BASIC ELECTRONICS
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LECTURE-9
ZENER DIODE CHARACTERISTICS

Hello everybody! In the series of lecture on basic electronics learning by doing we are moving on to the next lecture. You may recall in the previous lecture we discussed about zener diode. We talked about zener characteristics. We tried to understand how the zener characteristics come in the way; you saw in the last lecture and now we will try to look at some of the applications of zener diode. You know the equivalent circuit of a zener diode can be as I show on the screen.

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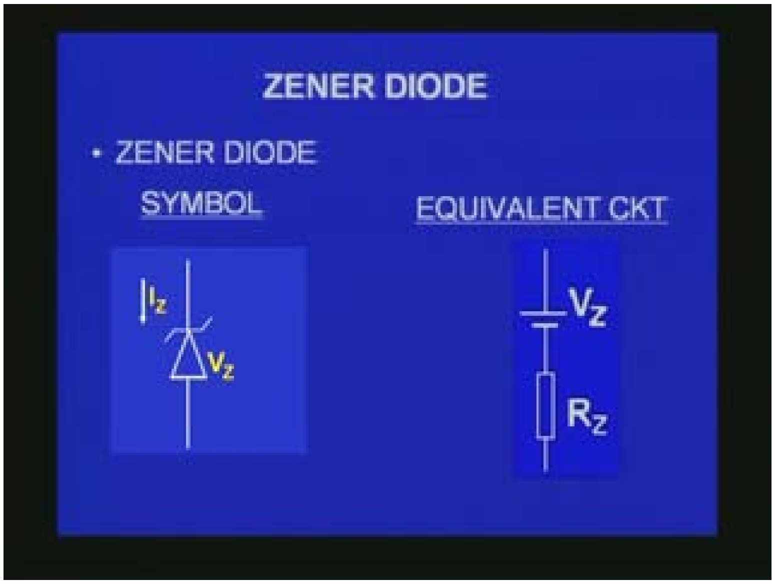
ZENER DIODE

- ZENER DIODE

SYMBOL

EQUIVALENT CKT

It could be with a voltage source corresponding to V_Z which is the beak down voltage and a series resistance R_Z. This is the equivalent circuit of a zener diode. We move on to the discussion on the applications of zener diode. One of the very important applications of zener diode is as a voltage regulator. What we mean by regulation? We already mentioned sometime back in one of the previous lectures that any power supply will be equivalently represented by a voltage source and an internal resistance or series resistance R_S.

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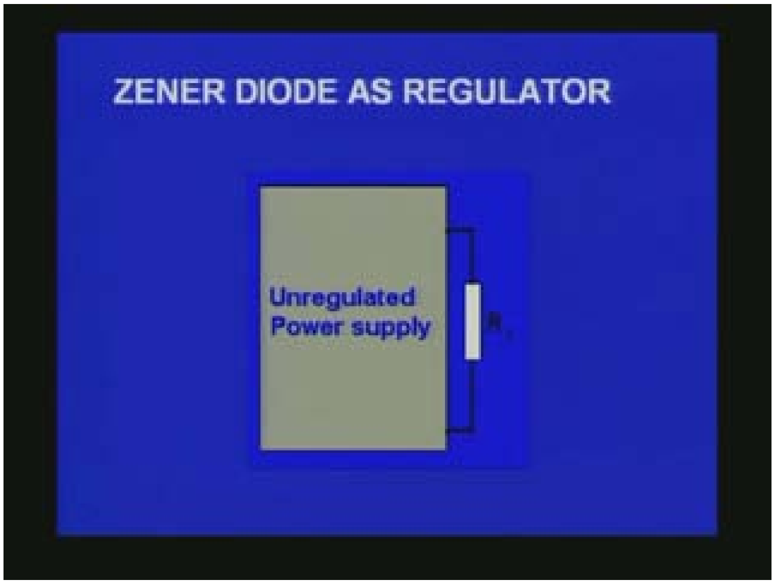

ZENER DIODE AS REGULATOR

Only an ideal source will have no internal resistance. The R_S will be zero for an ideal voltage source. For all other normal voltge sources that we come across there will always be an internal resistance even if it is the battery for example or a cell; it will have its own internal resistance which is non zero. When I connect the voltage source which is an unregulated voltage source as we call it to a load for example R_L, as you see on the screen, the voltage applied across the load resistance R_L in principle is expected to be a constant irrespective of what the load resistor that we connect. But because of the internal source resistance this voltage will not remain constant as we change the value of the load resistance. The load resistance here corresponds to whatever you are using the power supply for. We need the power supply to power for example an appliance which requires a DC voltage. It could be a simple function generator or it could be an amplifier. For all these things we require a DC source or DC power supply. The load here is any appliance which requires electrical energy. When I change the load or if the current which is being drawn by the appliance is different, it can happen all the time, then the voltage which is actually applied across the load will no more be a constant unless it is a regulated power supply. To explain it little more in detail I have shown both the circuits; the unregulated power supply on the left and I have also shown its equivalent resistance. If you look at the Thevenin's equivalent resistance of this unregulated power supply it will be equivalent to an ideal voltage source V connected in series with the internal resistance of the source R_S or R_{IN} as the case may be and this is the equivalent circuit of the unregulated voltage supply where here R_{IN} is a finite value and R_L is an external load resistor, resistors that you apply which can be the appliance that I was referring to.

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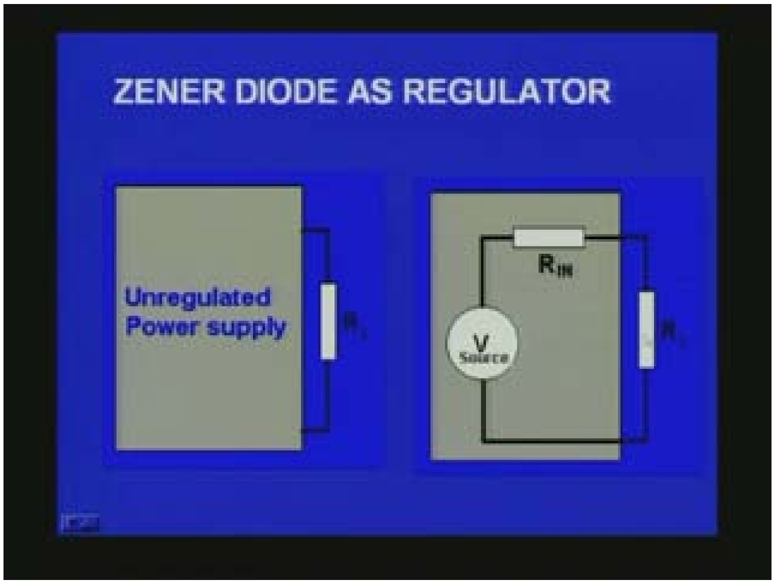

ZENER DIODE AS REGULATOR

What is going to happen because of that? I have given a small graph to illustrate this point. For example this is a 5V unregulated power supply. The Y-axis is voltage; the X-axis is the current. If I now change the load resistance for example I take the 5V supply; I connect different values of resistances across the 5V. For example if I apply 100 ohms the voltage may remain 5V. If I change the 100 ohms to 50 ohms, 25 ohms, 20 ohms, 10 ohms etc., if I keep on changing the value of the load resistance, if you keep on reducing the value of the resistance which I connect V/R corresponding to the load resistance will become greater and greater. That means the current which is flowing out of the voltage source will be increasing. If the current increases in an actual situation the 5V will not remain 5V constantly.

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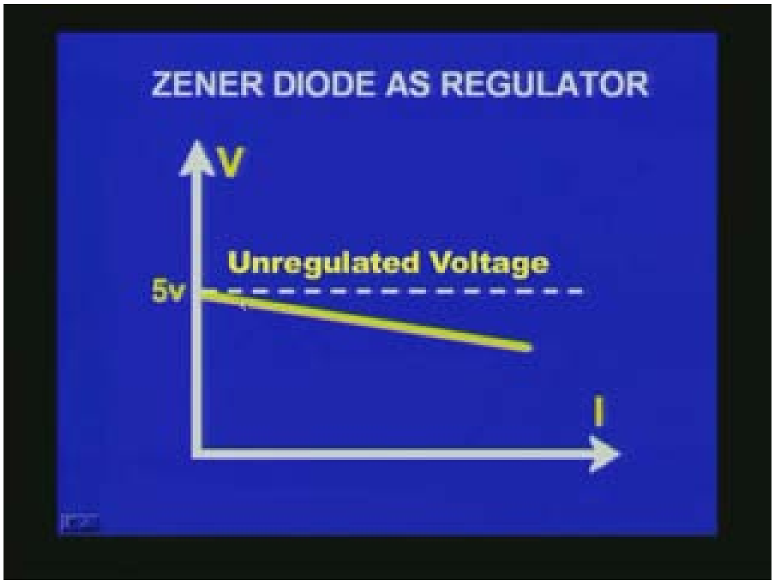

ZENER DIODE AS REGULATOR

What you expect from a power supply is the voltage should remain constant irrespective of the value of the current that I draw from the voltage source. But in reality as I increase the value of the current the voltage will keep falling. That is what is shown in this graph here. This is a typical characteristic of an unregulated power supply where the output voltage is not remaining constant and as I increase the load current the voltage keeps falling after some value and this is not a desirable characteristic of a good voltage source or voltge supply. If you want to avoid this fall in the voltage and if you want the voltge to remain constant irrespective of the load that you connect then you have to do something to the unregulated power supply and that is what is called the regulation. So you have to regulate an unregulated power supply to give a constant voltage output irrespective of the load that you connect.

