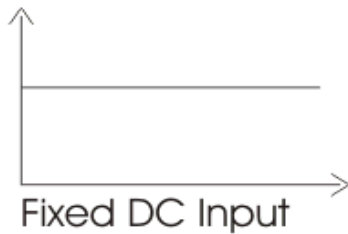


Choppers

is a basically static power electronics device which converts fixed dc voltage / power to variable dc voltage or power. It is nothing but a high speed switch which connects and disconnects the load from source at a high rate to get variable or chopped voltage at the output

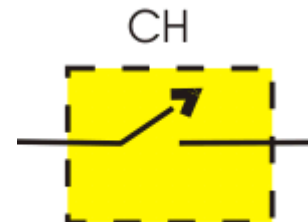


Chopper can increase or decrease the dc voltage level at its opposite side. So, chopper serves the same purpose in **DC circuit** transfers in case of ac circuit. So it is also known as DC transformer.

Devices used in Chopper

Low power application: GTO, IGBT, Power BJT, Power MOSFET etc. High power application: Thyristor or SCR.

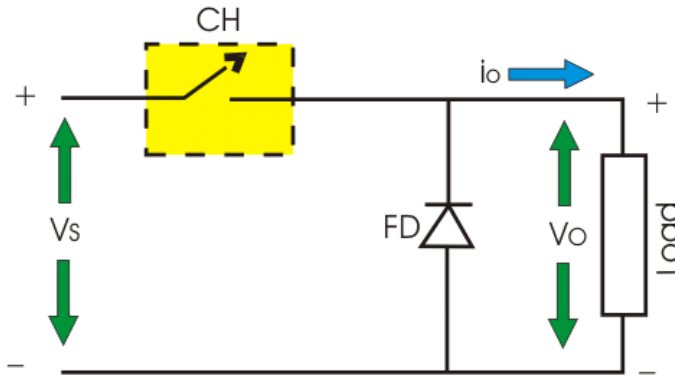
These devices are represented as a switch in a dotted box for simplicity. When it



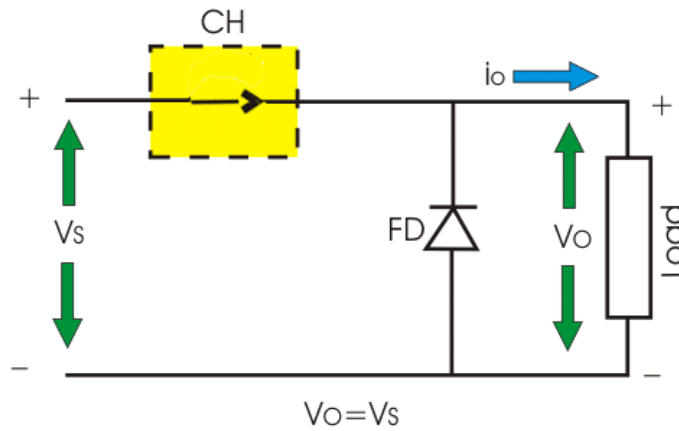
is closed current can flow in the direction of arrow only.

1) **Step down Chopper :**

Step down chopper as Buck converted is used to reduce the i/p voltage level at the output side. Circuit diagram of a step down chopper is shown in the adjacent figure.

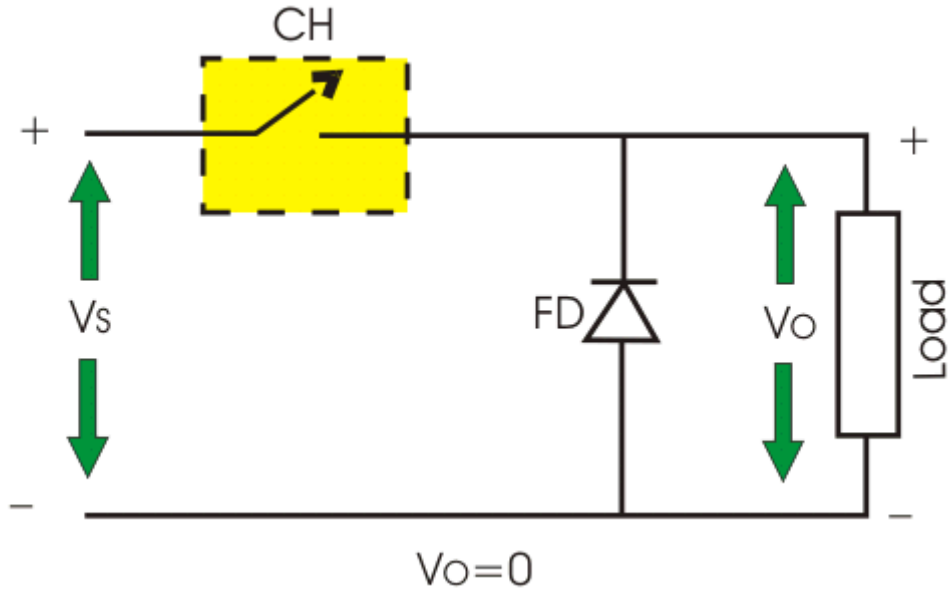


When CH is turned ON, V_s directly appears across the load as shown in figure.

