# Fundamentals of Power Electronics
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## Lecture - 73
## PWM Generation

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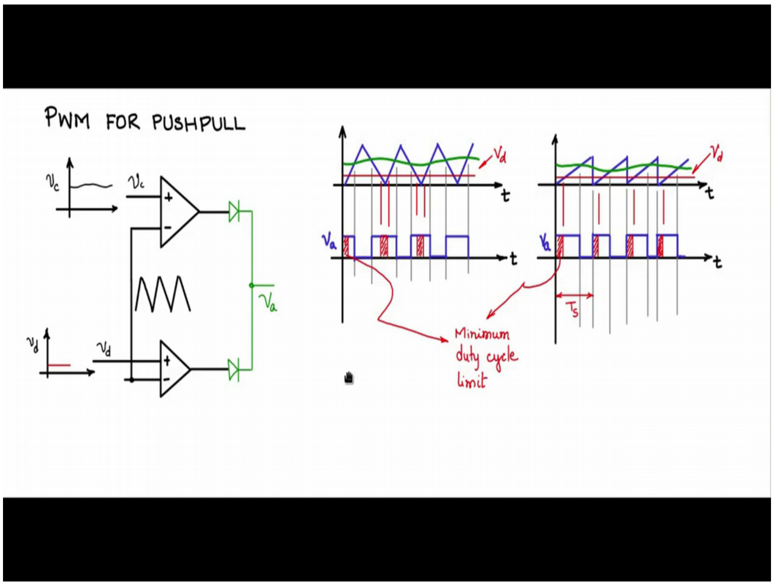


Let us now discuss how we will generate PWM for the push pull topology. Let me draw an op-amp comparator you have plus and minus, to the minus I will give a triangular carrier. And to the plus I will give the control signal or the control voltage like that which is supposed to modulate the triangular carrier. So, let us draw the waveform respect to t. I have this triangular carrier in this fashion 0 to some positive value and the modulation signal v c is shown here in green.

Let us see what is the output like, so, let us mark the intersection points and bring it down and bring it down in time and projected it on to the time scale. So, whenever v c is greater than triangle, because triangle we get the minus and v c control voltage to the plus. Whenever the control voltage is higher than the triangle the output will be positive otherwise 0, positive 0 it goes like that, depends upon what type of a op-amp your using, if you are using a bipolar amp then bipolar op-amp then it go positive minus positive minus like that.

So, let us say that we are having a unipolar op-amp with only vcc vss grounded. Therefore, you will see output going positive to 0 positive to 0 in this fashion just the thereby giving a pulse width modulated waveform. So, we will call this one as v a, this would be v a. There are many integrated circuit PWM integrated circuits that use instead of a triangular carrier, they use a saw tooth carrier much easier to generate.

So, they use that one this is also fine you will super impose you can super impose v c that is the control signal like this. And then mark of the intersection points in this fashion this whenever the saw tooth happens that is whenever the reset happens that would be the start of the period.

So, we can say period T s is of that duration here, and whenever the v c control signal is greater than the triangle of the saw tooth you have a high and a low high low so on. And you get a pulse width modulated waveform in this fashion. So, this is typically used in many PWM ics saw tooth because saw tooth generation is much easier.

Now, let me add one more op-amp one more comparator and to that comparator minus I am giving the triangular carrier or saw tooth carrier. And to the plus I am giving another signal fixed dc, I am calling that as vd and it ss a fixed dc. Let us see what this does and then the output of this 2, I will erase that that I will put 2 diodes here and or them. So, I am going or the output of these 2 one is having a control signal vc another is having fixed dc signal vd.

So, let us superimpose on this triangular on this triangular career and see what happens. So, you see that and here also this we call as vd this is vd. So, you see that here there is a minimum pulse width. So, here whenever the vc signal control signal is higher than vd there is no issue the operation is normal. When vd become lesser than vc, then what dominates is vd, and vd will dictate and it will issue a minimum pulse width command.

