JEPPIAAR INSTITUTE OF TECHNOLOGY

"Self-Belief | Self Discipline | Self Respect"

DEPARTMENT

OF

ELECTRONICS AND COMMUNICATION ENGINEERING

LECTURE NOTES

EC8351 – ELECTRONIC CIRCUITS 1

(Regulation 2017)

Year/Semester: II/03

2021 – 2022

Prepared by

Ms.S.SUREKHA

Assistant Professor/ECE

SYLLABUS

EC8351 **ELECTRONIC CIRCUITS 1** **L T P C 3 0 0 3**

OBJECTIVES:

- To understand the methods of biasing transistors
- To design and analyze single stage and multistage amplifier circuits
- To analyze the frequency response of small signal amplifiers
- To design and analyze the regulated DC power supplies.
- To troubleshoot and fault analysis of power supplies

UNIT I BIASING OF DISCRETE BJT, JFET AND MOSFET

BJT– Need for biasing — DC Load Line and Bias Point — DC analysis of Transistor circuits — Various biasing methods of BJT — Bias Circuit Design — Thermal stability — Stability factors — Bias compensation techniques using Diode, thermistor and sensistor — Biasing BJT Switching Circuits- JFET — DC Load Line and Bias Point — Various biasing methods of JFET — JFET Bias Circuit Design — MOSFET Biasing — Biasing FET Switching Circuits.

UNIT II BJT AMPLIFIERS

Small Signal Hybrid p equivalent circuit of BJT — Early effect — Analysis of CE, CC and CB amplifiers using Hybrid p equivalent circuits — AC Load Line Analysis- Darlington Amplifier — Bootstrap technique — Cascade, Cascode configurations — Differential amplifier, Basic BJT differential pair — Small signal analysis and CMRR.

UNIT III SINGLE STAGE FET, MOSFET AMPLIFIERS

Small Signal Hybrid p equivalent circuit of FET and MOSFET — Analysis of CS, CD and CG amplifiers using Hybrid p equivalent circuits — Basic FET differential pair- BiCMOS circuits.

UNIT IV FREQUENCY RESPONSE OF AMPLIFIERS

Amplifier frequency response — Frequency response of transistor amplifiers with circuit capacitors — BJT frequency response — short circuit current gain — cut off frequency — fa, fß and unity gain bandwidth — Miller effect — frequency response of FET — High frequency analysis of CE and MOSFET CS amplifier — Transistor Switching Times.

UNIT V POWER SUPPLIES AND ELECTRONIC DEVICE TESTING

Linear mode power supply — Rectifiers — Filters — Half-Wave Rectifier Power Supply — Full- Wave Rectifier Power Supply — Voltage regulators: Voltage regulation — Linear series, shunt and switching Voltage Regulators — Over voltage protection — BJT and MOSFET — Switched mode power supply (SMPS) — Power Supply Performance and Testing — Troubleshooting and Fault Analysis, Design of Regulated DC Power Supply.

TOTAL: 45 PERIODS

OUTCOMES:

After studying this course, the student should be able to:

•Acquire knowledge of ♣Working principles, characteristics and applications of BJT and FET♣Frequency response characteristics of BJT and FET amplifiers

•Analyze the performance of small signal BJT and FET amplifiers - single stage and multi stage amplifiers

•Apply the knowledge gained in the design of Electronic circuits

TEXT BOOKS:

1. Donald. A. Neamen, Electronic Circuits Analysis and Design, 3rd Edition, Mc Graw Hill Education (India) Private Ltd., 2010. (Unit I-IV)
2. Robert L. Boylestad and Louis Nasheresky, ―Electronic Devices and Circuit Theory‖, 11thEdition, Pearson Education, 2013. (Unit V)

REFERENCES

1. Millman J, Halkias.C.and Sathyabrada Jit, Electronic Devices and Circuits, 4th Edition, Mc Graw Hill Education (India) Private Ltd., 2015.
2. Salivahanan and N. Suresh Kumar, Electronic Devices and Circuits, 4th Edition, , Mc Graw Hill Education (India) Private Ltd., 2017.
3. Floyd, Electronic Devices, Ninth Edition, Pearson Education, 2012.
4. David A. Bell, Electronic Devices & Circuits, 5th Edition, Oxford University Press, 2008.
5. Anwar A. Khan and Kanchan K. Dey, A First Course on Electronics, PHI, 2006.
6. Rashid M, Microelectronics Circuits, Thomson Learning, 2007

(i) Half Wave Rectifier:-

Introduction:- This Rectifier circuit consists of Resistive load, Rectifying element (i.e) P-N Junction diode and source of a.c voltage, all connected in series. To obtain the desired d.c voltage across the Load, a.c voltage is applied to rectifier circuit using suitable step-up (or) step-down transformer.

$e = E_{sm} \sin \omega t$, $\omega = 2\pi f$.

N- turns Ratio:- $\frac{N_2}{N_1} = \frac{E_{sm}}{E_{pm}}$

$E_{sm}, P_m \rightarrow$ peak Value of secondary & primary a.c voltage.

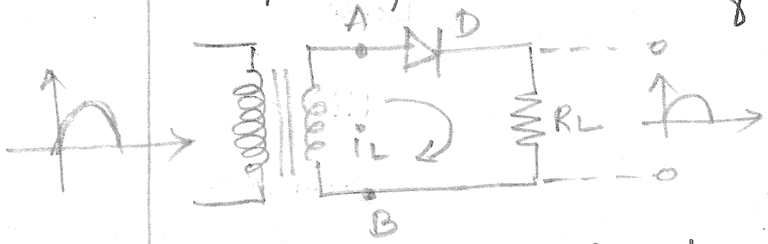


Fig (a): Forward Biased

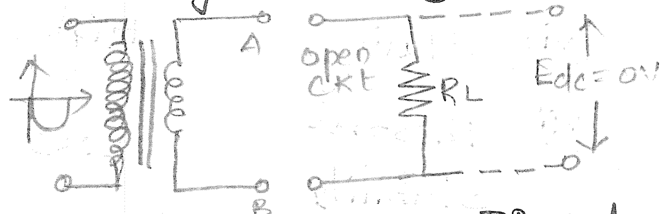


Fig (b): Reverse Biased.

Operation:- +ve Half cycle

'A' Becomes +ve with 'B'

Diode - Forward Biased

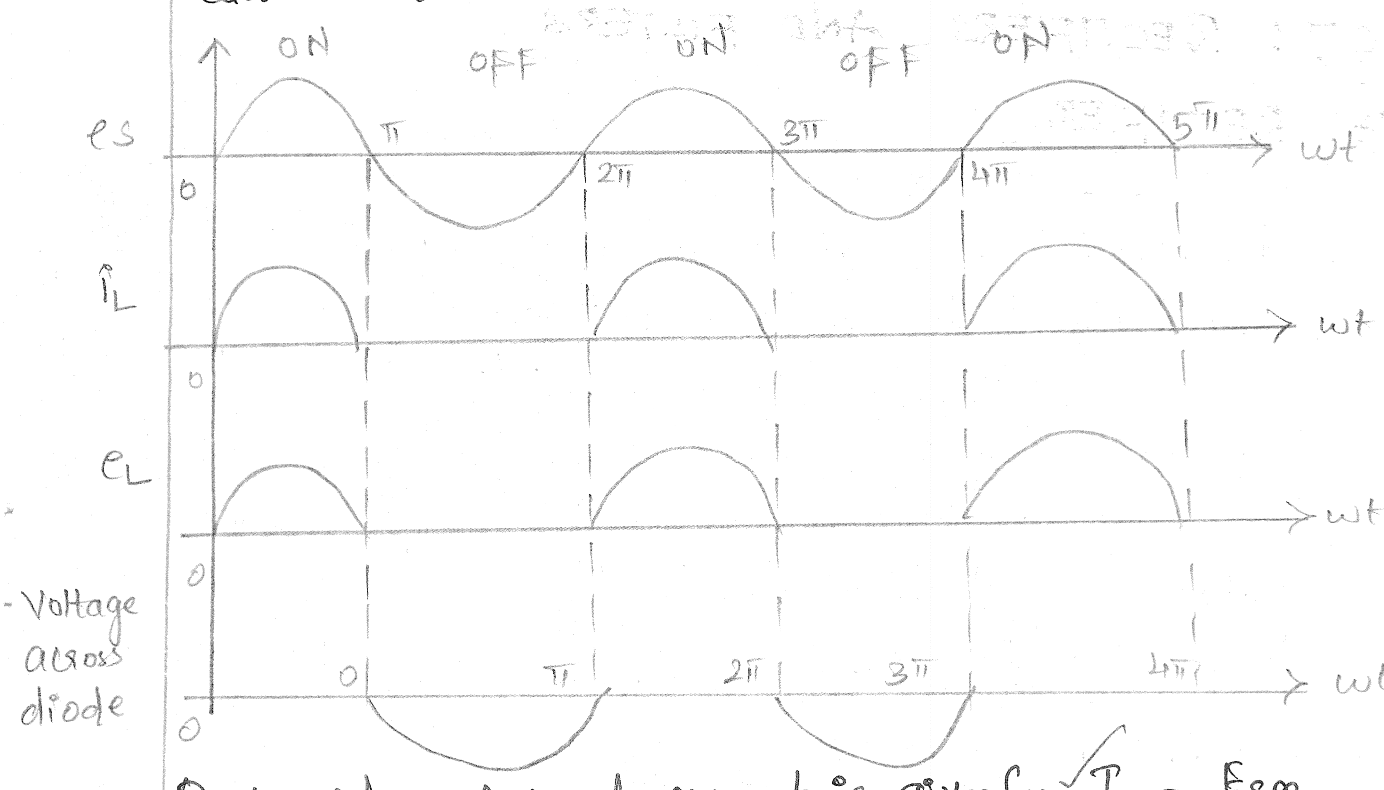
Current - Clockwise direction

-ve Half cycle:

'A' is -ve with 'B'

Diode - Reverse Biased

Current - No current flows.



Peak Value of Load current is given by, $I_m = \frac{E_{sm}}{R_f + R_L + R_s}$

$R_L \rightarrow$ Resistance of secondary winding of transformer

$R_f \rightarrow$ forward Resistance of diode

(i) Average (or) d.c. Value of load current (I_{DC}):-

$i_L = I_m \sin\omega t$, $0 \le \omega t \le \pi$,
$i_L = 0$, $\pi \le \omega t \le 2\pi$

$$I_{DC} = \frac{1}{2\pi}\int_0^{2\pi} i_L \, d(\omega t)$$

$$= \frac{1}{2\pi}\int_0^{2\pi} I_m \sin(\omega t) d(\omega t)$$

As No current flows during -ve Half cycle (i.e) $\omega t = \pi$ to 2π

$$I_{DC} = \frac{1}{2\pi}\int_0^{\pi} I_m \sin\omega t . d\omega t$$

$$= \frac{I_m}{2\pi}\left[-\cos\omega t\right]_0^{\pi}$$

$$I_{DC} = \frac{I_m}{2\pi}\left(-[-1-1]\right)$$

$$\therefore I_{DC} = \frac{I_m}{\pi}$$

(ii) Average d.c Load Voltage (E_{DC}):-

$$E_{DC} = I_{DC} \cdot R_L \Rightarrow \frac{I_m}{\pi} \cdot R_L$$

$$E_{DC} = \frac{E_{sm}}{(R_f + R_L + R_s)\pi} \cdot R_L$$

$$\therefore E_{DC} = \frac{E_{sm}}{\pi} \quad (R_s, R_f \to \text{Small}) \text{ Neglected}$$

(iii) RMS Value of Load current (I_{RMS}):-

$$I_{RMS} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi}(I_m \sin\omega t)^2 d\omega t}$$

$$= I_m \sqrt{\frac{1}{2\pi}\int_0^{\pi}\left(\frac{1-\cos 2\omega t}{2}\right) d\omega t}$$

$$= I_m \sqrt{\frac{1}{2\pi}\left[\frac{\omega t}{2} - \frac{\sin 2\omega t}{4}\right]_0^{\pi}}$$

$$= I_m \sqrt{\frac{1}{2\pi}\left(\frac{\pi}{2}\right)} \Rightarrow \frac{I_m}{2} \quad \ldots \sin(2\pi)$$

$= \sin(0) = 0.$

$$I_{rms} = \frac{I_m}{2}, \quad E_{L(RMS)} = I_{rms} \cdot R_L$$

$$E_{L(RMS)} = E_{sm}/2$$

(iv) D.C. power output (P_{DC}):-

$$P_{DC} = E_{DC} \cdot I_{DC} \Rightarrow I_{DC}^2 R_L$$

$$P_{DC} = I_{DC}^2 R_L = \left[\frac{I_m}{\pi}\right]^2 R_L$$

$$= \frac{I_m^2}{\pi^2} \cdot R_L \Rightarrow \frac{I_m^2}{\pi^2} \cdot R_L$$

$$P_{DC} = \frac{E_{sm}^2 R_L}{\pi^2 [R_f + R_L + R_s]^2}$$

(v) A.C. power Input (P_{AC}):-

$$P_{AC} = I_{RMS}^2 [R_L + R_f + R_s]$$

$$I_{RMS} = \frac{I_m}{2}$$

$$P_{AC} = \frac{I_m^2}{4}[R_L + R_f + R_s]$$

(vi) Rectifier Efficiency:-

$$\eta = \frac{P_{DC}}{P_{AC}} \Rightarrow \frac{\text{D.C o/p Power}}{\text{A.c i/p power}}$$

$$\Rightarrow \frac{\frac{I_m^2}{\pi^2} R_L}{\frac{I_m^2}{4}[R_f + R_L + R_s]} \Rightarrow \frac{\left(\frac{4}{\pi^2}\right) R_L}{(R_f + R_L + R_s)}$$

$$\div R_L \Rightarrow \eta = \frac{0.406}{1 + \left(\frac{R_f + R_s}{R_L}\right)}$$

$$\% \eta_{max} = 0.406 \times 100 \Rightarrow 40.6\%$$
$(\because R_f + R_s << R_L)$

(vii) Ripple Factor:-

Output of Half wave rectifier is not pure d.c but pulsating d.c The output contains pulsating components called ripples.

The Measure of ripples present in the output is with the help of a factor called ripple factor, denoted by γ.

Smaller the ripple factor closer is the output to a pure d.c.

Ripple factor: It is defined as the Ratio of R.M.S Value of the a.c Component in the output to the Average or d.c Component present in the output

Ripple factor

$$\gamma = \frac{\text{R.M.S. Value of a.c Component of output}}{\text{Average (or) d.c Component of output}}$$

$$I_{rms} = \sqrt{I_{ac}^2 + I_{dc}^2}$$

$$I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

$$\gamma = \frac{I_{ac}}{I_{dc}} \Rightarrow \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{DC}}$$

$$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

$$\gamma = \sqrt{\frac{\left(\frac{I_m}{2}\right)^2}{\left(\frac{I_m}{\pi}\right)^2} - 1} \Rightarrow \sqrt{\frac{\pi^2}{4} - 1} = 1.21$$

γ is very High.

