Introduction to Embedded System Design
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Lecture 10
Power Supply for Embedded Systems Continued

Hello, welcome to a new session for this online course on Introduction to Embedded System Design.

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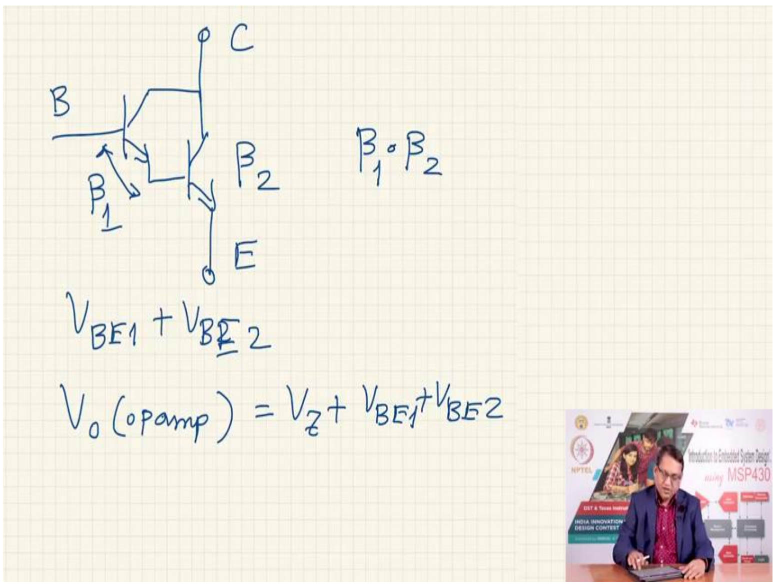

So, in this configuration, if we have the transistor, you want the transistor to handle more amount of current, then you can use what is called as a Darlington pair, where you use two transistor to multiply the beta and this is the typical configuration of a Darlington pair here. This becomes your collector, this becomes your base and this becomes your emitter. Here is the Darlington pair we used to transistors and defective gain, the current gain of this transistor.

If this is the gain, beta 1 is the gain of the first transistor and this is the current gain on the second transistor. The effective gain becomes beta 1 into beta 2. And so this configuration can handle much larger current. However, please note that now the base emitter voltage is no longer VBE it is VBE 1 for the first transistor, plus VBE 2 for the second transistor, and therefore, if you are going to use the Darlington pair in that power supply configuration, the V out has to overcome this.

And so the output voltage of the opamp will be set. Such that it overcomes this requirement. And so if I am going to use this power supply configuration and I want more current, which single transistor may not provide me the required current gain and I could use this Darlington pair.

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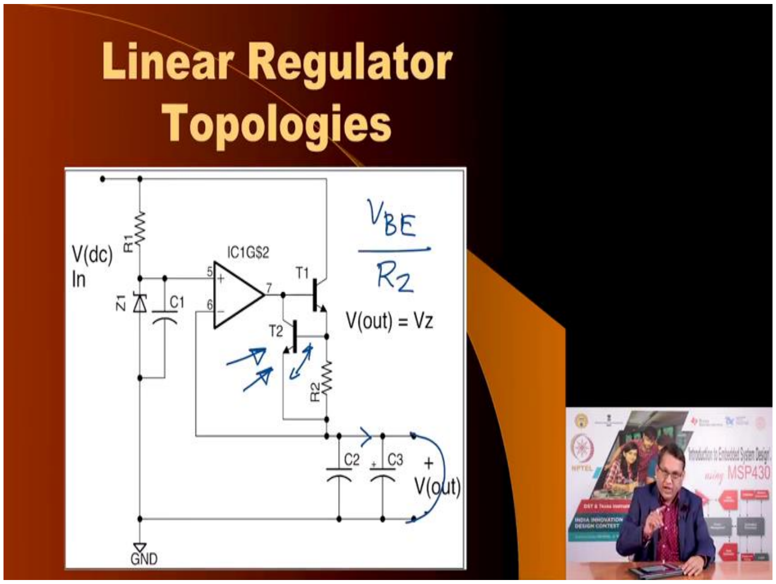

However, still, this power supply suffers from an inability to provide against any short circuiting attempt at the output. And so we must build in some mechanism so that short at the output does not end up destroying the power supply and the way it is achieved is through this circuit here, through the introduction of this transistor T2, this ensures that the current is never going to exceed a certain amount.

In this case, the maximum current that this power supply will provide is equal to the VBE of transistor T2 divided by the value of R2. So, if this voltage is say 0.7 volts and if you choose R2 to be 1 ohm that means this power supply can provide 700 milli amperes of current. What happens if you short it? If I short this power supply, yes, the current will try to exceed 700 milli amperes, at which point it will enable T2 it will turn T2 on and it will provide an alternative path for the current from the opamp instead of going into T1 and getting magnified by a factor of beta, which would lead to the destruction of T1, it would divert the current instead of going into T1, it would carry through this.

And since it would not be magnified by a factor of beta, it would protect the power supply. So, this is a standard method of short circuit protection.

