Basic Electronics
Learning by doing
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Lecture – 38
Unit junction Transistor (UJT)
(Characteristics, UJT Relaxation oscillator,
Diode pump stair case generator)

Hello everybody! In our series of lectures on basic electronics learning by doing let us move on to the next. But before we do that as usual let us try to recapitulate what we did during the previous lecture. You might recall in the previous lecture we discussed about the active filters using operational amplifiers.

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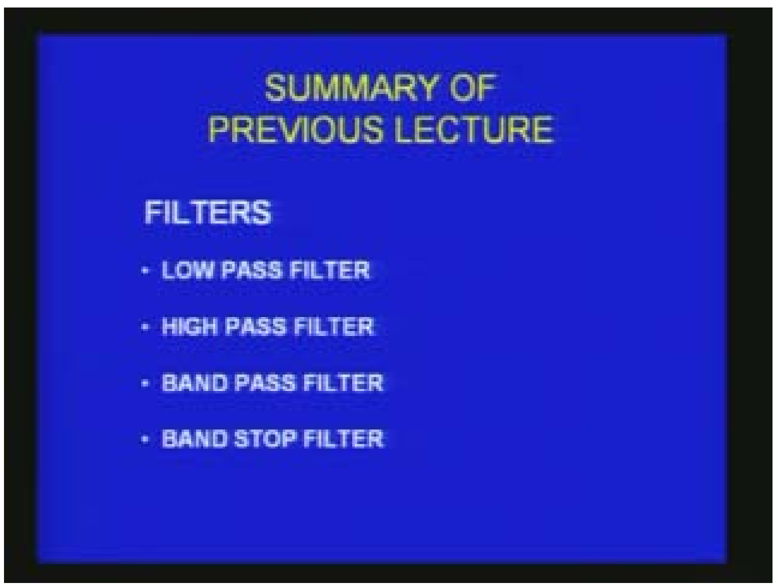

We discussed about four different types of filters. The low pass filter, the high pass filter, the band pass filter and the band stop filter. That almost brings us to the end of the different application circuits on operational amplifiers that we have been discussing for quiet sometime.

Now I want to go in this lecture into a new device which we have not discussed, one of the very important semiconductor devices which is called the uni junction transistor. We have discussed in our earlier lectures about the bipolar junction transistor where you have the two junctions the emitter base junction and the collector base junction. So this is called as bipolar junction transistor because the conduction also is bipolar in these transistors. The conduction contribution comes from both the holes and the electrons as we discussed. In this lecture I want to talk about a new device which is called the uni-junction transistor. This uni-junction transistor is very useful in several applications including oscillators. It is a very simple device. You have a n-type semi conductor which I call ‘n’ channel and you have a small region of the p type of semiconductor which I call here p plus.

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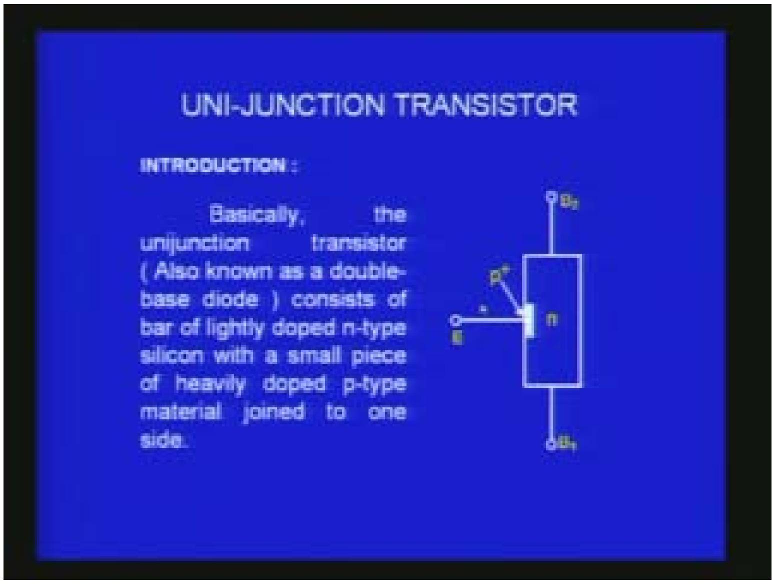

The p plus here means it is heavily doped p region; that is what it means when I say p plus because p itself is positive, p plus means highly doped p region. So you have an n region and a small region at which the p is doped. This type of semiconduction is formed and that p region is having one terminal which is called the emitter and the block of semiconductor, n type semiconductor which I call ‘channel’ has got two leads B_1 and B_2. These are called the bases. That is why it is called as double base diode. It is like a double base diode, a diode with two bases; consists of a bar of lightly doped n type silicon with a small piece of heavily doped p type material joined to the side. That is the basically the construction.

The device has got unique characteristics. Usually when the characteristics show a negative resistance region it becomes very useful in oscillators. This is one device which also shows a negative resistance in its characteristics. We will discuss that. When it is triggered the emitter current increases regeneratively until it is limited by the emitter power supply. That is the basic characteristics of this.

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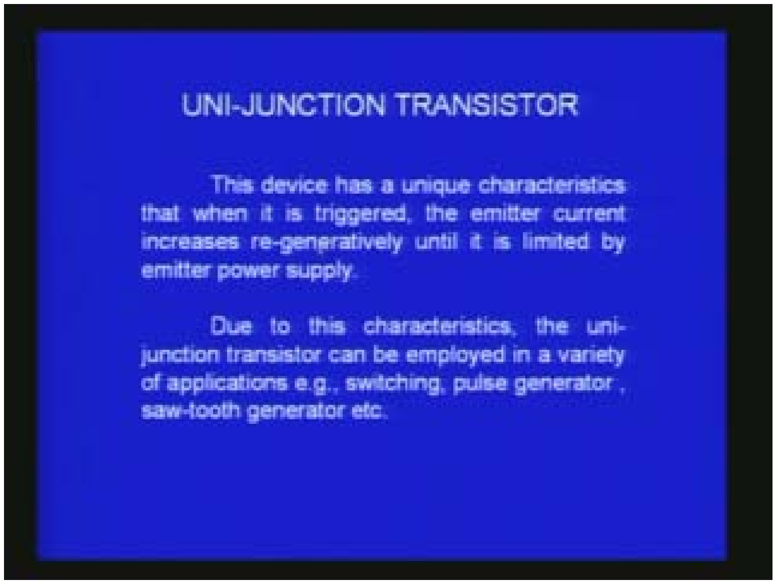

Due to this characteristics the uni-junction transistor can be employed in variety of applications like switching, pulse generator, saw-tooth generator, etc. We will also see some application circuits based on this device. If you look at the figure the n-type semi conductor is a basic resistor. Depending upon the doping level it will act like a resistance. That is why I have shown a resistance here inside this box which characterize the n-type semiconductor and you have a diode here.

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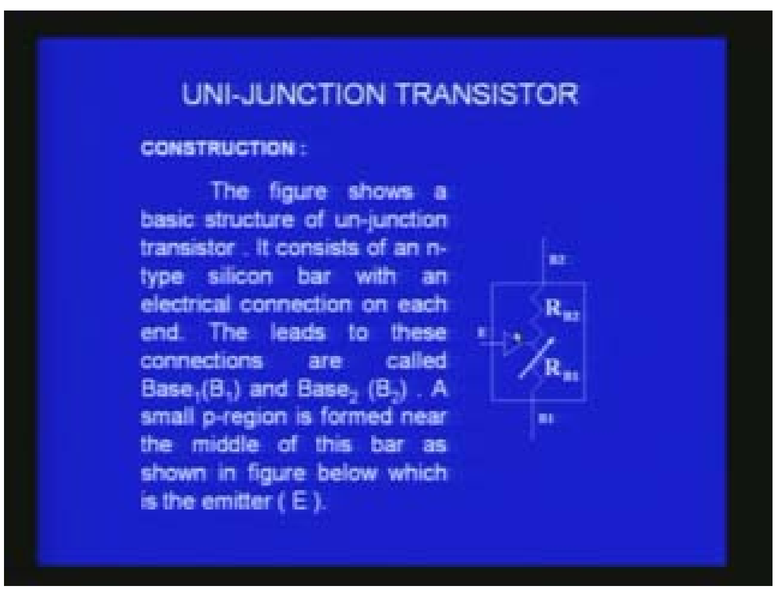

This diode is basically the diode corresponding to the p and the n junction formed at the end near the emitter. That is what is shown here in the form of a diode. Right across the place where the diode junction is formed I can have that as a point which is differentiating the two parts of the channel so that upper part has got some resistance magnitude called R_{B2} the lower part is called R_{B1}. I have shown an arrow at the bottom which shows that this is a variable path. This resistance is going to change during the operation of the device. This is basically what you would have in the device and the resistance of the silicon bar for doping will be what is called the inter-base resistance $R_{BB.}$ The resistance between the two base terminals B_1 and B_2 is what is called R_{BB} which is nothing but the inter-base resistance corresponding to the n-type semiconductor that we have.

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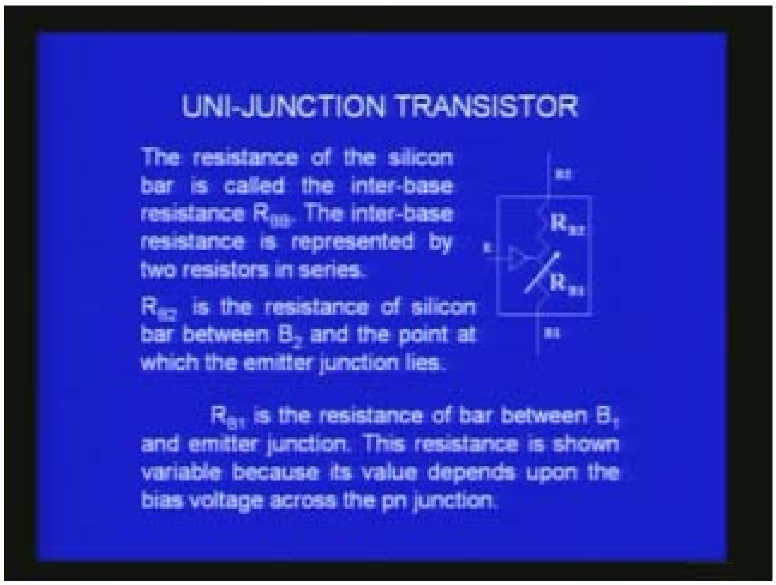

That R_{BB} is basically the series connections between the R_{B1} and R_{B2}. So R_{BB} should be equal to $R_{B1} + R_{B2}$. R_{B2} is the resistance of the silicon bar between B_2 and the point at which the emitter junction lies, around this point and R_{B1} is the resistance between this point and the base B_1. But this will depend on the bias between the emitter and base. This resistance is not a constant. It is going to vary whereas this part of the resistance R_{B2} is almost going to be a constant. The inter-base resistance R_{BB} is equal to $R_{B1} + R_{B2}$. The value of R_{BB} will be around 4 to 10 kilo ohms; 4 kilo ohms to 10 kilo ohms that is the range of resistance that we get for different devices.