Now let us look at the slide. You find here an unregulated power supply with a voltage source, V and an internal resistance R_{IN} connected to an external resistance load R_L. If you want to find out the voltage across the load V_L, it will be equivalent to V_S, the source voltage minus voltage across the R input that is internal resistance. VR_{IN} is the voltage that is developed across the R_{IN} and V_S is the voltage source, that is you have ideal voltage source and V_L will be the difference between these two as you can see from basic KVL, Kirchoff’s voltage law.

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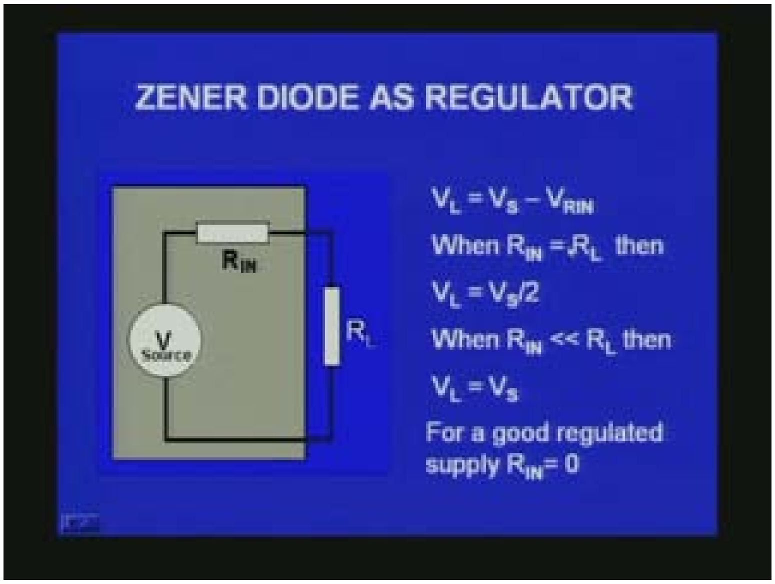

ZENER DIODE AS REGULATOR

$V_L = V_S - V_{RIN}$

When $R_{IN} = R_L$ then

$V_L = V_S/2$

When $R_{IN} << R_L$ then

$V_L = V_S$

For a good regulated supply $R_{IN} = 0$

When I have R_{IN} equal to R_L you can imagine what will be the value of V_L when R_{IN} is equal to R_L. This voltage source will have to be divided among these two resistors and you will get only half of V_S across the load. V_L is not a constant. It depends on R_L. If R_L is equal to zero then R is infinite. That means there is no load which corresponds to the load being absent here. That means it is open circuit here and there is no current flowing and there is no voltage drop across R_{IN} and whatever you get will be the total voltage, source voltage that you have. V_S will be measured between these two terminals. As I decrease the value of R_L till I get a situation where R_{IN} is equal to R_L the voltage will drop from V_S to a value which is $V_S/2$. If I decrease the value of R_L still further the current will increase further and the voltage also will drop further. This is going to be a problem. The voltage is not remaining constant as I change the value of R_L.

If I want a good regulation what should be the effect? If I make the value of R_{IN} zero or as small possible then the voltage drop which comes about because of the existence of R_{IN} will become less or almost zero if it is R_{IN} zero. In that situation most entire voltage will be available across R_L. When I say I want to prepare a voltage regulation what I mean by that is I am attempting to make my internal resistance of the source by some means to a very small value or if possible ideally to a value zero. That is what we mean by regulation, trying to reduce the value of internal resistance so that the output voltage will always remain constant irrespective of the current that you draw through the load.

Let me just recall for a minute the characteristics of a zener diode. You all remember it. I showed it in the previous lecture also. You have on the forward bias condition when V and I are there it is something similar to a normal diode. But when you come to the reverse direction V minus and I minus then it is remaining constant almost to the very small value of the current up to a value which is called V_Z which is the break down voltage and beyond that the zener breaks down and you would get a very large current but the voltage will almost remain constant.

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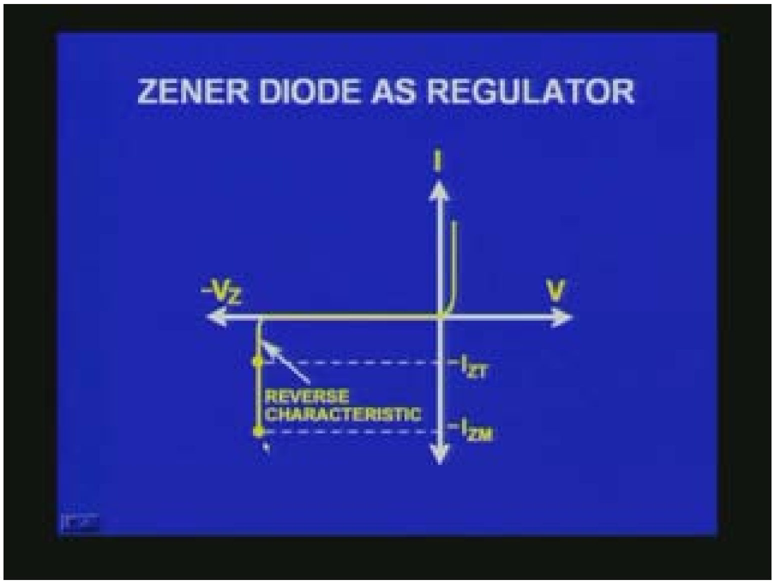

ZENER DIODE AS REGULATOR

This is reverse characteristics. Reverse characteristic suggest to us that after the break down the voltage remains constant for very large values of change in current. This is what we wanted to do with reference to regulation. You can see how a zener diode perhaps can be a solution for regulating an unregulated power supply. To bring things much clearer what I have done is I have actually rotated this for some convenience in this way when you would find irrespective of the increasing current the voltage remains constant.

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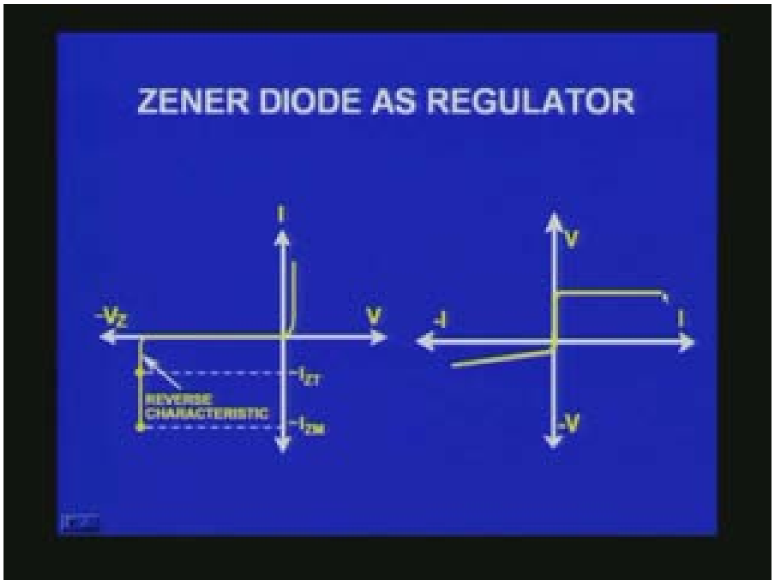

ZENER DIODE AS REGULATOR

This is noting but the characteristics of zener diode but you can see here the voltage remains constant in the breakdown region for very large values of change in current. This is what we want for an ideal voltage source or a good regulated voltage power supply and zener diodes can be used as a regulating device in an unregulated power supply.

How do we do that? If I need to design a regulated power supply for 5V then what do I do? You have to use a zener diode which has got the breakdown voltage of 5V. If you want the voltage source of 12V then I must use the zener diode which has got a breakdown voltage of 12V. Right! But you should remember the unregulated power supply that you have to use to regulate should have a voltage much larger than the zener breakdown voltage that we choose. That is if I want a 5V regulated power supply I should start with an unregulated power supply which is may be 9V or 10V. It cannot be very close to 5V which is the breakdown voltage of the zener that I have chosen. Why is it so? It is because you should ensure that the zener diode is operating in the breakdown region. Only in the breakdown region the voltage remains constant irrespective of the current flowing through the load and you must make sure that the zener is operated in the breakdown region. That is why you require much larger unregulated voltage source if I want to regulate to 5V or 9V as the case may be.

Let us take a simple example. If the input voltage is 9V and you want only 5V by using 5V zener diode then you have the balance of 9-5 corresponding to 4V which must be dropped across another resistance in series with the zener diode which is called R_S. A zener diode whenever it is used in the breakdown region you must have a series resistor R_S which will be used to bias a zener diode. It will be used to drop the excess voltage available over and above the breakdown voltage.

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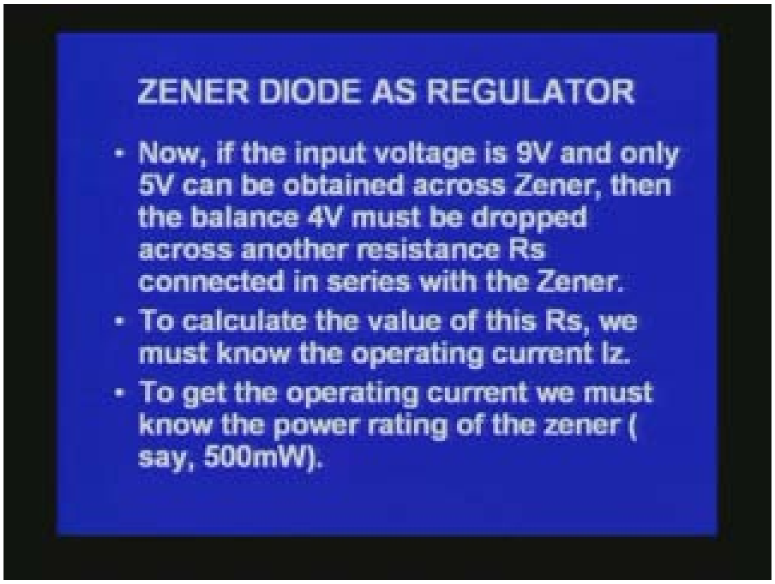

ZENER DIODE AS REGULATOR

- Now, if the input voltage is 9V and only 5V can be obtained across Zener, then the balance 4V must be dropped across another resistance Rs connected in series with the Zener.
- To calculate the value of this Rs, we must know the operating current Iz.
- To get the operating current we must know the power rating of the zener (say, 500mW).