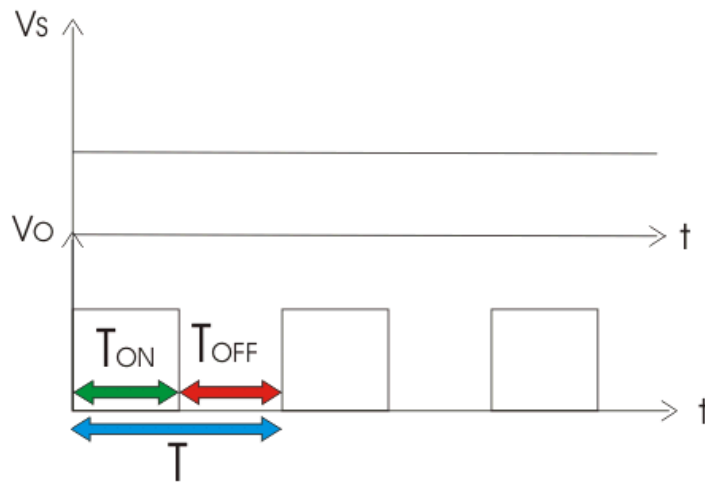


So $V_o = V_s$.

When CH is turned off, V_s is disconnected from the load. So output voltage $V_o = 0$.



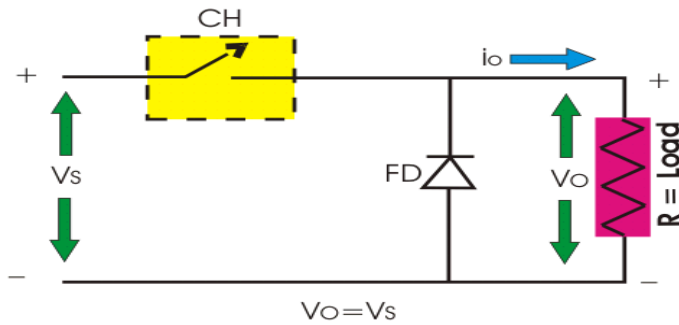
The voltage waveform of step down chopper is shown below:



T_{ON} → It is the interval in which chopper is in ON state. T_{OFF} → It is the interval in which chopper is in OFF state. V_s → Source or input voltage. V_o → Output or load voltage. T → Chopping period = $T_{ON} + T_{OFF}$

Operation of Step Down Chopper with Resistive Load

When CH is ON, $V_O = V_s$ When CH is OFF, $V_O = 0$



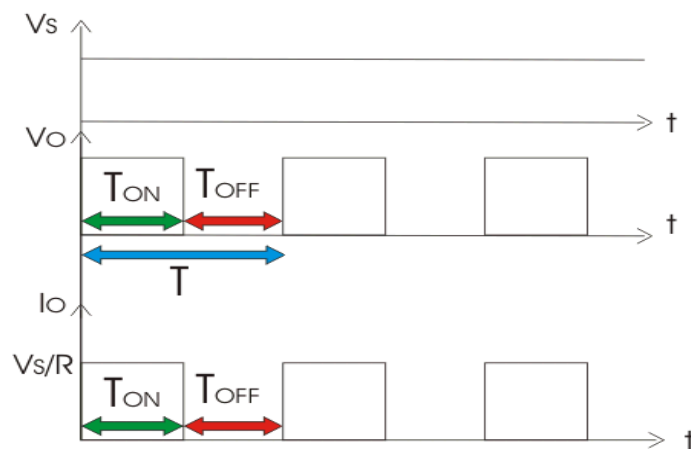
$$\text{Average output voltage } V_O = \frac{1}{T} \int_0^{T_{ON}} V_s dt = \frac{V_s T_{ON}}{T} = D V_s$$

Where, D is duty cycle = T_{ON}/T . T_{ON} can be varied from 0 to T, so $0 \leq D \leq 1$. Hence output voltage V_O can be varied from 0 to V_s .

$$\text{RMS output voltage } V_{or} = \sqrt{\frac{1}{T} \int_0^{T_{ON}} V_s^2 dt} = V_s \sqrt{\frac{T_{ON}}{T}} = \sqrt{D} V_s$$

$$\text{Therefore, Effective input resistance } R_i = \frac{V_s}{T_{savg}} = \frac{V_s}{D V_s / R} = \frac{R}{D}$$

So, we can conclude that output voltage is always less than the input voltage and hence the name step down chopper is justified. The output voltage and current waveform of step down chopper with resistive load is shown below.