So, you will be assured of a minimum pulse width and even in the saw tooth case minimum pulse width is assured. In the case of saw tooth case you see that always it is starting from one end. So, one end is determined because of this vertical drop reset one end is determined. So, modulation is always on the other end, in the case of the triangle modulation happens on both ends.

So, both the cases you have a minimum pulse width which will come into the picture. So, this will declare minimum duty cycle limit for the circuit. So, this way you can achieve minimum duty cycle even for single ended operations like the forward converter and the non isolated converters you can use this method.

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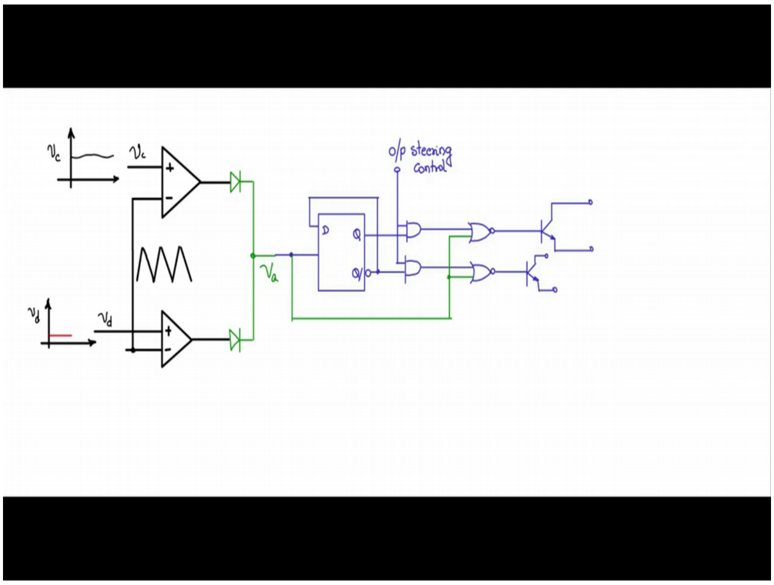


Let us now assume for now that we have a pulse width modulated waveform va. A single pulse width modulated waveform and using that single pulse width modulated waveform, let us develop the mutually exclusive drives that we can obtain or we should obtain for q1 and q2. q1 and q2 should have mutually exclusive on times and how do we get that. It is not exactly a 180 degree phase shifted waveform, you should understand that q1 is on for some time q2 is on for some time and then in between there are times when q1 and q2 are both off. So, we have to obtain a wave shape which will do that.

So, let us continue the circuit diagram further. Now from va, let it trigger clock of d flip flop. You have Q and Q bar and the output of Q bar, let us connected to D input. So, what do we have? We have a toggle flip flop. So, the output of the toggle flip flop, let me stare it through AND gates and the second inputs of the AND gates I will give it to 1 output steering control steer steering control op-amp. This has an important effect on the final output of the PWM I will discuss this. Just for now assume that this is either 1 or 0 a pin which can take value 1 or 0.

Now, the output of the AND gates are given to NOR gates like this, and output the NOR gates are given to the bjt or a transistor which can be further amplified and then driven driving the power switches. So, these 2 NOR gates we will have the second input coming from v a in this fashion.

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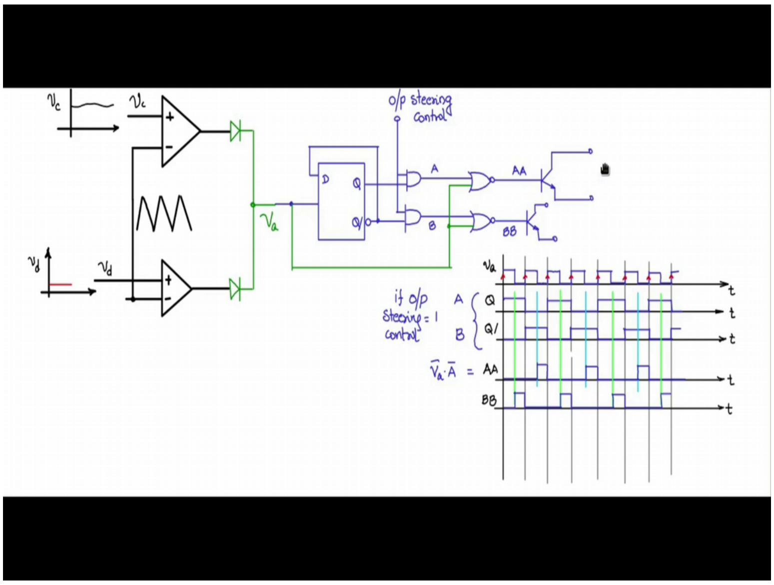


