Basic Electronics
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Module -5
Power Circuits and System
Lecture - 5
Regulated Power Supply

Today we will discuss about regulated power supplies which are required for maintaining a constant output voltage at the load side. In the earlier class when we were discussing about the rectifier circuits using diodes we have seen the application of the rectifier in the power supply, because when you have an AC voltage at the input the rectifiers are used to convert the AC into DC voltage. By use of filter circuits, using capacitor filter, we have seen that the ripple present in the output voltage after rectification was reduced. That output voltage from the smoothing circuit or the filter circuit after rectification is supposed to be a constant DC voltage which is fed to the load. But there are various reasons because of which the output voltage or the voltage at the load side does not remain constant. There is the need for a circuit which can regulate the output voltage at a constant value.

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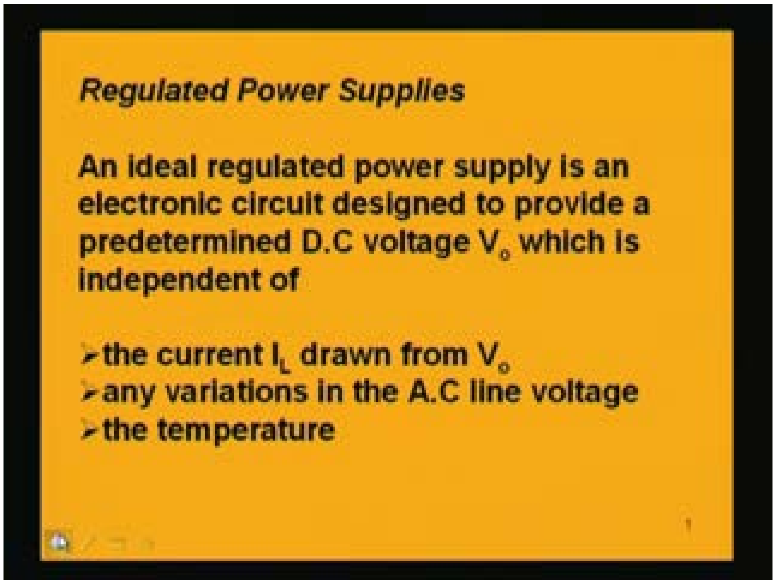

This type of circuit which is used in regulated power supplies is an electronic circuit that is designed to provide a predetermined DC voltage. This DC voltage is independent of the current drawn by the load from the DC voltage and it is also independent of any variations in the AC line voltage and also in any change in temperature. How the output voltage is affected by any change in the AC line voltage as well on the current drawn? How is it dependent as well on temperature change? We have seen in our domestic power supplies that we use in our houses that the line voltage does not remain constant; there is fluctuation in the AC line voltage which is supplied to us. Although it is supposed to be 230 volt, it is never supplied at that voltage and it so happens very frequently that there is fluctuation in the AC line voltage. Because the line voltage have these fluctuations, the effect will be that the output voltage that we are using for our devices in our houses also will have a variations in the voltage supplied to them. That is not desired because these fluctuations in the voltage being given to the household gadgets may damage them. So, it is required that we get a constant DC voltage even though the input AC line voltage varies.

Second factor which affects the output voltage at the load side is the load current. If we have variation in the load current drawn from the supply voltage, then that also changes the output voltage. Another factor is the temperature. Because of the temperature variations the regulator circuit which generally uses electronic components like transistors are affected. The change in temperature affects the operation of the electronic components in the regulated circuit and because of that also the output voltage does not remain constant. We have to now find out how we can maintain a constant voltage at the output and for that the regulated power supplies are used, where there is a regulator circuit which can maintain a constant voltage at the output even any of these factors, which I described just now is there. Even in the presence of any of these or all of these the output voltage is maintained at a constant value by this regulator circuit.

Today we will discuss about some of these regulator circuits and we will see how the regulation of the output voltage at constant value is maintained.

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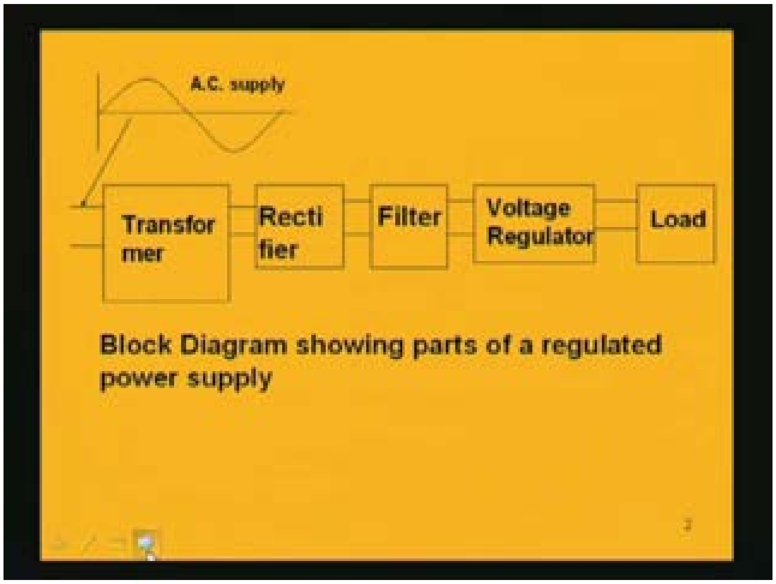

Again we go back to the block diagram representation of a regulated power supply that once we just touched upon while discussing the rectifier circuit using diodes. If we look into the block diagram representation of a regulated power supply having different components in between or in different stages we will have different devices like shown here. What is done is that we are having an AC supply voltage which is supplied by the electricity authority; that is given to us in the AC form and it is a high voltage. So, we have to first of all step it down to a level which can be handled by the rectifier that is done by using a transformer. The step down transformer which is used to step down the AC input voltage to a voltage which can be handled by the rectifier that is done here by this block which is a transformer.

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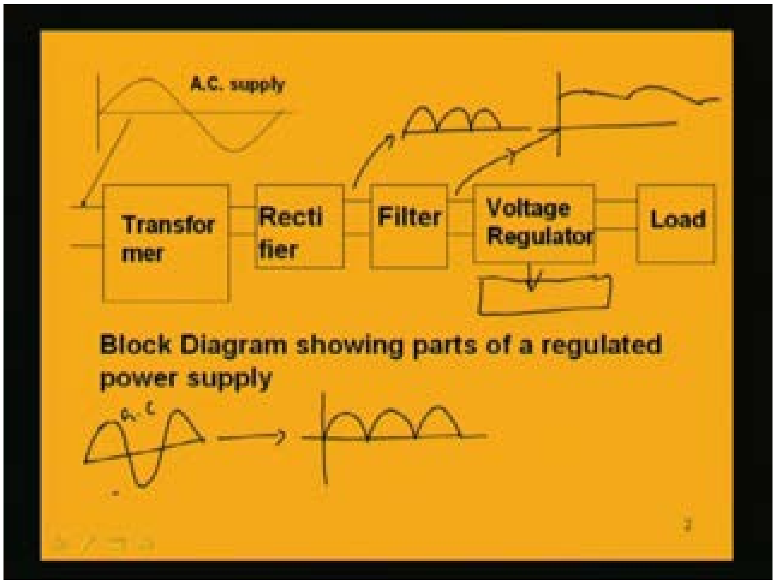

First of all the input voltage, which is an AC voltage this is the AC input; so this voltage is having a high peak value. Using this transformer we will first step down this voltage and this reduced voltage is fed as input to the rectifier. The rectifier which we discussed earlier like half wave rectifier, full wave rectifiers these are used for rectifying the AC input to convert it to DC. If I use a full wave rectifier after the transformer steps down this input voltage to its bearable level, it will be rectified. If I use a full wave rectifier I will get this type of output voltage which is rectified in both the halves.

After this rectifier here we will get this type of pulsating DC voltage. This is called pulsating DC because it is not purely DC. But we have to get a DC which is constant voltage from this pulsating DC. What is done here is, as we have earlier discussed we use a filter circuit having a resistor capacitor. We use a filter circuit and from this filter circuit we get the output as a voltage which is having this type of form. That means it is having ripples no doubt but it is in a better form than this pulsating DC. From the filter output we are getting this ripple. We get an output voltage with a ripple. Depending upon the design of the filter circuit we can reduce the ripple part. This can be assumed to be a DC voltage or more or less it can be said that we are getting a DC.

