Mechatronics
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Lecture - 05
Application of Transistors

Welcome to NPTEL online certification course on Mechatronics. Today we are going to discuss the Application of Transistors, which we have seen in the previous lecture plus I will be talking about two more type of transistors; that is field effect transistors and the metal oxide semiconductor field effect transistors. So, these are things which we will be discussing.

Now, because of bipolar junction transistor or the BJT is which we call in short base current characteristic, it can be used for amplified current or simple switch current on and off.

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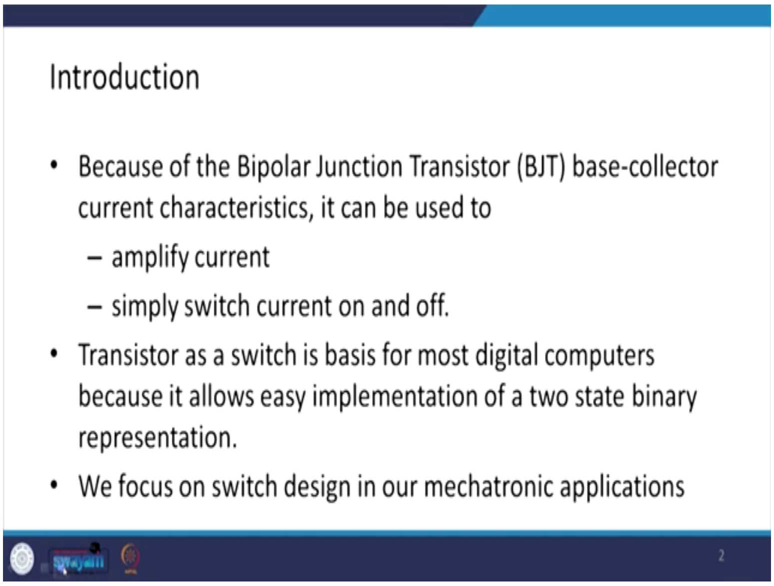

Now, these are the two principal applications of the BJT. Transistor as a switch is the basis for most digital computers, because it allows easy implementation of the two state binary representations. So, we will be discussing this binary representation in our further coming lectures.

But, just to understand at this stage I can say is that a binary state means either 1 or a 0. Now, we focus on the switch design in our mechatronic applications. So, we will be discussing more of BJT as a switch, in this lecture.

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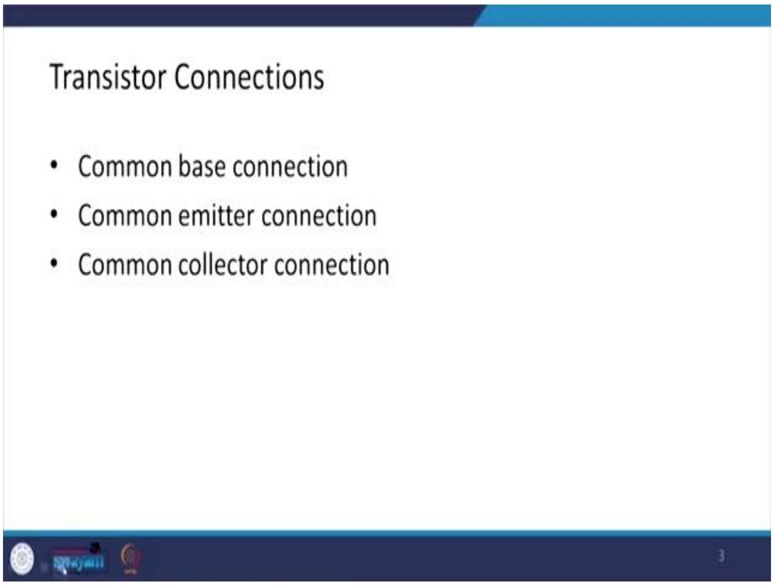

Now, coming to the transistor connections, there are three very popular configuration for the transistor connections, (a) base connection, (b) common emitter connection, and (c) the common collector connection.

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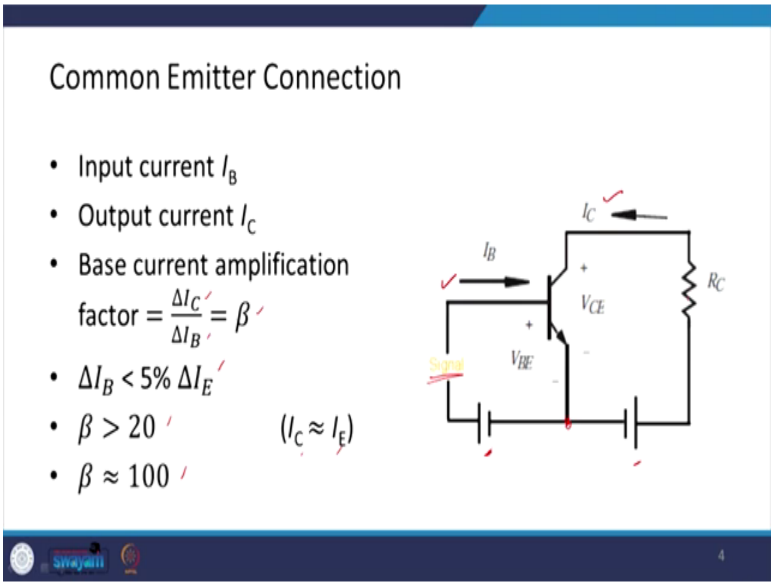

Let us look at this figure. This configuration is called a common emitter connection.

In this configuration, we have input current, I_B the emitter is common here, and output current is I_C. And, so, the base current amplification factor here is basically change in collector current divided by change in the base current and that is what we define and call it as β.

And, we know that this change in β is almost less than 5 percent of change in the emitter current. So, if I substitute here, because I_C is almost equal to I_E, we get β value to be more than 20. So, β is in practical transistors it is around 100. So, this is the common emitter configuration where emitter terminal is in common with the base as well as with the collector.

And, here is the signal basically we have the connections power supply for the base side, and power supply for the collector side.

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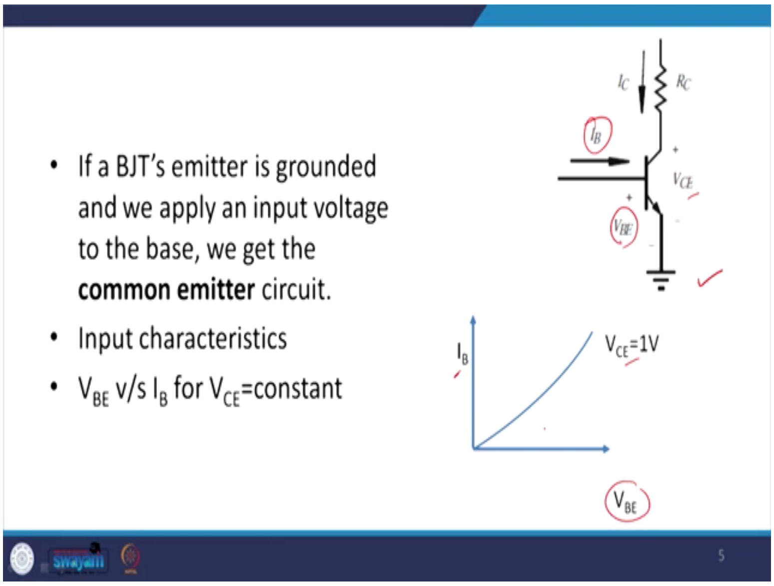

Now, if a BJT emitter is grounded and we apply an input voltage to the base, we call it as the common emitter circuit. So, this is the short notation for the common emitter connection. And, here input characteristic basically input is a V_{BE} that is V_{BE} versus I_B. So, if we plot V_{BE} versus I_B for a constant V_{CE} that is the voltage between collector and emitter. This is how we get the characteristic curve.

