Analog Electronic Circuits
Prof. Shouribrata Chatterjee
Department of Electrical Engineering
Indian Institute of Technology, Delhi

Lecture – 02
Diodes, introduction to the transistor

Welcome back to Analogue Electronic Circuits. Today is the second lecture and we are going to talk about Diodes and then if there is the time, we will start Introducing the transistor. But first we are going to talk about a few circuits with diodes; in the last class we had given an introduction to different abstractions for the diode. So, the diode is basically a p-n junction; however, we are not really as a circuits in a circuits class we are not going to be interested in what is going on inside the diode.

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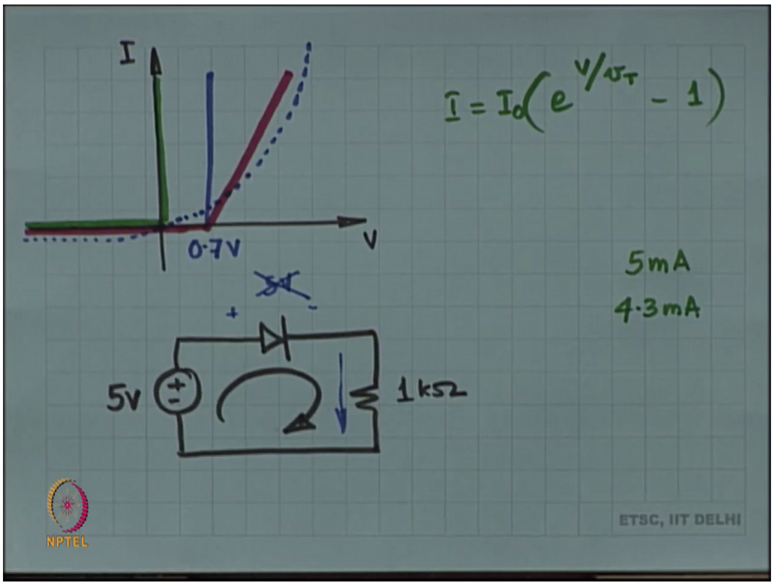

So, we are going to look at the overall I versus V graph and the overall I versus V graph; we had 3 abstractions, the ideal one in the last class this is the diode that I wished to purchase, but could not find in the market. This was the ideal diode then the diode that I believed I purchased or a second level abstraction was something like this. And a third level abstraction which is the actual diode is something that looks like this ok.

So, mathematically we represented O, we had this also in between I am sorry we had this also in between. So, we represented the green curve the blue line and the blue dashed line mathematically and the last dashed line has to pass through 0 and with that it came down to it boil down to something like this; I is equal to I naught times e power V by V T minus 1 something of this format alright.

Now, this is as far as the diode this; these are the 3 models for the diode the diode can be used in a circuit. So, imagine circuit that looks like this and you are asked to compute the correct one how will you find this out? So, the first question that you are going to ask is what is this diode? Is this diode an ideal diode like the green line, is it a diode like the blue line is it one like the red line or is it w dash line. So, let us do it step by step right.

So, what engineers do is first thy do the zeroth order approximation, then they do a first order approximation, then they do a the more difficult one if required and finally, they do the exact one only if absolutely required. So, normally they would not bother about the exact of it ok. So, let us do the green one the green line over there the ideal diode that I wished to purchase. So, if you think about that diode then all you have to work out is this diode is on or off. Because if it is on then the drop across it is 0 where as if it is off then the drop across it can be anything and the current will be nothing ok.

So, the current if at all is going to go in the direction of the arrow which means that it the diode is probably on ok. You can verify by contradiction let us say that the diode is off alright if the diode is off, no current is going through it, but any voltage can appear across it any negative voltage can appear across it. So, if no current goes through the diode then the drop across the 1 kilo ohm is 0 and then the drop across the diode is 5 volts, but that is not negative all right it is it is not negative.

So, we are we have to be in the negative axis if no current flows through; it can be any drop as long as it is negative, but this is a positive drop which means that our assumption is not true. So, therefore, the diode has got to be on not off; so, this is incorrect the diode is on if the diode is on the drop across it is 0, if the drop across it is 0 then the current in the 1 k is 5 milli amperes done this is method 1.

Now, let us work with the second approximation let us say that this diode cut in voltage is 0.7 volts. So, this is a very safe approximation if we are talking about silicon; a silicon diode normally as a cut in voltage of around 0.7 volts. In such a scenario what is going to happen if the diode on or off; once again if it is off, then the drop across it is positive which means that it is got to be on positive voltage is not going to be sustained its 5 volts across certainly more than 0.7 volts and therefore, current has to flow; that means, the diode is on.

Now, if the diode is on the drop across it is 0.7 volts and therefore, the drop across the 1 k is 4.3 volts which means the current through the 1 k is going to be 4.3 milliamperes. So, look at my answer first answer was 5 milli amperes, this was the zeroth order ideal diode that was not available in the market. The second one gave me 4.3 milli amperes and then you say all right. Let us not worry about these approximate answers; let us try to worked out the precise answer.

