk about power management IC, we have to talk about DC-DC converters.



Another application in self powered sensors which are targeted for ultra-low power applications like IoT. Highly efficient, miniaturized low power converters are used here and energy is harvested from freely available sources such as light, vibration, heat and RF. It is nothing but an application of your energy harvesting.

These self-powered sensors are used in different applications like structural health monitoring which is powering sensors from mechanical vibration and wireless charging. Then implantable biomedical like your pacemaker. So, charging battery from heartbeat or wireless charging. And most of these pacemakers are powered from battery. So, the life of a pacemaker is determined by the battery life. If you can increase the life of the battery or let us say we can recharge the battery then you can increase the life of these pacemakers. So, this could be another application of power management.

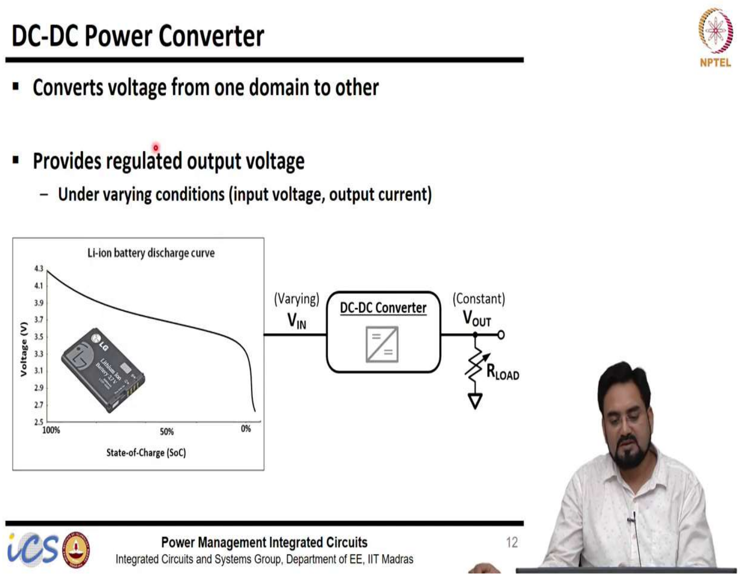
Health monitoring systems like wearable health monitors where you have multiple sensors attached to your body for different sensing purposes like your ECG monitor, your blood pressure monitoring, insulin pump or breathing activity. So, this could be another application of power management.



Discrete power converters use a separate chip for each portion of your power converter. So, obviously the passive components like your power inductors and capacitors have to be discrete. Then your controller and power FET are also discrete and your compensation network is also external or discrete.

Whereas integrated power converters integrate these 3 components which is your controller, your power FETs and compensation network everything on a single chip. The only external component or off-chip component will be your capacitors and inductors. The moment you integrate; a lot of components which are used on the board will go away. You will be using only 1 inductor and 1 or 2 capacitors outside. So, your board size will shrink as well as it looks much cleaner compared to your discrete solution.

So, our VLSI systems or integrated systems like cell phone or your tablets or any other hand held devices which are powered from your battery, they use integrated DC-DC converters because we have a limited board space.

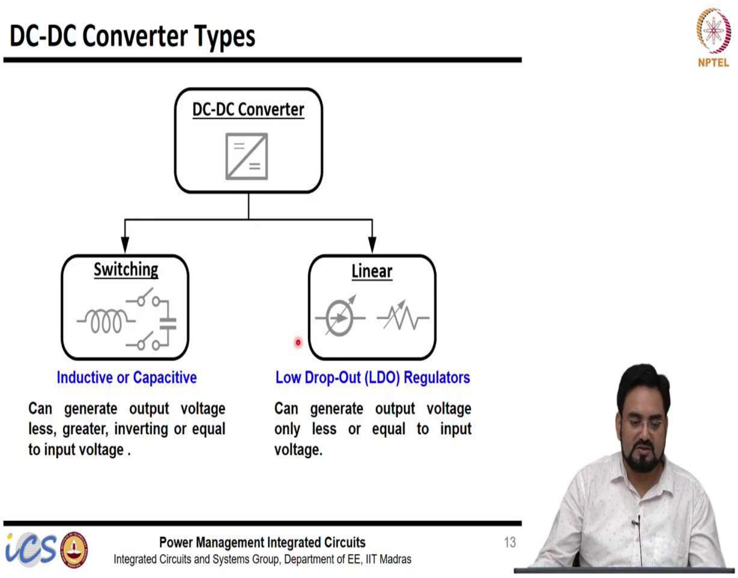


DC-DC converter:

It converts voltage from one domain to other. For example, if your input is 5 V and your system requires 1.2 V. Then you have to down convert that 5 V to 1.2 V regulated output voltage. Regulated voltage means it is a constant voltage across varying input voltage and output current or other varying conditions such as your temperature or tolerances in the components.