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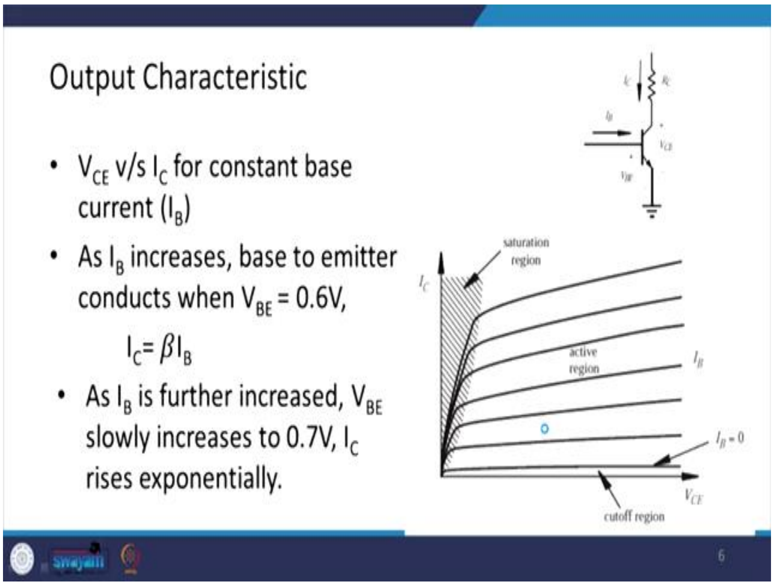

Now, let us look at the output characteristic. So, here for output characteristic, what we do is that we plot V_{CE} verses I_C for a constant base current value. So, we can see that as I_B increases, base to emitter conducts when V_{BE} value is around 6 volts. And, what we get I_C is equal to β times of the I_B, that is the current collector amplification.

Now, if we go on further increasing the I_B, V_B slowly increases to 2.7 volt and I_C rises exponentially.

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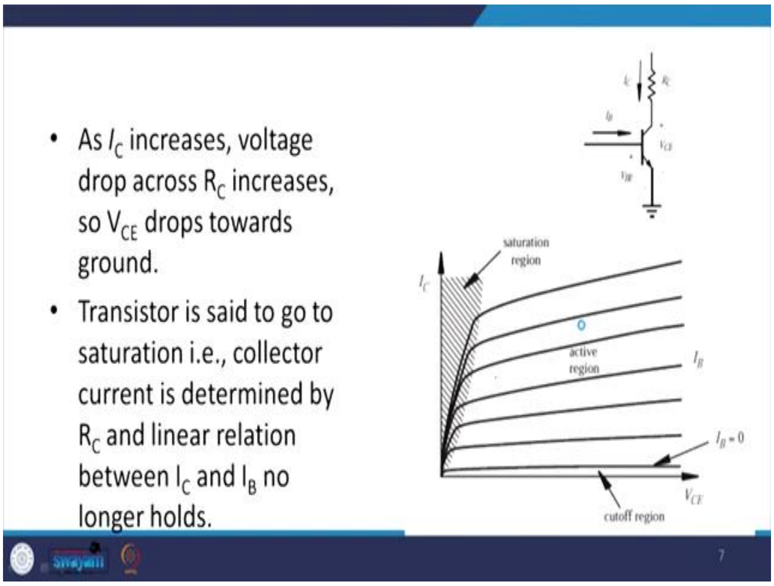

So, what happens basically as I_C increases there is lot of voltage drop across R_C. So, the V_{CE} drops towards ground its not 0, but it is very near to 0. And, the transistor is said to go saturation that is the collector current is determined by R_C. And, the linear relation between I_C and I_B no longer holds, this is what happens in the saturation region.

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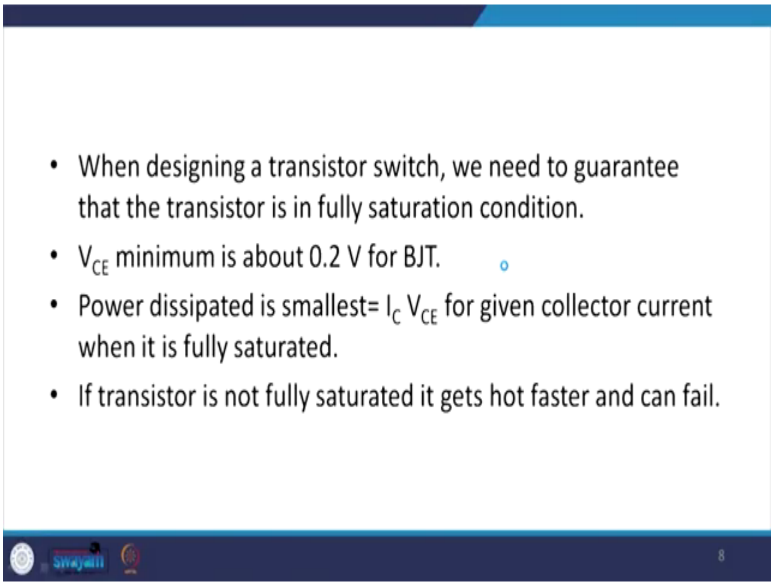

Now, when we are designing a transistor switch, we need to guarantee that the transistor is in fully saturation condition. V_{CE} minimum is around 0.2 volt for the BJT. And,

$$\text{Power dissipated is a smallest} = I_C\ V_{CE},$$

that is the current into voltage for a given collector current when it is fully saturated.

Now, if the transistor is not fully saturated it gets hot faster and can fail.

Now, let us look at how the bipolar transistor works as a switch which we mostly often use in the mechatronic system.

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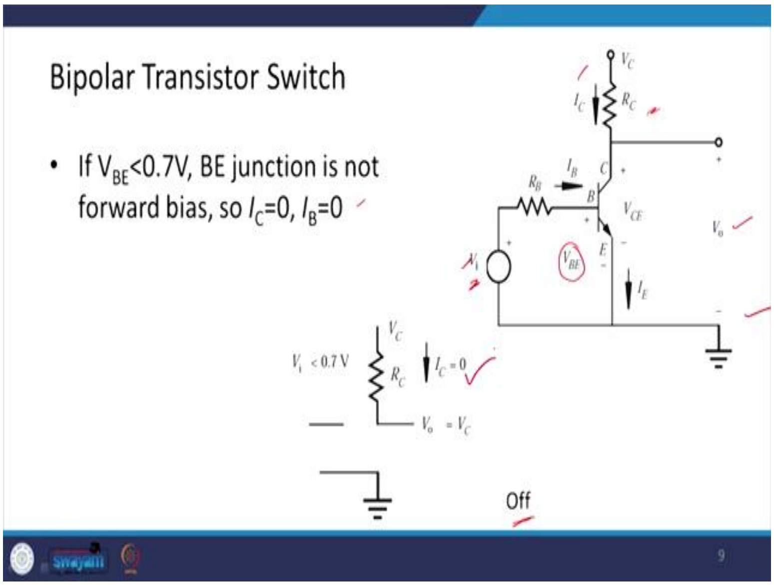

So, here this figure actually shows the circuit for the input side as well as for the output side. And, here we have a voltage V_i is the input and here V_0 is the output. Now, what happens? If, your V_{BE} that is the voltage between base and emitter is less than 0.7 volt, the base emmitor junction is not forward bias. And, if base emmitor junction is not forward bias, the I_C is equal to 0 and I_B is equal to 0 and the transistor state is the off state. So, we have I C is equal to 0 here.