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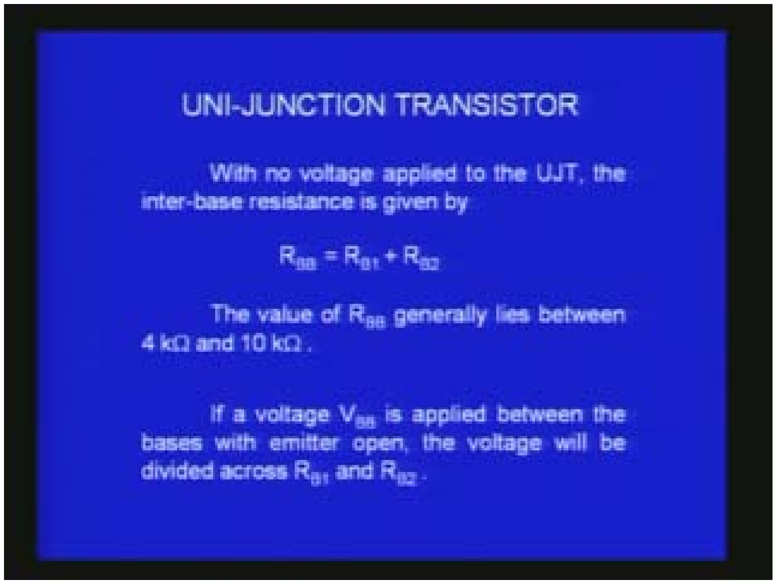

If a voltage V_{BB} is applied that voltage which is applied between the two bases is called V_{BB}. This voltage when it is applied between the bases with the emitter open this voltage will be divided by the R_{B1} and R_{B2}. So at the midpoint you will have a voltage which is corresponding to the values of R_{B1} and R_{B2}. What will be that voltage? That is the voltage which is coming across the resistance R_{B1}.

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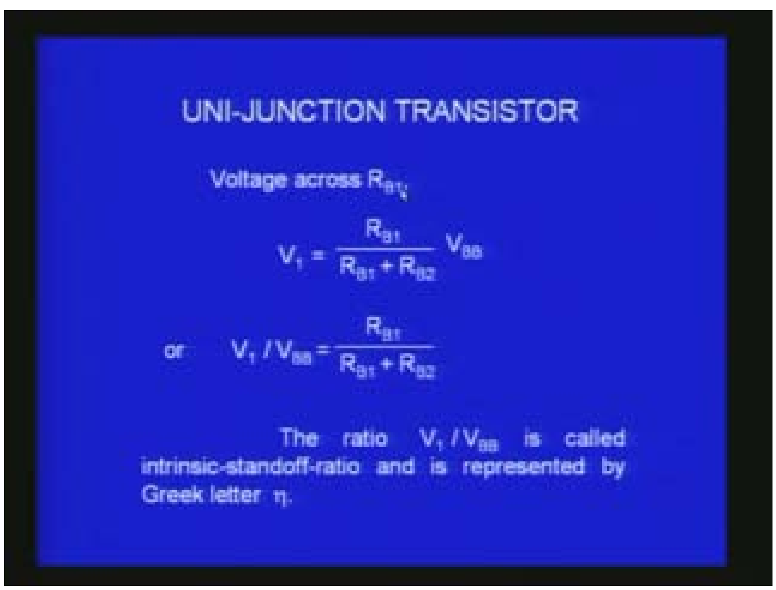

That will be V_1. It will be equal to R_{B1} divided by R_{B1} plus R_{B2} times V_{BB}. V_{BB} divided by R_{B1} + R_{B2} gives the total current. Current multiplied by resistance R_{B1} gives me the voltage developed across R_{B1} and that will be the V_1 voltage I call. The ratio V_1 by V_{BB} if

I bring it that will be proportional to R_{B1} divided by $R_{B1} + R_{B2}$ from this equation. This ratio is called the intrinsic-stand-off ratio. The R_{B1} divided by $R_{B1} + R_{B2}$ is called the intrinsic-stand-off ratio of the UJT, uni-junction transistor and it is represented by the Greek letter eta. I am showing here the character eta. Eta is equal to R_{B1} divided by $R_{B1} + R_{B2}$.

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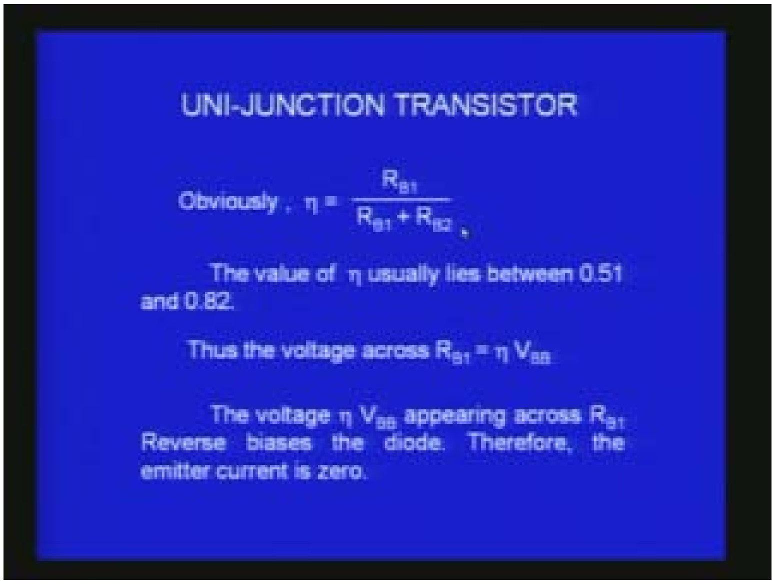

The value of eta usually will be within 0.5 to 0.8. That means what? The p-type junction will be formed near about the middle of that silicon channel n channel or above that junction, more than half. That is why it is either 0.5 or more than 0.5; nearly about 0.82. That will be the range. It will normally be given. For a given UJT it will be specified by the manufacturer and you can also determine that by performing an actual experiment, by performing a characteristics study. The voltage across the R_{B1} will be eta times V_{BB}. That is the voltage across R_{B1} or that is the voltage that will be connected to the n side of the diode. You have a diode there between the p plus and the n and right across the junction what will be the voltage? That is not the voltage at the bottom B_1or B_2 but it is something in between and that is provided by eta times V_{BB}. This you should remember for understanding the performance of the device.

To find out the characteristics of the UJT what you do is you try to apply between the emitter and the base V_1 a voltage source and keep increasing the voltage source.

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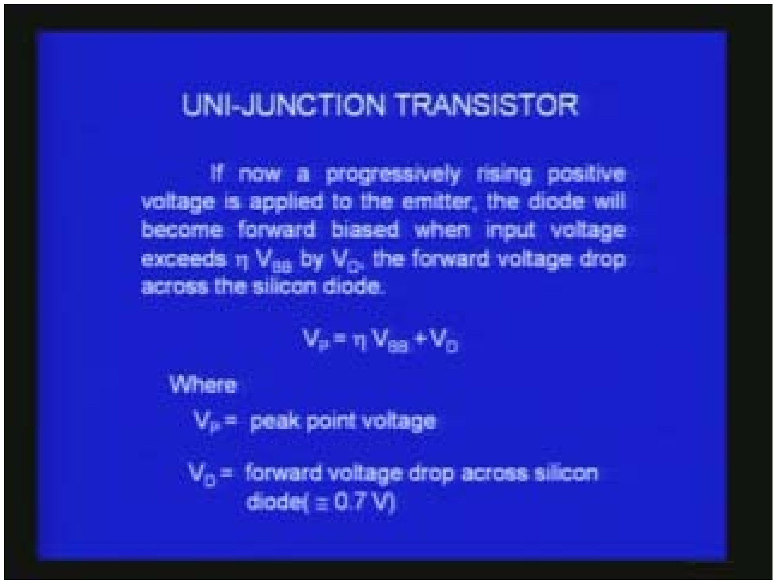

When I connect an emitter to zero volts the n side of the diode is at a voltage which is given by eta V_{BB}. It is positive by eta V_{BB} and the negative side or on the p side it is almost zero. The junction will be reverse biased because the n-type is having more voltage than the p side. What I do is I slowly increase the voltage source that I have connected between the emitter and the ground or the emitter and the B_1 and as I increase there will not be any current till I reach the threshold value, for the diode to be forward biased. If this is a silicon diode you have to have the voltage on the p side 0.7 volts more than the voltage on the other side of the diode. We know on the other side of the diode the voltage is eta V_{BB}. Unless I raise the voltage at the emitter point by a value equal to eta times V_{BB} + 0.7 the diode can never be forward biased. Once that happens the device is suddenly forward biased. There will be lot of holes and electrons exchanged at the junction and that is the reason why the R_{B1} suddenly changes because there is conduction now and that will change the characteristics. The characteristics of this ultimately should almost resemble the diode characteristics till this switching happens. After the switching it almost resembles the diode. So it will be like a diode.

Now I want to show you the equivalent circuit of the device. The R_{B1} and R_{B2} here are shown and the diode is shown. This part forms the actual equivalent circuit of the uni-junction transistor.

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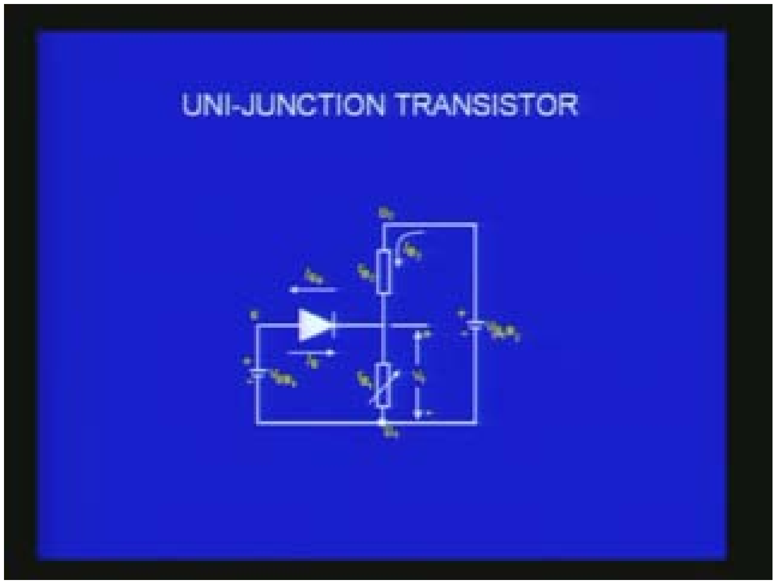

This power supply is called the V_{BB} and the power supply on the left side which is connected between the emitter and B_1 is called the V_{EB} power supply. Now I want to show you the circuit symbol for the uni-junction transistor. Circuit symbol looks very similar to a field effect transistor except that in field effect transistor the gate will be straight here. But in this case the emitter it is not called the gate here, it is called the emitter and the emitter shows a slant when it comes to the FET symbol.

