Basic Electronics
Prof. T.S. Natarajan
Department of Physics
Indian Institute of Technology, Madras

Lecture – 39
Silicon Controlled Rectifier (SCR)
(Construction, characteristics (Dc & Ac), Applications, Triac, Diac

Hello everybody! In our series of lectures on basic electronics learning by doing let us move on to the next. Before we do that let us recapitulate as usual what we discussed in our previous lecture.

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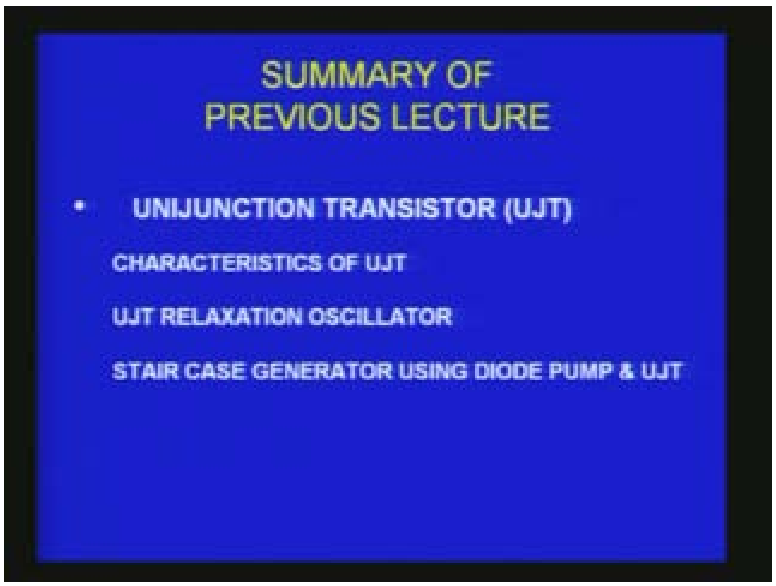

You might recall in the previous lecture we discussed about a new semi conductor device namely the unijunction transistor. We discussed about the characteristics of the UJT, how you get a negative resistance region and then how it can be used to design a UJT relaxation oscillator and then we also built using couple of diodes and capacitors a staircase generator, a wave form in the form of a staircase using the diode pump and the UJT. The diode pump used diodes and the capacitors and to limit the staircase wave we used the UJT to trigger the UJT and discharge the capacitor, etc. You might recall all that we discussed in the previous lecture.

In this lecture I propose to discuss another important semiconductor device which is called the silicon controlled rectifier, SCR. It is also called by the name tyristor. What is silicon controlled rectifier?

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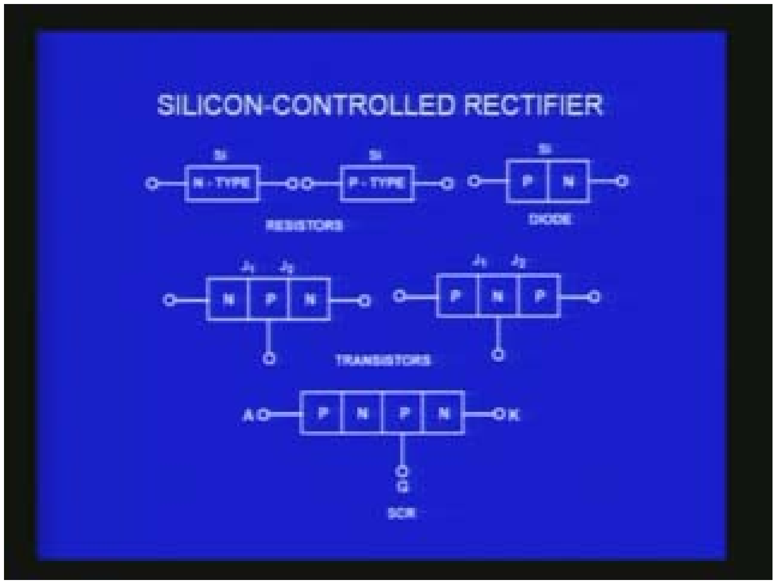

Before we do that let us understand how it came about? If I have a simple n-type silicon semiconductor as you can see on the screen, then it becomes something like a resistor. Depending upon the doping the resistance of this device will change, the conductivity will change by doping and therefore the resistance. You can have either n-type resistor or p-type resistor depending upon what you dope with. When you combine the two types in the same wafer then you can have a junction diode. This we have discussed in the earlier stage. p and n can form together a junction and it has got a very important property that only when it is forward biased it will conduct, when it is reverse biased it will not conduct or it offers high resistance when reverse biased and low resistance when forward biased. It is used for rectification to convert an ac which is bidirectional voltage swing to unidirectional swing corresponding to the dc. Then someone thought why not add one more layer beyond p and n? When I add I have a choice now. I can either have n- p- and n as three layers or p-, n- and p as three layers. This is nothing but our familiar bipolar junction transistor, BJT. You have two junctions, the base emitter junction and the collector base junction. You have J_1 and J_2. You have the emitter, base and collector. Similarly in the pnp transistor the configuration is the same except that it is formed with pnp as three layers.

If one thinks in similar lines what will happen if I add one more layer? If you think of adding one more layer you will have 4 layer device. A pnpn device and this is what we call a SCR, silicon controlled rectifier. A SCR is a 4 layer device pnpn and the p is called the anode and the n at the end is called the cathode and very close to the cathode there is a p region and that region is usually called the gate terminal. So you have an anode, you have a cathode and a gate. If you compare it with normal diode, you have only two layers p and n and you have an anode and a cathode. The anode is p side so that when I connect that to the positive of the battery and the n to the negative of the battery this will show low resistance. In the same way here this is again an anode and cathode that means it is also like a rectifier. But then you have an additional terminal at the p which is called the gate terminal. What will the gate do? The gate should control the flow of current from the anode to the cathode. This becomes a controlled rectifier. Otherwise it is just like any other rectifier like the pn junction diode. You have an anode and a cathode and it will conduct in only one direction. When I have a gate then I can control when it starts conducting in a given input. We will discuss this in some detail a little later. So a SCR is a silicon controlled rectifier. It is a silicon controlled rectifier because usually it is made out of silicon semiconductor.

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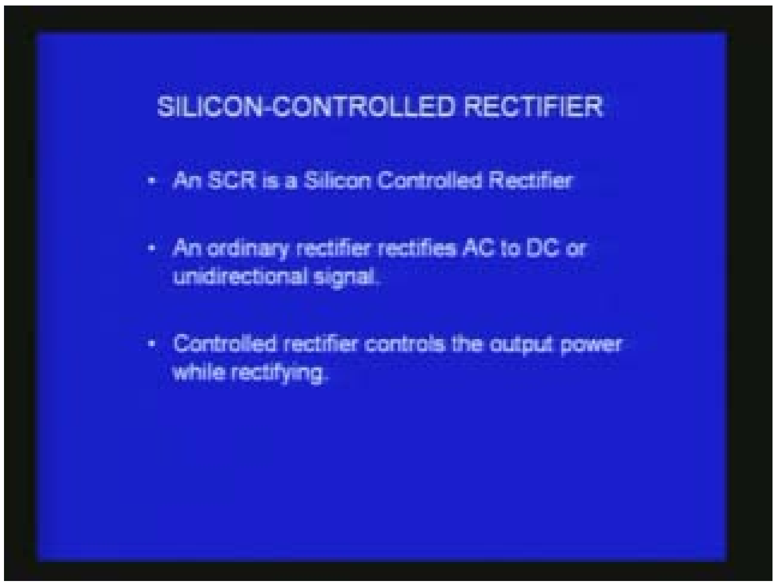

It is a rectifier because again it is going to be used for power control and it is a controlled rectifier because you have an additional terminal called the gate which controls the power delivered to the load. An ordinary rectifier converts AC to DC. That is what we call rectification and this means unidirectional signal current or voltage. A controlled rectifier controls the output power while rectifying. Let us try to understand little more. But why not germanium controlled rectifier? Once the silicon came everybody were impressed with the characteristics of the silicon semiconductor over the germanium semiconductor because the leakage currents in the silicon will be much less compared to germanium because in the germanium band gap energy is smaller, 0.7 volts. In silicon it is about 1.1 to 1.2 eV and therefore the higher thermal energies are required for pushing the valence electrons into the conduction band and the leakage currents in such devices will be very, very small and it is very important for a switch. SCR is basically a switch and a switch should have low leakage current because what is important in a switch is the ON resistance and the OFF resistance. That is why you should have least leakage current so that the ON/OFF resistances could be maximum and minimum as the …….

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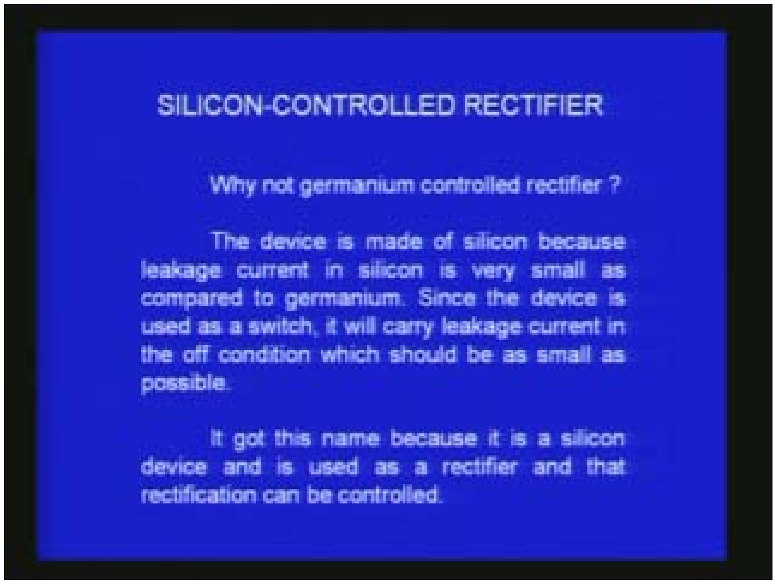

It is basically a rectifier, a controlled rectifier and it is a 4 layer device, alternately p-type and the n-type; 4 layers are there. This is what we should know. Why do we need that? Let me explain to you why we need this. If I want to control the speed of a fan what do I do? If I apply 220 V the fan will be running to the full. But sometimes we do not require the fan to run at full speed. So what do we do? We have a regulator. I do not know whether you have seen that. Most of the times, the regulator will be a big box. Now-a-days it has come in a very small box almost like a normal switch and that is because of these devices which we are discussing today, the silicon controlled rectifier and the rest of the things. Fan is a current controlled device. It is the magnetic field which is producing the rotational effect and therefore the magnetic field depends on the current. If I want to limit the current then I can reduce the magnetic field and correspondingly the torque and the rotation speed. When I want to do that the only way, we all know, from Ohm's law to reduce the current in a circuit is to increase the resistance in the circuit. In olden day regulators what we have is high wattage resistors and you can only switch the speed in steps. You will normally have full speed, 5, 4, 3, 2, etc. When you come to 3, 2, 1, etc, the speed will be very, very less, because you have added more and more resistors whenever you switch and thereby the current becomes less and less. That is the only way you can control the speed of a fan in the normal regulator you had in the olden days. Very rarely we see that. Only in some old houses you would find.

What have you done? You have introduced high wattage resistors in the path of the coil. Therefore the main current passing through the fan is now reduced because of the resistance introduced. But you should remember that this current will also flow through the resistance and usually you will have to use a large value of resistance because you are using large voltage, 220V and there will be an I square R dissipation through the resistor. That is an energy loss. If you touch the regulator after sometime you will find that it will be very warm because it is dissipating electrical energy and you have to introduce it because you wanted a lower speed. When you want a lower speed you have to introduce a resistance and that naturally brings a loss of electrical energy by way of heat. You may find that this is a very, very small loss. You may think like that. But imagine a big auditorium or cinema hall where there are hundreds of fans. All of them will have to have this type of a regulator for reducing the speed and if I use those regulators, enormous amount of heat energy will be dissipated over 3 hours or 4 hours and if you now calculate the actual power or energy dissipated through all these regulators over a period of 1 year, for example, you would find this loss in electrical energy will be very, very considerable and you may be even paying for it without knowing because the total energy consumption is what you are paying for. That is now the combination of the consumption for useful energy in terms of the speed of the fan and the unused energy in terms of heat energy lost in the regulator. It is not a very efficient way of controlling the speed of the fan. What we do is we introduce a special device, the silicon controlled rectifier. This silicon controlled rectifier can act like a switch to switch on the power delivered to the load or the fan in this case at any instant you want and thereby it can control the energy sent to that.

