Introduction to Embedded System Design
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Lecture 9
Power Supply for Embedded Systems

Hello, welcome to a new session for this online course on introduction to Embedded System Design. In the previous lecture, we looked at various aspects of the ecosystem that microcontroller requires and one of the important components was the design of the power supply or the requirements of the power supply by the microcontroller. In this lecture, we are going to look at power supply building block from a comprehensive point of view in terms of the requirements of the subsystems other than the microcontroller. What are the various ways we can design the power supply elements. We are going to discuss those.

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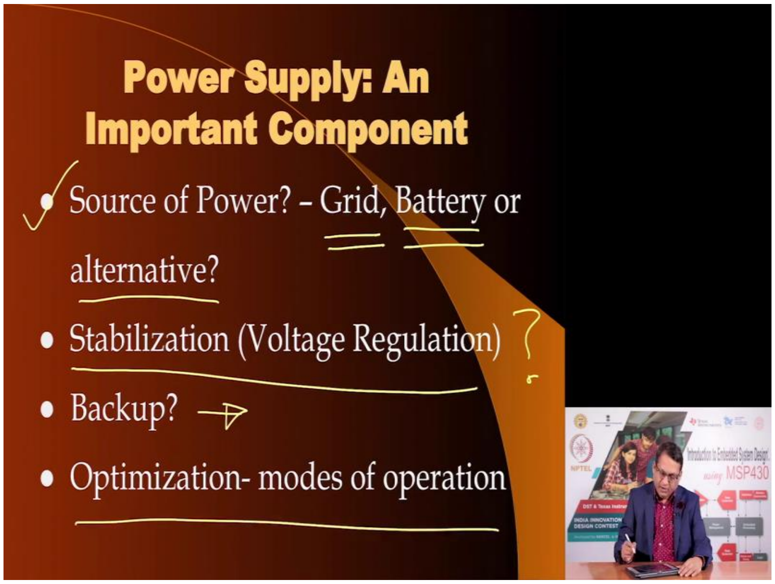

So, here is the here are the elements that we have to consider when we design the power supply, power supply is a very important component. The first question that we must answer as designers of embedded system is what is the source of power. Usually, if you have a embedded system which is going to be powered by mains voltage, then you would derive it from the wall socket, what we call as the grid power that is most common source of powering your embedded systems. But, if you are going to connect a cable between the source of power and your embedded product, then it would be restricted to a physical space. In some cases, you may want to involve a battery.

But battery is not a source of power it can only last so long depending upon the capacity of the battery and battery may need recharging if you are going to use rechargeable batteries or they may require that these batteries be replaced if they are non rechargeable. And the other option is that we may be using alternative sources of power.

Once you decide what is the source of your power, then the next question is, is the source of power very stable, even if it is stable if it is of a high value most embedded systems, the components that make up the embedded system require a low voltage low DC voltage and so, you must reduce the voltage and you must ensure that the reduced voltage is stable that there is no noise on it, it is not fluctuating.

And so, if it is fluctuating then you consider a question regarding the stabilization of that voltage, what we call as the voltage regulator that may be pressed into service to ensure that even though the input voltage may fluctuate or may vary or may even blank off, you may want to continue operating the system using some mechanism and it could involve a voltage regulator.

If the voltage the power source is sporadic, that is it may not be available at all times, then you must consider options of a backup. What are the various ways that you can create backup and last but not the least, given that you have some source of energy some source of power, you would still want to optimize the available power and this is very important in case the source of your primary source of your battery a source of your power is a battery.

You would want to optimize it utilization and so, the optimum the modes of operation which are dependent on the microcontroller features as we discussed in the previous lecture, you would want to invoke those modes, so, as to conserve available power.

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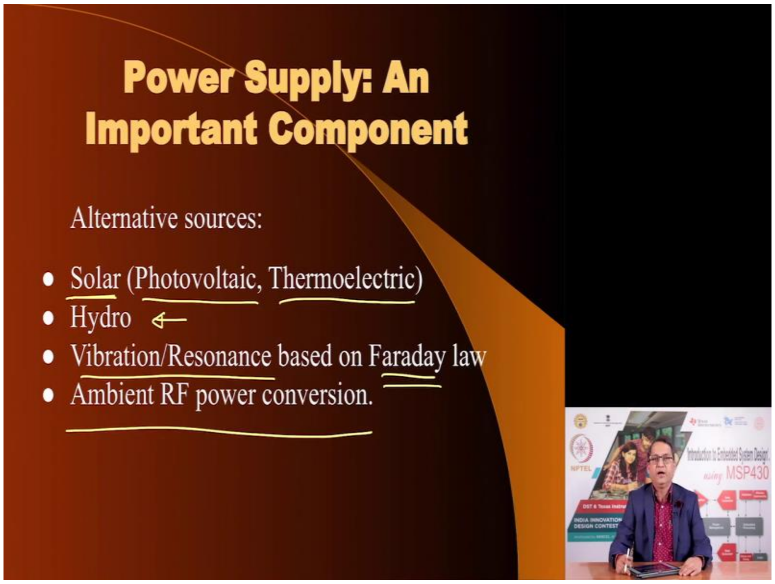

Let us go to the next slide. The sources other than the grid power, which is available through the wall socket, you could consider is it solar? If it is solar, solar itself is of two types one is photovoltaic which uses solar panels solar cells and the other is thermoelectric which uses the temperature difference applied to a peltier module to generate a voltage difference and this could be used to power your embedded system. Another option could be hydroelectric which means that your system is nearby a source of water which could charge which could power run a dynamo or a generator.

