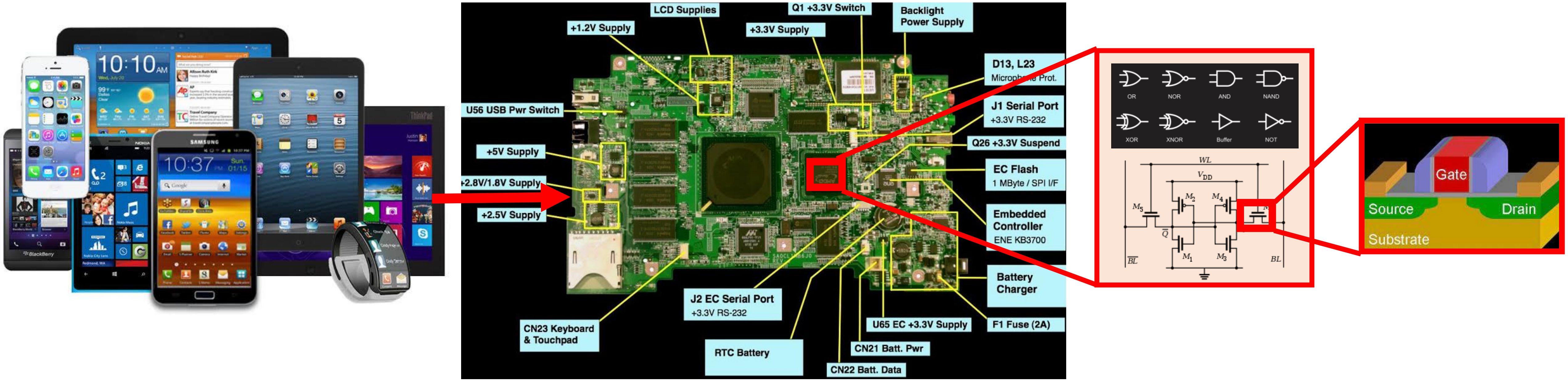

ESC201: Introduction to Electronics

Module 4: Non-Linear Elements

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