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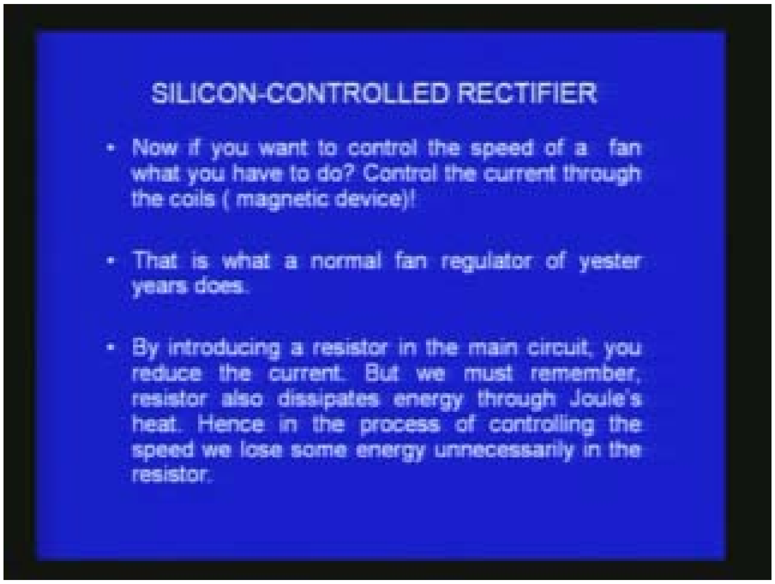

To control this silicon controlled rectifier, we have the gate. I have already showed you the gate terminal which is the control element and you will still have to use a resistor to control the power delivered to the load but this resistor will now come in the gate circuit, not in main circuit in series with the anode and cathode, but in the gate circuit between the gate and the cathode and the currents involved in the gate circuit are very, very small usually of the order of milli amperes. Whatever resistance you put there the energy dissipation in terms of heat energy in the gate circuit will be very, very insignificant and that will be able to switch the SCR at any required point and the large power delivered through the anode cathode circuit can be controlled by a small variation in the current in the gate circuit which is of the order of milli amperes and therefore total energy dissipation in the control of the fan will become very much reduced and certainly you would save lot of energy by using silicon controlled rectifiers. That is why if you buy modern time fans for industry or house you will find they will always give you a small regulator with a small knob which can be fixed in the switch board and that contains a device similar to the silicon which is actually a triad. It can control the power delivered to the fan and there is good saving of energy and an efficient method to control the rotation of the fan. I gave an example of the fan. But you can have several examples like in big studios where you have plenty of lights which are running to about 5000 watts, 1000 watts, 2000 watts, etc, for projecting on to the studio and all of them will have to be controlled. The intensity will have to be controlled. All can be controlled by such devices like the SCR and the triad.

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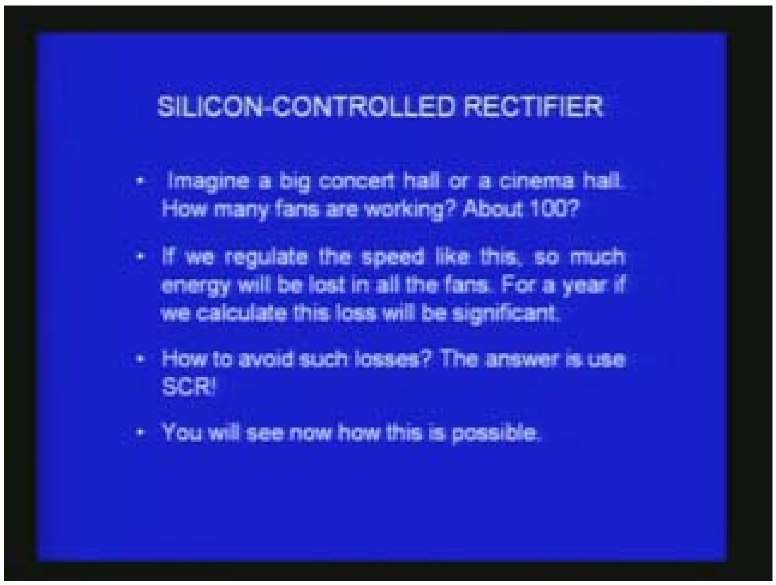

This is what I was mentioning to you. In a big concert hall when you have more than about 100 fans, the regulation becomes inefficient if you introduce resistors in the circuit. So we try to use SCR. I have given you some simple configurations of the SCR. This is very small SCR normally in the TO5 package. This is T05 package like the transistor SL100. Some of these we have used in our earlier lectures. It will be like this where you will have a tab at the bottom view and you will have 3 terminals, the cathode, the gate and the anode coming in the clockwise direction. Cathode, gate and anode will be the pins corresponding to this but this is meant usually for very low power control. If you want slightly higher power you have TO 221 to TO 225 packages which are for higher currents. They can withstand 5-6 amperes and the corresponding circuit symbol is anode and cathode. There are 2 diodes and then you have the gate. This is actually the figure of SCR. In the case of SCR you will have only one diode and one gate. The package is something similar to this and you would also see when I show the demonstration the actual device.

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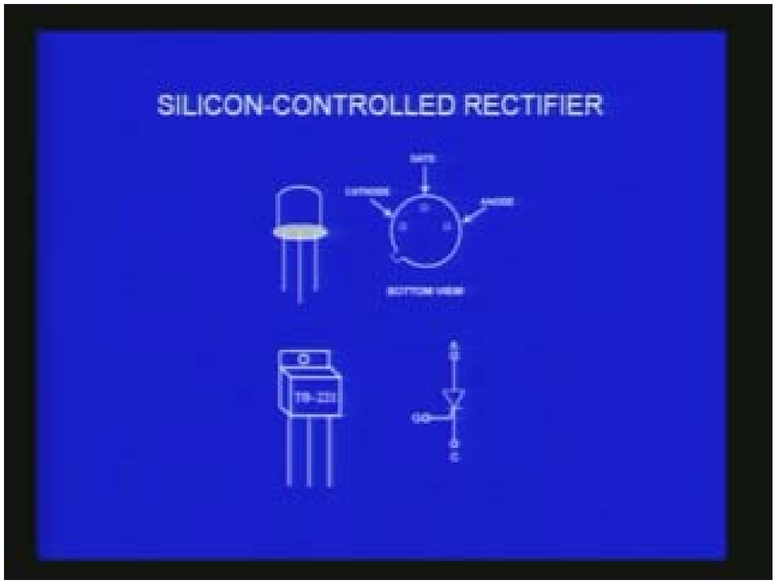

Now let us understand how the silicon controlled rectifier works? You have a pn pn region, a 4 layer device and that means it has to have 3 junctions.

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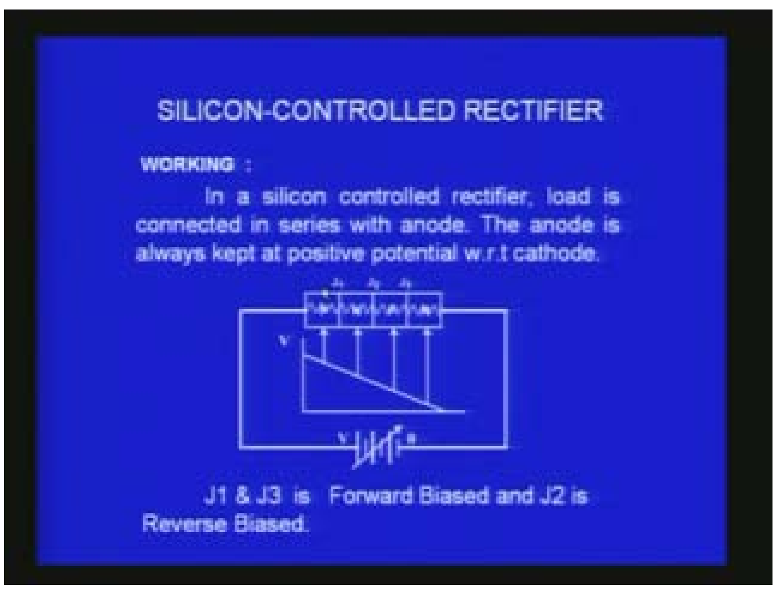

Between p and n we have J1, between n ad p J2 and between p and n again J3. J1, J2 and J3 are the 3 junctions and there are 4 layers. If I connect it to a large power supply with the plus connected to the anode and negative connected to the cathode and if I make it variable what will happen to J1, J2 and J3? Let us try to understand. To illustrate that, I have approximated this to a resistor here. If you look at this entire thing as a silicon block, then it has got a very specific resistance and if I connect a resistance at this point the voltage will be the applied voltage, full voltage and if I go along the resistor at different points, the voltage will be slowly decreasing till it comes to zero because there is a drop along the resistance we all know that from Ohm's law.

When I look at it in that perspective, the p- type is earlier than this n-type and this should be more positive than the n-type and this junction with the p-type more positive than the n-type should be forward biased. If you come to the J2, the n-type is more positive compared to the p-type and it will be reverse biased and J3 where again the p-type is coming before the n-type and it is slightly more positive voltage than this and this also will be forward biased. J1 and J3 are forward biased and J2 is reverse biased. That is the situation corresponding to this.

When I reverse bias this, what will happen? In this situation, J3 and J1 will be reverse biased and J2 alone will be forward biased. J2 alone is more positive here on this side whereas here this side n-type is more positive than p. Therefore this is reverse biased. Similarly this is also reverse biased. This alone is forward biased. There are 2 junctions which will be reverse biased when you reverse the SCR.

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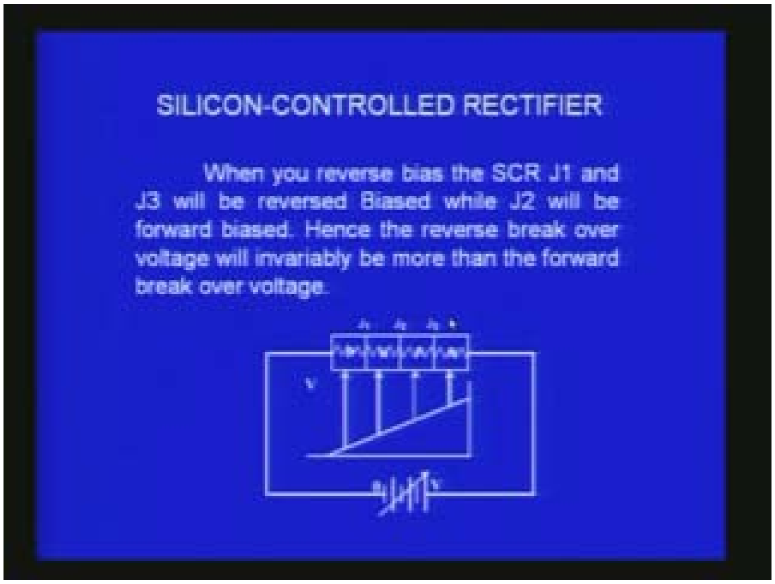

The silicon controlled rectifier is an ordinary rectifier with a control element. That I mentioned to you already. The current to the control element, which is termed as the gate terminal determines the anode to cathode voltage at which the devices commences to conduct.

