BASIC ELECTRONICS
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LECTURE-8
WAVE-SHAPING USING DIODE

Hello everybody! In our series of lectures on basic electronics, learning by doing let us move on to the next topic.

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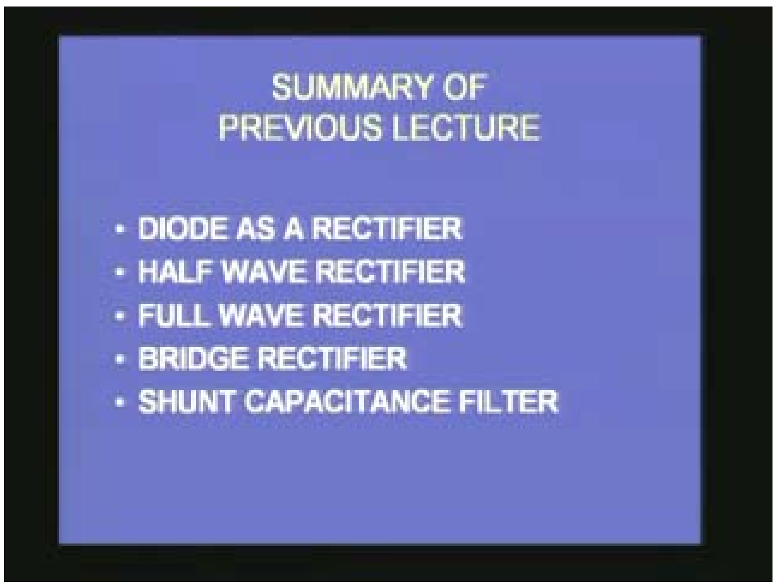

Before we do that let us quickly recapitulate what we learnt in the pervious lecture. We are now discussing about semiconductor p-n junction diodes. We saw in the previous lecture, diode as a rectifier as one of the applications of the semiconductor diode. We saw different types of rectifiers, half wave rectifier, full wave rectifier, bridge rectifier and also we saw shunt capacitance filter because we do have after rectification some ripple voltage which is some component of AC voltge along with a large amount of DC voltage. In order to remove the ripple which is an AC component we used a shunt capacitance and showed how that considerably reduces the AC component in the voltage output. Let us continue to discuss about other applications of p-n semiconductor junction diode.

I want to talk to you about wave shaping diodes. How diodes can be used for shaping different wave forms.

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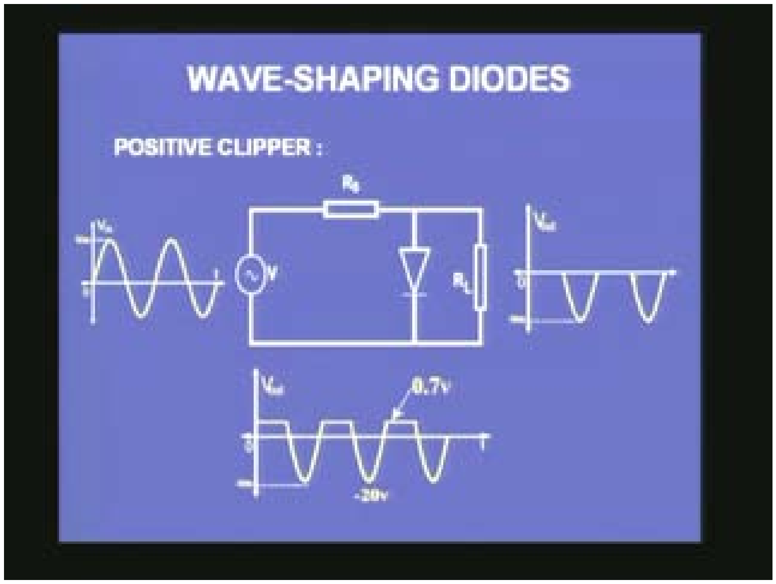

Normal wave form that you have and easy to get is the sinusoidal wave from the AC mains for example through a transformer. If you use a step down transformer you can get very low 6V or 9V AC voltage. Can I have different wave shapes developed using semiconductor diode from this sine wave? You can see on the screen the positive clipper where you have input sine wave connected to a simple circuit which has got one series resistor, one diode in this direction and one load resistor. If you monitor the voltage across the load resistor you would find it will have only the negative half of the sine wave. It has clipped the positive. Therefore it is called positive clipper. In the original sine wave which is given as the input you find you have both half like normal sinewave voltage. But after it passes through a simple diode, we know this already, this circuit we call this by a different name previously. We called it half wave rectifier. You have only half of the wave. This is one kind of the wave shape that you obtain by using a simple diode which is in this case a simple half wave rectifier. But you know how the circuit works also; I am sure.

When the voltage goes positive the diode is conducting because this end becomes positive compared to this end. The diode will be forward biased and so it offers low resistance. Entire positive half will go away like this. Nothing will come to the load. During the load it shows zero. But when the negative half comes this becomes negative and the diode becomes open circuit or high resistance and the entire load appears across the load. The negative voltage comes as shown in the graph. Similarly for the positive half there will not be anything and the negative half again you will get output. One half or the positive half of the sinewave will be clipped and it is called positive clipper. But you should remember this diode if it is a silicon diode, it will always drop about 0.7V when it is conducting fully and whatever voltage you get will be less 0.7 or the other way to look at it is when the positive half comes it is conducting and then there will be a 0.7V across the diode which will be appearing across the R_L. That is why in the actual circuit output wave form that is shown here in the magnified version you can see there is a 0.7V residual voltage. This is coming here and this comes because of the silicon diode. If I use instead of a silicon diode, a germanium diode this is will be only 0.1 or 0.2V when it is fully conducting. It is a positive clipper but with a residual small voltage of 0.7 still retained on the positive side.

This is one of the very simple applications using diode to develop different types of wave forms. What will happen if I invert the diode? I change the orientation of the diode; in this circuit here you find the diode is inverted and you have the input sinewave. The same circuit; everything is identical except that the diode has been inverted.

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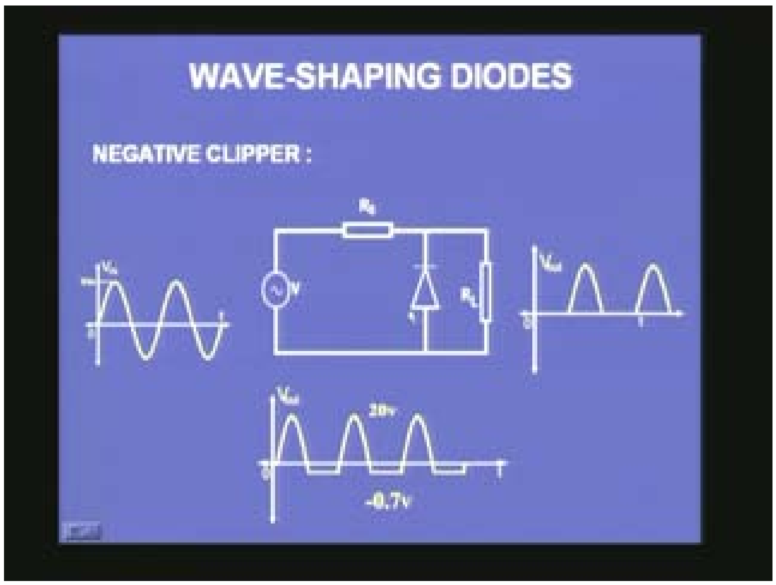

What is going to happen? It is a negative clipper because when this becomes negative, diode will become conducting. All the voltage will be short by this diode and nothing will appear across the load but when the positive half cycle comes, this end will become positive. That means the diode is reverse bias and the positive voltage will appear across the load. In the wave form the positive half’s are coming and the negative half cycles are not coming and this is a negative clipper. Here again you should remember in the similar case as before that when the diode is conducting it drops 0.7V across it. It is not zero volts and there is a residual 0.7V at the bottom of the wave form shown here. Both positive and negative clippers are two different types of wave shape circuits.

We can also add additional voltages along with the diode to make it a biased clipper, the clipper with an extra bias. For example I can add another battery over here. I will perhaps show you a demonstration later on. If I have a power supply here in whatever polarity, that power supply will come in series with the diode and when the diode will be conducting or not conducting will now be decided by the additional voltage source I have here and that case it will be called biased clipper. You can have two different types positive biased clipper and negative biased clipper. Thereby what I will be doing is I will be shifting the clip voltage up or down depending up on extra voltage source I add in the circuit.

We will move onto the next wave shaping circuit which is called a clamper. This clamper circuit is very, very useful. This is also called DC restoration circuit.