But this DC after we get from the filter circuit, it will be not constant against variation in the supply voltage at the input or the current drawn by the load because we are giving this output voltage from the filter circuit that is a DC voltage to our load which we want to drive with this voltage. If the load varies that means if we have the variation in the load current due to the variation in the resistances etc., in the output device because of this difference or because of this change in the load current this output voltage will be also varying.

We have to maintain this output voltage because this load does not want the voltage to be fluctuating. Here is the need for a circuit which is a regulator circuit; a voltage regulator circuit is used after this filter. This block diagram shows the different stages of a power supply which is regulated one. So, in today's class we will discuss about this voltage regulator. What is a voltage regulator circuit and what are the different types of voltage regulator circuits we are going to discuss.

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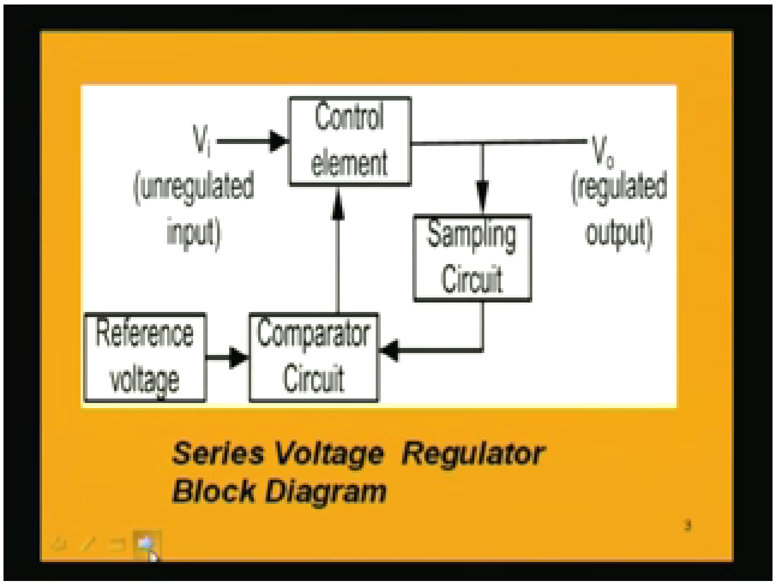

Before going into the discussion of the different circuit components in the regulator circuit, let us in general take the block diagram form of representation of a voltage regulator circuit. There are two classes of voltage regulator circuit. One is series voltage regulator circuit and the other is shunt voltage regulator circuit. The series voltage regulator circuit block diagram we are showing here where we are giving the input voltage V_i. There is a control element and the output from the control element is the voltage which is the regulated voltage.

There is a circuit which feed back these regulated output. That is we are feeding the output voltage through a sampling circuit to a comparator. This circuit is basically made of different resistances and this sampling circuit feeds back a portion of the output voltage into a comparator. Comparator means it compares two voltages. The voltage which is coming from the output through this feedback circuit, which is a sampling circuit, is compared with a reference voltage. So, there is a reference voltage being given. Here in the comparator circuit, the output voltage is compared with the reference voltage and then it drives this control element. The output from this comparator circuit drives this control element and this control element controls the output voltage to maintain it at a constant level. What is there inside each block? It depends on the various types of series regulator circuits. We will discuss a very simple series regulator circuit. Here we are having a series voltage regulator. It is having a transistor as the control element.

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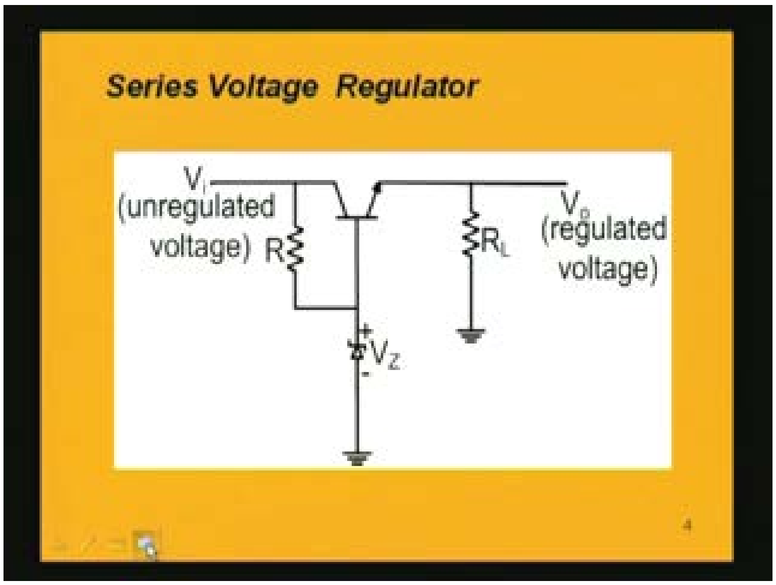

The transistor we are showing here is an npn transistor. This is the control element which controls the output voltage to keep it at a constant level. There is a Zener diode also having a Zener voltage V_Z and the reference as is shown in the block diagram, previously; this reference voltage (Refer Slide Time: 15:16) is provided by this Zener diode. What is happening in this circuit is that we are having an unregulated voltage at the input V_i; it may vary. The unregulated voltage means that the supply voltage which is the AC voltage, it can vary and we want to make the output voltage stay at a constant level. Even though this input is unregulated we want the output voltage to be regulated one.

That is done by this circuit. In what manner it does this - let us go to analyze that. The voltage which is at the output is obtained against this load resistance R_L and this transistor is the controlling element and we have a reference voltage given by this Zener voltage of this Zener diode. What will be this output voltage? That can be written as V_o equal to if we look into this circuit you will start from this ground.

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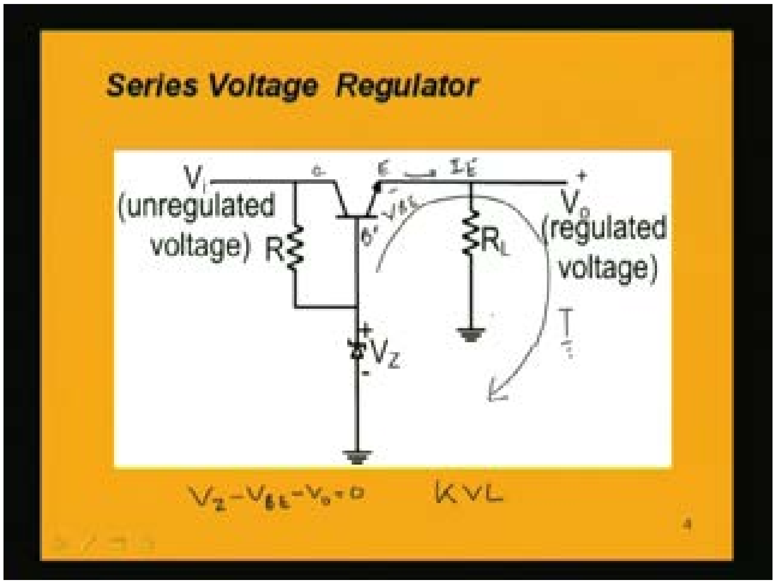

Actually V_o is plus minus is ground. So, this will be a loop. Applying KVL, we apply Kirchhoff’s voltage law to this loop; starting from this ground and ending again at this ground, this will complete one loop. We will get then V_Z minus to plus because a Zener diode is reverse biased. So, this p should be connected to negative and n should be connected to positive. We are having this Zener voltage which is V_Z. Then this point is base, this point is emitter and this point is collector. So, we get minus V_{BE} voltage between base and emitter; that is this voltage between base and emitter. So, V_Z minus V_{BE} equal to V_o. In the output circuit, we are getting this Kirchhoff's voltage law that V_Z minus V_{BE} minus V_o equal to zero or V_Z minus V_{BE} equal to V_o.

