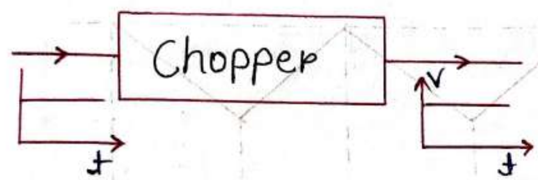
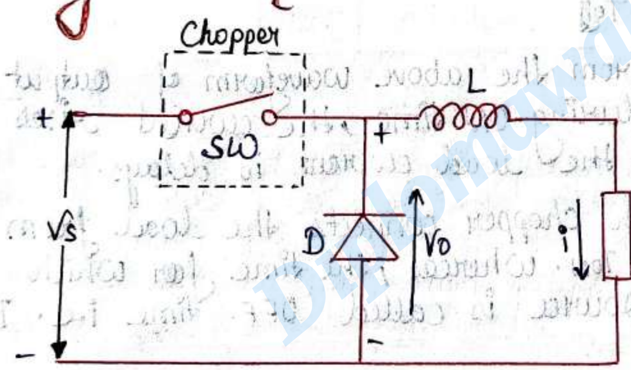
# Unit - 4

## 1.) Chopper...

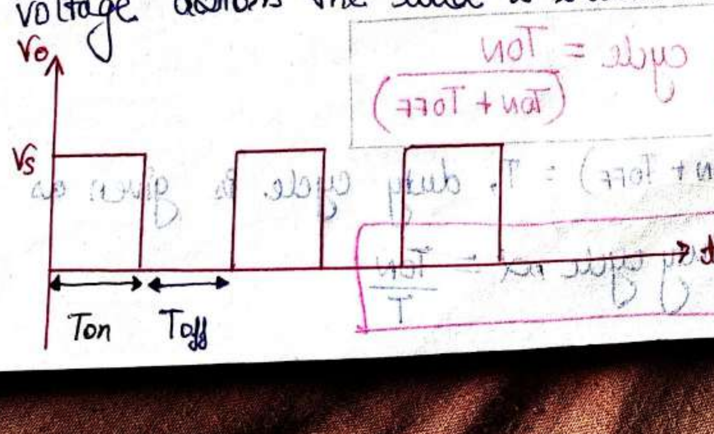
- A chopper is a static device that converts fixed DC input voltage to a variable DC output voltage. It is basically a high speed ON/OFF semiconductor switch.
- Chopper is fed through a constant DC voltage source and its output is variable DC voltage. The average value of output DC voltage may be less than or higher than the input DC voltage source.



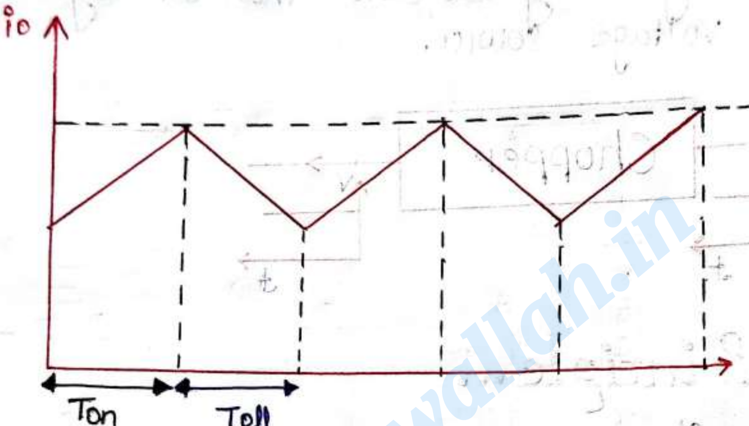

## # Working Principle...




- When the switch is ON, the load voltage is equal to the source voltage Vs and when the switch is OFF, load voltage becomes equal to ZERO.
- Thus, a chopped voltage across the load is obtained. The output voltage i.e voltage across the load is shown in figure below.



- It should be noted that, when the switch SW is made OFF, the load current finds its path through free wheeling diode D.
- Therefore diode D acts as a short and hence the voltage across the load becomes zero. The inductor makes diode D forward biased when the switch SW is OFF.
- Even through the switch SW is made OFF, the load current doesn't becomes ZERO. Rather, it flows through the free wheeling diode, inductor L and Load, the load current is continuous as shown below.