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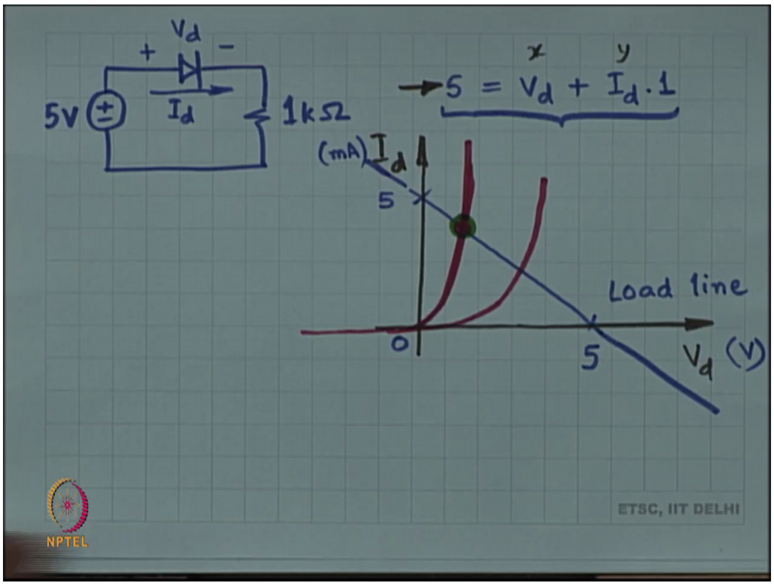

So, now I am going to attempt to work out the precise answer ok; how do I do it? KVL we will go we will write KVL. So, 5 volts is equal to the drop across the diode let us call it V d plus I d times one k and as long as the I d is in milli amperes if I choose the units of I d to be in milli amperes then one is right. So, this is my KVL look equation the other thing of course, is that V d and I d are related to each other, but let us not worry about it write now ok.

So, let us try to plot this equation on these axis; so, this particular equation is what I want to plot 5 is equal to V d plus I d times 1. Can you plot this on this on these axis V d and I d? How will it look like? Will it look like a circle, parabola what is it what is this equation of? 5 is equal to this is the x axis, this is the y axis yeah this is a straight line right.

And this is a straight line that; obviously, looks somewhat like this when you say V d is equal to 0 I d would be equal to 5 and if I d is equal to 0; then V d has to be equal to 5 ok. So these points these intercepts on the x and y axis a 5 milli amperes and 5 volts respectively ok; so this particular graph where you have worked out a KVL and you are writing out the you are plotting out the KVL this is called the load line.

So, the load line is a very important concept; it has nothing to do with the device equation its purely based on KCL and KVL right 5 is equal to V d plus I d times 1. Here there was no there was no diode involved right; it could have been a diode this need not have been a diode at all; this could have be any other device of your choice. This diode could have been forward biased and reverse biased whatever you want right this equation is always true and this is coming purely from KCL and KVL ok.

So, this is I have drawn it in blue, but this is a golden line as in this is the absolute truth KCL and KVL are always true which means load line is always true no matter what that device is and what is going on inside the device right; whether that is a p-n junction diode whether that is not a diode whether it is a vacuum diode, whether it is some other you know air gap whatever it is right this is always true alright.

Now, with this understanding the next thing that we do is we plot out the diode characteristics and think about it once. The way I have done it the diode characteristics need exactly the same variables V d and I d the same axis right. So, on the same axis I can plot the diode characteristics and the diode characteristics are going to look like this alright; maybe it is not so, bad maybe it is a something that looks like, this is better ok.

In which case we can work out what is the point of intersection between the diode characteristics and the load line the load line is the absolute truth whatever happens to the device this has to be correct KCL and KVL have to be satisfied which means that I d and V d always have to lie on the straight light.

Now, you bring in the diode and say that the because it is a diode; it has to follow this red graph and now if it also has to follow the rate graph then the only point that satisfies both the red graph and the fact that it has to satisfy KCL and KVL is this point of intersection. So, this is the actual point of operation alright and invariably what you are going to find is that this actual point of operation is going to be white clothes; white clothes to the second number alright. And the second number is actually a very good approximation of the exact result alright; is this technique a understood?

So, this is called the load line technique and the reason why we are studying diodes at all is one of the big reasons why we are studying diodes at all is to understand this technique this load line technique. Because the load line technique is going to occur in all kinds of places everywhere now in without any warning; I am going to start drawing a load line and then you have to recall what you studied in this diode lecture. So, it is load line technique understood alright.