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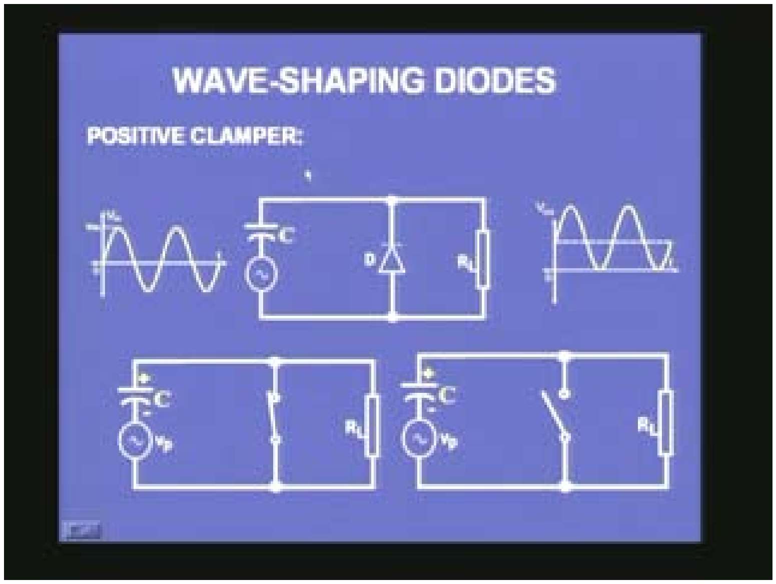

The average DC of this normal sinewave, you know, is along this. There is equal excursion on both sides of the zero. When I connect it to an ordinary voltmeter or ammeter it will read zero; because it is moving DC voltmeter will read zero. Because it is going up and down all the times at very high frequency, the average of this will be zero and that is what the normal voltmeter will show. You would be able to see that. But if I now push the whole wave form up so that the zero line comes over here at the bottom of the sinewave then it is called positive clamping. You have clamped it so that the entire wave form is only on the positive side. You can also clamp on the negative side thereby I shift the zero to the top, tangentially to the top of the sinewave. Then the whole form is only negative and therefore it will become negative clamper.

All these are possible with the same diode and one extra capacitor. You can see the circuit here. I have the sinewave which is shown here. That is the source, AC source from a transformer. You have a capacitor connected in series with the diode in the orientation shown here and there is a load resistance. When you look at the output wave form, the average of the DC line has been shifted up and the entire wave form is shifted up with reference to zero. This is called positive clamper.

How does the circuit work? Let us try to understand how the circuit is working. Let us go slowly. Look at the sinewave. The instant the sinewave goes negative this end will go negative and therefore this diode end will also be negative. Because the capacitor has infinite resistance, the same voltage will appear across here and this will be negative voltage and the diode will be forward biased. Because with reference to zero or the ground this will be negative and this is forward biased. That means during this negative excursion the diode will conduct and the entire voltage which is corresponding to the peak voltage of the AC input will come across the capacitor and the capacitor will get fully charged with the voltage which is equal to V_P; with this plus, with this minus these two. Once that happens, when the next positive half cycle comes, when this becomes positive here after for all positive this will be positive and this will be negative relatively and the diode will be open circuit. For all other future excursions the diode will have no more role to play. It has got role only for the first cycle when the input goes negative. It charges the capacitor to full Vp; afterwards the diode becomes almost open circuit for the rest of the time. Once it becomes open circuit or infinite resistance then this whole circuit is modified as AC source with the battery. The capacitor can be effectively considered as a DC battery with the voltage equal to Vp and that is coming here. A sinewave in series with the DC source Vp is coming in series and you have to add plus Vp to all the input sinewave that you apply. At the zero if you apply plus Vp, the zero will be shifted by plus Vp. That is what is shown at the output and every other point will keep on adding the Vp and the sinusoid will now be riding above a DC volts which is equal to VP and that is why the whole zero is now shifted by this Vp and you are able to get the full sinewave at the positive side only. You have clamped the sinewave so that the entire excursion is only in positive direction and this is a positive clamper.

I have shown here the equivalent circuit for the first negative cycle. When this becomes fully charged and this becomes on and once this happens then it becomes open circuit here. The diode is considered basically as a switch here and therefore this now becomes a battery coming in series with the AC and the output will become positive clamped. What will happen if I invert the diode?

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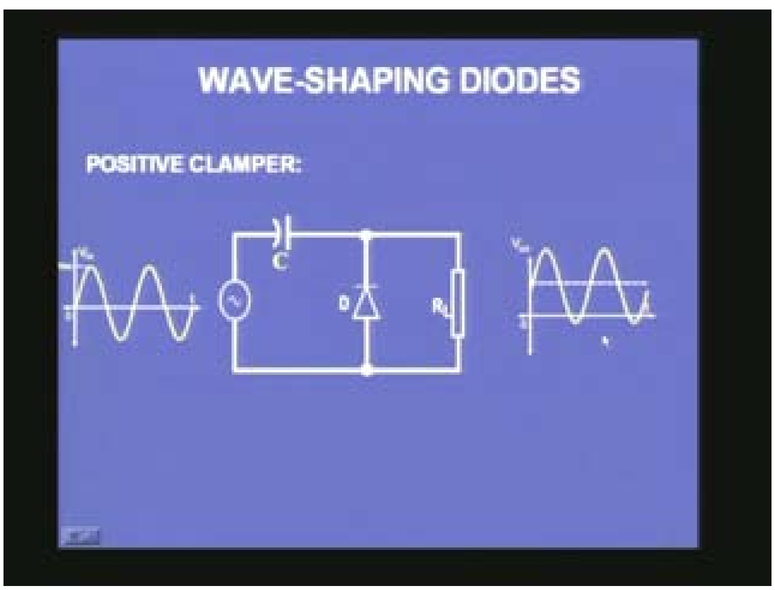

Here again you should remember that this diode is a non-ideal diode and there will be a 0.7V across that and it will not exactly be zero but it will be clamped at 0.7V. Actually 0.7 will be the loss that you would get with reference to the sine input that you have given and +0.7 to Vp and then to plus Vp etc., it will go and you loose a small information here with reference to 0.7V in the positive clamper. That we should remember.

Let us move on to the negative clamper. If I want to have negative clamper what we should do? I should just invert the diode. That is all I have to do. When I invert the diode then the whole argument again can be the same except that this diode conducts only for the positive half cycle and when that happens this capacitor will charge with this end positive, with this end negative and this becomes a DC supply with the polarity changed with reference to the previous case and once that happens then the diode is always open.

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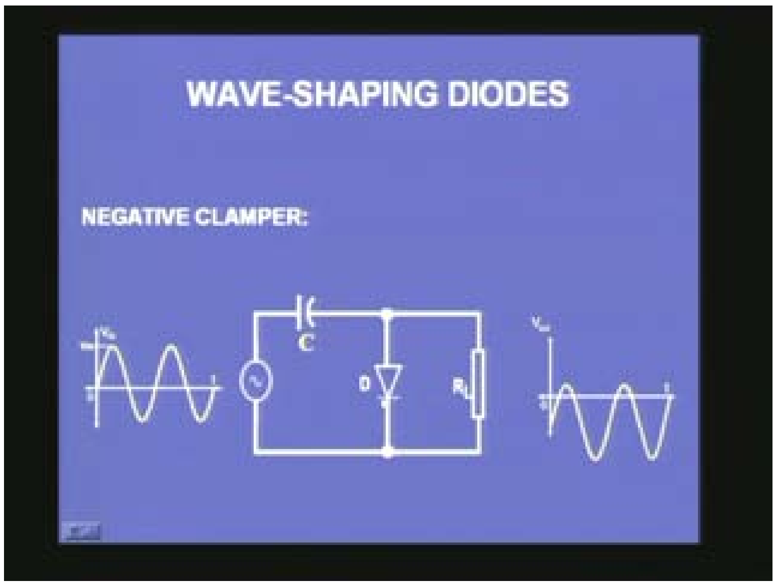

It is never forward biased after that and I have an AC source with a battery in series with this end plus and with this end minus and you start with minus when the V input is zero and then you keep on moving up and again there is a 0.7V which comes over here and you will be going from -0.7 to Vp. This 0.7 comes because the diode is a non-ideal diode. If it is silicon diode it will have a voltage across it which is equal to about 0.7 and that is what is shown here

Positive clamping circuit and negative clamping circuits are very, very useful in number of applications especially when you have a square wave which is moving both positive and negative. You want a square wave which is going from zero to some 5V or 10V. When you just put the diode and the capacitor as a positive clamper then you could restore the DC to the negative end and therefore it will become a full unidirectional voltage fluctuation or a square wave from zero to twice the peak value what you will get and if you use a voltage which is very large compared to 0.7, the entire thing will be available on the positive side.