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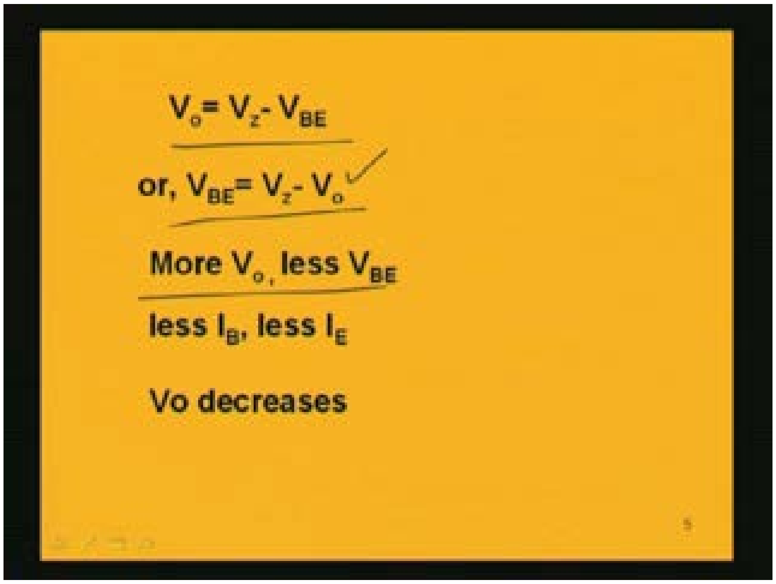

We get V_Z minus V_{BE} equal to V_o or we can write V_{BE} is equal to V_Z minus V_o. If input voltage increases then output voltage V_o also increases. There is a fluctuation. Let us consider that at some time the output voltage has increased. It is changing; output voltage is changing. Let us consider that initially the output voltage is increasing. Because supply voltage is increasing, obviously the output voltage will be also increasing. If V_o increases what will happen? If we look into this V_{BE} which is nothing but V_Z minus V_o, V_Z is the Zener voltage; it is a constant at the value of the Zener voltage. So, what will vary? If V_o varies, from this equation it is clear that V_{BE} base to emitter voltage of the transistor will vary. From this equation itself we can infer, we can see that if V_o is increasing somehow because of some supply variation, then as negative component of this equation increases that means V_{BE} will decrease. More V_o means if V_o is increasing then V_{BE} is decreasing.

If V_{BE} is decreasing what is effect on the transistor current? If base to emitter voltage decreases then the base current will decrease. Similarly because of this base current decrease, this emitter current will decrease. So I_E, which is flowing into the load will decrease. If this I_E, which is nothing but the load current, decreases then V_o will be decreased and it will be brought back to the earlier value. That means V_o will be kept constant. Even though V_o is increasing, then ultimately by this regulator circuit it is brought back. So, V_o will be kept all maintained at the same value.

Even if we now consider the other way that when V_o decreases then also we can see that it will be brought back to its earlier value because the opposite thing will happen if V_o is now decreasing. Then from this equation it is clear that V_{BE} will increase. V_{BE} increases means I_B increases; so, I_E increases, load current increases. V_o will be again increased and that means it will be kept at constant value. This is a very simple circuit; it is a voltage series regulator.

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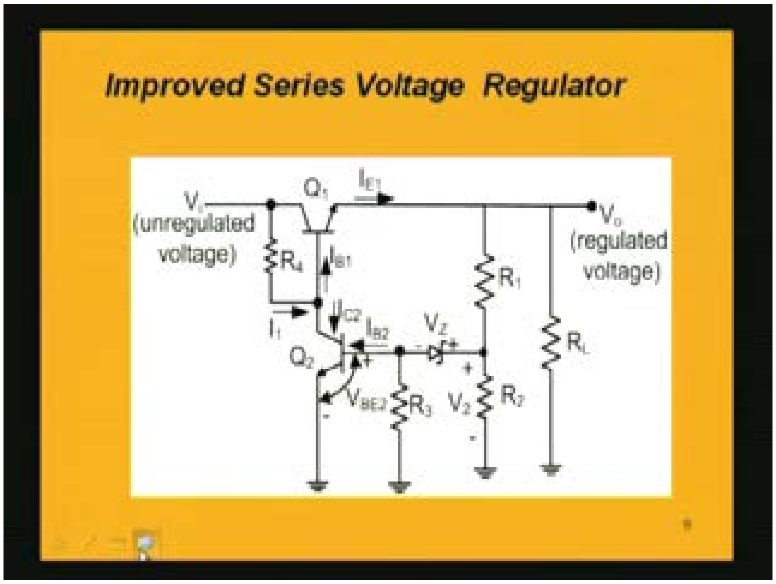

Another modification of this or improvement of this series voltage regulator is done in this circuit which is a bit or a little more complex than the earlier one but it is a better one. If you look into this circuit you can see there are two transistors Q_1 and Q_2 and there is also a Zener diode. V_Z is the Zener voltage and these resistances consist of the sampling circuit which we discussed or we mentioned in the block diagram. This sampling circuit is formed by the resistances R_1, R_2. This is the difference voltage V_Z. What is happening in the circuit? To explain that let us name the currents flowing in the circuit. Transistor Q_2 is having the base current I_{B2}, collector current I_{C2} and transistor Q_1 is having base current I_{B1} and emitter current I_{E1} which will be again going into load.

In this circuit if we find out the relation between the output voltage V_o and the voltage V_{BE2} for this transistor, let us see what this voltage V_2 is which is the voltage across this R_2. V_o has a voltage division taking place. R_1 and R_2 are two resistances. R_2 is grounded. If we find out the voltage across this R_2, we can find that V_o into R_2 by R_1 plus R_2 is this voltage across R_2. The voltage V_2 is again having in series this V_Z. V_Z is the Zener voltage across the Zener diode.

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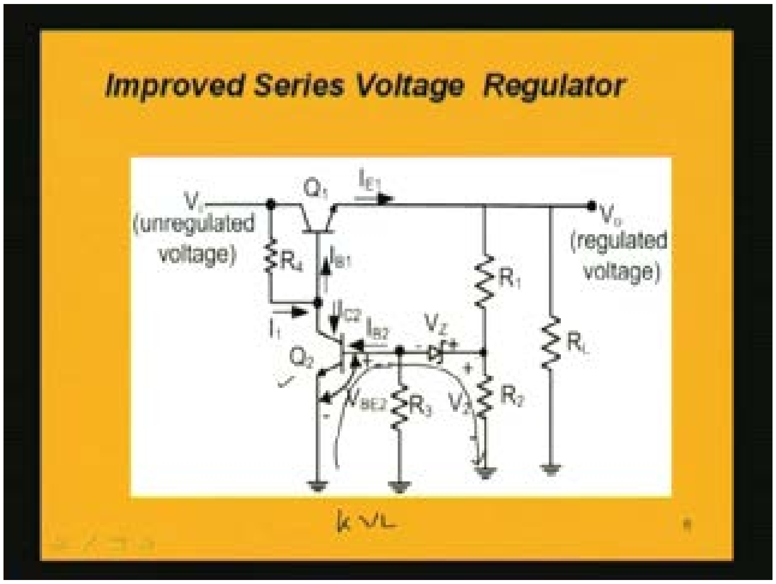

Now if we apply again KVL in this loop that is starting from here again ending in ground through this resistance R_2 what we get? V_{BE2} that is the base to emitter voltage for the transistor Q_2; this transistor I am considering, so V_{BE2} plus V_Z. Mind the polarities; because this is a reverse biased Zener diode, so this point should be negative, this point is positive and V_Z is the drop. V_{BE2} plus V_Z minus V_2 equal to zero.