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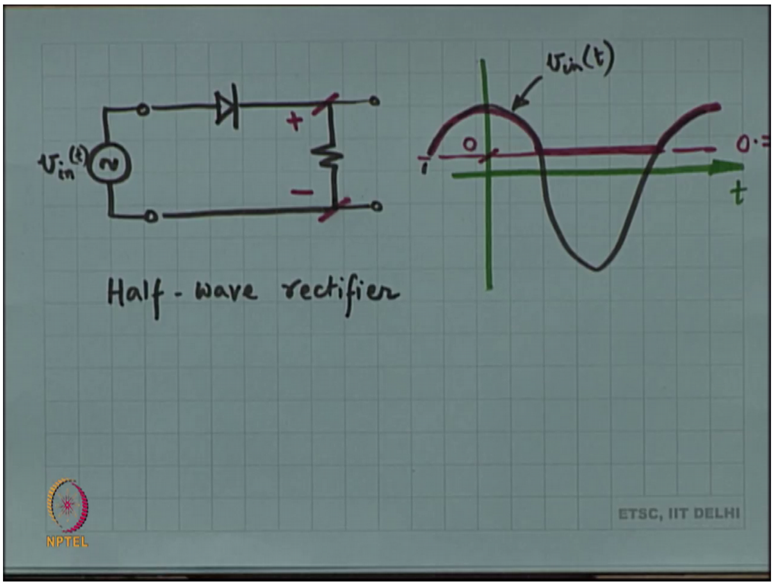

Few more circuits with diodes some things that you already know, one popular circuit is the rectifier is a very popular circuit this is called the half wave rectifier what happens in this? So, this is a sin wave the input is now a sine wave, what is the waveform? So, if we use let us use our second rule right we are going to go by this most of the time, you are going to make an approximation that the silicon diode conducts when the voltage is beyond 0.7 volts and does not conduct when the voltage is below 0.7 volts.

So, let us make this approximation and proceed ok. So, this is time and the input voltage is a cosine, it looks like this what is going to be the result? The diode will have a drop of 0.7 if it is on, if the diode is off the drop it can it can sustain any drop as long as it is backwards as long as the drop is negative.

So, in the positive half cycle during the positive cycle of the sine wave; there is the likelihood that the diode will be forward biased that it will sustain a drop of 0.7 volts. And that will happen only beyond the level of 0.7 volts suppose this is 0.7. So, only above this level you are going to get a forward bias current below this level you are not going to get any current what is there right.

So, if you think about it the drop across this resistor is just this portion and then when it is reverse biased; the drop there is no current which mean the drop across the resistor is 0 and so, on and so, forth ok. So, here the 0 is over here any questions? So, this is I did it a little fast because this is you are probably studies this many times before this is called a half wave rectifier great.

Now, somebody wanted to make a full wave rectifier; how will you make a full wave rectifier? Yes your favorite circuit full wave rectifier circuit; there are 2 full wave rectifier topologies one is probably your favorite.

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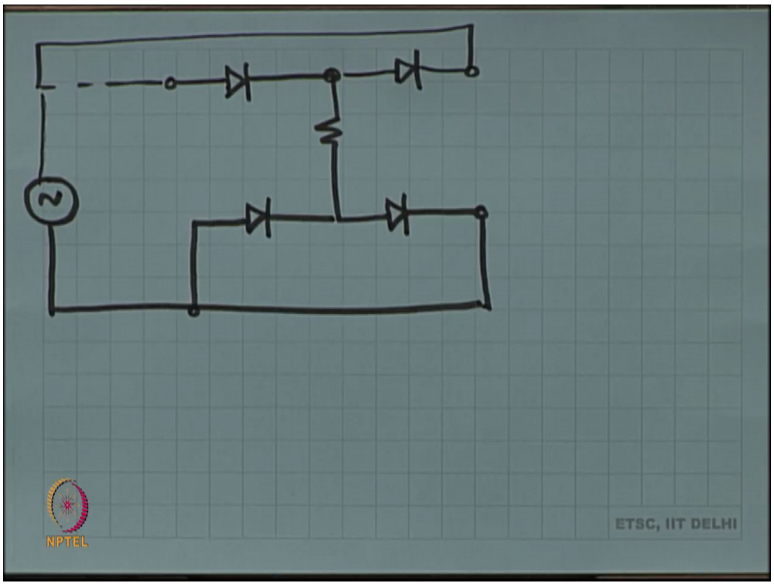

So, this is called the bridge rectifier. So, when the voltage is positive; it appears in this fashion ok, but when the voltage is negative it conducts in the opposite way.

Have I made a mistake? I think I have made a mistake let me draw it the ordinary way of drawing it, I think this is not correct. So, the way you are going to draw it is yeah.

