Fundamentals of Power Electronics
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Lecture - 83
Multi-stage base drive

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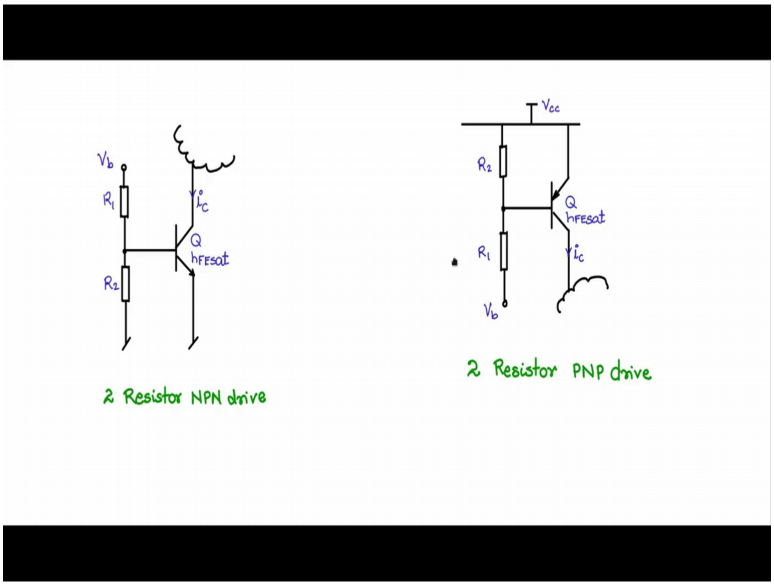

The two resistor NPN and two resistor PNP drive I am going to rewrite in this fashion you have the NP and BJT. And I am going to put the resistors vertical like this as a potential divider or an attenuator and take it in this fashion, I am calling this one as V b this is R 1 this is R 2 Q having an hFEsat and there is an i c load current flowing through it and this external load.

Now, this is a 2 resistor NPN drive which we discussed, only instead of putting R 1, horizontal I have just put them all vertical. You will understand the reason why I am putting it vertical, because it is much easier to form more complex base drives in this fashion.

The other dual is the PNP. So, the PNP where it is rail driven just like you are having ground as the common point, in the case that PNP you have the rail or the V cc has the common point. So, you have the base emitter resistor and the drive resistor here. So, this is the load V cc, V b, R 1, and R 2. And you have the Q with some HFEsat and you have collector current or the load current flowing in this fashion.

So, this is also two resistor, but PNP base try. So, in both these drive circuits it is only single stage you just have two resistors. So, if you have i c the current that should flow here, would be ib on which is two times ic by HFE sat; and the current that is flowing from R 1 is 2 ib on, which is 4 times ic by HFE sat is the current that is flowing

So, likewise here also the current that is flowing in sinking into the V b port will be four times i c by HFE sat. Now if HFE is low, let us say as the power level increases the HFE sat value decreases that is you may find the hFE at 10 amp level to be around 3 or 4. So, i c 10 amps divided by 3 would be around 3.3 amps on the base side. So, 2 i c by HFE sat would be 6.6 amps and 4 i c by which means 12 amps flowing through that.

So, one stage will not give you much of a reduction in the current. So, you may have to put multiple stages because, 12 amps you cannot show 12 amps from a PWM i c are from a microcontroller. So, you will have to reduce the current to a level, up to let us say micro amps whatever the sourcing or the syncing capability of the signalling source is here, based on that only you can directly connect it to the signalling source only if the current is made compatible.

So, therefore, if I want to make it still lower now let us say I have an 10 amps flowing through that, this stage is giving you HFE sat of let us say 5. So, here it will be 2 amps 2 into 2 amps, which is 4 amps and what will flow here will be, 4 and 4 plus 4 8 amps. 8 amps has to be source should sink into V b and in this case 8 amps should be source from V b.

So, let us say this becomes the load for the next stage. So, further I will put another stage which has let us say HFE of 10 and then you will get 0.8, two times 0.8 1.6 3.2 amps. Then further another stage from 3.2 amps will keep decreasing till you go to milliamps and micro amps, where the PWM i cs are micro controllers will be able to source or sink. So, multiple stages you may have to put to achieve particular level of current capability so that it becomes compatible with the signalling source.

So, for this we need to concatenate the BJT drives and this would be the basic drive alternately we will complement NPN PNP, NPN PNP and make multi stage drives. So, that is what I would like to show multi stage complimentary drives.