How do we calculate the value of R_S in a given situation? For this we should know the current that we would like to have as the operating current for the power supply. I call that I_Z in this case. How do we get the operating current? One way to get the operating current is we should find out the minimum and the maximum current that can pass through the zener without any damage to the device. If you go back to the characteristics you know already that breakdown region starts at some point which is called the knee point and that current will be the minimum current that I must have passing through the zener to be in the breakdown region.

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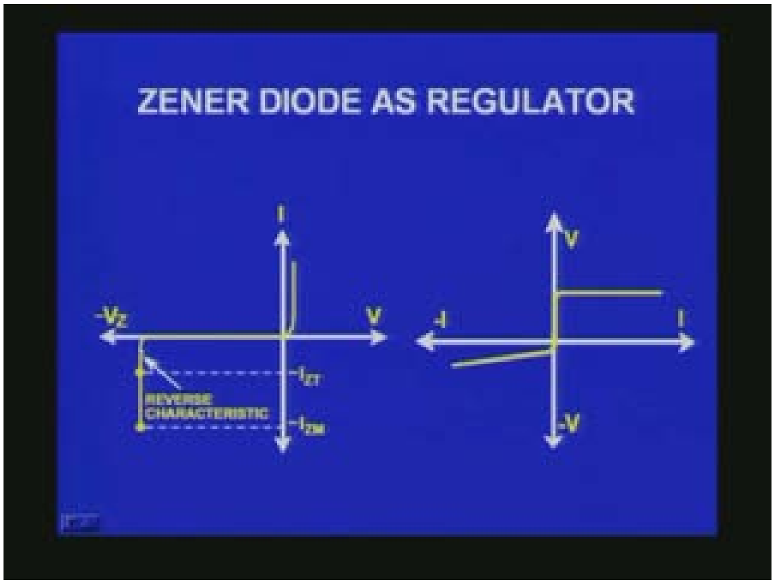

ZENER DIODE AS REGULATOR

I is the minimum; from the characteristics you can observe it. This is to ensure that any current above this will be having the zener diode in the breakdown region. Then what about the maximum current? The maximum current will be dictated by the power rating of the zener that you use. If you are using a zener diode of 600 milliwatt, 500 milliwatt, 1 watt you can buy zener diodes with different power rating. If I use for example 500 milliwatt and then I use a 5V zener then you can see the maximum the value of I_Z will be 500 milliwatt divided by 5V and you can see that it is about 100 milliamperes. What it means is you cannot have the current which is larger than 100 milliamperes passing through the zener.

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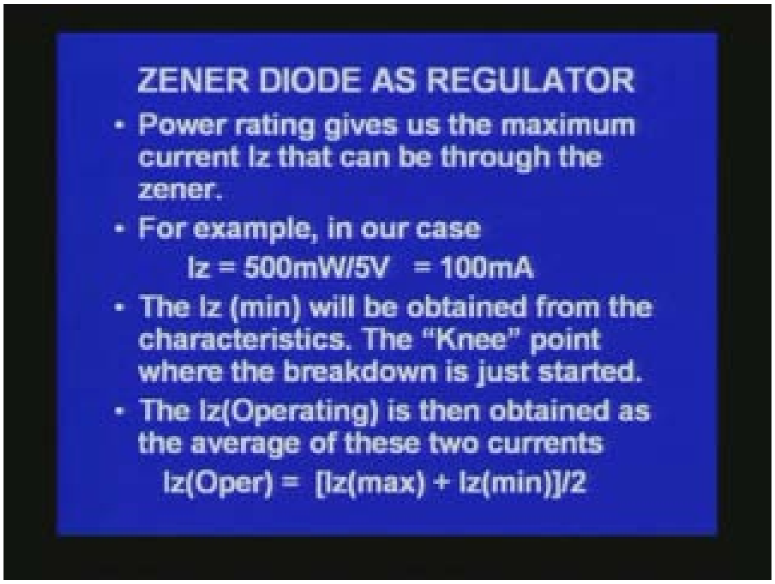

ZENER DIODE AS REGULATOR

- Power rating gives us the maximum current Iz that can be through the zener.
- For example, in our case
  Iz = 500mW/5V = 100mA
- The Iz (min) will be obtained from the characteristics. The "Knee" point where the breakdown is just started.
- The Iz(Operating) is then obtained as the average of these two currents
  Iz(Oper) = [Iz(max) + Iz(min)]/2

What would happen if I exceed this current? There will be joules heating. There will be heating of the zener and due to the temperature effect there may be an irreparable damage caused to the zener diode when I use it in a circuit which requires larger than 100 milliamperes current. The maximum current is 100 milliamperes. The minimum current is $I_{Z(min)}$ that is observed on the characteristics which is normally going to be few milliamperes 1 or 2; let me take it as let us say 1 milliamperes.

What is the operating current? The best way to operate is take the bold and mean. Operate the zener diode in a point which is equally away from this minimum current and the maximum and you find the average of the I_Z(max) and the I_Z(min). That can be chosen as your operating current. In this case you have 1 milliampere and 100 milliamperes and the average is approximately close to 100 milliamperes. Average is going to be 50 milliamperes. You can choose a resistance corresponding to 50 milliamperes. The R_S value can be calculated as 9V – 5V/50mA. That will be 4/50mA. That is the value of resistance. It will be around 80 ohms. 80 ohms will be the value of R_S if you want to operate the zener diode around 50 milliamperes. I have shown here R_S equal to 9–5/100mA which is 40 ohms. That means you should never use a R_S value which is smaller than 40 ohms if you want the zener diode to function properly. That is what we mean.

Again I have shown here I_Z(operating) will be I_Z(min) + I_Z(max) divided by two which is the average of these two values. R_S is V_Z/ I_Z(operating) from which we can calculate the value of R_S.

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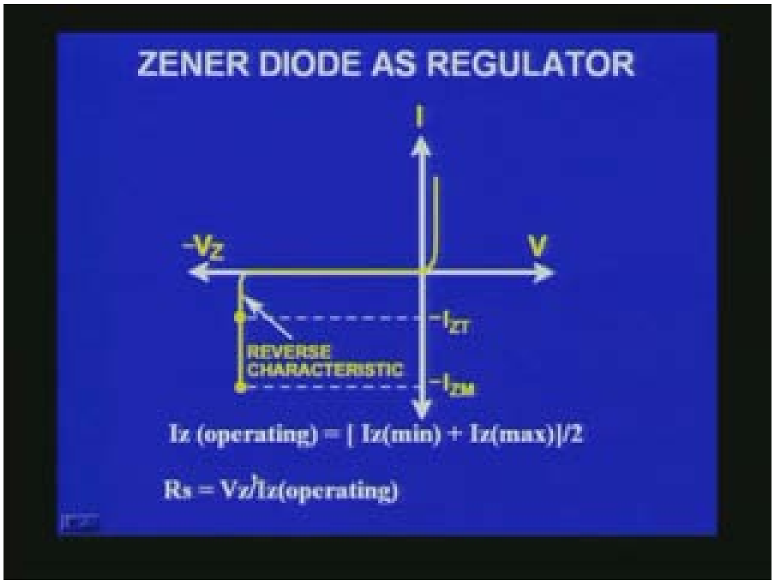

ZENER DIODE AS REGULATOR

Iz (operating) = [Iz(min) + Iz(max)]/2

Rs = Vz/Iz(operating)

All that we have do to is take the unregulated power supply which is shown here on the left side as Ei and this is your R_S which in this case is shown as R and you have your zener diode. You choose the R as mentioned just now and put your zener diode in the reverse bias condition so that it is under breakdown condition and this voltage will remain constant.

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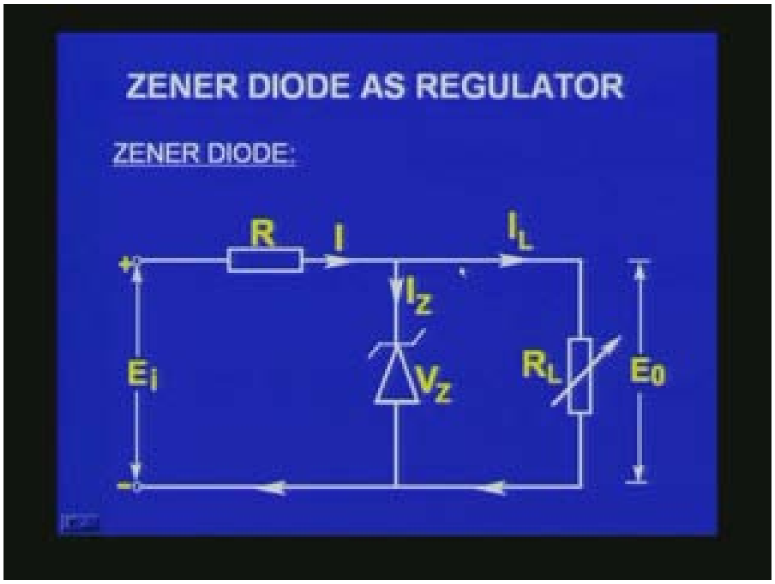

ZENER DIODE AS REGULATOR

ZENER DIODE:

Up to what value of R_L it will remain constant will have to be very carefully looked at. If I put R_L here and if I keep varying this there will always be a limit. That means there will be a minimum R_L value below which I cannot reduce R_L. Once that happens large current will flow through that and less current will flow through I_Z and the therefore zener diode may be pulled out of the breakdown and therefore this will cause the regulated voltage not to be well regulated and there is always a minimum resistance R_L which you can connect. But as far as the maximum value is concerned you can keep on increasing the value up to open circuit when the resistance becomes infinity here and then it is just the zener diode in the breakdown region, no other resistor connected and it will still be V_Z the voltage across the zener diode. This is one simple way of making a voltage regulator using the zener diode. We remember that there should always be a series resistor R_S connected to keep the zener diode operating in the breakdown region.