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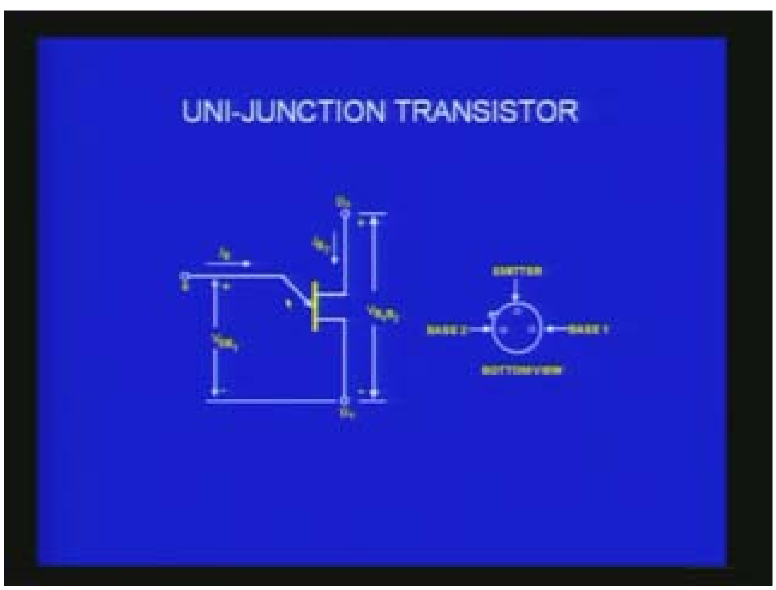

So you have small break here and this is corresponding to the UJT and you also remember the terminals are different here in the UJT. It is called B_1 B_2 the two bases and the emitter whereas in FET you will call it source, drain and gate; their designations are different, the terminal designations. One of the typical examples is 2646 FET which is what we will be using in our demonstrations. It has got the PIN diagram like this. You have a tab. This is a metal can. This is the bottom view of the metal can. You have a small tab here, small projection and this first terminal which is on this side of the projection at the bottom view is called the base 2 and the one which is coming immediately after the projection or the tab is called the emitter and the third one is called the base 1. It is the base 2, emitter and the base 1 with reference to the tab. This is the way you designate and this you should remember is a bottom view of the UJT. Having seen the UJT symbol and the pin associations let us directly go for the characteristics of the UJT.

In the picture on the left side of the screen you can see the characteristics, how it will be used for measuring the characteristics and on the right side I have a typical characteristic shown.

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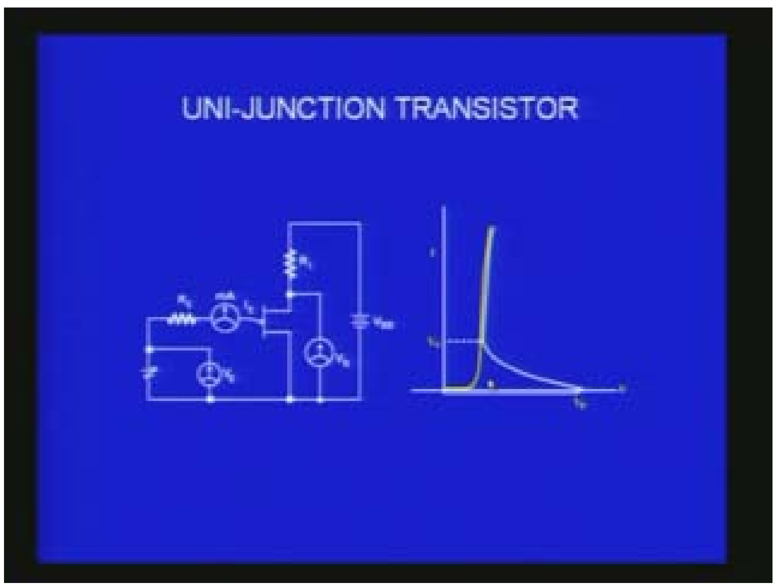

Before I go to that let us understand what we have done. If we want to do the characteristics what is that we have to do? You connect a power supply V_{BB} and monitor the V_B the voltage between the base and the ground. The ground is connected to B_1 and this voltage is called V_B and we also want to monitor the emitter current and I have put a current meter in series in the emitter line and I have put a resistor here for protecting the emitter base junction. Because once it is forward biased, the current will be very large and that should be limited. I have used emitter resistance R_E here and the voltage source here is called V_E and actually this line should come at the emitter line; at this point or at this point. That is the voltage I want to measure. The actual voltage applied across the emitter and the base of the UJT is what I want and you will have to now draw a graph. The x-axis is called emitter voltage the y-axis is called emitter current. I draw a graph between V_E and I_E for different V_B or V_{BB}. This is for one typical V_{BE} I have shown.

The diode between the p and n type channel of the UJT is always reverse biased till I reach a threshold voltage. What is the threshold voltage? Right across this diode the voltage on the n side will be eta V_{BB} and I must increase this voltage more than eta V_{BB} by 0.7 for this diode to conduct and eta V_{BB} + 0.7 will be approximately the threshold voltage up to which the diode is reverse biased. In the graph when I start increasing the voltage, there is no current because it is reverse biased and if at all there is a current it is very small current due to minority charge carriers and it is on the negative side of the y-axis and that is why you see a small parallel line here with a very small magnitude of the current till I reach a threshold voltage which I call in this case V_P to mention that it is the peak voltage. It is the maximum voltage that I achieve here. Till this maximum voltage it is going to be eta times V_{BB} + 0.7. Once that happens the diode is forward biased; immediately large carriers are exchanged and the resistance comes down. The R_{B1} resistance falls and the current suddenly increases. But the voltage drops and then it stabilizes beyond some point and this voltage where it is the minimum is called the valley point, valley voltage V_V. This is called the V peak and this is called V valley. After that it is only a normal forward biased diode and the yellow line that I have shown here corresponds to normal diode with a voltage here about 0.6 for silicon. The rest of the time it matches the diode characteristics. The difference comes only at the initial stages where initially it is reverse biased till it reaches a threshold value eta V_{BB} + 0.7 which is called the peak voltage. Once you exceed the peak voltage the emitter voltage drops and the emitter current increases slightly and beyond the valley point they almost resemble the normal diode characteristics. This is the characteristics of the UJT.

First we will try to see the characteristics of the UJT and later we will try to use the UJT for different applications. In the next picture I have shown you the same characteristics in a different orientation.

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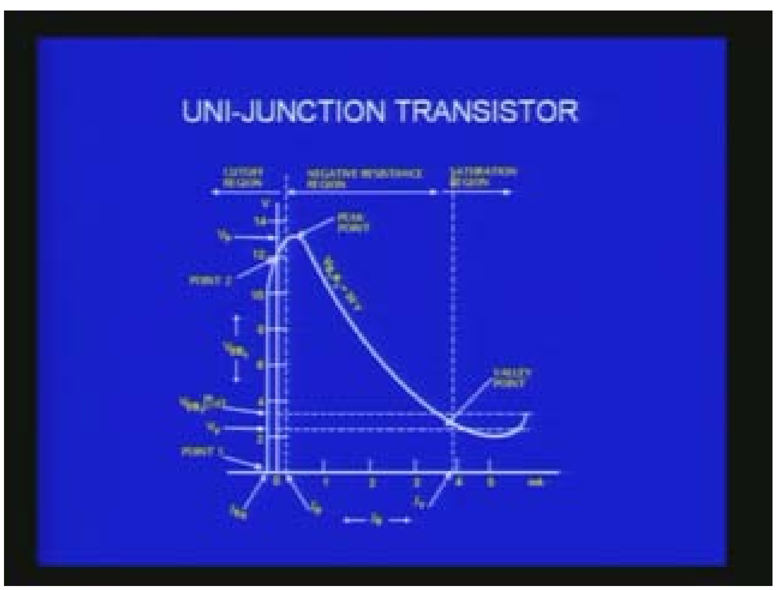

The voltage now is on the y-axis the current is on the x-axis. It is just turned that is all. Initially you have a negative saturation current till you reach the peak voltage. Once peak voltage is reached there is a drop in voltage and corresponding slight increase in the current and beyond the valley point you get a normal diode behavior that is all is shown here in schematics and there is one region called cutoff region which is on this side and the negative resistance. This is called negative resistance region because in a positive resistance when the voltage is increased current also increases whereas in the negative resistance region when the current increases correspondingly the voltage drops. When I increase the voltage here the current drops. You can look at it either way you want when the voltage increases the current drops and this is called the negative resistance and this negative resistance is very, very useful in oscillator because when I take a normal tank circuit which is an inductor and a capacitor, the inductor will have finite positive resistance and the capacitor is also a non-ideal capacitor. It will have its own leakage resistance. When I combine them you can charge the capacitor and detach it. Then the charge will start discharging through the inductance and the inductance will develop due to self inductance a large reverse voltage, back emf and that will charge the capacitor in the reverse direction. Again the capacitor can discharge through inductance in the opposite direction. You can get the oscillation of electrical charges between the inductance and the capacitance. That means the energy is exchanged in terms of electrostatic energy and electromagnetic energy through the inductance but then this will not sustain these oscillations because of the losses due to the positive resistance.

If I now connect a negative resistance device in parallel to this tank circuit then the negative resistance compensates for the positive resistance of the LC circuit. Then the oscillations can be sustained. That is the one way the new oscillators are designed with LC circuit in the device. You would have heard of number of such devices like the tunnel diode which is used for high frequency oscillations in the microwave range and this is a UJT which is also a negative resistance device. Therefore it can be used for constructing relaxation oscillators about which also we will see.

You have in the next picture a series of characteristics drawn for different V_{BB} value. This one graph that we have previously seen is for the 20 volts, when the V_{BB} value is 20 volts and the next one is now 15 volts and the third one is 10 volts. As I decrease the value of V_{BB} the peak voltage will also keep coming down. This point is the peak voltage here and this is the peak voltage. Peak voltage keeps coming down because peak voltage depends on eta times V_{BB} it is proportional to V_{BB}. When I decrease the V_{BB} naturally the peak voltage will also comedown. But beyond the valley point it will again almost coincide with the normal diode. The graph shown here is corresponding to the normal diode.