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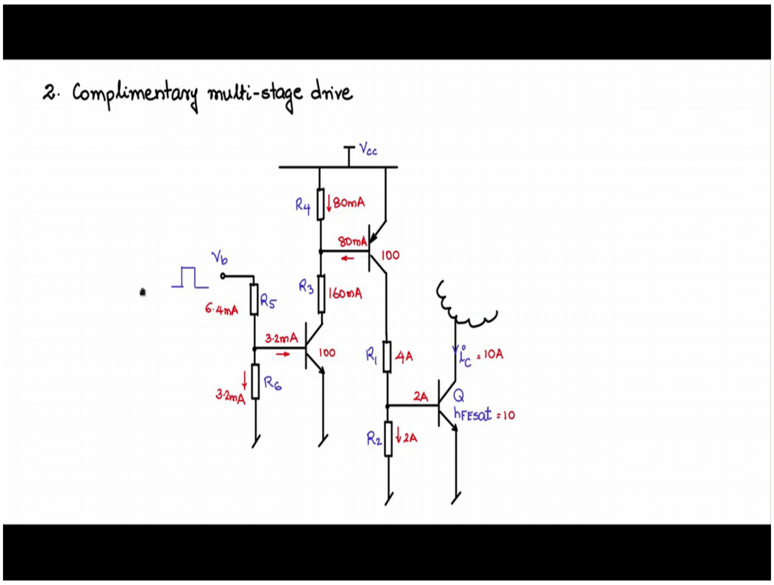

Let us now design a complementary multi stage drive or it basically means is that we will use NPN and PNP stages, alternately and make a multi stage drive. So, let us say we have this basic drive, you have an NPN BJT and this is the power BJT, the final stage which is supposed to handle the load external load and i c current flows through this, and to drive this we have this two register drive like this.

Now, let us say that the current drawn here is a large and it cannot be supplied by this V b source. So, we need to reduce the current further by putting multiple stages. So, let us do that. So, let me make some space and at this point instead of V b we will put one more stage, now I am taking the PNP stage here. So, I am taking the PNP stage and attaching it here, so this PNP stage the collector current for the PNP stage, will become the drive current for the next stage. So, this character current will be much lesser than this because of the hFEsat division.

Now, if you say that the current here is still further is still not low enough for the V b source to handle and you can add one more stage and reduce it still further, let us do that. Now let me make this connection, then at this point I will remove and now at this point you attach an NPN stage with a collector connected here, so that the collector current here will become the drive current for this.

So, let me place it there in that fashion. So, this is an NPN stage and this stage here you can give the drive signal input. So like that you can keep building the stages. Now, this is a three stage drive so complimentary drive because alternately you have an NPN stage you have the PNP stage and you have the NPN stage like that.

So, you can number the components in this fashion say we call this V b. So, this is one drive circuit if you want you can take an example to see how those look like, let us say that we would like to drive it with a pulse like this. Now whenever this pulse is low, whenever V b is low what happens when V b is low there is no drive current through R 5 and therefore, there is no ib on to this transistor. So, if there is no ib on to this transistor this transistor is off; if this transistor is off R 3 current cannot flow, which means there is no current flow through ib on current flow through this branch. And therefore, this transistor is not having i b on therefore, this transistor is off, if this transistor is off, then there is no drive current here and therefore, this transistor is off.

So, whenever V b is low this transistor is off, whenever V b is high V b is high there is a drive current through R 5 there is a current through the base of this transistor this transistor is on, there is a drive current flowing through R 3 right down to ground. And R 3 drive current if it is in this direction PNP will conduct, PNP will conduct and it is on and if PNP conduct there is a drive current flowing in this direction through this base. And therefore, Q is on and a collector current and therefore, the load current will flow through.

So, in this way it will operate; so if you make the V b signal low and high you will be able to switch the final transistor is on and off. So, if V b is low this is off V b is high the final transistor is on.

Now, let us say for example, the hFEsat of this final power transistor is 10 and the hFEsat of this transistor here PNP transistor is 100; and the signal NPN transistor is another 100. So, let us just go around calculating some numbers to get a feel. Now, let us say the load current max load current that needs to be handled is 10 amps.

So, if it is 10 amps what should be the i b on base current here, base current here should be ib on value which is 2 ic by hFE sat ic by hFE sat is 1 2 i c so this is 2 amps. And i b on current should also flow through R 2. So, here R 1 should handle 4 amps. So, 4 amps now becomes the collector current for this PNP transistor. So, if 4 amps supposed to be the collector current for the PNP transistor 4 by 100 40 milli amps is the base current at critical saturation turn on condition.

