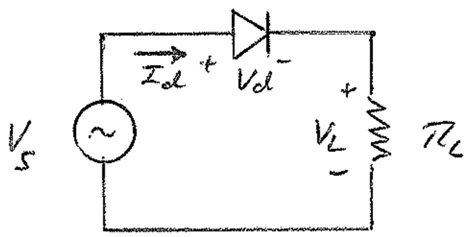
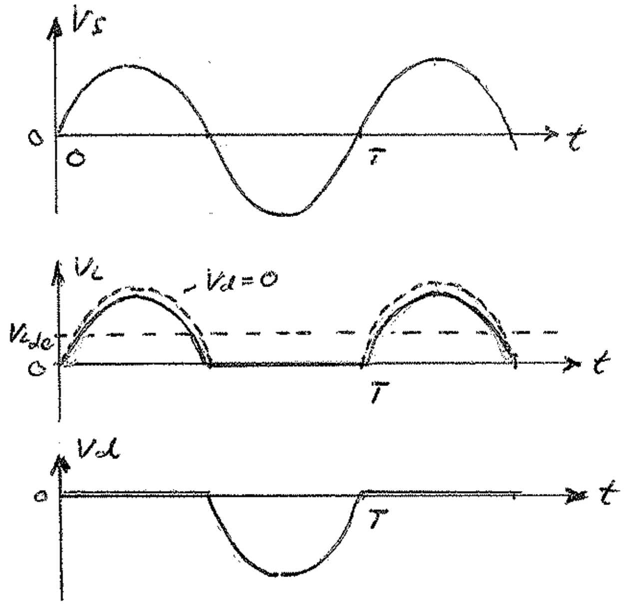
IV. Nonlinear Circuit Applications

1. Rectifiers

a) Half-wave Rectifier





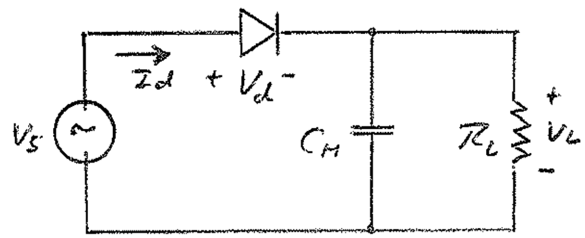
KVL: $V_s = V_d + V_L$

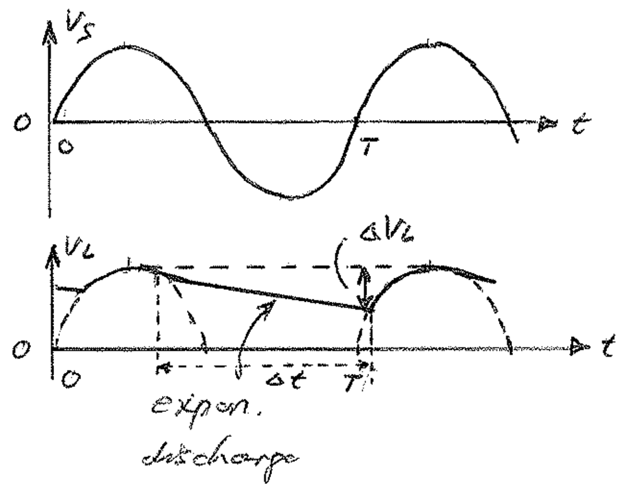
$\therefore \boxed{V_L = V_s - V_d}$

dc Component of V_L:

$$\left\| V_{Ldc} = \frac{1}{2\pi} \int_0^{\pi} \hat{V}_L \sin(\varphi)\, d\varphi = \frac{\hat{V}_L}{2\pi} \left[-\cos\varphi\right]_0^{\pi} = \frac{1}{\pi} \hat{V}_L \right\|$$