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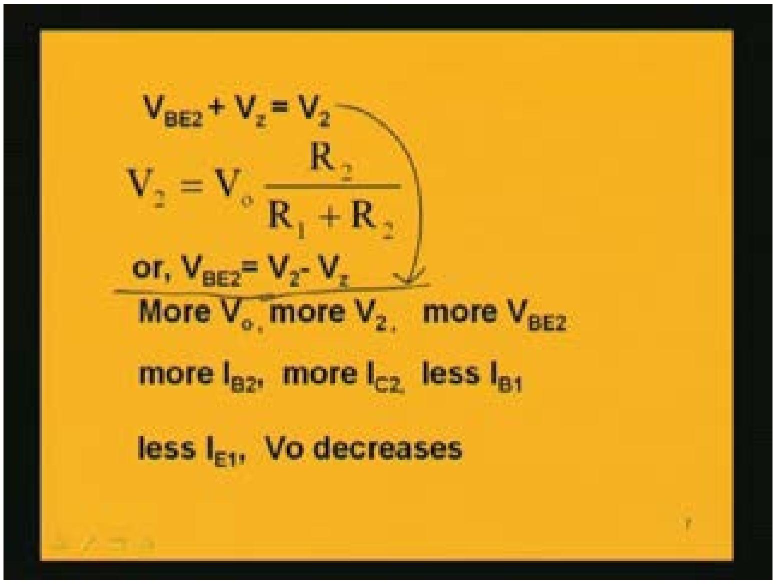

That means we can write V_{BE2} plus V_Z equal to V_2. V_2 is nothing but the voltage available across the resistance R_2 which is V_o into R_2 by R_1 plus R_2. We can simplify by writing V_{BE2} equal to V_2 minus V_Z; from here I am writing V_{BE2} equal to V_2 minus V_Z. Imagine that V_o is increasing; because of supply variation in the input supply, V_o that is the output voltage is increasing. If V_o increases what will happen? More V_o means V_2 will be more because simply V_2 is nothing but the voltage division across resistances R_2, the voltage available will also be more if the voltage V_o is more. More V_2 means V_{BE2} is more. That means in the diagram if we look into, the base emitter voltage of the transistor Q_2 is now high; more.

If the base emitter voltage is more that means this transistor Q_2 will have more base current I_{B2}. So, I_{B2} will be more and I_{B2} will be more means the collector current I_{C2} is also now high. So, transistor Q_2 has a higher base current as well as a higher collector current. What will happen to the other transistor if this collector current is high now which is the collector current for the second transistor Q_2?

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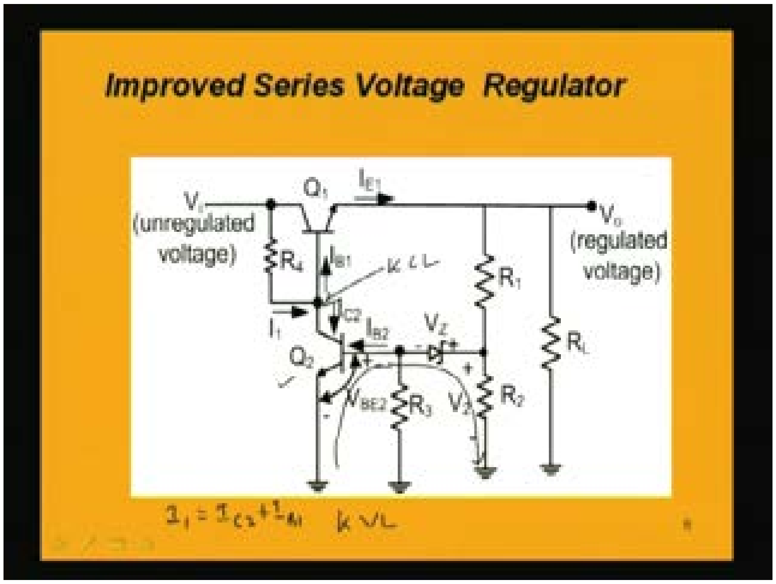

We have to apply Kirchhoff's current law at this node. At this point if we apply KCL, sum of the incoming current is equal to sum of the outgoing current. What are the incoming currents at this point? We can see here that one current is coming through R_4. So, through R_4 the current which is coming let us name it as I_1. I_1 is the incoming current; IC_2 is the outgoing current that is the collector current for the second transistor. The other outgoing current is I_{B1}, which is the base current for the first transistor. The direction of the base current in the first transistor will be towards the transistor. Because it is an npn transistor, so p must be positively connected so the current direction will be like this. We have here at this point I_1 the incoming current equal to sum of the outgoing currents I_{C2} plus I_{B1}.

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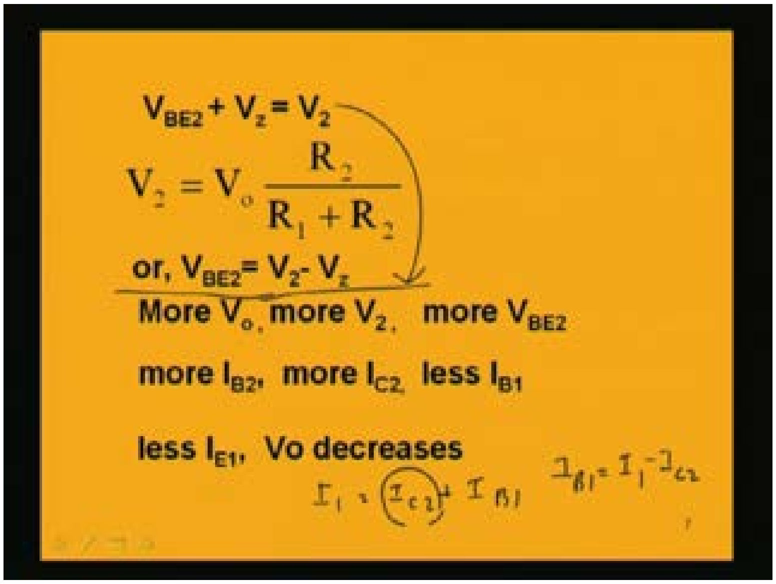

If this is so, now as I_1 equal to I_{C2} plus I_{B1} and just now we have seen that high or increased V_o means more I_{C2}, more collector current in the second transistor. If this collector current increases then what will happen to the base current? Because I_{B1} equal to I_1 minus I_{C2}, so as I_{C2} increases base current will reduce because I_1 does not change. As I_1 is not changing, that means we are getting a lesser base current I_{B1}. Lesser base current I_{B1} means in the transistor Q_1 we will have the current I_{E1} that is the emitter current flowing from the transistor Q_1 also lesser.

Finally we will get I_{E1} less means the load current which flows through the resistance R_L will be less, so V_o will be now less. The effect of increase of V_1 will finally reduce or decrease the V_o. That means it will be kept constant or it will be maintained at the constant value. This voltage regulator is maintaining the output voltage V_o at a same value even though V_o changes and we have seen that when V_o increases then it is pulled again down; that means it will be brought back to its original value. Similarly you can think about the other way. That means when V_o is now decreased you will find that it will be finally again increased and maintained at the same value.

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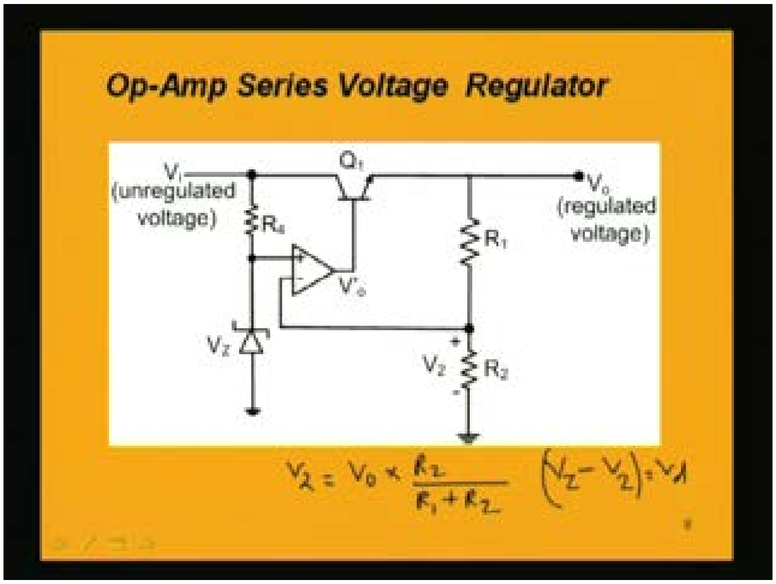

Another type of series regulator where an op-amp is used for the comparator is shown in this figure. We are having an op-amp, operational amplifier whose one terminal that is the positive terminal is connected to the Zener diode having the Zener voltage V_Z and the other terminal, the negative terminal or the inverting input terminal is connected here and the circuit R_1 and R_2 is forming the sampling circuit. What will happen in this circuit is that we have to look into the two terminals of the operating amplifier, op-amp. Here, this is the positive terminal and this is the negative terminal. The positive terminal is connected to V_Z, which is a constant voltage; it does not vary. Other point is connected across R_2; the voltage at this point will be dependent upon the output voltage. What is V_2? If we look into the voltage across this R_2, this is V_o into again voltage division, like the earlier case the voltage division is happening. V_o into R_2 by R_1 plus R_2. This is the voltage V_2.