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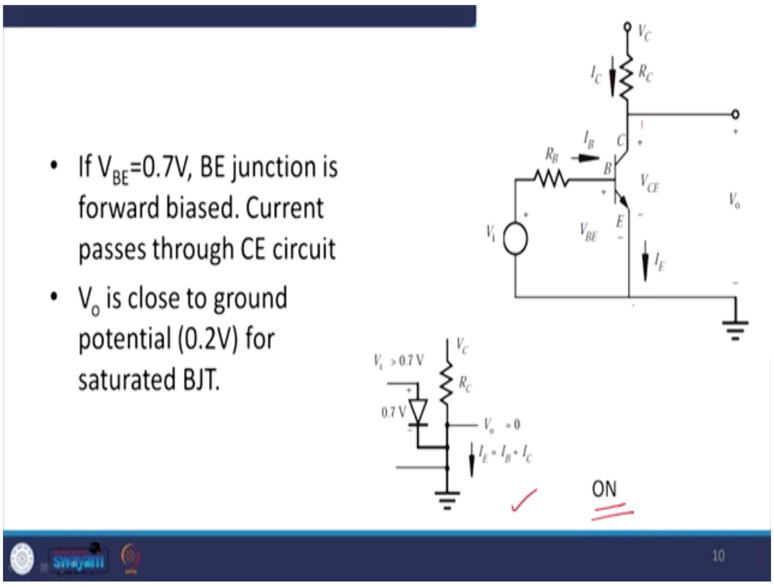

Now, if V_{BE} equals 0.7 volt, BE junction is forward bias and current passes through the collector that is CE circuit. And, in that case V_0 is the output voltage is close to ground potential 0.2 volt for the saturated BJT. So, this is the condition which is shown for the saturation state and in this condition, we can see that the transistor is in the on condition. Because you have a lot of current flows through the R_C, that is I_C is large.

And, there is lot of a voltage drop across R_C and so V_{CE} is almost ground value around say 0.2 volt. And, this property is used basically to switch transistor make on and off.

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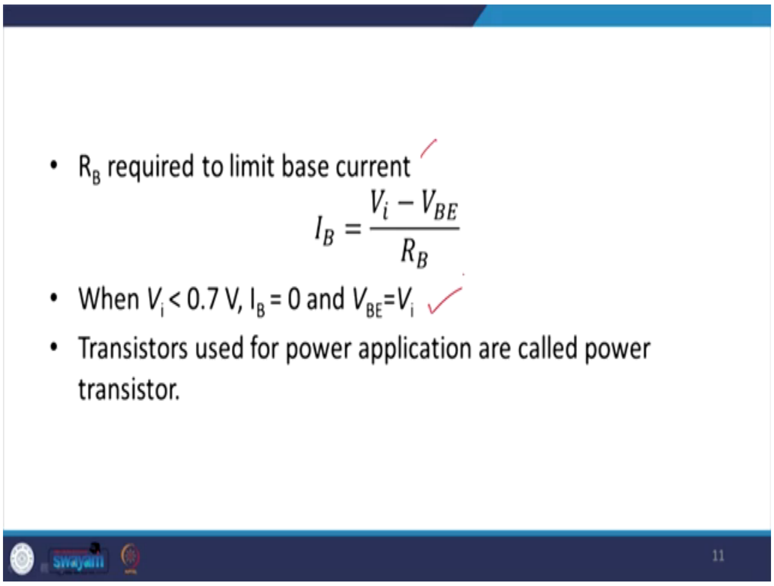

Now, what should the base resistor require to limit the base current. This we can find out by using the equation,

$$I_B = \frac{V_i - V_{BE}}{R_B}$$

When V_i is less than 7 volts, I_B is going to be 0. So, V_{BE} is going to be equal to V_i .

Transistors used for power applications are called power transistors. Now, this is how commercially you can have these transistors available from the market.

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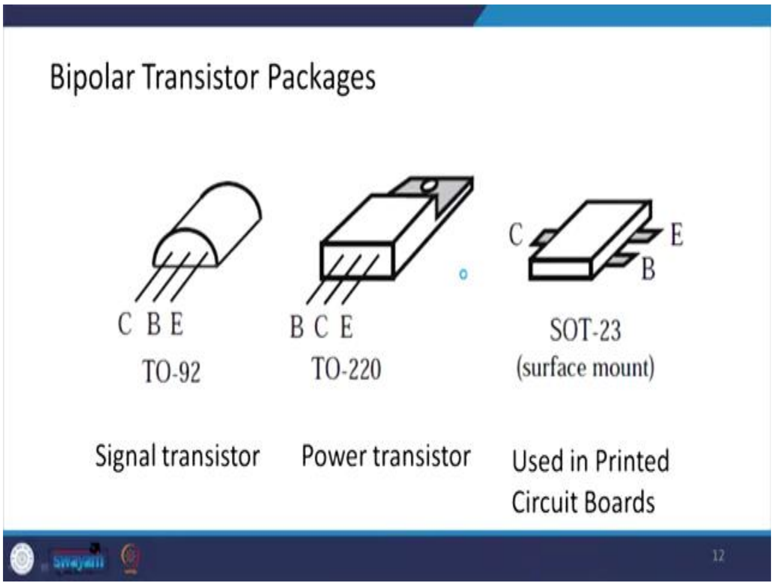

So, single transistor say T0-92 is this you have the collector port, base port, and emitter port. Similarly, the power transistors which are used in the power application is T0-220. These transistors could be of surface mount type, which could be used in the printed circuit board. So, they are just like say an example is SOT-23. So, here also we have collector base and emitter. And, this is how you get in the market.

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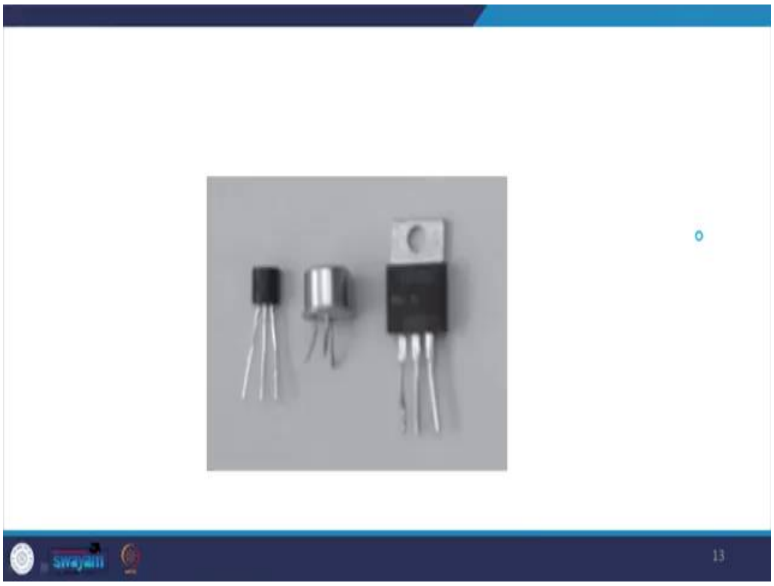

So, these you can directly get from the market of the shape.