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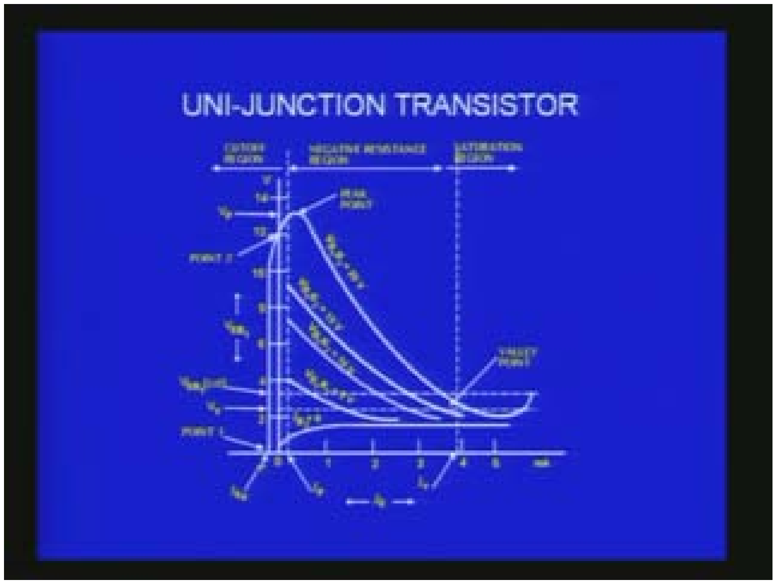

It almost reaches the characteristics of the normal diode. That is what I want to show you. You see here the cutoff region, the negative resistance region and finally the saturation region beyond which the current becomes almost independent of the voltage that you apply. You should recognize the various characteristics of the UJT for different values of V_{BB}. Now I would like to show you the actual characteristics of a UJT by going over to the demonstration table. Here you can see the circuit. It is the same circuit which we just now discussed.

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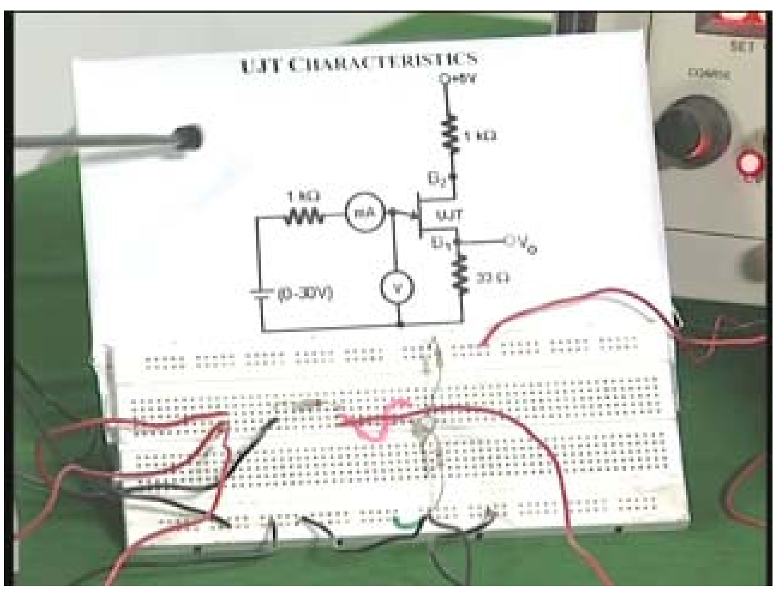

You have the current meter here for measuring I_E, the emitter current and you have a voltmeter connected between the emitter junction and the ground which will measure the V_E. We are going to draw a graph between V_E and I_E. This resistance is basically for safety to protect the diode and at the junction and then you have the two bases B_1 and B_2 and I have put two resistors here. One is about 33 ohms and the other one is about 1 kilo ohm. It can be still smaller. They will only reduce the total current. I have a 5 volts power supply. The V_{BB} that I am going to now try is about 5 volts and I will be keeping this 5 volts constant. I am going to vary this V_{EB} voltage from 0 to some 3 or 4 volts and let us see what happens at the ammeter and the voltmeter. Before I go to the ammeter you can see the UJT here, the metal can; a very small one and you have a tab. A very small tab is on this side and with reference to the tab the base one, base two and the emitter are understood and the wiring is done. This is the base two, this is the base one and this is the emitter side. This is the resistor 1K that I have shown here and I have connected this analog meter which is 0 to 10 milli ampere for measuring the I_E. This is the I_E current that is being measured using this and you also want V_E. This is the V_E. I will put it into voltmeter range. This measures the voltage between these two points. The red line and the black line both of them go to this meter and this is for the V_E.

Then you have another multimeter here that is connected between these two points. The V_{BB} voltage is actually 5 volts that is drawn from this 5 volts power supply. These two lines are connected to the 5 volts output of this power supply and I have a 0 to 30 volts power supply here which I am going to use as my V_E. I am going to increase the V_E voltage. Look at the current meter as I increase the voltage. The voltage is 1.25.

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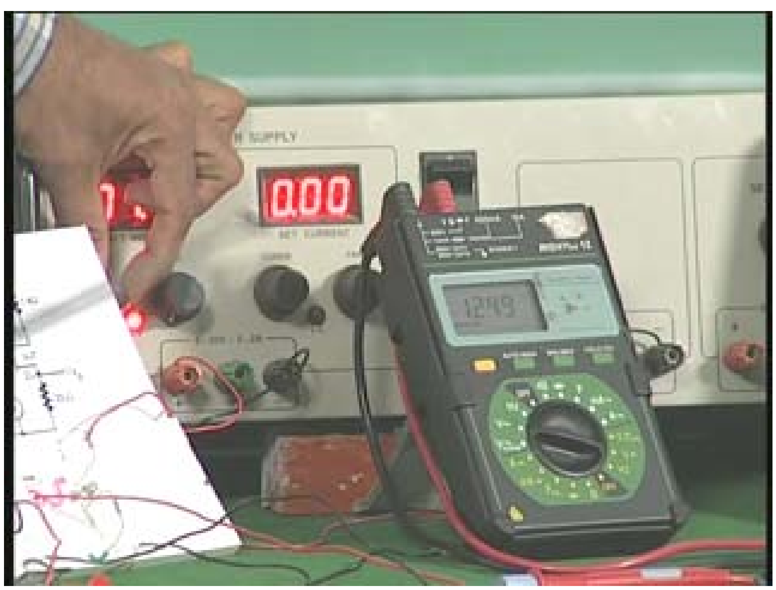

But there is no current here.

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The current is almost zero and the voltage is around 1.25. Now I still increase. It is about 1.8 still there is no current. Now I want you to focus only on this current meter. I keep increasing; 1.2 volts and now 2.2 volts, 2.3, 2.4, 2.5, 2.7, 3. Now suddenly the current has increased nearly to 2 milli amperes and now you observe the reading in the voltmeter. It is about 3.2.

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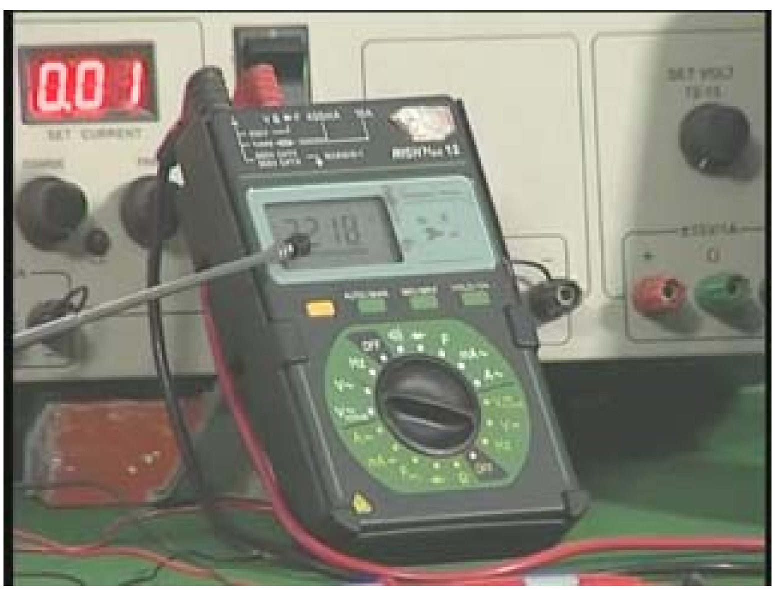

When V_E comes to around 3.2 suddenly there is a current in the current meter.

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That means the UJT is triggered. The threshold voltage has been crossed. So the threshold voltage should be around 3.2 volts. So eta times 5 volts which is the V_{BB} + 0.7 volts is what we get as 3.2 volts. If I further increase the voltage what happens to the current? The current keeps increasing when I increase the voltage. Till I come to 3.2 volts there was no current. Suddenly at 3.2 volts it becomes 2 milli amperes. If I keep increasing the voltage the current also slowly increases like a normal diode behavior.

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Beyond 2 milli amperes it behaves like a normal diode. I will do this once again. I will bring it back to the zero below the threshold point. The voltmeter reads 0.22 that means

220 milli volts. I am going to increase the voltage. I want you to see this meter and till I come to around 3 volts the current is not increasing at all. When I cross 3 volts now it is 2.8, 2.9, 3, 3.1, 3.2; when I exceed 3.2 this current meter showed a sudden jump from zero to 2 mill ampere. That means this R_{B1} which is inside is now different. The resistance has dropped and more current flows and it comes to 2 milli amperes and beyond this if I increase the voltage, the current will continuously increase. I want you to look at the multimeter. Now the reading is 3.2 volts. If I increase the voltage to 3.6, 3.7, etc there is a corresponding increase in the current meter and this behaves like a normal diode. One can draw carefully for different voltages a current. In steps of 0.5 you can go; 0.5, 1, 1.5, 2, 2.5. Till you get 3 no current is flowing. So it is zero along the x-axis. Once you cross 3.2 suddenly you are in 2 milli ampere. From 3.2 to 2 milli ampere you have to connect the line and beyond 3.2 the 2 milli ampere current increases slowly and you get a current which is increasing with voltage. It becomes more like a normal diode.

You saw in the actual experiment that the current is almost zero till you reach some value which is 3.2 in our case in the demonstration and beyond that you got a current corresponding to 2 milli amperes here.