(viii) **peak Inverse Voltage (PIV)**

It is the peak Voltage across the diode in the reverse direction (ie) when the diode is reverse biased. This is called PIV rating of a diode.

PIV of diode $= E_{sm}$ for Half wave rectifier

(ix) **Voltage Regulation:-**

$$\%\text{ Voltage regulation} = \frac{(V_{dc})_{NL} - (V_{dc})_{FL}}{(V_{dc})_{FL}} \times 100.$$

$$(V_{dc})_{NL} = E_{sm}/\pi$$

$$(V_{dc})_{FL} = I_{DC} \cdot R_L = \frac{I_m}{\pi} \cdot R_L$$

$$\Rightarrow \frac{E_{sm}}{\pi[R_f + R_s + R_L]} \times R_L$$

$$\% R = \frac{\frac{E_{sm}}{\pi} - \frac{E_{sm}}{\pi} \cdot \frac{R_L}{(R_f + R_s + R_L)}}{\frac{E_{sm}}{\pi} \cdot \frac{R_L}{R_f + R_s + R_L}} \times 100$$

$$\Rightarrow \frac{1 - \frac{R_L}{R_f + R_s + R_L}}{\frac{R_L}{R_f + R_s + R_L}} \times 100$$

$$\% R = \frac{R_f + R_s}{R_L} \times 100.$$

(X) **Transformer utilization factor (T.U.F):-**

$$\text{T.U.F} = \frac{\text{D.c power delivered to the Load}}{\text{A.c. power rating of the transformer}}$$

$$P_{dc} = I_{DC}^2 R_L \Rightarrow \left(\frac{I_m}{\pi}\right)^2 R_L.$$

A.c power rating of transformer

$$= E_{rms} \cdot I_{rms} \Rightarrow \frac{E_{sm}}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} = \frac{E_{sm} I_m}{2}$$

$$\text{T.U.F} = \frac{I_m^2}{\pi^2} \cdot \frac{R_L \cdot 2\sqrt{2}}{I_m^2 R_L} = \frac{2\sqrt{2}}{\pi^2}$$

$$\text{T.U.F} = 0.287$$

(XI) **Advantages:-**

a) only one diode is sufficient
b) ckt is easy to design
c) No centre tap on transformer is Necessary.

(XII) **DisAdvantages:-**

a) Ripple factor of HWR ckt is 1.21, which is high
b) Max. rectification efficiency is 40%, which is low
c) T.U.F is low showing that transformer is not fully utilised

(ii) **FULL WAVE RECTIFIER:-**

<u>Introduction:-</u> It conducts during both positive and Negative Half cycles of input a.c. input, two diodes are used in this circuit. The diodes feed a common Load R_L with the help of a Centre tap transformer. The A.c Voltage is applied through a suitable power transformer with proper turns ratio.

<u>Operation:-</u> <u>(+ve) Half cycle</u>

'A' is +ve w. 'B' is -ve.

(conduct) Diode D_1 → forward biased

(Not conduct) Diode D_2 → Reverse Biased

open ckts.

<u>(-ve) Half cycle.</u>

'A' is -ve w. 'B' is +ve.

(Conduct) Diode D_2 → forward Biased

(Not conduct) Diode D_1 → Reverse Biased

"Load current flows in both the Half cycles of ac voltage and in the same direction through the Load resistance."

$e_s = E_{sm} \sin \omega t$

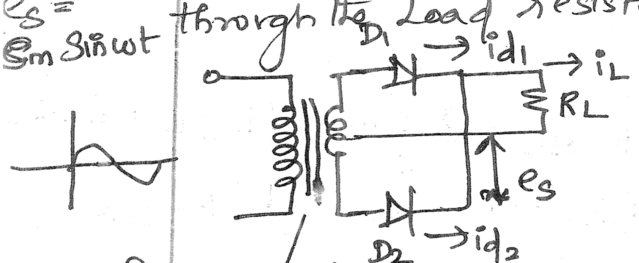
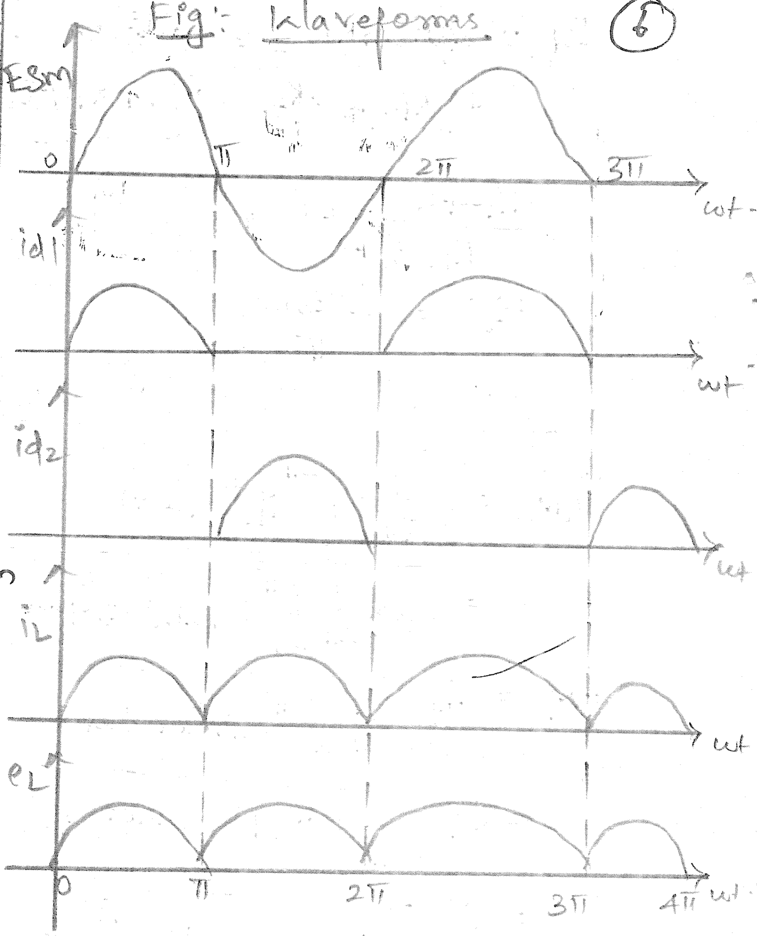


fig: Full Wave Rectifier

Centre tap transformer

The output Load current is still pulsating d.c and not pure d.c.

Fig:- Waveforms



(i) <u>Maximum Load current:-</u>

$$I_m = \frac{E_{sm}}{R_s + R_f + R_L}$$

R_f → forward Resistance

R_s → Winding Resistance

I_m → Maximum Load current

E_{sm} → Max. Value of a.c i/p voltage of secondary

(ii) <u>D.c. Load current:-</u>

$i_L = I_m \sin \omega t, \quad 0 \le \omega t \le \pi$

$$I_{av} = I_{DC} = \frac{1}{\pi}\int_0^{\pi} i_L \, d(\omega t) \Rightarrow$$

$$= \frac{1}{\pi}\int_0^{\pi} I_m \sin \omega t \, d\omega t$$

$$= \frac{I_m}{\pi}\left[-\cos \omega t\right]_0^{\pi}$$

$$= \frac{I_m}{\pi}\left[1-(-1)\right] \Rightarrow \frac{2I_m}{\pi}$$

(iii) <u>Average Dc Load Voltage (E_{DC}):-</u>

$$E_{DC} = I_{DC} \cdot R_L \Rightarrow \frac{2 \cdot I_m R_L}{\pi}$$

$$E_{dc} = \frac{2E_{sm}R_L}{\pi[R_f+R_s+R_L]} = \frac{2E_{sm}}{\pi\left[1+\frac{R_f+R_s}{R_L}\right]}$$

$$\frac{R_f+R_s}{R_L} << 1,$$

$$E_{DC} = \frac{2E_{sm}}{\pi}$$

(iv) RMS Load current (I_{RMS}):-

$$I_{RMS} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i_L^2\, d(\omega t)}$$

$$= \sqrt{2\times\frac{1}{2\pi}\int_0^{\pi} I_m \sin(\omega t)^2 d\omega t}$$

$$I_{RMS} = I_m\sqrt{\frac{1}{\pi}\int_0^{\pi}\sin^2\omega t\, d\omega t}$$

$$= I_m\sqrt{\frac{1}{\pi}\int_0^{\pi}\left(\frac{1-\cos 2\omega t}{2}\right)d\omega t}$$

$$= I_m\sqrt{\frac{1}{\pi}\left[\frac{\pi}{2}\right]} \Rightarrow \frac{I_m}{\sqrt{2}}$$

$$E_L(RMS) = I_{RMS}\cdot R_L \Rightarrow \frac{I_m}{\sqrt{2}}\cdot R_L.$$

(v) DC power output (P_{DC}):-

$$P_{DC} = \left(\frac{2I_m}{\pi}\right)^2 R_L \Rightarrow$$

$$\Rightarrow \frac{4}{\pi^2}\frac{E_{sm}^2}{(R_s+R_f+R_L)} \times R_L$$

$$P_{DC} = \frac{4}{\pi^2} I_m^2 R_L$$

(v) AC power Input (P_{AC}):-

$$P_{AC} = I_{RMS}^2[R_f+R_s+R_L]$$

$$\left(\frac{I_m}{\sqrt{2}}\right)^2(R_f+R_s+R_L) \Rightarrow I_m^2\left(\frac{R_f+R_s+R_L}{2}\right)$$

$$\therefore P_{AC} = \frac{E_{sm}^2}{(R_f+R_s+R_L)^2}\times\frac{1}{2}\times(R_f+R_s+R_L)$$

$$P_{AC} = \frac{E_{sm}^2}{2(R_f+R_s+R_L)}.$$

(vi) Rectifier Efficiency (η):-

$$\eta = \frac{P_{DC}\text{ output}}{P_{AC}\text{ input}} \Rightarrow \frac{\frac{4}{\pi^2}I_m^2 R_L}{\frac{I_m^2[R_f+R_s+R_L]}{2}}$$

$$\eta = \frac{8R_L}{\pi^2[R_f+R_s+R_L]}, \quad R_f+R_s << R_L$$

$$\eta = \frac{8R_L}{\pi^2(R_L)} \Rightarrow \frac{8}{\pi^2}\times 100 = 81.2\%$$

(vii) Ripple factor:-

$$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{DC}}\right)^2 - 1}$$

$$I_{rms} = I_m/\sqrt{2}, \quad I_{DC} = 2I_m/\pi$$

$$\gamma = \sqrt{\left[\frac{(I_m/\sqrt{2})}{(2I_m/\pi)}\right]^2 - 1} \Rightarrow \sqrt{\frac{\pi^2}{8} - 1}$$

$$\gamma = 0.48$$

(viii) Peak Inverse Voltage (PIV):

PIV of diode $= 2E_{sm}$.

(ix) Ripple Frequency:-

$$i_L = i_{d1} + i_{d2}$$

$$\Rightarrow I_m\left[\frac{2}{\pi} - \frac{4}{3\pi}\cos 2\omega t - \frac{4}{15\pi}\cos 4\omega t\right.$$

Ripple freq in FWR is $2f$ Hz.

(x) Voltage Regulation:-

$$(V_{dc})_{NL} = \frac{2E_{sm}}{\pi}, \quad V_{dc}(FL) = I_{DC}\cdot R_L$$

$$\%R = \frac{(V_{dc})_{NL} - (V_{dc})_{FL}}{(V_{dc})_{FL}} \times 100.$$

$$\%R = \frac{2E_{sm} - I_{DC}R_L}{I_{DC}R_L}\times 100$$

$$[I_m = E_{sm}/R_f+R_s+R_L]$$

$$E_{sm} = I_m[R_f+R_s+R_L]$$

$$I_{DC} = 2I_m/\pi$$

$$\% R = \frac{\frac{2I_m}{\pi}[R_f + R_L + R_S] - \frac{2I_m}{\pi} R_L}{\frac{2I_m}{\pi} R_L} \times 100$$

$$= \frac{R_f + R_L + R_S - R_L}{R_L} \times 100$$

$$\% R = \frac{R_f + R_S}{R_L} \times 100$$

$$\% R = \frac{R_f}{R_L} \times 100 \quad [\because R_S \text{ is small Neglect}]$$

(Xi) Transformer Utilization factor (T.U.F):-

$$\text{Secondary T.U.F} = \frac{\text{D.C power to the load}}{\text{A.c. power Rating of Secondary}}$$

$$= \frac{I_{DC}^2 R_L}{E_{RMS} I_{RMS}} \Rightarrow \frac{\left(\frac{2}{\pi} I_m\right)^2 R_L}{\frac{E_{sm}}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}}}$$

$$E_{sm} = I_m R_L$$

$$\Rightarrow \frac{\frac{4}{\pi^2} \times I_m^2 R_L}{\frac{I_m^2 R_L}{2}} \Rightarrow \frac{8}{\pi^2} = 0.812$$

T.U.F of HW circuit to be equal to 0.287.

T.U.F of primary Winding = 2 × T.U.F of HW ckt

$$\Rightarrow 2 \times 0.287 \Rightarrow 0.574$$

$$\text{Avg T.U.F} = \frac{\text{T.U.F of primary} + \text{T.U.F of Secondary}}{2}$$

$$= \frac{0.574 + 0.812}{2} = 0.693$$

(Xii) Advantages:-

a) D.c Load Voltage and current are More than HWR.

b) No D.c Current through transformer windings

c) T.U.F is Better as transformer Losses are Less.

d) Efficiency is Higher

e) Ripple factor is Less

f) D.C power output

(Xiii) DisAdvantages:-

a) cost of centretap transformer is Higher.

b) Higher PIV diodes are larger in size and costlier

c) PIV rating of diode is higher

(iii) Bridge Rectifier:-

It is essentially a full-wave rectifier circuit using four diodes forming the four arms of an electrical bridge.

→ To one diagonal of the bridge, the ac voltage is applied through a transformer if necessary and the rectified dc voltage is taken from the other diagonal of the bridge.

→ Main Advantage of this ckt is that it does not require a centre tap on secondary winding of the transformer.

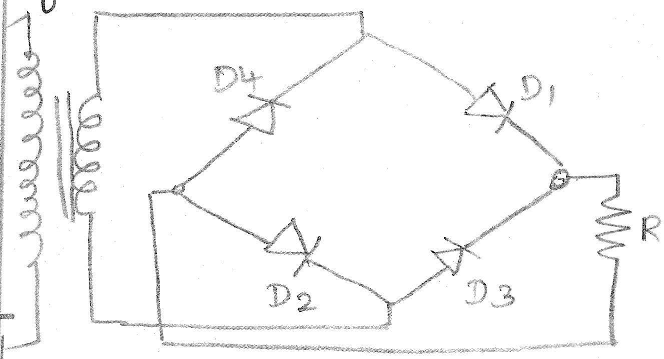


fig:- Bridge Rectifier.

Operation:- +ve Half of a.c input Voltage, A → +ve.