Operation Of Step Down Chopper with Inductive Load

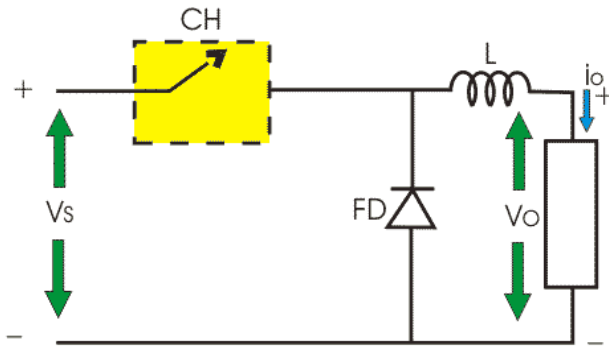
When CH is ON, $V_o = V_s$ When CH is OFF, $V_o = 0$

During ON time of chopper

$$V_s = V_L + V_o \Rightarrow V_L = V_s - V_o \Rightarrow L \frac{di}{dt} = V_s - V_o \Rightarrow L \frac{\Delta I}{T_{ON}} = V_s - V_o$$

Therefore, peak to peak load current,

$$\Delta I = \frac{V_s - V_o}{L} T_{ON} \dots\dots\dots(i)$$



During OFF Time of Chopper

If inductance value of L is very large, so load current will be continuous in nature. When CH is OFF inductor reverses its polarity and discharges. This current freewheels through **diode** FD.

Therefore, $L \frac{di}{dt} = V_o$

$$L \frac{\Delta I}{T_{OFF}} = V_o \Rightarrow \Delta I = V_o \frac{T_{OFF}}{L} \dots\dots\dots(ii)$$

By equating (i) and (ii)

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

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

$$\frac{V_s}{V_o} = \frac{T_{ON} + T_{OFF}}{T_{ON}}$$

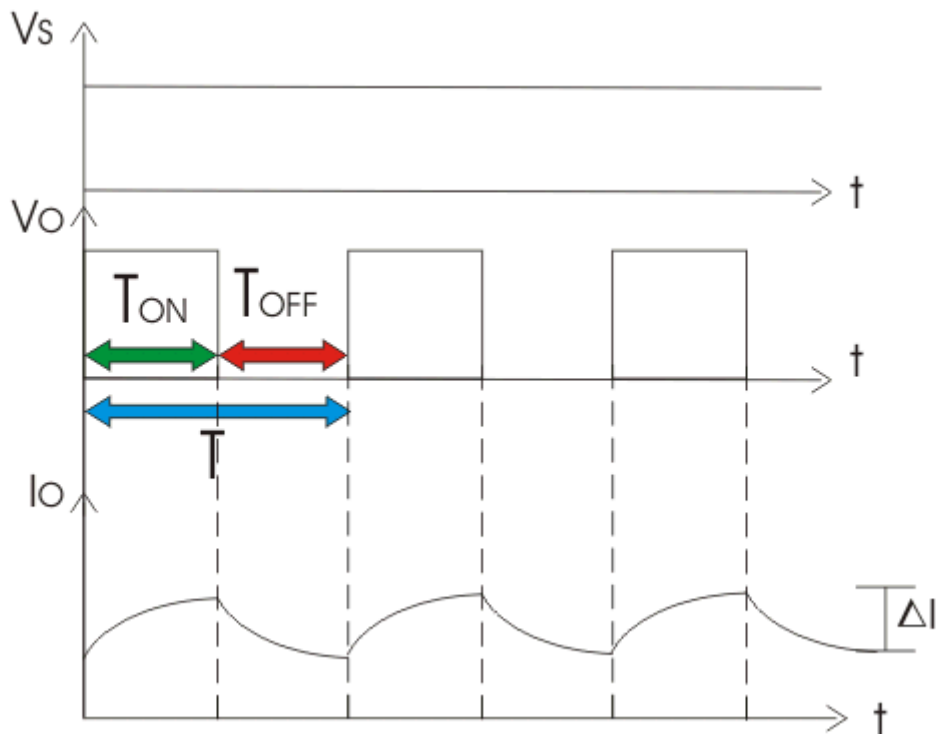
Therefore, $V_o = \frac{T_{ON}}{T} V_s = DV_s$

So, from (i) we get,

$$\Delta I = \frac{V_s - DV_s}{L} DT \left[\text{Since, } D = \frac{T_{ON}}{T} \right]$$