The third option is vibration or resonance based on Faraday's law and you may recall a project or a couple of projects that I showed where I had used a tube consisting of enclosed magnets and outside the tube there was copper windings and when the magnets went pass through the copper wires, it produces more produced voltage based on the Faraday's law and this could be used to power your system.

In case you do not have these options, another possible popular mechanism to power your embedded system is the availability of Ambient RF radio frequency source, whether that radio frequency source is available in free space, such as radio transmissions from broadcast transmitters or these days through the cell phone towers, you could use them and in fact, the one of the applications I showed the RFID card used radio frequency transmissions to receive the radio waves to try convert them, and then use them for powering the microcontroller of the embedded system. So, these are some of the alternative sources of power that you could consider when you are designing your embedded system.

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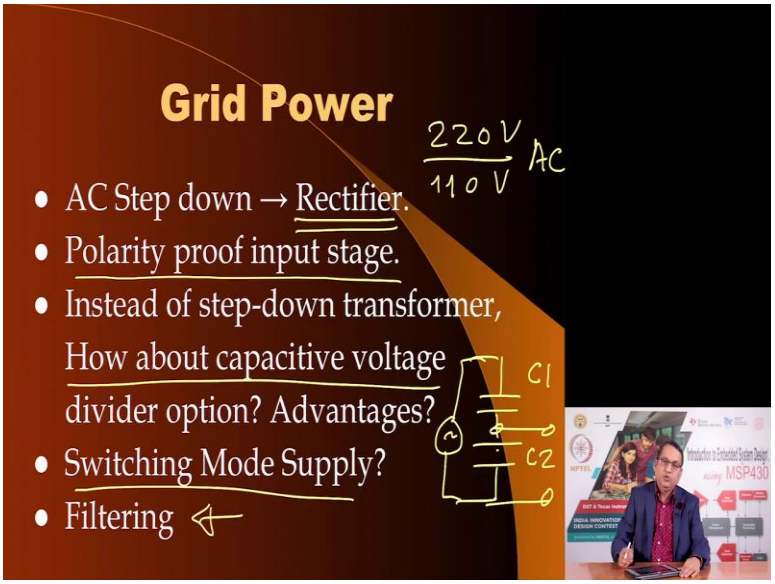

If the primary source of your power is the grid, then the grid voltage is typically 220 volts in large parts of the world. In some cases the voltage is 110 volts. So, grid power would be either a 220 volts or 110 volts and these voltages even if it is hundred 10 volts is way beyond what you would require also these are AC voltages and so you have to consider the first option, first requirement of stepping it down to usable levels and then to rectify it meaning convert from AC to DC.

If you are going to reduce it, step it down to usable levels and if you are going to, for that you would use a transformer the transformer would give you AC voltage, you cannot just connect it to your system because the transformer would have a polarity, you do not want to apply a reverse polarity to your circuits.

So, some sort of polarity proof design of the input stage of your power supply which is polarity proof or polarity safe you would have to incorporate and in the next slide will show the two options that we have. Another way is that instead of using a step down transformer which is the case in most of the situations, can you reduce the voltage by any alternative means? Because a step down transformer is bulky, is expensive. Is there a way to reduce the voltage in some way and one method that is often used is using a capacitive voltage divider, think of it like this, that if

I were AC voltage source, I can create a voltage divider using two resistors. But I can also create a voltage divider using two capacitors.

If I use two capacitors, then here is my AC source and I tap the voltage here. Then, because the capacitors are reactive components, they do not dissipate any power. I would have a more efficient power supply system, I would ensure the ratio of these two capacitors C 1 and C 2, such that the voltage across C 2 is within usable limits and then I would rectify it and I would I could use it to power my system.

In fact, many of the LED bulbs that are becoming available the cheap varieties often use capacitive power supply and these are very low cost, but the there are some disadvantages that such a power supply is not isolated and therefore, human interaction has to be stopped you cannot interact with such a power supply because it is likely to give you a shock but LED lamp you usually put it in the socket and you never touch it. And therefore, using a capacitive drop power supply is a good option, it is inexpensive and it serves the purpose.

Another option is and it is a very very common approach is to use a switching mode power supply. In this switching mode power supply, which is being used in phone and portable device chargers, you without the weight and bulkiness of a traditional step down transformer, what it does is it takes the AC voltage and rectifies it right away.

And usually such switching power supplies are also called as Universal Power Supplies which means, that the same power supply will operate in a 220 volt domain as well as 110 volt domain because when you are producing a when you are creating a product, you do not want to have alternative options that if this is to be sold in countries which have 220 volt supply then this is the power supply to be used and if it is to be sold in countries which have 110 supply then you have a separate power supply.