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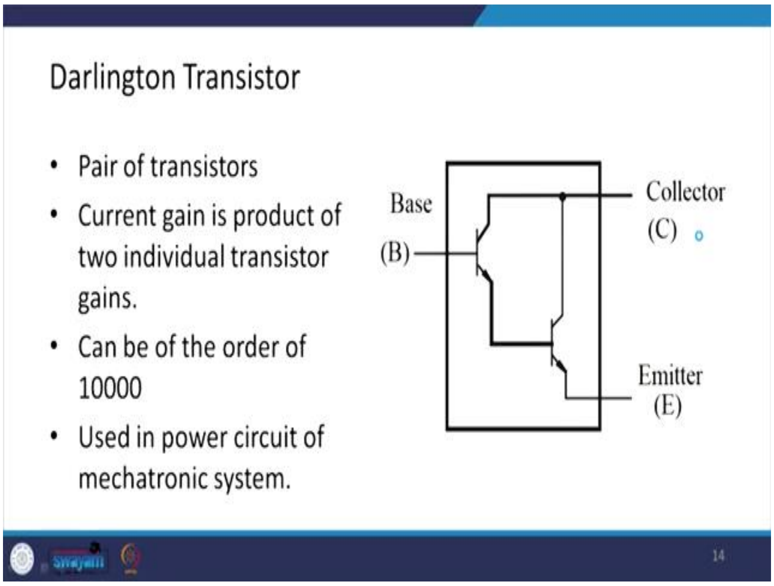

Now, there are type of transistors called Darlington transistors, which are often used in the mechatronic circuit. And, these are the pair of transistors basically the two power transistors, emitter is connected to the base of the second transistor. And, this way their collectors are connected together.

So, this is the base for the combined one and this is the emitter for the combined one. So, for the are pair of transistors, current gain is product of the two individual transistors gain in this case. And, this value could be of the order of say 10,000 and these are used in the power circuit of the mechatronic systems.

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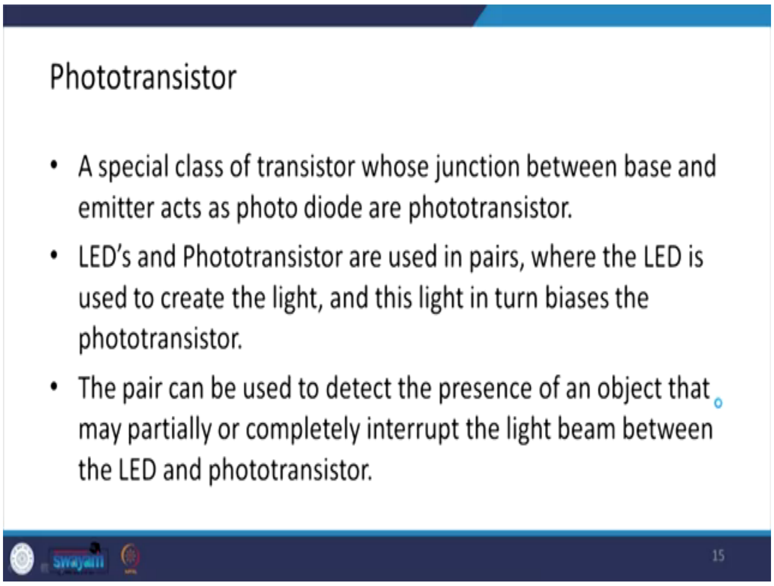

Then, we have another type of transistors called phototransistor. These are special class of transistors whose junction between base and emitter acts as a photodiode. And, these are what we call it as the phototransistors.

Now, LEDs and photo transistors are used in pairs basically, where the LED is used to create the light and this light in turn biases the phototransistor. The pair can be used to detect the presence of an object that may partially or completely interrupt the light beam between the LED and the phototransistor.

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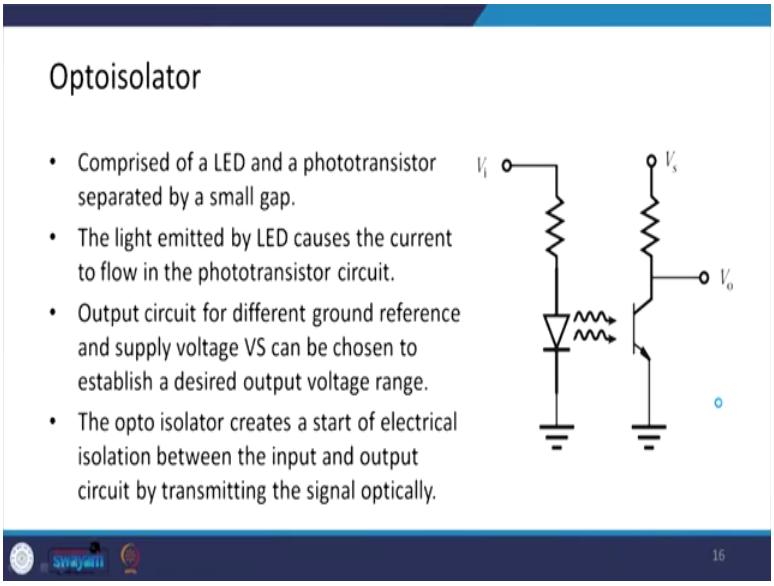

Next, let us see the optoisolator as the name indicates this is the combination of LED and transistor that could be used for the isolation purpose. So, it comprised of a LED that is light emitting diode and a photo transistor separated by a small gap. The light emitted by LED causes the current to flow in the photo transistor circuit and output circuit for different ground reference and supply voltage can be chosen to establish a desired output voltage range further the opto isolator creates start of electrical isolation between the input and output circuit by transmitting the signal optically.

So, let us take an application for this it is an angular position of a robotic scanner.

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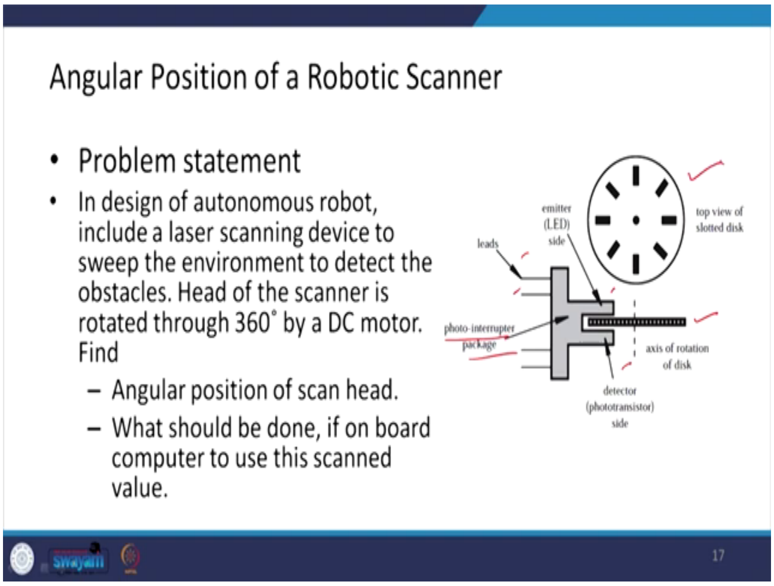

So, we can see that there is a photo interrupter package here, the leads are here for the connection purpose and there is a emitter that is LED side, and there is a detector here on phototransistor side. And, here this is a disk and axis of rotation of disk, if you see it from the top this is how it looks like.