- It may be seen from the above waveform of output current of chopper that, during ON time, the current rises whereas during OFF time, the load current io delays.
- The time for which chopper connects the load from source is called ON time i.e Ton. whereas, the time for which load is disconnects from source is called OFF time i.e. Toff.

# Duty Cycle...

Duty cycle of chopper is defined as the ratio of ON time to the total time period. It is denoted by symbol $\alpha$. Total time period is the sum of ON and OFF time.

$$\text{Duty cycle} = \frac{T_{ON}}{(T_{ON} + T_{OFF})}$$

Assuming $(T_{ON} + T_{OFF}) = T$, duty cycle is given as below.

$$\text{Duty cycle}, \alpha = \frac{T_{ON}}{T}$$

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# Chopper Control Schemes...

In a converter, there are two basic methods of control used to vary the output voltage. There are –

- Time ratio control
- Current limit control

- **Time Ratio Control**

In time ratio control, a constant k given by $\frac{T_{ON}}{T}$ is varied. The constant k is called duty ratio. Time ratio control can be achieved in two ways.

→ Constant Frequency

In this control method, the frequency ($f = 1/T_{ON}$) is kept constant while the ON time T is varied. This is referred as pulse width modulation (PWM).

→ Variable Frequency

In variable frequency technique, the frequency ($f = 1/T$) is varied while the ON time T is kept constant. This is referred as the frequency modulation control.

- **Current Limit Control**

▸ In a DC to DC converter, the value of the current varies between the maximum as well as the minimum level for continuous voltage.

▸ In this technique, the chopper (switch in a DC to DC converter) is switched ON and then OFF to ensure that current is kept constant between the upper and lower limits.

▸ When the current goes beyond the maximum point, the chopper goes OFF. While the switch is at its OFF state, current freewheels via the diode and drops in an exponential manner.

▸ The chopper is switched ON when the current reaches the minimum level. This method can be used either when the ON time T is constant or when the frequency ($f = 1/T$).

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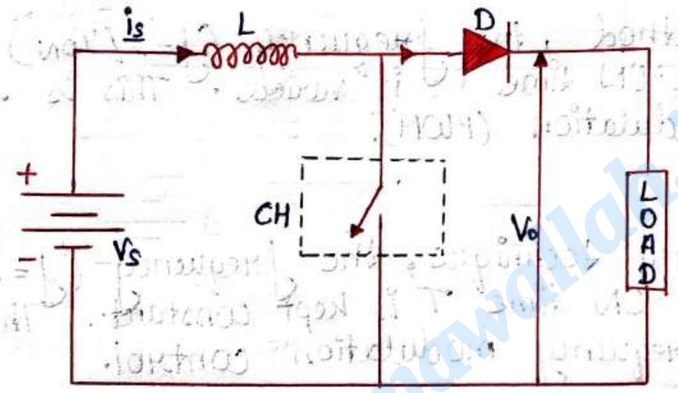
## 2.) Chopper Classifications...

Depending on the voltage output, choppers are classified as —

(i) Step Up chopper (boost converter)
(ii) Step down chopper (buck converter)
(iii) Step Up/Down chopper (Buck-boost converter)