Half-wave Rectifier with Hold Capacitor





Ripple ΔV_L

$$\boxed{\Delta V_L = \hat{V}_s\left(1 - e^{-\frac{\Delta t}{\tau}}\right) \approx \hat{V}_s \frac{\Delta t}{\tau}}$$

where $\tau = R_L \cdot C_H$

$\Delta t \approx T$

$$\therefore \quad \boxed{\Delta V_L \approx \hat{V}_s \frac{T}{R_L C_H}}$$

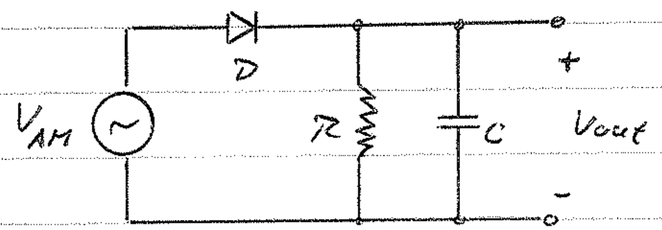
To obtain a smooth output voltage with little ripple,

$R_L C_H \gg T$

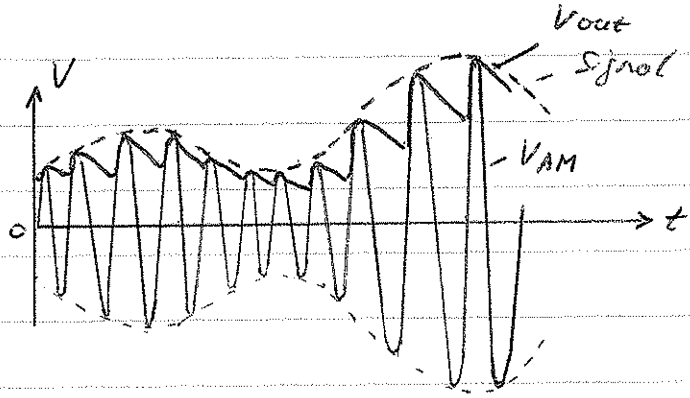
Important application of a half-wave rectifier

AM Demodulator (Envelope detector)

Basic Configuration



$\tau = RC$



$$\boxed{V_{AM} = A(t) \cos \Omega_c t}$$

Ω_c: carrier frequency

$A(t) = A_o \cos \omega_o t$

ω_o: momentary sign. freq.

The RC time constant τ of the detector must be chosen such that the maximum slope of the output voltage is at least as large as the maximum slope of the envelope, i.e. the AM input signal before modulation.

Thus

$$\mathrm{Max}\left\{\frac{d}{dt}\left[A_0 \cos \omega_0 t\right]\right\} < \mathrm{Max}\left\{\left|\frac{d}{dt}\left[A_0 e^{-\frac{t}{RC}}\right]\right|\right\}$$

$$A_0 \omega_{0_{Max}} < A_0 \frac{1}{RC}$$

$$\therefore \quad \left\| RC < \frac{1}{\omega_{0Max}} \right\|$$

On the other hand, the RC time constant should not be smaller than the period of the carrier, since then the hold effect would be very weak.

$$\therefore \quad \left\| RC > \frac{2\pi}{\Omega_{cMin}} \right\|$$

We thus obtain the following condition for the time constant $\tau = RC$ of the envelope detector