So, I can write the problem statement as a say design of an autonomous robot, which include a laser scanning device to see the environment to detect the optical. Now, head of the scanner is rotated through say 360 degrees by a DC motor. Now, find the angular position of the scan head and what should be done if on board computer is to use this scan value.

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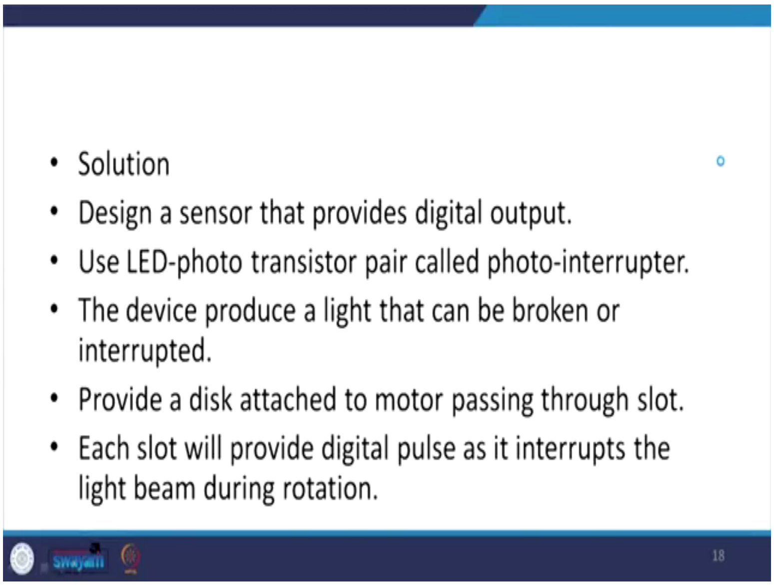

The solution is basically, design a sensor that provides the digital output.

So, what we can do? We can use LED phototransistor pair called a photo interrupter, and the device produce a light that can be broken or interrupted with the help of the holes, which are provided on the disk. Now, provide a disk attached to motor passing through the slot and each slot will provide digital pulse as it interrupts the light beam during the rotation.

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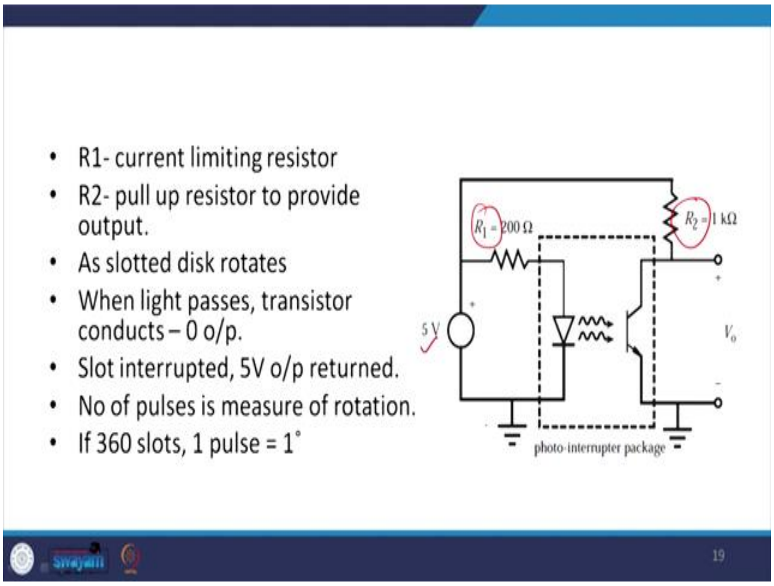

So, here is the circuit here, say this one is the current limiting resistor and this is the pull up resistor to provide the output. As slotted disk rotates, when light passes, transistor conducts and there is a 0 output. And, when the slot interrupts these 5 volts, which is there that is return at the output. And, number of pulses is measured of the number of rotations. So, for example, say if there are 360 slots 1 pulse will be basically corresponding to 1 degree.

Next, let us look at the field effect transistors.

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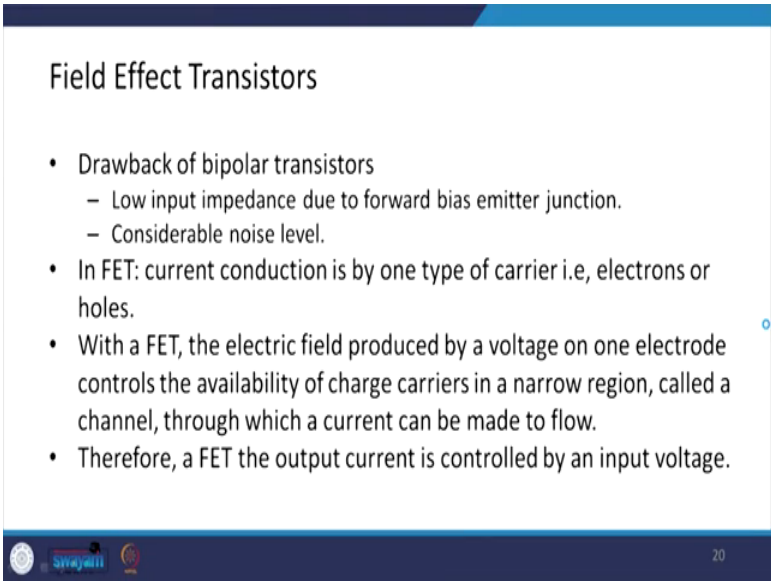

The bipolar transistor has certain drawbacks. These are that the low input admittance due to the forward bias emitter junction. We know that, the emitter base junction is the forward bias input side, and there is a considerable noise level.

Now, in field effect transistor the current conduction is by any one type of carrier that is either electrons or holes.

Whereas, in case of BJTs, we have seen that the current conduction is a combination of the motion that is due to that motion of the holes as well as the electrons. Now, with field effect transistor and electric field produced by a voltage on one electrode, it controls the availability of charge carrier in a narrow region, which we call it as a channel through so the current can be made to flow. Therefore, in FET the output current is controlled by the input voltage. Let us look at how it is constructed?