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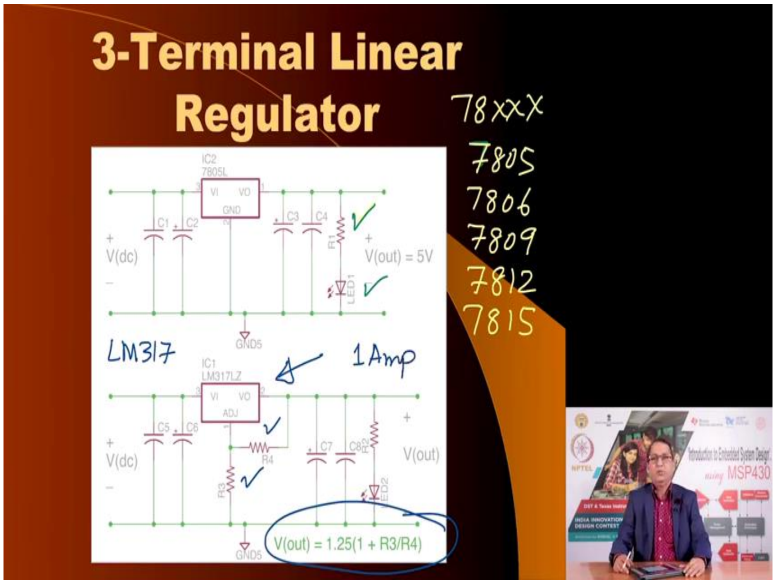

Three terminals, regulators of the type that we have been discussing, the 78xxx series I have illustrated, two simple regulator configurations. One is a 7805, you see, these are the additional components that you require apart from the regulator, a couple of capacitors are the input and output and nothing else. Maybe an indicator to indicate that the power supply is on with the help of this resistor here and LED this is a simple 5 volt linear regulator in case you want the output voltage to be other than what fixed output voltage regulator, such as 7805 can provide, for example.

In fact, this is a complete series you get 7, 8. 7805, then you also have 7806, 7809, 7812 and so on, 7815. And in fact, there is also a counterpart of for negative voltages, which is 79 series, if you want an voltage for example, of 9.5 volts, then you can utilize this three terminal adjustable voltage regulator where it uses this formula, V out is equal to 1.25 volts which is the reference voltage inside this and R3 by ratio of R3 by R4 here R3 and R4 and you can tell there R3 and R4 values to give you whatever arbitrary voltage within the range of output voltages that are available with this adjustable 3 terminal 3 terminal voltage regulator.

This number is LM317, and this gives you an adjustable output voltage with the current of maximum of 1 ampere.

This could be used, but as I mentioned, these are all of the past these days, people do not use traditional 78 series of voltage regulators for the, for the problems that I mentioned, that they require a large dropout voltage and they required a large percent current.

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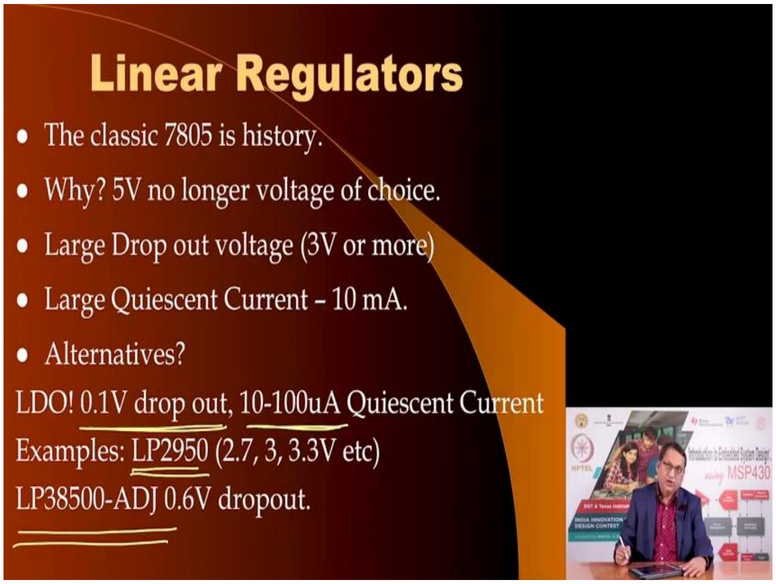

Instead, people are using low dropout voltage regulators. And I already mentioned the characteristics that they offer. A low voltage of 0.1 volt drop out and about 10 to 100 micro amperes of quiescent current. Here are some examples. If you want to power a 5 volt or a 3 volt or a 2.7 volt circuit, you can use LP2950 this comes in various versions which provide 2.7 or 3 or 3.3 even 5 volt output another adjustable voltage regulator of the LDO variety is LP38500.

And this requires a 0.6 dropout voltage, which is still much lesser than the 3 volts that are 78 series requires. Now, linear regulators are great, they are simple to use. But one of the big problems is that they are very wasteful. If your battery is say 12 volts lead acid battery and you want to power your circuit at 5 volts, so the linear voltage would get a difference voltage about 7 volts. And if your system is consuming one ampere of power, let me illustrate this. This is the important point here.