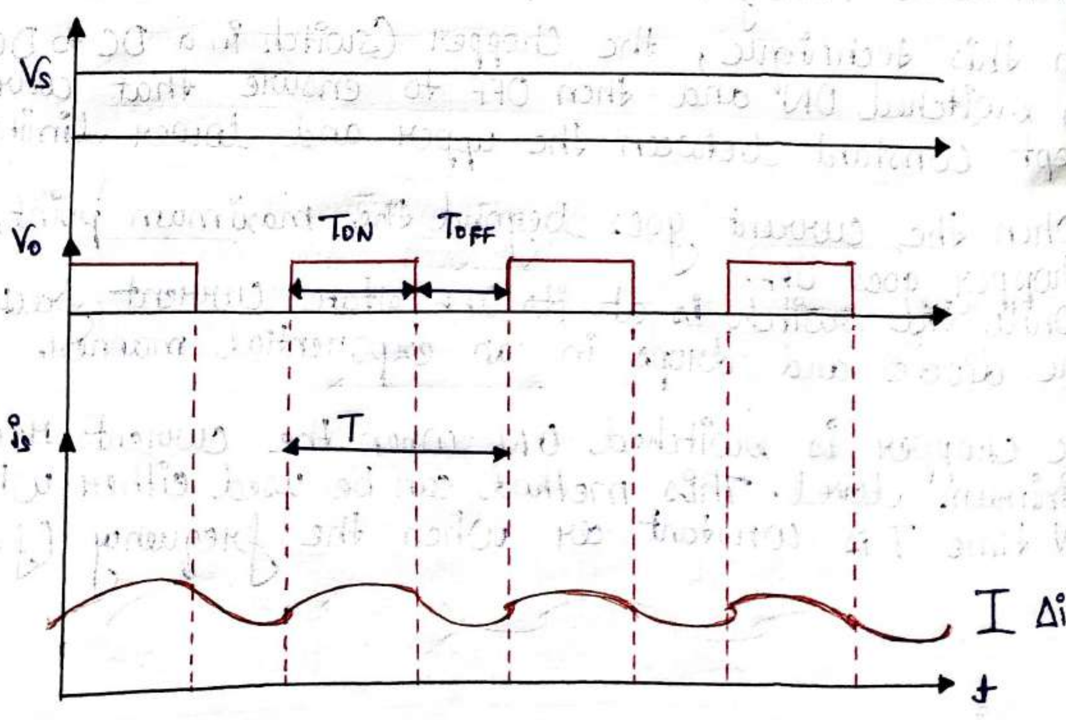
### # Step Up Chopper...

The average voltage output ($V_o$) in a step up chopper is greater than the voltage input ($V_s$).




★ Current and Voltage Waveforms

$V_o$ (average voltage output) is positive when chopper is switched ON and negative when the chopper is OFF as shown in the waveform below.



Where

$T_{ON}$ time interval when chopper is ON.
$T_{OFF}$ time interval when chopper is OFF
$V_L$ Load Voltage
$V_s$ Source Voltage
T Chopping time period = $T_{ON}$ + $T_{OFF}$.

$V_0$ is given by –

$$V_0 = \frac{1}{T}\int_0^{T_{ON}} V_s dt$$

When the chopper (CH) is switched ON, the load is short circuited and, therefore, the voltage output for the period $T_{ON}$ is zero. In addition, the inductor is charged during this time. This gives $V_s = V_L$

$$L\frac{di}{dt} = V_s, \quad \frac{\Delta i}{T_{ON}} = \frac{V_s}{L}$$

Hence, $\Delta i = \frac{V_s}{L} T_{ON}$

$\Delta i$ = is the inductor peak current. When the chopper (CH) is OFF, discharge occurs through the inductor L. Therefore, the summation of $V_s$ and $V_L$ is given as follow –

$$V_0 = V_s + V_L, \quad V_L = V_0 - V_s$$

But
$$L\frac{di}{dt} = V_0 - V_s$$

$$L\frac{\Delta i}{T_{OFF}} = V_0 - V_s$$

$$\Delta i = \frac{V_0 - V_s}{L} T_{OFF}$$

Equation $\Delta i$ from ON state to $\Delta i$ from OFF states gives.

$$\frac{V_s}{L} T_{ON} = \frac{V_0 - V_s}{L} T_{OFF},$$

$$V_s (T_{ON} + T_{OFF}) = V_0 T_{OFF}$$

$$V_0 = \frac{TV_s}{T_{OFF}} = \frac{V_0}{\frac{(T + T_{ON})}{T}}$$

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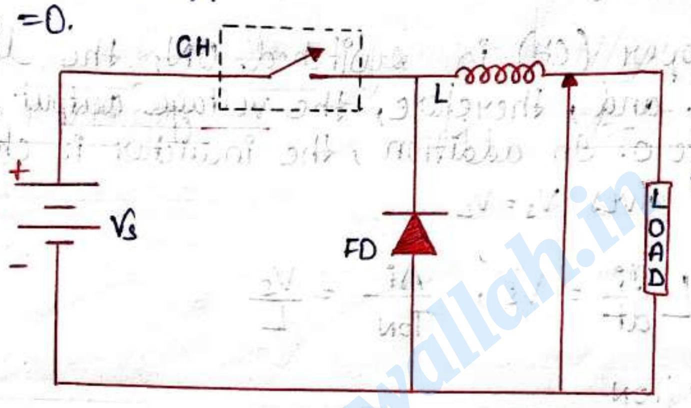
This give the average voltage output as,

$$V_o = \frac{V_s}{1-D}$$

The above equation shows that $V_o$ can be varied from $V_s$ to infinity. It proves that the output voltage will always be more than the voltage input and hence, it boosts up or increases the voltage level.