These power supply power supply solutions are designed so that they can cater to any supply voltage from 100 volts to 250 volts. In these they take the AC input rectified directly, which would give them a maximum rectified voltage of about 340, 50 volts and then they power a small electronic circuit, that electronic circuit produces a switching waveform which is in the high frequency domain. The typical power line switching frequency is 50 or 60 hertz, which increases the size of the transformer. But if you increase the frequency the relationship between size of the transformer and the frequencies inverse proportionality and so, if you increase the frequency it reduces the size.

So, switching mode power supply use about 100 kilohertz or a few hundred kilohertz of switching frequency which lead to a very small tiny transformer. Having a transformer also isolates the power supply DC side of the power supply from the mains. And so, most of the chargers whether they are for cell phones or for whether they are for your laptop computers fall in that category. So, you could consider using a switching mode power supply also and after you have rectified your voltage you would want to filter it before you stabilize that voltage.

So, let us see what all elements are required for creating the power supply. If you have rectified and you have reduced the input voltage from the mains supply to a low voltage and you want to power your system, you want to ensure that the polarity of the voltage does not affect your circuit.

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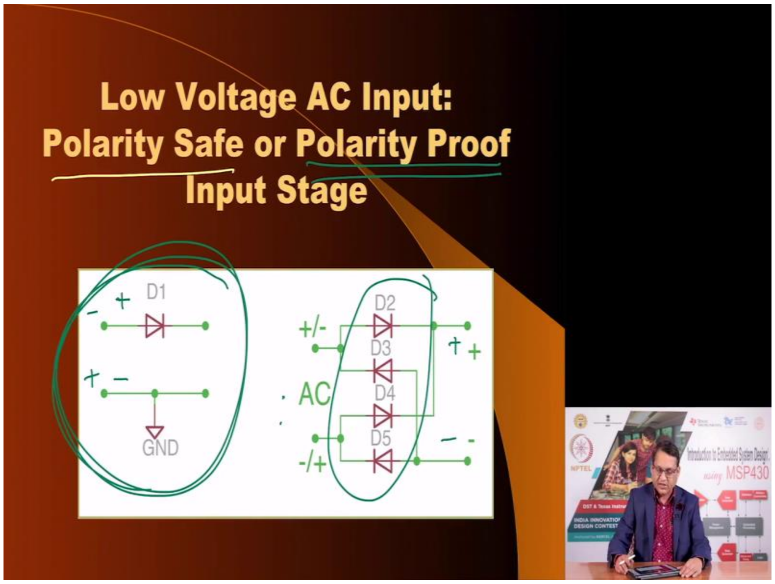

So, we have two options one what I call as polarity safe so this is a polarity safe option, let me choose a different color of the pen. So, this is a polarity safe option meaning if the polarity here is not plus and minus here, it would not damage the system because this diode will block. If the polarity applied here is minus and plus like this, this diode will block and will prevent damaging the rest of the components.

If you want polarity proof meaning irrespective of the polarity, your system should still continue to operate, then instead of a single diode, you can utilize a bridge rectifier configuration as seen here, this is the bridge rectifier component configuration. This will ensure that whether you apply a DC voltage or a low AC voltage, you will get a fixed polarity which is plus here and minus here and then this could have further filtering and regulation to power your embedded application. So, these could be considered.

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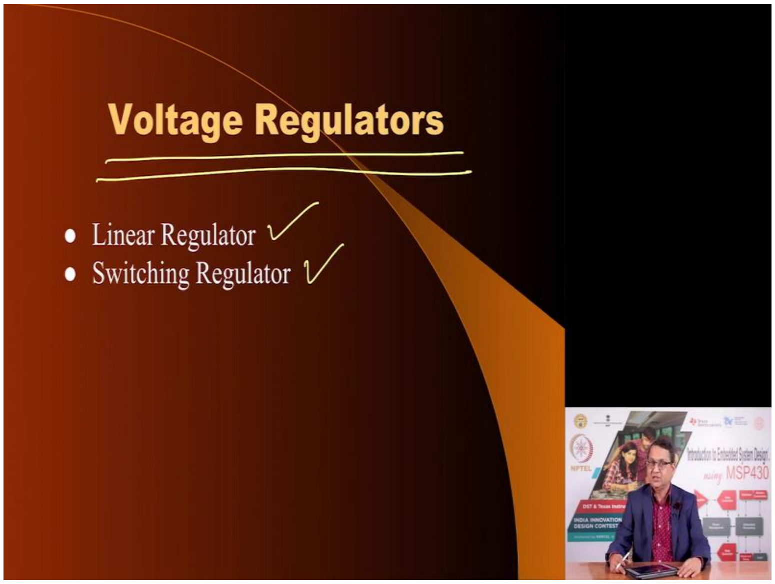

Now once you have rectified or reduced the voltage and then rectified the AC voltage and you have filtered it, you would want to employ a voltage stabilization circuit and these voltage regulators are of two categories, two types, one is called the linear regulator and the other is called switching regulator. Both use electronic components and yet and they use the same components for example, they use transistors they use rectifier diodes they use reference diodes and yet one class of circuits is called linear regulator, the other is called switching and what is the difference? How is the difference?