I will quickly show you a simple demonstration with the simulation. I have a breadboard in which I have some of the circuits connected. Let me look at the positive clipper. You can see the diode is connected in the directions shown with this end positive and this end negative. You have a transformer here and you have an oscilloscope here. The transformer is switched on; I will switch on the oscilloscope. Immediately you can see the positive end has been clipped and what you get is only the negative excursion of the input sinewave.

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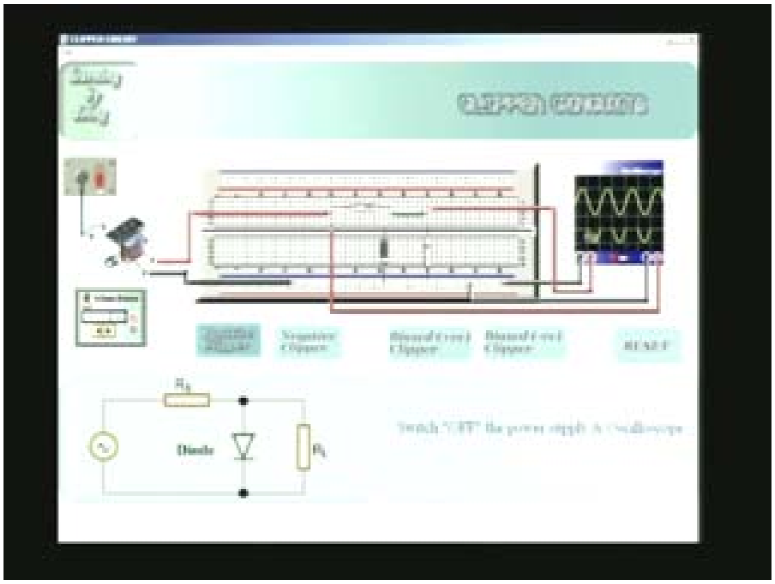

These are the load; this is a series resistor and this is diode connected in this direction. The circuit is shown here. The same circuit is implemented here. R_S, I have put the resistance here. In general this could be the internal source resistance of any AC input or the transformer as the case may be. If I want to look at the negative clipper let me switch off and take the negative clipper. I will reset now. You see the direction of the diode has been changed and the circuit again is shown here. The diode also has changed in direction. I will switch on the transformer. I will switch on the oscilloscope. Immediately you will find the negative half has been clipped and you get only the positive cycle on the oscilloscope. Both the input and the output are shown here.

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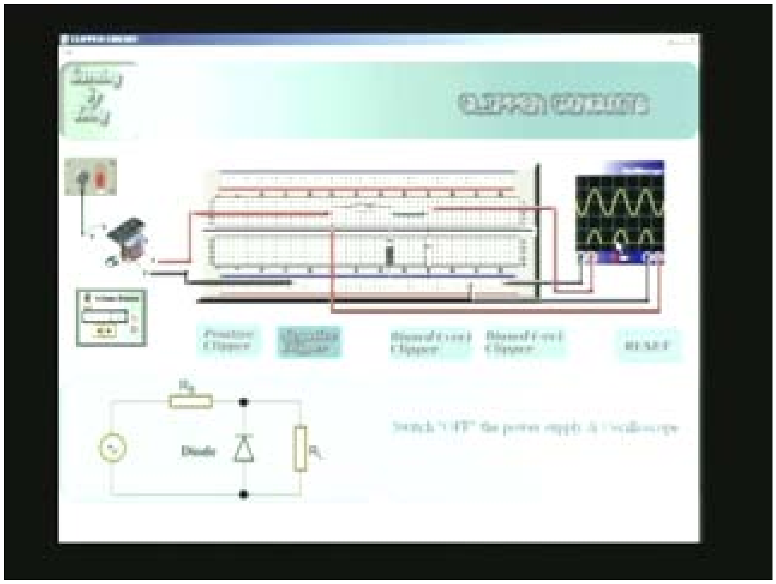

Both of them are very similar, as I already mentioned to you, to a normal rectifier. Let me quickly switch off and go to the biased clipper. Let us say a biased positive clipper. What is happening? You again have the same circuit with one R_S and diode for a normal positive clipper but in addition you have got a power supply here, DC power supply. I am using a voltage source and the input from the voltage source is connected in series with the diode as in the circuit. Now let us see what happens. I switch on here; I switch on the oscilloscope. May be I should switch on the power supply. Because the power supply is having zero volts it is equivalent to having no bias and therefore it is a same positive clipper that you had previously.

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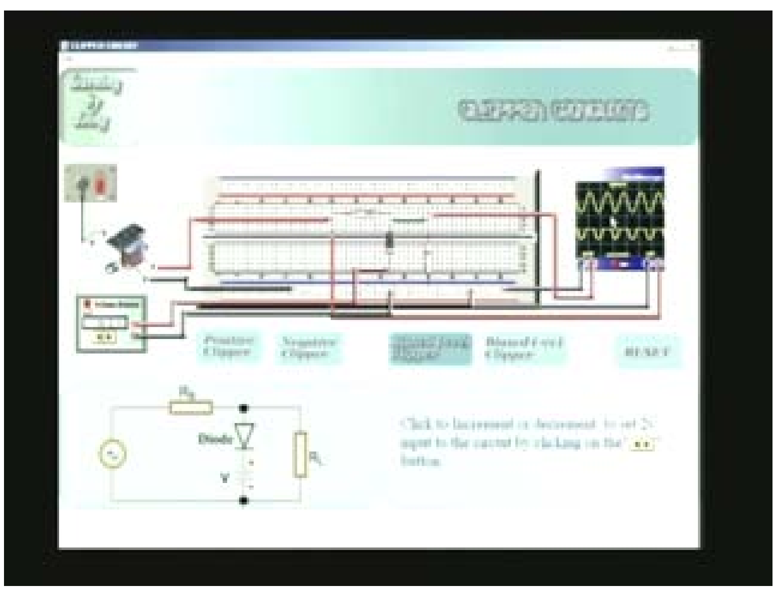

Let me try to increase the voltage. I applied 2V now. Immediately you can see the wave form has moved up little bit by the 2V because it is coming in series.

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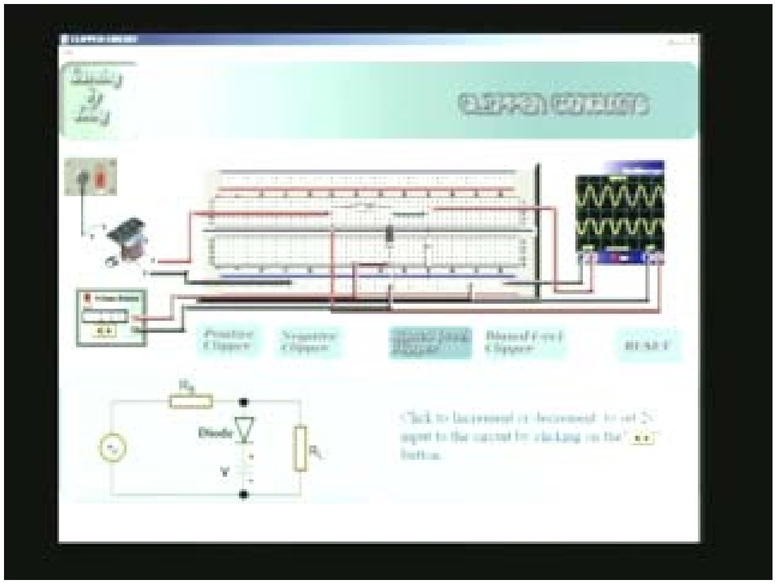

That means I must have here a voltage which is larger than this voltage. If this voltage is V, I must have V+0.7 to make this diode to conduct and that is what is shown here. This is the extra 2V that is coming here. Actually it will be 2.7V because 0.7V will always come in the circuit. I can increase to 4V, 6V as the case may be and thereby I will be able to shift this still further if I want. You can also have a voltage source in the opposite polarity and correspondingly it will be shifted in the other direction, the opposite direction. This is a positive biased clipper, with the positive bias.

I will switch off and move on to the negative clipper. Here again I have a diode inverted and you can also see the voltage source is also inverted. I switch on the power supply, the transformer and the oscilloscope. You can see initially the power supply is zero and it is nothing but the well know negative clipper.