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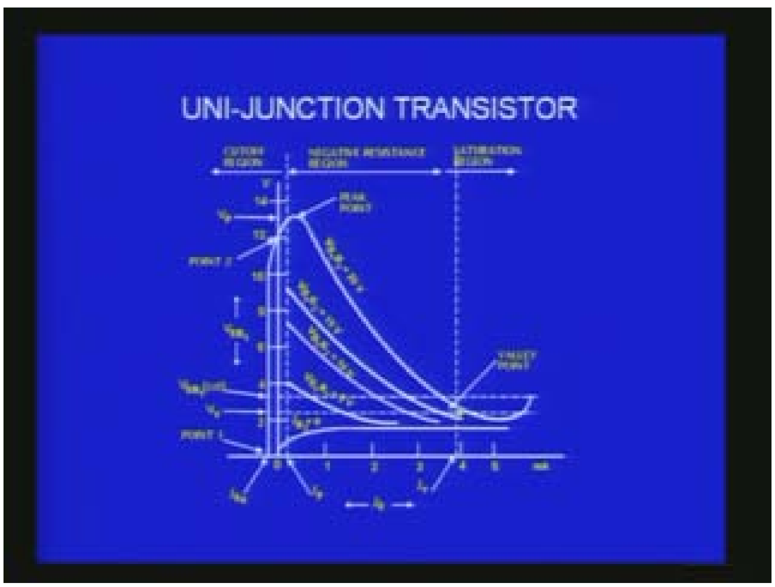

You have to draw from this point to this point a straight line because it was quick sudden change. This variation is sudden and this is the negative resistance region and beyond that it goes in a normal scheme like I have shown in this ….. It is zero and then beyond V_P suddenly it comes to 2 milli ampere and beyond that it for small changes in voltage there is large variation in the current. It becomes more like a diode.

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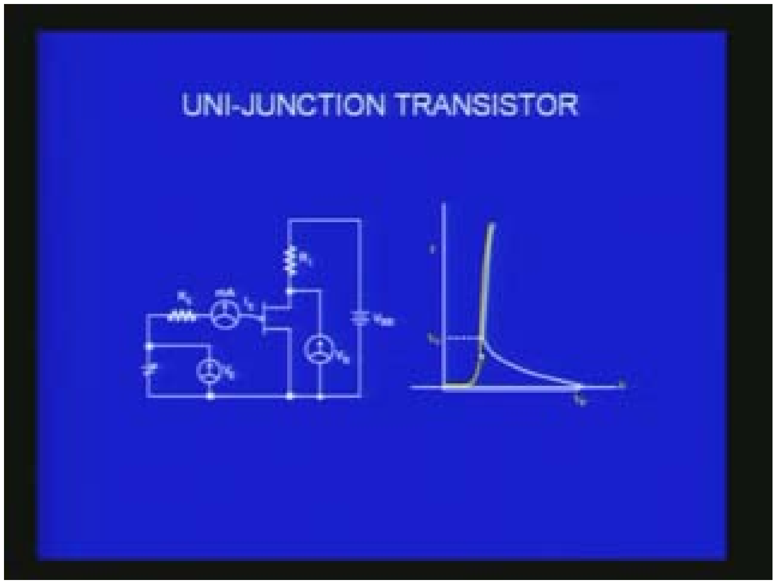

The yellow line is corresponding to the normal diode and the white line that you see corresponds to the characteristics of the UJT. We have now seen the characteristics of the UJT. What is it that we can use it for? What are the applications circuits that we can try to use UJT for? I am going to talk about a relaxation oscillator using UJT. We have already seen relaxation oscillators using different devices. For example you have used basic transistors to form the bistable and astable multi vibrators. They are also some kind of relaxation oscillators because the two transistors are not working all the time. They relax for some time and they conduct for some time alternatively and it is called a relaxation oscillator.

In all relaxation oscillators there will be a time constant involved, an RC circuit involved. In this UJT relaxation also you will have an RC circuit. In the case of operational amplifier we had a relaxation oscillator and here I have shown you the circuit of a relaxation oscillator. I have played a very simple trick here. What is that I have done? I have used an R and a C at the emitter circuit; from the same V_{BB} I have connected and the midpoint of RC I have connected to the emitter. You have the same two resistors here at the R_{B1} and R_{B2} connected externally and you have a R_E and you have a C. This R_E can also be a variable resistance. The moment I switch on the power supply the current will start charging the capacitors through the 10K resistor that I have connected here. As the charge is accumulated here the voltage across the capacitor will keep increasing. Initially the UJT is reverse biased because this voltage at this point will be much less than the voltage the corresponding eta V_{BB} that you have across the diode and when the charge accumulates on the capacitor the voltage at this point keeps increasing exponentially and when it reaches the threshold value V_P which is eta V_{BB} + 0.7 suddenly the diode will be forward biased. The UJT will be triggered and the UJT between the emitter and the base one will be conducting and so entire charge will be discharged.

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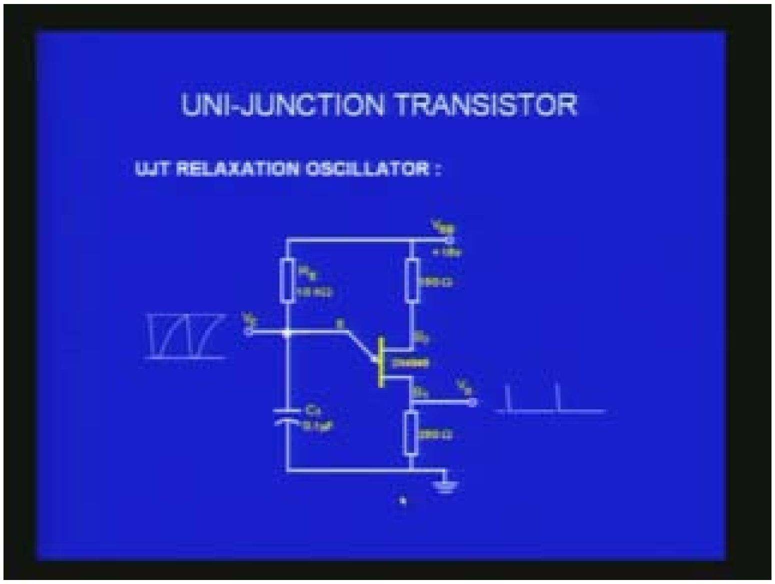

Once it is discharged the capacitor becomes empty. The charging can start all over again and the voltage will become less and the diode is again reverse biased and the accumulation of the charges will start. The graph will be an exponential growth of the voltage till it reaches V_P and once it reaches V_P it suddenly discharges because the UJT starts conducting and it becomes zero again. The charging starts and so you get something like a saw tooth wave at the end of the capacitor. The dc voltage which is shown here schematically will be a saw tooth wave depending upon the RC time constant. Here it is shown slightly curved because it depends on the time constant. If I increase the value of the R I can make it straighter and it will resemble more like a saw tooth.

What will happen if I monitor the voltage at this point across the base? I have resistor and then Whenever the capacitor discharges there will be large current flowing through the UJT and this 250 ohms resistor and there will be a sudden pulse coming over here. Once it is discharged again the diode will be reverse biased and the current will be zero and you will get zero volts. When the next discharge happens again there will be a spike or a pulse and then you will have a zero. In this place you will get a series of pulses every time the UJT conducts suddenly and these pulses can be used for triggering other devices like the silicon controlled rectifier, etc which we will discuss in the next lecture. This is what you get at the V_C and at the V_P. You get a charging happening and suddenly a discharge and again charge discharge, charge discharge.

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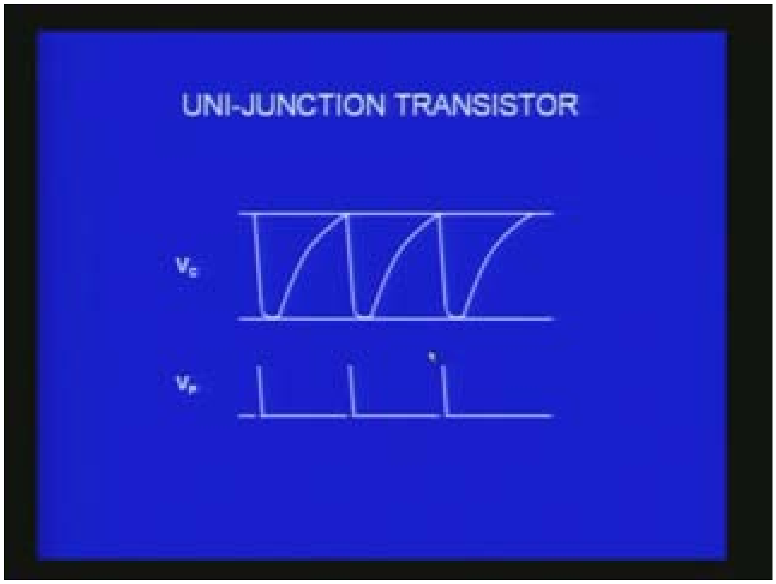

Therefore it is called a relaxation oscillator because the UJT is relaxing for some time suddenly discharging and then relaxing, etc. Instead of one capacitor you can have multiple capacitors and you can also have a variable resistor here.

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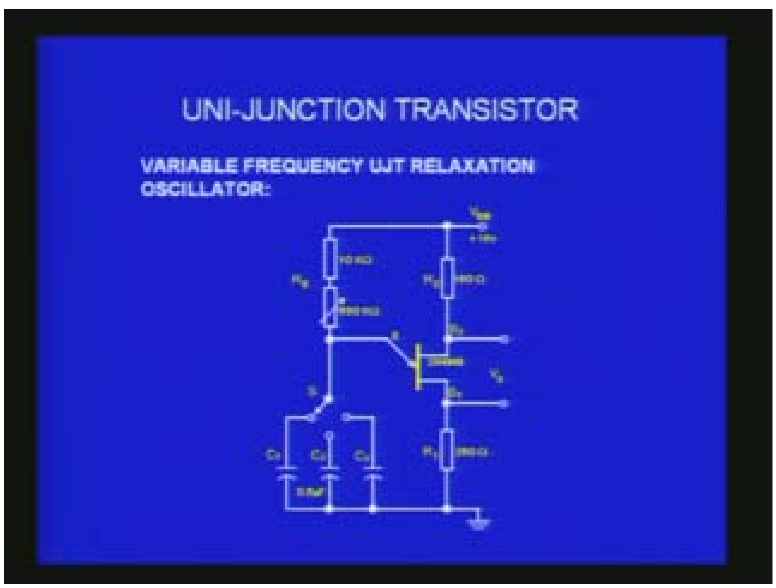

By changing these things you can have different frequencies of the pulses that you get at the saw tooth. You can have variable frequencies by using R and C variable and you will be able to get a variable frequency UJT relaxation oscillator. I will try to show you a demo of the UJT relaxation oscillator. Look at the relaxation oscillator circuit which is shown here. It is exactly the same as what I showed you. I have a variable resistor which is a 10K resistor here in this case. You can see the 10K resistor and you have the capacitor, 0.1 micro farad and this is the UJT 2646 and you have a resistor here, another base resistor and the applied voltage is 5 volts.