But if you allow i b arm value which is 2 times i c by HFE sat so it will be 80 milliamps. 80 milliamps flows in this direction 80 milliamps will flow through R4 and 160 milliamps flows through R 3 and that becomes the collector current for this transistor.

So, 160 milliamps by 100 is 1.6, 2 times that will be 3.2 milliamps which is i b on for this transistor 3.2 milliamps supposed to flow here also. Then the drive current here will be in R 5 will be 6.4 milliamps. So, here in this circuit for this particular set of numbers if you have a source V b having this kind of a pulsed nature and is capable of sourcing 6.4 milliamp. Then at least greater than 6.4 milliamp. Let us say the sourcing capability of V b is 10 milliamp then this circuit will work nicely it will be able to source its 0.4 milliamp and then operate this final power transistor at 10 amp.

So, this is how the drive circuit this drive circuit behaves. In fact, you should always design from the load side and start working back towards the low signal side. So, you will see the current values decreasing gradually as it goes stage by stage to the lower power side then you know that you are on the right track and not making mistakes.

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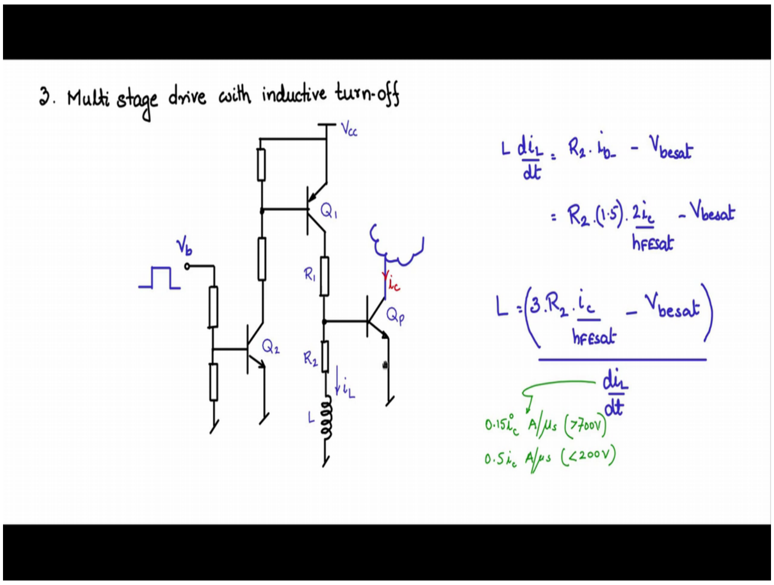

Let us discuss another variant of the multistage drive, now with an inductive turn off improvement enhancement. So, essentially the multistage drive that we discussed similar circuit we will use, but with a modification in just one component. So, I am going to introduce an inductor here, apart from a resistance here an inductor is also added to the main power transistor base. So, this is the PNP so which means the PNP drives stage and the PNP drive stage followed by an NPN drive stage. So, as before we have 2 resistor drive circuits like this. So, each transistor is having a two resistor drive, this is another two resistor drive this is another two resistor drive apart from the two resistor you also have a inductor.

So, now let us say V b which is having a pulsed waveform like this, this is actually duty cycle control. And the power the final stage the power is actually drawn to load so that a load current flows through the external load. So, this is the external load and you have the load current flowing as collector current here i c, this is Q p Q 1 Q 2 and that is V cc.

Now, you see the operation exactly similar to the multistage complementary drive circuit, when V b is low 0, there is no drive current flowing here Q 2 is off and Q 2 is off there is no drive current flowing here. Q 1 is off and Q 1 is off there is no drive current flowing here, no current through this rl branch no base current Qp is off so ic is 0.

Now, when V b goes high when V b goes high during this period, you will see that there is a drive current i b on flowing through the Q base of Q 2 Q 2 is on. Once Q 2 is on there is 2 i b on flowing through this, i b on through the base current through the base of Q 1 and Q 1 is on and on Q 1 is on, there is a drive current flowing through in this direction there is a current flowing through this resistance and inductance branch is a base drive Q p is on and collector current i c will flow. So, this is the basic operation of this circuit, let me mark this current i L to indicate it is a current which is flowing through L will call that one as R 1 this is R 2.

So, now let us say what should be the value of L, we know how to find the value of R 1 and R 2 and in the steady state the voltage across L is 0. And therefore, the entire V b sat is coming across R 2 and V b sat by i b on will be the current that flows through R 2.