$$\boxed{\frac{2\pi}{\Omega_{cMin}} < RC < \frac{1}{\omega_{0Max}}}$$

AM Radio: $\quad 0.5\,MHz \le F_c \le 1.6\,MHz$

$$f_0 \le 4.5\,kHz$$

$$\therefore \quad \left\| 2\,\mu s < RC < 35.4\,\mu s \right\|$$

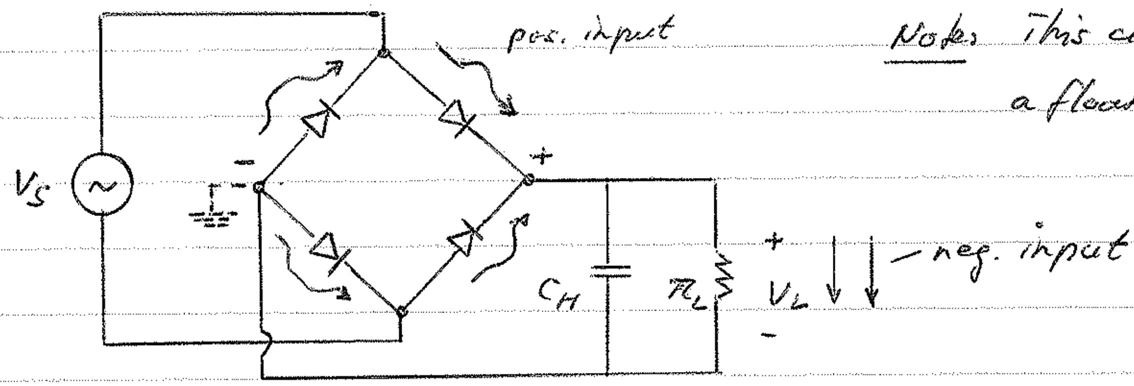
Choose RC as the geometric mean of the upper and lower bound

$$\left\| RC \approx 8.4\,\mu s \right\|$$

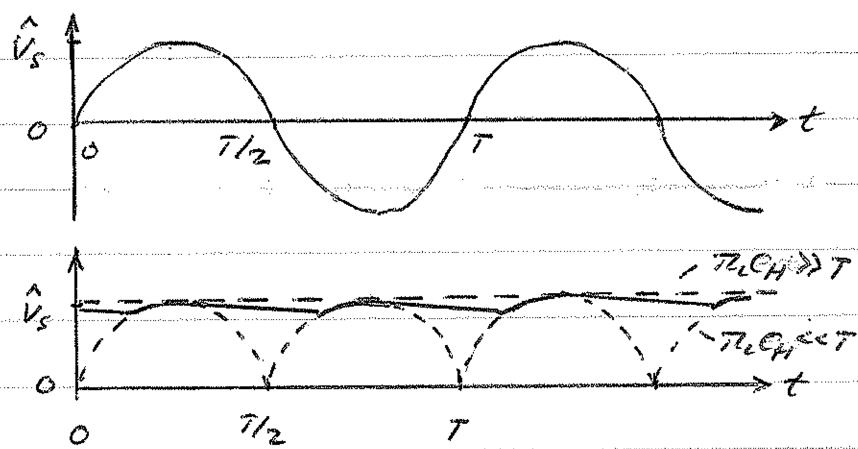
e.g. $\left| \begin{array}{l} R = 1\,k\Omega \\ C = 8.2\,nF \end{array} \right|$

b) Full-wave Rectifier

b1) Bridge full-wave Rectifier



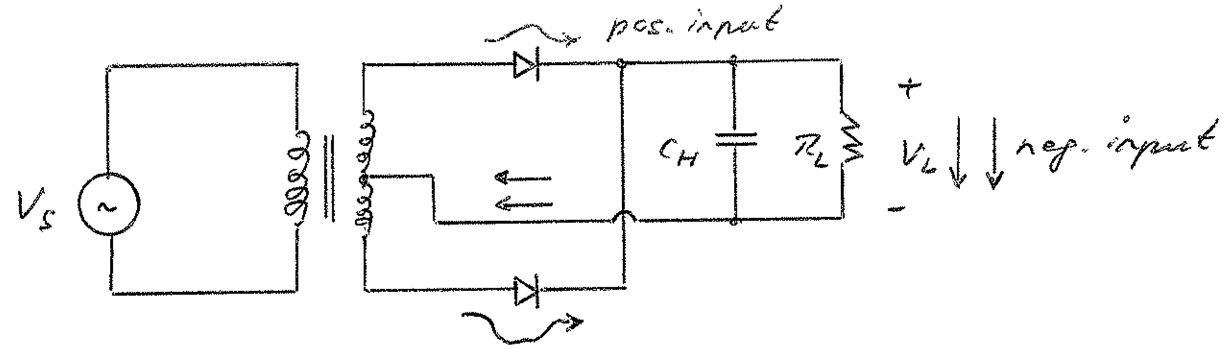
Note: This circuit requires a floating source!