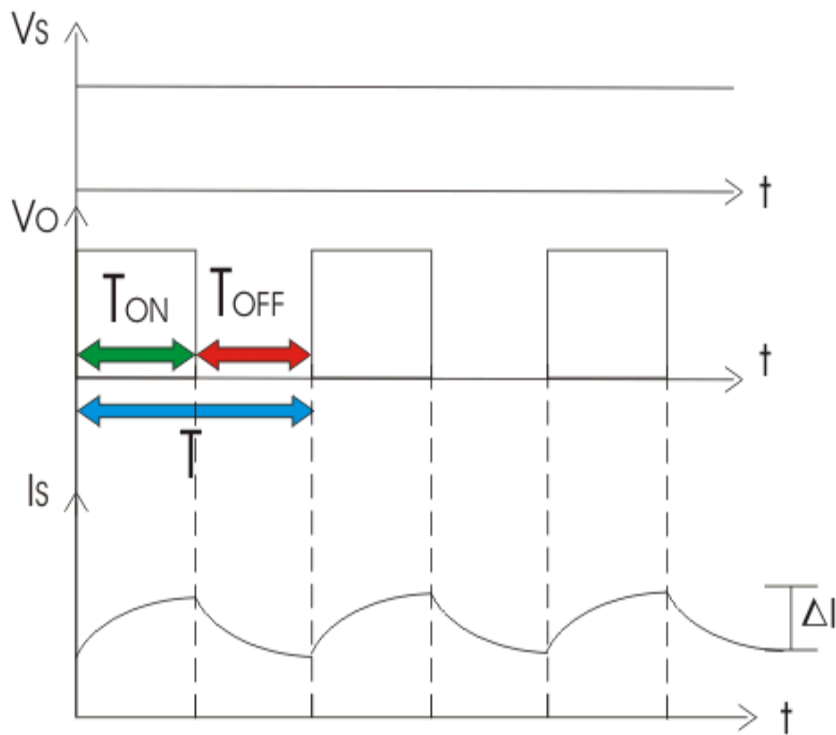
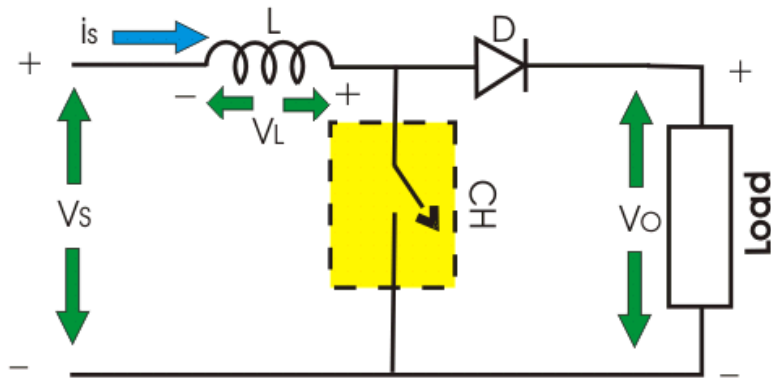
$$= \frac{V_s(1 - D)D}{Lf} \left[f = \frac{1}{T} = \text{Chopping Frequency} \right]$$

The output voltage and current waveform of step down chopper with inductive load is shown below



2) Step up Chopper or Boost Converter

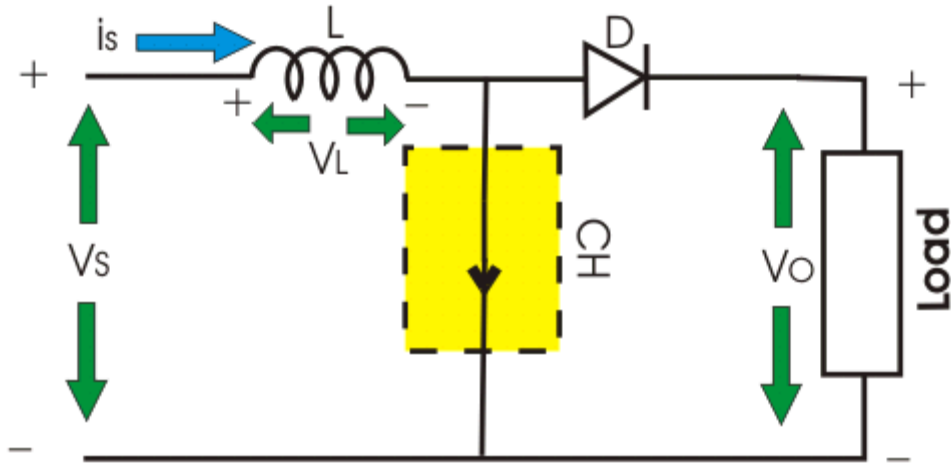
Step up chopper or boost converter is used to increase the input voltage level of its output side. Its circuit diagram and waveforms are shown below in figure.