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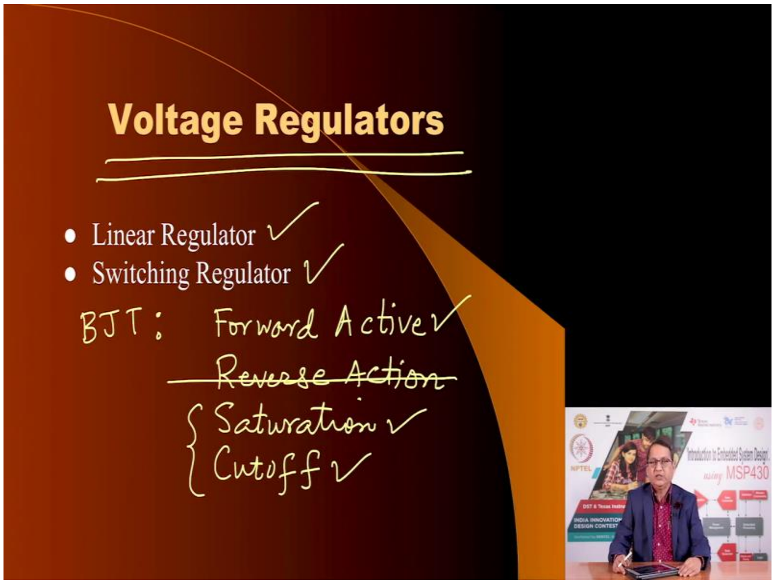

You know, how does it reflect, one the if I look at a BJT transistor then there are four modes of operation in which the BJT works. One is forward active, the other is reverse active mode of operation for a BJT, the third is saturation and the fourth mode of operation is cut off. Usually, the transistor is operated either in the forward active mode or in the saturation mode or in the cutoff mode, reverse action is reverse active mode is often not used.

Now, such circuits in which the transistor primarily operates in the forward active region, they lead to class of circuits and class of regulators what we call as linear regulators. On the other hand, if you do not want the transistor to operate in the forward active region, you could operate it in the switching region using saturation and cutoff.

And when you build a power supply regulator using the transistor which operate in primarily in the saturation and cutoff region, such regulators are termed as switching regulators. Each one has an advantage over the other. And we will consider the advantages and disadvantages of both these types of regulators.

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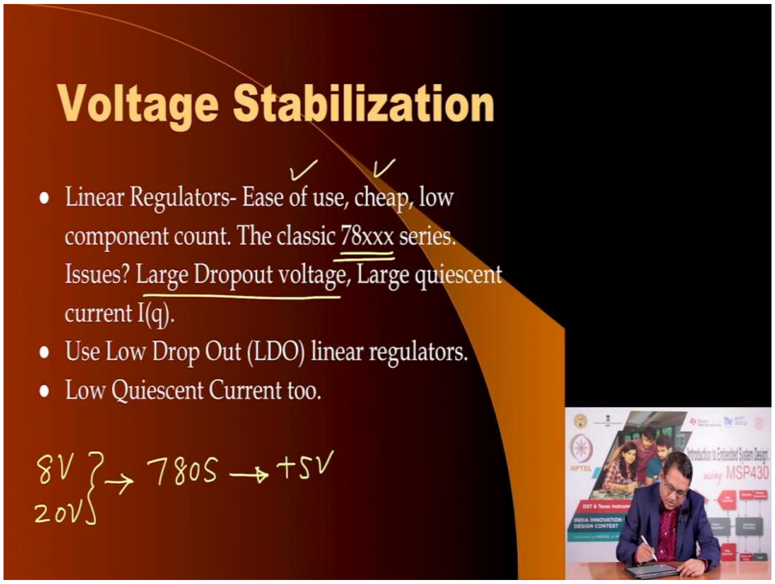

Linear regulators where the BJT or the active element operates primarily in the forward active region, they are very easy to use, they are inexpensive and they do not require any other component other than the voltage regulator, if it is of a integrated nature. The classic example of a linear voltage regulator is what is called as the 78 xxx series for example, you may have used a 7805 in your electronic circuit design. And this provides a plus 5 volt power supply when the input could be anywhere from 8 volt to more than 20 volts.

So, you can provide this as the DC voltage and this regulator will give 5 volts and there are many other components, many other output voltage options available 5 volts is one of them. But this is historically, this was designed in 60s and 70s they were very popular at the time, but nowadays there are a lot of reasons why people are not using these anymore. One of the reasons is that they require a large dropout voltage, what is a dropout voltage? Let us look at.

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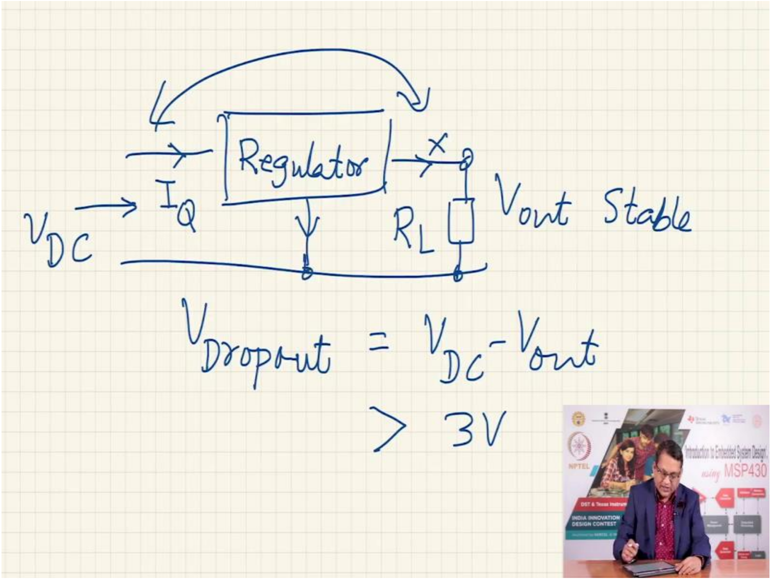