# Step down Chopper...

This is also known as a buck converter. In this chopper, the average voltage output $V_o$ is less than the input voltage $V_s$. When the chopper is ON, $V_o = V_s$ and when the chopper is off, $V_o = 0$.

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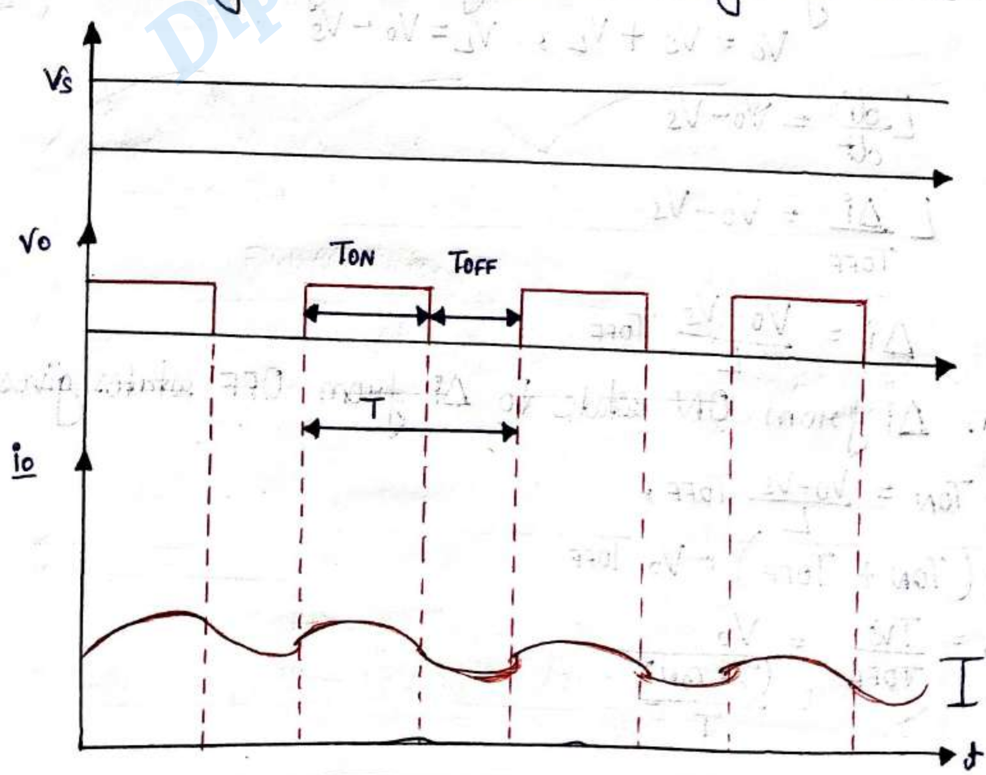
★ Current and Voltage Waveforms

For a step down chopper the voltage output is always less than the voltage input. This is shown by the waveform below.



When the Chopper is ON -

$V_s = (V_L + V_0)$, $V_L = V_s - V_0$, $L\frac{di}{dt} = V_s$

Thus, peak-to-peak current load is given by,

$$\Delta i = \frac{V_s - V_0}{L} T_{ON}$$

Where In the above figure....

Where FD is free-Wheel diode.