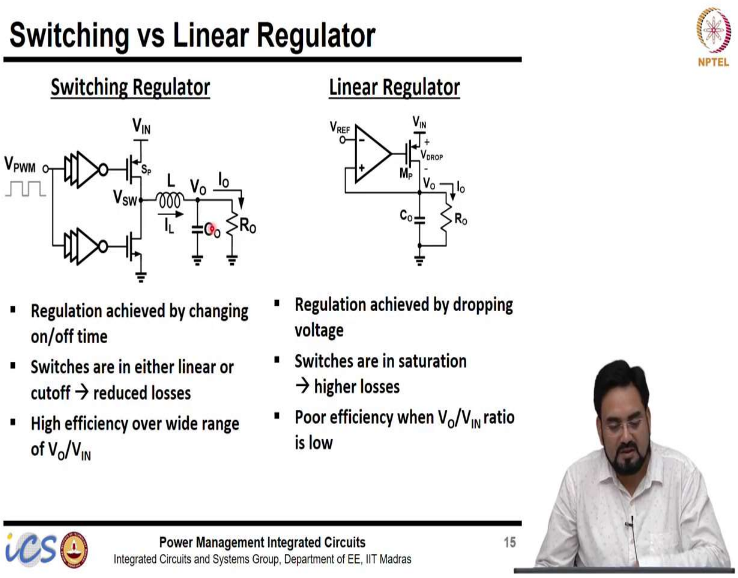
So, most of these systems or the chips which are used in an integrated system they require constant voltage. And that's why we have a very tight specification on regulation. Most of these converters may not be outside ± (5 to 10) % variations. For example, if output voltage is let us say 1 V then it cannot go beyond 0.9 V to 1.1 V, it should be within that range and that is why we need regulated output voltage.

Example is your lithium-ion battery charger. When it is fully charged the voltage will be 4.3 V to 4.5 V and when it is fully discharged it will be around 3 V. So, battery output is not fixed and it is varying a lot. Most of the time we say 3.6 V but it is not exactly 3.6 V, it is a typical voltage. But depending upon whether it is fully charged or when it is near to fully discharge your voltage may be different. And since my system requires constant voltage, you have to take this battery voltage and pass it through a DC-DC converter and then generate different supplies. Different systems will require different voltages. So, most of the time we require multiple DC-DC converters to cater to different power requirements.



These DC-DC converters could be of 2 types. We mainly categorize them as switching and linear regulators. Switching regulators use inductors and capacitors while LDOs does not require any inductor.

LDO can generate output voltage only less or equal to input voltage while switching regulators can generate output voltage less, greater, inverting or equal to input voltage. Depending upon the requirement you can decide whether to choose a linear or switching regulator.



Switching regulators:

In the left side basic circuit diagram is shown. Only the power stage is shown. It works on the principle of PWM modulation where input is a PWM signal and based on the duty cycle of this PWM waveform, the output voltage can be varied. These switches PMOS and NMOS are either in linear or cut off. So, in the linear the on resistance of the switches is kept very small.

So, whenever you are delivering the current to the load, you turn on the switches and high current will flow in these switches. And if you keep the on resistance of the switches very small then I^2R losses will be minimized. So, you alternatively turn on and off these switches. So, during the on time you turn on the PMOS and during the off time you turn on the NMOS.

So, you will see a continuous current flowing into the inductor. And that is how we reduce the losses here. And when you are not operating these converters you basically turn off these 2 switches completely and it will go in high impedance mode. So, high efficiency is achieved over a wide range of V_o/V_{in}. Because your losses here is mainly conduction loss (I^2R loss) which is fixed. So, it is not depending on your output voltage.

Linear regulators:

Regulation is achieved by dropping the voltage. For example, let us say I need V_o of 1.2 V and my input is 5 V then I will drop 3.8 V across the FET and the leftover will be your V_o.

The voltage we are dropping will cause a huge loss in this power FET. Because I am drawing a very high current let us say 1 A and I am dropping 3.8 V in this FET. So, I am losing 3.8 W in the power FET.

