Fundamentals of Power Electronics
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Lecture - 81
BJT base drive

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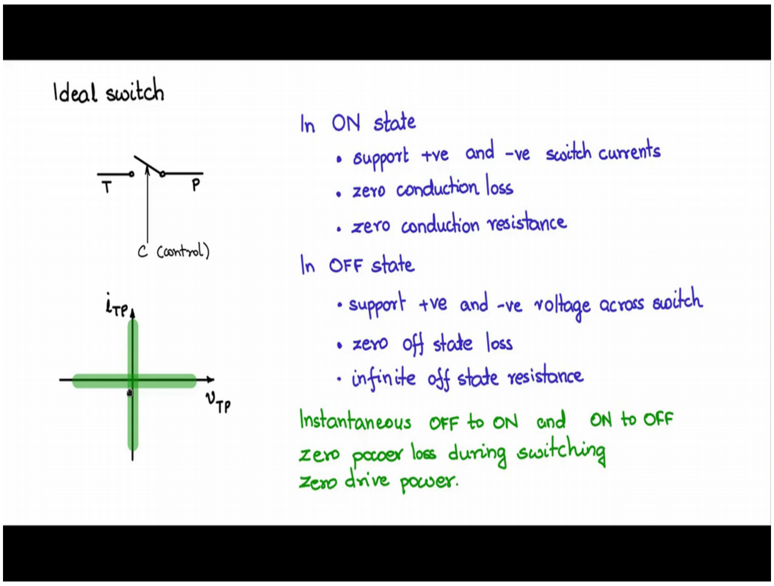

Before we try to design drive circuits for practical BJTs and MOSFETs let us try to understand what an ideal switch is. It will give us more insight while the designing the drive circuits for practical switches. Now, consider a switch like this, it has a pole and it has a throw and there is a control pin which will control the single pole double, single pole single throw switch.

Now, this consider it is an ideal switch. Now, what is the i v character of an ideal switch, what is the iv static characteristic of an ideal switch? So, let us draw the iv characteristic x axis is the voltage axis, voltage across the switch which is v TP and current through throw and pole that is i TP.

Now, for an ideal switch we would like that when the switch is ON the current to be able to flow both in the positive and also in the negative direction meaning T to P and P to T also and during the time on the switch is OFF we would like the voltage across the switch that is to be supported by the switch. That it should, it should be capable of supporting both the forward voltage and also the reverse voltage, positive voltage and also the negative voltage.

Now, this would be the characteristics of an ideal switch, a static characteristic where you have the i axis covering both the positive and the negative current, v axis covering both the positive and the negative voltages. Let us now list down the characteristics of the ideal switch. Now, let us say in the ON state when the switch is on, as we saw from the static characteristic we should say that it should allow current flow from T to P and allow current flow from P to T also, that is support both positive and negative switch currents.

Next the zero conduction loss meaning when the switch is ON there is a current flow there should not be any i square or loss within the switch or there should not be any drop across the switch only under such conditions will zero conduction loss happen. So, let us say one of the character of an ideal switch is that when the switch is ON there is no power loss in it. As a corollary feature you have zero conduction resistance. So, when the switch is ON there is no resistance the switch resistance is zero and therefore, the drop across the switch is zero and therefore, the conduction loss is also zero.

In the OFF state when the switch is OFF again looking at the characteristic it has to support voltage. So, it should be capable of supporting both positive and negative voltage across the switch, this is one character of the ideal switch and also like during ON state, during OFF state also there should be 0 of state loss no leakage current should be flowing through the switch. And the resistance when the switch is OFF should be infinite should be infinite meaning 0 leakage currents flowing through the switch and also meaning 0 losses in the switch.

Another important character of an ideal switch is that switching the switch from ON state to OFF state, OFF state to ON state should be instantaneous it should be in 0 time which is not so in a practical switch, but this is a desirable feature in an ideal switch. This also implies that if it is instantaneous if this switching ON and switching OFF happens in zero time it also means that there is no power loss during switching.

So, zero power loss during switching. So, switching transitions happen in a lossless manner. So, therefore, switching losses are zero, then this also implies that the drive circuits to drive this control pin of the single pole, single throw switch these drive circuits will have zero drive power requirement. So, therefore, just only the information signal is sufficient to be given to the C pin to switch the switch ON and OFF.