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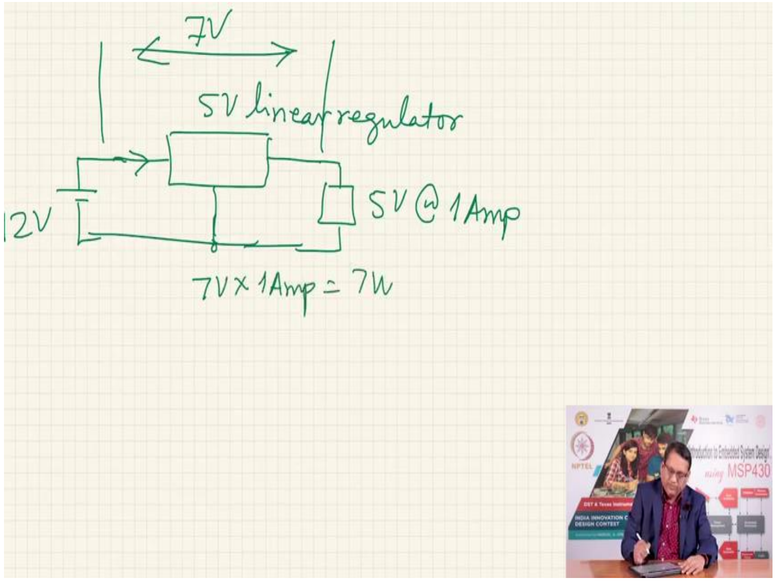

So, if I am using a 78 or linear regulator of whatever type, irrespective of whether it is a LDO or a traditional 78 series, I have let us say this is a 5 volt regulator, 5 volt linear regulator. And let us say I want my load hear whatever the load is, is consuming 5 volt at a maximum of 1 empire of current that it is expected to consume. And let us say my source is a battery which is a lead acid 12 volt battery, even if I do not consider any quiescent current being consumed by the power supply regulator.

Still, the difference of this and this is 7 volts. And it is going to provide the battery is going to be you are going to take of a 1 ampere of current from the battery, therefore the power supply has to dissipate 7 volt into 1 ampere, which is equal to 7 watt as heat because you only are going to consume 5 volts at 1 ampere, and so a linear regulator is not a very preferred method of powering portable applications which use a battery.

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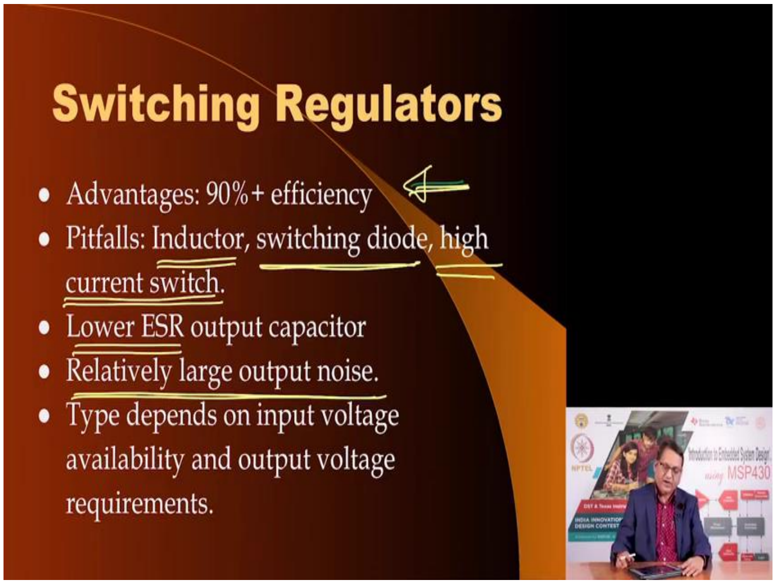

What are alternatives that instead of linear regulator, we use switching regulators, switching regulators as against the linear regulators, where the active elements operate in the linear, forward, active region. The elements which make up a switching regulator do not operate in the linear region forward active region. They are either turned on or turned off, meaning they are either saturated or cut off. And this leads to a high efficiency, typical efficiency figures that you may expect is of the order of 90 percent.

The disadvantages that give you this efficiency and to operate in the switching mode, it requires an external inductor. It requires a switching diode, which in some cases could be integrated on the power supply chip. And it also requires a high current switch, which can turn itself on and off. Other requirements are that it requires output capacitors to filter the noise that would come because now your regulating elements are switching on and off.

You require a capacitor, but this has to be a special type of capacitor called low ESR, ESR stands for equivalent series resistance. If the series resistance of a capacitor is large, it would prohibit the capacitor from quickly stabilizing the voltage because the R and C time constant would slow it down and so you need capacitor which are qualified as low ESR even after filtering the output voltage, you still have relatively large output noise compared to a linear regulator and the type of the switching regulator that use will depend on what is input voltage that is available and what the output voltage that you expect.