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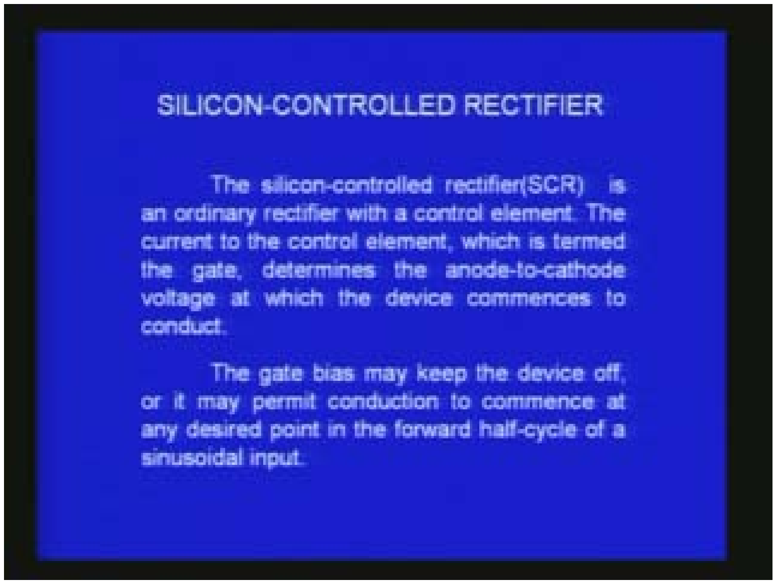

The gate bias may keep the device off or it may permit conduction to commence at any desired point in the forward half cycle of the sinusoidal input because we are always looking at input sine wave. How it is going to rectify into a DC. The SCR is a very widely applied ac power control device. There are other devices such as the DIAC and TRIAC which are also related to SCR.

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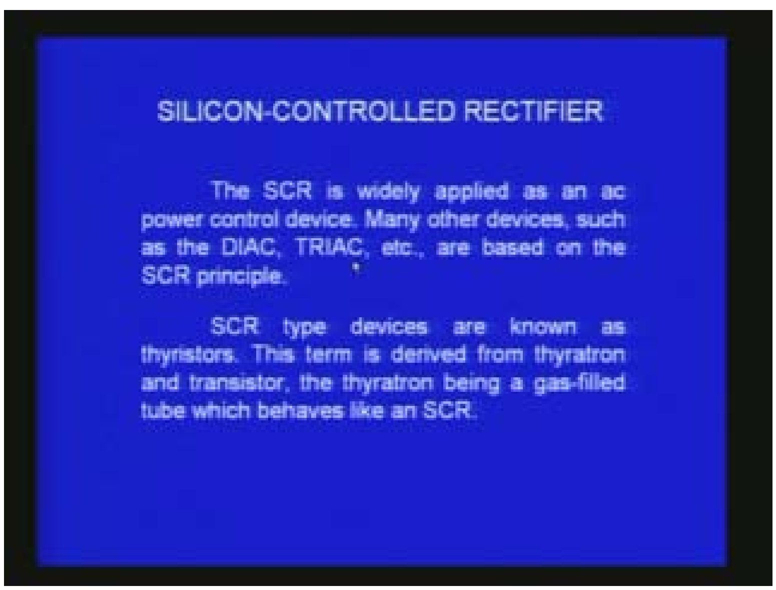

DIAC is a switching device, TRIAC is a triode ac. Triode means 3 terminals and it is used for ac and this is for full power control of the ac. These are based on the principle of SCR. These are also known as, as I mentioned to you, thyristors because in olden days a similar device which is a switching device was used by using vacuum tubes. You have heard of the gas filled triode. The gas filled triode was called the thyratron and that is having a very similar behaviour like the SCR and to remember that which was called thyratron, this is called thyristors because it is based on semiconductor device.

The SCR is a true electronic switch which will make it conduct or non-conduct. That is why it is called a rectifier. It can change an alternating current into a direct current and at the same time control the amount of power fed to the load.

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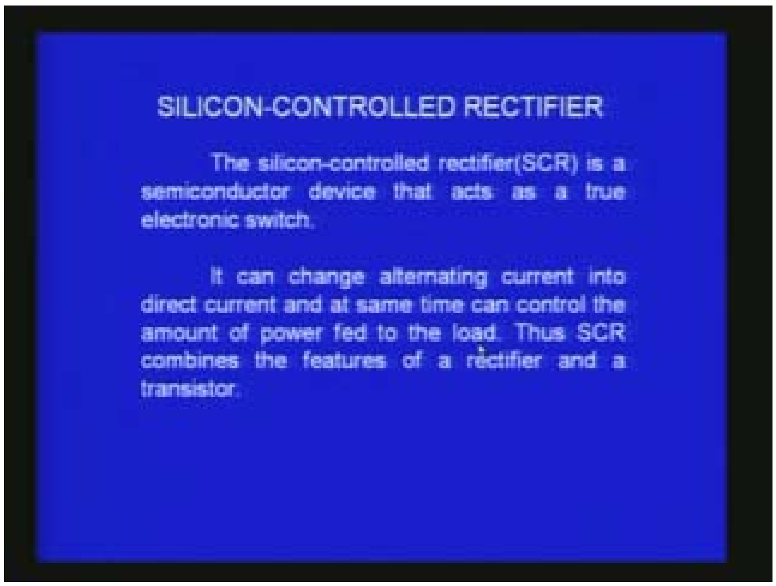

It combines the features of a rectifier and a transistor to control, active control.

If you look at the npn device, this is P_1. The n region I have separated as n_1 and n_1 prime and the P_2 region also I have separated as P_2 and P_2 prime and then I have n_2 region. If I now look at it, the pnp is actually a transistor. npn is also a transistor. They are 2 transistors separated and then they are connected internally. That is what it is. The corresponding circuit diagram I have shown here. There is an emitter here. There is a collector and the collector is connected back to the other transistor and the emitter of this second transistor is connected to the base of the first transistor. Therefore there is an internal feedback here between the 2 terminals. Ultimately what you have is an anode, a cathode and a gate terminal. That is what we have here. This is the equivalent circuit. When you do a circuit analysis, which I am not going to do here, you would find that this model comes out very handy for understanding the behaviour of the SCR.

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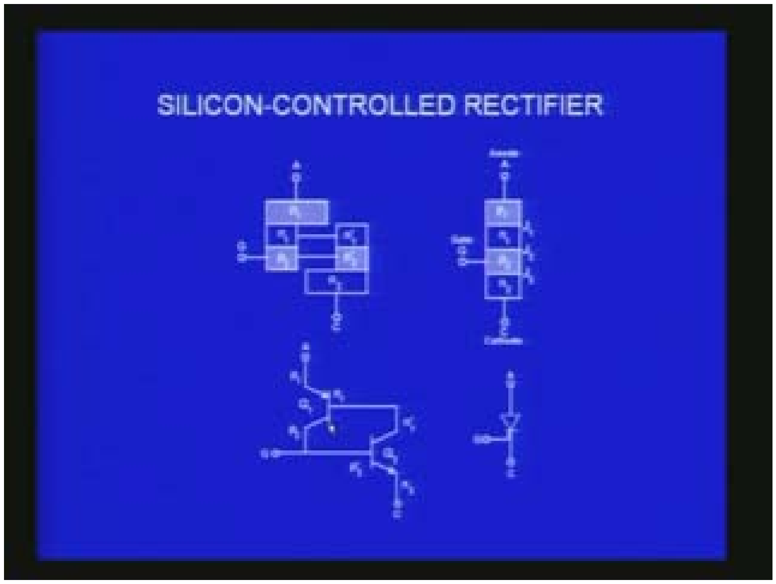

I have shown an actual SCR here, the 4 layer device and the corresponding symbol. There is only one diode here and a gate, anode and cathode and the gate is very close to the cathode. That is what you should remember and the easy direction of current flow is from the anode to cathode. That is why the diode symbol with the arrow pointing towards the cathode is shown here. This is the circuit symbol and let us now try to understand the construction.

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The pn junction is added to the junction transistor and the resulting junction is the 4 layer device of a silicon controlled rectifier. In the normal operating condition, the anode is kept positive for forward biasing with reference to the cathode and the gate normally will be kept at a low positive potential. If I don't give any voltage to the gate what happens?

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If I keep on increasing the dc voltage connected between the anode and cathode at some critical point, which is similar to the Zener breakdown voltage, the thyristor will start conducting due to the forward break over voltage. Zener diode, if it is reverse biased when you exceed a maximum voltage, limiting voltage it starts conducting continuously due to avalanche effect. In the same way this also will start conducting beyond some voltage, that we call the forward break over voltage.

Let us see the characteristics. The SCR has got 2 states one state corresponding to when it is turned ON it conducts heavily and the other corresponding to turning it OFF when there is no conduction through that and the SCR behaves like a switch. It can either switch ON or switch OFF. There are 2 ways to turn the SCR. The first one is to keep the gate open and increase the supply voltage between the anode and cathode till you reach the break over voltage or the break down voltage corresponding to the avalanche breakdown. The second which is more common is to turn it on by using a current through the gate terminal.

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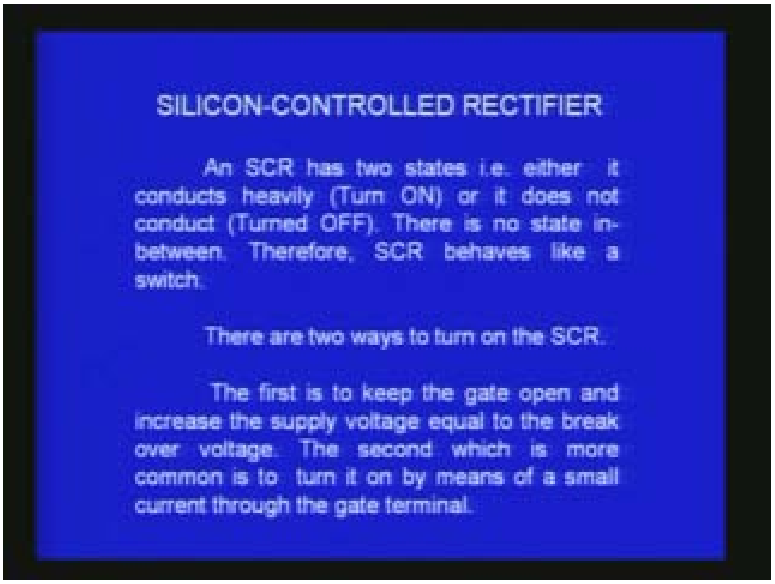

You may be able to bring down the break down condition even before you reach the break over voltage and you can make it conduct at any other voltage below the break over voltage. That is the advantage of the gate terminal. You can turn ON by using the gate terminal. But what about turning OFF the switch? When you want to turn OFF you cannot turn OFF using the gate. That means if I cut off the current from the gate will it switch OFF? No. It will not. The gate can help only to switch the device ON but it cannot help in switching it OFF. That is what you should remember all the time.

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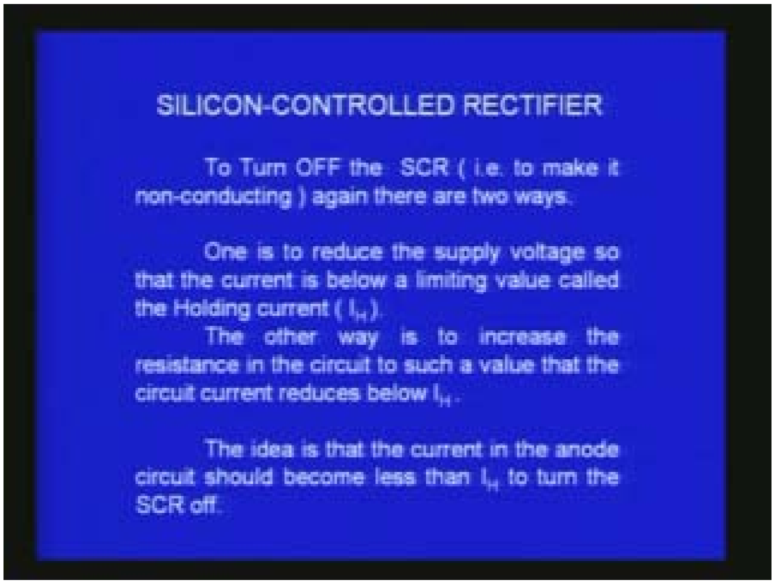

How do I switch off the SCR? The only way to bring the SCR to an OFF state is to bring the current flowing through the anode and cathode to a value below a limiting value called the holding current, I_H. What is the holding current? It is the current which I should hold above which only it will be in conduction and below which the SCR will come into OFF state or non-conducting state. How to reduce the current to below the holding current? There are 2 ways. Either you can reduce the voltage you have applied between the anode and cathode then by Ohm's law the current also should reduce or keep that voltage constant by introducing the resistor in the circuit of the anode and the cathode and increase the resistance so that the current keeps coming down and when it comes below the holding current I_H, then this here will come off. These are the various things that you should remember when you look at the SCR. I have shown you the VC characteristics of the SCR.