So, if this is the if this is the regulator, if this is my regulator and I apply a DC voltage here which is unregulated meaning it could be fluctuating in nature and I want V out which is fixed and stable. The difference between this and this is called dropout, v dropout is equal to V DC minus V out and V dropout has to be greater than 3 volts for the 78 series of regulators. Also, even if I have not connected any load, if this is the place where I could connect load, even if I do not connect any load, you will find that these linear regulators consume some current and this is called the Quiescent current this current If it is not, if it is going into the regulator.

This is your regulator if certain amount current is going in, even though there is no current going out. And obviously, this current has to come out through the ground terminal reference terminal.

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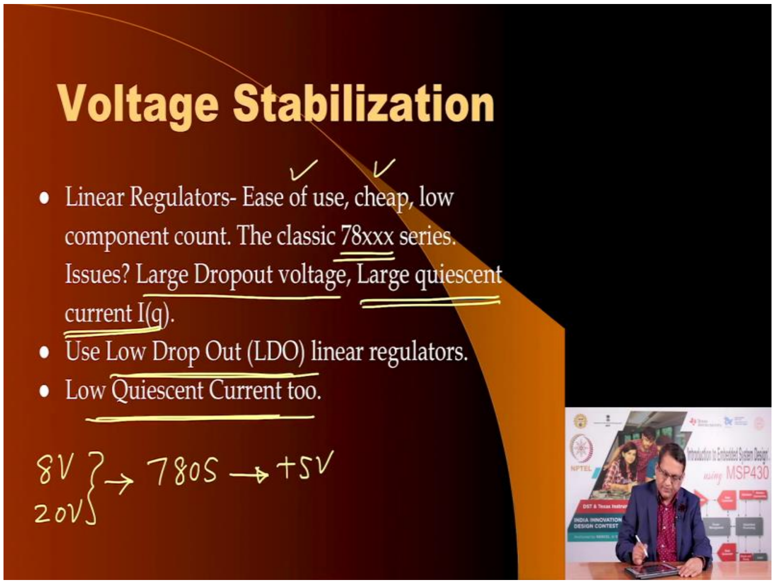

This is the Quiescent current and these 78 series of regulator suffer from a large Quiescent current, how large this is typically 10 milli amperes and the dropout voltage has to be more than 3 volts, which means 3 volt into 10 milli ampere roughly 30 milli watts of power is being wasted, just to power the, just to keep the regulator working and in current technology environment 30 milliwatts is a huge amount of power which you do not want to waste merely as heat.

What are the alternatives? Well, instead of using traditional 78 series types of voltage regulators, they have developed a low dropout voltage regulators they are called LDO regulators and they also offer low Quiescent current.

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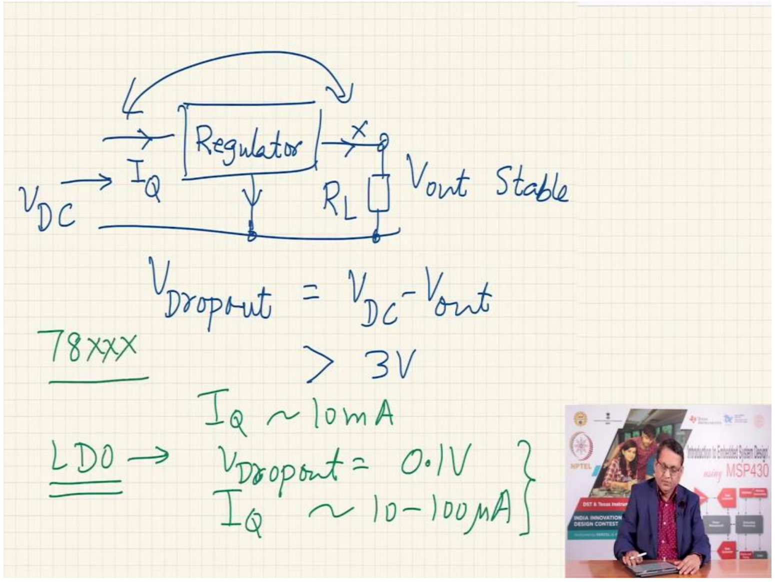

Let us see what are the numbers in if I look at the 78 series of regulators, I have roughly 3 volt and IQ is of the order of the Quiescent current is of the order of 10 milliampere. But if I look at other options that is use LDO, then LDO will give you a V dropout as low as 0.1 volt and IQ as low as 10 to 100 micro ampere. So, if you are going to design your power supply for embedded application and you are forced to use a linear regulator for various reasons it is advisable to use a LDO type of linear voltage regulator instead of their traditional 78 XXX series.