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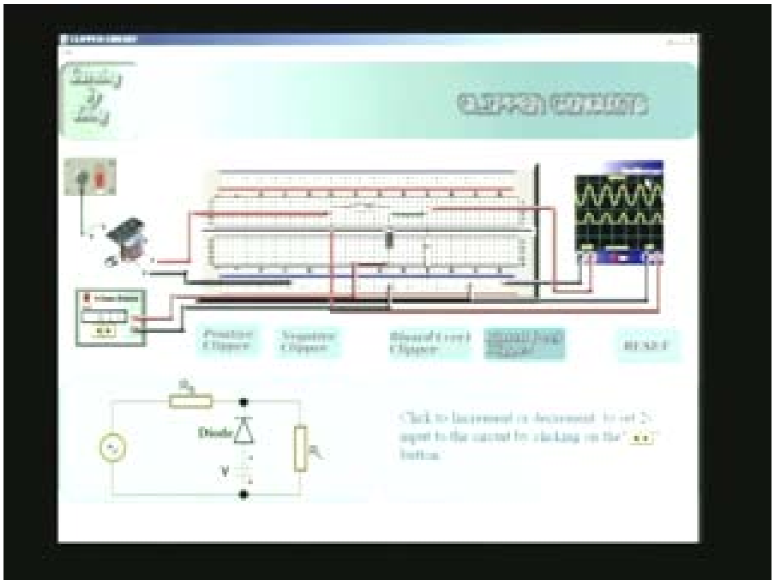

If I increase the voltage by about 2V you can see it is depressed by another 2V because it has to increase over and above the 2V for the diode to conduct here and that is the reason why this is coming in this way. The positive clipper and the negative clipper and positive biased clipper and negative biased clipper can be used for shaping the different sinewave. You can actually combine the two. That is you can have in parallel one diode connected and another diode in the opposite direction as a negative clipper and you can choose the voltages. Thereby you would find you can ultimately convert a sinewave into a square wave if you wish. By using two clippers in parallel, one positive clipper and other negative clipper with the bias also you can have the amplitude of the square wave to any value you want. I will switch off and perhaps I will show you a demonstration of the actual experiment and then we will move on to the next part.

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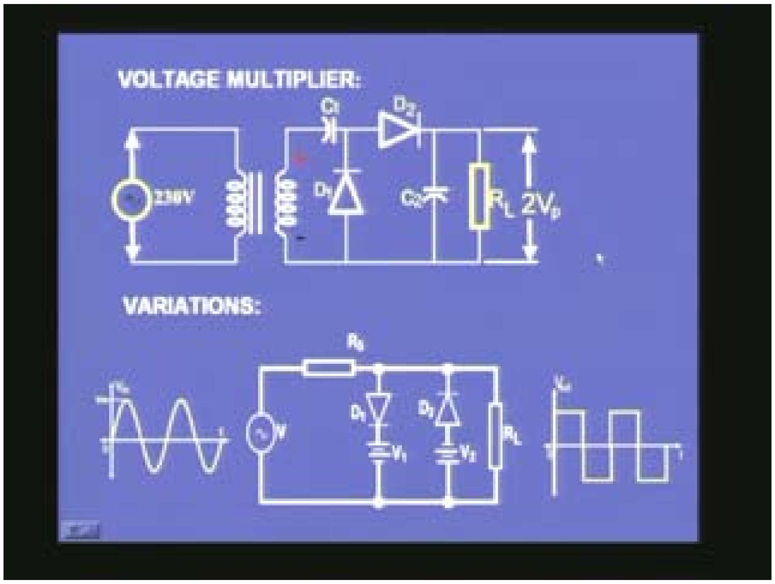

You can see on the oscilloscope a positive clip voltage. This is actually a negative clipper. You can see the negative half is clipped and you have only the positive half. The corresponding circuit is here. You have the resistors, you have the diode and you have the load and the output is coming from a transformer and the output is measured using an oscilloscope. Depending upon the direction of the diode, the diode is in this direction. Therefore you find it is acting as a negative clipper. The negative voltage has been clipped and you get only the positive half cycle.

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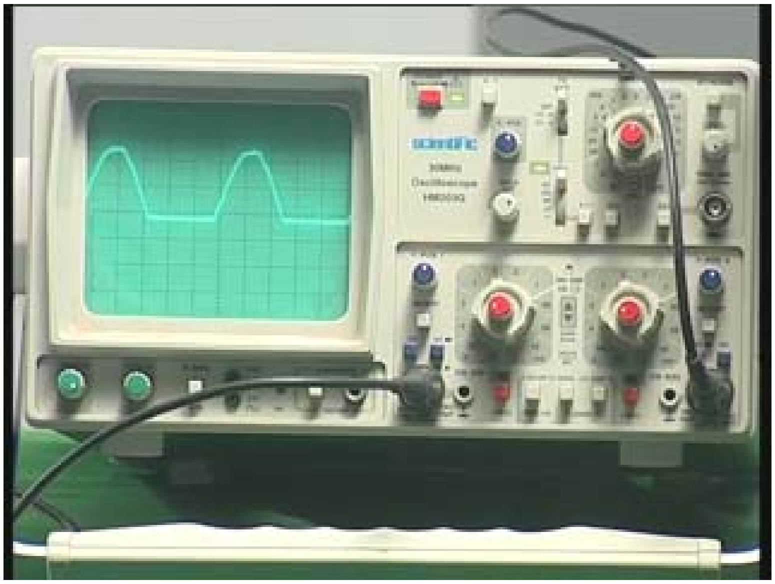

I can a give a bias to this from a voltage source. I will remove here and give the bias; negative to negative and positive to positive. I am connecting a voltage source in series with a power supply. You can see the zero has shifted. I will show you by just grounding that. You can see this is the ground. It is at the center. When I release it you can see the zero has been shifted below due to the additional power supply that is out coming here.

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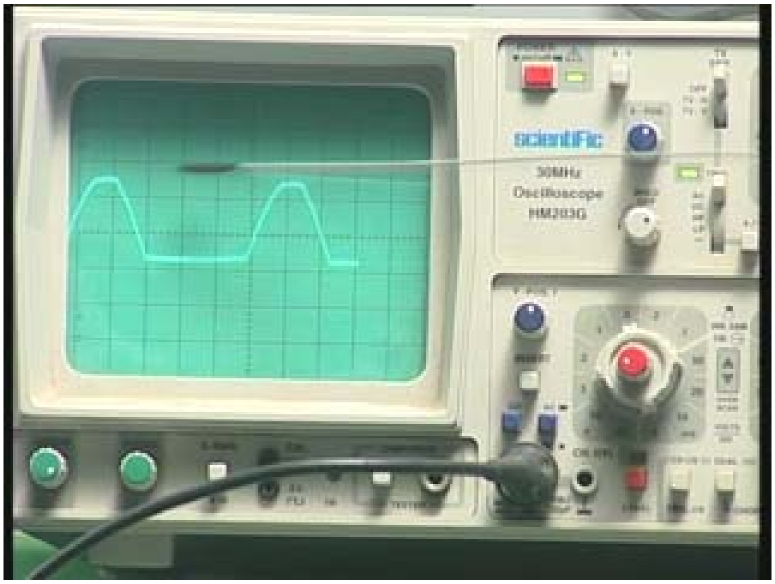

So the total voltage will be around 9V, peak voltage and these two voltages are shown here as small depression. The most important point is the zero of the line is here. When I ground the input of the oscilloscope you see the ground line. When I release it you can see it is moving down. I switch off the power supply and then we will restore the negative half cycle.

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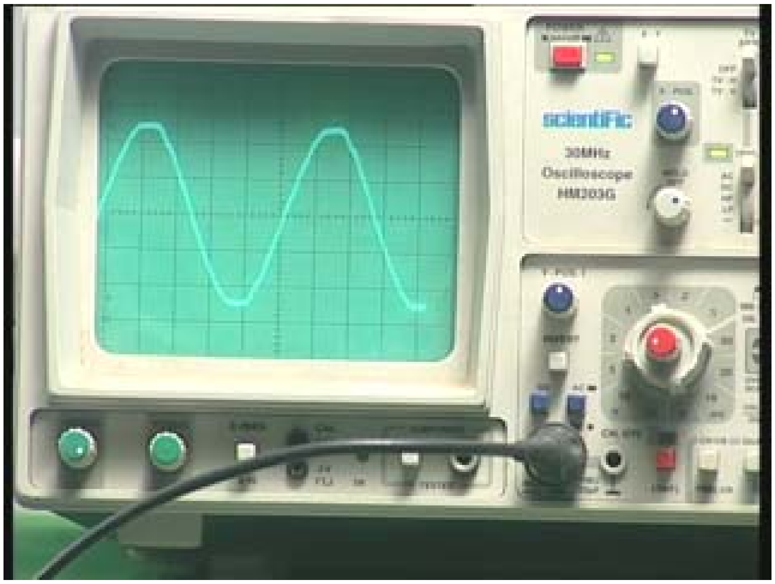

Right now you get the full wave which is the input wave. The moment we restore you would find there is a depression. When I applied 2V this was shifted up little bit corresponding to the input DC volts.