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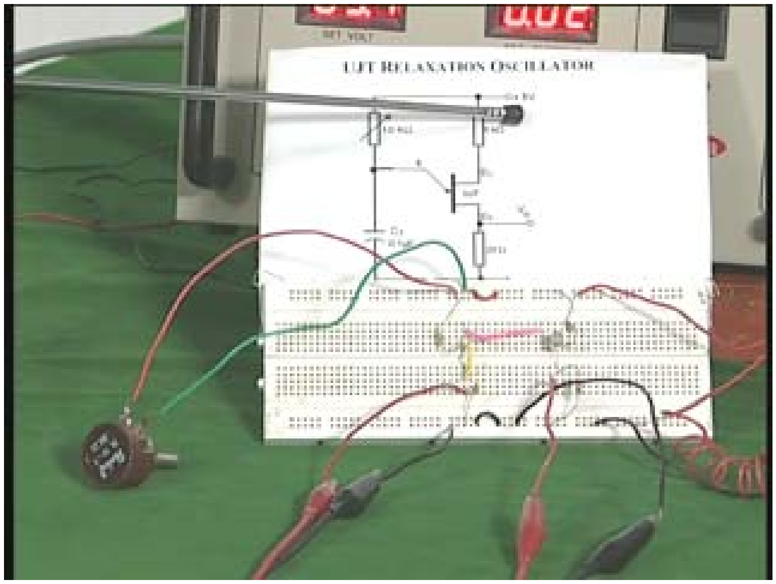

I want you to look at the UJT here and the two resistors and one variable resistor is here along with another series resistor and there is a capacitor. The oscilloscope is connected between the end of this capacitor and the ground and another channel of the oscilloscope is connected across the resistor here in the base to check the pulses. Here at this point I should get saw tooth wave. At this stage I should get pulses correspondingly. Look at the circuit completely here and then look at the oscilloscope. Now see the screen of the oscilloscope. There is a continuous increase in voltage till it reaches V_P. Once it reaches V_P there is a sudden conduction through the UJT and the voltage drops and again it builds up across the capacitor and drops. So you get something like a saw tooth here and whenever it is dropping it is actually because the UJT is conducting. At that place across the resistor and the UJT you will get a pulse. You are able to see the pulses here at every point when this voltage drops.

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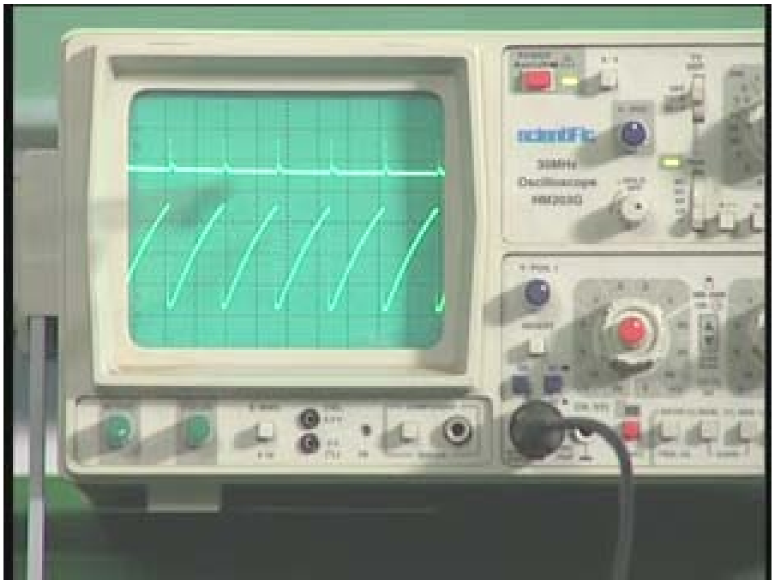

I now vary the resistance which is here in the circuit by using the potentiometer here. If you look at the oscilloscope when I change the resistance the frequency will also change. Now you can see the frequency of the oscilloscope changes, the saw tooth wave because I am now changing the potentiometer which is used for charging the capacitor.

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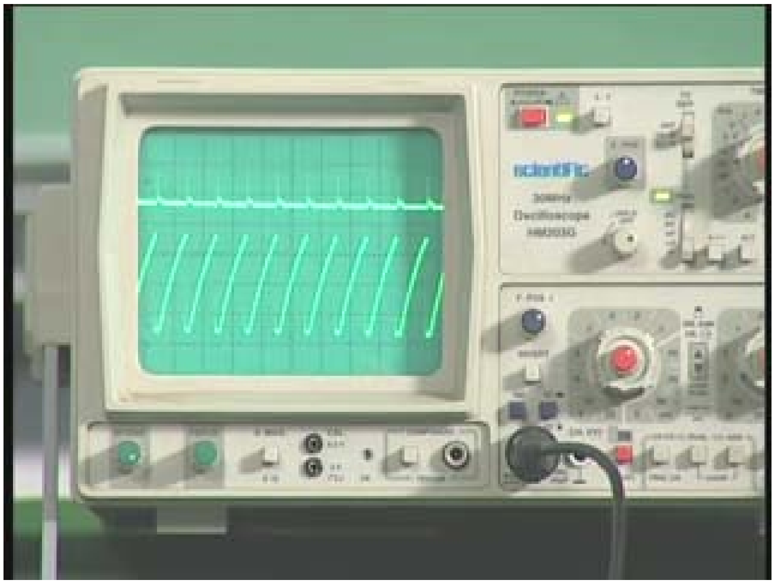

That way I can change the frequency. I can also change the capacitor connected here. The capacitor can be modified by using a band switch and you can also use this. By using these two you can have different ranges of frequencies obtained for both the capacitors, the saw tooth as well as the voltage that you get here the pulses, you can change them.

You can make use of this as a good sharp pulse generator as well as a saw tooth wave generator.

We saw the demonstration of the relaxation oscillator using the simple UJT. I want you to also look at another very interesting, nice example of how UJT can be used in a practical situation. I am going to talk to you about a diode pump. You know about the cycle pump where you use it for inflating the cycle and a charge can be pushed by using this diode pump and as the name suggest it has only some diodes. See the picture on the screen.

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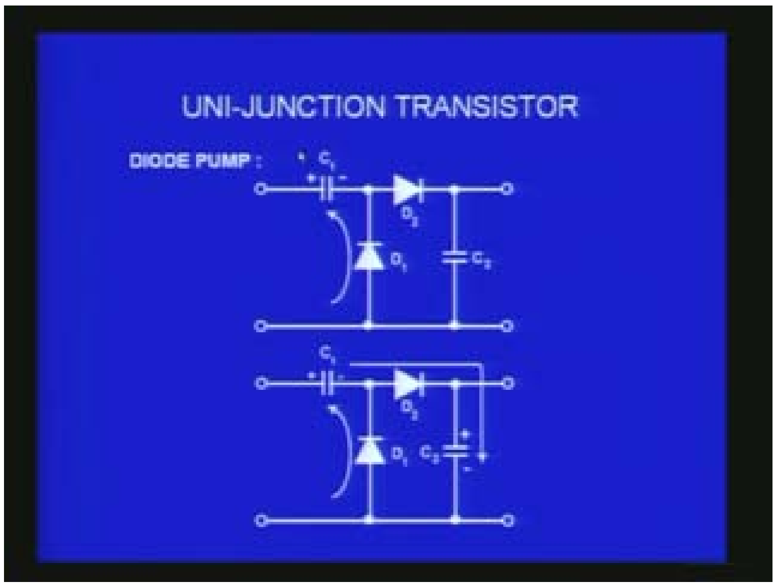

The diode pump is nothing but two capacitors C_1 and C_2 and two diodes D_1 and D_2 connected in this form. You have a diode D_1 connected to this capacitor C_1 and from there you have another diode D_2 connecting to the C_2 and this is what I call a diode pump.

If I apply a negative voltage pulse between these two terminals, when I apply a negative going pulse then the negative going pulse this will be negative with reference to this and this diode will be forward biased. This is more positive than this point and the diode will be forward biased. If I assume ideal diode the entire voltage will then charge the capacitor. If the peak voltage of this pulse is $-V_P$, the V_P will charge the capacitor. The capacitor will have plus on this side, minus on this side. This will have a voltage which corresponds to V_P here. Actually this should be plus this should be minus here (Refer Slide Time: 39:38). You have a plus and minus. What is going to happen is this capacitor C_2 should be nearly 10 times or more compared to the C_1 and so this is of larger capacity and so the charges which are accumulating on this plate will start flowing through this diode and then accumulating on the C_2 immediately. When the next pulse comes once more you have the charges flowing through this and charging the C_1 and immediately C_1 is trying to push all the charges through this diode to the C_2 because C_2 has larger capacity and slowly every pulse will charge this and then go here like the suction of a pump and the exhaust. You would take the air from outside and push into the tyre. That is what is happening here. The charges are pushed into the capacitor and then they are pushed back into the second capacitor. That is what is shown in this picture. It goes here and it comes over here (Refer Slide Time: 40:38). That is how it is charging. What is going to happen is when I get the negative voltage this voltage here will keep increasing continuously every time by one step corresponding to the V_P that you have here and capacitor you will get a staircase coming over here.

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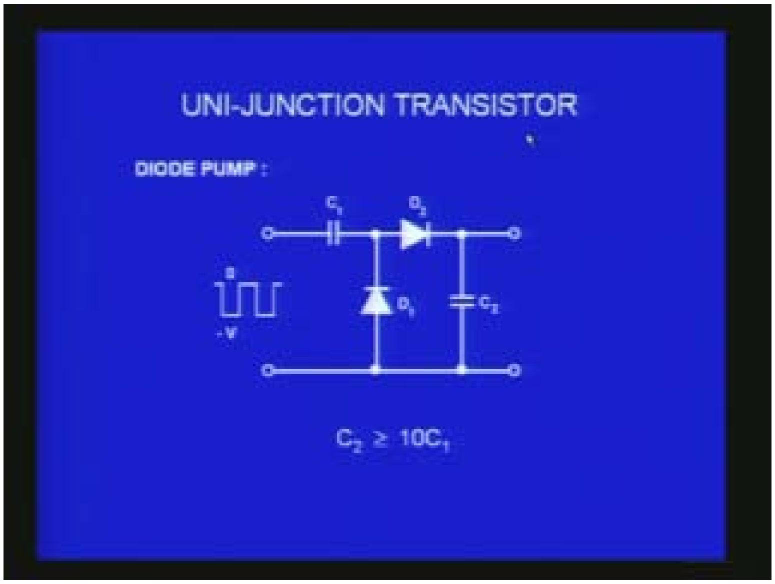

But the problem is we do not know when to stop the staircase. The voltage here will start increasing every time the pulse comes, little by little. Then I must try to put it such that beyond some point it will again discharge so that the staircase can start all over again. For that I can now use a UJT here because in a UJT there is a V_P, peak voltage. Till the peak voltage comes the staircase can build up. Once the peak voltage comes it immediately makes the UJT conduct and discharges the capacitor and the staircase is brought to zero and again the whole staircase you can start building up once more. I have a diode pump connected between the emitter and the base of an UJT which is connected to a V_{BB} between the base one and the base two which is what I want to show you in the next class. Here the full circuit is shown. Here you see the diode pump with one capacitor here another capacitor here, two diodes and that is connected to the UJT. In the relaxation oscillator you have a variable resistor, instead you connect this. This is going to step up the voltage across the capacitor and when it comes beyond V_P it will discharge through the UJT and it will again come down and the staircase will start building up again.