Let me quickly show you a simple demonstration. You can see there is a breadboard and you have a power supply; you have the multimeter; everything is in position. Let me try to do two types of experiments; one in which I am going to vary the voltage input. I take a variable voltage source as an unregulated voltage source and I want to vary this voltage and find out what happens to the output voltage. Will it remain constant? Then the second experiment would be I will keep this voltage constant and vary the value of the load and see what happens. These two are called two different characteristics of a regulated voltage supply. One is called line regulation. When I change the input voltage and see whether the output remains constant it is called line regulation and when I change the load and keep the input constant then it becomes a load regulation. The line regulation and the load regulation are two important characteristics of a good regulated power supply. That is what we will do; first as an experiment later on we will try to understand little more about these things.

First let me choose the experiment and then I will switch on the power supply. I have switched on the voltmeter. There is 8V applied at the input and this resistance is about 120 ohms in this case and the zener is about 4.9V and I have connected a load 250 ohms. At this end I have connected a current meter, multimeter in current range and I am measuring the voltage across the load using a multimeter. When I increase the voltage to 9V here you can see the output remains constant at 4.9 and the current is 34mA. How do I get 34 milliamperes? This is 4.9V and this is 250 ohms. This current is actually the series current which is flowing through the R_S and that is actually given by V_{IN}-V_Z/120 ohms. V_{IN} is 9V, V_Z is 4.9Vor 5V and the difference is about 4V/120 ohms. That is what is obtained as the current here.

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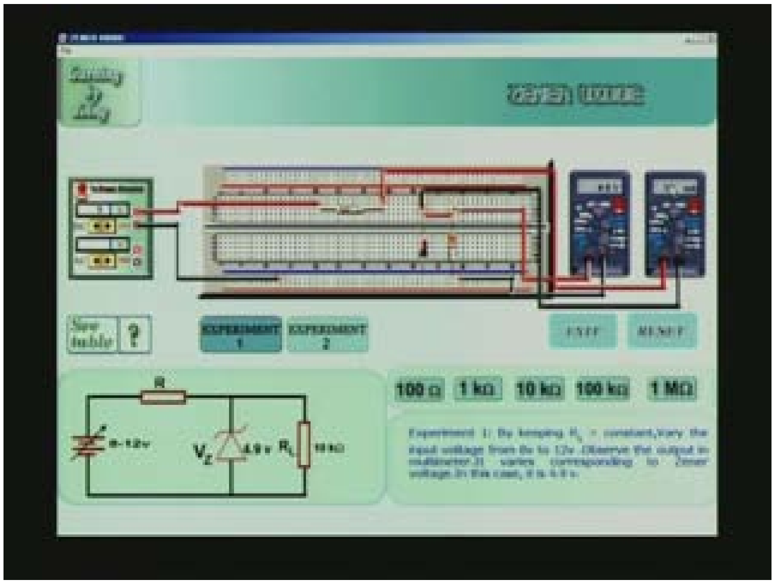

If I increase it to 10V you can see still current is increasing but the voltage remains constant. When I go to 11V also you find the output voltage remains constant at 4.9V. I vary over a range of values from 8V to 10V and you find the output voltage remains constant and the series current through R_S is changing depending up on the input voltage that I change. But zener voltage remains constant. So this can be used for regulating an unregulated power supply.

Now let me move on to the second part which is basically to change the load keeping the input voltage constant at 10V. I am going to change the load resistances to some fixed values of resistors here and find out what happens to the output voltage. Let me switch on the power supply and the multimeter; the same circuit that I used previously. I have the fixed voltage of 10V applied at the input and you have the R_S of 120 ohms and the zener diode corresponding to 4.9V. Let me first connect a 100 ohms resistor as the load. You have 4.9/100. That is what you get as the current here, 42.5mA. If instead of 100 ohms if I change it to 1K you would find it is about 42.5 milliamperes.

Now I connect 100 ohms. The current meter is actually connected in series with R_S. It is not the load current which I am measuring. Even though I change the value of the resistors the current is not changing here because it is this current which is being measured in series with the R_S. You can in principle put a current meter in series with the load also. Then the load current will keep on changing depending up on the value of the resistors that I connect here.

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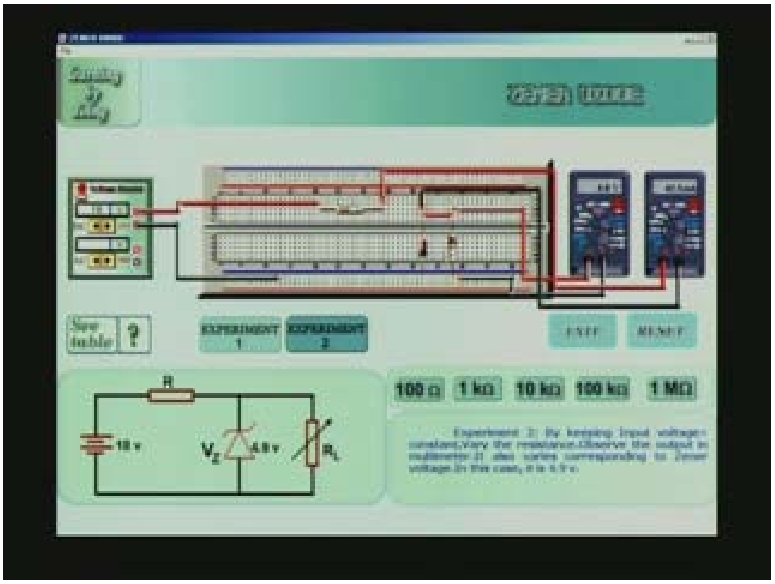

I move on to another resistor 10 K. The voltage remains constant and if put 100 K still it will be constant because as I increase the current here the load current will decrease and the total current will be divided here. Some part will move to the zener diode and the rest will flow through the load resistance. If I increase the load resistance more of the current will flow through the zener diode and less current will flow through the load resistance. You must make sure that this bifurcation of the input current through these two does not exceed the maximum value of the current that is possible through the zener diode corresponding to the power rating of the zener diode.

Let me move on to the next part. What we are now trying to do is we are calling this as a shunt regulator. You are using the zener diode as a shunt in front of the unregulated power supply and as I already mentioned to you there are two parameters which are very important with reference to performance of a regulator. One is called the line regulation the other is called load regulation. What are they? The line regulation is defined as the change in the output voltage delta V not corresponding to a 1V change in the voltage, V_S. Delta V not by delta V_S is called the line regulation and it is usually expressed in millivolts per volt and the load regulation is defined as a change in the V not, the output voltage corresponding to 1mA change in the load.

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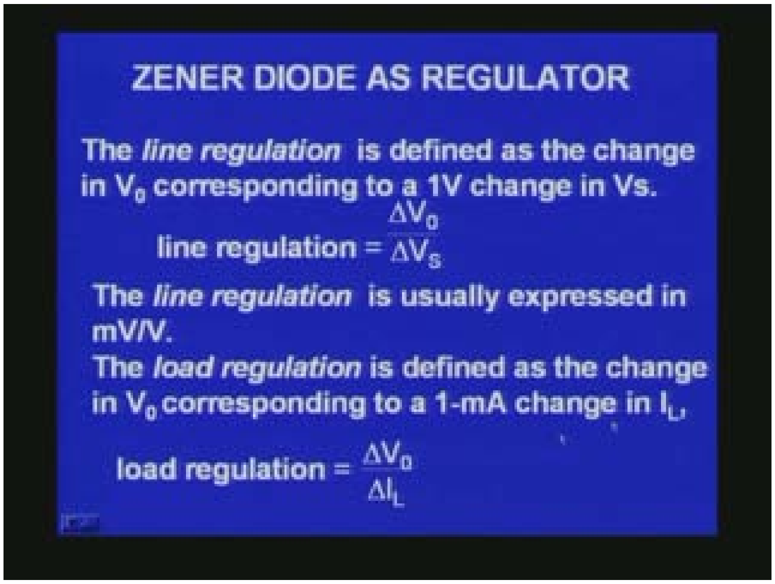

ZENER DIODE AS REGULATOR

The *line regulation* is defined as the change in V_0 corresponding to a 1V change in Vs.

$$\text{line regulation} = \frac{\Delta V_0}{\Delta V_S}$$

The *line regulation* is usually expressed in mV/V.

The *load regulation* is defined as the change in V_0 corresponding to a 1-mA change in I_L,

$$\text{load regulation} = \frac{\Delta V_0}{\Delta I_L}$$

It is delta V not by delta I_L, the change in output voltage corresponding to a change in the load current corresponding to 1mA.

Let me quickly take an example of a zener diode which has got a fixed voltage drop of 18V. This zener diode which is shown in the figure has got a breakdown voltage of 18V across it.