We will move on to the next which is actually a positive clipper. For this you know what we have to do. We have to interchange diode. The rest of the circuit is identical and when the diode is reversed you would find the zero. This is about 0.7V. The zero is here and when I release it, it is moving up.

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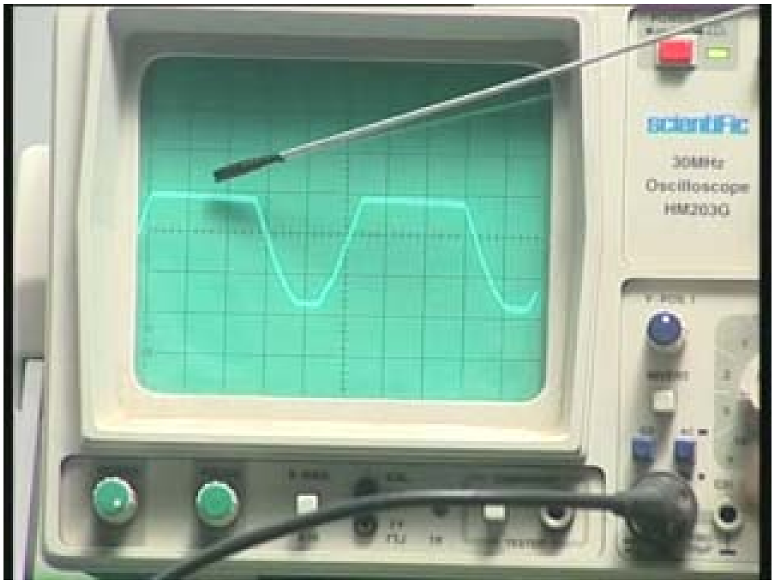

If I want to give a bias to this then you can see this point can be moved up or down by the voltage applied.

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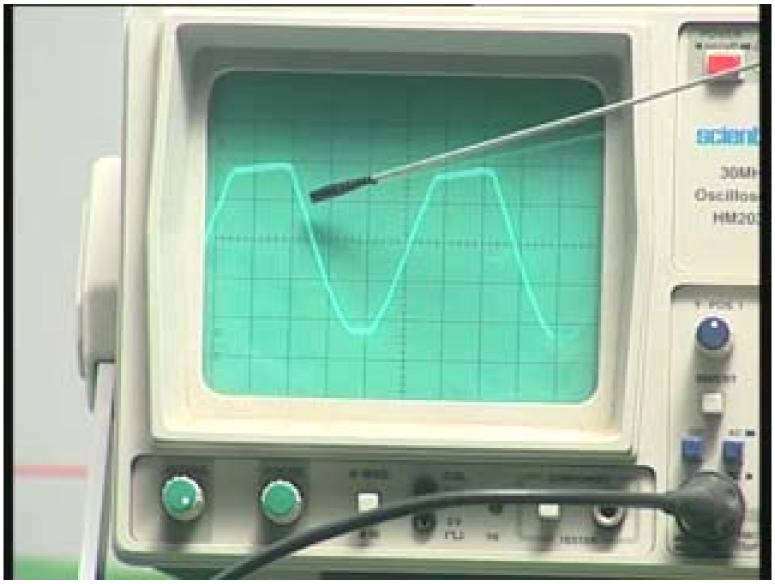

If I increase the voltage you can see this is moving down or up. So depending upon the input voltage you can see this moving up. If you now decrease the voltage you can see it is moving down. The voltage being read there on the power supply is about 4.7V. It is moving up the zero. The zero is still in the same place. It has now moved up by extra voltage because of the extra bias that is provided and therefore this is a biased positive clipper. The positive half has been removed.

Let us move on to the clamping circuit where you know what is going to happen. We will use a diode and the capacitor. We will use the diode and the capacitor and depending upon the direction of the diode the capacitor will get charged and you would get the additional voltage which is corresponding to the V_P coming across the output load and you will see the clamping action. It is important to see how the camping action takes place.

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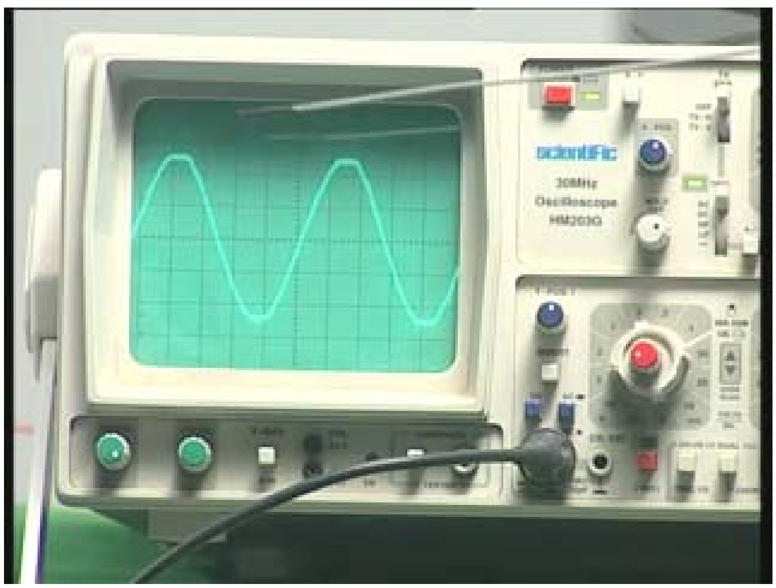

We will switch off the power supply. Now we have the sinewave. You can see the sinewave. The zero is here. In all oscilloscopes there is an option here for AC coupling and DC coupling. This is one of them. You can see AC and DC. The other one is ground. When I press the ground switch you see only the ground line. That means the input is grounded. I release that. Now I have s sinewave which is having a zero at the center, symmetric sinewave. That is because it is AC coupled. If I press this switch it will become DC coupled. When I say DC coupled all the voltage, whatever that comes, only the DC part will be coupled and therefore the whole wave form is shifted. This is actually positive clamping. You can see that the positive end has come to the bottom of the sinewave. I hope you can see that. May be if can reduce. You can see now. The entire sinewave is above the zero only.

In a clamping circuit the most important point is how it should be connected to the oscilloscope and how it should be tested. I have now introduced AC coupling. If I use AC coupling because there is a capacitor here the DC will be stopped and the clamping effect is not seen in this circuit. This sinewave is symmetric to the zero. You do not see the clamping. Only when I DC couple, the entire DC comes over here and you will be able to see the clamping action here. Here what is happening is this capacitor which is in series with the diode gets fully charged for the first half cycle when it goes negative and therefore that Vp is always coming in series with rest of the half rest of the sinewave. At that time this diode becomes open circuit and then you have the DC sources across the capacitor coming in series with the AC and therefore the whole voltage is shifted by that much DC which is corresponding to that V_P and you can also see there may be a small 0.7V associated with this which cannot be seen here very clearly. But you should always remember that 0.7 is there.

If I want to do negative clamping you know what we have to do? We have to just invert the diode. That is all. When we invert the diode, you would find the negative half cycle will charge the capacitor. You will have minus V_P coming in series with the input sinewave and therefore it will be clamped with the negative.