So, this will be the steering logic that we will be using for the PWM, let me push this bit up. So, now, let me mark this is A and this has B and this has AA and this has BB, so, that we can distinguish the waveforms. Now let me say that va we have va it is a PWM modulated waveform. Now let me divide the time into segments each of ts width.

So, within that ts you are having a portion of the waveform a pulse width modulated waveform which appears like this which we just develop for va. So, you have the pulse width developed, pulse width modulated waveform coming like this. Now this is given to the clock of the d flip flop.

So, let us say that the D flip flop will be triggered edge triggered on the rising edge and on so the rising let the toggling action happened. So, Q will go high on every rising edge sorry, the Q will toggle on every rising edge. So, let us say it starts from 0 it goes high here and on this rising edge Q will go low. And then again on this rising edge goes high here again low high low like that.

So, you just toggle flip flop toggling Q bar is opposite of 180 degrees phase opposite of Q. So, it starts with a low, then toggles high low high low like that, so, this way you get the Q bar output also. Now, you see this AND gate if the output steering control is 1 then A is same as Q, B is same as Q bar.

So, let us say that this are A and B waveforms if output steering control is equal to 1, meaning that the AND gates are enable. So, this will pass through A and B coming to 1 of the inputs of the NOR gates. So, what is AA and BB? We will see that. So, AA and BB, now this is waveform A and this is waveform va this is NOR gate. So, it will be A plus va whole bar which is A bar and va bar is not it.

So, this is Va bar A bar waveform. So, let us, let me look at only those portions where you will get a pulse. So, I am just marking this portions. So, you see this is A bar, A bar this will be high and during that time va bar this portion will be high. So, I am what I am showing here in the cursor, likewise this portion. So, I am marking those portions then I am drawing the AA waveform, so, it will be high only on this.

Now BB let me mark it is now B bar into B bar and va bar. So, you will see these are the portions where BB will go high and I will write it down like that. So, you see here AA and BB waveforms are mutually exclusive, you can give q 1 on here q 2 on, q 1 on, q 2 on, q 1 on, so on. and these are pulse width modulated, because they are coming from the primary pulse width modulated waveform va.

so, in this way you can generate 2 mutually exclusive dts period waveforms which can be given to 2 different switches q 1 and q 2 and where they are never on simultaneously, they are mutually exclusively on. So, this are the kind of pulse steering that we do and give it to the switches q 1 and q 2 of the push pull circuit.

Here again you will see that there is no correction for flux walking, typically many of the PWM ics do not provide correction flux working you have to do that externally. However, you do also find PWM ics which give flux working correction.

Another point you have to note is what happens when the output steering control pin is 0. When output steering control pin is 0 A and B are 0, this latch and this points are out of action. So, va comes directly to the NOR gates of these 2 AA and BB both will be same except inverted. And you will have a pulse width modulated waveform both same AA and BB both same simultaneously. So, you can use that one to drive tools drive a single switch or 2 switches with enhanced drive capability