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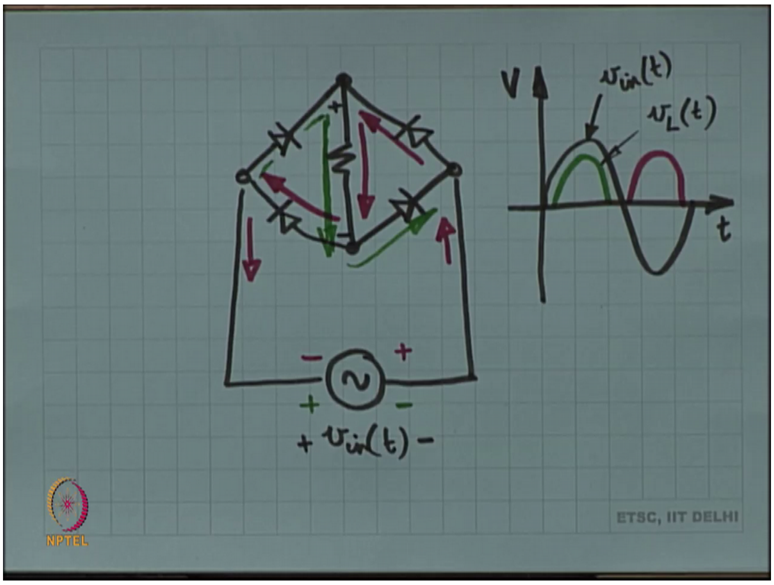

This is a better way of drawing it that is why this is the way it is always drawn ok. So, when the voltage is positive, that is when this voltage is more right when the polarity is this side is plus and this is minus then current flows in this fashion through the 2 diodes.

However, when the when the polarity is reversed when I have plus on the other side and minus on the other side ok; I want the same current the current to flow in exactly the same direction. And therefore, what I do is I place 2 more diodes and now the current goes like this ok. So, that is when the polarity is reversed fine is this understood? So, this is called the full wave rectifier and you have studied this before exactly like the half wave rectifier, but now it operates on both cycles both half cycles.

So, this is the green and the red are corresponding to the voltage drop across the resistor in the 2 different cycles; half cycles. So, what I have drawn on the graph this x axis is time and the y axis is voltage. So, this is your input voltage right and this inset; this is the voltage across the load; that is what has been done in the graph. And the gap between the 2 is 2 times the diode drops right 2 times the diode drop because there are 2 diodes that appear in series alright.

So, this is called the bridge rectifier this is also very familiar diode circuit and there is also one more topology for the full wave rectifier with the, it has a transformer unit. So, we are not going to bother about it right now. There is one nice circuit called the peak detector or the envelope detector and that is an offshoot of the half wave rectifier let us quickly take a look at that. So, this is the standard half wave rectifier ok.

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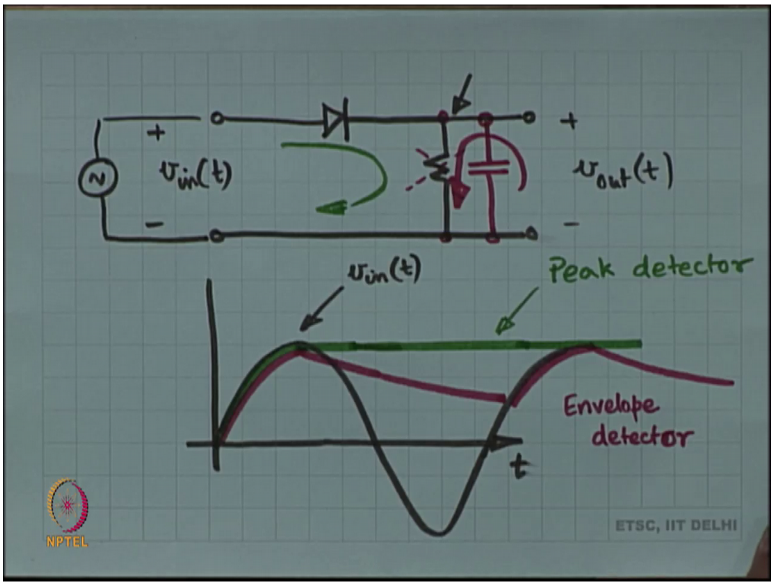

This is the standard half wave rectifier, now what I am going to do is I am going to add capacitor across the output terminals. So, I have added a capacitor across the output terminals; for a second let us even forget the resistor existence. So, let us forget about this all together now what is going to happen? Basically I replace the resistor with the capacitor actually they can co exist.

This there is no problem there, but let us just throw it out. Now what is going to happen? Suppose, this is the wave form v in of T and let us say that the diode is an ideal one that I is the ideal one that I could not really find in the market let us say that it is an ideal one.

So, the drop across it is nothing if it is forward biased the, and it can sustain any reverse bias voltage ok. So, under these circumstances what is going to happen? Let us define the starting point we have the capacitor. So, the capacitor should have any initial condition let us give it an initial condition of 0 charge. So, at time T equal to 0 the charge on the capacitor is nothing.

Let us start with that now what is going to happen? In the forward cycle, the capacitor the current the current is going to flow in the forward cycle and the capacitor is going to slowly charge up all the way to the top correct; any problem with that? No problem. But when it comes to dropping down with charge the capacitor has to discharge and when the capacitor has to discharge the current has to flow backwards back into the source is that right?