Diode D_1 & D_2 → forward biased

Diode D_3 & D_4 → Reverse biased

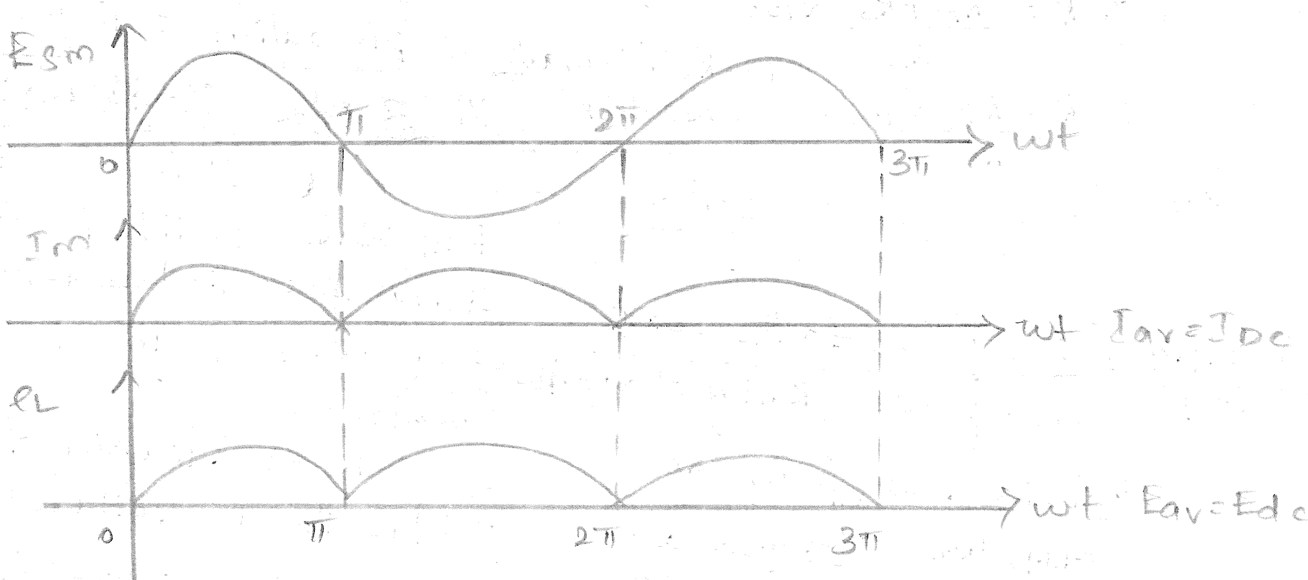
D_1 & D_2 → connected in series With Load & Current

In Negative Half cycle

B → +ve, D_3 & D_4 Diode – forward biased

D_1 & D_3 Diode – Reverse biased.

Diode D_3 & D_4 Conduct in Series with Load & current.



(i) Maximum Load current:

$$I_m = \frac{E_{sm}}{R_s + 2R_f + R_L}$$

$$E_{dc} = I_{dc} \cdot R_L \Rightarrow \frac{2E_{sm}}{\pi}$$

$$E_{rms} = \frac{I_m}{\sqrt{2}} R_L \Rightarrow \frac{E_{sm}}{\sqrt{2}(R_s + R_f + R_L)} \cdot R_L$$

$$P_{DC} = I_{DC}^2 R_L \Rightarrow \frac{4}{\pi^2} I_m^2 R_L$$

$$P_{AC} = I_{RMS}^2 [R_s + 2R_f + R_L]$$

$$= I_m^2 \left[\frac{2R_f + R_s + R_L}{2}\right]$$

$$\eta = \frac{8R_L}{\pi^2 [R_s + 2R_f + R_L]}$$

$$\% \eta_{max} = 81.2\%$$

$\gamma = 0.48$. T.U.F = 0.812

(ii) Advantages:-

a) No centre tap is required in the transformer secondary.

b) Transformer gets utilized effectively

c) As 2 Diodes conduct in series in each Half cycle, inverse voltage appearing across diode get shared. ckt for High voltage applica[tions]

d) current in both primary & secondary of power transformer flows for entire cycle & hence for a given power output, power transformer of small size & Less cost

(iii) Applications:- In power supply circuits, In Rectifier type Meter to convert a.c voltage to be measured to d.c, used as rectifier in power circuits to convert a.c to d.c.

Quns:- (*) Explain the working of Bridge Rectifier. Derive the expression for R.M.S. Current, PIV, ripple factor & efficiency. (16m)

(*) What are the Adv & Dis Adv of Bridge Rectifier. ~~(6m)~~ (10)

(*) Derive the expression for the Rectification efficiency, Ripple factor, Transformer Utilization factor, ~~form factor~~ and peak factor of Halfwave Rectifier. (8m)

(*) Draw and explain the Working of Halfwave Rectifier (6m)

(*) Draw and explain the Working of Full wave Rectifier & derive all the parameters. (6+10m).

Ans: [Above].
[May-10, Dec-11, Dec-02, Dec-06, May-12, May-14]

Sl.No	Parameter	Half Wave	Full Wave	Bridge Rectifier
1.	No. of diodes	1	2	4
2.	Ripple frequency	50HZ	100HZ	100HZ
3.	PIV rating of diode	E_{sm}	$2E_{sm}$	E_{sm}
4.	Avg D.C current (I_{DC})	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
5.	Avg D.C Voltage (E_{DC})	$\frac{E_{sm}}{\pi}$	$\frac{2E_{sm}}{\pi}$	$\frac{2E_{sm}}{\pi}$
6.	R.M.S current (I_{RMS})	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
7.	D.C power output (P_{DC})	$\frac{I_m^2 R_L}{\pi^2}$	$\frac{4}{\pi^2} I_m^2 R_L$	$\frac{4}{\pi^2} I_m^2 R_L$
8.	T.U.F	0.287	0.693	0.812
9.	A.C power output $P(AC)$	$\frac{I_m^2 (R_L+R_S+R_f)}{4}$	$\frac{I_m^2 (R_f+R_S+R_L)}{2}$	$\frac{I_m^2 (2R_f+R_S+R_L)}{2}$
10.	Maximum rectifier efficiency (η)	40.6%	81.2%	81.2%
11.	Maximum Load current (I_m)	$\frac{E_{sm}}{R_S+R_f+R_L}$	$\frac{E_{sm}}{R_S+R_f+R_L}$	$\frac{E_{sm}}{R_S+2R_f+R_L}$
12.	Ripple factor (γ)	1.21	0.482	0.482

Qn:- Compare all the parameters with the Bridge, Full Wave, Half Wave Rectifier. (6m)

Ans: [Above].

Problems [Rectifier]

(70) A 5kΩ load is fed from a **Bridge Rectifier** connected across a transformer secondary supply. The ratio of No. of primary turns to secondary turns is 2:1. Calculate d.c. load current, d.c. load voltage, ripple voltage and P.I.V. rating of diode.

Try it yourself

Given: $R_L = 5k\Omega$, $N_1:N_2 = 2:1$, $E_p = 460$

i) E_S :- $\frac{E_S}{E_p} = \frac{N_2}{N_1} \Rightarrow E_S = 230V$

ii) E_{Sm} :- $E_{Sm} = \sqrt{2} \times E_S = 325.269V$

iii) I_{DC} :- $I_{DC} = \frac{2I_m}{\pi}$, $I_m = \frac{E_{sm}}{R_L}$

$\therefore I_{DC} = 41.41mA$

iv) E_{DC} :- $E_{DC} = I_{DC} \times R_L \Rightarrow 207.07V$

v) Ripple factor :- $RP \times V_{DC} \Rightarrow 0.482 \times V_{DC}$

$\Rightarrow 99.8V$.

vi) PIV :- PIV = E_{sm} of Bridge

$= 325.25V$.

(71) A **Bridge Rectifier** is applied with input from a step down transformer having turns ratio 8:1 and input 230V, 50Hz. If the $R_f = 1\Omega$, $R_S = 10\Omega$ and $R_L = 2k\Omega$. find
(1) DC power output (2) PIV across each diode (3) % efficiency (4) % regulation at full load.

Soln :- $E_p(rms) = 230V$, $\frac{N_2}{N_1} = \frac{1}{8}$, $R_f = 1\Omega$, $R_S = 10\Omega$, $R_L = 2k\Omega$.

i) $\frac{E_p(rms)}{E_S(rms)} = \frac{8}{1} \Rightarrow E_S(rms) = 28.7V$

ii) $E_{Sm} = \sqrt{2}\, E_S(rms) = 40.6586V$

iii) $I_m = \frac{E_{sm}}{2R_f + R_S + R_L} = \frac{40.6586}{2\times1 + 10 + 2\times10^3}$

$I_m = 20.2mA$

iv) $I_{DC} = \frac{2I_m}{\pi} = 12.859mA$

(1) $P_{DC} = I_{DC}^2 R_L \Rightarrow (12.859\times10^{-3})^2 \times 2\times10^3 \Rightarrow 0.3307W$

(2) PIV = E_{Sm} = 40.6586V

(3) $P_{AC} = (I_{rms})^2 (2R_f + R_S + R_L)$

$= \left(\frac{I_m}{\sqrt{2}}\right)^2 (2R_f + R_S + R_L)$

$= \left(\frac{20.2\times10^{-3}}{\sqrt{2}}\right)^2 (2012) = 0.410W$

(4) $\%\eta = \frac{P_{DC}}{P_{AC}} \times 100 \Rightarrow 80.56\%$

(5) V_{DC} on No Load $= \frac{2E_{Sm}}{\pi} = 25.8840V$

V_{DC} on full load $= I_{DC} \cdot R_L \Rightarrow 25.718V$

% regulation $= \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$

$= 0.645\%$.

(72) A **Full Wave Rectifier** is fed from a transformer having a centre tapped secondary winding. The rms voltage from either end of secondary to centre tap is 20V. If the diode forward resistance is 3Ω and that of half secondary is 5Ω, for a load of 1kΩ calculate.

$R_L = 1k\Omega$

Soln :- $E_S = 20V$. $R_f = 3\Omega$. $R_S = 5\Omega$,

a) $E_{Sm} = E_S \times \sqrt{2} = 20\sqrt{2} = 28.2843V$

b) $I_m = \frac{E_{Sm}}{R_f + R_S + R_L} = \frac{28.2843}{3 + 5 + 1000} = 28.06 mA$

c) $I_{DC} = \frac{2I_m}{\pi} = \frac{2\times28.06}{\pi} = 17.8634m$

(i) Power delivered on Load :-

$= I_{DC}^2 R_L \Rightarrow [17.8634\times10^{-3}]^2 \times 100$

$= 0.3191W$.

(ii) % Regulation at full Load :-

$V_{NL} = \frac{2}{\pi} E_{Sm} \Rightarrow \frac{2}{\pi} \times 28.2843 = 18V$

$V_{FL} = I_{DC} R_L \Rightarrow 17.8634\times10^{-3} \times 1000$

$= 17.8634V$

% regulation $= \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$

$= \frac{18 - 17.8634}{17.8634} \times 100 \Rightarrow 0.8\%$

(iii) Efficiency at full load :-

$$\%\eta = \frac{D.C\ o/p}{A.C\ i/p} \times 100$$

$$= \frac{8}{\pi^2} \times \frac{1}{1+\frac{R_f+R_s}{R_L}} \times 100$$

$$= \frac{8}{\pi^2} \times \frac{1}{1+\left(\frac{3+5}{1\times10^3}\right)} \times 100 = 80.413\%$$

(iv) TUF of Secondary :-

$$= E_{rms} \cdot I_{rms} \Rightarrow 20 \times \frac{I_m}{\sqrt{2}}$$

$$= \frac{20\times28.06\times10^{-3}}{\sqrt{2}} = 0.3968\,W$$

$$\therefore TUF = \frac{Dc\ power\ o/p}{A.c\ Rating} = \frac{0.3191}{0.3968} = 0.8041$$

(13) In a Full Wave Rectifier a signal of 300V at 50Hz is Applied at the input. Each diode has an internal resistance of 800Ω. If the Load is 2000Ω. Calculate

Soln :- Assume centre tap FWR. Es(rms) = 300V, Rf = 800Ω, RL = 2000Ω

(i) $E_{sm} = \sqrt{2}\,E_s(RMS) = 300\sqrt{2}$ V

$$I_m = \frac{E_{sm}}{R_f+R_L} = \frac{300\sqrt{2}}{800+2000} = 0.1515A$$

(ii) $I_{DC} = \frac{2I_m}{\pi} = \frac{2\times0.1515}{\pi} = 96.46\,mA$

(iii) $P_{DC} = I_{DC}^2 R_L \Rightarrow [96.46\times10^{-3}]^2 \times 2000$

$= 18.61W$.

$$I_{RMS} = \frac{I_m}{\sqrt{2}} = \frac{0.1515}{\sqrt{2}} = 0.10712A$$

$$P_{AC} = I_{RMS}^2 (R_f+R_L)$$

$$= (0.10712)^2 \times 2800 = 32.13W$$

$$\%\eta = \frac{P_{DC}}{P_{AC}} \times 100 = \frac{18.61}{32.13} \times 100$$

$\%\eta = 57.9152\%$.

(14) A Diode has an internal resistance is 20Ω load from a 110V r.m.s source of supply calculate

Assume Halfwave

Soln :- $R_f = 20\Omega$, $R_L = 1000\Omega$ $E_s(rms) = 110V$.

(i) Efficiency of rectification :-

$$E_{sm} = \sqrt{2}\times(E_s)_{rms} = \sqrt{2}\times110 = 155.563V$$

$$I_m = \frac{E_{sm}}{R_f+R_L} = \frac{155.563}{[20+1000]} = 0.1525A$$

$$I_{DC} = \frac{I_m}{\pi} = \frac{0.1525}{\pi} = 48.54A$$

$E_{DC} = I_{DC} \times R_L$ on full Load

$= 0.04854 \times 1000 \Rightarrow 58.54V.$

$$\eta = \frac{4}{\pi^2} \times \frac{1}{\left[1+\frac{R_F}{R_L}\right]} = \frac{4}{\pi^2} \times \frac{1}{\left(1+\frac{20}{1000}\right)}$$

$\eta = 0.3973 \Rightarrow 39.73\%$

(ii) Ripple Factor :- = 1.21 as HWR.

(iii) % Regulation from No Load to full Load :-

No Load d.c. Voltage, $(E_{DC})_{NL} = \frac{E_{sm}}{\pi}$

$$= \frac{155.563}{\pi} = 49.5172V$$

$$\therefore \text{Voltage Regulation} = \frac{(E_{DC})_{NL} - (E_{DC})_{FL}}{(E_{DC})_{FL}}$$

$$= \frac{49.5172-48.54}{48.54} \times 100 = 2.013\%$$

(15) A Step down transformer having turns ratio 10:1 and input 230V, 50Hz is used in a Half-wave rectifier. The diode forward resistance is 15ohms. and resistance of Secondary winding is 10 ohms. for a Load resistance of 4kohms, calculate avg and rms value of Load current and Voltage, rectification efficiency and ripple factor.