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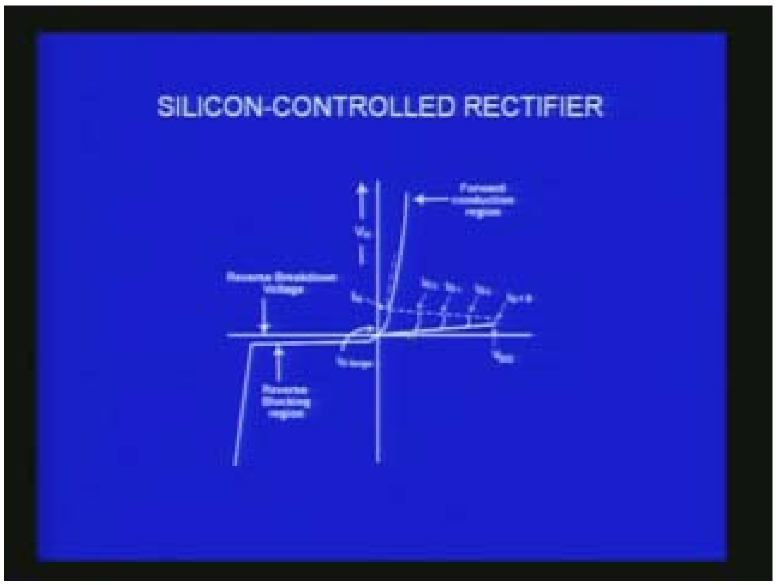

X-axis is the voltage, y-axis is the current. When I go along the x-axis if I do not have any gate current it will come up to this point which is marked here as V_{BO}, which is called the forward break over voltage and at that stage the SCR will start conducting. Once it conducts, that means it is switched on, the voltage across the SCR will be a very, very small voltage somewhere here. It is a very, very small voltage and it should be something like 100, 200 V. But this will be almost close to 1V. It will come quickly to this conduction region and if I now keep increasing the applied voltage the current will increase like a normal diode with very little change in the voltage across the device but the current will increase enormously depending upon the voltage I apply. This shows that it is on the conduction region. The SCR is conducting. Now if I apply a gate current I_{G0}, I_{G1}, I_{G2}, etc then depending upon the magnitude of the gate current I can switch this off much below the break over voltage or still below depending upon the magnitude of the current. These are different points at which it will break and then it will come over here. When I want to switch off, I will bring down this anode cathode current to a very low value below the threshold which is called the I_H or the holding current. When I bring it below the holding current, then from this point it will come to this point. Only if I increase the resistance in the circuit the voltage will remain constant. If I apply 200 V and if the SCR is ON, across the SCR there is only 1V. What happens to the rest of the volts? The 199V will have to be applied across the load that we have connected in the circuit. Thereby the power is now delivered to the load. That is what we see. What we have on the left side is the reverse bias and it is like a normal Zener diode except that this reverse break over voltage will come too far away compared to the forward break over voltage because there are 2 junctions now which are reverse biased. After that it behaves something like an avalanche effect and you have a reverse blocking region in this region and reverse breakdown voltage beyond that point. This will be the characteristics of a silicon controlled rectifier.

How to obtain the characteristics? I have got a circuit here. I am going to show you with a low voltage power supply so that you can reasonably understand. Even though you can put 100, 200 V here I am going to use a 30 V power supply here which I have been showing you all the time. I have a current meter here. Because the voltage is small, the current is going to be small in milli amperes. So I have put a 0-10 mA current meter and I have put a 1 meg ohm potentiometer which I am keeping in zero. That means this resistance is not included initially and I have put safety resistance 4.7 kilo ohm here and this is the SCR and the cathode is connected and there is a voltmeter here between the anode and cathode of the SCR to measure the voltage across the SCR. If you look at the gate side I have connected 5.6 kilo ohms in series and a current meter 0-500 micro amperes and 0-5 V I have put in a potential divider with a 10k resistor so that I can change this voltage and find out at what current, the output voltage, the SCR triggers ON, the SCR starts conducting.

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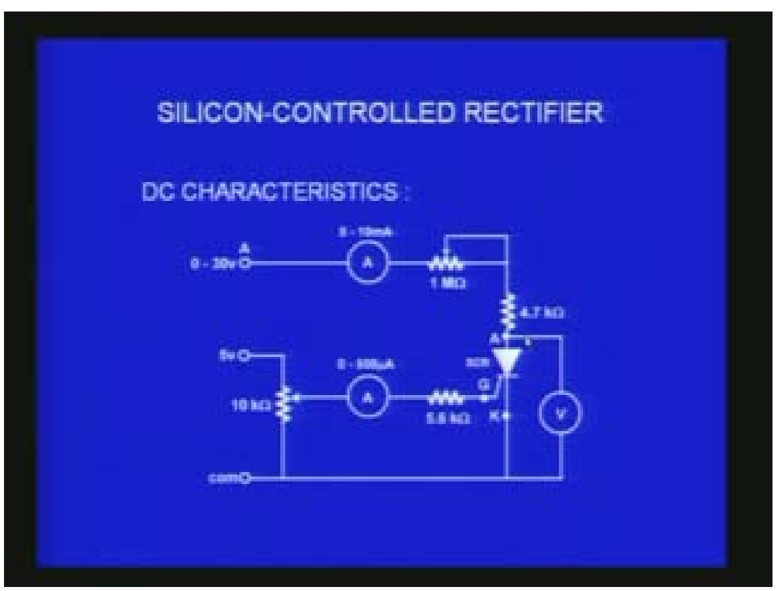

If I keep it at 30 V, this is not enough to break this SCR. The forward break over voltage will be 200-300 V. It will be very difficult to make this conduct with 30V and I have to give greater current. If I move this wiper on the 10k potentiometer at some current you will have enough current to forward bias that junction. Immediately there is enormous conduction here and the SCR will be triggered ON. Once the SCR is triggered ON this voltage which was staying at 30V will suddenly come to very low voltage of nearly 1V and the current will also show a large value here because it is now conducting.

If I remove this gate current by switching off this 5V power supply, the voltage here will be around 1 V. This current will be large depending upon the resistance. The SCR cannot be switched OFF by switching off the gate current. That is what I want you to realize. If I want to switch off the SCR what is that I should do? I should reduce the current below the holding current, this primary current, the anode current. I have 1 meg ohm resistor. I will start increasing the value of the resistance here till the current comes to very minimum value corresponding to the holding current. Immediately at that time, this voltage the moment it comes to off state, this is OFF and the entire voltage will appear across the SCR and this voltmeter will show 30 V. This is what I want you to recognize as the DC characteristics.

I will show you the demonstration of the voltage. Before that I want to recapitulate some of the important terms.

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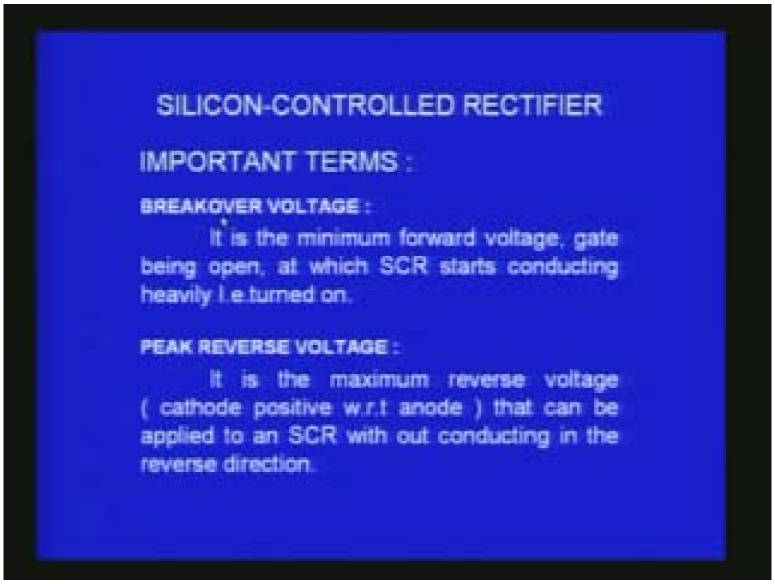

Break over voltage I explained to you already. It is the minimum forward voltage with the gate open at which the SCR starts conducting heavily. Peak reverse voltage is the maximum reverse voltage with the cathode positive that can be applied to the SCR without conducting in the reverse direction. Holding current is the maximum anode current, gate being open at which SCR is turned OFF from the ON condition.

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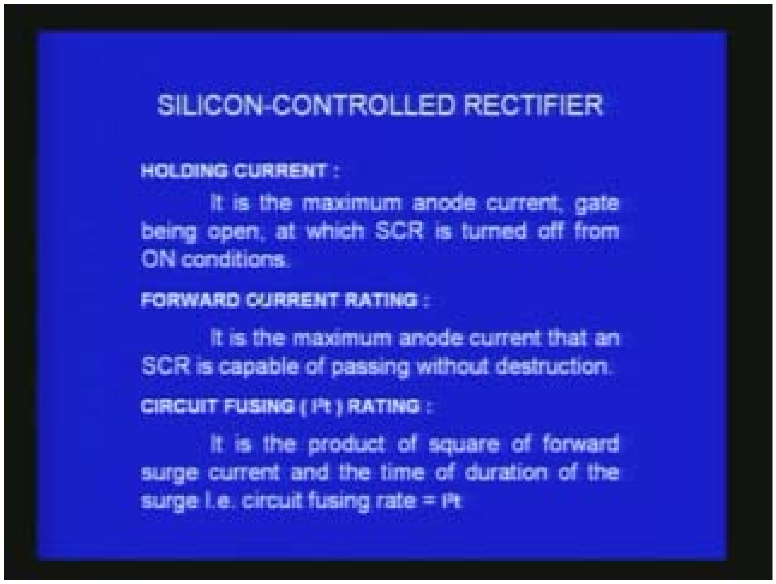

Forward current rating, circuit fusing, etc are all also important points and I am going to use a SCR which is called C106.

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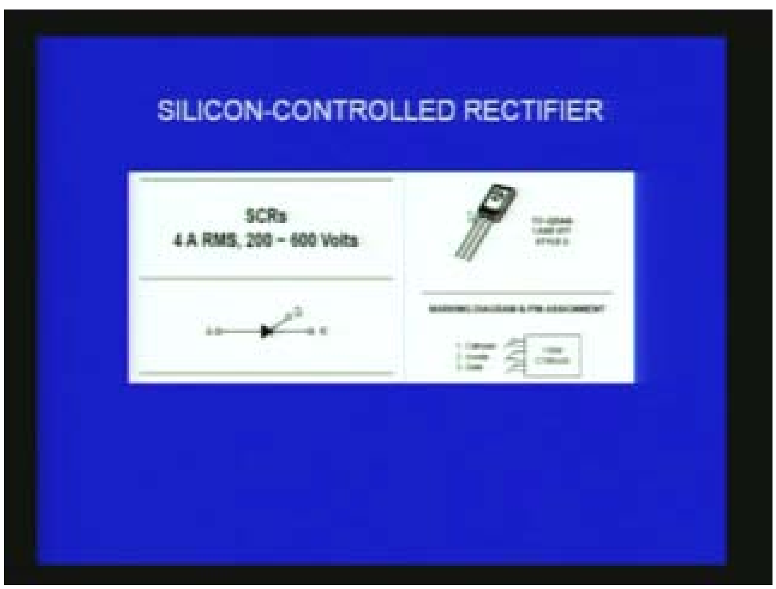

This is a TO225AA package. Here I have got 3 leads and the A, K, G leads are shown here, the cathode, anode and the gate and it is capable of handling 4 amperes of current and 200-600 volts you can apply between the anode and the cathode. These are the characteristics. There are few more characteristics here.