Now, if the current has to flow back into the source the diode is not going to allow that which means that this capacitor is allowed to charge up, but not discharge. So, therefore, since the current cannot go backwards this is going to continue; this voltage is going to be held for how long? No current all the way in the discharge path and then during this period during this half cycle there no current any way because the diode is reverse biased which means that the next time this voltage comes back up.

Now, there is an opportunity for the capacitor to charge maybe may be it might charge if it has reason to. So, this voltage is going to continued to be held, continue to be held and if in the next cycle it goes beyond that voltage the only there I some charging that is going to happen; if it does not go beyond that voltage then it this is just going to continue ok. So, this is called the peak detector right? It just detects the peak the maximum of v in of T ok.

Now, let us throw the resistor now back in. So, this resistor is now back now tell me what happen? Yeah what is going to happen? It is the same thing just that that capacitor now can discharge through the resistor. So, yes it charges up it charges all way up, but when it comes to discharging; there is a now a path for the capacitor to discharge through the resistor ok. And that will have a time constant of R time C alright and if RC is large enough then it may be wont completely discharge before the next cycle hits it. So, in the next cycle again it will charge out and then again it will slightly discharge till the next cycle hits it and again it will charge right. So, this way every cycle it can the circuit works out its new peak every cycle right and this kind of a circuit if you think of a many many cycles then it just follows the envelope of the signal.

So, this is called in envelope detector this is a; the technique that used to be used long back for amplitude modulation demodulation amplitude demodulation right this is this is to be the technique how ok. So, what is amplitude modulation?

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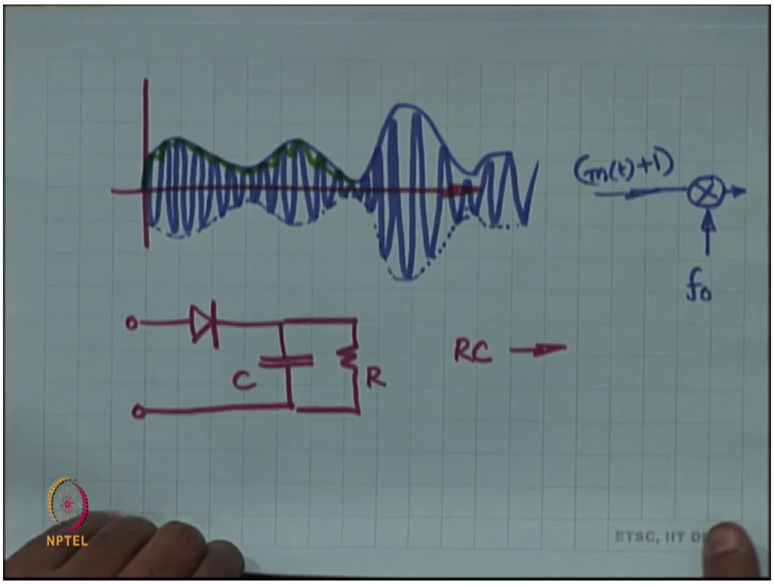

You just have; your message suppose this is your message signal and this m of t is going to be multiplied by the carrier right actually m of t plus constant is going to be multiplied by the carriage.

When you multiply by the carrier effectively what you are going to do is and remember the carrier frequency is much larger than the message right that is how it is. So, you have your m of t plus the constant; this is getting multiplied by f naught n this sine wave is at f naught and this overriding signal is m of t plus that constant plus 1.

So, this is your traditional amplitude modulation and now you pass this signal through my envelope detector. So, what is my envelope detector? It is nothing much diode capacitor that would have been the peak detector, just the diode capacitor. But I will also put a resistor such that in every cycle the RC time constant CR and RC is such that in every cycle it falls a little bit, but not completely ok. So, that if the circuit is able to work out a fresh peak; the fresh amplitude.

So, what is going to happen? Let us do it with the different color. So, first it is going to track and it is going to start falling, but in the next cycle it again tracks, false, tracks, false, tracks and false right over all what you see is; it is more or less going to find out, workout what the envelope of the signal almost and that is the message. So, you have a kind of a worked out the message signal all you need to now do is low pass filter this and clean up the things get rid of the DC component.

And then it is your message is ready. So, you have to low pass filter this. So, RC is already a low pass filter and you just have to choose the time constant nicely; so, that it does the job and then you have to remove the DC that is you put a blocking capacitor and remove the DC and that is it, then you amplify it and send it to the microphone. So, this is an AMD modulation circuit alright also known as an envelope detector. So, an envelope detector detects the moving amplitude of the signal ok.