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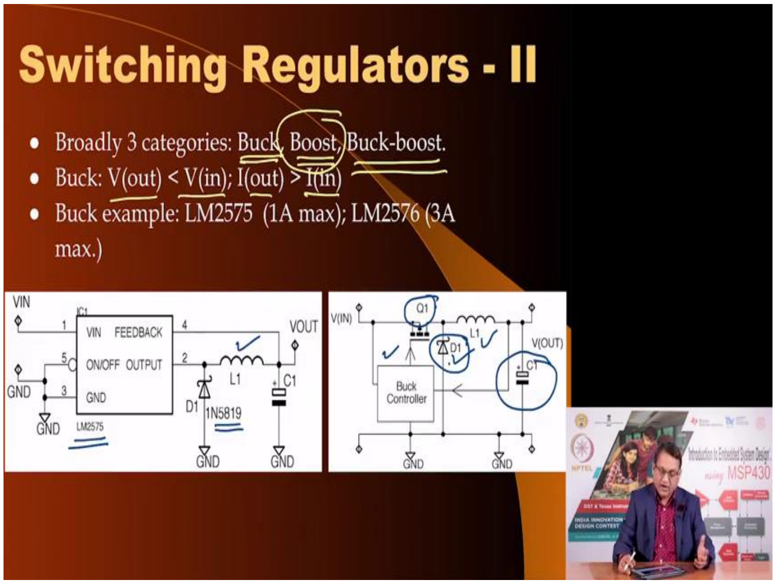

They are of three primary types, one is called buck voltage regulator, where the word buck means to bend, that is the output will do less than the input voltage. In some cases, you can use a boost type of voltage regulator where you can if your input is say 1.5 volts alkaline battery, and you want 3 volts output, you would use a boost regulator, this is a great advantage because the linear regulator cannot perform this function. They cannot increase the output voltage more than the input but switching regulator can, especially in which case you will have to use this boost type of regulator in case your battery voltage could be more than the output required sometimes.

And sometimes it can fall below the required output, you would need a regulator of the type called buck, boost. In bulk voltage the output voltage is less than the input, but the output current can be is more than the input current. And the this is the topology of the circuit topology of a buck regulator, the buck controller. You need one switch here and switching diode D1 is a switching diode, this is the inductor. Unfortunately, you cannot integrate and inductor on a chip.

You can integrate this transistor, you can integrate this diode, but the inductor cannot be integrated. So inductor and this output capacitor, which I mentioned, low ESR capacitor have to be still outside. Here is an example of a commercially available, complete integrated switching regulator LM 2575.

You still need this switching diode and an inductor and it will reduce the output voltage compared to the input voltage and do it very efficiently.

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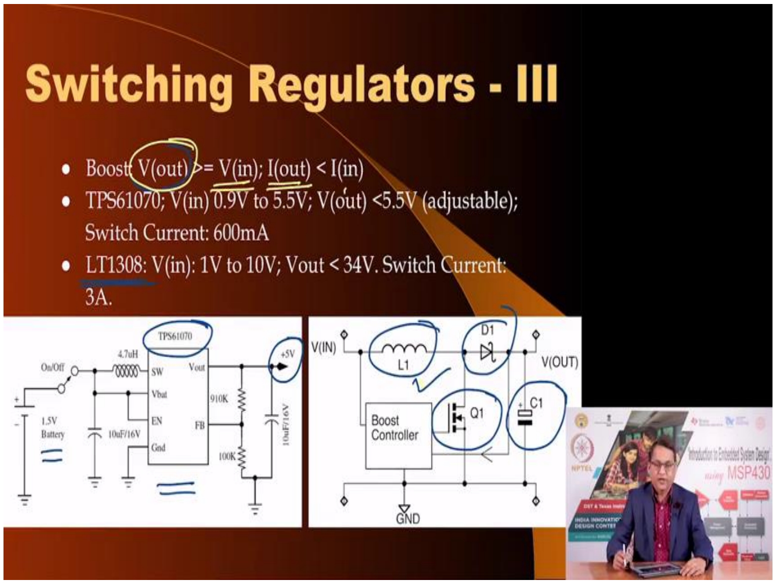

In case you need the output voltage to be more than the input voltage, then use a boost type of voltage regulator where the output voltage, as you see here, is more than the input voltage, but then the output current is less than the input current because at the end of the day, power has to be conserved.

If the input voltage is less than the output voltage, the input current will be more significantly more so that the product of input current and input voltage is a little bit more than the product of output voltage and output current. Here is an example this is the topology of switching regulator boost type switching regulator. It still uses an inductor, it still uses the switching diode and it still uses the high current switch, except the location of these three components has changed and this is the low ESR capacitor.

Here is a available example in for TPS61070 is a switching boost type of switching regulator available from Texas Instruments and using a 1.5 volt battery you can get, say 5volt or 3.3 volts which is suitable to power your small embedded applications. Other example is you could use linear technology LT1308 where the input can be in the range of 1 to 10 volts and can provide output voltage up to 34 volts and the switching current can be up to 3 amperes. Switching current means the current that it uses at the input, it is not the output current.