So, these are some of the classic features of an ideal switch; however, you should know that none of these features are fully met in a practical switch, as we have seen even in the static characteristic of BJT diodes and MOSFETs they do not reflect the static characteristic of the ideal switch.

So, we have to consider the shortcomings in each of the switches and try to design drive circuit which will try to make up for the shortcomings and take it to as good semiconductor switch electronics switch as possible.

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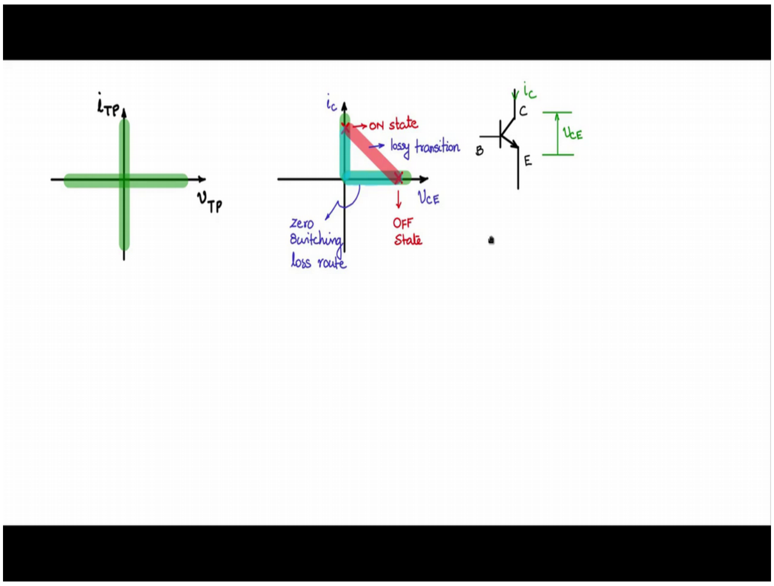

We see here the static characteristic of an ideal switch, during the ON time we see that the ideal switch is capable of supporting both positive currents and negative currents to flow through it, throw to pole and pole to throw. And while the switch is OFF it can support a positive voltage across the device and also negative voltage across the device.

Now, as again this how does the static characteristic of a practical semiconductor switch appear? Let us take BJT for an example and see how it static characteristic looks like. So, let us say this is the symbol of the BJT we have the collector, this an NPN, BJT, base, emitter the voltage across the collector and the emitter we will indicate it like this and the current through the collector i C.

Now, you can have on the x axis v CE voltage drop across collector and emitter of the

BJT and collector current i C as the current through the switch. So, we know that the collector current is unidirectional, it can only flow the positive direction from C to E, there cannot be a current flow from E to C. So, this can support only positive direction of current flow when the switch is ON, and when the switch is OFF the BJT can withstand only positive voltages across collector and emitter. And therefore, only this portion of the static characteristic or potential operating points. So, this is how a practical switch will look like.

Now, let us say that there is an operating point here, what does it mean? It is on the x axis it is supporting a voltage current is zero which means it is in the OFF state. So, the switch is in the OFF state zero current is flowing and it is supporting some positive voltage across the collector and emitter.

Now, let us call this as the OFF state. Now, let us take another point on this axis like this are shown, here there is some finite current for this operating point and the voltage across the switch is zero, what it basically means is that this is the ON state and it is supporting a positive current. Now, if I have to transition from OFF state to the ON state one way is to go along this line with zero current, go along this line at zero current then at zero voltage go along this line and reach this operating point.

Now, if you take this route at every point on this route the power loss is 0, in all this portion to the route current is zero and then once 0 voltage is reach in all this portion of the route voltage is 0. So, therefore, in transiting from the OFF state to the ON state you do not lose any power. Likewise while coming back you also do not lose power if you are using this route.

So, in this route you have zero switching losses so which basically means that if I am using a switching with zero voltage and zero current then you have zero switching losses. On the other hand the practical switches try to reach the other state directly crossing through the linear region. So, when you cross through the linear region there is finite voltages and current in between and there will be loss in the device. So, these are all the switching losses and the device should dissipate them through heat sinks and remain cool; however, the efficiency will come down.

So, this route is a lossy route and the lossy transition, we should actually try to avoid that such a route, but all practical semiconductor devices do have this. They directly go through the linear region to reach other state and back again through the linear region to reach the OFF state. We should try to make this as quick as possible to reduce the switching losses or you we try to put additional circuit such that does not go to the linear region, but goes through this route.