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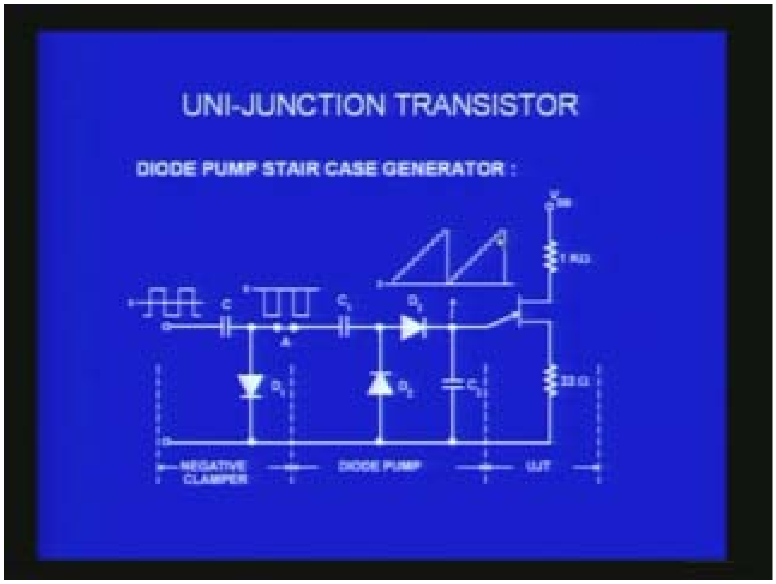

That is what I have here. But unfortunately in any normal pulse generator or function generator what you will get will be an excursion on both sides with reference to a common zero. So minus V peak to plus V peak, the voltage will be going up and down. I want only a negative peak not the positive peak. I can either use a diode or I can use a clamping circuit which we have already studied by using a capacitor and a diode.

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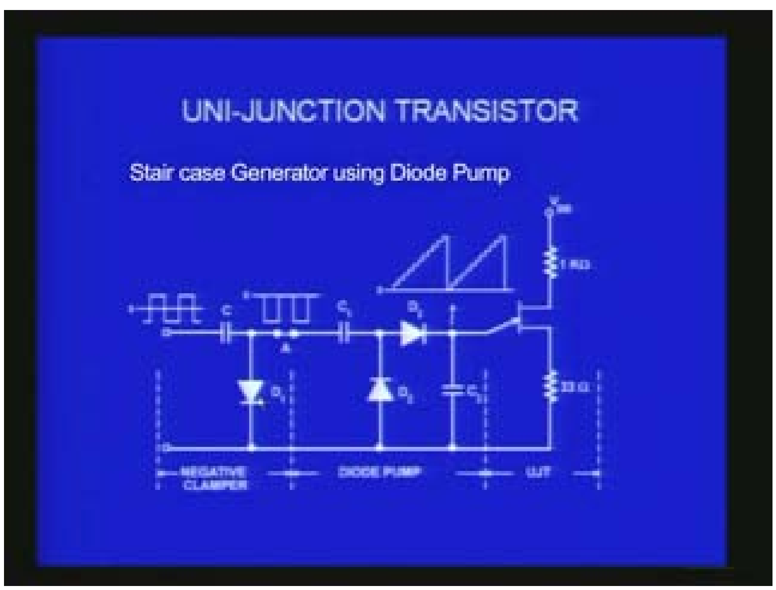

I have put here a negative clamper so that when I apply this voltage at this point the charges will be charging, the peak voltage will be coming over here and that will become a battery and beyond that you will get only the other cycle and you will get $-V_P$ as the peak voltage at this point, negative clamped circuit. This negative clamper will make this voltage come out like this and that is given as the input for the diode pump and that will be a series of stairs and the height of the stairs will not be the same as the peak voltage here. The charge will be the same but the capacitance is more and at this point it will be V_P but here it is the same charge will …. q by c will be the …. and because C is 10 times, this voltage here will be nearly 10 times less if the capacitor is 10imes more and if it is 5 volts here it will become 0.5 volts, the staircase will be 0.5 volts every time. Like that it will increase. This is what I want to show you.

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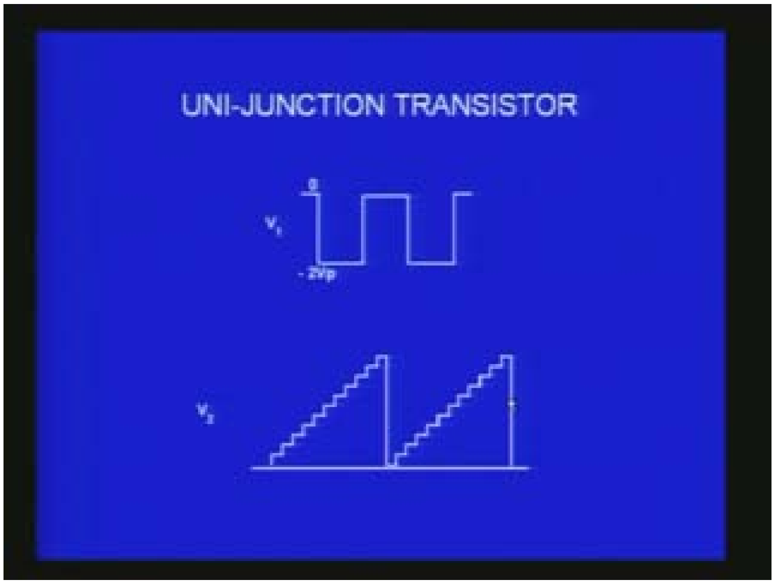

This will be the input 0 to $-2V_P$ because we have clamped and this threshold will be corresponding to the threshold voltage of the staircase generator. The stair case generator in some sense can be looked at as a digital to analog converter. These are all digital signals because you have only pulses; zero to high and back to zero or zero to minus and then zero etc. So this is a digital input. What you get is an analog output, continuous variation of these pulses and this is in one sense can be also considered as the digital to analog converter and this staircase generator is useful in many applications including curve tracing case of transistors and other devices. When you want to change the base voltages in steps you can use the staircase generator at the base so that it goes in steps of some voltage and the base current keeps increasing. So this can be used for several such applications.

Now I want to show you the actual diode pump working. The same circuit I have drawn on the bread board and then you will see how it works. You can see a staircase generator using a diode pump. The first part of the capacitor and diode is a clamping circuit, negative clamper and next what you have is a diode pump with two capacitors and two diodes and in the third stage what you have is the UJT where the emitter is connected to the output of the diode pump and B_1 B_2 is connected to 5 volts here, the two resistors.

Everything else is the same, very similar to what you saw except that in the relaxation oscillator you had a resistor here.

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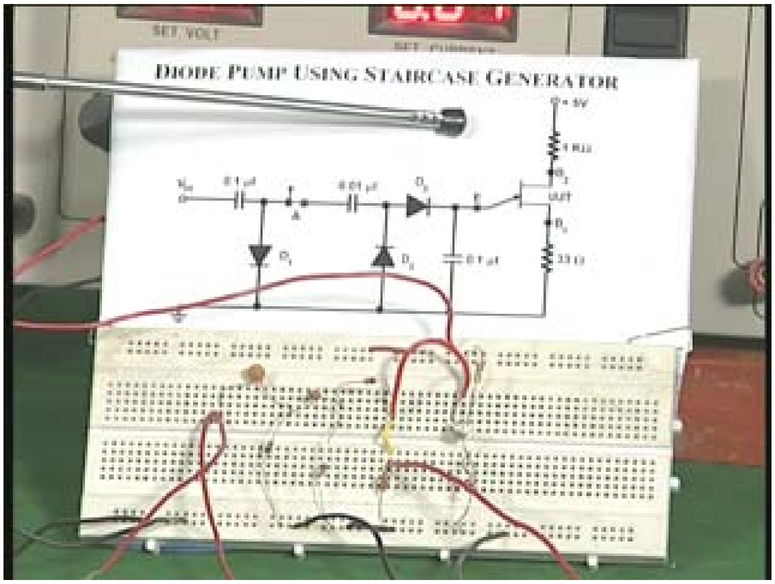

That resistor is removed now. In that place the diode pump is connected at the emitter point. This capacitor is there even earlier. Now what is going at happen at this point? This input signal will be clamped negative at this point and that is connected here and if I monitor the voltage here I should get a staircase and if I monitor at the input you will see the square wave. Look at the oscilloscope. The bottom one is the input voltage. At the bottom all the pulses are going up and down and what you see here is the capacitor voltage.

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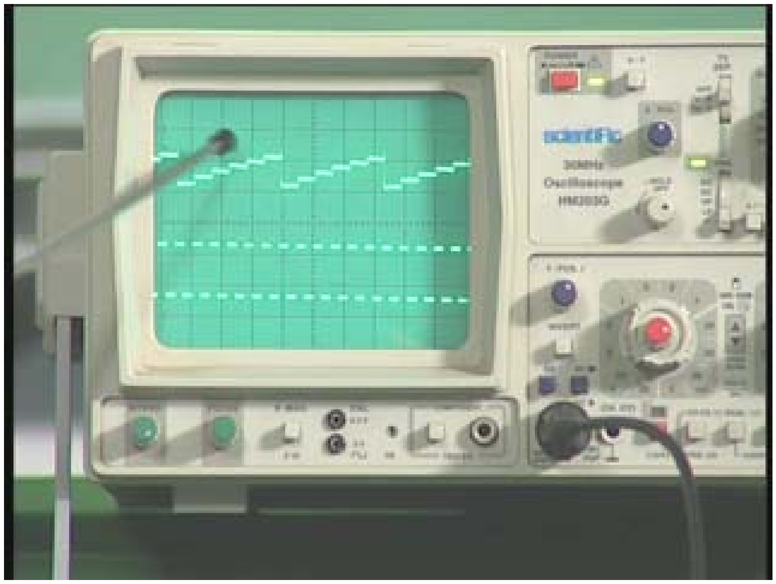

I can increase or decrease the V_{BB}. The number of steps increases now if I increase. The number of steps is increasing.