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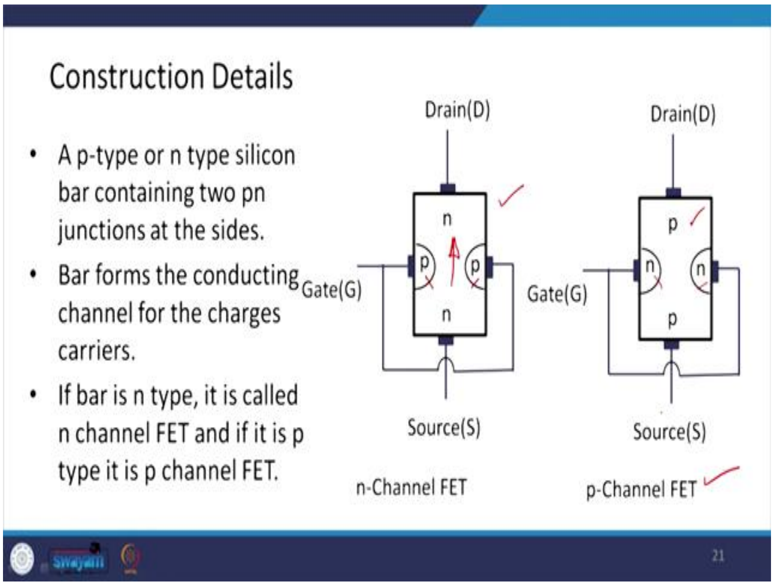

So, here a p-type or n type silicon bar contains two pn junctions at the sides. So, basically there is a bar, say this is a n type of bar and a p-type or n type silicon bar. So, this is your n type silicon bar, this is your p type silicon bar. And, this has got two pn junction at the side. So, one pn junction is here and another pn junction is here.

Similarly, in this case one np junction is here and another np junction is here. And, this bar forms the conductive channel for the charge carrier. If a bar is n type, it is called n channel FET and if it is p type, it is called the p channel FET as it is shown over here.

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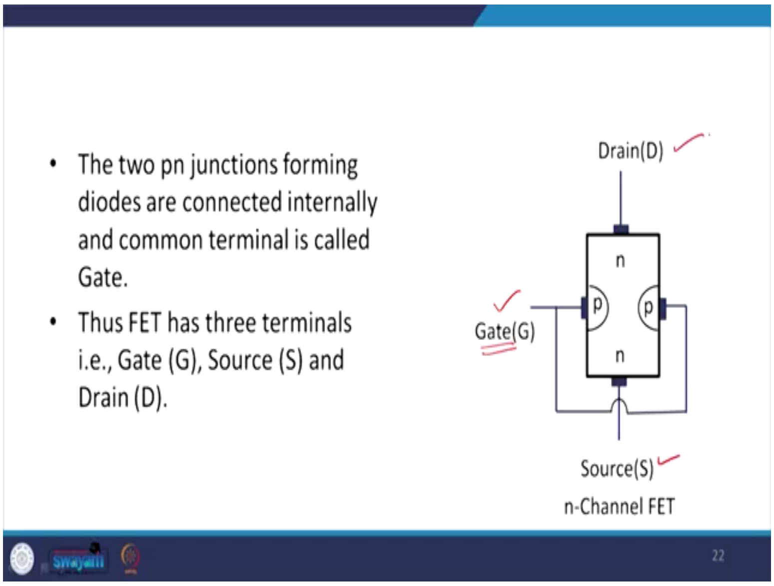

These two pn junctions forming diodes are connected internally and common terminal is called gate. So, FET has basically the three terminals, first is called Gate, second is called Source, and third is called Drain. These source and drains are interchangeable.

Here, I have shown only n channel FET, similarly we can have explanation for the p channel FET also.

Now, let us look at the polarities of FETs field effect transistors.

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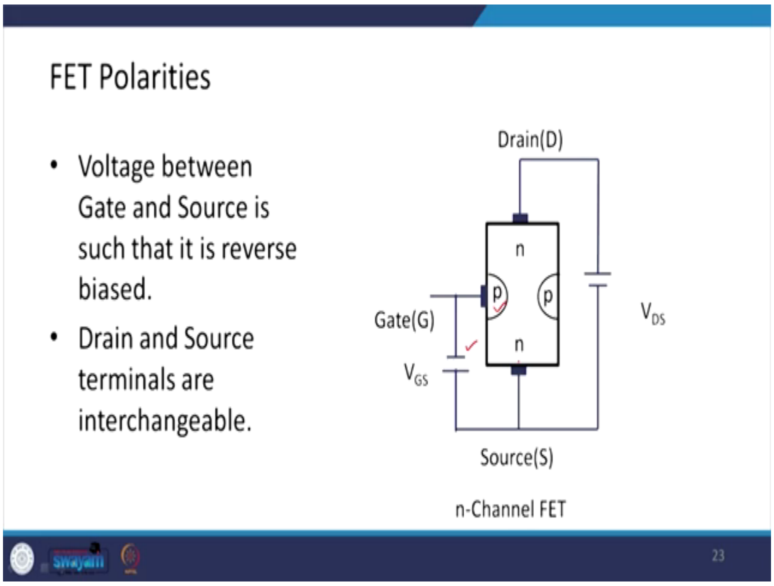

So, here the voltage between gate and source is such that it is reverse bias.

So, you can see that this is p type here and this is going to be the negative of the battery say V_{GS} which is going to be connected to the p type and positive is going to be connected to the n type. So, this is reverse bias and a drain and source terminals are interchangeable as I said earlier.

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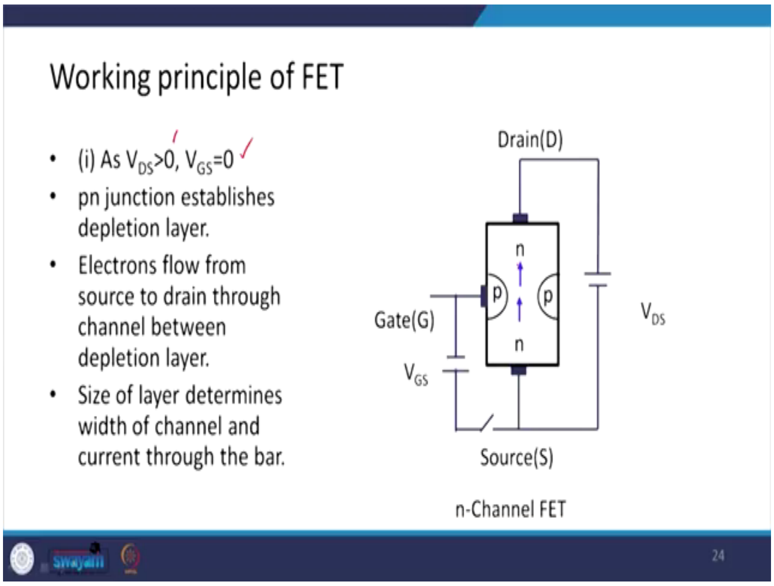

So, let us look at the working principle of field effect transistor. So, we will see that there are basically two conditions, say first condition is the voltage between the drain and a source is greater than 0, and between a gate and a source is equal to 0. At this condition pn junction establishes a depletion layer and electrons flow from source to drain through channel between this layer. So, the electron flow from the source to drain through the depletion layer and size of layer determines width of the channel. And, current flow current through the bar.