ripple is a function of the ratio $\frac{1}{C_H R_L}$

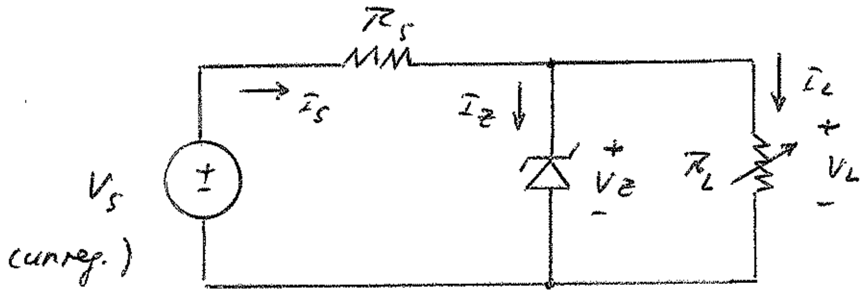
In order to obtain a completely smooth dc output voltage, one generally applies a <u>voltage regulator</u> circuit to the output of the rectifier.
An alternative solution is to employ a <u>lowpass filter</u> which cuts off all harmonics of the input frequency.

b2) Center tapped transformer full-wave rectifier



2. Voltage Regulators

Basic Configuration (with Zener diode)



A voltage regulator can be used to remove a ripple from an input voltage and (or) to maintain a const. output voltage over a range of loads.

Example 1 $\quad V_S = 20V$ (const.)

$V_Z = 10V$

Determine R_S so that V_L remains constant at 10 V while the load resistor R_L varies between $R_{L\,min} = 100\,\Omega$ and $R_{L\,max} = 1k\Omega$.

Solution KVL: $V_S = I_S \cdot R_S + V_Z$

$$\therefore \boxed{R_S = \frac{V_S - V_Z}{I_S}}$$

KCL: $I_S = I_Z + I_L = \text{const.}$ (for $V_S = \text{const.}$)

Condition that $V_L = V_Z$ $\boxed{I_Z > 0}$ otherwise $V_L < V_Z$

$$\therefore I_S > I_{L\,max} = \frac{V_Z}{R_{L\,min}}$$

$$\therefore R_S < \frac{V_S - V_Z}{I_{L\,max}} = \frac{V_S - V_Z}{V_Z} R_{L\,min}$$

$\boxed{R_S < 100\,\Omega}$ Note: If $R_L = R_{L\,max}$, we obtain a minimum load current, hence $I_Z > 0$ is met under all conditions

If we select $R_S = 90\,\Omega$, then $\boxed{\begin{matrix} I_{Z\,min} = 11.11\,mA \\ I_{Z\,max} = 101.11\,mA \end{matrix}}$

The Zener diode must therefore be capable of dissipating a maximum power of

$$\boxed{P_{Z\,max} = V_Z \cdot I_{Z\,max} = 1.011\,W}$$

$$P_{Z\,max} = V_Z \cdot \left(\frac{V_S - V_Z}{R_S} - \frac{V_Z}{R_{L\,max}} \right)$$

If $P_{Z\,max} < 1W$ then increase R_S $\quad R_S = 95\,\Omega \quad I_{Z\,min} = 5.3\,mA$

$I_{Z\,max} = 95.3\,mA$

$$\therefore \boxed{P_{Z\,max} = 0.95\,mW}$$

example 2: $6V \le V_S \le 7.5V$

$100\Omega \le R_L \le \infty$

$V_Z = 5V$

Determine R_S and the max power dissipated by the zener diode.