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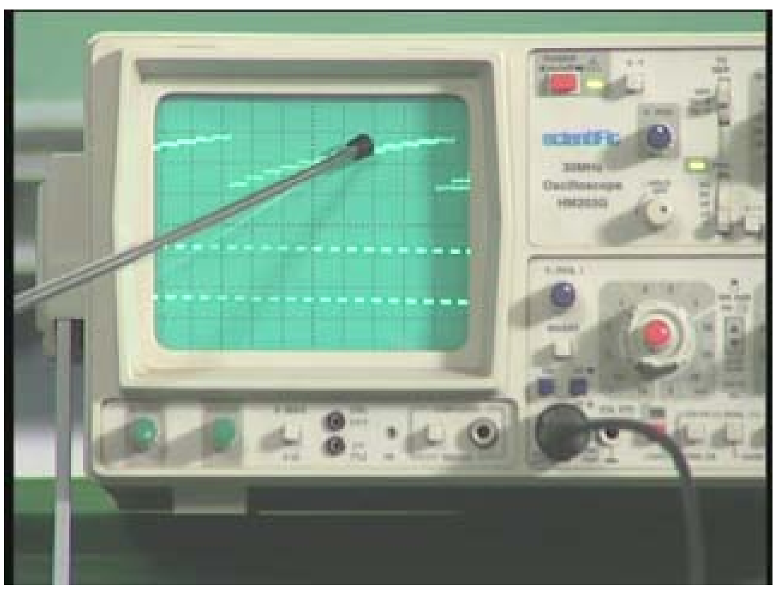

Now I decrease the voltage. Number of steps is 1, 2, 3, 4, 5 only. Now I increase the voltage. The number of steps is increasing as I keep increasing because what I am changing now is the V_P. The V_P is changed when V_{BB} is changed and more staircase come. The number of stairs has increased and you are not even able to resolve the pulses here but you get very nice staircase over here. I also want to show you the clamping that is happening here. Let me show you the input. See the oscilloscope. When I ground the input you see what happens to this? The line that you get is the ground line. This is ground line.

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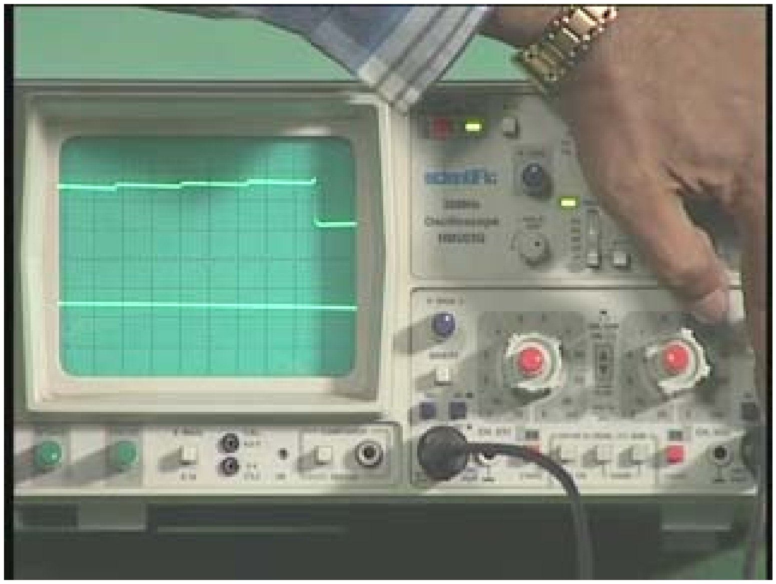

This is the ground line and that is symmetric with reference to the pulse. The pulse is symmetric about the ground line. So this is the input. I take the input from there. I want to monitor after the negative clamping. The input is given here from the function generator and immediately that input is also monitored at one channel of the oscilloscope and after that clamping circuit, one capacitor and diode, I have taken the output and that also is being monitored in the oscilloscope. In the oscilloscope I have two signals one is corresponding to the input the other one corresponds to the output after the clamping.

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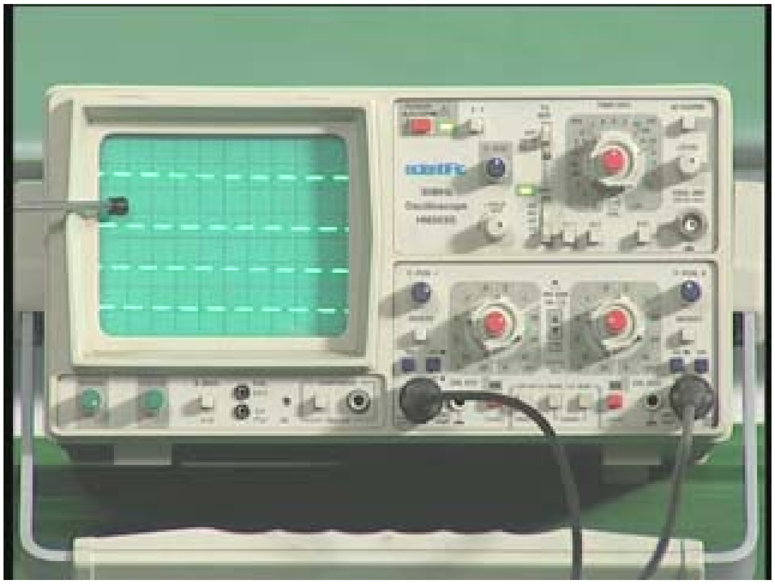

I want to show how to test the clamping. If I now connect this to the ground point, if I ground the input, in this case the ground is symmetric with reference to pulse both sides of the pulse you have. Whereas if I take after the clamping, if I make it ground you see where the ground is. Ground is at the top the rest of the pulse is at the bottom.

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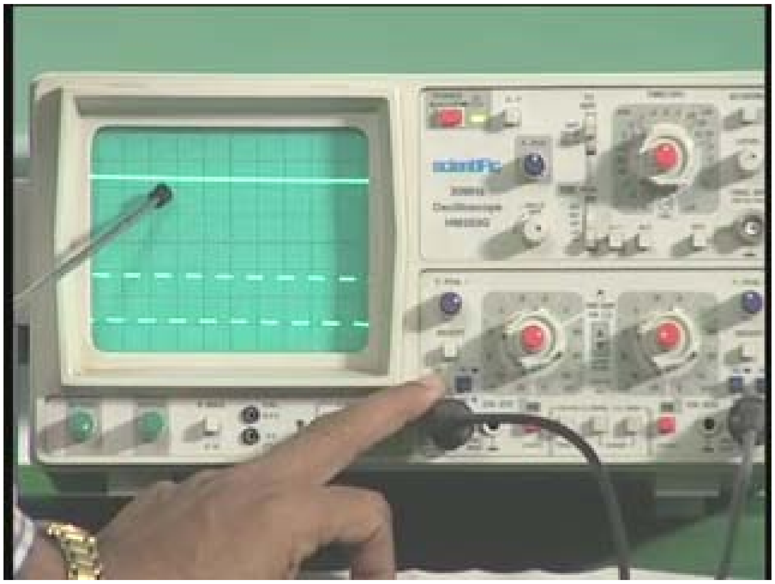

That means the dc part has been shifted to this end. That is what we mean by clamping circuit. We have seen it also in clamping circuit and in this case it is symmetric whereas in the other case it is at the top. For this you should remember that the two inputs will have to be dc coupled not ac coupled. If it is ac coupled again you will get the symmetric line only. You must try to make it first dc coupled. That mean there is no capacitor at the input and then you try to ground. The line comes here. That means it is negatively clamped and then it is ready for giving to the diode pump and what else you have is a diode pump and then output is connected to the UJT. We have already seen that we get a staircase. The height of the staircase can be increased by increasing V_{BB}, the voltage here corresponding to V_{BB}. We have applied very low voltage and with that we were able to get. This 3 volts is the voltage that we applied to the V_{BB} and if I increase it I will get more number of steps and if I decrease it I will get less number of steps.

The other way to do that is I can also increase the amplitude of the function generator. If I increase the amplitude of the function generator I am increasing the height of the steps, individual steps and I will get less number of steps if I decrease the amplitude here and I can also change the frequency here; when I change the frequency that will also change the number of steps. When I change the voltage V_{BB} I am actually changing the threshold voltage corresponding to UJT and the number of steps is altered by altering the threshold voltage. When I change the amplitude of the function generator I am also changing the number of steps by changing the step height. They are different; the step height will vary by this and the number of steps will vary by changing the V_{BB}. That is what you should recognize.

What we saw now is a very simple circuit for generating staircase waves where the number of steps in the staircase as well as the height of the stair case can be very easily modified by using the amplitude variation as well as the V_{BB} voltage variation at the dc supply. This staircase can be used for different applications. This also a digital to analog converter in one sense and one simple application which you can try is to use this staircase voltage to the base of the transistor and give this input square wave to the collector and the emitter of the same transistor and then if you monitor on the x-y ranges of an oscilloscope you would find for every one step there will be a pulse between the emitter and the collector. There will be a sweep of that voltage and so you increase the base voltage, you apply a large voltage in the emitter current. Then you apply another increased step of base voltage and you sweep the collector emitter voltage. You keep doing this at regular intervals. On the oscilloscope you will see the complete family of output characteristics for different base currents.

In a transistor if I can get that graph it becomes very easy in the design of different circuits. Especially when you are manufacturing transistors in millions you would like to know how the performance of the transistor is. For that you use very sophisticated instrument which is called a curve tracer. In that all a person has to do is insert the transistor into the three sockets emitter, base and collector marked there. The entire family of characteristics will be shown on the oscilloscope screen. For doing that one simple way is to have this type of staircase generator connected to the base and the pulse generator which is at the input is connected between the collector and the emitter and you will be able to sweep the various base currents and then you will get the curve tracer. It is a very nice, simple application of the staircase generator.

We have seen what a uni junction transistor is. What is its geometric construction and what is its circuit symbol and how it can be used? How to obtain the characteristics of the uni junction transistor and what are the special features of the characteristics like the negative resistance, temperature, negative resistance region, etc and then we also saw how this uni junction transistor can be used in a typical application for the case of a relaxation oscillator and then how the frequency can be varied and we can also get pulse generated out of this relaxation oscillator and then as a third application I gave you a simple example of how a diode pump using only diodes and capacitor can be connected to the UJT at the output to obtain a staircase by wave form using the UJT and the diode pump. Thank you very much.