So, these are some these were some interesting circuits using diodes; you can also 2 of the peak detectors to make a voltage doubler. I will leave it to you to figure out how that is done, you can use 3 envelope 3 peak detectors and use them intelligently to make 3 times the amplitude and so, on and so, forth. So, I am going to leave that to you may be that will appear in the homework and please work it out. With this I am going to start with a I am going to stop talking about diodes, diodes is not the main stay of this not the focus of analog circuits; you can make some interesting circuits with diodes, but you can only go so, much because the diode is passive.

So, now we are going to start working with active devices and the transistor is an active device is an example of an active non-linear device.

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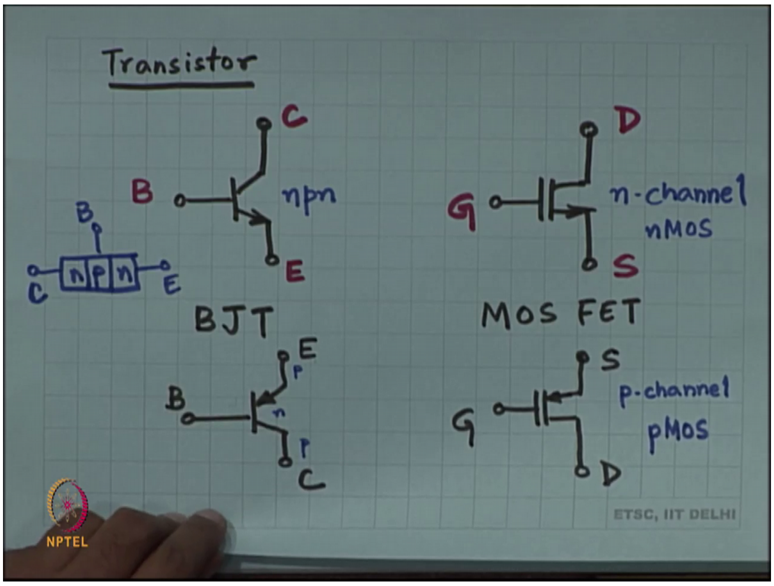

In your undergraduate syllabus, there is a transistor called the bipolar junction transistor that is very popular in the books and so, on. However, the B J T has being phased out from most systems, most systems no longer use the bipolar junction transistor at all most modern systems. So, if you are in this day and age you are not really going to be that much interested in the B J T; it is just an academic interest.

The more popular transistor today is the MOSFET; so, this is called the acronym based bipolar junction transistor and over here the acronym is Metal Oxide Semiconductor MOS, Field Effect Transistor FET. So, there are many different kinds of FET's; MOSFET is one FET; F E T. Metal Oxide Semiconductor Field Effect Transistor and in this course, we are going to focus primarily on the MOSFET in passing we will mention the B J T just because it is there in your books and in some exams; it might be asked what the B J T is all about and how to work out circuits with the BJT's; these things might come in exams; however, beyond exams the B J T is of no relevant whatsoever ok.

So, I have drawn the symbols so, far right for the B J T and the MOSFET these are both transistors right. This is this terminal is called the base, the emitter and the collector and similarly in the MOSFET this terminal is called the gate, this is the source and the drain. Now there are 2 different flavors of BJTs; one flavor is the npn right this is called the npn B J T because that is how it is made, it is made with a block of silicon n type, p type and n type ok. So, this is how it is made ok.

So, that is why it is called an n p n B J T; likewise this particular MOSFET, this flavor of MOSFET is called an n-channel MOSFET or a lot of people in short call it an n MOS transistor ok. So, there are 2 more flavors there is sorry there is one more flavor for the B J T and that is called the pnp B J T ok, this is emiter is p type and n type and collector is p types; so, this is called a pnp B J T.

And similarly there is another flavor of the MOSFET which is called the p channel MOSFET and lot of people call it the p MOS transistor fine. So, there are a few more symbols that I am going to draw and all of these symbols are equivalent. So, the B J T this is the only symbol right some people draw a circle around the BJT, but that is ok.

You need not draw the circle around the B J T, it is still exactly the same as the B J T for the MOSFET there are few a few more symbols that a lot of people use.

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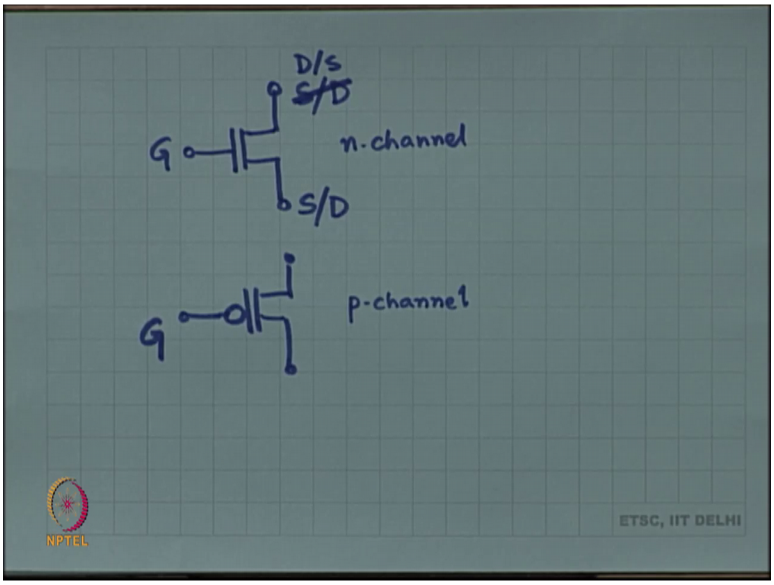