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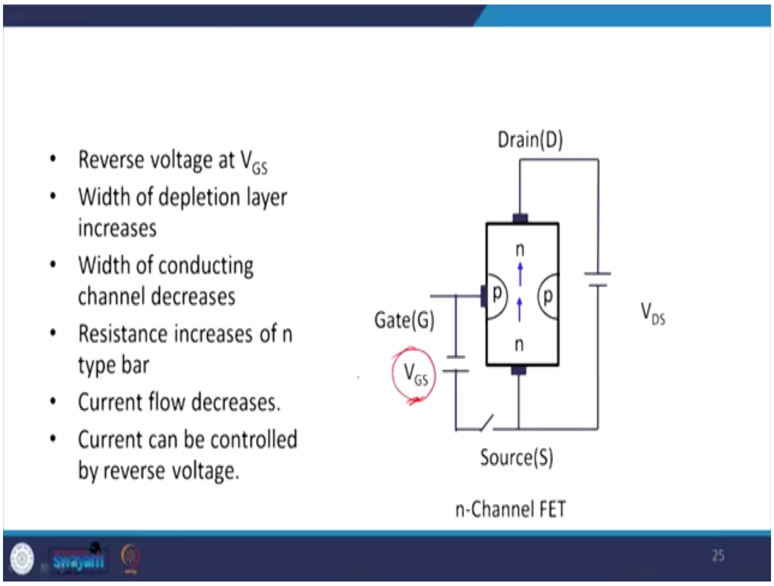

Now, if a reverse voltage V_{GS} is applied here, then what will happen is that the width of the depletion layer will increase. And, if width of depletion layer increases, width of conducting channel will decrease. And, because of this the resistance increases in the n type of bar and the current flow decreases. So, this is what we can see that, the current flow can be controlled with the help of this voltage V_{GS}.

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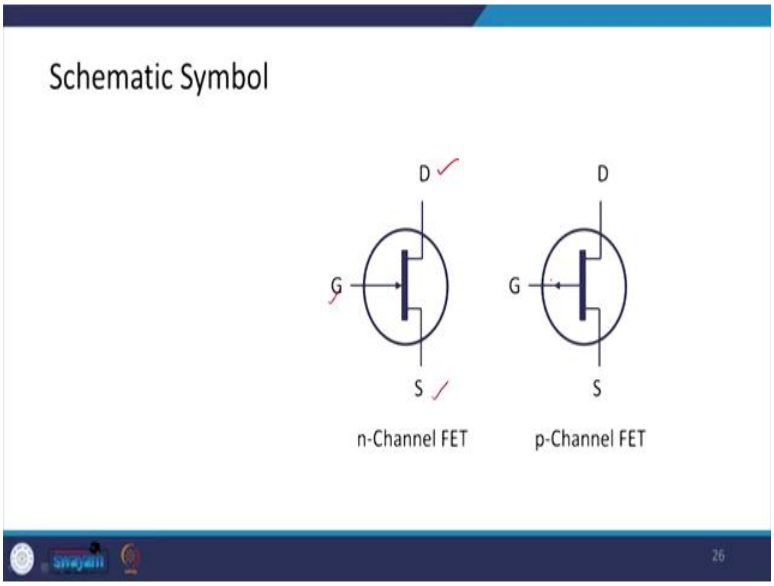

So, coming to the schematic for the FETs; this is for the n channel FET, we say source, gate, and the drain here. And, here in the n channel there is an arrow provided in this direction in case for the gate. And, for p channel again you have the three terminals, but here arrow is in the opposite direction. So, this is how they are symbolically represented.

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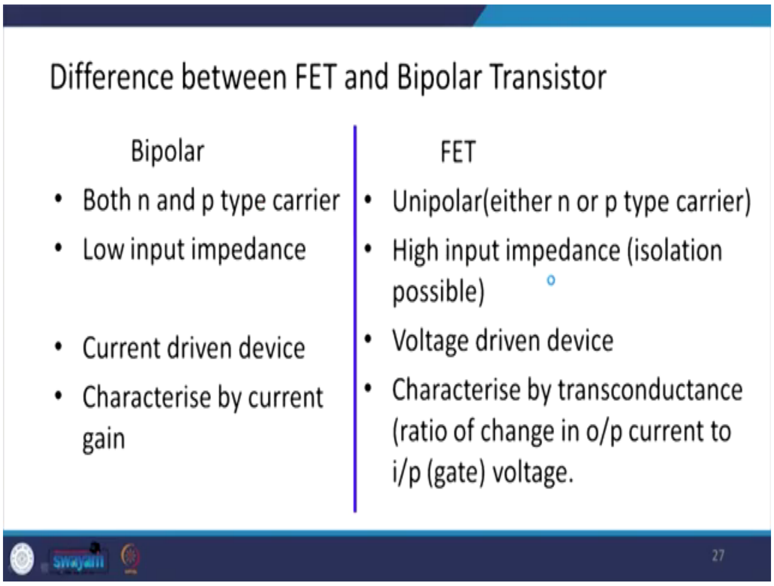

Now, coming to the difference between the FET and the bipolar transistor, the bipolar transistor current conduction is because of both n and p type carrier. Whereas, in case of field effect transistor current conduction is unipolar, that is either n type or the p type carrier will be conducting the current.

In case of bipolar there is low input impedance, in case of field effect transistor we have the high input impedance. So, because of this the isolation is possible.

And, bipolar transistor are current driven devices whereas, field effect transistors are voltage driven devices.

And, bipolar transistors are characterized by current gain whereas, the field effect transistors are characterized by the transconductance which is nothing, but ratio of change in output current to the input gate voltage.

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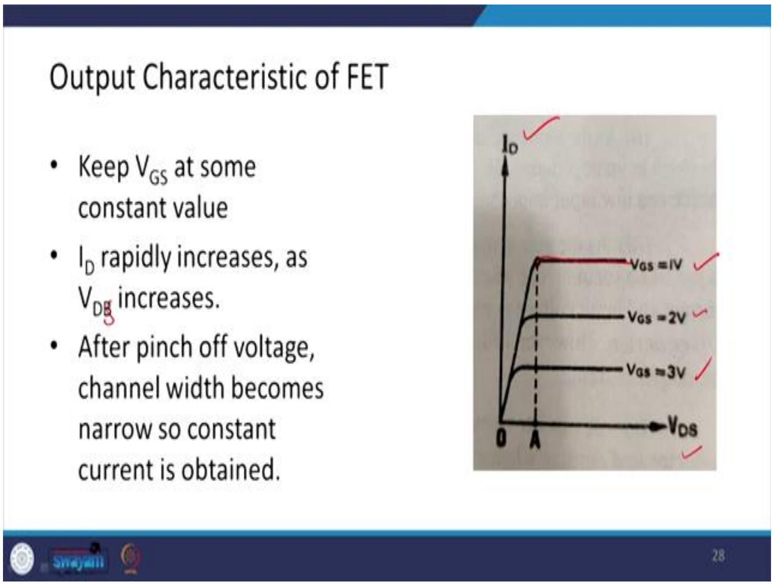

If we look at the characteristic of field effect transistor, then we can see that, if we keep V_{GS} that is the voltage between the gate and the source is at some constant value. I_D rapidly increases as V_{DS} increases basically. After pinch off voltage the channel width becomes narrow, and we get the constant current. These figures are shown for the different values of voltage between the gate and the source.