This op-amp is like a comparator. It is a comparator circuit; it is comparing the two voltages which are present at the non-inverting and the inverting terminals. What will be the output voltage from this op-amp let us name it as V_o dash. That will be dependent upon the differential input present between the two terminals. V_Z minus V_2, V_2 is this voltage; so, this voltage is the differential voltage which is available at the input terminal for this op-amp. The output voltage V_o dash which is nothing but the gain of the op-amp multiplied by the differential input V_d, which is nothing but V_Z minus V_2. If this voltage at the output increases, V_o suppose is increasing what will happen? If V_o increases this voltage V_2 also increases because V_2 is nothing but V_o into R_2 by R_1 plus R_2. If this voltage increases, the differential input which is the difference between V_Z and V_2 will now decrease.

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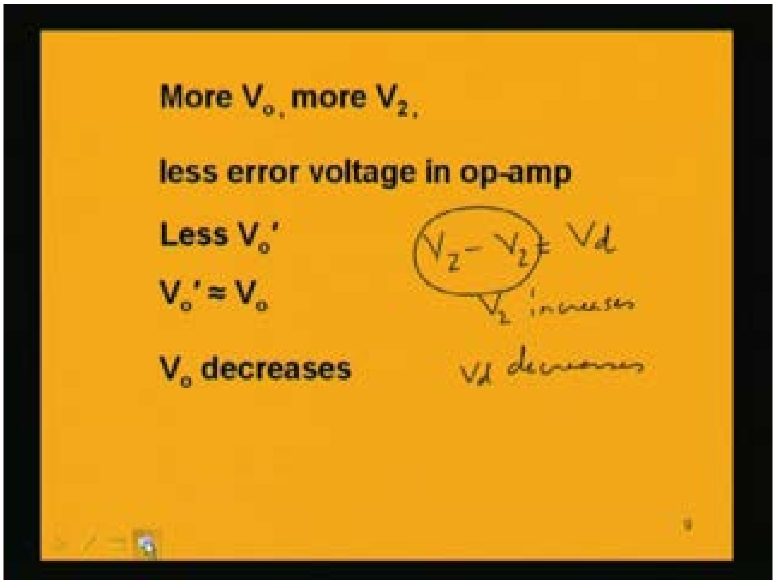

If V_Z minus V_2 is the differential input, say V_d, when V_2 increases, then the differential input V_d decreases because the negative component is increasing means the whole quantity V_Z minus V_2 will decrease. If this decreases, the differential input decreases, the output from the op-amp will decrease. What happens is that V_o dash will now decrease and V_o dash and V_o are almost equal. Basically, this is an emitter follower and the output voltage V_o is almost equal to V_o dash because V_o dash minus V_{BE} is this voltage V_o but V_{BE} is very small. So, you can almost say that V_o dash equal to V_o that means now V_o will be also decreased. From the whole analysis we see that even though V_o is increasing, the regulator circuit is acting in such a way that finally V_o is decreased. The resulting outcome is that finally the output voltage V_o is maintained at the constant level.

In this circuit which is using an op-amp as a comparator we have seen that the change in the output voltage is balanced again by bringing it back to the earlier value and that can be also verified for decrement of the output voltage. Same analysis can be done in a similar fashion because if V_o is decreasing, V_2 is decreasing. So, the difference in the input will now increase. V_o dash will increase. So, V_o which is equal to V_o dash will be now again increased. It will be maintained at the constant value. This type of voltage series regulator circuits that we have discussed is one type of voltage regulator.

Other type of voltage regulator which is there is the shunt voltage regulator.

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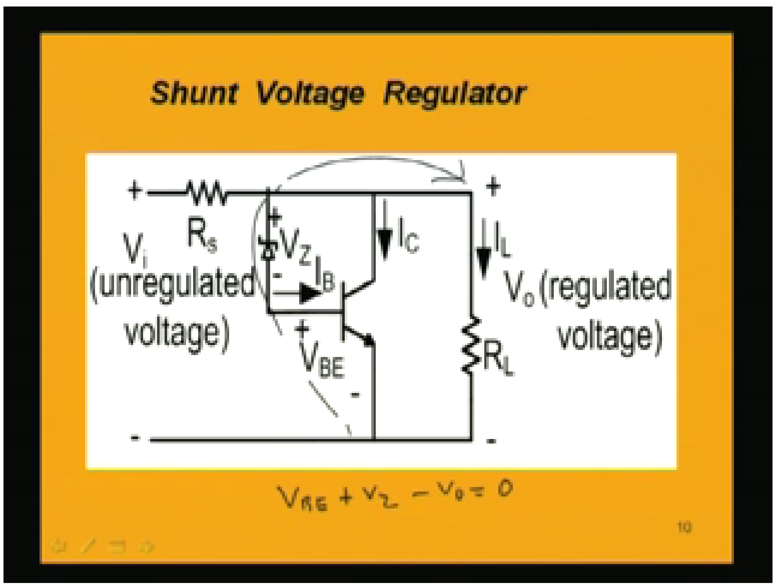

In the shunt voltage regulator, as the name is shunt the immediate thing that comes to mind is that it is shunting away some current. That is exactly what is happening. If we look into this circuit having the shunt voltage regulator, we are having the Zener diode as well as transistor here also. The output voltage is across this load resistance; V_o is across this load resistance R_L and a load current which is flowing in this resistance R_L is say I_L. I_L is the load current. I_L into R_L is equal to V_o that is the output voltage.

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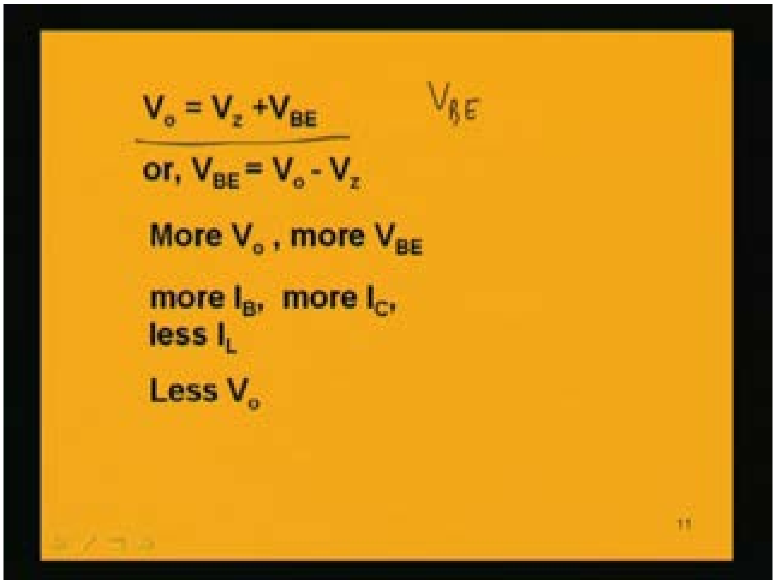

If we now apply again the Kirchhoff's voltage law here in this circuit, if we see this voltage output V_o and apply in this loop, this is the loop suppose we are considering starting from this point then you come to this again back to this point, then what will be the Kirchhoff's voltage law? It will be V_{BE} plus V_Z minus V_o equal to zero. V_{BE} we are starting from this point. We are starting from this point so V_{BE} rising voltage plus V_Z minus V_o equal to zero. That means we can write down V_o equal to V_Z plus V_{BE}; so, that is what is written. V_o equal V_Z plus V_{BE}.