Now, L di b by dt, so from the faradays law L di L by dt is equal to the voltage in this loop. So, there is a drop across this there is a V b sat drop across the base emitter of Q p positive here, negative here and therefore, vl will be R 2 into i b minus. So, when you are turning off that time at that instant inductor is not going to allow a instantaneous drop in the current therefore, there will be a change in the polarity of the voltage across the inductor and it will drive a current in this direction as I am showing in the cursor. So, that it will enhance it will speed up the base charge recombination and turn off will be faster.

So, during the time when you are turning it off here Q 1 will go off and this drive current will be cut off, but this drive current will not be immediately cut off the inductor current will see to it that, there will be a freewheeling that needs to happen here. And this will recombine the base charges and then quickly go to switch off condition. So, during the time of turn off the current here will call that an i b minus and there is this drop and then there is this drop opposing minus V bsat. i b minus we know is nothing, but 1.5 times ib on that we how during turn on of Qp i b on is nothing, but 2 ic by hFEsat. So, you have 1.5 into to ic by hFE sat minus Vbe sat.

So, therefore, L is 3 times this 1.5 into 2 3 times 2 2 ic by hFE sat minus Vbe sat. So, this whole thing divided by d i L by dt will give you the value of L. Now what should be di L by dt it is a designer choice and we normally have some empirical rules for good design 0.15 15 percent of max i c amps per microsecond will be this value. And this is for high voltage transistors 700 volts greater than 700 volts because, it takes longer for the voltage to transit from a larger voltage to 0 and 0 to and 0 to the V cc or the whatever the rating of this transistor voltage rating of this transistor is in that particular circuit.

For low voltage circuits applications we can use 0.5 i c amp per microsecond for less than 200 volts transition. So, here because it is just lower voltage transition, you can afford to going for much quicker recombination and turn off. So, you should also remember that higher the faster the switch off higher will be the dv by dt of the power semiconductor switch and that particular power coming semiconductor switch should be capable of withstanding the dv by dt which means that in the datasheet you will have to look at the dv by dt rating also. This 0.15 i c amp per microsecond and 0.5 i c amp per microsecond are reasonable starting values and then after that you can fine tune the design to get better values of L and turnoff values.

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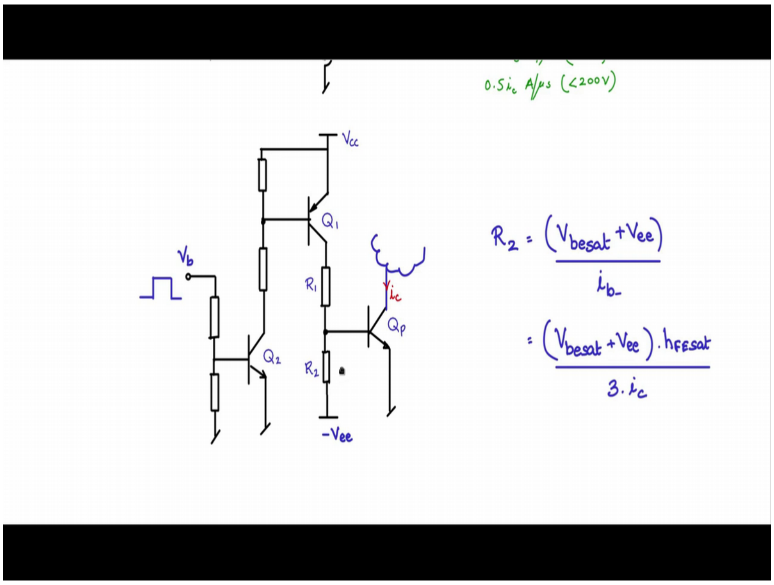

In literature you may find slight variation to the circuit in this fashion, let me remove the inductor and then R 2 is connected to a minus power supply. So, this multistage drive circuit, you will see in some drive circuits this R 2 immediately after the first stage the R 2 that is connected from base 2 emitter sometimes the other end of the R 2 resistor is connected to minus power supply.

So, what changes in the calculation of R 2 is this? R 2 equals, now there is a V b sat and there is a minus V ee divided by i b minus for turn off. So, that is the current that will flow through this and because of the existence of this minus power supply it is able to pump the necessary may necessary reverse base drive to turn off this BJT quickly, so therefore, the turn off is faster.

So, if you continue with this i b minus which is 1.5 times i b on you will see V b sat plus V e e divided by divided by 3 times ic by hFE sat. So, I put hFE sat on and the top here numerator there. So, this is the value of R 2 so, this is the modification that will happen here so that the turnoff of Q p is speeded up.