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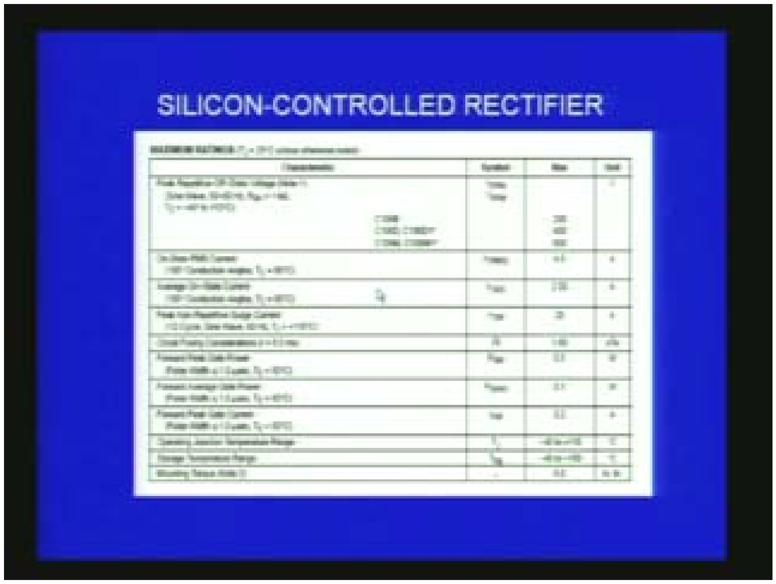

The most important point in all devices is that one should learn from the data sheet. You must look at the data sheet because data sheet is the data given by the manufacturer. He gives you all the limits within which his device can be operated. One should carefully go through that and you will find that 200, 400 or 600 volts you can operate with this device and different variations and the RMS current is about 4 amperes. All the important details will be available here. One should go through and try to understand the characteristics of the device. They also give you the characteristics. How it will look like? You can see exactly similar to the one I showed you. That characteristic is shown demarking correctly the various regions of operation.

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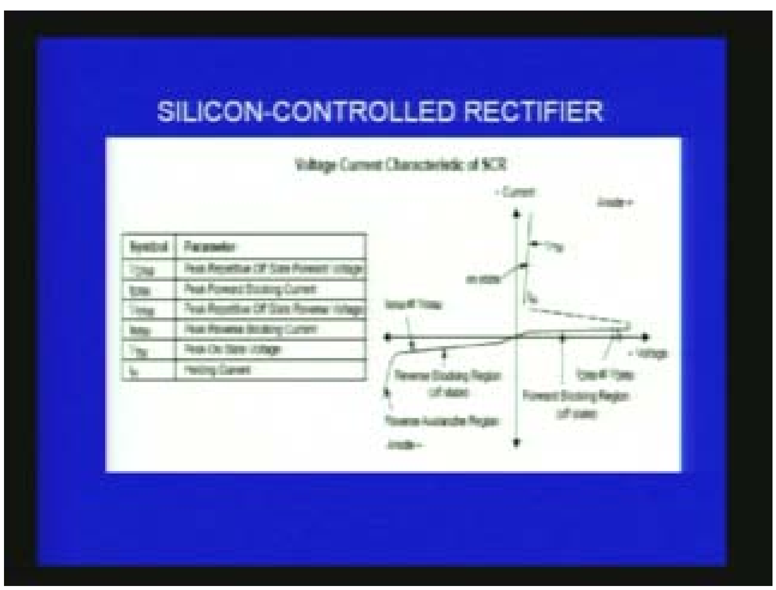

With this let me show you an actual demonstration with SCR and we will see the characteristics. Look at the circuit here. It is the same circuit which I discussed. You have a current meter for measuring the anode current.

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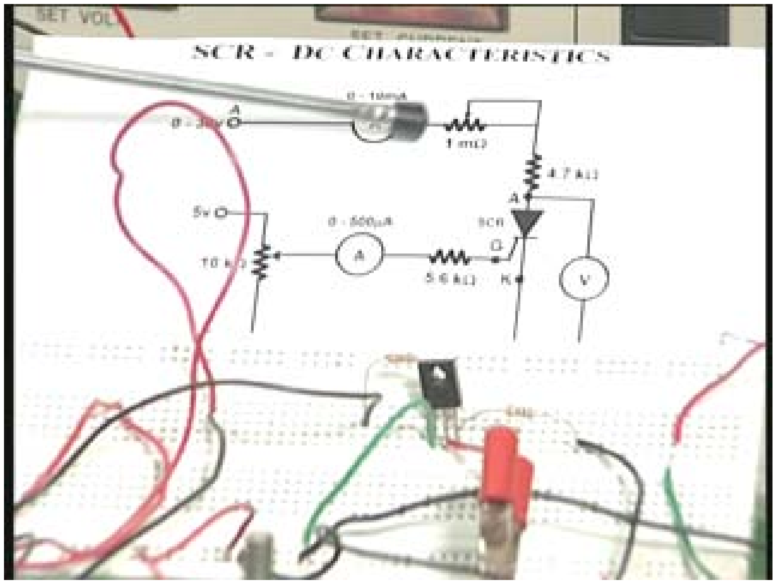

You have the 1 meg ohm resistor. This is the 1 meg ohm resistor that you have in the circuit here and you have another 4.7 k resistor and then this is the SCR; the C106 TO225 package is here and then the gate. The cathode is connected to ground and there is a voltmeter. I have a voltmeter connected there. The gate I have connected 5.6 k ohms and a small 0-500 micro ampere ammeter and there is a 5V potentiometer with a 5V supply which can vary the voltage and thereby I can change the current. This is what I have. Exactly same as the one I explained to you. The actual deice is here and the resistors are all connected and the wiring is done. This is for measuring the gate current and this is measuring the anode to cathode voltage. I have maintained it at 19.8 or nearly 20V and this gate current is almost zero now. There is no gate current.

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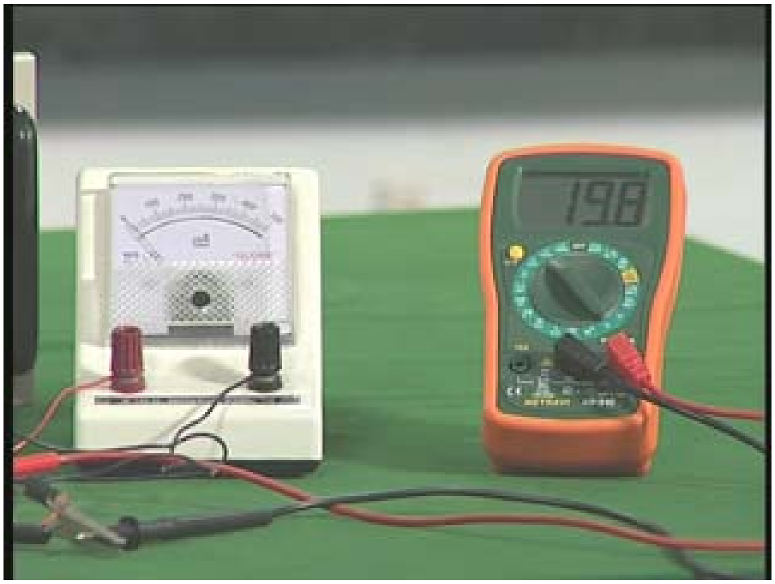

There is also another multimeter here which is measuring the anode cathode current and it is in milli ampere position and it is very, very low, 0.002. What I am going to do is I am going to vary this position so that I will apply larger and larger voltage. It is now in the minimum position. Now I will increase it so that there is a current. Observe this micro ammeter for the gate current when I am changing. I have kept these two close together so that when the current here becomes large, the voltage here will become less. That means the SCR has broken down. It has come into conduction state and this voltage will become less than 1 volt. When this current reaches a critical value, this will happen. I want you to observe these two. Now I am going to change the gate voltage so that the current starts building up here. Please observe only those two meters when I change. Now you can see that a large current of nearly 300 micro amperes is flowing and what has happened here? It has come to 0.5 V.

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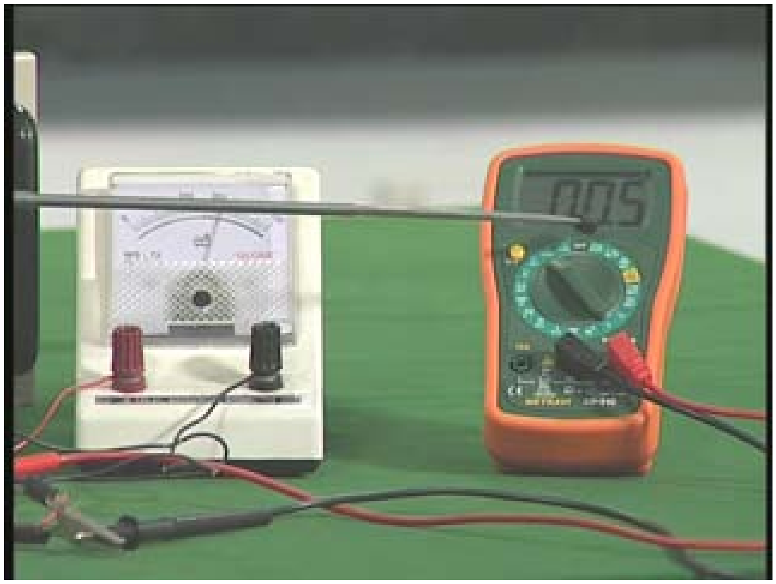

When the large gate current triggers the SCR, the SCR is ON so the 20V which we applied has become 0.5 which clearly shows the SCR has come into conduction state. This is the gate current. Now I am going to reduce the gate current. Keep observing only here. See what happens? I have reduced the gate current to very low value as you can see here; almost zero and still it is only 0.5 volts. That means the SCR is still conducting. If I want to bring the SCR to OFF state only way I can do is by increasing the resistance in the circuit. Another potentiometer I am going to vary. Look at this current here. Now the current is decreasing because I am increasing the 1 meg ohm resistor in the circuit. When it comes to very low value then it will suddenly become zero. That means the SCR has come into the OFF state. I am decreasing now; 24, 23, 19, 17, 14; very low value 0.15 milli ampere. If you look at the voltmeter, it has come back to 21 V.

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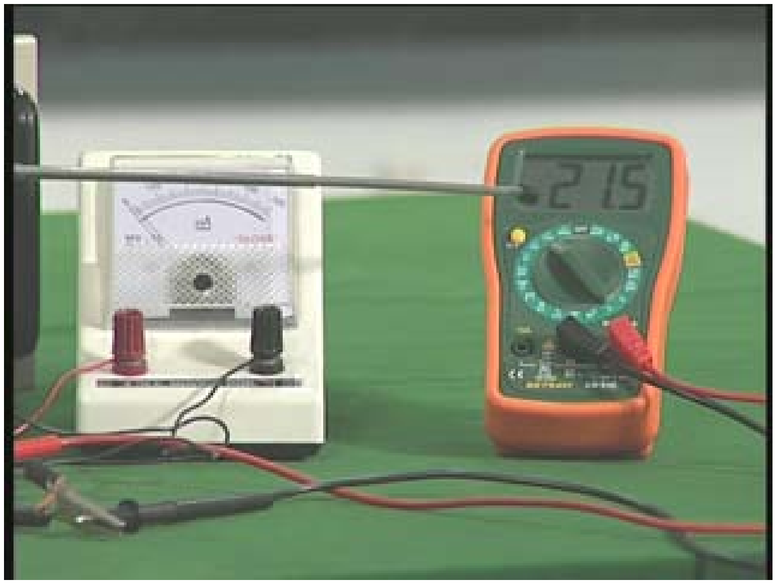

The SCR has come into OFF state when the current came below the holding current. The holding current is about 7 milli ampere. When I bring below 7 milli ampere, again it has come to ON state and it is showing 20 V. We saw the DC characteristics of SCR where we applied a DC voltage on the gate and we also applied a DC voltage on the anode to cathode and as I increased the gate current the SCR came into OFF state. When I reduced the gate current the SCR was still in the ON state and finally when I reduced the main current below the holding current, the SCR came into OFF state.