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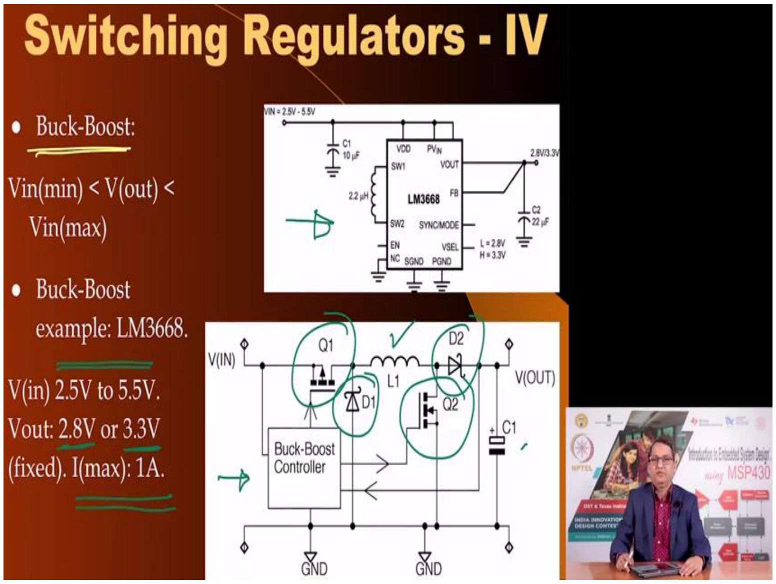

The third regulator type of switching regulator is the buck boost, as the name suggest it can operate either as in the buck mode or the boost mode, depending upon what is expected at the output and at that time what is the input voltage. For example, if the input output voltage requirement is say 3.3 volt and the input voltage is 6 volts the regulator will switch in the buck mode.

If the voltage falls below 3.3 volt the regulator will seamlessly switch into the boost mode so that from 3 volts input, it can continue to provide 3.3 volt power supply. Typically, this is the situation in your smartphones and mobile phones where the source of energy is a battery. The nominal voltage of these batteries 3.6 volts when it is fully charged, it can be as high as 4.2 volts and you can safely discharged this battery up to 3 volts. And the required output voltage could be 3.3 volts as one of the voltage requirements of a microcontroller.

So, if you are going to regulate this voltage, this battery voltage, you have to use a buck boost regulator so that when the battery is fully charged, the regulator operates in the buck mode. As the battery gets discharged and tries to fall below 3.3 volts, the regulator seamlessly switches into the boost mode and continues to supply 3.3 volts.

Here is an example, and here is before that here is the topology of a buck boost controller. Now it has merged the two components of buck and boost, so you have twice the number of high current switches two switching diodes and only 1 inductor, and based on the requirement, it would either switch to Q1 and even or Q2 and D2, depending upon whether it is the buck mode or the boost mode and maintain the output voltage to required values.

Here is a commercially available example of a buck boost regulator. This is LM3668, originally from National Semiconductors but National Semiconductor is today part of the Texas Instruments. And so this is being produced by Texas Instruments. It has input voltage range of 2.5 to 5.5 volts. The output is fixed, either you can choose the 2.8 output or 3.3. And the output maximum output current you can draw out of buck boost regulator is 1 volt.

So, here we have considered the three common topologies for switching regulators, which could be very common, which would be very commonly used in embedded applications.

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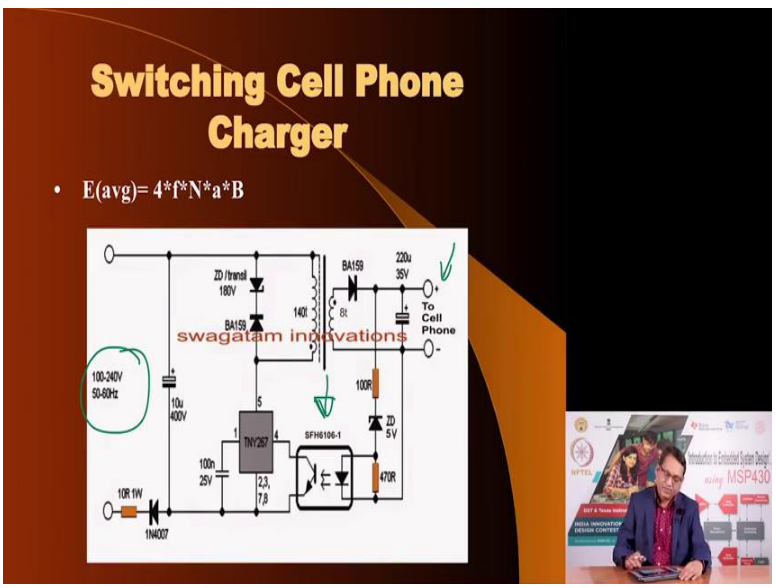

Here is an example of a cell phone charger where you take the input voltage from the source, which could be 100 to 240 volts, and you still provide 5 volt output, but with the output and input are well into isolated using this opto coupler. I am not going to go into the design of this, but this ensures a very efficient power supply for a charging the batteries in such portable applications.