Operation of Step up Chopper

When CH is ON it short circuits the load. Hence output voltage during \$T_{ON}\$ is zero. During this period inductor gets charged. So, \$V_s = V_L\$

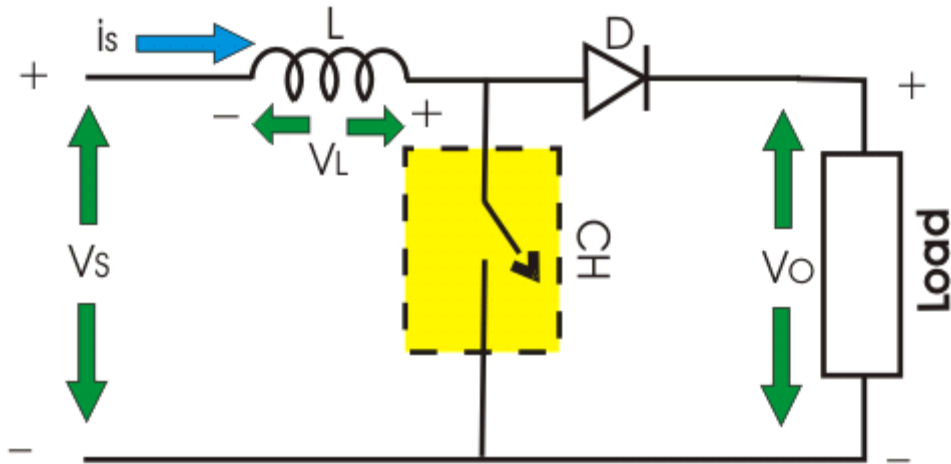
$$L \frac{di}{dt} = V_s \Rightarrow \frac{\Delta I}{T_{ON}} = \frac{V_s}{L} \Rightarrow \Delta I = \frac{V_s}{L} T_{ON} \dots (iii)$$



Where ΔI is the peak to peak inductor current. When CH is OFF inductor L discharges through the load. So, we will get summation of both source voltage V_s and inductor Voltage V_L as output voltage, i.e.

$$V_o = V_s + V_L \Rightarrow V_L = V_o - V_s \Rightarrow L \frac{di}{dt} = V_o - V_s$$

$$\Rightarrow L \frac{\Delta I}{T_{OFF}} = V_o - V_s \Rightarrow \Delta I = \frac{V_o - V_s}{L} T_{OFF} \dots (iv)$$



Now, by equating (iii) & (iv),

$$\frac{V_s}{L} T_{ON} = \frac{V_o - V_s}{L} T_{OFF} \Rightarrow V_s (T_{ON} + T_{OFF}) = V_o T_{OFF}$$

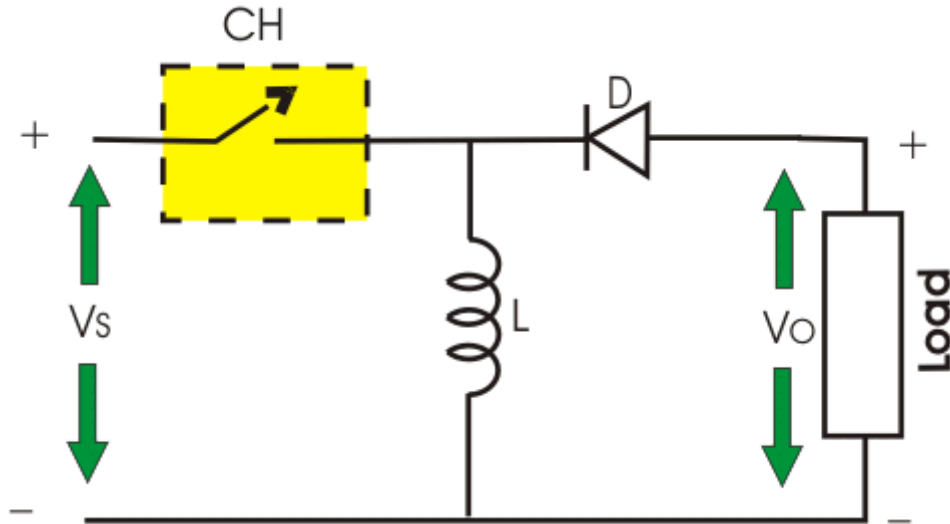
$$\Rightarrow V_o = \frac{T V_s}{T_{OFF}} = \frac{V_s}{(T - T_{ON})/T}$$

Therefore, average output voltage, $V_o = \frac{V_s}{1 - D}$

As we can vary T_{ON} from 0 to T , so $0 \leq D \leq 1$. Hence V_o can be varied from V_s to ∞ . It is clear that output voltage is always greater than the input voltage and hence it boost up or increase the voltage level.

Buck-Boost Converter or Step Up Step Down Converter

With the help of Buck-Boost converter we can increase or decrease the input voltage level at its output side as per our requirement. The circuit diagram of this converter is shown below .