SCR is not used for DC. We have to use it in AC. The great advantage of using SCR in AC is that in the AC signal every time The frequency of the AC signal that we apply is 220V, 50 Hz. 50 Hz is the frequency, that means the voltage goes from +220 to -220 V 50 times in a second. When the voltage goes sinusoidally from zero to 220V and back to zero automatically the anode to cathode voltage is brought below some minimum value and therefore below the holding current and therefore the SCR will come into OFF state. When I switch on the SCR during the positive half cycle, while it goes through the negative half cycle automatically it goes below and the SCR comes into OFF state every time without any effort from our side. If I now make the SCR conduct at a particular point, in every half cycle the same point that is the current required at the instantaneous voltage for the SCR to switch ON and the SCR will switch on only at that voltage.

If I keep the gate current corresponding to 100 V on the anode to cathode voltage, then SCR will always trigger only at 100V. After that only the voltage will be applied across the load. What you get across the load will be a distorted sinusoidal output. For example I have shown you this circuit here. I have put the gate current also from the same AC. The AC is connected to the anode and the cathode with the load here and I have also connected a potential divider derived from this and I have put a diode. It is rectified and I have a DC current here flowing which is also in the form of sinusoid now and when I increase this position it can trigger at 90 degrees. In this sinusoid this corresponds to zero volts, this corresponds to 90, 180, 270 and 360. That is corresponding to one cycle.

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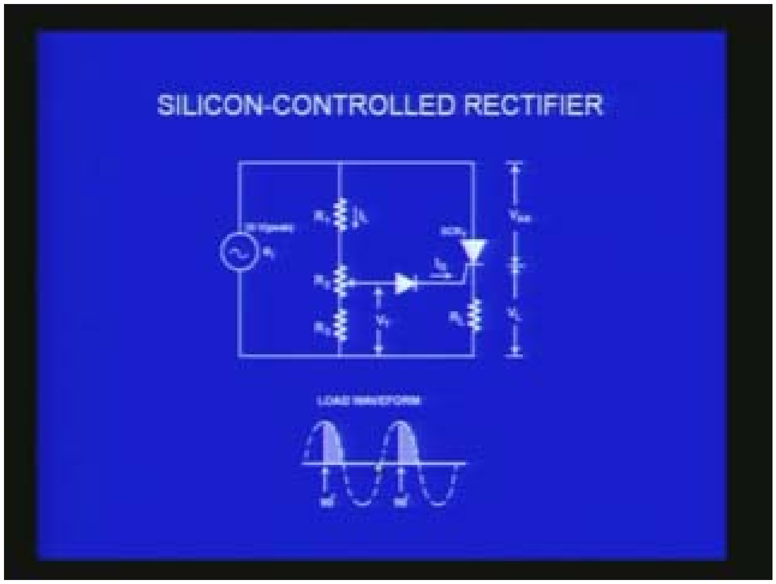

When I take the one cycle at this point, at 90 degrees the current is sufficient. At 200 volts it will break down. Beyond that the voltage will become 0.5 or less than 1 volt across the SCR. The rest of the voltage, 200-1 volt is applied across the load and load gets the power delivered. The shaded area is actually the voltage applied across the load and that corresponds to the energy delivered to the load and when it comes to zero automatically the holding current comes to very low value and SCR comes into OFF state and in this region the break over voltage is very large. It is reverse biased SCR and it is not ON and again it is not ON till I reach the same point, 90 degree point on the next half cycle. That is the current that I have kept here and again it conducts. Like that for every half cycle only a portion of the half cycle is delivered across the load.

If I reduce the current I can make it switch on here, here or here. That means in any angle between zero to 90 degrees I can switch the SCR ON. But I cannot go beyond 90. When I want to go beyond 90, there is a corresponding point below 90 and SCR will trigger here itself and it will not wait for this to come when the gate current is available and if I want to control more than 90 degrees then I cannot use a DC like this. I have to use a pulse. If I use a gate pulse then I can shift the pulse to this point or this point so that it is available only at that instant and at that instant whatever is the magnitude of the gate current for that the voltage will be applied at this point and it will trigger at the point and I can vary this conduction angle by more than 90 degrees if I use pulses on the gate circuit. That is what is shown here. I am applying different pulses and I can shift the pulse with reference to this zero point anywhere and correspondingly make this conduct at any point. For here it is conducting beyond 90 degrees here and below 90 degrees here.

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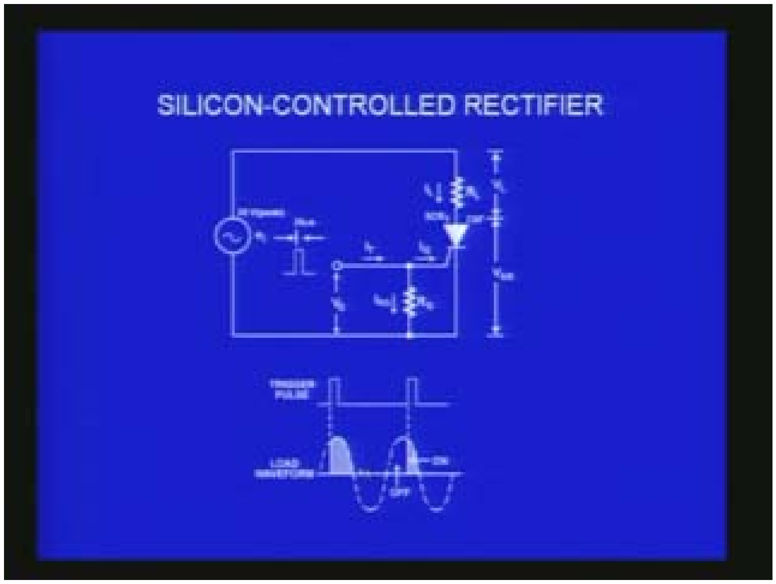

The area here is different. But this cannot happen in different cycles. It has to be the same and these pulses will have to be synchronized with the AC pulse and that is one of the difficult parts. We can also do it by other means. For example what I have shown here is a simple thing. I will also show a demo.

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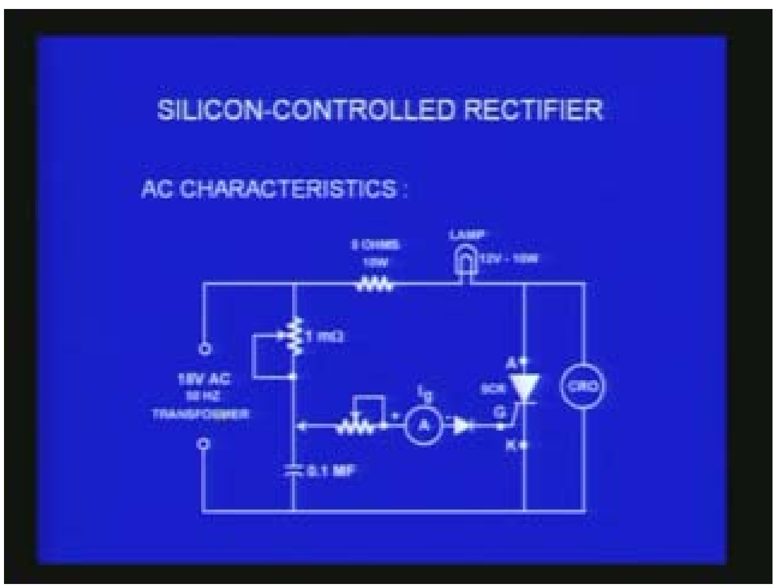

I have applied voltage source here and I have got a RC combination here, resistance and capacitance and the RC combination can give you a phase shift and that phase shifted sine wave is what I am applying after rectifying through the diode as the gate current. Thereby I can change the AC, convert it into rectified DC that is coming through the gate change the position by changing the phase shift by using this RC combination and thereby I will be able to control more than 90 degrees on the gate pulse and I have put a lamp here. This is one of the very important applications. Lamp is a non-inductive load and it is very simple to show. I am showing a 12V, 10W auto lamp and its intensity can be controlled by controlling a potentiometer which is in the gate circuit, not by a potentiometer in the main circuit. If it is in the main circuit, the dissipation will be large. If it is in the gate circuit, the gate current is in milli amperes and the dissipation will be very, very small and I will be able to control the intensity by controlling the amount of energy delivered to that by switching the SCR at some desired points from 0-180 degrees. That is what I am trying to do and we will also see the wave form on the CRO when I do that. I like to show you this demonstration before I go into the other aspects of SCR.

I want you to see the circuit here for the AC characteristics. You have an input AC. This is actually got from a high current transformer and I have two RC networks and then this is the small load here. This is a lamp and then the SCR. This is the CRO. I measure the voltage across the SCR through the CRO so that I can see the wave form and the angle control and the gate current is derived from the RC network. There is a phase shift here by 1 by omega CR and that is being applied after rectification because it is still AC. I have rectified it by using this diode and give only the DC current at the gate between the gate and the cathode.

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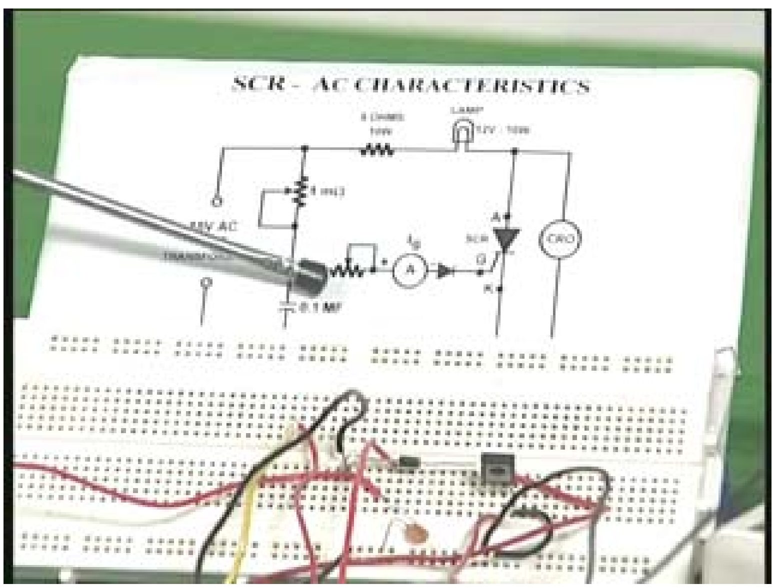

The same circuit is wired here. Exactly in the same way there is a capacitor and the resistor and there is also the diode and what you have here is a transformer. This is a transformer. The input is the 220V mains and the secondary is around 18 V and that is connected through an auto lamp and a small resistor here to reduce the voltage and this is the resistance that you find in the circuit. This resistance is mounted on the panel here. This is the resistance which is changing the RC phase shift and when I change this intensity of this light will become different. I can control the intensity. Look at the lamp.

As I change the phase shift, the intensity is increasing. That means SCR is triggered even before and more voltage is applied. Now it is very bright.

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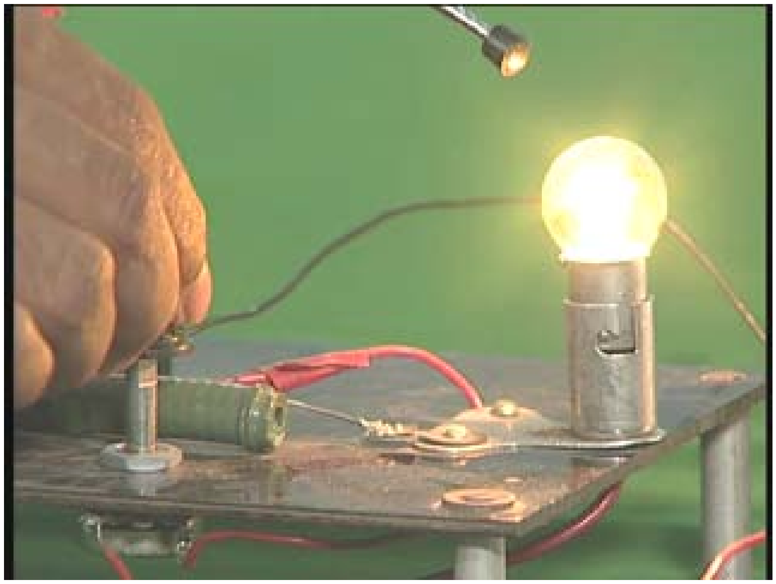

I can change the intensity of the lamp by changing the potentiometer which is in the gate circuit. That is what I am trying to do. That means the energy dissipated in this potentiometer is very small because it is in the gate circuit which is handling only few milli amperes of current. But this voltage, the voltage applied across the load is a large voltage and that can be controlled very easily using this arrangement. This is the knob that you see in a fan regulator also. But the circuit there is slightly more complicated because it is an inductive load. You have to use some filters because what you get ultimately will be a pulse. Look at the oscilloscope figure.