We can further write it down as V_{BE} equal to V_o minus V_Z. If now V_o increases, say; imagine V_o is increasing because of supply variation. More V_o means more V_{BE} because V_Z is constant. V_Z cannot vary because this is a Zener diode voltage; after breakdown this voltage is equal to V_Z. What will increase? Because of increasing of $V_{o,}$ V_{BE} will increase; more V_o means more V_{BE}. What will happen then? If V_{BE} the base emitter voltage of this transistor increases, then the base current increases. So base current will increase and the base current increases mean the collector current increases. If this current increases which is shunted away from this total current, then the current which is left to flow in the load will be decreased.

This total current minus this I_C is equal to I_L. If I_C is increased, then I_L will decrease. I_L is decreased means V_o will be also decreased. We have initially increasing V_o but as increasing V_o shunts away more collector current then finally the load current I_L will decrease. That means V_o will be also decreased and it will be maintained at the same level. This was a shunt regulator using a simple circuit.

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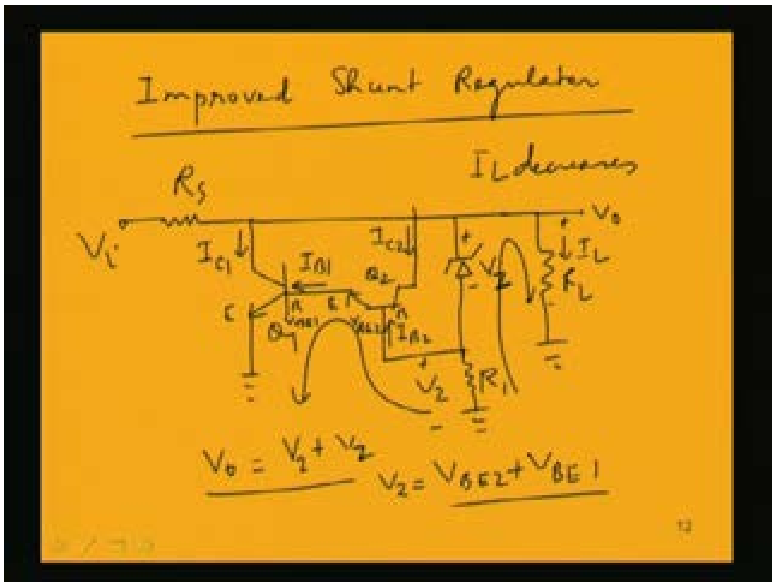

Another circuit is an improved version of this shunt regulator, improved shunt regulator we will discuss, which is having two transistors. Let me draw the circuit. We have two transistors. They are connected as shown here. We have a Zener diode also, the load resistance R_L. This is V_o. In these two transistors, which are npn transistors, let us name that is transistor Q_1, this is Q_2 and input voltage is V_i and this Zener diode is having voltage V_Z. The load current is I_L.

The currents flowing in the transistors let us name as I_{B2} for this second transistor and the collector current for the second transistor is I_{C2}; in this direction it will be, it is an npn transistor. For Q_1, the I_{E2} for this transistor becomes the base current for the first transistor. This is I_{B1} which is nothing but I_{E2} and the collector current for this first transistor is say I_{C1} and the voltage across this resistance R_1 let us name, as earlier, as V_2.

In this circuit what will happen when V_o changes? Here also we will apply again the Kirchhoff's voltage law. What is V_o? V_o equal to V_Z plus V_2 because if we complete this loop, V_2 plus V_Z equal to V_o. This is the Kirchhoff's voltage law applied in this loop. V_2 can be written as V_o minus V_Z. Again what is V_2? It is voltage across this resistance R_1. If we again apply Kirchhoff's voltage law in this loop, having gone through these two transistors it will be V_2 minus V_{BE2} this is the base, this is the emitter for this transistor Q_2 and this is the base, this is the transistor for this first transistor.

If this is V_{BE2} and this is V_{BE1}, so V_2 equal to V_{BE2} plus V_{BE1}. What will happen now if V_o changes? V_o is increasing; for example we are assuming that V_o is increasing. V_o is increasing means the voltage available across R_1 is increasing because V_o is equal to V_Z plus V_2 but V_Z is constant. It is a Zener diode break down voltage. So, if V_o increases then the effect is that V_2 also increases having this V_Z as constant. If V_o increases, V_2 increases and V_2 increases means V_{B1} and V_{B2} both increase because their sum increases and these are almost similar type of transistors. The base to emitter voltage rating for the two transistors will be similar. So, if the voltage available V_2 is increasing that means V_{B2} and V_{B1} also increase.

What will happen if V_{BE2} increases? Then the base current in the second transistor increases, so I_{B2} increases.

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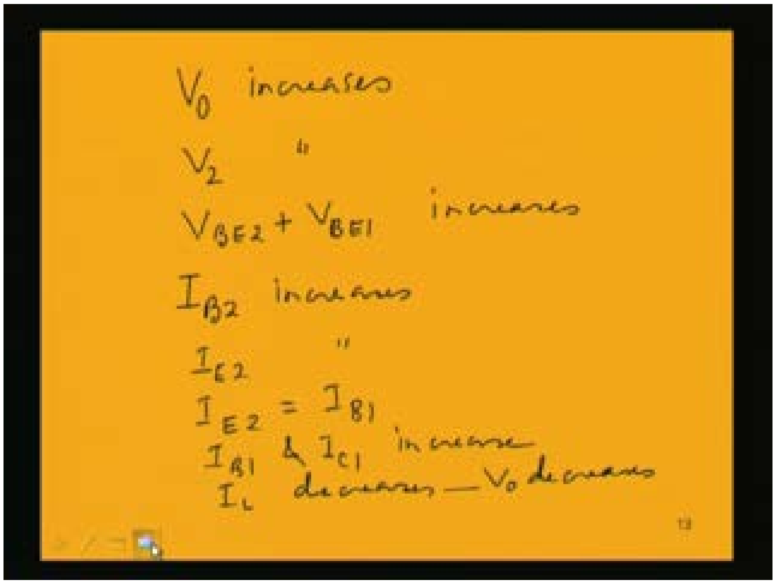

What will happen is if we write down say V_o increases then the effect is that V_2 increases. So if V_2 increases, then the effect is that V_{BE2} plus V_{BE1} increases. That means the base current in the second transistor increases. If the base current in the second transistor increases, then what will happen is that the emitter current in the second transistor I_{E2} that is also increased. So, I_{E2} increases but I_{E2} is nothing but the base current in the first transistor because if you look into the circuit, this emitter current in the second transistor is nothing but the base current in the first transistor. So, base current in the first transistor also increases and base current in the first transistor increases mean collector current in the first transistor also increases; so, I_{B1} and I_{C1} increase. I_{B1} and I_{C1} increases that mean if collector current I_{C1} increases, I_{C2} also is increased; earlier we have seen.

The currents which are shunted away are increasing means finally what is left? Load current is decreasing, so I_L decreases. Because of increase of I_{C1} and I_{C2} the load current I_L is now decreasing. Load current decreases means V_o which is nothing but I_L into R_L will decrease. Ultimate effect is that the load current I_L decreases, so V_o decreases. Initially V_o increased but finally V_o decrease means it is kept at constant value. This is one type of shunt voltage regulator. If we find out the voltage that is maintained constant, V_o then, finally we get that V_o is not changing even though the supply voltage changes.