One popular symbol that is used in a lot of digital circuits is just this without the arrow; if you draw it like this is actually let us call it. So, this terminal either could be the drain or the source right because there is no marker, likewise this terminal could have been the source, but it could also be the drain, there is no marker ok.

However, this is the gate now when you draw it like this; this MOSFET is probably being used as a switch ok. And when you are using at a switch the switch is either on or it is off, when the switch is on it does not matter which is source, which is drain. And when the switch is off it still does not matter which is source, which is drain either the switch is on; so, it is a short circuit or it is an open circuit.

So, the connection between source and drain is either a short or on open alright. So, that is the likely operation of the circuit when it is drawn when the when the MOS device is drawn in this fashion, that is what it probably is being used for; it is being used as a switch ok. And this particular device is n-channel alright that is the symbol now there is a parallel and in the parallel one.

So, the gate is the only terminal that is relevant these 2 can be anything other source or drain right; this particular device is a p channel device and its switches on when the gate is low. So, there is a bubble right remember your digital circuits ok; whenever you put a bubble it implies not happening ok. So, these are also a symbols for the MOSFET, but remind you that these symbols are going to be used only under situations, where the MOSFET is going to be operated as a switch so; that means, digital circuits.

So, these are symbols used primarily in digital circuits ok; then there is one source of confusion the MOSFET comes with a fourth terminal.

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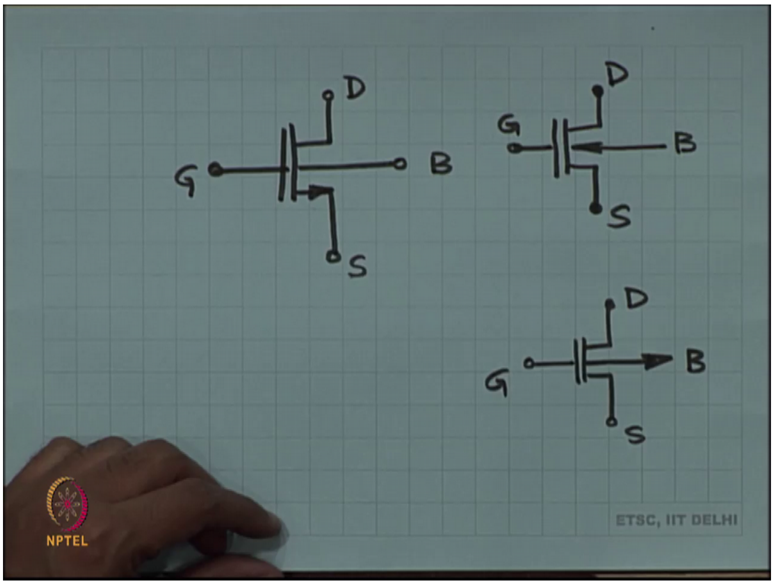

So, there is actually one more terminal in the MOSFET. So, the MOSFET is not a 3 terminal device, it is a 4 terminal device ok. The fourth terminal is the body; so, one possible symbol is just like this, another way is to put an arrow.

But once again over here because there is no clear identification which is drain, which is source this device is probably being used as a switch. In case of the p MOS device this is a n-channel, in case of the p channel device; the symbol is opposite ok. So, these are some of the symbols; so, we are not really going to use any of these right.

At best sometimes we might point out the existence of the body, but mostly in this course; we are going to stick with these symbols right. For the B J T n-channel n p n pnp BJTs and n-channel MOSFET, p-channel MOSFET this is what we are going to stick to; most likely all right. Sometimes, we might show this symbol if we want special work to be done with the body.

Now, with an understanding of these symbols let us also point out the few conventions. So, in a in electronics in your circuit theory course whenever you have drawn circuits; you might have drawn circuits like this right.