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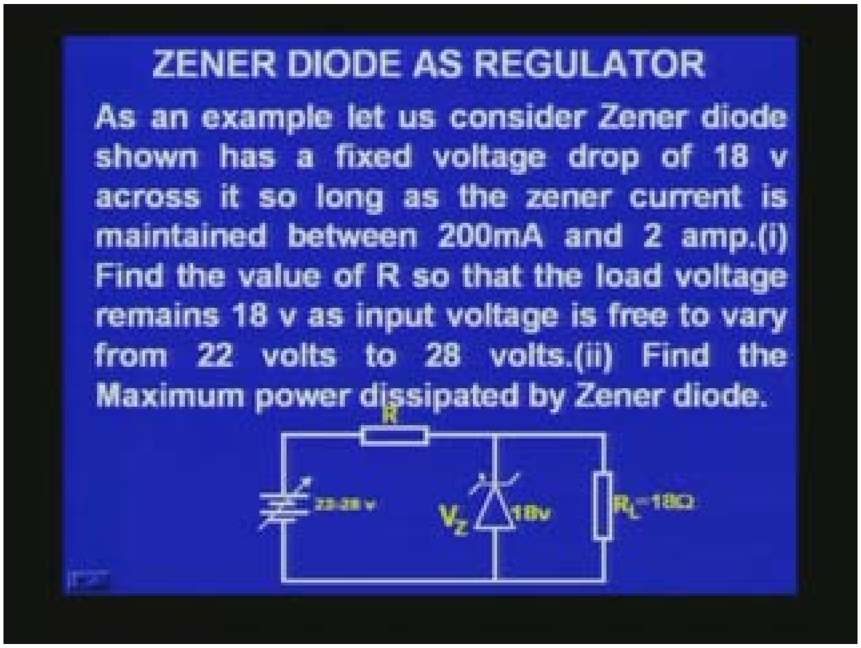

ZENER DIODE AS REGULATOR

As an example let us consider Zener diode shown has a fixed voltage drop of 18 v across it so long as the zener current is maintained between 200mA and 2 amp.(i) Find the value of R so that the load voltage remains 18 v as input voltage is free to vary from 22 volts to 28 volts.(ii) Find the Maximum power dissipated by Zener diode.

So long as the zener current is maintained between 200mA and 2A then what will be the value of R? Find the value of R so that the load voltage remains 18V as the input voltage is free to vary from 22V to 28V and find also the maximum power dissipated by zener diode. This is a very simple problem.

You have a power supply whose voltage can be varied from 22V to 28V and the zener diode has got a breakdown voltage of 18V and your load is around 18 ohms and the input voltage vary from 22V to 28V as I already mentioned to you. The minimum voltage across the R will be corresponding the minimum input voltage which is 22-18 the voltage across the zener. That is equal to 4V and the current through R when the maximum current flows through R_L is I_L(max), maximum load current plus the minimum zener diode current. The current flowing through the zener will be minimum the current flowing thought the load will be the maximum. That means it is 18V/18 ohms corresponding to the maximum load current plus they have already mentioned that the current I_Z can go from 200mA to 2 A. This is about 200mA.

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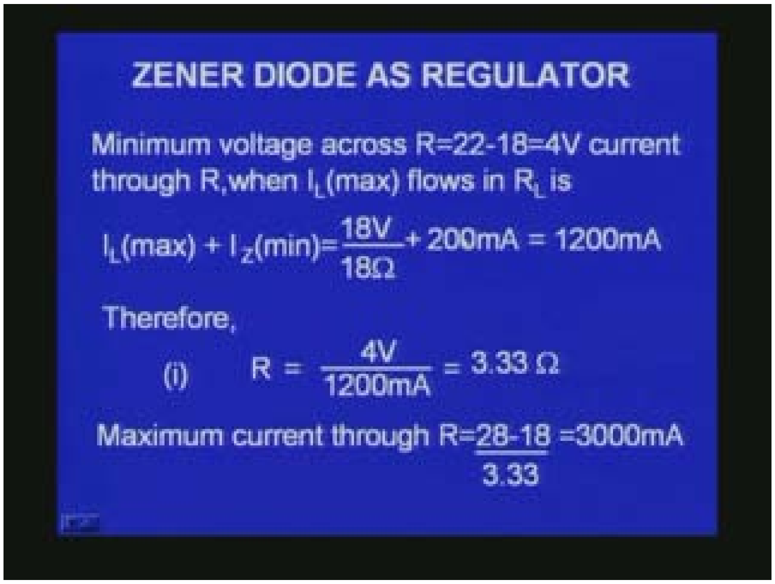

ZENER DIODE AS REGULATOR

Minimum voltage across R=22-18=4V current through R,when I_L(max) flows in R_L is

$$I_L(\text{max}) + I_Z(\text{min}) = \frac{18V}{18\Omega} + 200mA = 1200mA$$

Therefore,

(i) $$R = \frac{4V}{1200mA} = 3.33\ \Omega$$

$$\text{Maximum current through } R = \frac{28-18}{3.33} = 3000mA$$

The total current will be 1200mA, 1.2A. What will be the value of R for providing this type of a variation? R will be equal to 4V divided by the total current which is equal to around 3.3 ohms and the maximum current through R is 28 because the voltage can go up to a maximum of 28 from 22; 28-18/3.3 gives me the maximum current that can flow through a series resistor R and that in this case is 3Aor 3000mA. But the I_Z(max) is actually 3000-1000 mA which is equal to 2000 mA which is within the limit of I_Z specified in the problem. They said I_Z can vary from 200mA to 2 A and 2000mA is only 2A and even when the load resistance maximum is around 3 A there is no harm done because it will still be within the limits specified and this value of R is good enough.

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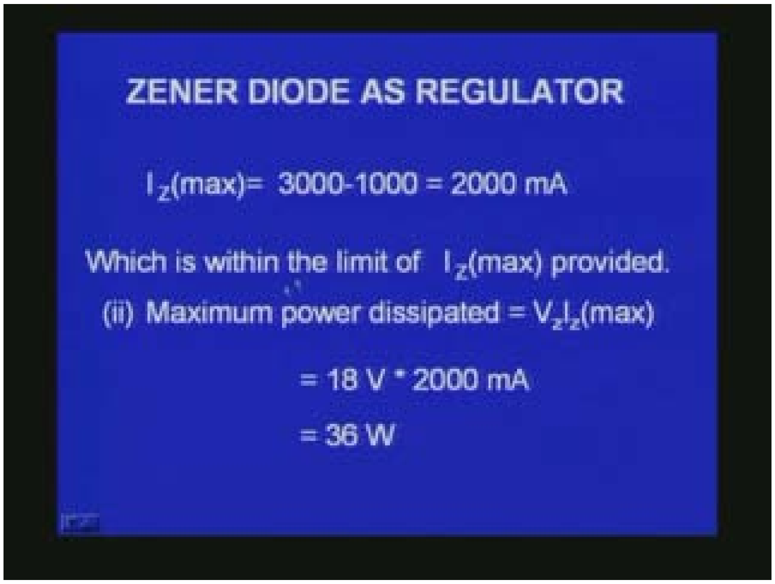

ZENER DIODE AS REGULATOR

$I_Z(max) = 3000-1000 = 2000$ mA

Which is within the limit of $I_Z(max)$ provided.

(ii) Maximum power dissipated = $V_Z I_Z(max)$

$= 18$ V * 2000 mA

$= 36$ W

What is the maximum dissipated power across the zener diode? That is given by voltage into current V_Z into I_Z maximum and that is 18V is the V_Z value; 2000 mA to 2A is the maximum current to the zener. So that corresponds to 36 watts. So you have to use a 36 watt zener diode and this type of a design can be achieved.

Let me quickly move on to the table and show you a simple zener regulator and we actually use a 4.9V zener and we have used the regulated power supply as an unregulated power supply because I can vary the input voltage and see how the output voltage remains constant. So you can see the circuit here is also shown for simple understanding. There is the voltge source here V_S and there is this R_S. I have connected in series current meter, milliammeter and this is your zener which has got a break down voltage of 4.9V. Then I also want to measure the load current. I introduce one more current meter in series with the load R_L and what I measure across the R_L is the output voltages V not.

I have a series resistor which is around I think 100 ohms here and I have a zener diode. I hope you can see the zener diode here. This is the zener diode which has got 4.9V break down voltage and this is the load.

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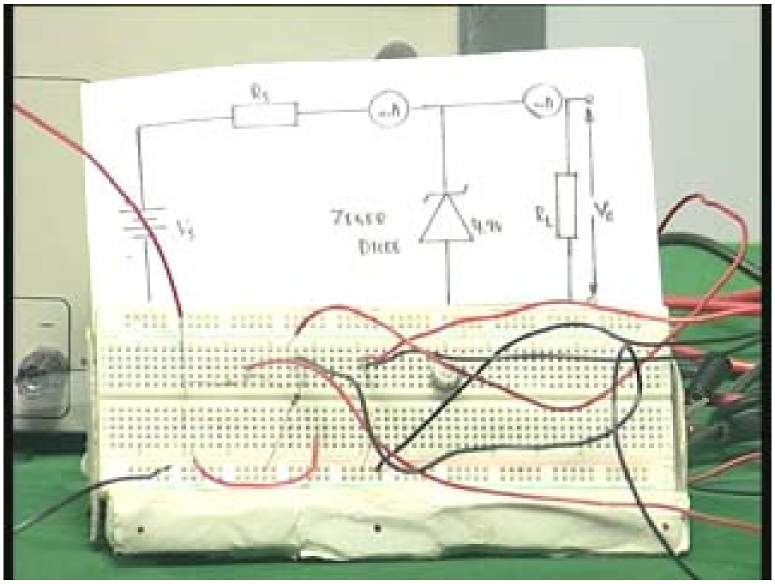

I have connected the input from a regulated power supply, the plus and minus terminals and I have connected one current meter which is actually this. This is the current meter corresponding to the series resistor R_S. This is the current meter. I have switched on the two multimeters. I have kept this in current mode and I have kept it in DC current. Here I selected DC current. Similarly I have put it in voltage mode and kept it in DC volts. Now everything is ready. You can see this current meter is this and this is the zener diode and this current meter is here and this voltmeter is here. You try to observe. I am going to switch on the power supply. I have kept around 8V. You can see the current is around 8V. The voltage is around 4.8. The load current is around 15mA.