So, let us design the drive circuits keeping this kind of a background in mind. In order to design drive circuits just the static characteristic is not sufficient we need to understand the dynamic behaviour of the switch.

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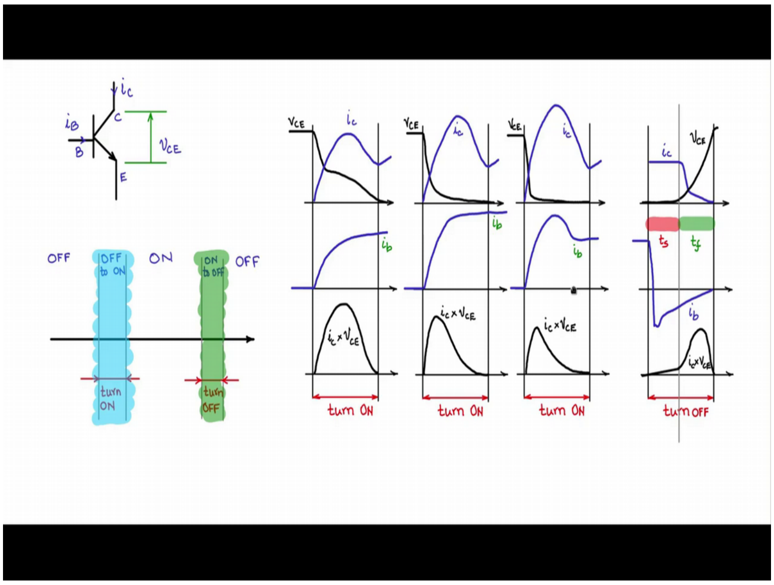

So, let me now, write down an NPN BJT switch like this. So, an NPN BJT switch voltage across collector and emitter let me indicate like this, this is collector the base and the emitter; the collector current flows in this fashion and there is a base current here. So, the base current here initiates the triggering of the switch to turn it ON or OFF. So, base current is the control signal or the trigger signal.

So now, let us divide the time into four parts. So, let me make the division. So, let us say here first the transistor was OFF, and then there is a portion of time here OFF to ON. This is switch ON of the transistor, then there is the ON state of the BJT and then there is an ON to OFF or switch OFF of the BJT back to the OFF state. So, the cycle repeats. So, this time period is the turn ON time period and this time period is called the turn OFF time period.

So, in order to understand the switching behaviour of the switch let us try to look bit more in depth into this these parts turn ON part and this part the turn OFF part in a bit more detail. So, let me first take the turn ON part and let me zoom it so, I am going to plot four waveforms on this let me tell you what they are going to be.

So, first this is called the turn ON time. Now, here it was OFF state so, the switch was OFF and there was a positive voltage v CE which was being which should supported by the OFF switch. And there is a zero base current here ok, at this point, at this instant I am initiating a base current to flow through this device here. So, let us say the base current has a finite rise time and then moves in this fashion and that is called i b

Now, because of this i b the v C which was here tends to drop like this in this fashion. Now, this is called v CE; and what happens to the collector? As the v CE is dropping the collector current is increasing. So, the collector current increases and during the turn ON time it increases more than what is required and then comes down to whatever is dictated by the load.

Now, if I multiply instantaneously v CE into i C I will get here the power instantaneous power curve during the turn ON period. So, this is multiplication of i C into v CE. The instantaneous value of i C and v CE instantaneous i and v CE keep on multiplying and then plot this curve. So, this looks like this. Now, let us say this; now with relative to this i b let me make few changes so that you try to get some more insight.

So, next I will place another similar segment turn ON segment and let us view the same waveforms. Now, i b i slightly increase, i increase i give a higher value of i b. If I give a higher value of i b what happens what happens to the v CE waveform v CE was OFF here. So, that v CE and how does it evolve? So, you will see that it goes much more smoothly and quicker towards the ON state and you will see a slight rise in the collector during the turn ON period and then again it comes back and settles at the same value which is then later controlled by the external load.

Now, this is i c. Now, what is i C into v CE looking like during this period here. So, you see that there is because v CE drops quickly there is a drop here and then the height is reduced and this is the ice in to v CE the instantaneous power curve, you will see that it has reduced significantly.