Ultimately, I am drawing 5 W from the input, I am delivering only 1.2 W and I am losing 3.8 W in the power FET. That is the only way we can regulate the output; by simply dropping the voltage. This is the main drawback and that's why these switches are mostly operated in saturation not in linear.

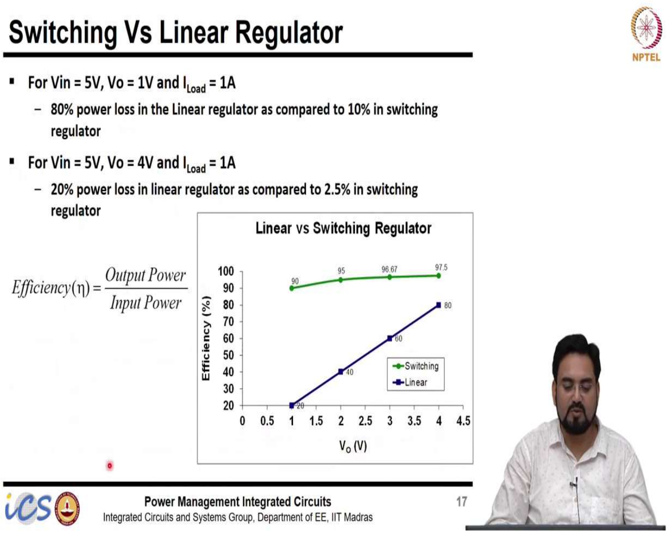
Because we are dropping a huge voltage across the power FET and we know that from the transistor theory if V_{ds} is large they will be operating mostly in saturation. So, it has a poor efficiency when V_o/V_{in} is low which means your V_o is much smaller than V_{in}. If V_o is very close to V_{in} then you will achieve very high efficiency. So, mostly the efficiency is driven by the dropout voltage.

And more than 90% of the power requirement is met by switching converters. The main reason is your efficiency. Because I want my battery to last like 1 or 2 days. So, once you charge your cell phone you want your cell phone battery to last for the whole day at least which is only possible if you have very high efficiency.

Which means, whatever the power I am I am extracting from the battery, I want to utilize each and every bit of that. I do not want to lose anything. The more you lose means the battery time will reduce actually.

So, rest 10% of the power will be delivered by your linear regulator provided that you have a very small dropout. Let us say you have a 1.3 V input, 1.2 V output and 1 A output current. So, only 100 mW you are losing in the power FET. So, your efficiency here will be obviously more than 90%. In that case you can use a linear regulator.

But we know that the moment you hook up anything directly to the battery and battery voltage we know that it's varying a lot. So, if my output requirement is 1.2 V then I cannot use a linear regulator here because I will lose everything in power FET and my efficiency will be very poor. That's the reason any system which is directly powered from your battery, 90% of the power will be delivered by a switching regulator and rest of the power will be delivered by your linear regulators so that overall system efficiency remains very high.



For example, let us say V_{in} = 5 V, V_o = 1 V and load current is 1 A. If I am using a switching regulator then my efficiency will be very high and let us say I maintain the efficiency as 90%. And obviously it will depend on how you size your power FETs.

In a switching regulator at 1 V output voltage, I am delivering only 1 Watt and at 4 V output voltage I will be delivering 4 Watt. But my loss remains the same because load current (I) is same and R_{loss} is same. So, I^2R remains same. So, let us say I have designed my switches in such a way that I get a 90% efficiency at 1 V then at higher voltage obviously I will get more efficiency because now 4 Watt I am delivering and I am losing only 100 mW.

And when I am at 1 V, I am delivering 1 Watt and losing 100 mW. So, at 4 V I will get 97.5% efficiency. So, you can see that throughout the output voltage range from 1 V to 4 V my efficiency is always more than 90% at 1 A load current. Whereas in linear regulator as dropout voltage increases efficiency reduces as shown in the efficiency plot (blue curve).

As I keep on increasing the output voltage, I am reducing the dropout voltage. So, my efficiency will keep increasing. So, at 4 V I am losing 1 Watt out of 5 Watt. So, 1 Watt is lost and 4 Watt is delivered. So, efficiency is now 80%. As V_o gets closer to V_{in} , you will see that efficiency will hit more than 90%. That's why when your dropout voltage is very low, you can achieve very high efficiency from linear regulators and we prefer to use that over switching regulators because switching regulators require inductors and linear regulators do not require inductors. So, it is cheaper to implement and it takes lesser area.

So, depending upon the dropout voltage or total power you are delivering you will decide where I want to use linear and where I want to use a switching regulator.