When the chopper is OFF, polarity reversal and discharging occurs at the inductor. The current passes through the free-Wheel diode and the inductor to the load. This gives,

$$L\frac{di}{dt} = V_0 \quad \text{......} (1)$$

Rewritten as - $L\frac{\Delta i}{T_{OFF}} = V_0$

$$\Delta i = V_0 \frac{T_{OFF}}{L} \quad \text{......} (2)$$

Equating equations (i) and (ii) gives;

$$\frac{V_s - V_0}{L} T_{ON} = \frac{V_0}{L} T_{OFF}$$

$$\frac{V_s - V_0}{V_0} = \frac{T_{OFF}}{T_{ON}}$$

$$\frac{V_s}{V_0} = \frac{T_{ON} - T_{OFF}}{T_{ON}}$$

The above equation gives;

$$V_0 = \frac{T_{ON}}{T} V_s = DV_s$$

Equation (i) gives -

$$\Delta i = \frac{V_s - DV_s}{L} DT, \text{ from } D = \frac{T_{ON}}{T}$$

$$= \frac{V_s - (1-D) D}{Lf}$$

$$f = \frac{1}{T} = \text{chopping frequency}$$

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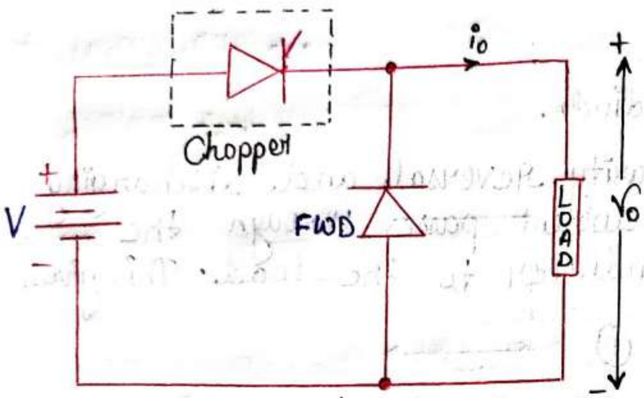
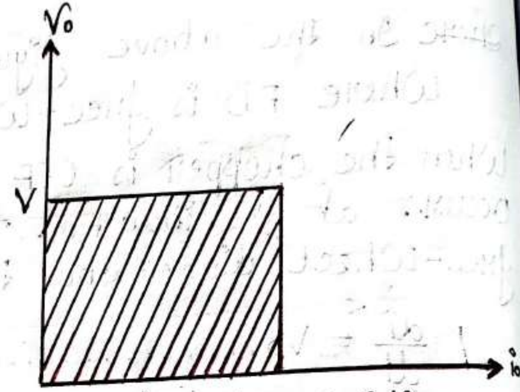
## 3.) Working of first quadrant Choppers...

### Class A Chopper...

First quadrant chopper is also called as Class A chopper and class E chopper.




Class A Chopper




$V_0$-$V_i$ Characteristics

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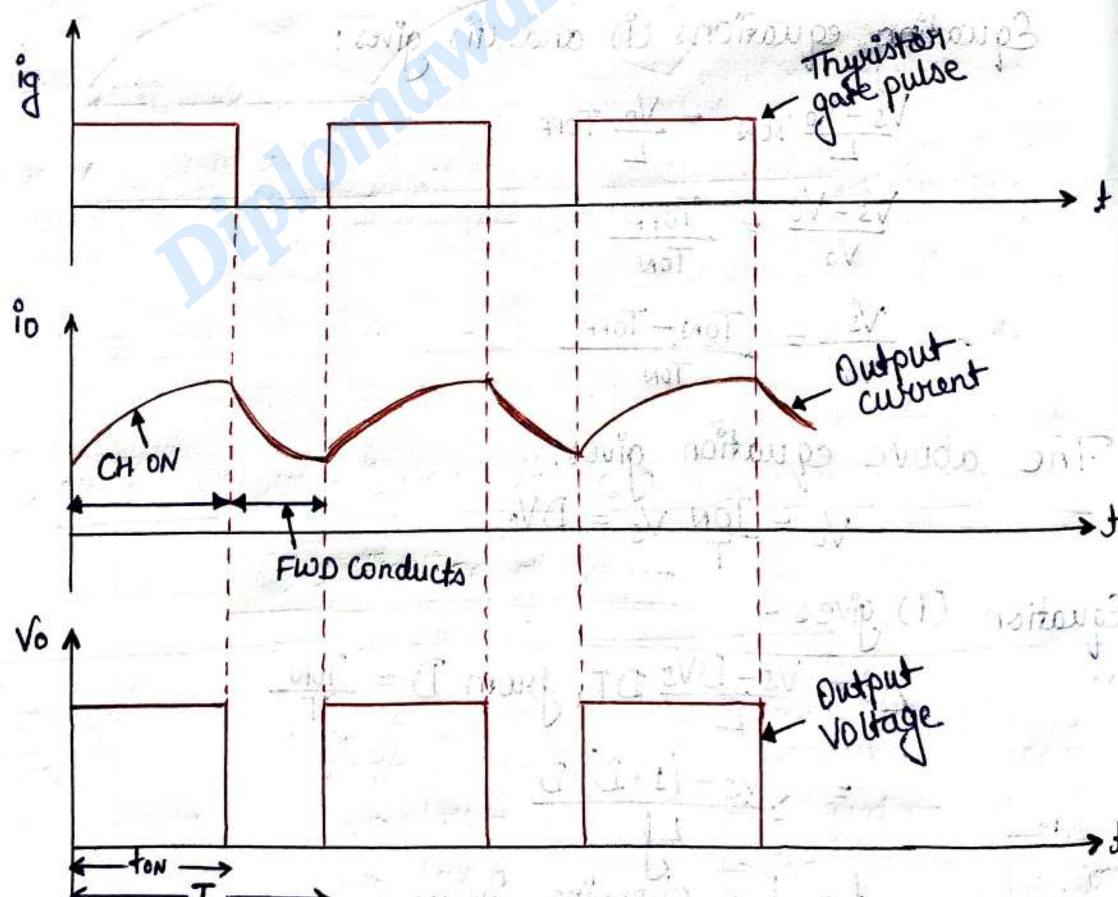
★ Waveform