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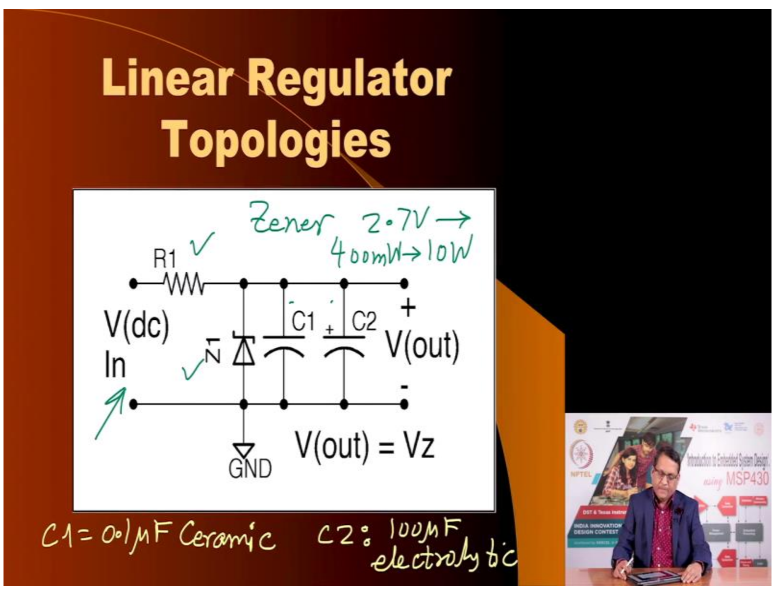

I am going to show you certain voltage regulators starting from the simple ones to more complex ones. So, look at this circuit here, the input voltage is the voltage that you would get after the grid power or whatever is the original source of your power it is reduced to low voltage levels then rectified and filtered and it is applied here. The simplest regulator would use a zener diode, you can get Zener diodes from as low a voltage of 2.7 volts to a higher voltage and in power ratings of 400 milliwatts to 10’s of watts, maybe 10 of 10 watts, and so it could be used to create a power supply system.

This is not a very efficient system for various reasons, but you would also it uses several components one you need a series limiting resistor you need the actual Zener diode and you need two capacitors as I mentioned, one of the capacitors the C one would be a ceramic capacitor and C two would be an electrolytic capacitor typical numbers are for C one would be a 0.1 micro farad ceramic and C two could be a 100 micro farad of suitable voltage rating of the type of electrolytic.

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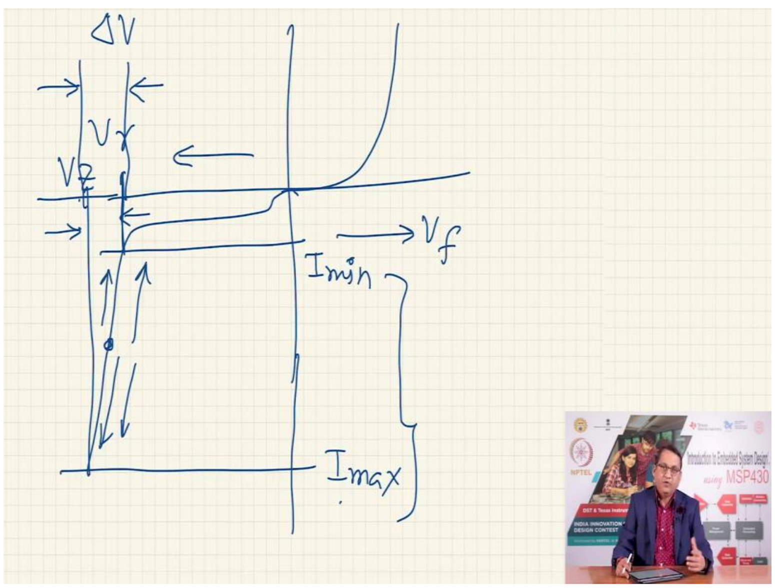

So, this is one simple now what is the problem with this power supply topology? Is that it operates the zener in the reverse region, so, this is the voltage V f, this is the reverse voltage V are and this is the point where your V Z the Zener principle kicks in. This is the minimum current, I mean that must flow through the Zener diode for it to regulate the voltage and based on the power dissipation characteristics of the diode this could be the I max.

Now, you see this is a large range, but from the minimum to the maximum you get certain variation in the input voltage. So, if you bias your zener at the center point if the input voltage changes and reduces then it is going to go in this direction, it would have, the Zener diode will conduct less current. If the input voltage increases, it would travel in this direction and it would pass more current through the Zener diode. The Zener diode acts like a shock absorber against the shock that is the variation in input voltage or variation in the load current.

If the load current changes because you have changed the amount of current being consumed in the output, it has only one way to go which is through the zener diode. So, if the load reduced if the input voltage is constant and the load current changes, if the load current reduces, the rest of the current has to flow through the zener diode and it will move it in this direction.

If the load current increases, the operating point will shift in this direction leading to a variation of output voltage of this nature. How much is this voltage, you have to refer to the datasheet of the zener diode to estimate that.