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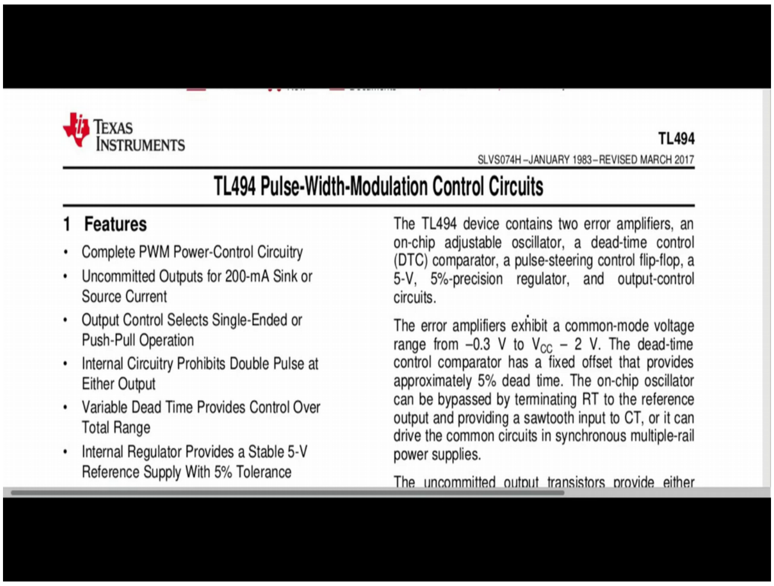


A typical PWM IC of the structure that we just now described is a TL494 pulse width modulation ic. Very simple around 10 rupees in cost and the block diagram internal block diagram it is a Texas instruments IC internal block diagram is similar to the similar to the one that we discussed.

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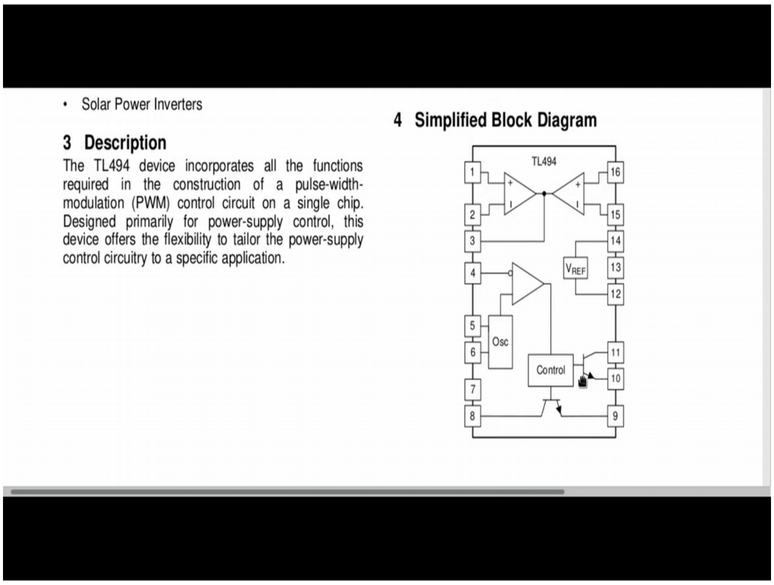


It has a simple block diagram this is a 16 pin IC and easily available in the market.

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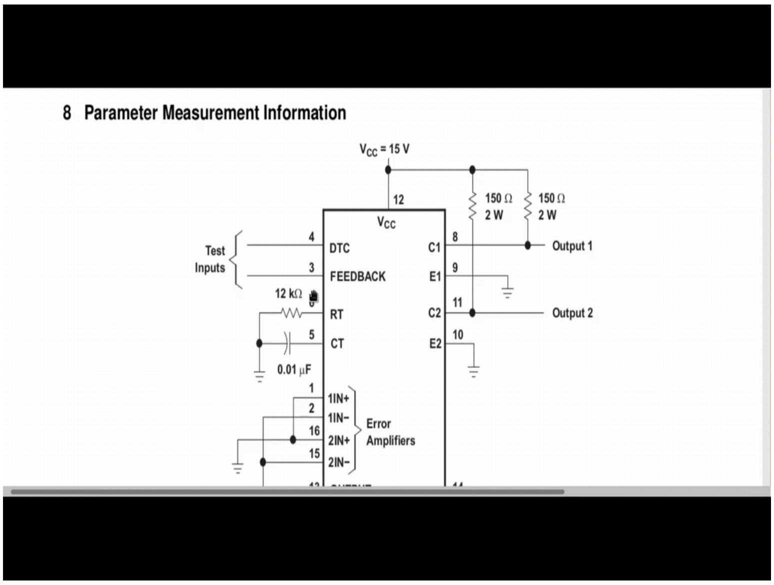