Now, I will make one more change to the turn ON base current, I am going to give a base current in this fashion I give a kind of a small surge base current during the turn ON and then bring it back down to the normal operating base current. Now, this turn ON surge base current we will make the v CE to go down much faster, it will go into the ON state much quicker and then there will be an i C which goes high and then comes back to the normal operating i c.

What happens to the power curve? So, you see that during the time an i C is large v CE has already reached the ON state. So, most of the power dissipation will be in this zone. So, we will see that there is a peaking of the power dissipation i C into v CE curve and then goes down quickly. So, you see that the power dissipation is much reduced in this case.

So, typically we would like to give here the base current with a turn ON surge current which is higher than the normal operating base current. So, you give a turn ON surge current and then let it settle down to the normal operating base current you will get the best switching speeds and not only that the power dissipation is lower.

Now, what happens during turn OFF? So, during turn OFF I am going to focus here ON this portion, you are going from ON state to the OFF state. Now, let me see the same waveforms how it looks in the turn OFF condition.

Now, I am going to split the turn OFF into two zones here I will explain what that zones is it will become evident the moment you look at the waveforms. So now, look at the base and the base current was at this level and then I am going to initiate turn OFF of the base current. So, let the base current be turned OFF so, base current is turned OFF actually were removing the base drive, but the base current here then starts going negative means there is some base charge which is the remote from the base the trans base of the transistor.

Remember that the BJT is a semiconductor device and there is some base charge which is stored in the base capacitor of the transistor and that has to be released and that has to flow out in the negative direction. So, that is this negative base current and then as the base charge gets removed you will see that the base current finally, dies down to zero.

So, even though you have initiated removal of the base current here you have stopped the base drive, here it takes some time for the base charge to recombine and this is the area under this curve is the base charge that has been removed and that takes a finite time.

Now, this base current and now, if you look at the collector current, the collector current actually you see the states almost unchanged till this vertical line that I have drawn and then it starts to decrease and then go to 0 into the OFF state. So, this period where nothing much happens in the collector current or even in the collector or emitter voltage this period is called the storage period.

So, this call the storage period because most of the base charge is in the process of getting removed. So, majority of the base charge will get removed up to this period and then only later when there is a only a small amount of base charge removed this actually shows a trend towards switch OFF.

Likewise if I look at the v CE waveform nothing much happens up to the storage period looks as though the transistor is still continuing to be in the ON state then when majority of the base charge is removed here you will see that the voltage starts to increase and then starts to support the forward voltage.

What about the power curve? Even in the power curve here during this period v CE is 0 not much a power dissipation there. So, if I take i C into v CE here there is only a slight increase there is a slight power dissipation and majority of the power dissipation happens here when it is passing through the active region. So, this moves in this fashion. So, this is the i C into v CE curve and this is actually the turn OFF loss, instantaneous value of the turn OFF loss

So, our job is to keep during turn ON this portion as small as possible by a providing turn ON surge base current and then allowing it to settle to the nominal base current and during turn OFF we need to provide path for the base current to reverse so that the base charges of the BJT are removed. And during first portion of the turn OFF period which we call as t s or the storage period you will see you will not see much change in i C and v CE because the base charges are in the process of getting removed and majority will get removed at the end of storage time.

Further on the remaining time is called the t f or fault time and that is when the current is actually falling down to 0 and v CE is rising to block the power or voltage and that is when actually majority of the switching will turn OFF switching loss occurs and we need to keep that one to minima.

So, the nature of the base drive that we have to give look at this is the turn OFF portion you give a surge base drive for ON and then you will have to have a non state base current and then while turning OFF we will have to have facility for negative base current so that there is a possibility of current flowing in the negative direction and sinking somewhere only then the base charges can be removed. So, if we give a base drive for the BJT where the currents or of this form of this shape then you will be actually generating a proper base drive for the BJT. So, keeping this background in mind let us design some base drives for the BJT.