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If I decrease it little bit you can see the series current also decreases. If I come below 4.6, this voltage is also decreasing the voltage across the load. If I bring it above 6 or 7V it is around 4.7. If I go still further for example 8.3 it is still around 4.8V. If I go to 10V still it is around 4.9V.

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Irrespective of the change in the input voltage the output voltage is not changing. It is remaining constant very close to about 4.9. But the current is around 15.54 across the load and this current has actually increased enormously. If I change the input voltage the current is changing but this voltage across the zener remains a constant 4.9. This current will also remain constant because that is dictated by only the load resistors that I have connected. So five point nine divided by this is around three point three, 330 ohms; it is around 15mA.

I take out the resistance; I will keep it constant at this point; I remove the load resistor. The current becomes zero here. The current is zero because I have removed the load resistors. In place of that let me connect a larger value of resistor for example when I connect the 1Kohm resistors correspondingly the current has decreased to about 5mA but the voltage remains constant at 4.98.

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The input current is nearly more than 25mA. The rest of the 20mA will be flowing through the zener diode. Only 5mA flows through the load. The rest of the current is flowing through the zener diode.

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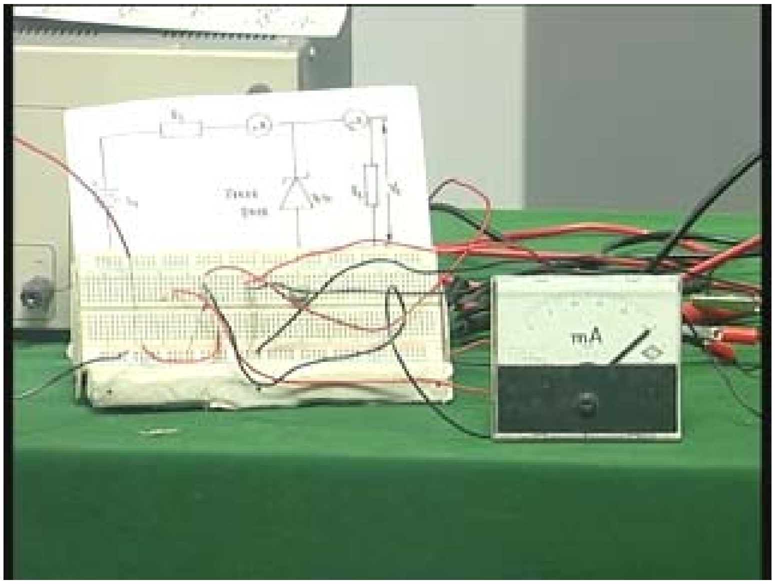

Similarly I can still increase the load resistor by removing the 1K resistors. Let me connect a 10K resistor. The current has become 0.5mA, 500microamperes and the voltage is 5.06 very close to 5.49. This voltage is still remaining constant but this current has decreased to load current and this input series current is high all the time. The zener diode can be used to regulate the unregulated power supply and we can now calculate by changing here by a known value the change in the output voltage. That will tell us output voltage about line regulation. Similarly I can vary the current here by changing the resistance and find out how much the voltage is changing for a 1mA change in the current. If I calculate, that will correspond to the load regulation using the zener regulator.

We do have a good regulated power supply when we use the zener diode as a regulating device. But unfortunately if I want larger current say 1A or 10A as the case may be I must use a zener diode which has got a large power rating. As I want larger and larger current for my load I have to go in for a zener diode which is having much higher power rating and the zener diode with higher power ratings are all, as we can expect, will be more expensive. They are very expensive compared to the zener diode of 500 millivolts or300 millivolts as the case may be. Is there a way to improve the current output from a zener regulator? The answer is yes we can do that by using an additional transistor.

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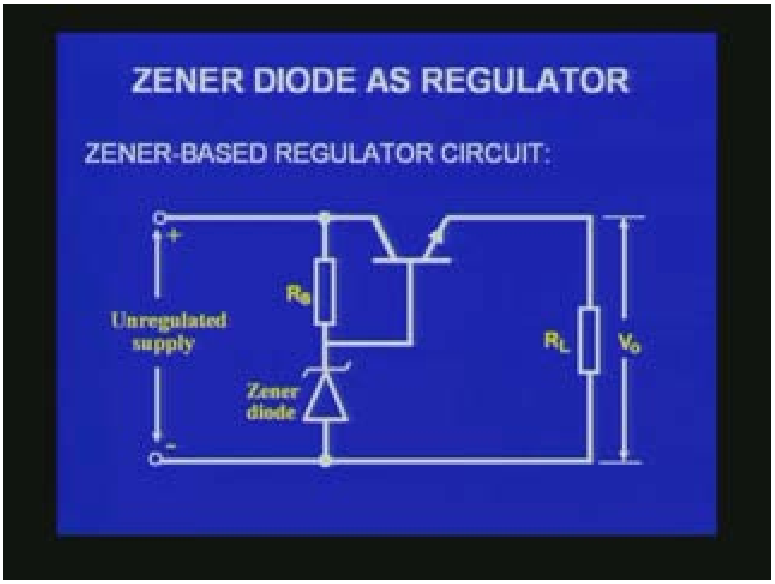

ZENER DIODE AS REGULATOR

ZENER-BASED REGULATOR CIRCUIT:

I have not discussed yet about transistors but still it is very easy to understand here as a simple application and the details of the device will be discussed in a later lecture. Now I will just mention to you as the extension of regulation principle how a transistor can be used to boost the current at the load having even a zener diode which has got a lower power rating. That means even though I use a normal zener diode which has got about 500 millivolts power rating I can still have much larger current than what I would normally calculate as my I_Z(max) because now I use a transistor. Basically you can understand for the present the transistor as a simple current amplifying device. If I have the base current I_b here I will get a collector or emitter current which will be several times larger than the base current. That is the basic feature of a transistor.

This current amplification is called beta or hfe which we will discuss later. This multiplication factor which is coming between the base current and the emitter or the collector current of a transistor is exploited in this case to design a regulated power supply which will give me a much higher current rating than what I would otherwise get from a normal zener diode. The configuration is as shown in the figure. You can see I do have the R_S still, the series resistor and you have the zener diode and the junction of these two are connected to the base of the transistor and the collector is connected to the unregulated power supply and the emitter is connected to the load. This configuration even though it looks slightly complicated you can see I have drawn it in a different way here side by side. This is the old circuit and this is a new circuit which I have drawn for simplicity because some of you may be able to identify this as a very simple configuration of an emitter follower.

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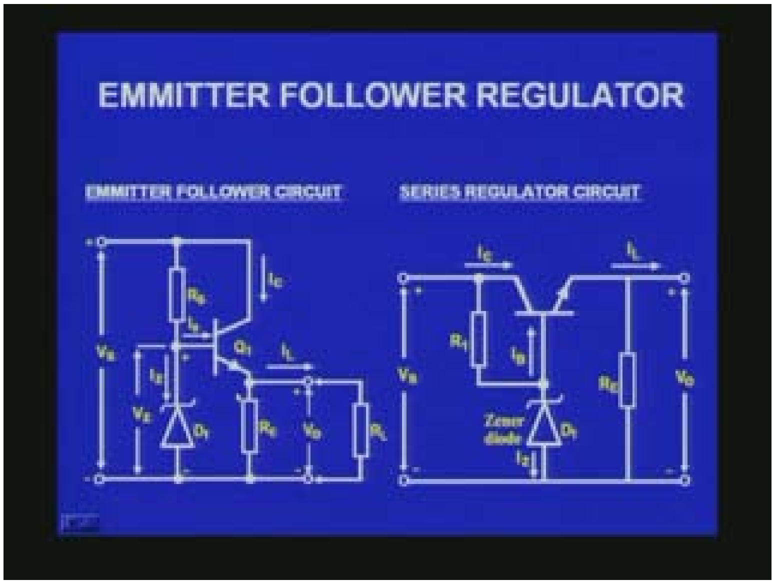

EMMITTER FOLLOWER REGULATOR

EMMITTER FOLLOWER CIRCUIT

SERIES REGULATOR CIRCUIT

We will discuss about this little later. This characteristic of emitter follower is that it will make the output impedance very, very small. Regulation means reducing an internal source resistance of an unregulated power supply to a very minimum value and emitter follower has got low output impedance. An emitter follower output can become a part of regulated voltage supply. That is the principle behind this here. Even if there is a very small current I_B here I will have nearly 100 times or 200 times depending upon the current gain of the transistor the value of load current can be about 100 to 200 times larger value and this simple transistor which is called the bass transistor here can be used to boost the current capability of a zener based regulator circuit. That is what I want to mention here.

In a more complicated circuit you can in principle use an amplifier which will amplify the input signal to a larger value and this amplifier is actually a different amplifier here. That means it amplifies the difference in voltage at the input and the difference in voltage as you can see is here between the voltage across the zener diode is connected to one part of the amplifier the other part is connected to a point which is provided by the potential divider. R_1 and R_2 at the output are provided as a potential divider and this point is connected to the other end of the amplifier. We look at the difference in voltage between V_Z and a point which is proportional to V_{out}. This voltage will be V_{out} multiplied by R_2

divided by R_1 plus R_2. That is the potential divider that we already discussed in the earlier lecture.