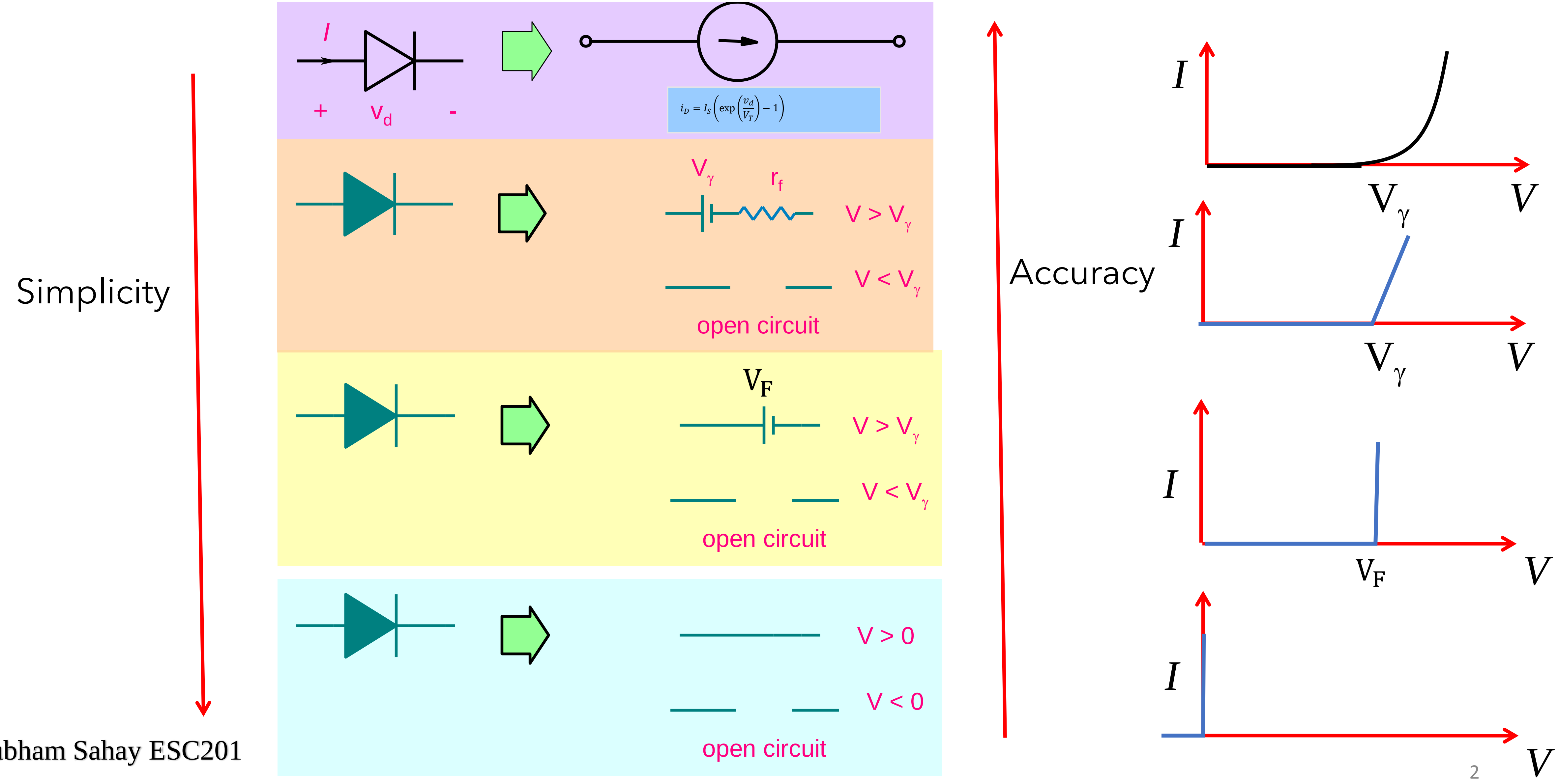
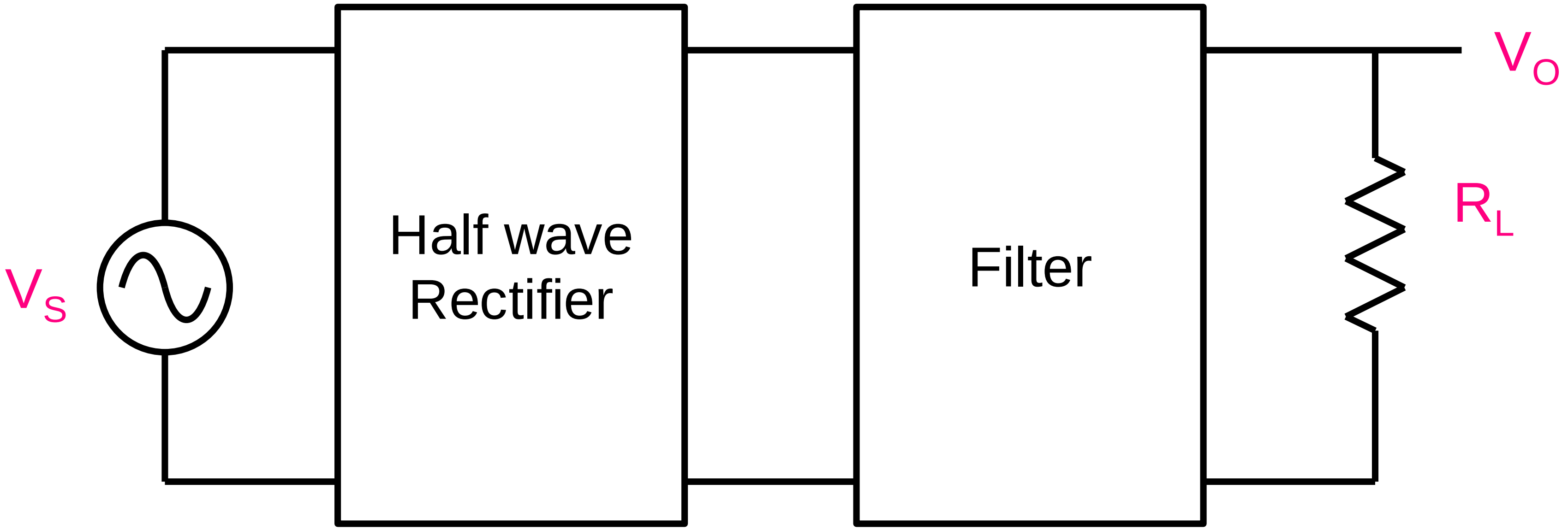
Assistant Professor,
Department of Electrical Engineering,
IIT Kanpur