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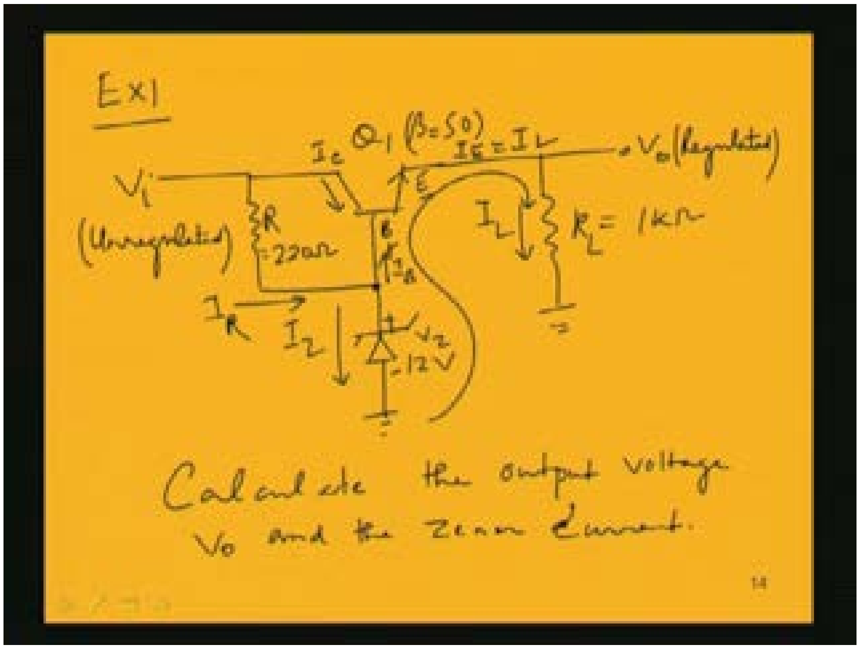

If we consider again this series voltage regulator circuit, to do an example let us take the series voltage regulator circuit which was first taken, having the simple circuit with these parameters given. I am again taking up the first circuit that we discussed having a Zener diode, 12 volt. Let us take this Zener diode as 12 volt and this resistance R is 220 ohm. V_i is the unregulated supply voltage, Q_1 is the transistor; it is having a beta value of say, 50. It is an npn transistor and the load resistance R_L is 1 kilo ohm. This is the voltage V_o which is the regulated output you should get. V_i is unregulated and by using this voltage regulator circuit we should get V_o which is a regulated voltage.

For this circuit, which is the circuit of a voltage regulator you are asked to calculate the output voltage V_o and the Zener current. Find out V_o and I_Z. I_Z is the current through the Zener regulator; that is this current actually, I_Z. These are the polarities of this Zener diode to which it is connected; it should be the reverse breakdown. Now let us do this example. You are asked to find out V_o. V_o is the voltage across this resistance R_L, which is the current I_L into R_L. I_L into R_L will be V_o. We have to find out V_o. How can we find out V_o? V_o can be simply found out if I apply Kirchhoff's voltage law in this loop;

because if I apply Kirchhoff’s voltage law here, it will be V_Z minus V_{BE} because this voltage between base and emitter of this transistor is V_{BE}. So, V_Z minus V_{BE} will be V_o.

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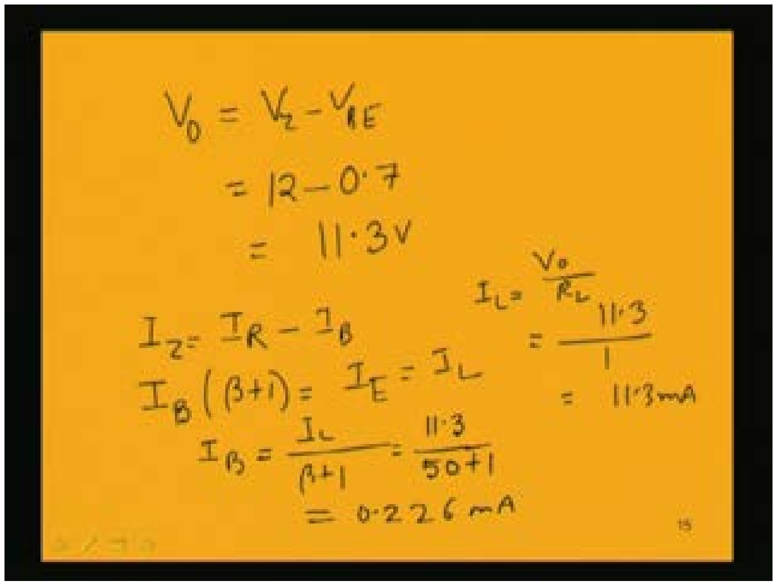

Let us find out in that way; it is a simple way to find out V_o. By looking into the circuit and applying Kirchhoff’s voltage law in this loop, it is V_Z. This is wrong; this is not plus, plus will be here and minus will be here. Because this is Zener diode polarities should be connected; this is P, it will be negative and N is positive. We get raising voltage V_Z minus fall in voltage V_{BE} that is equal to V_o; V_Z minus V_{BE}. We know what V_Z is. It is given as 12 volt, given in the circuit and V_{BE} we know. Already we know that V_{BE} is the voltage across the base emitter and that voltage is 0.7 volt for silicon and it is the standard value taken even though it is not specified. That means we get 11.3 volt as the output voltage V_o.

Now you are asked to find out the Zener current. In order to find the Zener current, what is the law that we are going to apply at this point? It is Kirchhoff’s current law. So, KCL being applied at this point let us name this current as I_R. This current, base current in this transistor is I_B. What will be this I_Z? This is the outgoing current, incoming current I_R minus I_B will be I_Z. So, I_Z equal to I_R minus I_B. We will have to find out what is I_R, what is I_B? Then only we can find out I_Z. I_R can be found out by finding the potential between these two points V_i minus V_Z; this potential is V_Z divided by R, 220 ohms that will give us I_R. Here base current I_B has to be found out. This base current can be found out if we know the collector current I_C. I_C by beta is base current. But how can we find out the collector current?

Collector current is nothing but this current which is flowing through this collector current and we will assume here that I_C is almost equal to I_E and I_E is nothing but this load current. I_E is this load current I_L, which we already found out. If we know this I_E or we can also see that I_B into beta plus 1 equal to I_E. Even without assuming I_B, by equalizing I_C and I_E, we can also see that beta plus 1 into I_B is equal to I_E. Once we know I_E which is nothing but the load current, if we find V_o dividing by R_L we will get the load current and that is equal to I_E. Then you can find out what is I_B. So, I_B equal to I_L divided by beta plus 1. Now, what is I_L?

I_L is V_o by R_L. V_o we have find out to be 11.3 volt, R_L is given as 1 k. 11.3 milli ampere because this is 1 kilo ohm; so, 11.3 milli ampere is the load current which is nothing but the emitter current because the emitter current is I that is flowing into the load for this circuit and so putting here 11.3 by beta plus 1; 50 plus 1 is 51. So, 11.3 by 51 will be the base current and that is equal to 0.226 milli ampere.

We know base current. What is the current I_R?

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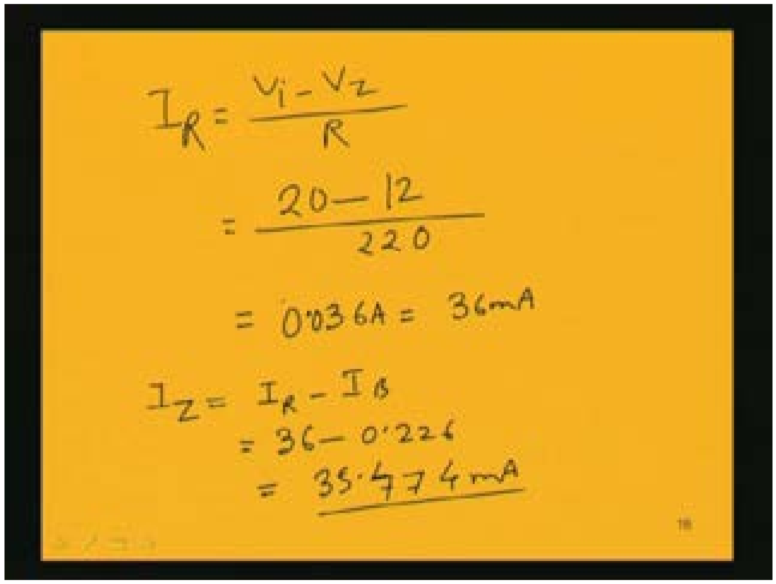

I_R is V_i minus V_Z by R and V_i is given in this circuit. V_i is actually 20 voltage, unregulated voltage is 20 volt. 20 volt minus the Zener diode voltage which is 12 volt divided by R. R is 220 ohm, so this will be in ampere. The value of this I_R is, you calculate this; it will be 36 milli ampere. It should be equal to 36 milli ampere. That means it is 0.036 ampere, which is equal to 36 milli ampere. So, we know I_R is 36 milli ampere, we know I_B. So, you can find out I_Z. I_Z is equal to I_R minus I_B. So, 36 minus I_B is 0.226 milli ampere and that gives 35.774 milli ampere, almost equal to 36 milli ampere. The Zener current is 35.774 milli ampere and the output voltage was found to be 11.3 volt.