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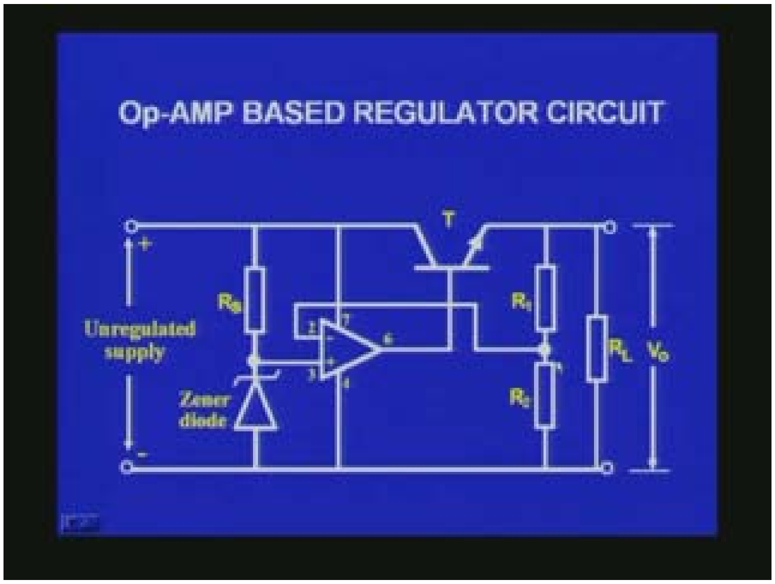

OP-AMP BASED REGULATOR CIRCUIT

This voltage is going to be proportional to the V_{out}. If the V_{out} changes this voltage can change and if this changes this is not going to change because it is a zener diode in the break down region this voltage will remain constant. Only this voltage will change. If it changes there will be a corresponding amplified voltage here which will make this transistor which is used here in this application as a variable resistor. This variable resistor will vary in the value of resistance and thereby keep the voltage across the load constant. That means it is regulating the output voltage by using the bass transistor T, the transistor that we have here by using an error amplifier here as a regulator. This is a slightly more involved circuit but this is very useful for regulating an unregulated power supply.

Now-a-days standard regulated power supply can be obtained very quickly by using what we know as three terminal I_C regulators. Before I go into that I want to just mention to you that you would always have a situation where the value of the load will be reduced to such a low value that you will be drawing a very large current which may some times damage. For example if I inadvertently connect the wire between the output terminals it corresponds to short circuiting the power supply. When you short circuit the power supply that means you are almost connecting zero resistance across the terminal. This will correspond to a very large current flowing through the regulator. This might spoil the devices inside. If you want to avoid that means if you want to protect the power supply or the regulator against short circuit any inadvertent short circuits then you have to design a current limiting circuit. The idea behind current limiting circuit is to use a resistor here R_{10} between the base and emitter of a special transistor, additional transistor. This is different from the earlier transistor I used. This transistor has got the resistors R_{10} between the base and emitter and it come in series with the load current.

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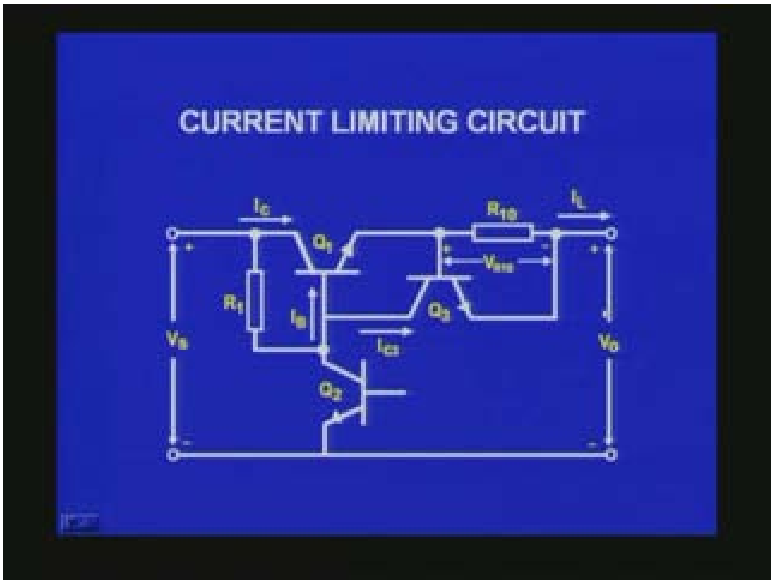

CURRENT LIMITING CIRCUIT

When I increase the load current there will be a voltage drop across that. As long as this voltage drop is less than the voltage required to forward bias this transistor nothing will happen, the load current will flow. But when I draw a large load current which makes voltage drop across R_{10} nearly 0.7 or little more than that then this will make the base of this transistor larger in voltage than the emitter by this voltage across R_{10}. If it is 0.7 for example in the case of silicon this Q_3 will be switched on. When it is switched on the current will start flowing through this to avoid Q_1 transistor and the output will be almost reduced to zero. You will be drawing a maximum load current through the transistor but the output voltge will become zero.

When I short circuit the current beyond the load current that I set I can make a device to close. The output will become almost zero and therefore no damage will be done because the current will be bypassed to another path and no damage will be done to the device that is being used in the regulator. How do I choose the R_{10}? I can easily choose R_{10} by knowing the maximum current I want to limit. For example if I want 1A current I will have to have 0.7V here to make this transistor on for forward biasing the transistor in the case of the silicon transistor. 0.7V divided by I which is 1A is around 0.7 ohms. If I connect 0.7 ohms in place of R_{10} I will have maximum current of 1A and if I try to exceed the current beyond 1A, the output will be almost close to zero. That way we can calculate the short circuit current which I want to limit, the value of the current.

I have shown the characteristics here corresponding to that. This is voltage output verses load current and when the load current increases initially because it is a regulated supply the voltage remains constant for a large value and then when I increase the $I_L$max, which is the maximum rated current, immediately the output voltage drops to zero and the short circuit current will be slightly larger value than the $I_L$max that we have seen.

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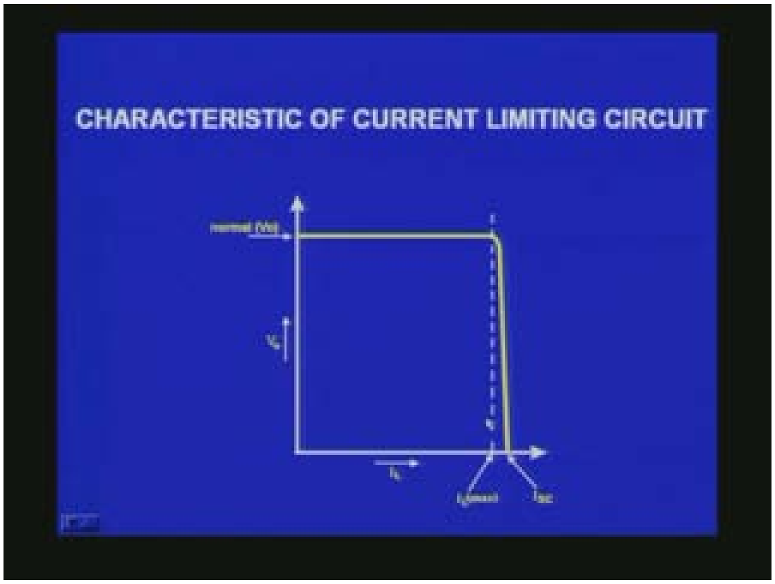

CHARACTERISTIC OF CURRENT LIMITING CIRCUIT

This is one type of current limiting that is being employed. There are several other types of current limiting circuits that can be used but a good voltage regulator should be having a constant voltage and it also in principle be protected against any short circuit and I wanted to highlight these two aspects of a very good regulated voltage supply. I have shown here how we can use a three terminal integrated circuit regulator which is now very popular and you can make quickly in the lab a regulated power supply.

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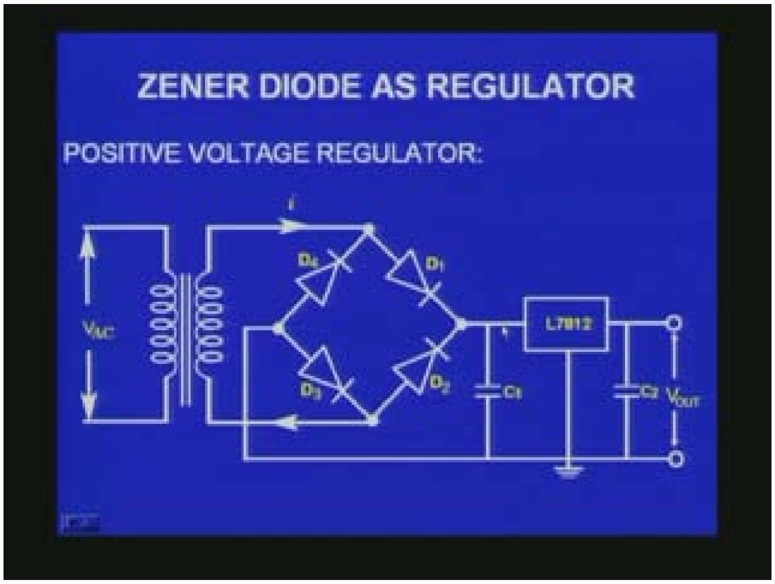

ZENER DIODE AS REGULATOR

POSITIVE VOLTAGE REGULATOR:

We have already seen how you can make an unregulated power supply of any value. For example you want to use a bridge rectifier here. We use the step down transformer which will give the output voltage which is around 20V or 12V as the case may be. Then I can use a bridge rectifier in the following mode which we have already discussed and output I have put a capacitor here which is about 1000 microfarad to filter out all the ripple voltages and then I can connect a three terminal regulator which has got three terminals as it is mentioned. You have an input, you have a ground and you have an output. What is the circuit that we have here? It actually contains the different circuits that I just now mentioned. You have an internal zener regulated power supply with a zener regulator and a bass transistor and a current limiting device all built in integrated circuit form and if I give the input here and if I take the output here the output will be a constant value. The value of the constant is given by the last two digits of this IC number. 7812 for example means it is a 12V positive regulator. The output voltage will be positive and it is around 12V. It is very easy for us to build a regulated voltage source by using a very simple transformer, bridge rectifier, filter capacitor and a three terminal IC regulator. One can also make a negative power supply. Before I go to that may be I will show you the actual circuit of a positive voltage regulator.