First quadrant chopper – Output Voltage and Current Waveform

★ **Working...**

- When chopper is ON, supply voltage V is connected across the load i.e, $V_0 = V$ and current $i_0$ flows as shown in figure.
- When chopper is OFF, $V_0 = 0$ and the load current $i_0$ continues to flow in the same direction through the free wheeling diode.
- Therefore, the average values of output voltage and current i.e., $V_0$ and $i_0$ are always positive. Hence, Class A chopper is a first quadrant chopper (or single quadrant chopper).

Class A chopper is a step-down chopper in which power always flows from source to load. It is used to control the speed of dc motor. The output current equations obtained in step down chopper with R-L load can be used to study the performance of class A chopper.

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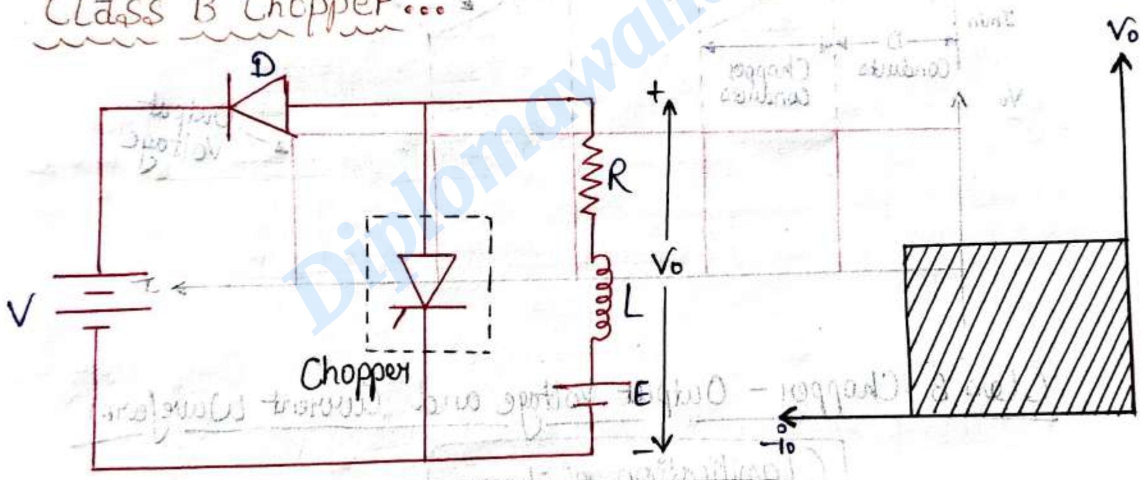
# Working of Second quadrant Chopper...

Class B Chopper...