Solution. KVL: $V_S = I_S R_S + V_Z$

KCL: $I_S = I_L + I_Z$

Condition to maintain $V_L = V_Z$

$$I_{S\,Min} = \frac{V_{S\,Min} - V_Z}{R_S} \geq \frac{V_Z}{R_{L\,Min}} = I_{L\,Max}$$

$$\therefore \left\| R_S \le R_{L\,Min} \frac{V_{S\,Min} - V_Z}{V_Z} = 20\Omega \right\|$$

Select $R_S = 15\Omega$

$$\therefore \left\| \begin{array}{l} I_{i\,Max} = \dfrac{V_{S\,Max} - V_Z}{R_i} \cong 0.167A \\[2ex] P_{Z\,Max} = V_Z\left(I_{S\,Max} - \dfrac{V_Z}{R_{L\,Max}}\right) \cong 0.833W \end{array} \right\|$$

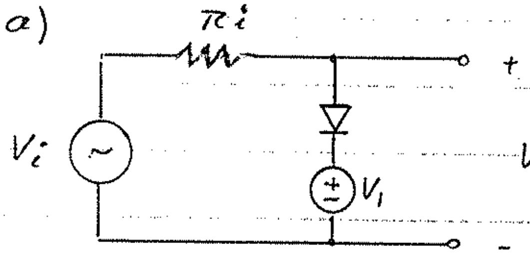
Check $I_{Z\,Min} = I_{S\,Min} - I_{L\,Max} = \dfrac{V_{S\,Min} - V_Z}{R_S} - \dfrac{V_Z}{R_{L\,Min}} = 0.017A > 0$

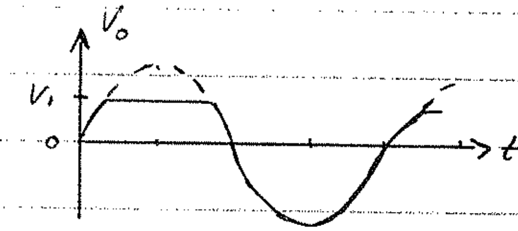
Thus $V_L = V_Z$ under worst case condition!

1.3.4 Clipping and Clamping

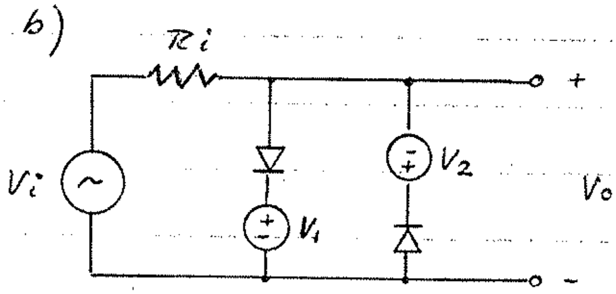
Clipping circuits are used to limit voltage excursions.

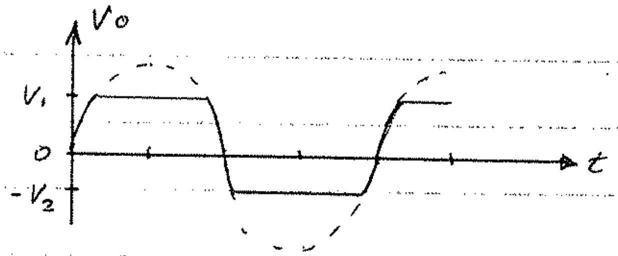
a)