Soln :- $N_1 : N_2 = 10:1$ $R_f = 15\Omega$, $R_s = 10\Omega$

$R_L = 4k\Omega$. $E_p(RMS) = 230V$.

$$\frac{N_1}{N_2} = \frac{E_p(RMS)}{E_s(RMS)} \quad (i.e)\ \frac{10}{1} = \frac{230}{E_s(RMS)} = 23V$$

$$\therefore E_{sm} = E_s(RMS) \times \sqrt{2} = 23\times\sqrt{2}$$

$= 32.5269V$

$$\therefore I_m = \frac{E_{sm}}{R_f+R_s+R_L} = \frac{32.5269}{15+10+4\times10^3} = 8.0812\,mA$$

$$\therefore I_{av} = I_{DC} = \frac{I_m}{\pi} = \frac{8.0812}{\pi} = 2.5723\,mA$$

$$\therefore I_{RMS} = \frac{I_m}{2}(\text{Halfwave}) = \frac{8.0812}{2}$$

$= 4.0406mA$

$$\therefore E_{DC} = I_{DC} \cdot R_L = 2.5723\times10^{-3}\times4\times10^3$$

E_{RMS} = R.M.S. Value of o/p Voltage

$= I_{RMS} \cdot R_L \Rightarrow 16.1624V$

$\gamma = 1.21$

HALF WAVE RECTIFIER POWER SUPPLY :

(i) CAPACITOR FILTER CIRCUIT :

→ When a sinusoidal alternating voltage is rectified, the resulting waveform is a series of positive or negative half cycles of the input waveform, it is not direct voltage.
To convert to direct voltage, a smoothening circuit or filter is needed.

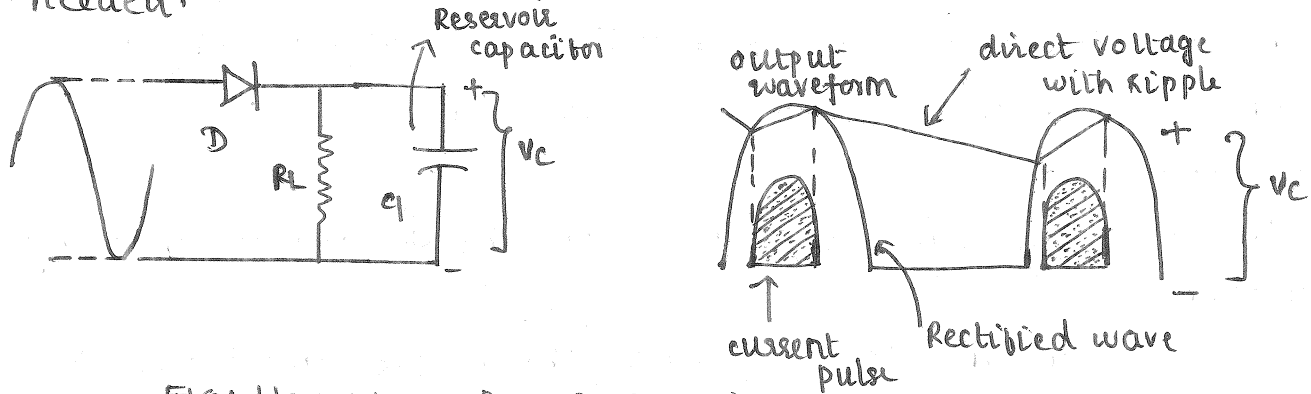


Fig 1: HALFWAVE RECTIFIER WITH OUTPUT WAVEFORM

Fig. consists of a single capacitor filter (C1) and a load resistor (RL). The capacitor termed as a reservoir capacitor is charged almost to the peak level of the circuit input voltage when the diode is forward biased. This occurs at V_{pi} as shown in below Fig:

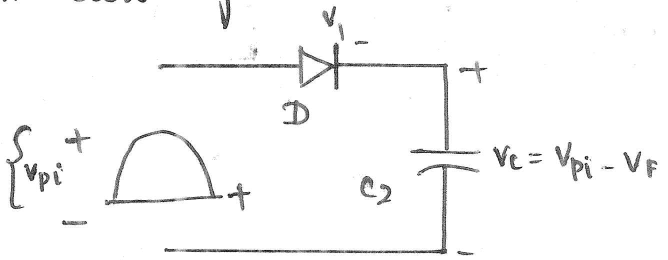


Fig. C1 charged to $V_{pi} - V_F$

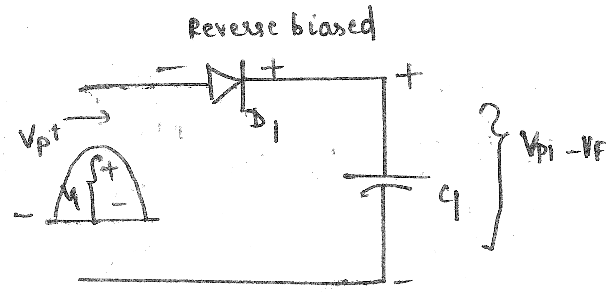


Fig. D1 is reverse biased when V_i falls below V_{pi}

→ The peak capacitor voltage $\boxed{V_C = V_{pi} - V_F}$

→ When the instantaneous level of the input falls below V_{pi} the diode becomes reverse biased.

→ The capacitor begins to discharge through the load resistor (RL) when the diode is reverse biased. So V_c falls slowly as shown by the capacitor voltage in the Fig 1.

→ The diode remains reverse biased throughout the rest of the positive half cycle.

→ Current flows through the diode to recharge the capacitor at this point, causing the capacitor to reach $(V_{pi} - V_F)$.

→ The circuit output is then a direct voltage with a small ripple waveform superimposed.

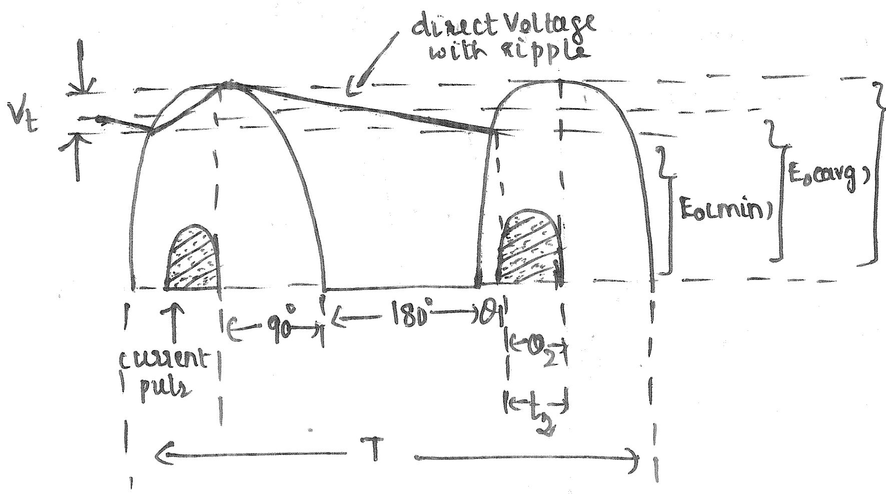
RIPPLE AMPLITUDE AND CAPACITANCE:

→ The amplitude of the ripple voltage is affected by three parameters. such as reservoir capacitor value, load current and capacitor discharge time.

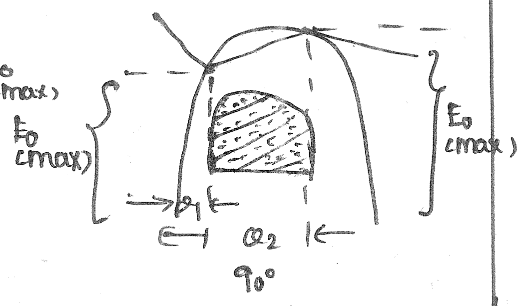
→ The discharge time depends upon the frequency of ripple waveform.

→ With a constant load current, the ripple amplitude is inversely proportional to the capacitance.

→ The reservoir capacitor value can be calculated from load current ripple amplitude and the capacitor discharge time.



CAPACITOR WAVEFORM AMPLITUDES ANGLES & TIMES



RELATIONSHIP B/W $E_o(max)$ & $E_o(min)$

The waveform parameters are:

a) E_{ave} = average dc o/p voltage
b) $E_o(max)$ - maximum o/p voltage
c) $E_o(min)$ - minimum o/p voltage
d) T - time period of ac i/p waveform
e) V_r - ripple voltage p-to-p amplitude
f) t_1 - capacitor discharge time
g) t_2 - capacitor charge time
h) θ_1 - phase angle of i/p from 0 to $E_o(min)$
i) θ_2 - Phase angle of i/p from $E_o(min)$ to $E_o(max)$.

RELATIONSHIP BETWEEN $E_{o(max)}$ and $E_{o(min)}$:

Since the input wave is sinusoidal,

$$E_{o(min)} = E_{o(max)} \sin\theta_1$$

which gives $\theta_1 = \sin^{-1} \frac{E_{o(min)}}{E_{o(max)}}$

$$\theta_2 = 90^\circ - \theta_1$$

Time period, $T = \frac{1}{f}$ where f = frequency of ac i/p waveform

t in degree $\Rightarrow$ $t/\text{degree} = \frac{T}{360^\circ}$

$$t_2 = \frac{\theta_2 T}{360^\circ}$$

and $t_1 = T - t_2$

Taking current as constant,

$$C = \frac{I_L t_1}{V_r}$$

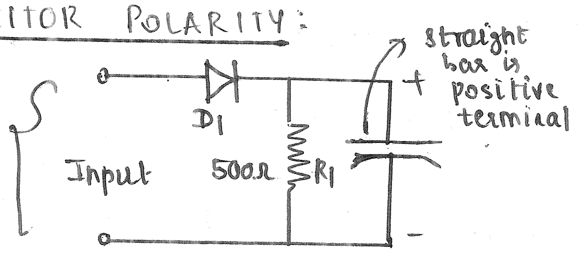
CAPACITOR SELECTION:

→ Large standard value capacitor is always selected in case of a reservoir capacitor.

→ The standard value capacitors are available with ±20% tolerance. capacitors of more than 10μF, the tolerance is −10% to +50%.

→ The dc working voltages can be quite small for large value capacitors. Else capacitor dielectric may breakdown.

CAPACITOR POLARITY:



If the capacitors are incorrectly connected, polarized capacitors explode. This have tragic consequences for the eyes of an experimenter.

The positive terminal is represented by straight bars on the component graphic symbol. This should be connected to the positive point in the circuit.

APPROXIMATE CALCULATION:

APPROXIMATION 1:

(i) Assume the load current is constant.

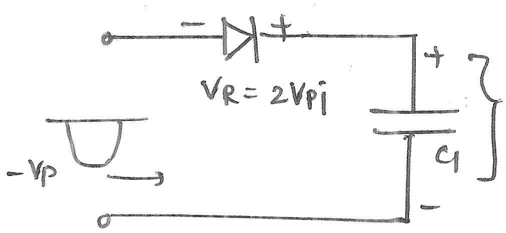
(ii) Normally, the load current changes by small that it has no significant effect on the calculation.

APPROXIMATION 2:

Discharge time (t_1) is approximately equal to the input waveform time period (T) $\boxed{t_1 = T}$

DIODE SPECIFICATION:

The selected diodes must be able to survive higher levels.



The diode has $-V_P$ at anode and $+V_P$ at cathode, so diode peak reverse voltage is

$$V_R \approx 2V_P$$

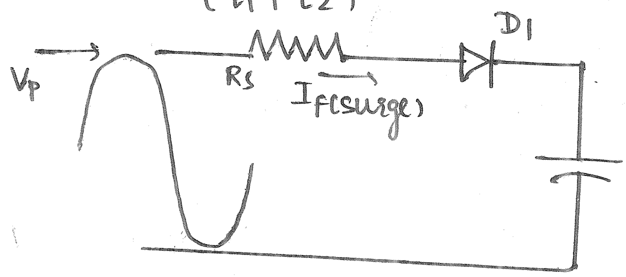
The average forward current that a diode pass is equal to the dc output current.

$$I_{F(av)} = I_L$$

The diode of a halfwave rectifier with a reservoir capacitor does not conduct continuously but repeatedly passes pulses of current to recharge the capacitor. each time the diode becomes forward biased. So the current pulse is known as repetitive surge current and is designated as I_{FRM}.

I_{FRM} over time period T must be equal to I_L.

$$I_L = \frac{I_{FRM} \times t_2}{(t_1 + t_2)} \implies I_{FRM} = \frac{I_L (t_1 + t_2)}{t_2}$$



SURGE LIMITING RESISTOR (R_S) IN A HWR

The purpose of a low resistance surge limiting resistor (R_s) connected in series with the diode D_1 is to limit the level of any surge current that might pass through the diode. If switch-on occurs, the ac current is,

$$I_{F(surge)} = \frac{V_p}{R_s}$$

$$\Rightarrow \boxed{R_s = \frac{V_P}{I_{FSM}}}$$ when $I_{F(surge)}$ is maximum (I_{FSM})

TRANSFORMER SELECTION:

A power supply transformer is normally defined in terms of rms input and output voltage and current. The input is usually 115V, 60Hz supply and the transformer peak output voltage is calculated by adding the rectifier voltage drop to the power supply peak output.

The peak voltage is converted into rms to give the secondary value.

$$V_{s(rms)} = 0.707 \, (E_{o(max)} + V_F)$$

for a HWR with resistive load, $I_{rms} = 2.2 \, I_{L(dc)}$.

for a HWR with capacitive filter, $I_{L(dc)} = 0.28 \, I_{s(rms)}$

$$\Rightarrow I_{s(rms)} = 3.6 \, I_{L(dc)}.$$

The transformer primary current is

$$\boxed{I_{p(rms)} = \frac{V_{s(rms)} \times I_{s(rms)}}{V_{p(rms)}}}$$

(8M) (X)

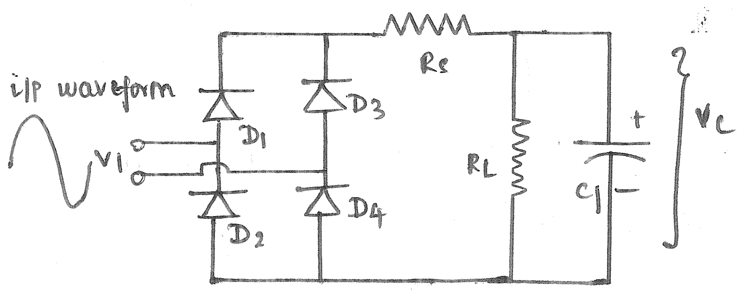
Qn: Give a detailed account on half wave rectifier power supply with necessary specifications and selections.

* FULL WAVE RECTIFIER POWER SUPPLY: (Qn) (X)

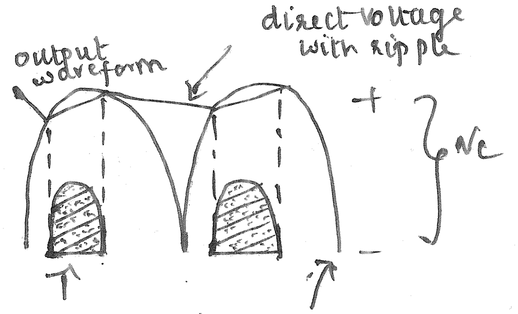
Qn: Explain in detail about the full wave rectifier power supply with necessary waveforms and diagram.