This is the positive voltage regulator in …… 221 package. That is the outline, transistor outline package that you have here. This is an IC regulator as I mentioned to you. It is not a transistor IC. It has got three leads. One is the input; the other is a ground and the third one is the output.

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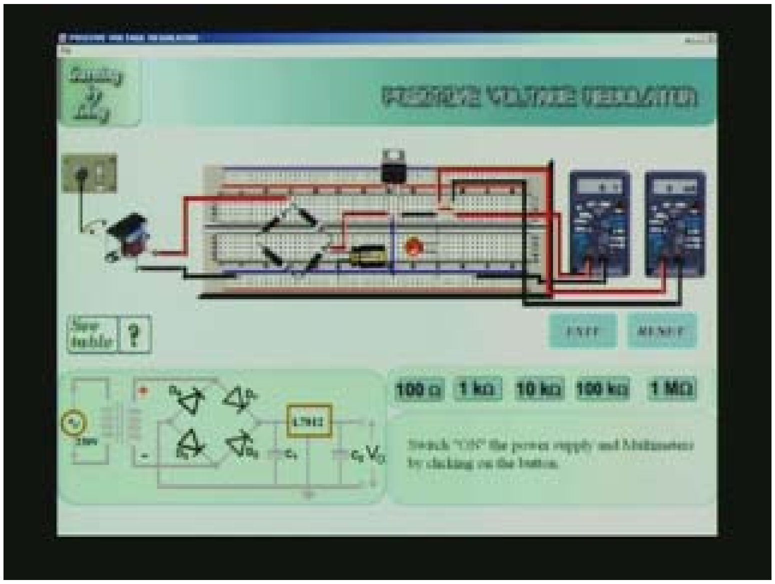

Switch "ON" the power supply and Multimeters by clicking on the button.

I connect it to the breadboard here and I have a diode rectifier, bridge rectifier here and I have the transformer here. I switch on the power supply and I switch on the voltage and the current meters. The output voltage is 12V and because I have not connected any load the current is zero. If I now connect a 100 ohms resistor you will find it is around 120mA. Because this is 100 ohms, 12V is the output, I get 120 milliampere. I can change the different load resistors and correspondingly the load current also changes. This actually measures the output voltage across the load and the load remains constant 12V for different value of resistors that I have and as I already mentioned to you this IC regulator is also short circuit protected.

We can also design a regulated power supply with negative output voltage. You require both types of power supplies. Here again you have a transformer and a bridge rectifier but in this case you use IC regulator which is a negative regulator and it is 7912. 7812 is a 12V regulator, 7912 is a negative voltage regulator and you should remember this negative end is connected to the IC and the positive end is connected to the ground.

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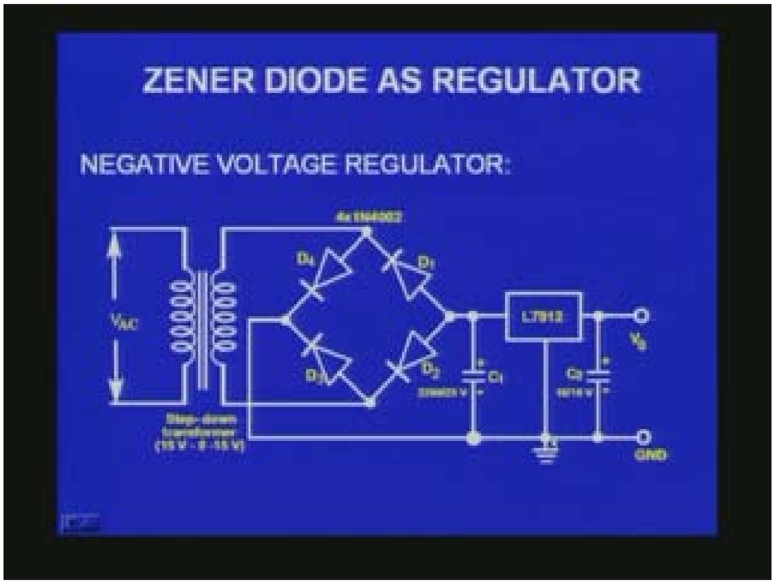

ZENER DIODE AS REGULATOR

NEGATIVE VOLTAGE REGULATOR:

This becomes a negative regulator and rest of the circuit details are similar to the one which we have already seen and this provides a negative voltage regulator. If I combine these two I can have what is known as a dual power supply. You can have both positive and negative outputs with reference to a common ground or zero and this will be very useful when we go into operational amplifiers; some of them require dual power supply. That means you require both positive and negative output with reference to zero.

Let me quickly show you the circuit of a negative IC regulator. Again you can see there is a bridge rectifier. This is the transformer output connected to the bridge rectifier and a filter 1000 microfarad capacitor is connected here and you have this regulator. It is similar to the positive regulator except that it is 7912 corresponding to the negative voltage and rest of the voltmeter are there and if I switch on the power supply and the multimeter the output is -12V and if I apply different current you can get correspondingly different load currents corresponding to the different loads.

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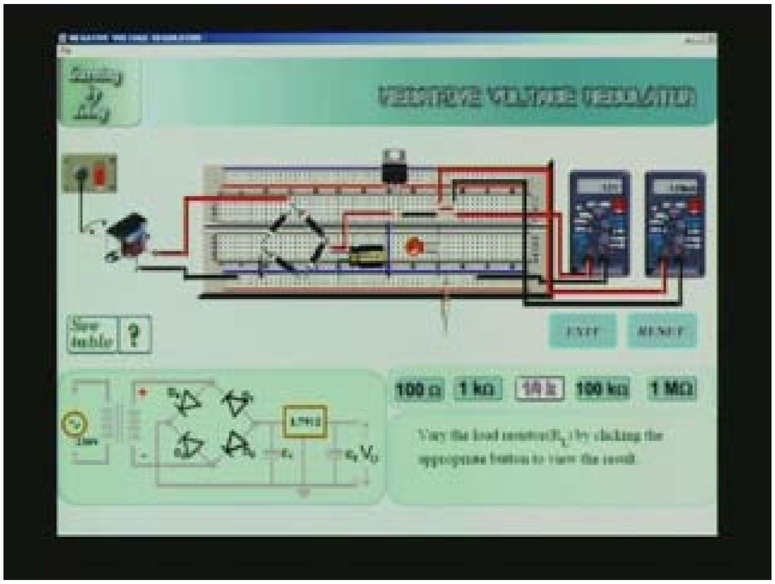

In principle one can quickly build a positive voltage regulator or a negative voltage regulator as the case may be corresponding to the one that he wants to use in the lab by using this type of a simple arrangement. That is what I wanted to give you. Let me quickly show how we can also go for dual power supply, a split power supply regulator. Here again you have the same transformer but a center tab transformer and the center tab is maintained as the common terminal zero and you have both 7812 and 7912 connected as shown in the picture.

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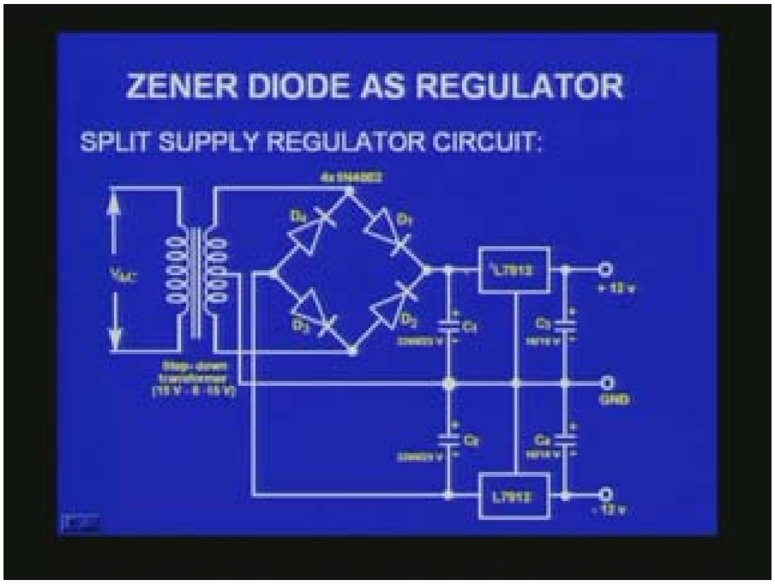
ZENER DIODE AS REGULATOR

SPLIT SUPPLY REGULATOR CIRCUIT:

The positive is connected to 7812, the negative end is connected 7912 and the capacitors will have to be carefully connected in the circuit at proper polarity and then you will get three outputs 0, +12 and -12V. All can be obtained by a very simple configuration as shown in the picture. I would perhaps show you the actual working of this positive regulator or any one of the regulators in the next lecture before I go on to the next topic which is about transistors and their characteristics. Thank you!