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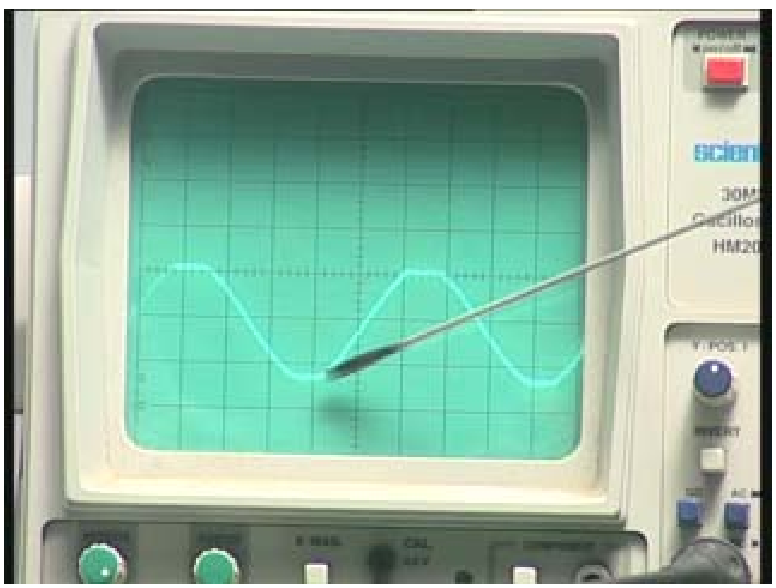

I have not changed anything on the dial of the oscilloscope. Just I inverted the diode. Immediately you can see the sinewave with reference to the zero line is down below. Previously it was above and now it is below. So this is negative clamping. Right! Let us continue. We have seen that by doing an actual demonstration using a set of diodes we are able to have positive clipping, negative clipping, positive and negative clampers and this can be used for different types of wave shaping. We can also use diodes for voltage multiplication.

I have given a circuit here. This is a transformer; you have an input from the mains, 230V and you have got a diode and the capacitor. It is something like a clamping circuit here and there is one more diode here connected to another capacitor C_2 here and this is R_L.

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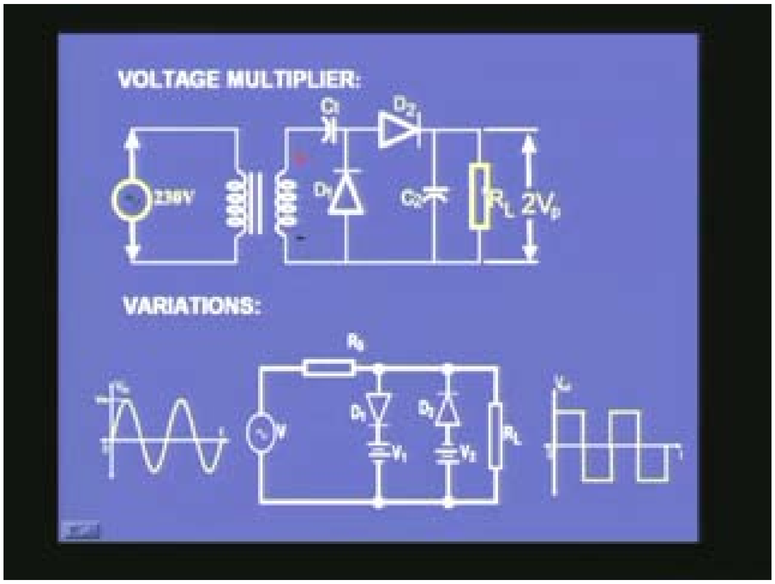

If you have a circuit of this type then for one half cycle, when this becomes plus and this becomes minus the diode will conduct and you have a positive V_P across the capacitor and that will make this diode conduct and therefore that will move on to here. During the negative again this will charge the capacitor through this path. Over that V_P one more V_P will be building on to this capacitor C_2. The voltage across the R_L if you take it will be twice the V_P. So you have doubled the voltage. This is a voltage doubler. You also call this circuit as a diode pump because you can see it is taking one charging cycle through this and another charging cycle through this. It is like two suctions and the exhaust pump of a motion of a pump. The voltage across R_L will be twice V_P. It is a voltage doubler. I have also shown on the same screen a circuit that I was explaining to you how the two clipping circuits can be combined in the same circuit to obtain a square wave from an input sinewave by suitably varying V_1 and V_2.

I have shown another picture of the same doubler, voltage doubler, ground doubler where I have two capacitors and voltage across this capacitor will be twice the voltage that you apply.

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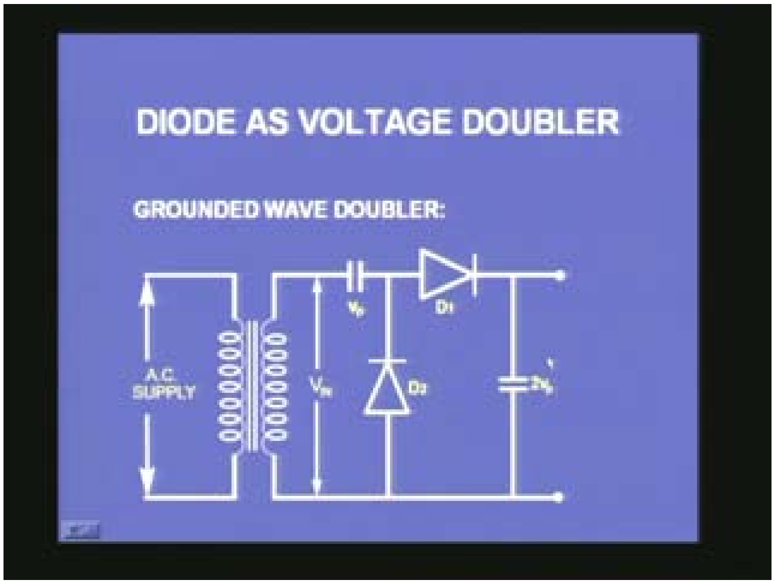

So this is a voltage doubler. In some applications you will be requiring instead of 220V may be 440V. Then you can use a voltage doubler and obtain that. There is another configuration for the same voltage doubler which is called full wave doubler. You have two diodes and you have two capacitors.

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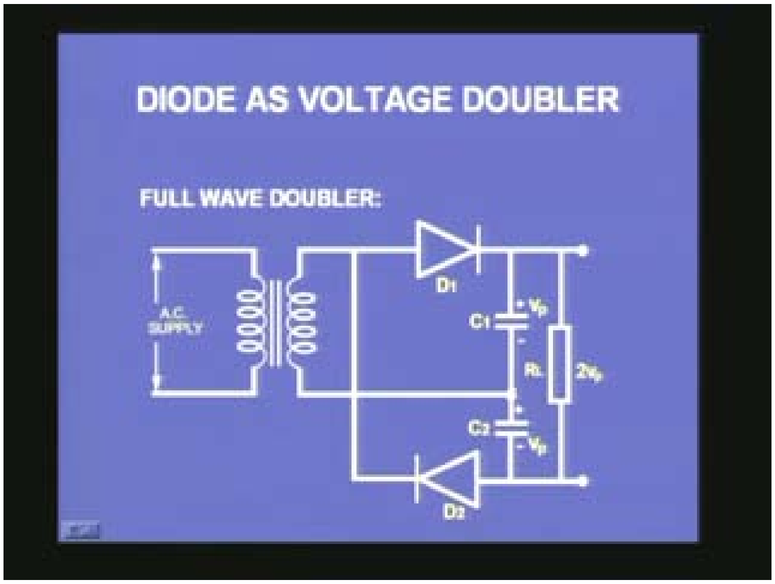

But what is going to happen is during one half cycle, this capacitor will charge from the transformer. This diode D_1 and C_1 will be working and therefore this C_1 will be charged to plus V_P. During the negative half cycle this will become plus and therefore this diode will conduct; this diode will conduct like this. So the voltage will move in the direction shown and the capacitor C_2 will also be charged to V_P. So you will have one V_P here plus another V_P here. Both of them are coming in series, it is like two batteries connected in series. If you measure the voltage across the load, you will have two times the V_P, twice V_P. So this is again a full wave voltage doubler. I have discussed two different circuits for the voltage doubler. You also have similarly voltage triplers etc. They can be used for multiplying voltages to large values.

We will move on to another type of the diode. We have so far seen different types of wave shaping using normal p-n junction diode. Now we will move on to a special type of a diode which has got some relation to what we have already discussed. It is going to be useful in applications to whatever that we have seen so far. That is the Zener diode or break down diode.