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Now, I have put together a list of various topologies, including the source and the regulator and so on, so one option could be you use a line frequency transformer, when I use the word line frequency means 50 or 60 hertz to stop drop down the voltage, followed by linear regulator, which could be fixed or variable. You could have that but use a switching regulator buck or boost. You could have a completely switching power supply. As I showed in the previous slide, you could have a capacity attenuator meaning instead of using any transformer, at the input you could use capacitance to attenuate and then have a Zener regulator.

You could use alkaline battery followed by a buck or boost topology based on your voltage requirements.

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You could use a lithium battery with a boost to give you 5 volts. You could use lithium battery with buck boost to give you 3.3 volt, for 5 volt output. You only need boost because the battery voltage is never going to exceed 5 volt so a boost type of switching regular is sufficient. If you want a power supply, which is 5 volts plus 3.3 volts, you and the source of power is lithium, then you would use boost for 5 and then using a buck or a LDO you could get 3.3 from either directly from the lithium or from the boost you could use at the output of the boost regulator you could use a LDO to give you 3.3 volts.

You could use radiofrequency transmissions using an antenna and they are extremely low power. But they are enough for many applications, as is illustrated of a in the RFID application, you could use a Faraday based generator, you saw two examples of tube with the magnet and coil, copper wire of coil to produce voltage, this would be rectified and then filtered and then you would you would use appropriate regulator to get stabilise voltage.

You could also have a solar panel which would charge a battery followed by a regulator to provide. Another method is using the resonance, vibration inherent in buildings which have air conditioning because the air conditioning equipment, these buildings are vibrating at a certain frequency. There are solutions where you have power converter which will stick to the wall of these buildings.

They are tuned to the frequency at which the building is vibrating and they provide miniscule amounts of power but often times this is sufficient for powering monitoring equipment. And then you could use a thermoelectric based solution what is called a TEG which essentially is a thermocouple or a regulator based on that to power your application.

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Modern ICs are designed such that the chip is partitioned in several parts the periphery of the IC often is operated at higher voltages and the inner parts are operated at higher frequency and therefore lower voltages so has to maintain a uniform power dissipation across the chip so as to maintain a uniform participation.

Oftentimes, they may have a separate analogue subsystem and I have already discussed that how to power it. And this would require multiple power supply voltages required by such ICs.

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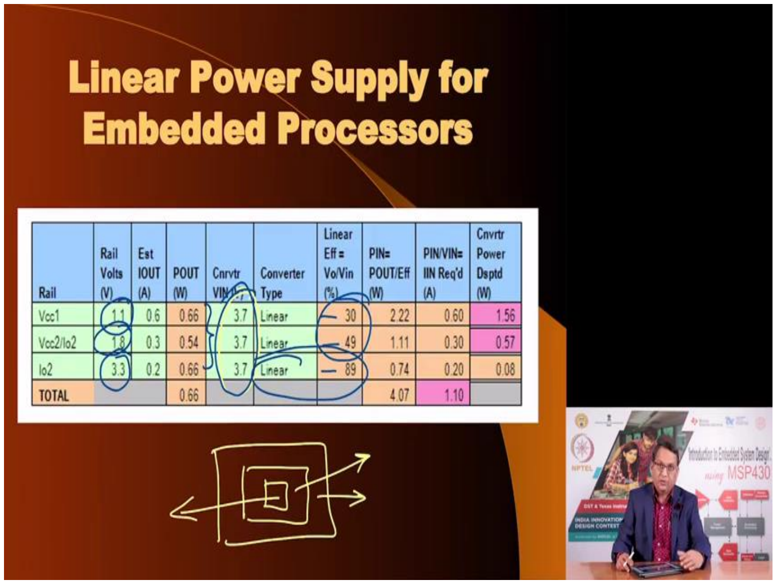

In the next slide I have taken from the data sheet of a high end Texas Instruments microcontroller. And as you see, it requires three power supply voltages 1.1 volts, 1.8 volts and 3.3 volts and you see the current expected out of these three power rails is such that the product is more or less uniform, so that when I have if I have this, IC usually it will be split in three parts, the periphery, the middle part and the core.

The core will be operated at the lowest voltage because it is going to operate at highest frequency. The periphery will be operated at highest voltage because it can then provide large noise margin but it will have to operate at lower frequencies and the middle one would be an intermediate voltage. And each of these parts consume an amount of current such that the product of current and voltage is pretty much uniform so that the entire chip dissipates uniform amount of power so that there are no voltage differences which may lead to thermoelectric effects or they may produce physical warping in the chip.

One solution is to use a linear type of regulator for all the three power sources where the input is a lithium battery as can be seen. This is typically a lithium battery voltage and you see the first power supply would be 30 percent efficient, the second will be almost 50 percent and the last one where the output voltage very close to the battery voltage will give you about 90 percent of efficiency. And this is not an acceptable solution because you are wasting so much power in these two power supply voltages.

And the solution is not to replace all the power suppliers with switching regulators because this power supply is already giving you about 90 percent efficiency. You will not gain much by replacing a linear regulator with a switching regulator because it may give you better efficiency of 2, 3 percent, but at a much higher cost of additional components.