Operation of Buck-Boost Converter

When CH is ON source voltage will be applied across inductor L and it will be charged. So $V_L = V_s$

$$L \frac{di}{dt} = V_s \Rightarrow \Delta I = \frac{V_s}{L} T_{ON}$$

$$\Rightarrow \Delta I = \frac{V_s}{L} T \frac{T_{ON}}{T}$$

$$\Delta I = \frac{DV_s}{Lf} \left[\text{Since, } \frac{T_{ON}}{T} = D \text{ and } \frac{1}{T} = f = \text{Chopping Frequency} \right] \dots (v)$$

When chopper is OFF inductor L reverses its polarity and discharges through load and diode, So,

$$V_o = -V_L$$

$$L \frac{di}{dt} = -V_o \Rightarrow L \frac{\Delta I}{T_{OFF}} = -V_o \Rightarrow |\Delta I| = -\frac{V_o}{L} T_{OFF} \dots (vi)$$

By evaluating (v) and (vi) we get,

$$\frac{DV_s}{fL} = -\frac{V_o}{L}T_{OFF} \Rightarrow DV_s = -V_oT_{OFF}f$$

$$DV_s = -V_o\frac{T - T_{ON}}{T} = -V_o\left(1 - \frac{T_{ON}}{T}\right) \Rightarrow V_o = -\frac{DV_s}{1 - D}$$

$$\left[\text{Since, } D = \frac{T_{ON}}{T} = \frac{T - T_{OFF}}{T} \right]$$

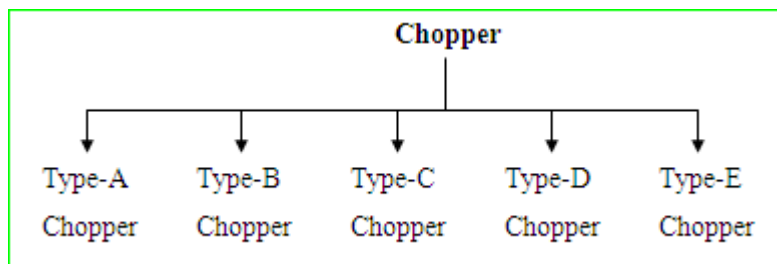
Taking magnitude we get,

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

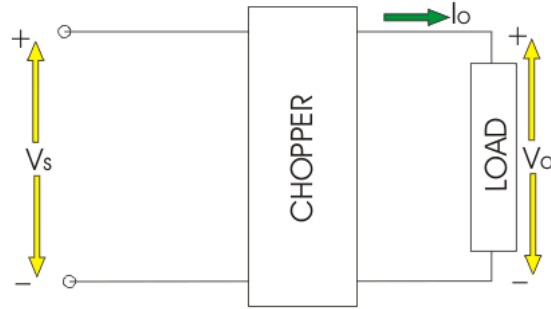
D can be varied from 0 to one. When, $D = 0$; $V_o = 0$ When $D = 0.5$, $V_o = V_s$
 When, $D = 1$, $V_o = \infty$ Hence, in the interval $0 \leq D \leq 0.5$, output voltage varies in the range $0 \leq V_o \leq V_s$ and we get step down or Buck operation. Whereas, in the interval $0.5 \leq D \leq 1$, output voltage varies in the range $V_s \leq V_o \leq \infty$ and we get step up or Boost operation.

According to direction of output voltage and current

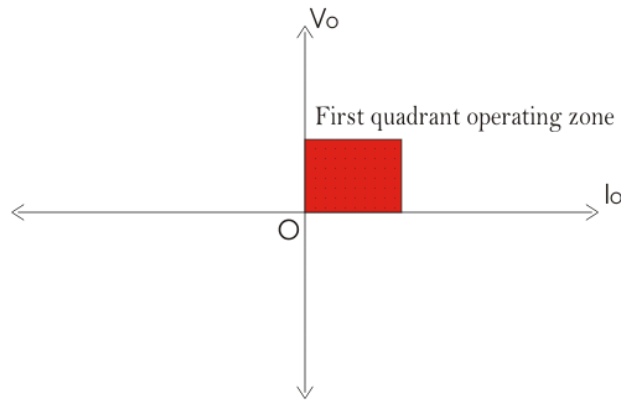
Semiconductors devices used in chopper circuit are unidirectional. But arranging the devices in proper way we can get output voltage as well as output current from chopper in our required direction. So, on the basis of this features chopper can be categorized as follows :



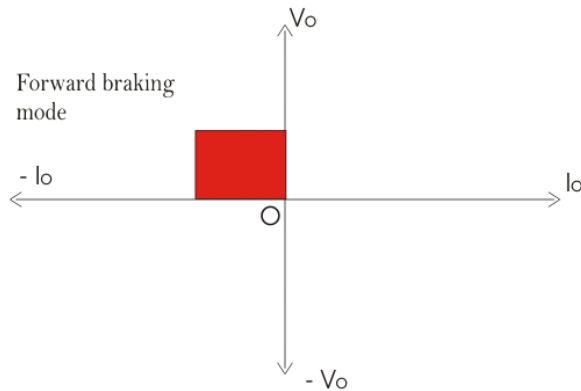
Before detailed analysis some basic idea regarding $V_o - I_o$ quadrant is required here. The directions of I_o and V_o marked in the figure – 1 is taken as positive direction.