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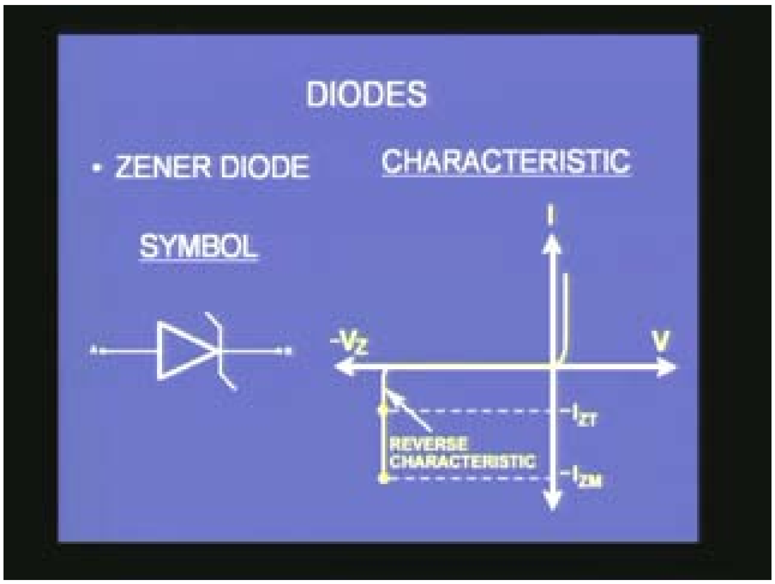

The symbol for the zener diode or break down diode is shown on the circuit. It is like a normal diode with two wings shown here in opposite directions. So this is the circuit symbol of a break down diode or zener diode. The characteristic of a zener diode will be as shown in the figure. This is the voltage axis and this is a current axis. In the forward bias when the voltage is positive it is almost like a normal diode. It starts conducting from about 0.7V and so you have a behavior similar to a normal p-n junction diode. But when you reverse bias in a normal p-n junction diode what will happen? For very large value of voltages, in the reverse direction the diode will not conduct.

For example one of the diodes can have 1000V as reverse break down voltage. You have to go up to 1000V if you really want to go in to the break down region. That is a normal diode which is used for rectification. Because in rectification you have maximum about 220V in the mains or you will usually use along with the step down transformer which will have a peak voltage of may be 10, 20V, etc., and you never come into the situation where there is break down. But in the case of a zener diode we deliberately operate the zener diode in the break down region. So the application of the zener diode comes in the break down region. Therefore you would deliberately keep the zener diode break down voltage to be reasonably low like 4V, 5V, 10V, 24V depending upon whatever application you have in mind and break down voltage will be much smaller for most of the zener diodes because their applications are in the area of voltage regulation about which we will see in some detail later.

Right now let us look at the reverse characteristics of a zener break down diode. Beyond some voltage corresponding to V_Z on the reverse bias there is a break down and once the diode breaks down what is going to happen is current is going to be very large for very small change in voltage. This is an important characteristic of the break down. How does the break down happen? Let us briefly explain to you how the break down happens? For example let us take a zener diode with break down voltage of about 4V or 5V. That means what is going to happen is when I reverse bias the voltage will appear across the break down or the depletion region of a normal p-n junction diode which I already explained.

The entire voltage will come across the depletion layer. In the depletion layer there are electrons and holes due to minority carriers. Depletion region in principle has got no charge carriers. But at a given temperature they will always be some bonds broken due to the thermal energy and you can have an intrinsic conductivity of very few electrons and holes generated due to the thermal effects. These electrons will be now within the depletion region and depletion region is a very, very small region of the order of the microns in size and if I apply about 1 or 2V or 4V, for example 4V divided by micron will give me a very high electric field in between the depletion region. This high electric field will be able to rip off some of the electrons from the other atoms in the depletion region and then these electrons will also get accelerated due to the applied field.

There is a field emission due to very high field and once emission happens they are accelerated by the field. They come in collision with the other electrons in the atom and large number of electrons will be generated very quickly and you will have very large current flowing. That corresponds to the break down. It is an avalanche effect. But you can have zener diode with different break down voltages. Those which are below 6V are basically due to what is know as the field effect and they are also called zener diode. But the break down is basically due to field effect and these are the actual suggestions given by Zener. But there are other diodes more than 6V; for example 12V zener and 24V zener. Actually the break down happens not because of the electric field but because of the avalanche effect. So they are basically avalanche diodes. Those diodes which have break down less than 6V are called zener break down. The ones which have got more than 6V are all basically avalanche break down diodes. What is the idea of the avalanche break down diode? In avalanche break down there is a large field again but depletion width will be very large and the field will not be enough to rip off the electrons from the atom, but they are good to accelerate the intrinsic electrons that are there in the depletion region which will get accelerated. They will hit against other electrons, they will release electrons; more electrons are generated. They are accelerated, more kinetic energy is produced, still more large number of electrons are generated.

So quickly there will be an enormous amount of electrons produced due to collision and then that will lead to a very large current and correspondingly the break down. So this type of a break down which is initiated by the accelerating electrons is called an avalanche breakdown. The other break down which I explained is basically due to electric field available at the depletion region for voltages which are very small, less than 6V for example are called zener break down voltages.

How do we know there are two different types of break down mechanisms operating? The best way to know is by using temperature effect. I will not go into the detail but I can mention to you if you use temperature as a parameter for a zener break down and avalanche break down they will behave differently. That is what I will tell you. I will perhaps encourage you to look into some books related to this and try to understand how to differentiate using thermal effect the avalanche and zener break down mechanism. Our interest is more on application and let me quickly tell you how this happens.

I now take a diode and obtain its characteristics. In the forward bias it will behave exactly like a normal diode; no difference. But when I go on to the reverse bias if I keep on increasing you know what is happening in a normal diode. When I reverse bias and keep increasing the voltage the current will be very, very small because it is reverse biased, the resistance is very high and the small current is due to the intrinsic carriers and the current will be very, very small of the order of few microamperes. But the moment I reach the break down region, there will be a break down initiated. Once that happens as you can see on the graph here the voltage will remain constant but the current starts increasing. You can see the current increases.

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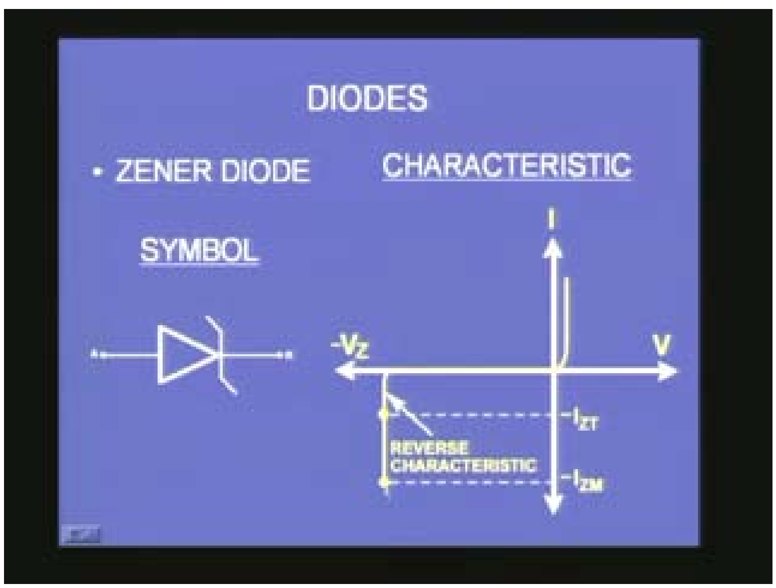

This turning point in current is called the knee point for the break down and there is another upper limit beyond which you should not go because once the break down happens the current is not controlled by the zener diode. The current is controlled by external resistors. That is the reason zener diodes will always be used along with a series resistor R_S. We must include a series resistor R_S when we use a zener diode in application because once a break down happens the current will be only limited by the external resistor R_S and not by the zener diode. Zener diode will become almost zero resistance. So if you do not have a R_S it will be amounting to shorting the power supply and you must always have a series resistor in series with the zener diode when you are operating at reverse break down. You can go on with the current in the reverse direction but beyond some point the current will be so large that there will be enormous heating produced and that heating may hamper the zener diode. The zener diode instead of breaking down may become not useable at all. Because of high temperature the zener diode can become defective. You should always make sure you limit the current in the zener diode when it is reverse biased.

What is the maximum current that I can have under reverse bias condition? That will be decided by the wattage or the power rating of the zener diode. You can buy zener diode in the market for 300 milliwatt, 600 milliwatt, 1 watt, 10watt and 100 watt. But what do you mean by that? That will tell you the maximum current I can have under reveres bias condition in a break down region. If for example I have 600 milliwatt zener with 6V then you know what is the maximum current that I can apply? I can have 600 milliwatt divided by 6V that is about 100 milliamperes. So I cannot go beyond 100milliamperes in a diode which is having 600 milliwatt power rating and 6V break down voltage when I operate the 6V. The maximum current, I_{ZM} will be decided by the power rating and I_Z minimum will be decided by the new voltage which will be generally about 1 or 2 milliamperes. So from 1 or 2 milliamperes to about 100 milliamperes for a 600 milliwatt example you can have any current in between and operate it in the break down region.