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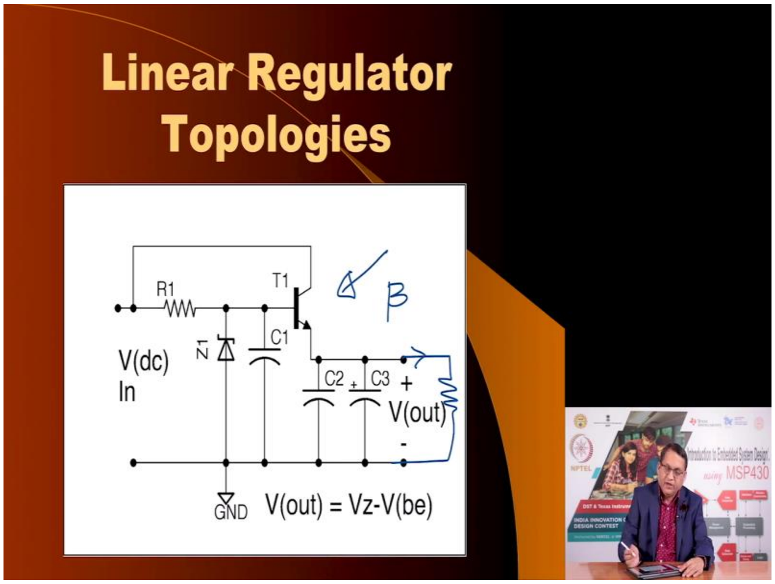

Now, we would like to reduce this variation, which would lead to a bad specification, bad voltage regulation feature of this power supply. And so, we use an alternative mechanism, we use this zener diode together with a what we call as a series pass transistor in this case a emitter follower. Now, because the transistor has a gain current gain of beta and the load is going to be connected here, if we have the same amount of load as in the zener only power supply the zener current would be reduced by a factor of beta.

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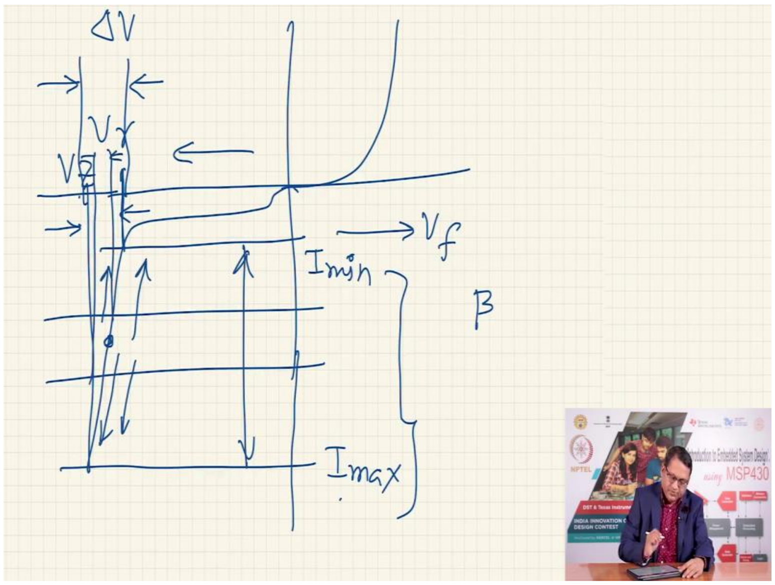

Which means if I look at this, instead of this entire variation, the variation would be reduced by a factor of beta which means it might be restricted to a smaller region if it is restricted to a smaller region, the corresponding variation in the voltage gets reduced.

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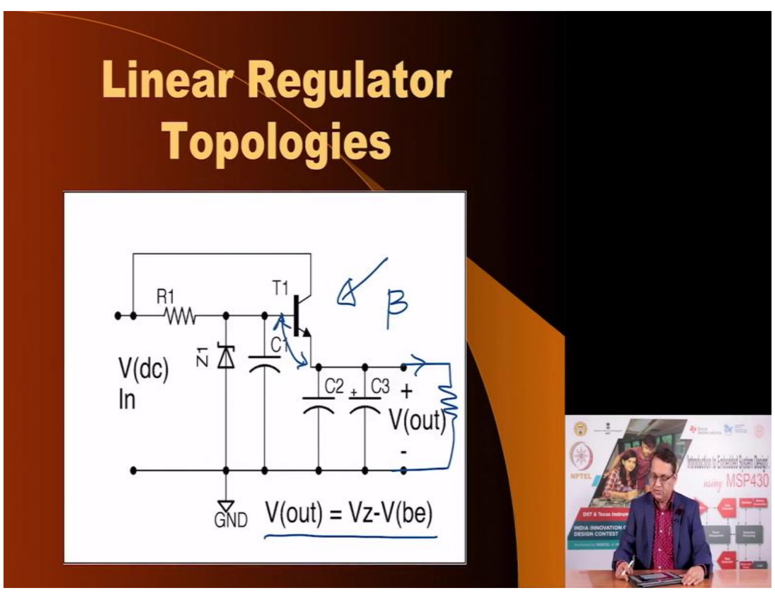

And so, if I use this topology, where apart from the zener voltage, I use a series pass transistor, it would give me a better voltage regulation figure. However, the output voltage is no longer equal to zener voltage it is equal to zener voltage minus the voltage drop across the VBE of the series pass transistor, this can be easily compensated by adding a normal diode in forward bias.