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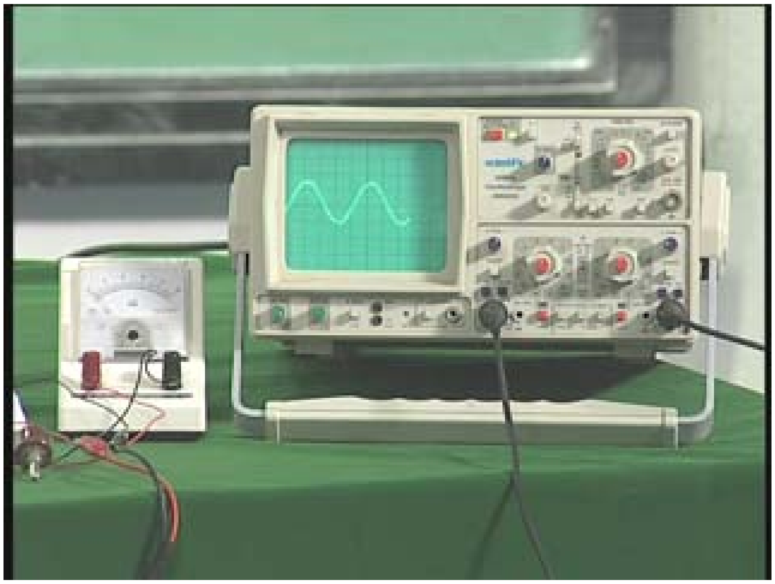

Initially the entire sine wave is seen. When I change the potentiometer, it is triggered at this point.

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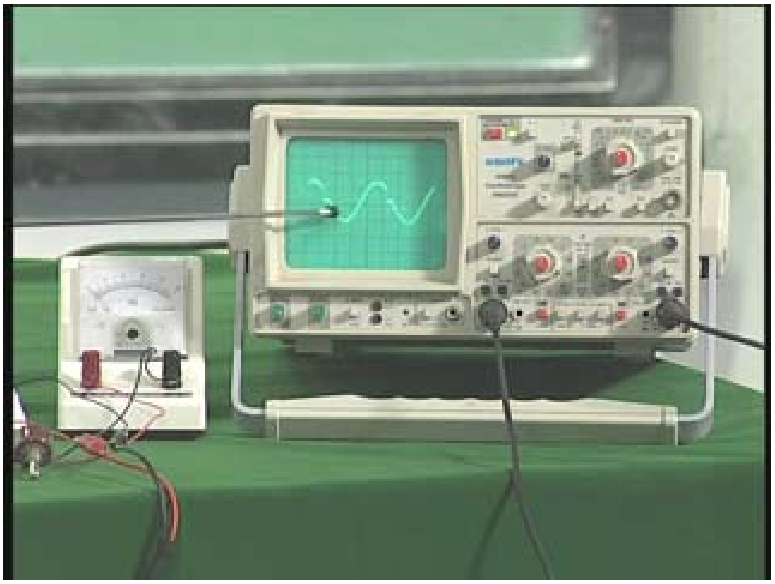

This small portion is the portion which is going into the ……. If I increase the potentiometer, the horizontal portion increases. That means it is now triggered almost 90 degrees.

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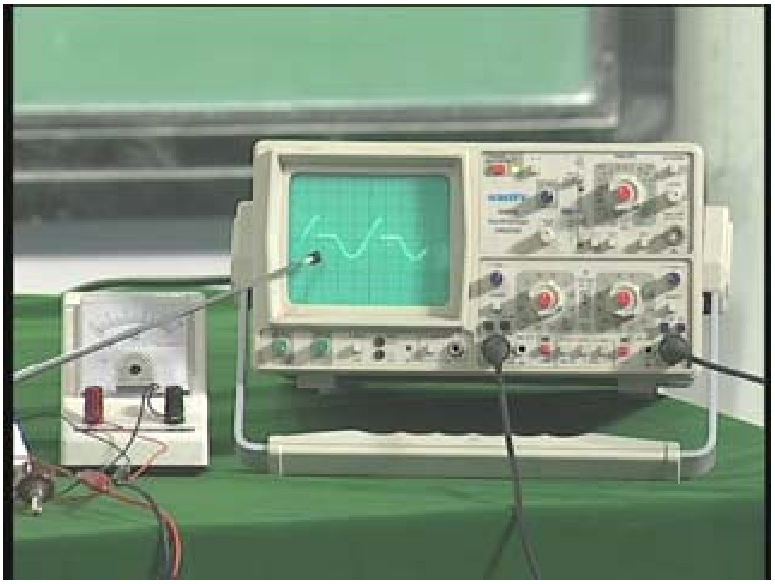

Now it is beyond 90 degrees. Only this amount is across the SCR. The rest of the voltage is applied across the load. That should correspond to very bright lamp. You can see the lamp is very bright here also. This corresponds to this signal. It is only triggering, even at this point when it will be about 5-6 V. Then the entire 18 volts, this peak, the entire voltage is applied across the load. The load is very bright. If I increase that this side is very, very small. It is beyond 90 degrees and the voltage applied across the load will be very small. If you look at the intensity of the lamp now it is very, very small. The energy applied to the load is changed by changing the angle of conduction and that is what is clearly seen here.

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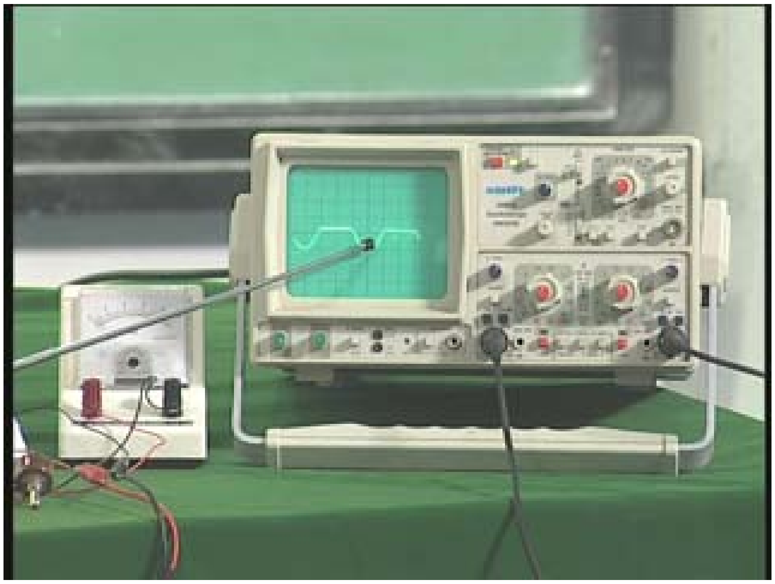

Now it is almost full bright and then if I reduce it the variation can be changed corresponding to the wave form that you see here. This is corresponding to the AC control of the SCR. When I use AC I am able to control the actual power delivered to the load, in this case a lamp. The most important thing is because I have used only one SCR I am able to get only half wave rectified signal across the load and that half wave rectified signal can now be controlled. The energy delivered which is normally the area under the curve can be controlled by changing the switching at different angles along the half wave rectified signal. That is the principle of controlling the energy.

What happens when I want to go for full wave?

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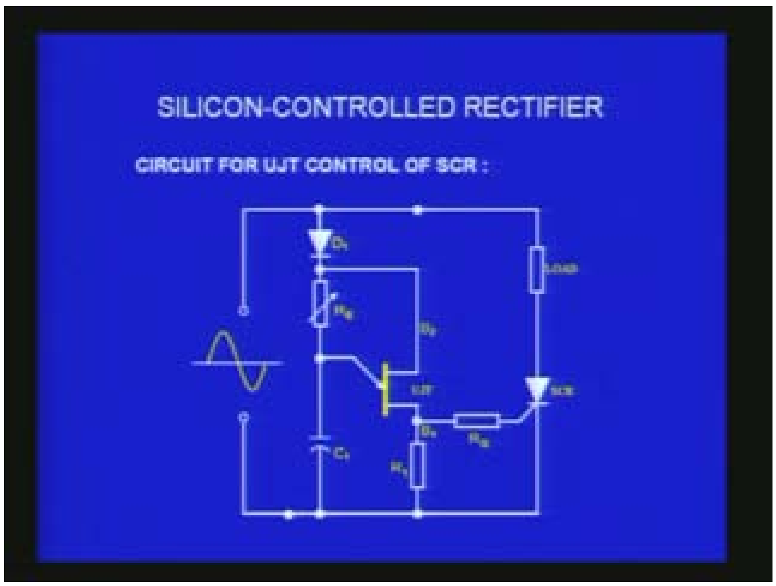

Many of the fan and other devices require a full wave, full wave AC control. If I want to do for full wave then I have to use 2 SCR's for both the things. Instead what we do is we go for what is known as a TRIAC. I already mentioned to you. You see on the screen this is a TRIAC, triode AC. When I use a TRIAC again you have same two anodes A_1 and A_2. There is no cathode because the signal can be both this side positive, this side negative and this side positive, this side negative when the AC changes and both A_1 and A_2 are called anodes and you have a gate. You have a single gate only. If I use 2 SCR's I will have 2 gates which have to be controlled. A TRIAC is cleverly designed by controlling the layers and you find only one gate. By controlling it you can control both half of the AC signal, make it to conduct at any desired angle. If I do it at 60 degrees on the positive cycle again at 60 degrees on the negative cycle it will trigger and there will be a corresponding pulse both on the negative side and the positive side.

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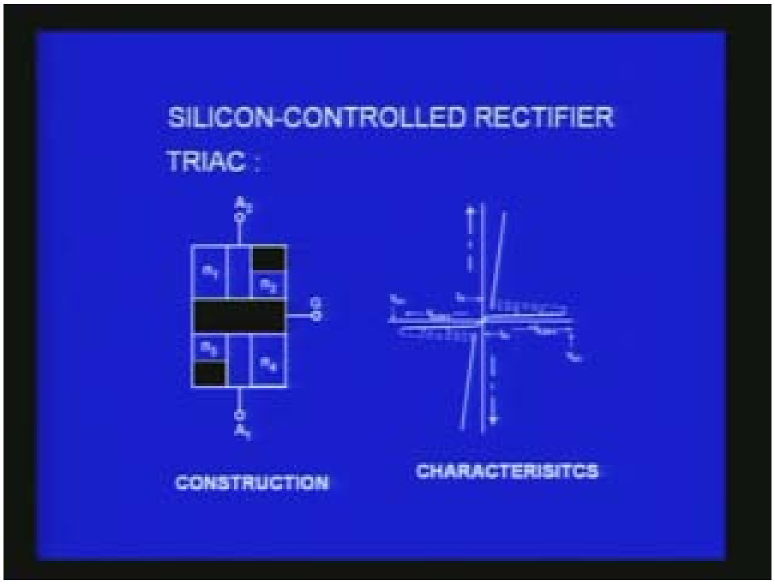

The characteristic of the TRIAC is something like this. Just as you have a forward bias characteristic you also have a similar reverse characteristic. It is exactly identical reverse characteristic and rest of the things are all same. You can have different gate currents and you also have a holding current. These are the characteristics of a TRIAC briefly because it is a basic electronics course I do not want to go into more details of the actual construction and design. This is the equivalent circuit of the TRIAC.