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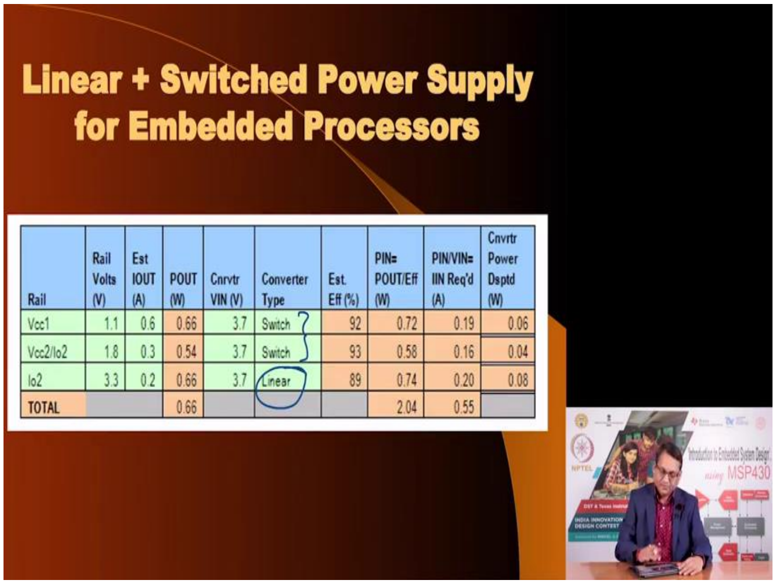

And so an ideal solution would be one in which the two, these two power supply's regulators are replaced with switching regulator and the third one is still maintain at of a linear type. This is the expectation out of a designer when you are designing a complete embedded system, you have to consider the power supply requirements of the microcontroller and other components in your system and to design voltage regulators compatible with the requirements.

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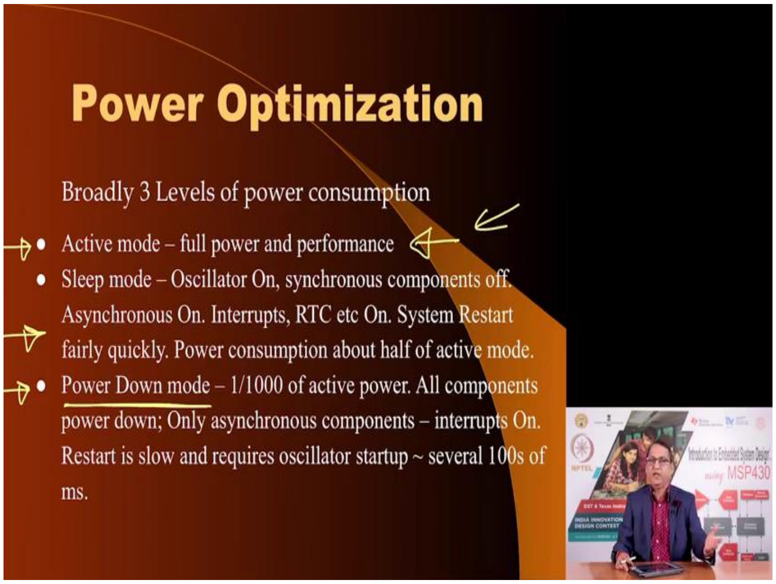

Microcontrollers, modern microcontrollers try to conserve available power based on the required performance required at any given point of time by at least having three modes of operation. One is the active mode where you are operating at full capacity, full performance, such as in a mobile phone or a smartphone. If you are using it the microcontroller inside is operating at the highest capability but when you are not using the mobile phone, it is lying down and you are not receiving any phone call or any SMS, then it tries to save power by switching the display off and so on.

And also maybe some internal circuit elements are switched off. The clocks signal to these subsystem is turned off so as to conserve power. And the last mode of operation is powered down mode where the clock oscillator itself is switched off because clock oscillator is one of the largest power consuming elements in a logic circuit. By turning it off, you can save power if you are not going to use the system.

Let me tell you your mobile phone yours, whether it is smartphone or your regular non smart mobile phone indeed offers these three modes of operation when you are using it it works in the active mode, when you are not using it, but it is still on and you keep it on your table or somewhere it is in tries to go into sleep mode. And when you so called switch it off, you think you are switched off the mobile phone? Sorry, mobile phone is never switched off. It only enters this power down mode.

And you actually you do not have on-off switch on a mobile phone, the so called on-off switch is only a soft switch, which only is used to change the mode of operation from active mode to power down mode. In power down mode your battery is still connected to the microcontroller, the microcontroller is still getting supply voltage, except it is not doing anything. Why? Because the main source of clock, which is responsible for all actions and activities on the microcontroller, has been turned off.

And to get back into any of the other modes sleep or active mode, you have to press that so-called on-off switch you to hold it, pressed for much longer duration, which ensures that the oscillator starts oscillating, the oscillations are stabilized, and only then when the clock oscillator starts working correctly, does it activate the rest of the circuitry on your microcontroller and then it starts working.