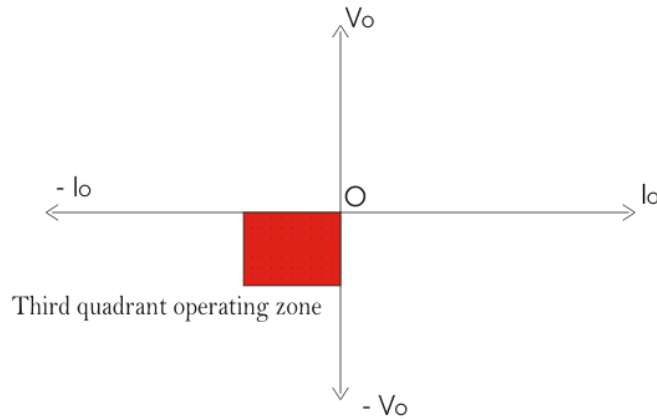
If output voltage (V_O) and output current (I_O) follows the direction as marked in figures then the chopper operation will be restricted in the first quadrant of $V_O - I_O$ plane. This type of operation is also known as forward motoring.



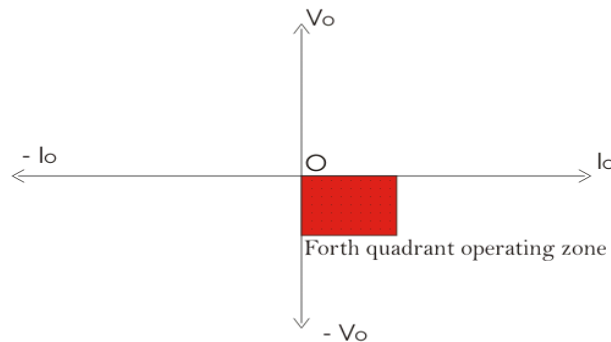
When output voltage (V_O) follows the marked direction in fig. 1 but current flows in the opposite direction then V_O is taken positive but I_O as negative. Hence the chopper operates in the second quadrant of $V_O - I_O$ plane. This type of operation is also known as forward braking.



It may also happen that both output voltage and current is opposite to the marked direction in figure – 1. In t his case both V_O and I_O are taken as negative. Hence chopper operation is restricted in third quadrant of V_O - I_O plane. This operation is called reverse motoring.



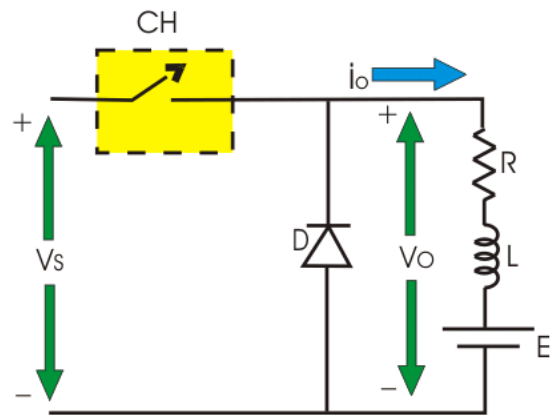
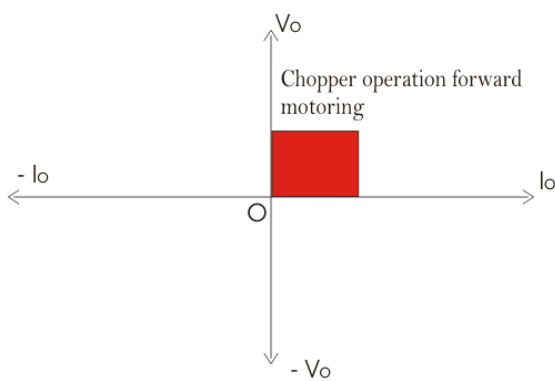
If output voltage is opposite to the marked direction in fig. 1. then it is taken as negative. But output current follows the direction as marked in fig. 1 and considered as positive. Hence chopper operates in 4th quadrant of $V_O - I_O$ plane. This mode of operation is called reverse braking.\



N ow we can proceed to detailed analysis of different types of chopper. Some choppers operate in a single quadrant only, which are called single quadrant chopper. Some choppers operate in two quadrant also which are known as two quadrant chopper. It is also possible that a chopper operates in all the quadrants, which are known as 4-quadrant chopper.