→ Full wave rectifiers require filter circuits to convert the output waveform to direct voltage.

→ It also consists of a reservoir capacitor and a surge limiting resistor which operates exactly similar to half wave rectifier circuit with few important exceptions.



RECTIFIER WITH RESERVOIR CAPACITOR



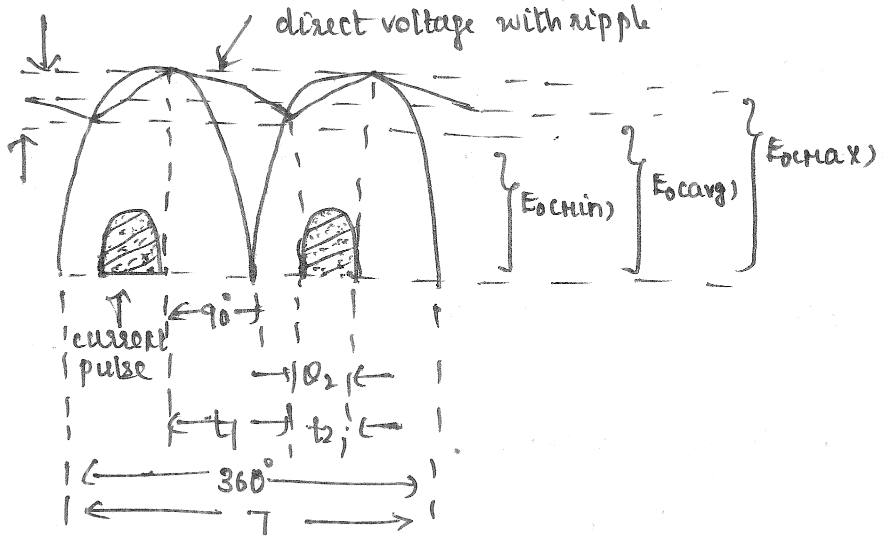
WAVEFORMS

$$\theta_1 = \sin^{-1}\frac{E_{o(min)}}{E_{o(max)}}$$

$$\theta_2 = 90° - \theta_1$$

} similar to HWR

and time $t_2 = \frac{\theta_2 T}{360°}$



WAVEFORM FOR ANGLES & TIMES

It is seen that the capacitor discharge time for a HWR is equal to the waveform time period (T), whereas for a FWR, it equals T/2

$$t_1 = T/2 - t_2$$

Using the correct value of a reservoir capacitance for a full wave rectifier can be calculated from

$$C = \frac{I_L t_1}{V_T}$$

Similarly, the repetitive current I_{FRM} can be determined as

$$I_{FRM} = \frac{I_L (t_1 + t_2)}{t_2}$$

The diode average current is equal to the half the load current

$$I_{F(ave)} = \frac{I_L}{2}$$

Another difference between FWR and HWR power supply circuits concerns the reverse voltage applied to the diode. When the instantaneous input voltage is $+V_P$, the reverse biased voltage across D_3 is $V_R = V_P - V_F$

or $V_R \simeq V_P$

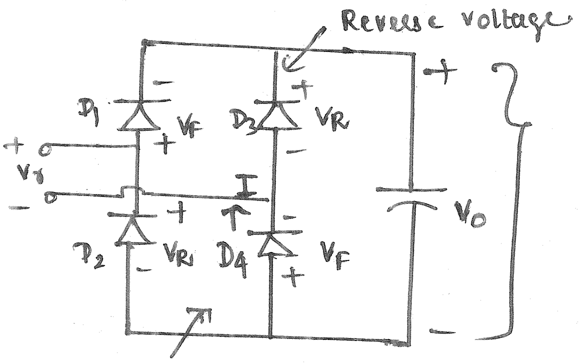


Fig: DIODE REVERSE VOLTAGE FWR CIRCUIT

TRANSFORMER SELECTION:

The transformer specification for a FWR is similar to the HWR. Two diode voltage drops involved in calculating the secondary rms voltage.

$$V_{S(rms)} = 0.707 (E_{o(max)} + 2V_F)$$

For a FWR with capacitive filters, $I_{L(dc)} = 0.62 I_{S(rms)}$

As with all transformers, the primary current is

$$I_{P(rms)} = \frac{V_{S(rms)} \times I_{S(rms)}}{V_{P(rms)}}$$

⊛ VOLTAGE REGULATORS:

→ A rectifier with appropriate filter requires a good dc power supply. The main disadvantage is that the dc output voltage changes with change in the input voltage or load current. since the dc output voltage is not constant, this type of power supply is called unregulated power supply.

→ In order to ensure a constant voltage supply regardless of the variations in input voltage or current, a voltage stabilization device called voltage regulators are used.

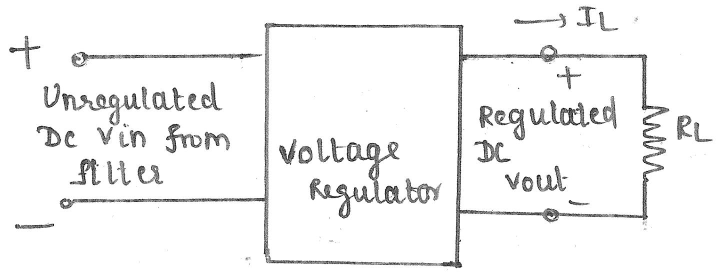
→ The voltage regulator circuit keeps the output voltage constant inspite of the changes in load current or input voltage.

(I) Qn: Define voltage Regulator (2M) ⓧ

A voltage regulator is a device designed to keep the output voltage of a power supply as nearly as constant as possible.

(I) BLOCK SCHEMATIC OF REGULATED POWER SUPPLY.

Qn: Sketch and explain the block schematic of regulated power supply ⓧ (6M)



The input to a voltage regulator is an unregulated dc supply while the output is regulated dc output voltage Vout which is almost constant.

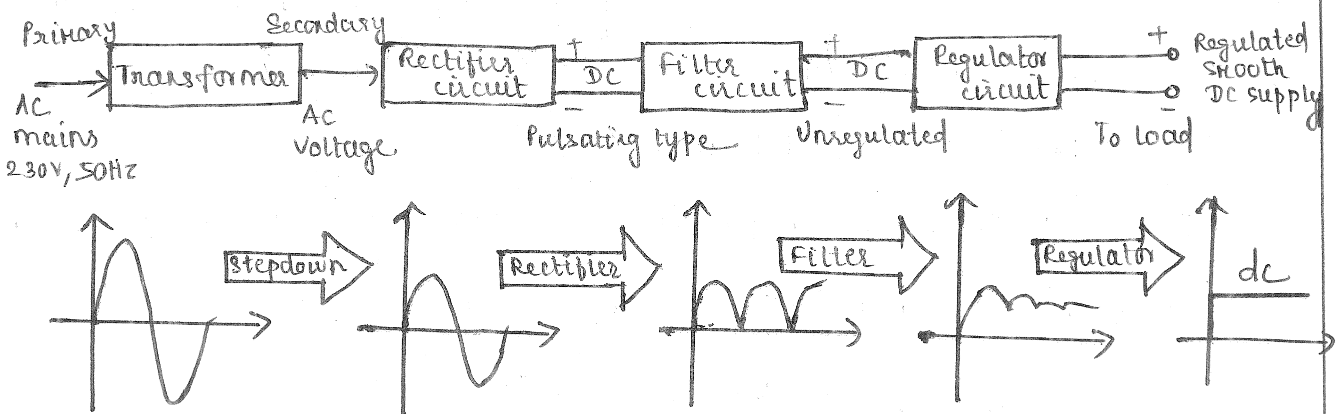


Fig. BLOCK SCHEMATIC OF RPS WITH WAVEFORMS

→ The transformer steps down the ac voltage inputs, to the level required for the desired dc output.

→ The rectifier converts this ac voltage into a pulsating dc voltage containing ripples in it.

→ Then the filter circuit reduces the ripple content and tries to make it smoother.

→ Still then the filter o/p contains some ripple. called unregulated dc voltage.

→ Then the regulator circuit is used to make the output dc voltage constant. The output is called dc voltage to which the load can be connected.

(II) POWER SUPPLY PERFORMANCE PARAMETERS / CHARACTERISTICS OF VOLTAGE REGULATORS:

Qn: Explain the significance of power supply performance of a dc series regulator (6M) or (8M).

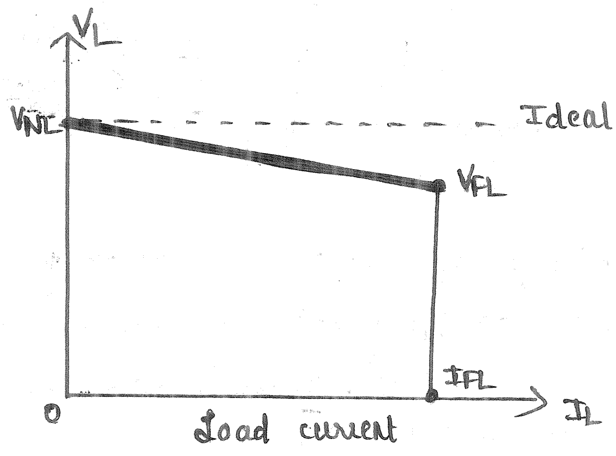
(i) LOAD REGULATION:

The load regulation can be defined as the change in the regulated output voltage when the load current changes from minimum to maximum.

$$\text{Load Regulation} = V_{NL} - V_{FL}$$

V_{NL} - No load voltage & V_{FL} - Full load voltage

$$\%\ \text{load regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$



(ii) LINE REGULATION (SOURCE REGULATION) :

The line regulation can be defined as the change in regulated load voltage for a specified range of line voltage.

$$\text{Line Regulation} = V_{HL} - V_{LL}$$

V_{HL} - High Line load voltage V_{LL} - Low Line load voltage

$$\%\ \text{Line Regulation} = \frac{V_{HL} - V_{LL}}{V_{nominal}} \times 100$$

$$= \frac{\Delta V_{out}}{\Delta V_{in}} \times 100\%$$

(iii) OUTPUT RESISTANCE :

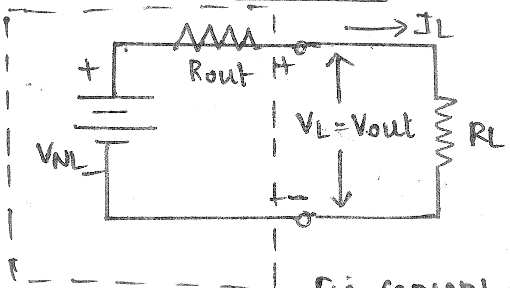


Fig. Concept of Rout

When no load is connected to output terminal, the current I_L is zero. Hence $V_L = V_{NL}$.
When load R_L is connected,

$$V_L = V_{out} = V_{NL} - I_L R_{out}$$

Practically, Rout is very small in the range of milliohms. The value of Rout is obtained from the slope of load regulation characteristics. (Refer Load Regulation topic graph).

$$R_{out} = \frac{\Delta V_{out}}{\Delta V_L}\Bigg|_{V_{in}\text{ and Temperature constant}}$$

(iv) VOLTAGE STABILITY FACTOR (S_V) :

S_V is the percentage change in the output voltage which occurs per volt change in the input line voltage with load current and temperature as constant. Smaller the SV, better the performance of power supply.

$$S_V = \frac{\Delta V_{out}}{\Delta V_{in}}\Bigg|_{I_L\text{ and Temperature constant}}$$

(v) TEMPERATURE STABILITY FACTOR (S_T) :

The temperature stability of a power supply will be determined by temperature coefficients of various semiconductor devices.

$$S_T = \frac{\Delta V_{out}}{\Delta T}\Bigg|_{V_{in}\ \&\ I_L\text{ constant}}$$

This should be as small as possible.

(vi) RIPPLE REJECTION:

The output of a rectifier consists of ripples. So ripple rejection is a factor which indicates how effectively the regulator circuit rejects the ripples and attenuates it from input to output. If V_R is the ripple voltage then RR is given by

$$RR = \frac{\text{Ripple in output}}{\text{Ripple in input}} = \frac{V_{R(out)}}{V_{R(in)}}$$

In decibels, $RR' = 20 \log_{10} RR \text{ dB}$

As $V_{R(out)}$ is always less than $V_{R(in)}$, RR' ie RR in dB is always negative when defined as $V_{R(out)}/V_{R(in)}$.

(vii) TOTAL CHANGE IN OUTPUT VOLTAGE:

If input voltage, load current and temperature are affecting the regulator output voltage, then the total change in output voltage is $\Delta V_0 = S_V \Delta V_{in} + R_0 \Delta I_L + S_T \Delta T$

(III) LINEAR / BASIC VOLTAGE REGULATOR:

The basic voltage regulator consists of:

(i) Voltage reference, V_R (ii) Error amplifier
(iii) Feedback network (iv) Active series (or) shunt control element.

→ The voltage reference generates a voltage level which is applied to the comparator circuit, which is generally an error amplifier.

→ The second input to the error amplifier is from the feedback network.

→ The error amplifier converts the difference between the output voltage and the reference voltage into the error signal.

→ This error signal then converts the active element of the regulator circuit, in order to compensate the change in output voltage.

→ Transistor is used as an active element. Thus the output voltage is maintained constant.

(IV) TYPES OF VOLTAGE REGULATORS:

Qn: Explain with the block diagrams, the basic types of voltage regulator circuits (8M) (or) (13M) (-X)

There are two types of voltage regulators available, namely,

(i) series voltage Regulator
(ii) Shunt Voltage Regulator

(i) SERIES VOLTAGE REGULATOR:

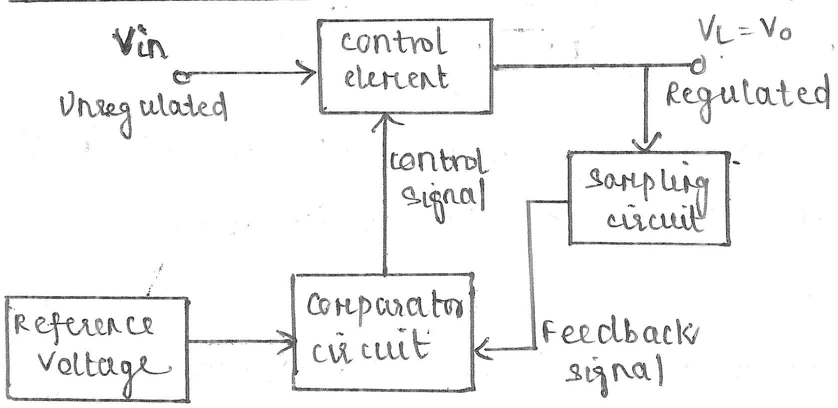


Fig: BLOCK DIAGRAM OF SERIES VOLTAGE REGULATOR

→ If in a voltage regulator circuit, the control element is connected in series with the load, the circuit is called series voltage regulator circuit.

→ The unregulated dc voltage is the input to the circuit. The control element controls the amount of input voltage, then gets to the outputs.

→ The sampling circuit provides the necessary feedback signal.