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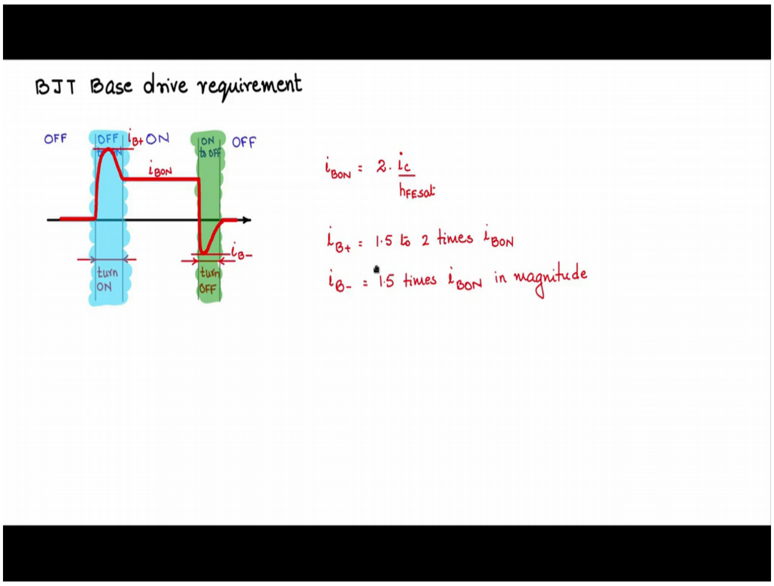

Now, we can summarise the BJT base drive requirement. So, base drive for the BJT means base current and how should be a typical base current be for switching ON and switching OFF the BJT device. So, let us say the base current during the OFF state, the base current is 0 and during the turn ON portion you give a base current surge and then it will settle to a lower value which will be the normal on base drive.

So, this we saw will reduce the power dissipation turn ON power dissipation and then you keep it continuously on such that the BJT is in the ON state you have to give a value of i B greater than i C by h FE sat or i C by beta. And then during the time when you want to turn OFF you need to make it go negative possibility for sinking capability of the base the base drive circuit should have sinking capability and then it will settle and go back to 0 in the OFF state. So, this will be the typical base drive current wave shape that will be required for BJT switching BJT

Now, let us mark this peak value we will call it as i B plus and this normally ON value will call it as i B ON and this negative base current peak value will call it as i B minus we will use this symbols labels so that consistently we know what we mean and we can visualize when we use when we use these i B plus i B ON and i B minus symbols. So, i B ON; i B ON is the normal ON state of the BJT switch which means you will be providing at least greater than i C by h FE sat. So, normally i B ON we will give two times i C by h FE sat.

So, when you give two times i C by h FE sat it is going to drive the transistor into saturation. So, you are sure that the transistor the BJT is going to be in saturation. So, this is a thumb rule that normally designers follow, 2 i C by h FE sat good starting value to use. Then i B plus the turn ON surge that magnitude value will be 1.5 to 2 times i B ON and i B minus the turn OFF negative magnitude is 1.5 times i B ON in magnitude.

Now, these are typical design guidelines there is no formula for this, these are thumb rules empirical by nature. So, these have worked for many designers all over the world. So, it is a good starting value to start with these design and then find unit from there on.

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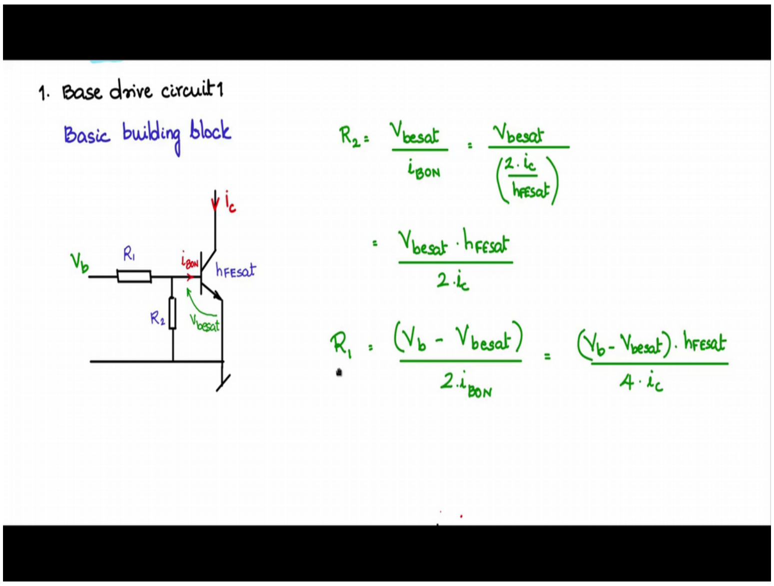

So, let us now draw our first base circuit base drive circuit. So, this base drive circuit that we are going to draw now will be the basic building block of most base drive circuit very important and very popular. So, it is very simple it consist of the transistor, this is the transistor BJT that needs to be switched ON and OFF. It consist of just two components for driving the drive circuit, it has resist one resistor and another resistor like this connector in this fashion.