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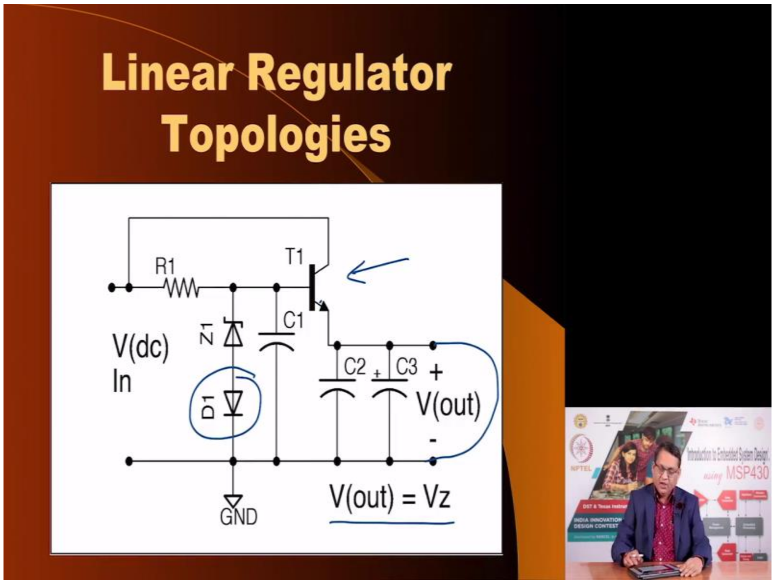

So, that now the output voltage is equal to zener voltage. This power supply still has problems for example, if I were to short this for some reason because of a fault or because of some user adventure it would draw a huge amount of current through this transistor, this transistor will try this supply that current, but eventually it will lead to a huge amount of power dissipation across this transistor by this transistor, it would increase the temperature of the transistor and eventually it will destroy the transmitter, there is no protection available in this power supply.

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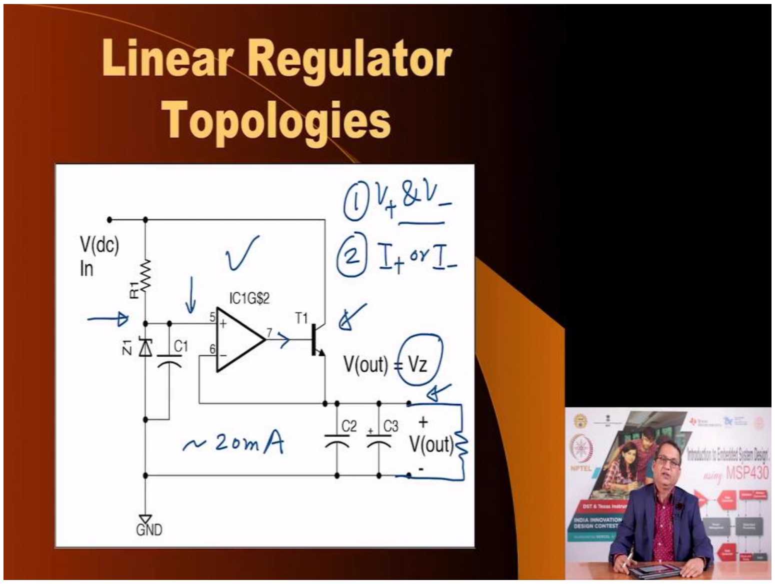

Now, let us look at another variation of the same instead of a simple transistor, I am going to use a volt op amp. Now, the op amp because of the feedback, it applies. I am sure you are aware of how op amp's work, they operate on two principles, one the voltage between the on the V plus and V minus terminals is near identical and two and this voltage is identical or near identical because the gain of the operational amplifier is very large and to the current going into the positive terminal or the negative terminal is very low and for ideal situations you can take that current to be 0.

Similarly, the voltage difference between the plus and the minus in ideal situations can be taken to be 0. In reality that is not the case. Anyway, we can use these two rules of thumbs to see how this op amp circuit together with the transistor can work as a linear voltage regulator, I apply zener voltage as in the previous case at the non inverting terminal, the principle of operational amplifier is to ensure that when you have negative feedback, the two terminals input terminals will have identical voltage therefore, if the positive terminal the non inverting terminal has a voltage equal to Vz, the circuit will ensure that the inverting terminal of the power supply also is equal to Vz.

Which means the output is equal to this zener voltage and the amount of current that you would want to draw from the output terminal because after you connect the load it will draw some current will be handled by the transistor. Why? Because if you try to draw too much current an op amp is not designed to handle large amounts of currents typically, the maximum current that you can draw out of an op amp is of the order of 20 milli amperes.

But if you want to design a power supply, which is capable of delivering hundred milli amperes you must boost that current capability by using a transistor here T one also operates as a voltage follower, but it provides you a beta amount of current gain. So, if the beta is say 100 that means 20 milliampere and 200 this configuration can safely give you about two amperes of current. Thank you very much. I will see you very soon.