Before I go to the actual demonstration of zener characteristics I will bring out the most important point with reference to the zener diode and that is you have the voltage which is a constant here; the current is changing. The current is in Y-direction, negative y-direction. The voltage is here. The voltage is the same for all these currents. This end can be several amperes; this end is milliamperes. Over a very large range the voltage is almost constant which is shown very sharply perpendicular. But in reality is not. It will have a slight slope. That slope is the resistance of the zener in the break down region which will be very few ohms, a very small value. So the upper limit is decided by the power rating of the zener. We will quickly move on to show you a demonstration of zener characteristics and then perhaps in the next lecture we will discuss about the application of the zener diode in power supply regulation.

You will remove the load here. I have a series resistor and a zener diode. Is it forward biased or reverse biased we have to see. Let us increase the voltage. The voltmeter is connected across the zener and there is a current meter connected across at this point in series with R_S. There is a current meter that is connected here. It is showing milliamperes and first we must do the forward bias. The voltmeter shows around 6V applied. You get reasonable amount of current, nearly 10 milliamperes of current and the voltage is only 4.9V.

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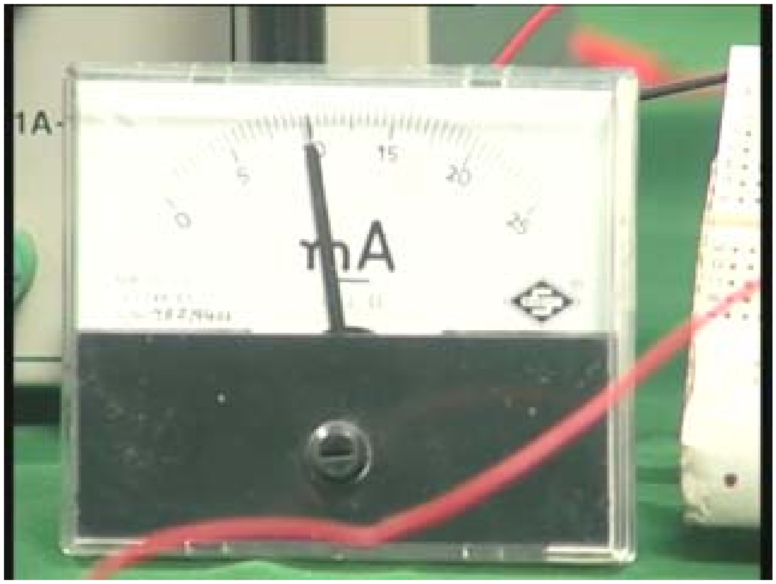

You can see here the voltage. Now let us decrease the voltage. As you go to lower and lower voltage you find it starts slowly decreasing. Let us stop here. Now it is around 2V. The current is almost nothing and it is about 1.5V because at this stage the current is only due to intrinsic conductivity. It is not in the break down region and therefore there is no current here. Let us again increase. As we increase this voltage keeps increasing. The voltage across the zener is measured by this and when it comes to 4.9 afterwards the current starts increasing here in the current meter. When I increase the voltage still further the current is increasing but the voltage in the voltmeter still reads only 5V. The voltage is not changing; 4.9 to 5V.

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There is only 0.1V variation. The variation in the voltage is very, very small but the variation in the current is reasonably large.

Now forward bias the diode. We will reduce the voltage. Reduce the voltage to zero. We will change the diode. The diode has been changed. That means it is now forward biased as you can see. The same voltmeter is there. It is showing some millivolts. Now it starts increasing very, very slowly. The voltage you can see is increasing slowly. Let us go very slowly; start from zero. Let us use the fine control. We use the fine control to increase; two hundred and odd millivolts. There is no current and the entire voltage is here across the zener. Let us still further increases the voltage; still further to nearly 500 millivolts. 0.516 V is nothing but 516 millivolts and that is the voltage across the zener. Still there is a very slight movement in the current which is not significant. Let us start increasing the voltage little more. Now you can see the current starts moving. Now the current is moving; still further may be 5 milliamperes.

You can see what is the voltage across the diode? The voltage across the diode is only 0.7 which corresponds to silicon diode. If you still further increase the voltage to ten milliamperes, the voltage across the diode is still about 0.79 only. The voltage across the diode is only 0.79.

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We have reached around 10 milliamperes. The diode is behaving like a normal forward bias diode. When you forward bias up to 0.6V in the voltmeter there is no increase in the current. Beyond 0.6V the voltage is changing very slowly; 0.6, 0.65, 0.7, 0.79 etc. But the current starts increasing in the current meter. This is corresponding to a normal forward biasing of a diode and we saw previously what happens when we reverse bias it. May be we will quickly go into the reverse bias once more to highlight that point. Just change the diode. Now the diode is reverse biased here. But the rest of the circuit is identical. Let us start increasing the voltage. As we increase the voltage initially there is no voltage drop across the diode. There is no current here. Please increase the voltge continuously, slowly. Now it is around 4V. Applied voltage in the power supply is around 4.6 or 4.7 V.

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There is a very small current now coming into this and the voltage here is not much at all. Let us go further 5V. The current is around 5 milliamperes. The volt meter reads 4.81V.

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This is already very close to break down region which is around 4.9. It is 4.8. Only when it comes to 4.8 it starts changing and the current only now increases. If I increase the input voltage still further you see the current immediately increases to 10 milliamperes or so. Now it is about 6.3V applied; about 10 milliamperes current. But the break down voltage remains constant at 4.9V. It has not changed. In the reverse bias condition the voltage across the zener remains constant but the current keeps on increasing to any value beyond that. If I now keep on increasing the input voltage then beyond some range the zener diode will have enormous current. If you go beyond the scale for example large current will flow through the zener diode and the zener diode will get heated up and in the process the zener diode may be spoiled due to the enormous thermal energy produced in this. One has to very careful about the maximum reverse diode current that can be passed. So your current in the reverse bias condition can never exceed the limit. That limit is achieved or understood by knowing the power rating of the zener. You should know the power rating of the zener and divide the power rating by the zener break down voltage. That will give you the maximum current that can be passed though the zener. With this if you use the zener diode you will be able to use a zener diode safely.

We have seen the basic characteristics of the zener diode. When you forward bias a zener diode it acts like a normal diode. But when you reverse bias its break down voltage is deliberately kept very low so that the break down voltage comes within 10V or 5V or 6V as the case may be because one of the major applications of the zener diode is in voltage regulators. What do you mean by voltage regulator? You want the voltage to be constant, regulated irrespective of the changes in the input voltage or changes in the load. Depending upon the load the current drawn from the power supply will change. When the load is changing or when the input voltage is changing still the output voltage should remain constant. Then that power supply we call as a well regulated voltage supply. To obtain a well regulated voltage supply zener diode can be used as a very useful device. That is what we should look as an application of the zener diode and quickly I will summarize whatever we have seen over this one hour and that is with reference to the different wave shaping circuits using a simple diode.

How you can have positive clipper, negative clipper and how you can combine them to get different types of wave shapes from sinewave input. Then we also saw about clamping circuit; positive clamper, negative clamper and they are very useful in several other applications which we will come across in future and then we talked about a new type of a diode which is basically a zener diode which is used for voltage regulation and I also explained to you that there are two types of zener diodes. One is called zener break down. There are two types of break down mechanism. One is the zener break down mechanism the other is called avalanche breakdown mechanism. The zener break down mechanism usually happens for low voltages up to about 6V.

If you have zener diode less than 6V break down voltage they will be mostly operated on zener break down mechanism which is a field effect break down mechanism. The other one is the avalanche break down mechanism which happens for voltages beyond 6V and that is basically due to the electrons getting accelerated, heating against other electrons, releasing some more and all of them contributing to a large current quickly; to an avalanche effect and that is an avalanche break down.

I also mentioned that the distinction between the two break down mechanisms can be obtained by looking at their temperature behavior. When I heat the junction what happens to the break down voltage? Is it increasing or decreasing? That will indicate to us indirectly whether it is a zener break down or an avalanche break down. I also showed you demonstration of zener characteristics where in the forward bias direction the voltage was increasing around 0.7 or so; the current was increasing enormously beyond 0.7 which is a normal behavior of any p-n junction diode. But when I do the reverse characteristics till about 4V or so there was no increase in the current and beyond about 4.6, 4.7 the current starts increasing. After 4.9 which is a break down voltage for the zener we used the voltage remained almost at 4.9 to 5V but the current started increasing enormously thereby showing that we are already in the break down region and i also mentioned that especially when you are in the break down region you must be very careful to add a series resistor to protect the zener diode. Because once a break down happens the current is decided only by the external resistor and then we also should remember that the wattage of the zener is the most important parameter that tells us the maximum current that I can operate a zener. In the next lecture we will see the application of the zener diode in voltage regulating circuits. Thank you!