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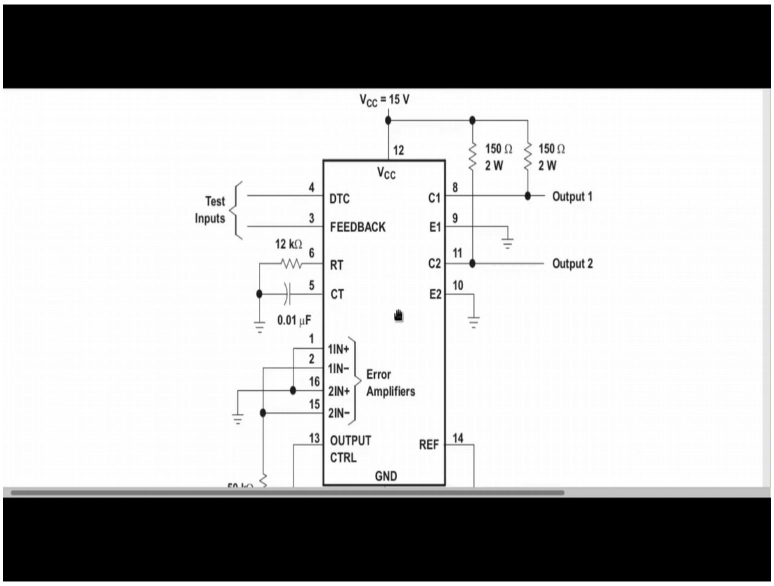


Download its data sheet and you can see there is a test circuit here and you can set the carrier frequency by setting the RT CT waveform. And if you monitor the voltage waveform at pin 5 across CT, you will see that it is a saw tooth carrier.

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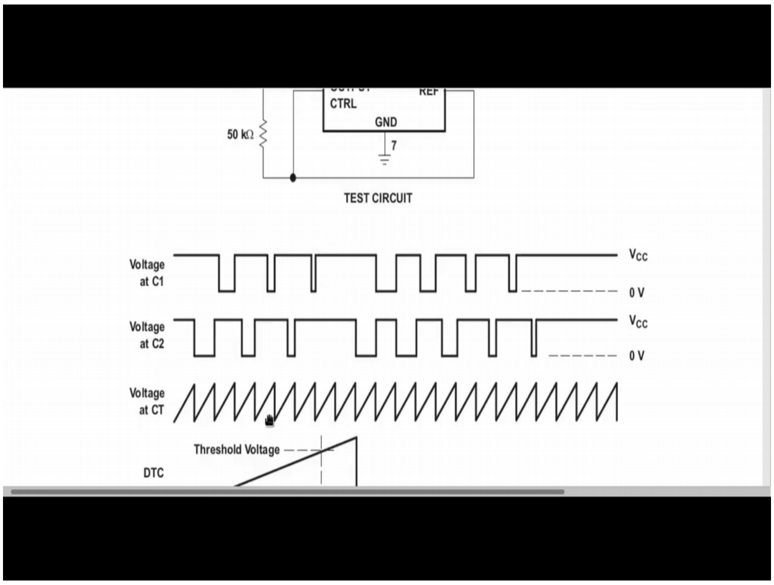


So, this is based on a saw tooth career and then you have 2 output waveforms C1 and C2 C1 and C2 collectors their internal transistors, collector 1 ammeter 2, collector 2 emitter 1 which you can externally connect and take out the take out the PWM outputs.