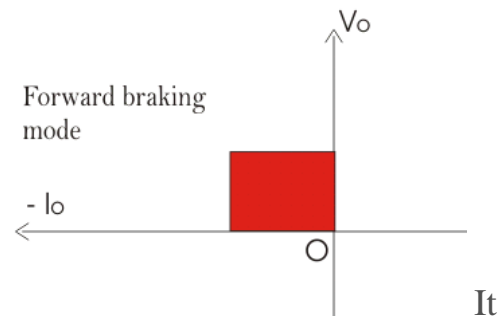
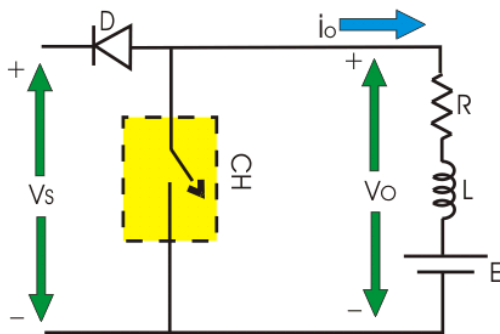
Type-A Chopper

It is a single quadrant chopper whose operation is restricted in first quadrant of $V_O - I_O$ plane. The circuit diagram is shown as below : When CH is ON both V_O & I_O follows the direction as marked in the figures. So, both are taken as positive hence load power is positive which means power is delivered from source to load. When CH is OFF current freewheels through diode. Hence V_O is zero and I_O is positive. In type-A chopper it is seen that average value of V_O and I_O is always positive. This is also called step down chopper as average value of V_O is less than the input voltage. This type of chopper is suitable for motoring operation.



Type-B Chopper

This is also a single quadrant chopper operating in second quadrant of $V_O - I_O$ plane. The circuit diagram is shown in the following figure.



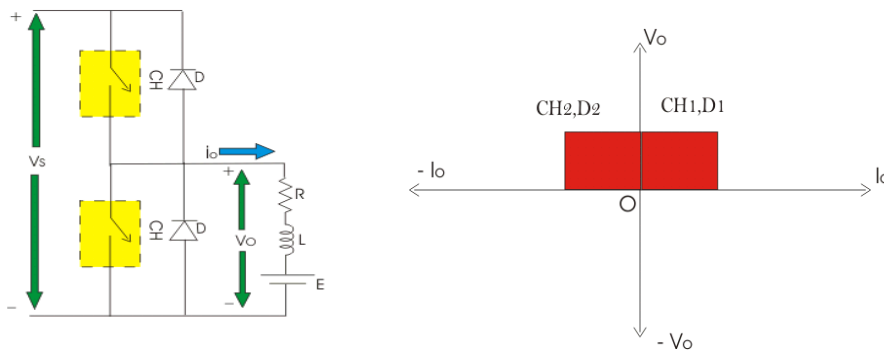
It is interesting to note that load must have a DC voltage source E for this kind of

operation. When CH is ON V_O is zero but current flows in the opposite direction as marked in figure. When chopper is OFF

Which exceeds the source voltage V_S . So current flows through diode D and treated as negative. Hence current I_O is always negative here but V_O is positive (sometimes zero). So, power flows from load to source and operation of type-B chopper is restricted in second quadrant of $V_O - I_O$ plane. This type of chopper is suitable for forward braking operation.

Type-C Chopper

This is a two quadrant chopper whose operation is bounded between first and second quadrant of $V_O - I_O$ plane. This type of chopper obtained by connecting type-A and type-B chopper in parallel as shown in the figure.



When CH_1 is ON current flows through abcdefa and inductor L will be charged. Hence output voltage V_O and current I_O both will be positive. When CH_1 is OFF, induction will discharge through D_1 and current I_O will flow through same direction with zero output voltage. So, we can see the operation of CH_1 is nothing but the operation of type-A chopper by which we can operate a chopper in the first quadrant. When CH_2 is ON, output voltage V_O will be zero but output current I_O will flow in opposite direction of current shown in the figure and inductor will be charged up. When CH_2 is OFF Output voltage

$$V_O = \left[E + L \frac{di}{dt} - IR \right]$$

5This exceeds the value of source voltage V_S . So current flows through diode D_2 and treated as negative. Hence output voltage V_O is always positive and output current I_O is always negative here. We can see operation of CH_2 is nothing but operation of type-B chopper by which we can operate the chopper in the second quadrant. We can conclude that the operation of type-c chopper is

the combined operation of type-A and type-B chopper. This type of chopper is suitable for both forward motoring and forward braking operation.

Good luck

الدكتور محمد سعدي