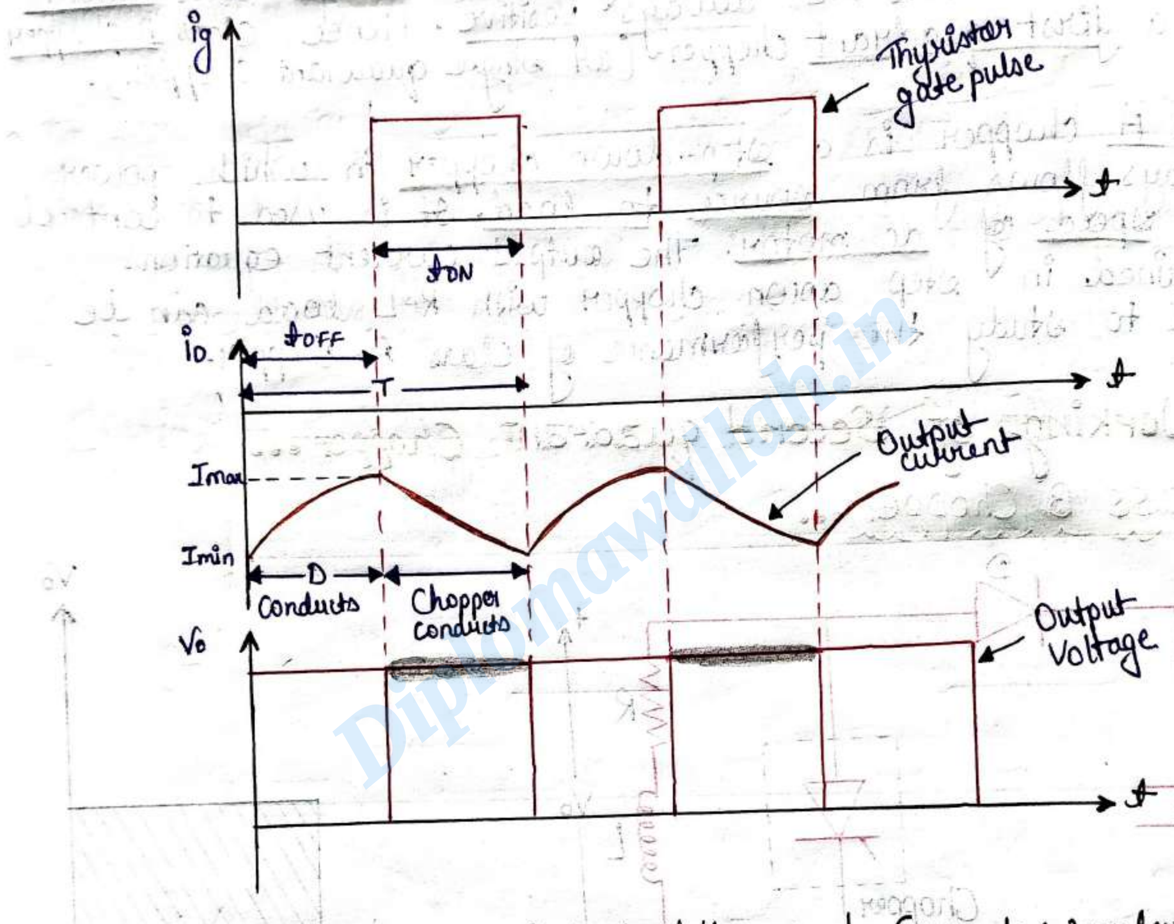

It is a Step Up chopper

★ **Working...**

- When chopper is ON, $V_0 = 0$ and E drives a current $i_0$ through L and R in a direction opposite to that. During the ON period of the chopper, the inductance L stores energy.
- When the chopper is OFF, diode D conducts, $V_0 = V$ and part of the energy stored in inductor L is returned to the supply. Also the current $i_0$ continues to flow from the load to source.

- Hence the average output voltage is positive and average output current is negative. Therefore class B chopper operates in second quadrant.
- In this chopper, power flows from load to source. Class B chopper is used for regenerative braking of dc motor.

★ Waveform...




Class B Chopper – Output Voltage and Current Waveform

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**Classification of chopper**

- Based on I/P O/P voltage
  - Step up chopper
  - Step down chopper
- Based on direction of o/p voltages current
  - Class A
  - Class B
  - Class C
  - Class D
  - Class E
- Based on ckt operation
  - 1st quadrant
  - Two quadrant
  - four quadrant
- Based on commutation method
  - Voltage comm.
  - current
  - load
  - Inputs