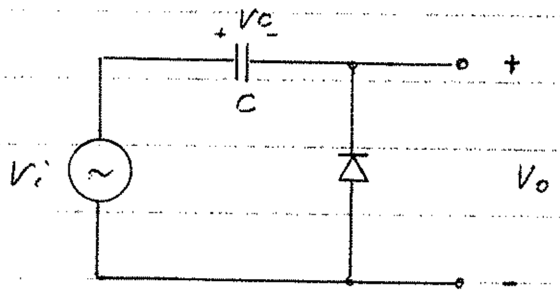


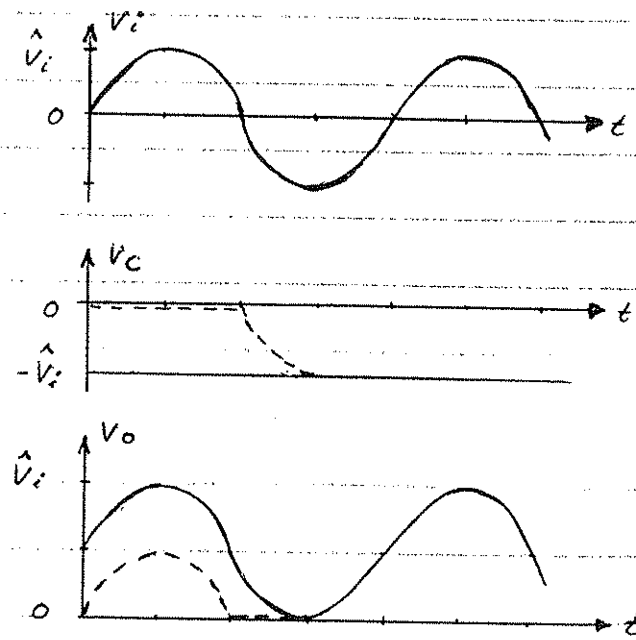
b)





Clamping is used to make sure a voltage never goes negative (or positive.)

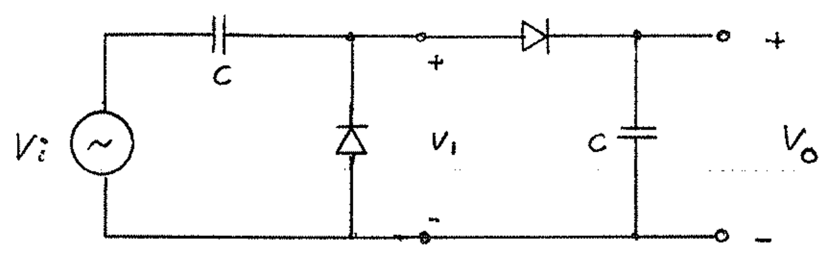


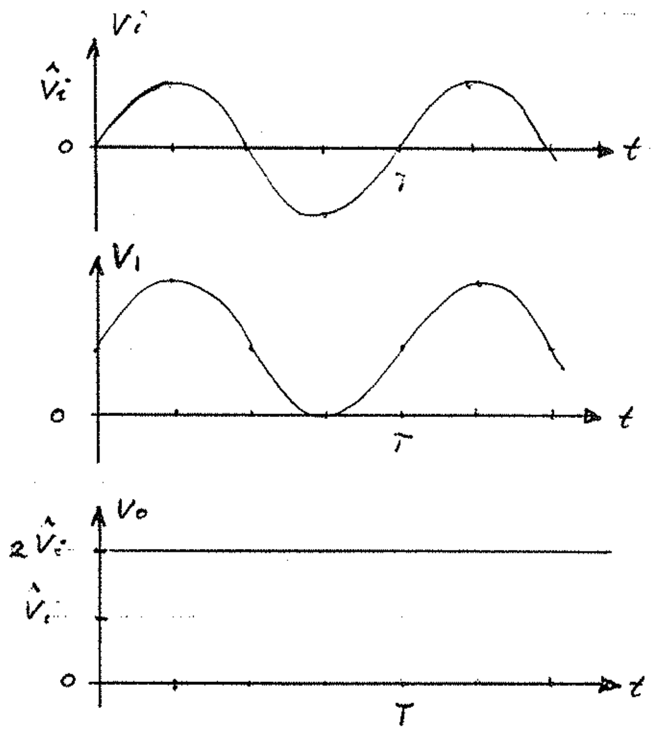


$V_i = V_c + V_o$

$\Rightarrow \underline{V_o = V_i - V_c}$

Cascade of clamping circuit with simple rectifier.





voltage doubling

Voltage multiplier