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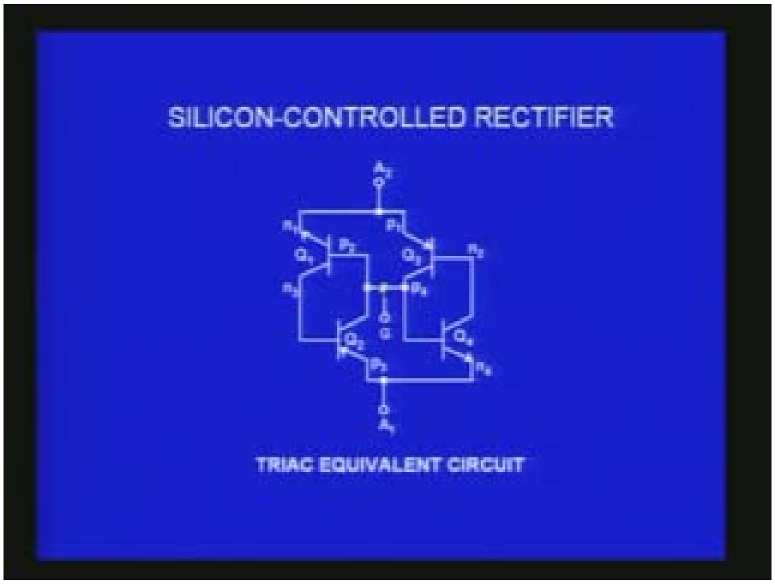

I would like you to read little more on those. This is the symbol of a TRIAC.

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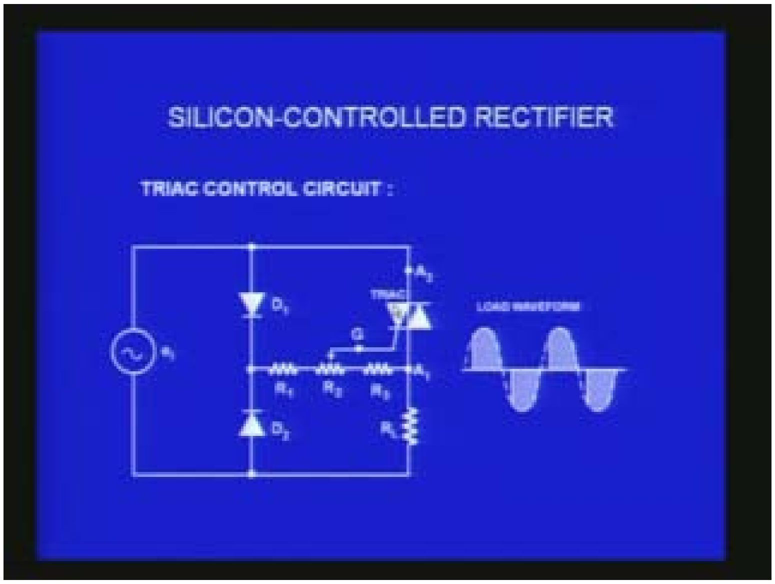

You have 2 diodes in both or opposite directions. This is anode for this diode and this is anode for this diode. That is why it is called A_1 and A_2 and you have a single gate and the circuit is very similar to what we have seen already. You are controlling the gate voltage. Thereby the area under the graph is what you have as the energy supplied to the load and both sides you have this. By moving this potentiometer I will change the conduction angle here from 0 to 180 degrees. That means I can make the entire energy available at the load or no energy available at the load, but by controlling the current in the gate. That is what you should recognize and we get enormous energy saving in terms of the losses that can happen if I introduce such devices in the main circuit. This is a TRIAC and there is also another device called DIAC which is again a switching device and that is shown here.

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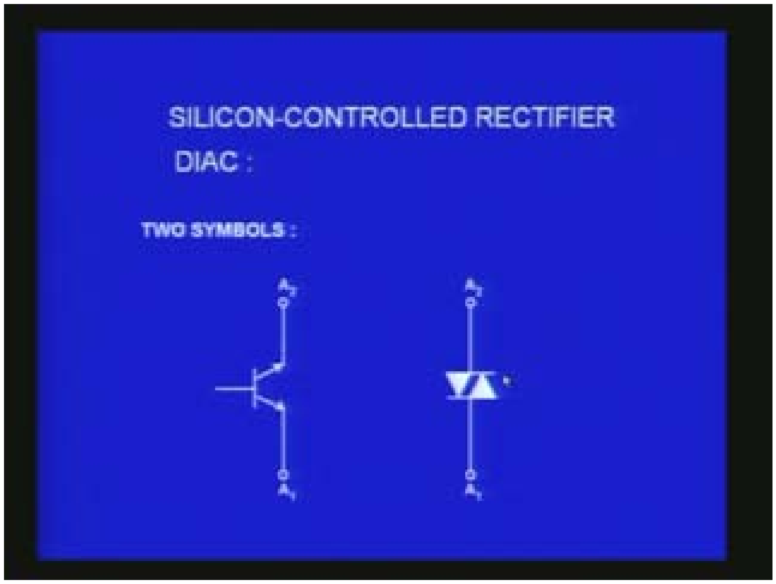

This is also combined along with the TRIAC to control.

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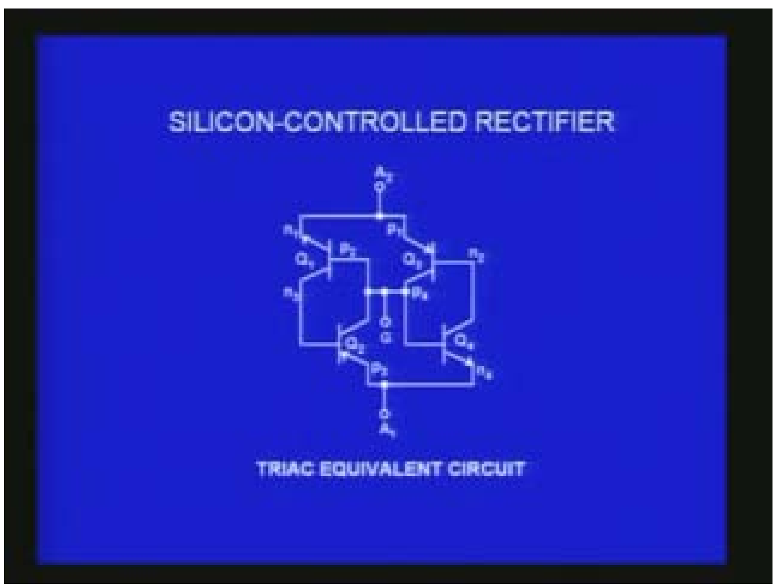

You may also have sometimes TRIAC and DIAC in one device which is called a QUADRAC. More important is applications of SCR. SCR can be used as a static contactor or for power control about which we talked about.

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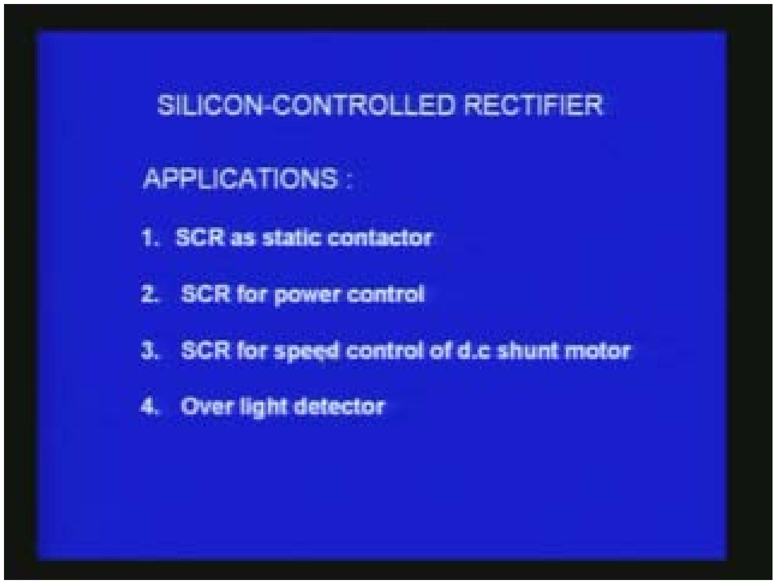

It can also be used as speed control for d.c shunt motor or over light detector about which I also mentioned. There is also another variation of the device which is called light activated SCR.

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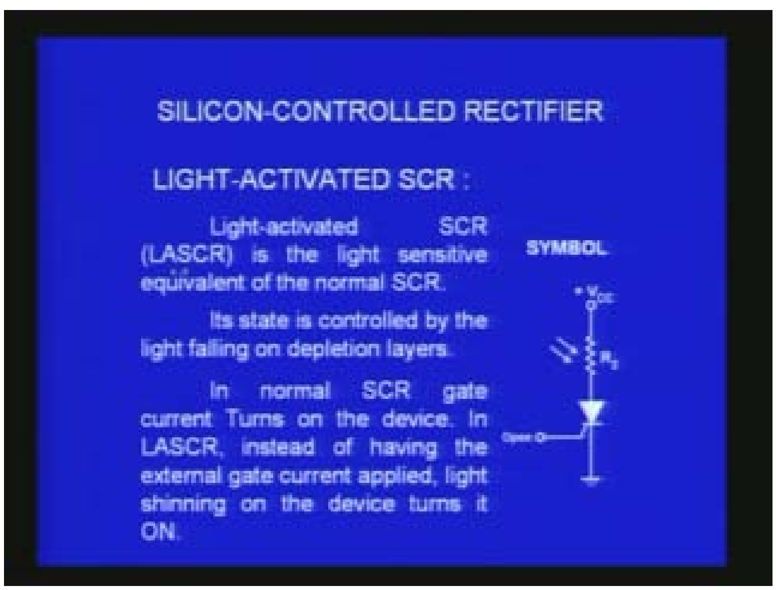

Light activated SCR is sensitive to light. Instead of the gate you send the light on the SCR. The resistance will change and thereby the gate current will change and so it will be activated. The state is controlled by the light falling on the depletion layer and the normal SCR gate current turns on the device. In light activated SCR, instead of having the external gate current, light shinning on the device turns it ON. This is very, very useful in light operated switches.

We already studied about UJT.

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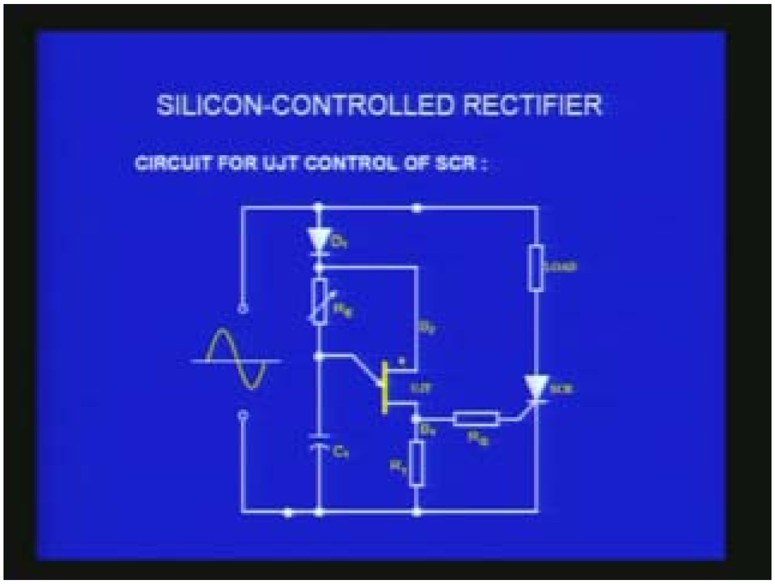

One of the very important applications of UJT is to apply controlled pulses on the gate of the SCR. I can combine an UJT and a SCR as shown in this circuit. With an RC circuit I take the rectified output and connect it to B_2 and B_1 and I put a resistance through an RC network and connect the emitter of the UJT to this. Depending upon the pulse, the eta V_{BB} plus V_D will be reached here and that will discharge the capacitor and I will get a pulse here. This pulse can now trigger the SCR at any given point. By changing this resistance I will be changing the phase and therefore the conduction angle of the SCR very easily. This circuit is something which you can try and see how UJT with the relaxation oscillator type of a combination can provide pulses to control and the SCR can be controlled. I have used the power supply from the same AC. Then only it will be synchronized. That is why I have used here and I am using this RC to phase shift the pulses and I will be able to use the UJT to control the gate of the SCR. There are different types of circuits available for controlling the SCR. SCR is a very important device to be used for power control applications and the variations of the SCR like TRIAC, DIAC and light activated SCR are also very useful in different application circuits. Thank you very much.