So, these are the modes of operation, these are broadly the three modes of operation are typical microcontroller may offer more varieties in the active mode. It may offer more variety in the sleep mode and power down mode. In fact, as we will start discussing the MSP430 microcontroller, you will see that it offers many, many sub modes which would be classified as sleep or power down modes, so that the you end user you the designer has more options to choose from so as to conserve whatever battery power that is available.

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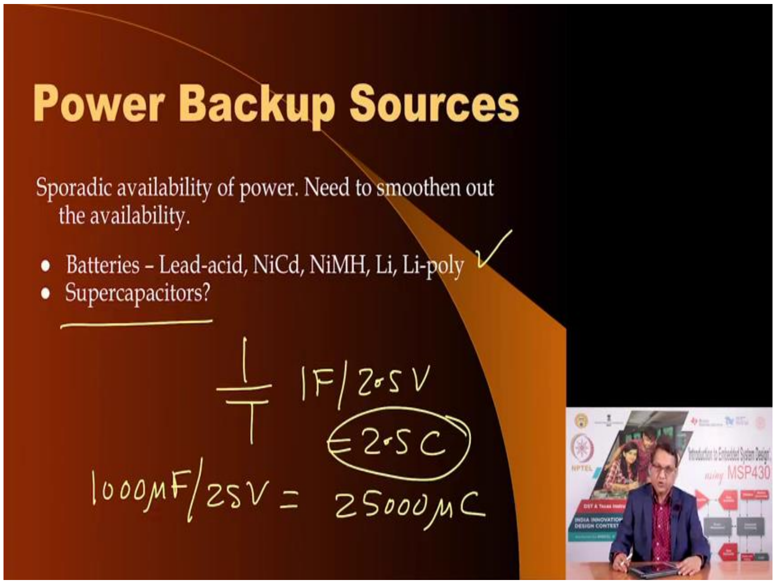

Again, to backup the source you may need to use certain types of batteries. And these days another alternative is to use super capacitors. Super capacitors are ordinary capacitors with huge amounts of capacities. For example, in one of the projects that I showed you, it used a super capacitor, which was a 1 Farad 2.5 volts capacitors and you know, the amount of energy that this capacitor is capable of storing, it is equal to 2.5 coulombs, which is a huge traditionally the capacitors that you used in your power supply filtering typically say 1000 micro farad at 25 volts.

This is just 25000 micro coulomb which is a much smaller fraction compared to the capacity of a super capacitor. So, super capacitor could also be used a super capacitor is far better than batteries because it has much longer life and it is not as hazardous for disposing compared to battery.

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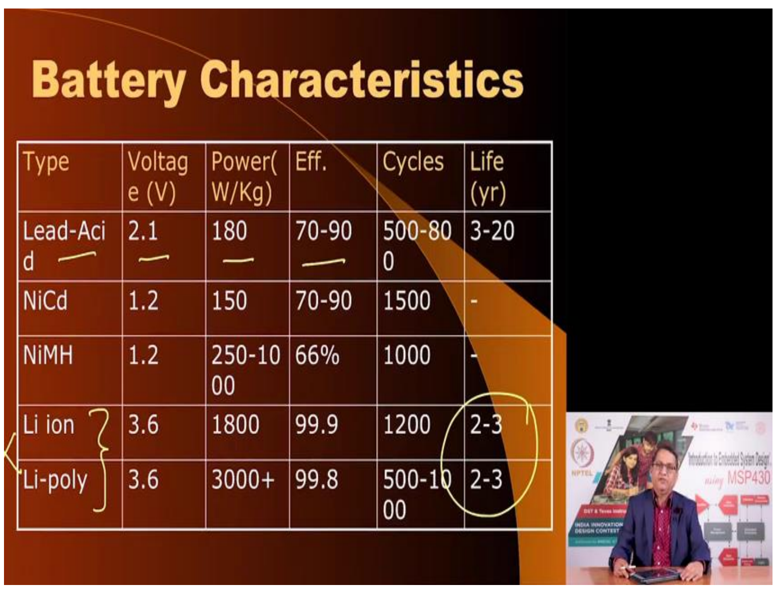

These are the typical commonly available batteries these days that people are using, you need to know the type of battery, the terminal voltage, what is the power versus weight ratio, what is the efficiency and how many times can you charge and discharge this battery?

And this can be an important consideration depending upon the product that you are designing. If you are making a cell phone kind of product, you could perhaps use lithium iron or lithium poly. But if you are going to fly outer space probe where the lifetime is only a few years in the in these kind of batteries, but your outer space probe may take several years to reach its destination. Certainly these type of batteries are unsuitable to power the backup as a backup power in such a space probe.

So, you have to find alternative other types of battery chemistries which have which may not be as efficient as lithium iron or lithium poly, but they have much longer life cycles. With this we come to the end of this lecture. I will pick up from here in the next lectures we are going to now get on to understanding the MSP430 microcontroller and the architecture and other issues related to this microcontroller. Thank you very much I will see you very soon.