→ The comparator circuit compares the feedback with the reference voltage to generate the appropriate control signal.

→ If V_o decreases due to increased load, then error detector produces an output that causes the control element to increase V_o.

→ Similarly, any tendency of V_o to increase, results in a signal that causes the control element to reduce V_o.

① TRANSISTOR SERIES REGULATOR (OR) EMITTER FOLLOWER SERIES VOLTAGE REGULATOR:

(6M) (X)

Qn: Draw a neat circuit diagram of an emitter follower series voltage regulator circuit.

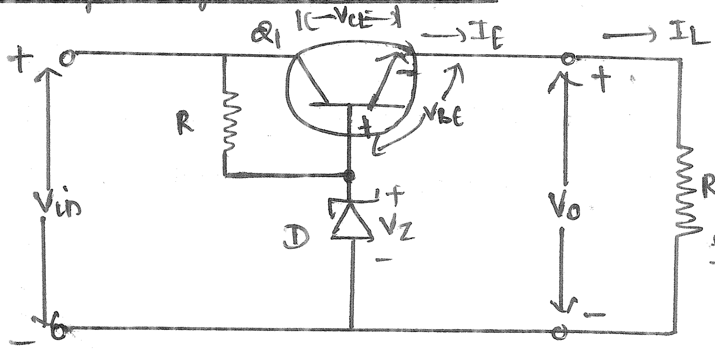


Fig. EMITTER FOLLOWER SERIES VOLTAGE REGULATOR

→ The basic series voltage regulator is called emitter follower series voltage regulator. This is employed to overcome the limitation of shunt regulator (Next topics).

→ The transistor Q_1 is the series control element while the zener diode D is the reference voltage provider.

→ The zener diode is reverse biased, so that it works in the breakdown region. Zener is connected in the base of Q_1 while the emitter of Q_1. The base emitter junction is always forward biased.

OPERATION:

From the fig, $\boxed{V_o = V_Z - V_{BE}}$

Apply KVL to the input side,

$$V_{in} = V_{CE} + V_o$$

$$\boxed{V_{CE} = V_{in} - V_o}$$

For transistor Q_1, $I_E = I_B + I_C$

$\because$ I_B is very small, $I_E \simeq I_C$.

$$I_E \simeq I_C = I_L$$

Now $I_B = \frac{I_C}{\beta} = \frac{I_L}{\beta}$

where I_Z = zener current & I_R = current through R.

$$I_Z = I_R - I_B$$

The load current, $\boxed{I_L = V_o/R_L}$

EXPRESSION FOR VOLTAGE STABILITY FACTOR (S_V):

The voltage stability factor for emitter follower series regulator is given by

$$S_V = \frac{R_Z}{R + R_Z}$$

where R_Z = ac resistance or dynamic resistance

The value of R_Z is very small and by selecting the large value of resistance R, S_V can be reduced. Its ideal value is zero (0).

EXPRESSION FOR OUTPUT RESISTANCE:

The output voltage R_o can be defined as the ratio of applied voltage V to current I. For emitter follower SVR,

$$R_o = \frac{V}{I} = \frac{R_Z + h_{ie}}{1 + h_{fe}}$$

It can be reduced by selecting a transistor with high value of h_{fe}.

DISADVANTAGES OF EMITTER FOLLOWER SERIES VOLTAGE REGULATOR:

(i) The changes in V_{BE} and V_Z due to changes in temperature appear at the output.

(ii) Due to large power dissipation, heat sink is necessary which makes the circuit bulky.

(b) OP-AMP BASED VOLTAGE SERIES REGULATOR:

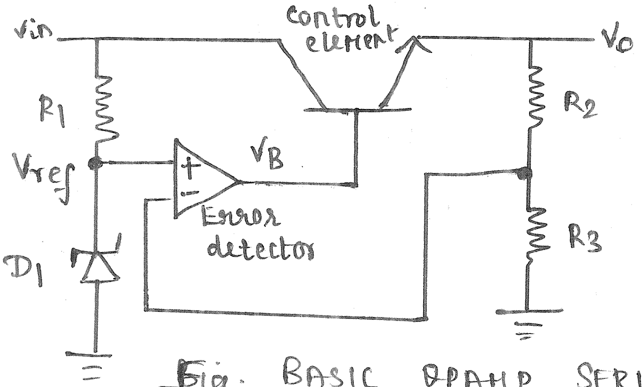


Fig. BASIC OPAMP SERIES VOLTAGE REGULATOR

REGULATING ACTION:

→ The resistive voltage divider formed by R_2 and R_3 senses any change in the output voltage.

→ When the output tries to decrease, due to increase in load current I_L caused by a decrease in R_1, a proportioned voltage decrease is applied to the op-amps inverting input by the voltage divider.

→ The small difference voltage (error voltage) is developed across the opamp's input.

→ This difference voltage is amplified, and the opamp's output voltage V_B increases.

→ This causes Vout to increase until the voltage to the input again equal to the reference voltage.

The closed loop gain $\boxed{A_{CL} = 1 + \frac{R_2}{R_1}}$.

(ii) SHUNT VOLTAGE REGULATOR:

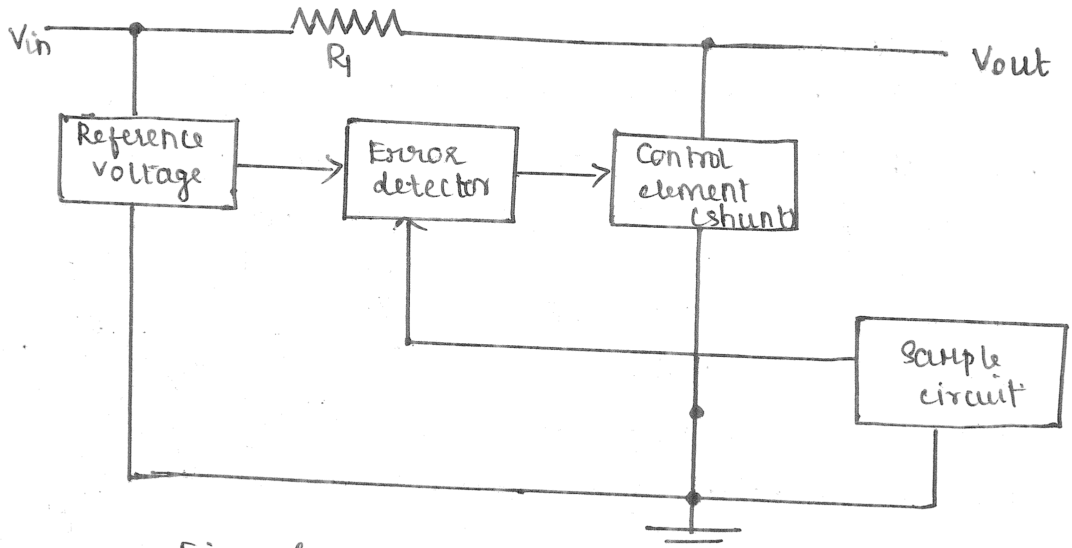


Fig: BLOCK DIAGRAM OF SHUNT REGULATOR.

→ If the control element is connected in parallel with the load, then the regulator circuit is called shunt voltage regulator.

→ The operation of the circuit is similar to that of series regulator, except that regulation is achieved by controlling the current through parallel transistor Q_1.

(a) TRANSISTOR SHUNT REGULATOR: (6M) (X)

Qn: Draw and explain transistor shunt regulator.

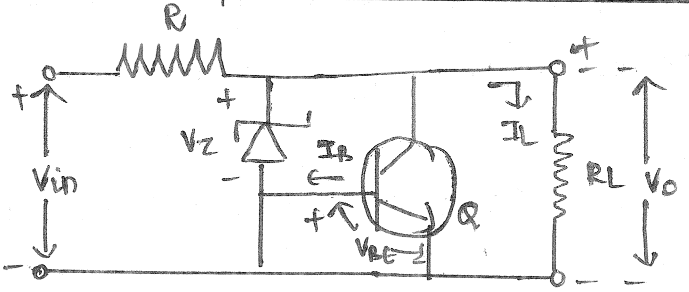


Fig: TRANSISTOR SHUNT REGULATOR

→ A transistor is used as a control element and is being connected in shunt or parallel with the load.

→ The output or load voltage is equal to the sum of zener voltage V_Z and the base emitter voltage V_{BE} of the transistor.

$$V_O = V_Z + V_{BE}$$

REGULATING ACTION:

→ Assume that the unregulated input voltage increases. Due to this, the load voltage V_L also increases.

→ As a result collector current of the transistor I_C also increases.

→ This causes the input current I_i to increase, which inturn increases the voltage drop across the series resistance R. consequently load voltage decreases.

→ It is valid because of the voltage drop across series resistance V_R and the load voltage is equal to the input voltage at all times.

$$V_i = V_R + V_L$$

Flow diagram:

$V_i \uparrow \rightarrow V_L \uparrow \rightarrow V_{BE} \uparrow \rightarrow I_B \uparrow I_C \uparrow \rightarrow V_R \uparrow V_L \uparrow$

Switching Regulator:

The operating principle of switching regulator is completely different than that of linear regulator. Switching regulator requires an external transistor and a choke. The series pass transistor in such a regulator is used as a controlled switch and is operated in cut off region (or) saturation region. Hence the power transmitted across such a transistor is in the form of discrete pulses rather than a steady flow of current.

When the transistor is operated in the cut off region there is no current and dissipated no power. while when it is operated in the saturation region a negligible voltage drop appears across it and hence dissipated very small power. provided max current to load.

Therefore switching regulators uses the fact that if duty cycle of the pulse waveform is varied, the average value of the voltage also changes proportionally.

$$\text{Duty cycle } \delta = \frac{t_{on}}{t_{on}+t_{off}} = \frac{t_{on}}{T} = t_{on} f$$

t_{on} - On time of pulse ; t_{off} - off time of pulse.

The basic switching regulator consists of four major components

(a) Voltage source

(b) Switching transistor

(c) Pulse generator

(d) Filter.

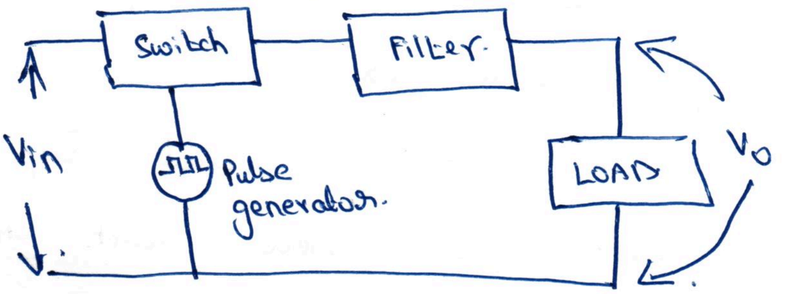


fig. Basic switching regulator

Switched Mode Power Supply :- (SMPS)

A power Supply is an important element of any type of electronic circuit. It provides the Supply for the proper operation of circuit. The Successful operation of the cir depends on the proper functioning of the power Supply. Mos of the electronic circuits requires a smooth dc voltage as that of batteries. The power Supply in a circuit tries to provides such a constant voltage.

The regulator in a power Supply is an important unit which keeps the output dc voltage Constant under the variable load and variable input Condit

Need of Switched mode power Supply :-

A linear regulator power supply has following limitations

a) The required input step down transformer is bulky and expensive.

b) Due to low line frequency, large values of filter Capacitor are required.

c) The efficiency is very low

d) As large is the difference between input and output voltage more is the power dissipation in the series pass transistor.

e) The need for dual Supply is not economical and feasible to achieve with the help of linear regulators.

To overcome all these limitations SMPS are needed.

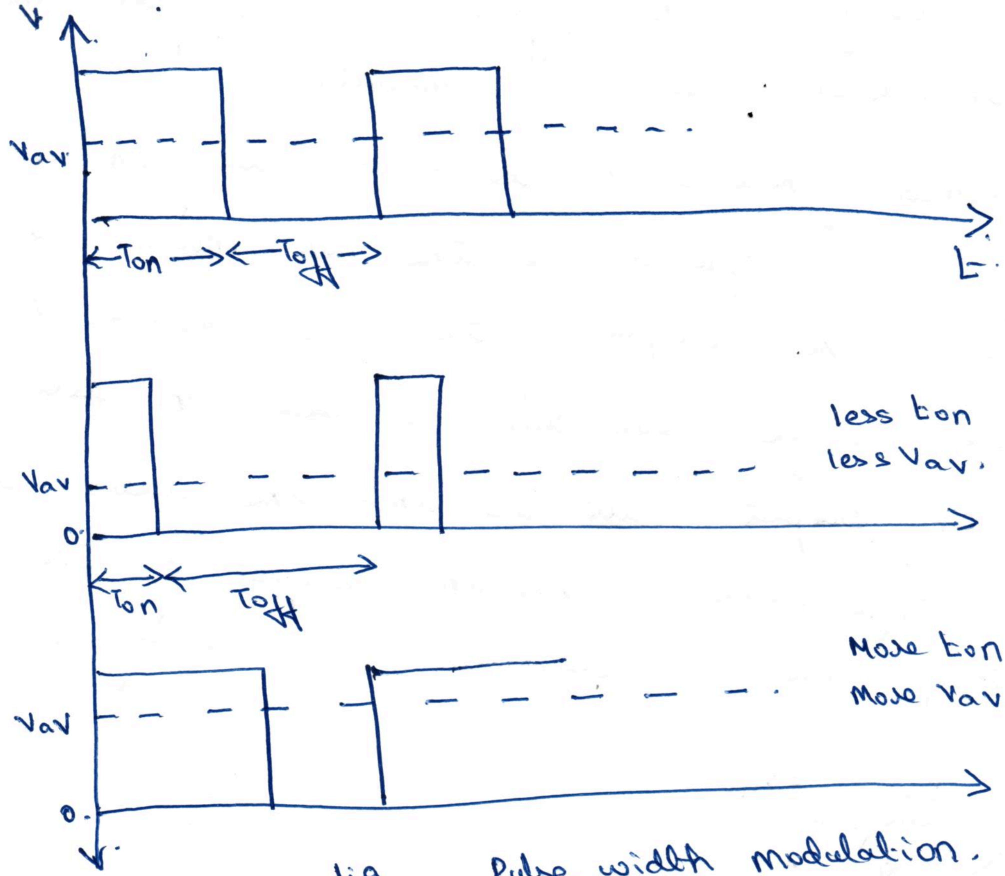


fig. Pulse width modulation.

The switch is generally a transistor. The pulse generator output makes it ON or OFF. The pulse generator produces a required pulse waveform. The most effective range of pulse waveform frequency is 20 kHz. and the most commonly used filter is RLC.

Switching Voltage Regulator :-

The block diagram of basic switching voltage regulator which uses transistor Q as a switch is shown in next page.

Working :-

The part R_2/R_1+R_2 of the output is fed back to the inverting input of error amplifier. it is comp with the reference voltage. The difference is amplified and given to the comparator inverting terminal.