So, this BJT is the BJT to be operated and these two are the drive circuits. So, you give a base signal here and the currents are limited by this R 1 and R 2. So, there is this current i C which is decided by the external load and here you have to give a i B ON to turn ON the BJT two full ON condition.

We will call this one as a R 1 and this one as R 2 and the character of this BJT after your selected you will know from the datasheet what is h FE sat value or it is also sometimes called the beta value this is V besat. So, when the BJT is ON as the saturated condition the base emitter voltage is called V besat it will be around 0.7 volts.

So now, let us design the value of R 2. R 2 is we know the voltage across R 2 is V be sat. So, V be sat divided by how much current will one allow through R 2, normally current equivalent of i B ON will be allowed through R 2. So, I will say i B ON. So, this will be V be sat by i B ON. And what is i B ON? i B ON is 2 times i C by h FE sat, 2 times i C by h FE sat. And therefore, we can say V be sat into h FE sat by 2 times i C, will be the equation that one can use for choosing R 2.

You can also choose the power rating of R 2 because you know the current that is going to flow through that i B ON, i B ON into root of the duty cycle will give the rms current and thereby you can find the irms square into r power dissipation of the resistance.

Now, how to find the value of R 1? So, there is a drive signal V b, let us say coming here and will name it as V b. Now, what is the voltage drop across R 1? V b minus V b sat this is V b sat potential. So, V b minus V be sat is the voltage drop across R divided by R 1 will be the current throw it, what the current throw it there is i B ON flowing through R 2 there is i B ON flowing through into the base of the BJT. So, 2 i B ON will be flowing in R 1. So, 2 times i B ON and i B ON it; so, we know is 2 i C by h FE sat. So, V b sat into V b minus V besat and h FE sat divided by four times i C. So, this will be the equation to select R 1.

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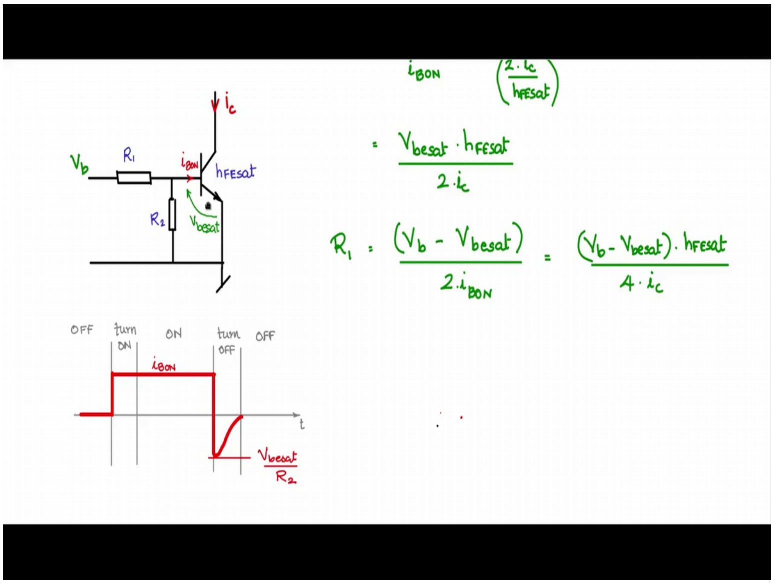

For this circuit let us see how the dynamic characteristic look like. So, let us plot against time t, this is the OFF state, ON state you have the turn ON you have the turn OFF and this is the OFF state. So, during OFF state i B is 0. So, that is the current here is 0 and during the time when you want to turn it on the ON state i BO N this is i BO N; however, there is no special arrangement in the circuit to provide a turn ON surge, it will just go and stick to i B ON right even during turn ON. And during turn OFF because of R 2 there is a path for reverse current to flow here so that the base charges recombine.

So, we have a negative base current flowing in this fashion. So, this value is V b sat divided by R 2 current will be flowing through that and here it is i B ON. So, this is how the drive currents will look like for a circuit of this type. There is no speed up, but otherwise you have other aspects of the drive current requirements being met. So, this is a very very simple base drive circuit and it is a building block for many other complex base drive circuits, which we will see later.