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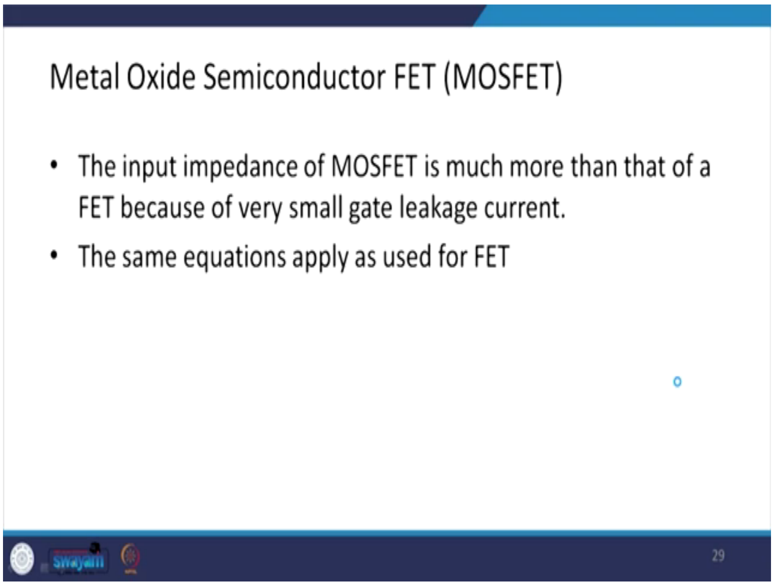

Next, let us talk about and another important transistor, which we call it as the metal oxide semiconductor FETs or in short it is very popular with the name MOSFET. For the MOSFET the input impedance of the MOSFET is much more than that of the FET because of very small gate leakage current. The same equations which were applied for the FETs, are also applied for the MOSFET.

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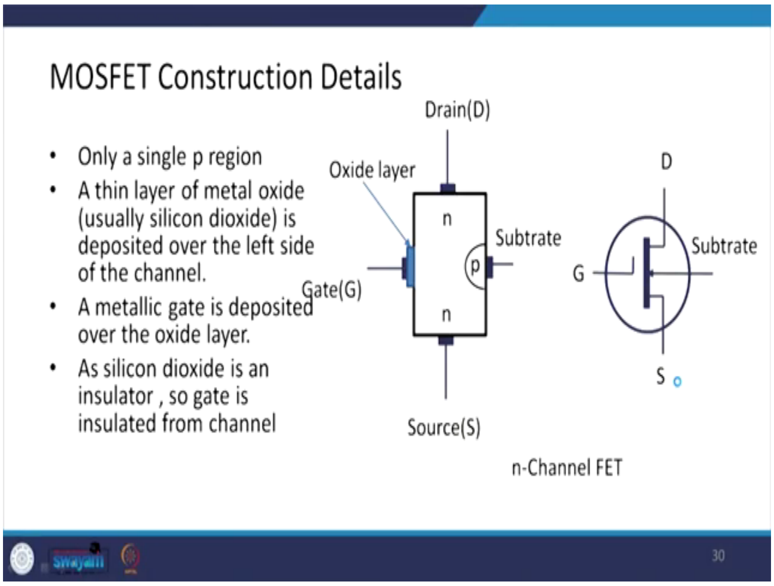

If we look at the MOSFET construction detail then here what we can find is that there is a source and a drain. And, in this case only one pn junction is there and a metal oxide layer usually silicon dioxide is put into it. At the top of it the gate is a metal is deposited over here.

As the silicon dioxide is an insulator so the gate is insulated from this channel.

This is how it is a represented symbolically and this one is called substrate.

So, we have the substrate, gate, a drain, and the source.

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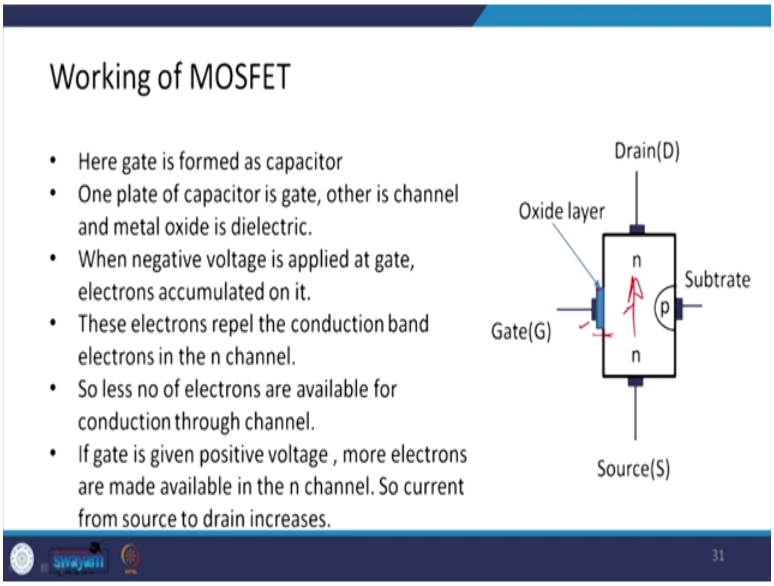

Now, let us see the working of the MOSFET. Here gate is formed as a capacitor. So, what happen basically, our gate is metallic and our channel is also metallic and there is an oxide layer in between. So, this oxide layer basically acts as a dielectric. This portion actually behaves as a capacitor. So, one plate of capacitor is gate other is channel and the metal oxide is dielectric.

Now, when negative volt is applied at the gate the electrons are accumulated on it and these electrons repel the conduction band electrons in the p channel. So, the smaller number of electrons are available for conduction through the channel. Now, if we do the reverse thing that is if gate is given a positive voltage, then in that case more electrons are made available in the n channel. So, current from the source to drain increases and this is how the MOSFET basically works.

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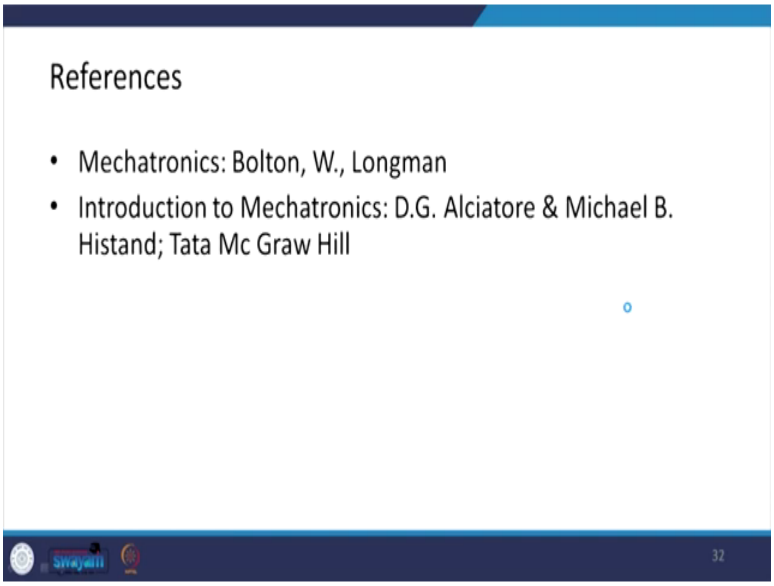

These are the references which I have used especially the second book, you can see the Introduction to Mechatronics by Alciatore and Histand for further reading.

Thank you.