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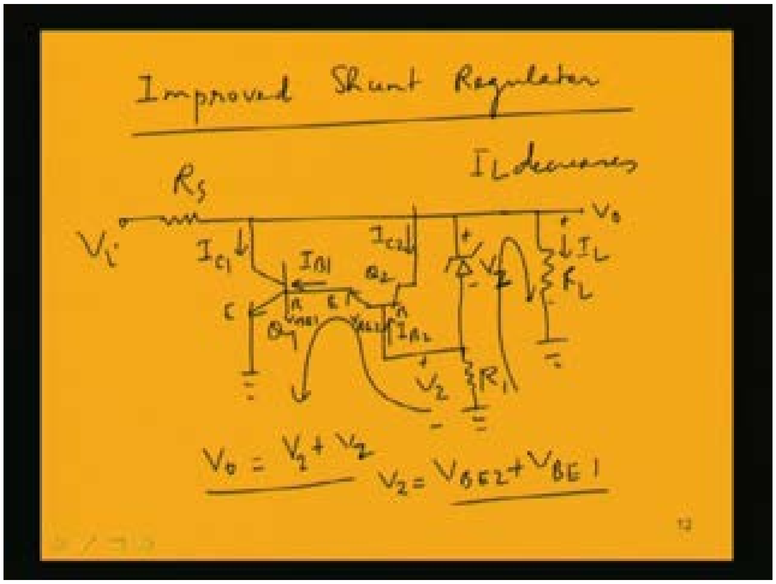

In the last circuit we discussed improved shunt regulator. Here the voltage at this output can be found from this relationship.

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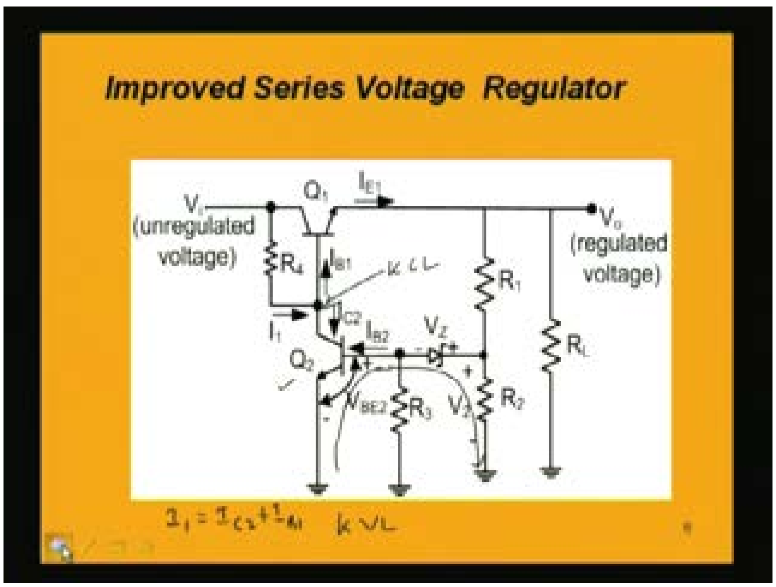

Similarly if we consider the improved series voltage regulator, here we have found out this V_2 equal to V_o into R_2 by R_1 plus R_2.

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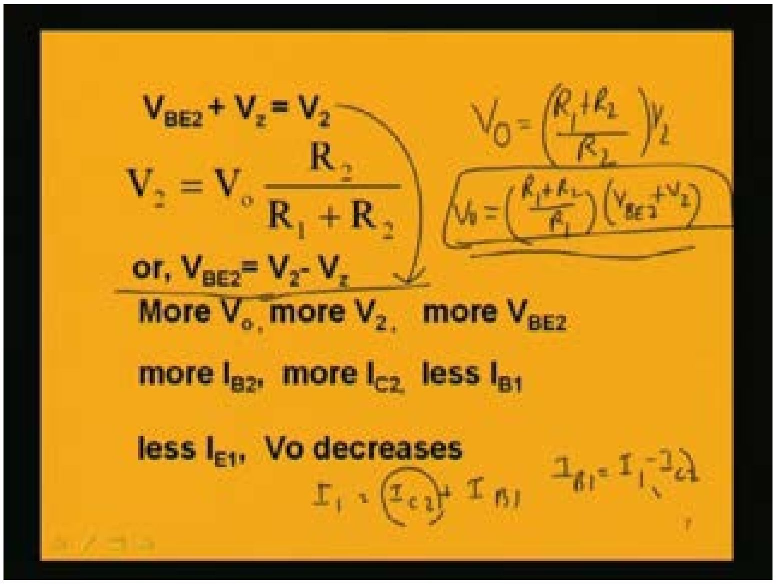

In this circuit if you are asked to find out what is V_o, then we can write down that V_o is equal to R_1 plus R_2 by R_2 into V_2 and now what will be V_2? V_2 is equal to V_{BE2} plus V_Z; so R_1 plus R_2 by R_1 into V_{BE2} plus V_Z. This is the output voltage. If we look into the expression for this series voltage regulator which was using two transistors then, we have an output voltage V_o which is maintained at this value. Look into this expression for this output voltage; for a particular voltage regulator circuit, R_1 and R_2 are constant. They are not going to vary. Then V_Z, Zener diode after breakdown that voltage is also constant. V_{BE2} will be almost constant at that particular transistor base to emitter voltage. So, the output voltage V_o is basically constant. That can be seen from this expression itself. So, whatever changes occurs in the output voltage that is just taken care of by the controlling circuit which is the transistor and the output voltage will be maintained at a constant value.

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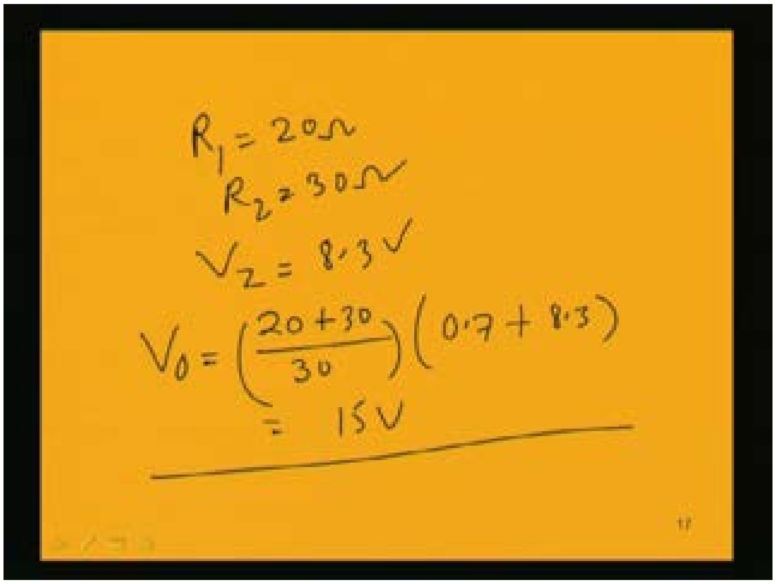

For example if we take one case where R_1 and R_2 are given as say, 20 ohm and 30 ohm and you are using a Zener diode having say 8.3 volt; so what is the output voltage, at what voltage it is maintained? It is 20 plus 30 by 30 into V_{BE} is 0.7 plus 8.3. It is 15 volt. So, the output voltage is maintained at 15 volt constant and the change or fluctuations which may arise due to change in the supply voltage or the load current change that is taken care of by this transistor.

In today's lecture we have seen how voltage regulator circuit is used to maintain a constant voltage and a regulated power supply which is required for our daily as well as other different uses. Regulated power supply using semiconductor devices like transistors, Zener diodes we can get an output voltage which is a constant voltage even though there may be fluctuations in the input supply voltage or the load current. This voltage regulator circuit is backbone of the regulated power supply.