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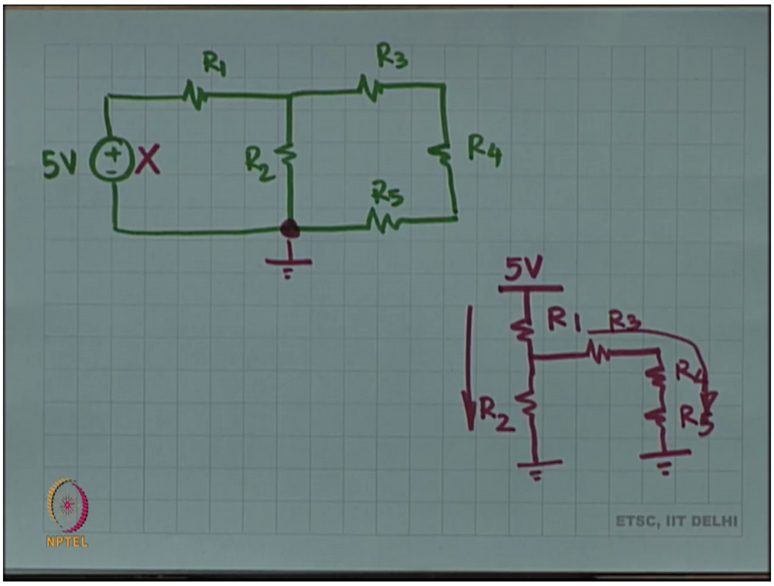

You might have drawn complicated circuits like this and you would have been asked questions to analyze and so, on and so, forth. In electronics, these voltage sources might not be shown; in invariably we do not do this voltage sources at all number 1. So, we do not show the voltage source it is just not shown I will show you how I am going to re draw this circuit in electronics. Number 2 is this point the reference point is going to shown as ground. So, this same circuit is going to be drawn; now in electronics in this fashion.

So, let us suppose this is the circuit and suppose this is not a circuit theory class, suppose this is an electronics class; we are no longer going to draw like this, we are going to draw it like this. So, if this have been 5 volts, I will just point out that this is 5 volts is this understood? This is going to be the new style of drawing for electronics, you are going to start with the power supplies at the top right and ground is going to be at the bottom, ground is nothing much it is just a reference point right.

We are all going to refer to ground and then the circuit is going to be drawn; however, it is any questions about this is going to be the style. This kind of a style also tells you that and immediately you know the direction of the current because current is going to flow from top to bottom ok. Higher potential to lower potential, higher potential is going to be drawn above, lower potential is going to be drawn below naturally all currents are going to downwards ok.

We are all going to go from the top to the bottom; we are going to use this convention all through. Is that clear? Now when we draw the transistor this convention is implied when I draw the transistor like this.

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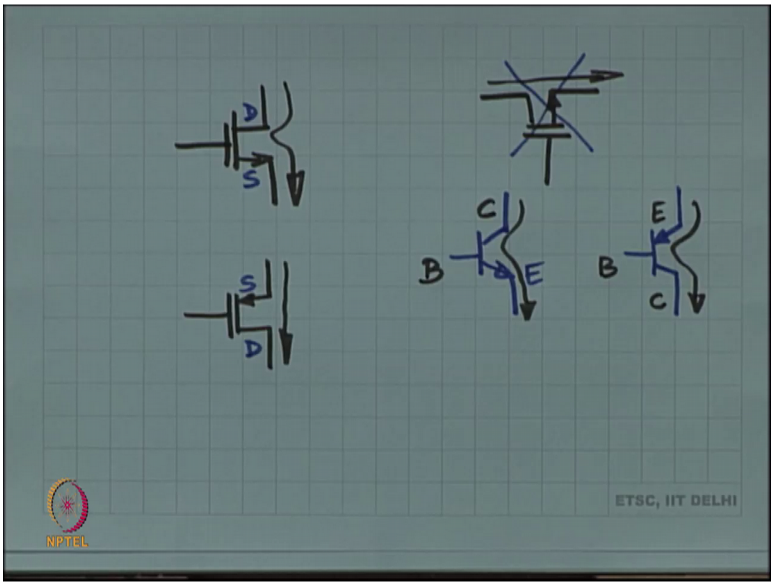

Notice that current is going to go from top to bottom and remember if you draw the transistor like this; it is very very difficult to work out which way the current is going because it is not going from top to bottom anymore; it has to go like this alright.

So, this is not used this kind of a drawing is no good; we are going to avoid this kind of drawing unless absolutely necessary, we are not going to draw like this; we are always going to draw like this. The p MOS the p-channel MOSFET again current flows from top to bottom ok; the arrow in the device always points in the direction of the current; so, these are some of the conventions.

Quick thing to remember is that the arrow the device is always on the source; never on the drain, the arrow is always on the source; whether it is p MOS or n MOS; the arrow is on the source ok. The other terminal is the drain; is that fine? And likewise when you draw the B J T, the arrow is always on the emitter current flows in the direction of the arrow.

So, in this case current is going to flow from top to bottom this is npn and the pnp device current is again going to flow from top to bottom and which is the emitter? The one with the arrow is always the emitter alright is this fine? So, with this introduction we are going to move forward, this is largely what I have talked about today as far as the transistors are concerned.

I have only talked about symbols and conventions ok; in the next class we are going to actually start working with the transistor. We are going to introduce the transistor characteristics and then we are going to start working with the transistor and start making circuits with it.

Thank you very much and hope to see you soon.