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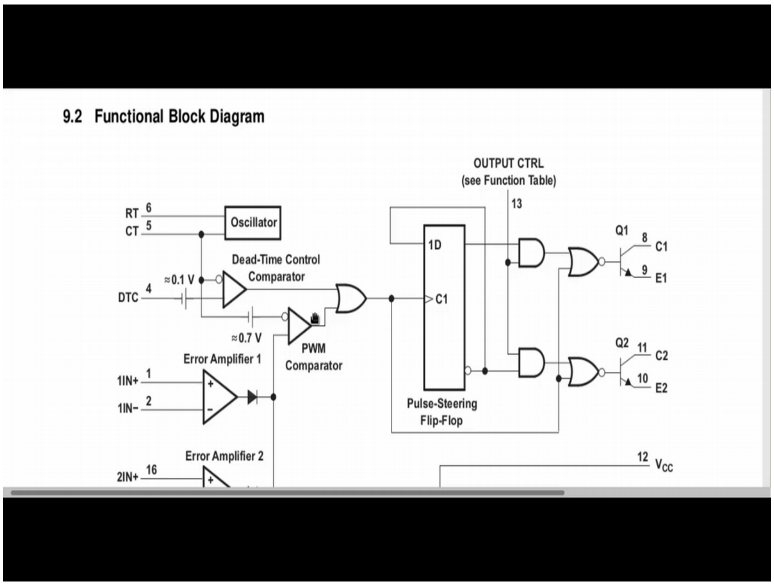

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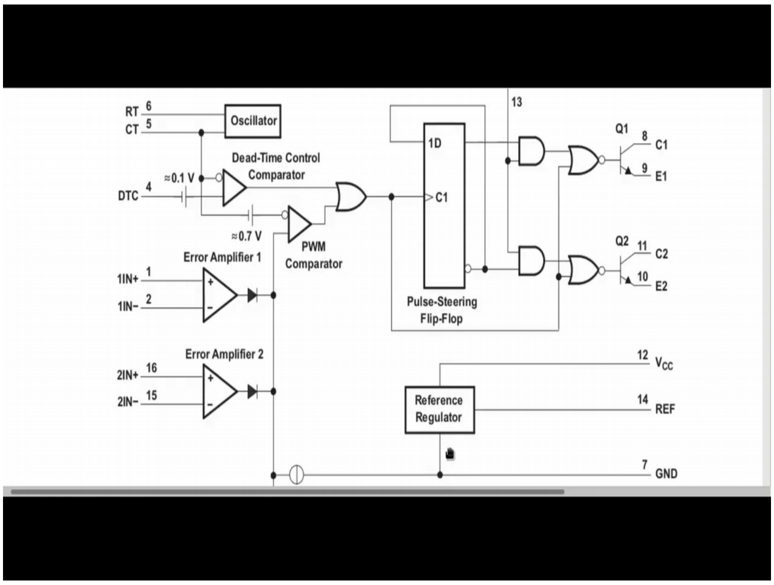


The functional block diagram similar to the one that we discussed, you see all an internal oscillator RT CT generating the saw tooth saw tooth. There is a dead time controller comparator, there are 2 other comparators error amplifier 1 and 2 they are internally odd. And there is a PWM this given to the clock, there is a D flip flop with toggle flip flop mode operation. When you have the steering control logic and 2 AND gates and then the NOR gates given to the internal transistors. There is an internal reference voltage which you can use.

So, you see the logic is very similar when you give the output steering control 1, then you will see that you can, you will get mutually exclusive output which you can use for pushpull circuit or even half bridge circuit and full bridge bits circuits. When you make the output control pin 0, then the PWM directly comes to both and both are identical, PWM outputs. You can use the 2 internal bjt is to enhance the drive signal. So, this an interesting and easily available popular PWM IC available on the market.

Another way of providing pulse width modulated wave forms to q one and q 2 in mutually exclusive intervals of time. Along with providing corrections or flux walking can be done with this following circuit.