The Oscillator generates a triangular waveform at a fixed frequency. It is applied to the non-inverting terminal of the Comparator. The output of the Comparator is high when the triangular voltage waveform is above the level of the error amplifier output. due to this the transistor Q remains in cutoff state. Thus the output of the Comparator is nothing but a required pulse waveform.

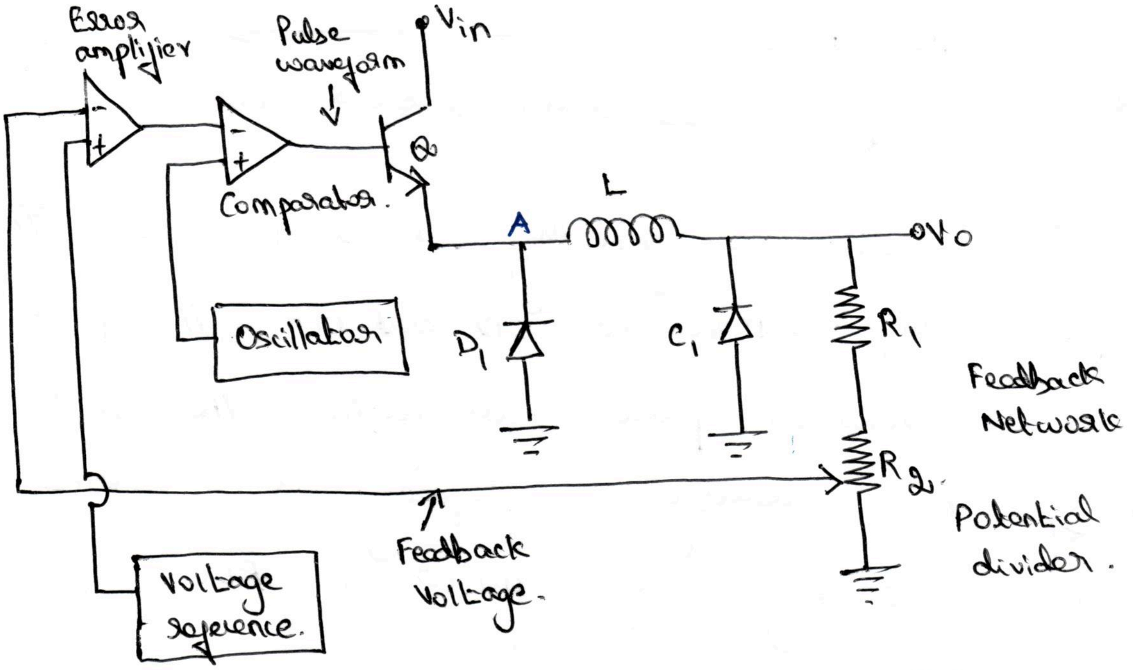


fig. Block diagram of switching regulator.

The period of the pulse waveform is same as that of oscillator output say T. The duty cycle is denoted as $\delta = t_{on}/T$. This duty cycle is controlled by difference between the feedback voltage and reference voltage.

when Q is on in saturation state, the entire input voltage Vin appears at point A. This current flows throug inductor.

when Q is off, L_1 still continue to supply current through itself to the load. The diode D_1 provide the return path for the current. The Capacitor C_1 act to smooth out the voltage and the voltage at the output is almost dc in nature. The output voltage V_0 expressed mathematically as

$$V_0 = \frac{t_{on}}{T} V_{in} = \delta V_{in}.$$

The range of operating frequency to get max efficien(cy) is 10 to 50 kHz.

Types of Switching Regulators:-

The switch mode regulators use an inductor and there is no input to output isolation. On the ~~otherhand~~ otherside Converters use transformer and may provide input to output isolation.

There are three basic Configurations of switching regulators.

1. step down (OR) Buck Switching regulator
2. step up (OR) Boost Switching regulator
3. Inverting type switching regulator.

1. Step down Switching regulator :- (Buck)

It Consists of inductor L and series transistor Q which act as a switch. The reference for error amplifier is provided by zener voltage V_Z. The output is fed back to error amplifier through potential divider. The pulse width oscillator controls the operation of Q as

ON or OFF depending on the load requirement.

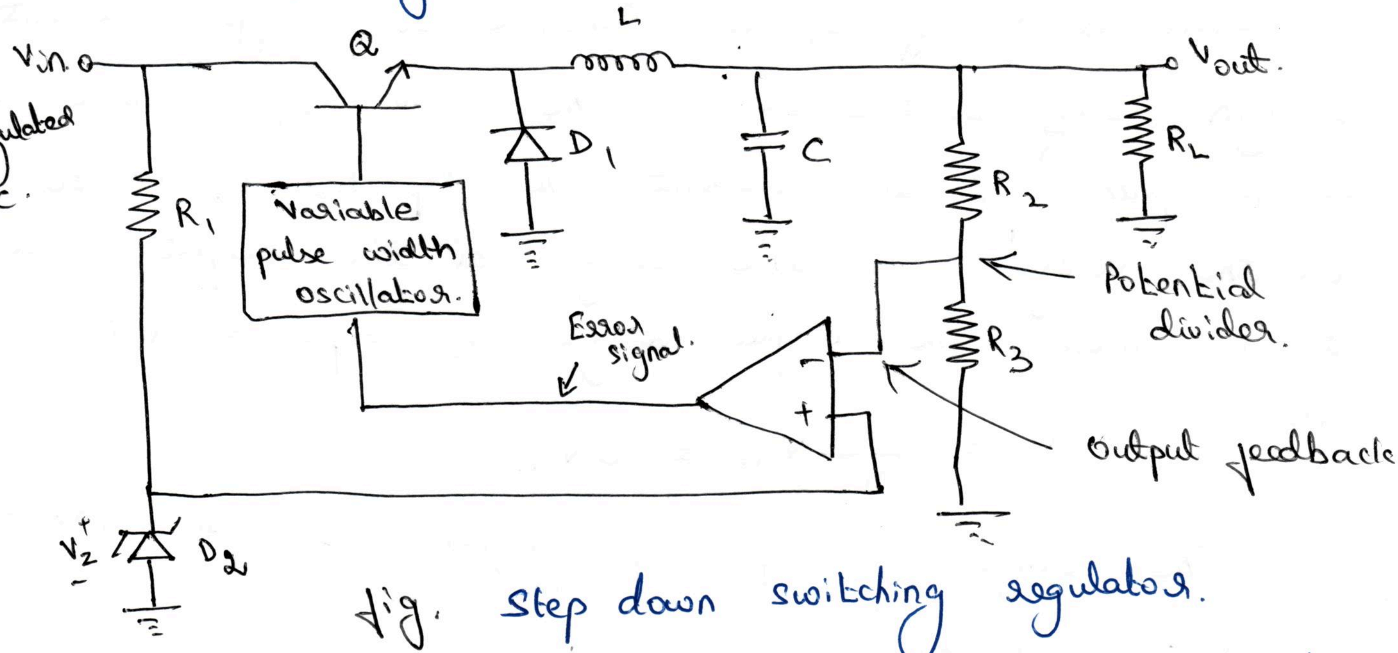
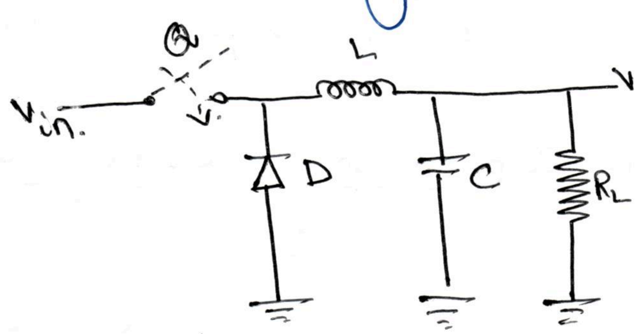


fig. Step down switching regulator.

The transistor Q is used for switching the input voltage for the required period of time, which is dependent on load current requirement. The L-C filter averages the switched voltage.

<u>Working</u>:-

The variable pulse width oscillator controls ON/OFF periods of Q. when ON time is more compared to OFF time the capacitor charges more increasing the output voltage. on the other hand when OFF time is more compared to ON time the capacitor discharge more, reducing output voltage. Thus adjusting the duty cycle δ of transistor the output voltage can be regulated.

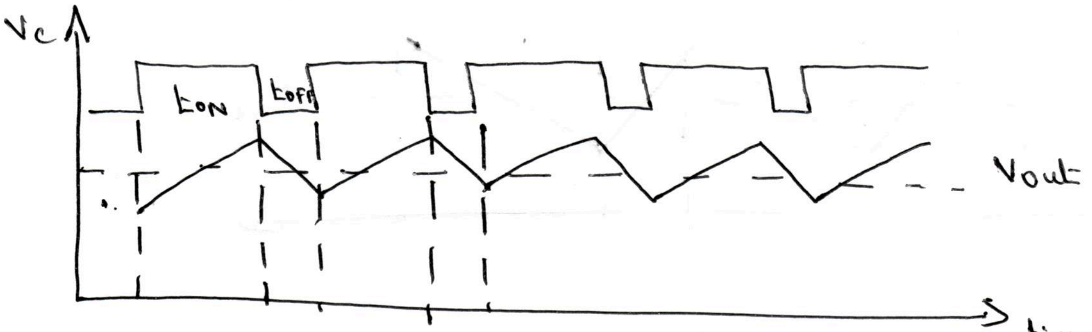


Equivalent Circuit.

$$\delta = \frac{t_{ON}}{t_{ON} + t_{OFF}} = \frac{t_{ON}}{T}$$

a) If output voltage decreases:

The voltage across R_3 decreases. The reference V_Z is fixed. Thus error at input of error amplifier is more. This produces pulse of higher width as the output of the variable pulse width oscillator. As pulse width is high t_{ON} is higher for Q. This increases the charging of the capacitor C producing more output voltage. Thus decrease output voltage get compensated.



$t_{ON} > t_{OFF}$

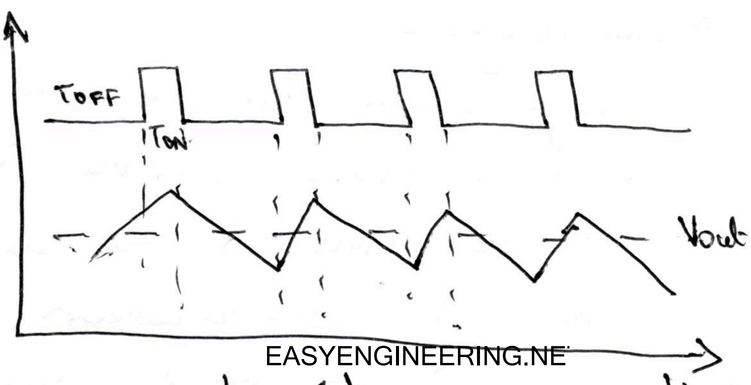
b) when output voltage increases:

The voltage across R_3 increases. The reference V_Z is fixed. The error at the input of error amplifier decreases. The output of the error amplifier controls the output of variable pulse width oscillator. It produces pulse of smaller width which reduces t_{ON} for Q. This makes the capacitor C to discharge more to offset any attempt of increase in output voltage.

∴ The output voltage is

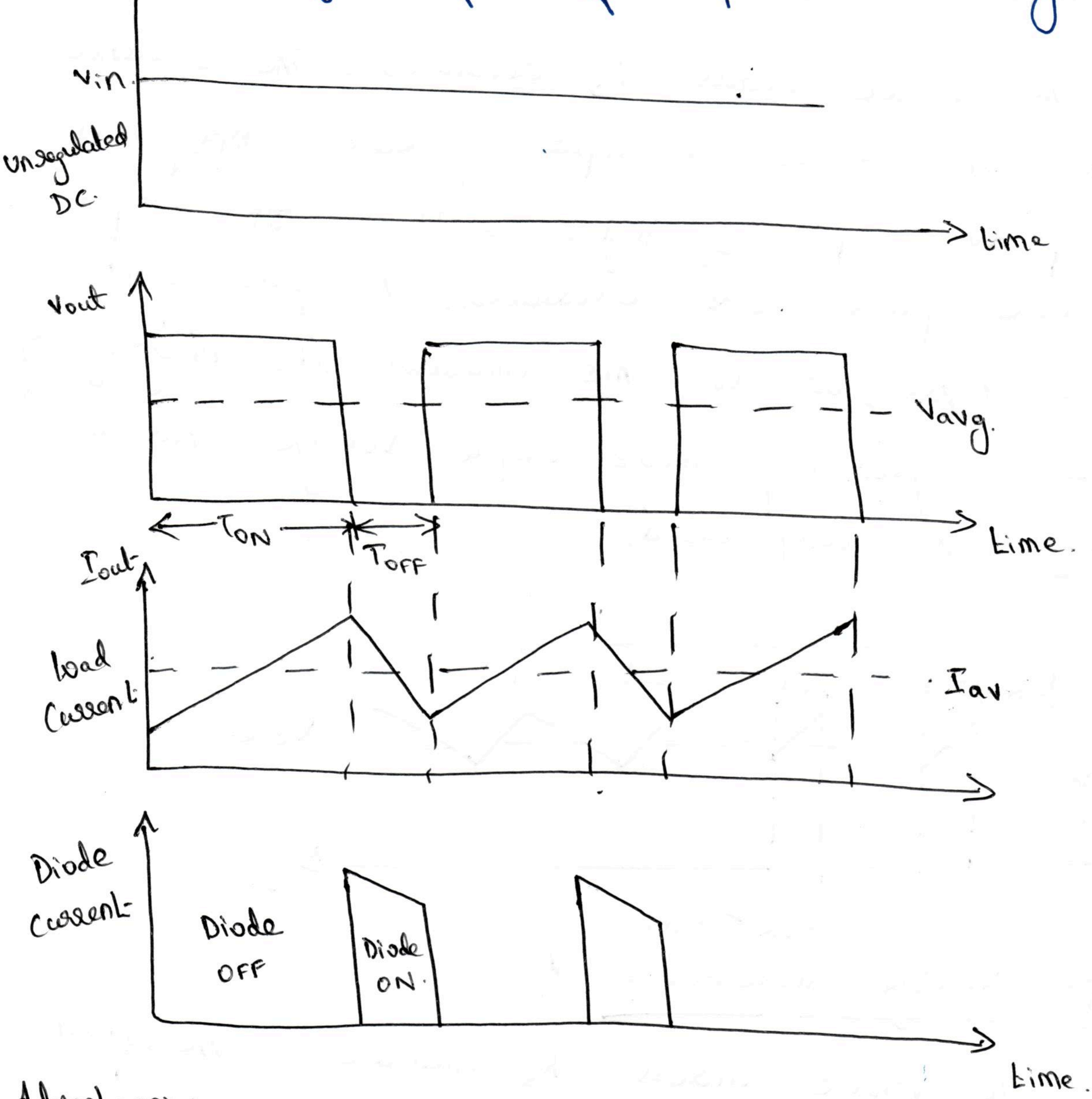
$V_{out} = \delta V_{in}$.

where $\delta = t_{ON} f$



$t_{ON} < t_{OFF}$

Fig. Waveform of step down switching regulator.



Advantages:-

1. Higher efficiency
2. Simple to design.
3. low ripple Content
4. Small output filter
5. large tolerance of line voltage regulation.