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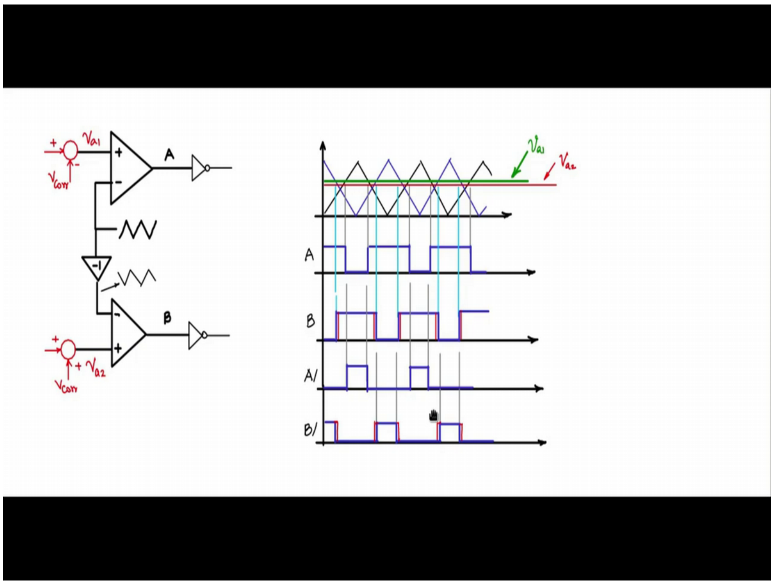


So, let us say we have this op-amp comparator and the minus is the triangular carrier. And this triangle career I will invert it and then give it to the minus of another op-amp. So, let us say va the pulse width modulate; the pulse with modulation fundamental that is the modulating signal va is given in this fashion this is a modulating signal. Now the inverted wave form will look like this opposite of that one, and let us say the output of the comparators are A and B they will be the pulse width modulated signals.

So, if i put this triangular carrier like this is the triangle and the inverted triangular carrier in this fashion. And let us say va we are giving same va for both the comparators and this is va, let us draw A and B signals. So, the points whenever these are the crucial crossover points for that black triangle here.

The points wherever va is more than the triangle you will see it the high otherwise low. So, this will be the output signal A, and for B you are comparing with the blue where the inverted triangle, so, you will likewise get a signal like this. So, observe here that they are low at mutually exclusive intervals of time.

So, if you put an inverter, so, let us say we want to get A bar B bar by putting an inverter like this and you can invert these 2 wave forms. And you will see that you will get the A bar waveform like this and the B bar waveform like this. Now these are mutually exclusive these are signal that will switch the transistors at mutually exclusive intervals of time.

Now, how do we add correction? Now this is a circuit where you can easily add corrections independently to the A side or the B side waveforms PWM waveforms. So, let me erase here and at this point let us have the correction to the control signal analog control signal itself.

So, the output of the pi the flux walking pi which resulted in voltage correction value. We can include it at this point here where you are subtracting from the control signal, analog control signal before comparing, and one side you are adding it. So, in one side you will add and another side will subtract. So, that you get a difference and we call that an va 1 and va 2, so, if this is va 1, va 2 will be like this.

Now it depends upon the v correction signal sign if it is minus v a 1 will be higher va 2 will be lower. If this is plus va 1 will be lower va 2 will be higher depending upon that the pi controller anyway will take care of it and correct that part.So, if you see va 1 for A and A bar, let us say it is we have already drawn. And for if you take va 2 comparing it with the blue triangle inverted triangle, you will see small changes here and because of the intersection points. And you will see slight change in the pulse weights.

So, va 1 if it is having d 1 ts va 2 will be having d 2 ts where d 1 ts and d 2 ts are slightly different. And v correction is 0, then both will match and both will have the same dts pulse widths. So, in this way we can give differential pulse widths to the q 1 switch and the q 2 switch. So, that you can you bring about correction for flux working and balancing out the flux, so, that you have a 0 average flux.