Disadvantages:-

1. Single output and no isolation between input and output.
2. Slow transient response compared to linear regulator.
3. Due to finite reverse recovery time of communicating diode the instantaneous short circuit occur across the source due to which active switches may fail.

Step up Switching Regulator :- (Boost)

The basic elements used in this type are identical to those used in step down type but their arrangement is different.

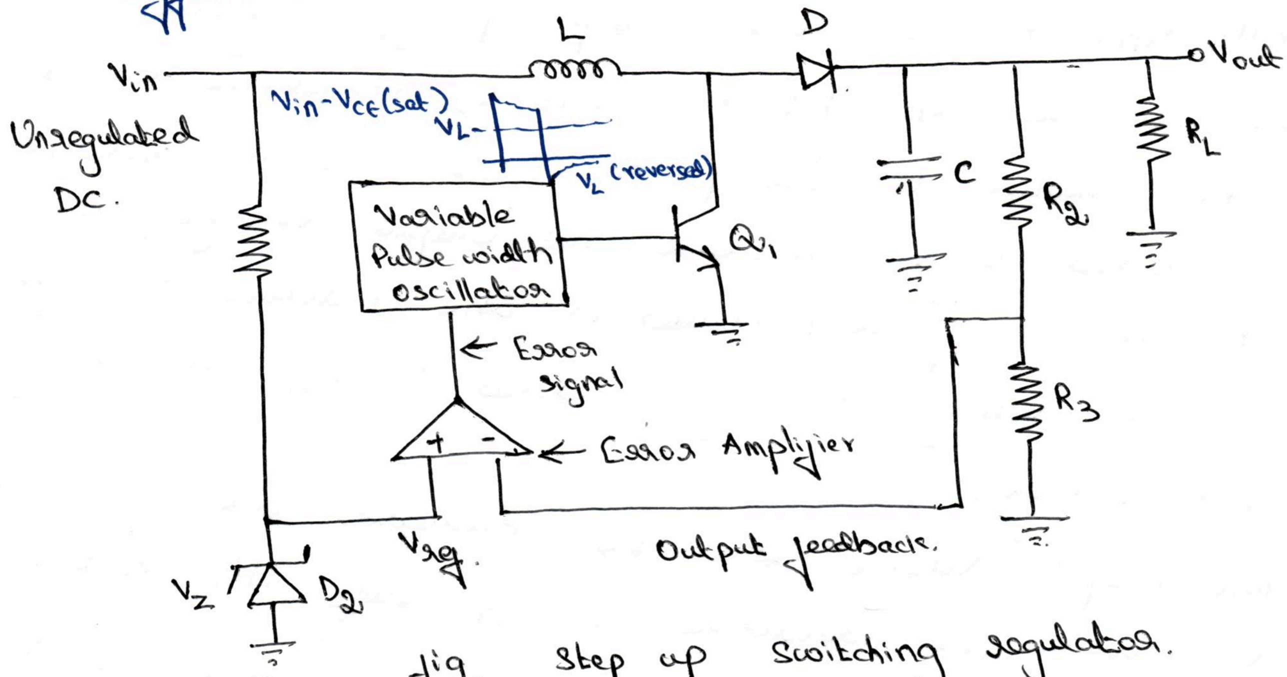


fig. step up switching regulator.

Working :-

Case (1) : when Q_1 is ON, V_{CE} is donated as $V_{CE(sat)}$ and the voltage across L suddenly become $[V_{in} - V_{CC(sat)}]$ as shown in fig. This expands the magnetic field around the inductor very quickly. This voltage across L can be obtained by applying KVL to Vin. during ON time of Q the voltage across inductor start decreasing exponentially from its initial max value $[V_{in} - V_{CE(sat)}]$

Case (2) : when Q_1 is OFF the magnetic field of the inductor L collapses and its polarity get reversed. This is because an inductor current can not change instantly. Thus value of V_L attained after exponential decrease when Q_1 is ON now get reversed as shown in the fig. Due to reversal of polarity it gets added to V_{in}.

The diode D_1 is forward biased due to reversed V_L and capacitor C now charge to V_{in} + V_L. The output voltage is voltage across capacitor C. which is $V_{in} + V_L$. which is more than V_{in}. Thus it act as step up type regulator.

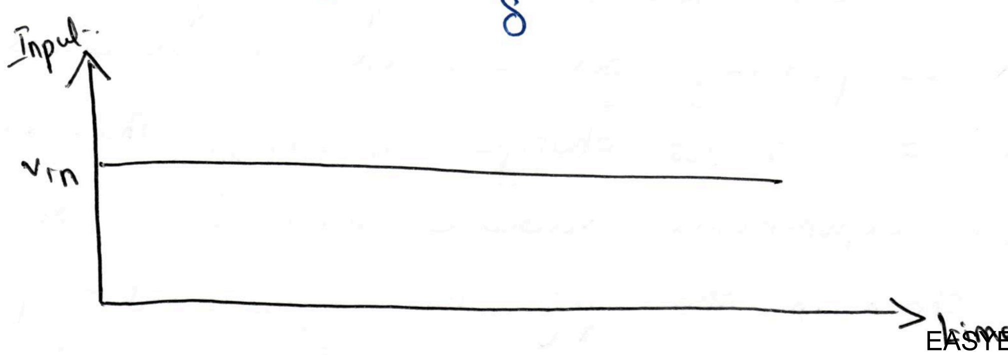
It can be seen that how much V_L should be added to Vin. The shorter the ON period of Q_1 greater voltage will get added to Vin increase the output voltage. The longer the ON time of Q_1, smaller is the inductor voltage V_L and less voltage will get added to Vin, decreasing the output voltage.

when output voltage tries to decreases due to increase in load current (or) decrease in Vin itself then ON time of Q_1 get reduced thus Vin increases compensating for the decrease in it.

when output voltage tries to increase then ON time of Q_1 get increased. This reduces voltage across the inductor. Thus the less voltage gets added to Vin, reduce its value. This compensate for the attempted increase in output voltage.

Expression for the output voltage.

$$V_{out} = \frac{V_{in}}{\delta}$$



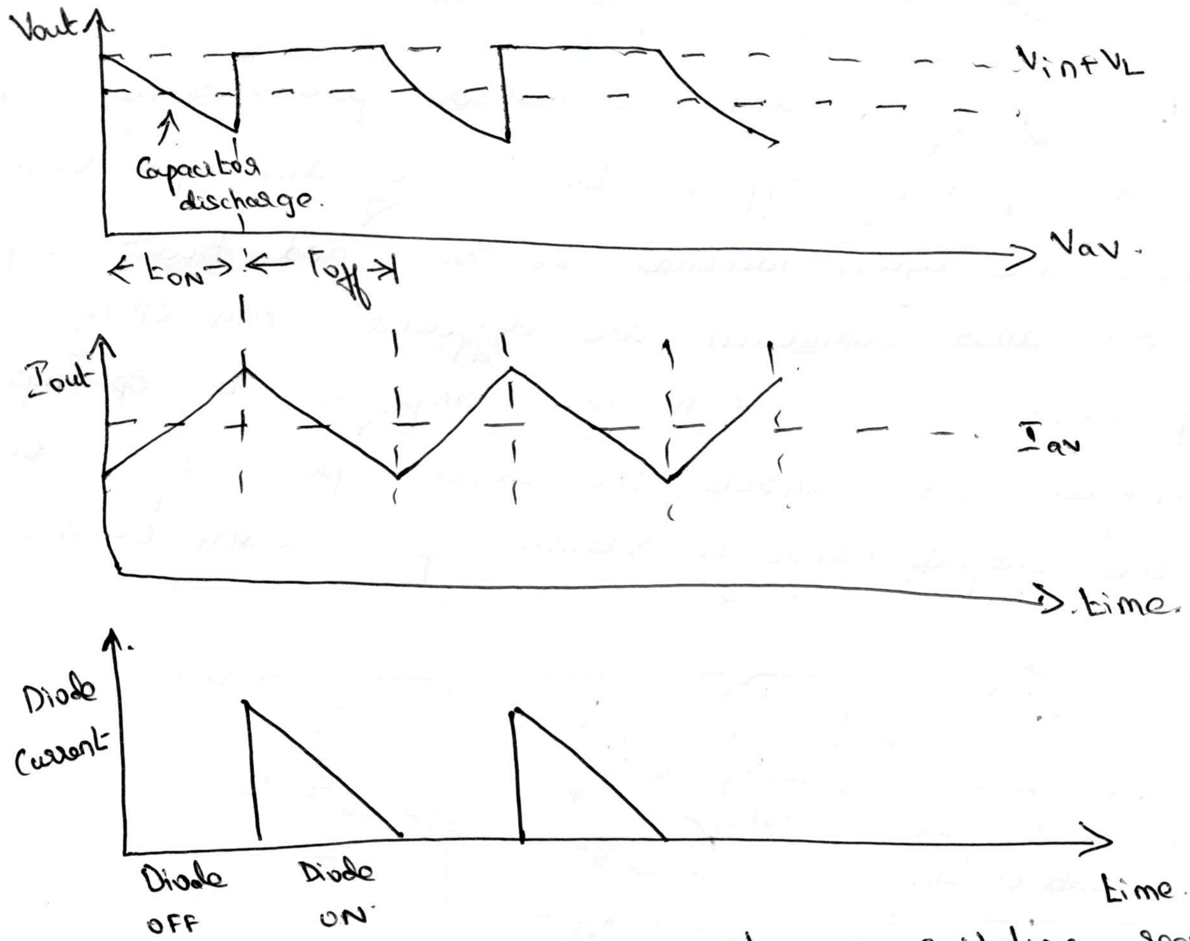


fig. waveform for step up switching regulator.

Advantages:

1) The output voltage is higher than input voltage.
2) Efficiency is high greater than 90%.
3) low input ripple current.

Disadvantages:

1) The duty cycle is limited to 50% to avoid the continuous current mode if regulator enters the continuous current mode, it stops regulating the output. Thus for a minimum input voltage range max duty cycle is limited.
2. Due to restricted duty cycle the peak collector current is very high. This limits its output power rating.

Voltage Inverter type Switching Regulator (Buck - Boost)

This type of switching regulator produces an output voltage having polarity opposite to that of the input voltage. The elements are again identical to buck and boost type regulator but their connection are different. Any change in output produces error which get amplified by op-amp error amplifier. This controls the ON/OFF period of Q to regulate the output through variable pulse width oscillator.

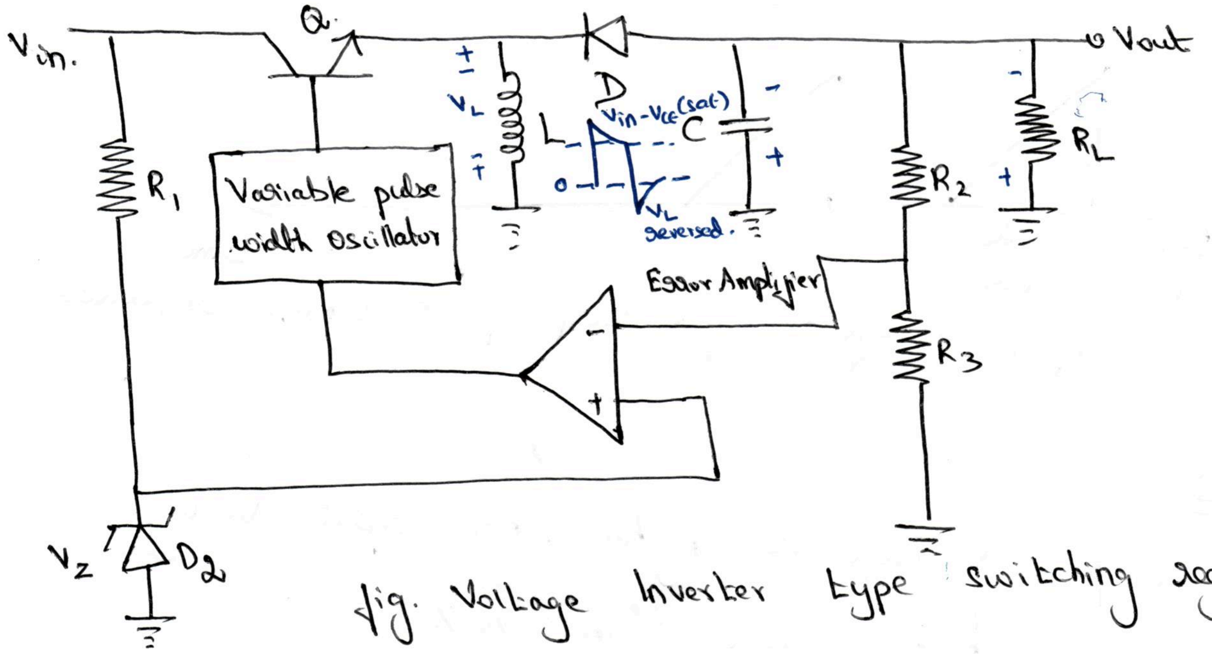


fig. Voltage Inverter type switching regulator.

Working:-

Case 1:- The Q goes into saturation and the voltage across it drops to $V_{CE(sat)}$ which is about 0.3V. Due to this voltage across inductor suddenly rises to $[V_{in} - V_{CE(sat)}]$ and magnetic field around it suddenly expands. Due to connection of diode D_1 in this situation it is reverse biased. The inductor voltage starts exponentially decreasing from the initial value $[V_{in} - V_{CE(sat)}]$.

Case 2: Now if Q_1 is turned OFF, the magnetic field across L get collapsed but inductor current can not change instantaneously. Thus voltage across inductor V_L reverse its polarity.

Due to reversed V_L, the diode D_1 is now forward biased. The capacitor charges through D_1 producing output voltage of opposite polarity to that of V_{in}. Hence the regulator is called voltage inverter type.

The repetitive on-off action of Q_1 produces a repetitive charging and discharging of the capacitor C which is smoothed by the LC filter action. The less period Q is ON, higher is the output voltage, the greater time Q is ON, smaller is the output voltage.

Power Supply performance and testing:-

The power supply is the heart of any electronic equipment. Hence for the high quality and reliable operation it is necessary to verify the power supply performance by conducting the tests. The test specification must include all the safe operating limits such as temperature, line condition, regulation values etc. The various test equipment required to test a power supply are.

(i) DC power supply which is capable of supplying voltage and current for the test.

(ii) Electronic (or) dynamic load which is capable of handling various system requirements.

iii) Accurate voltmeter, wattmeter and Ammeter.

iv) An oscilloscope with bandwidth of 500 MHz or more for measurement of noise.

v) Network analyzer (or) frequency response analyzer for stability measurement.

Testing Procedure and Specifications:

The various test used to check the performance of a power supply are discussed below.

(i) First switch ON

(ii) Inrush current test

(iii) Transient recovery time test

(iv) Static load regulation test

(v) line regulation test.

(vi) Periodic and Random deviation test (PARD)

(vii) Efficiency test

(viii) Power factor.

(ix) Start up time

(x) Short circuit output current

(xi) over voltage shutdown

(xii) leakage current

(xiii) Hold up time.