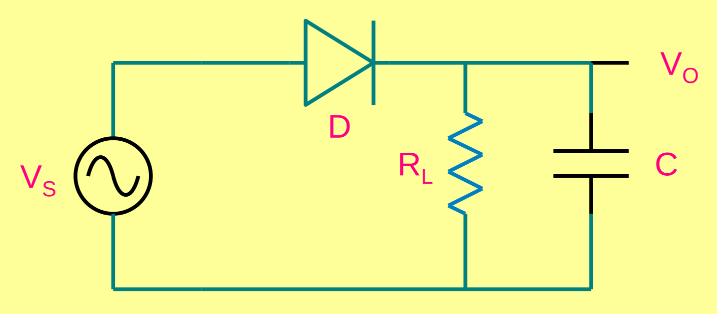
Summary: approximations

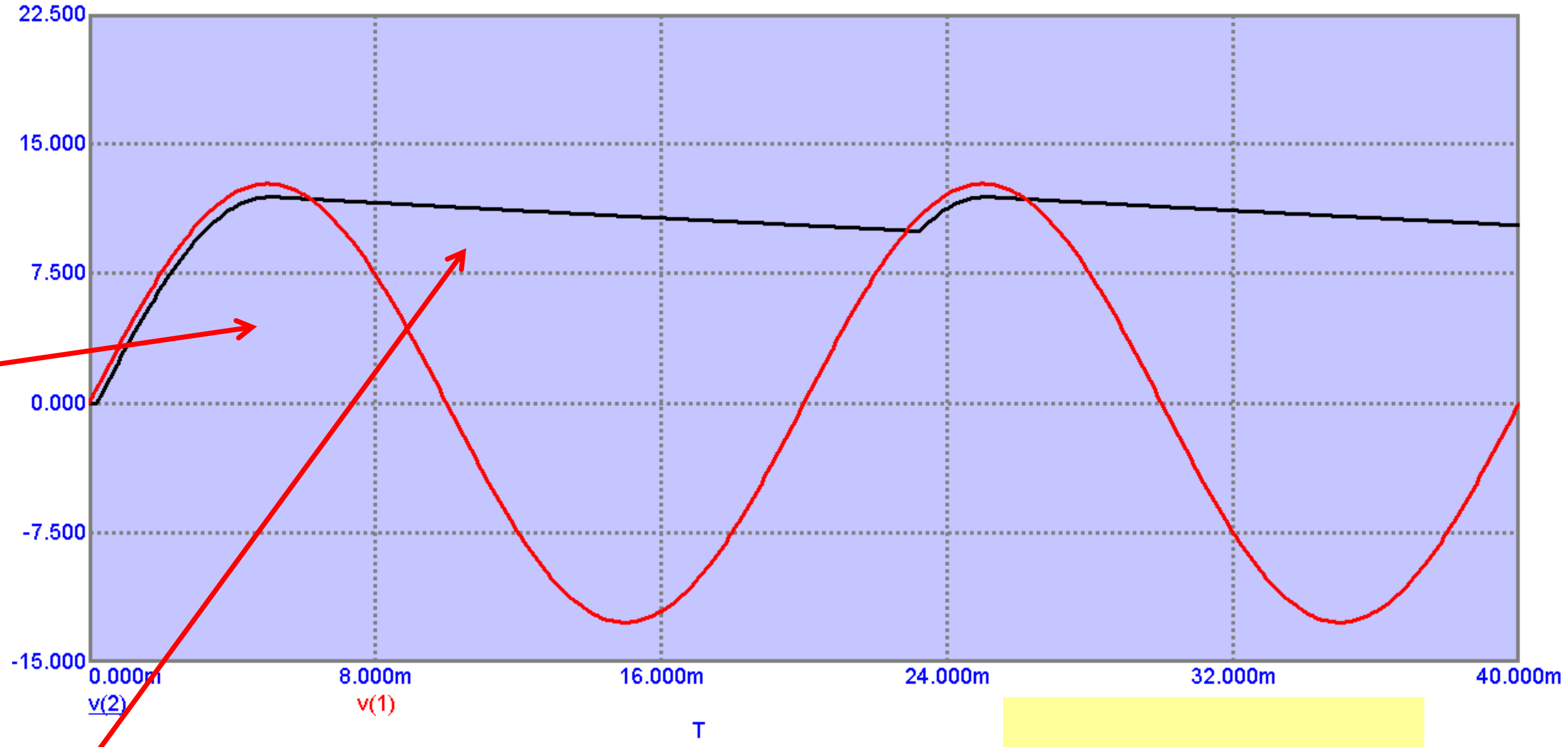


Power supply: block diagram



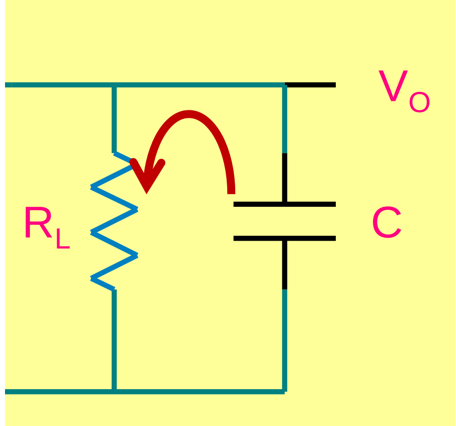
Filtered output





Diode is forward biased

Diode is reverse biased

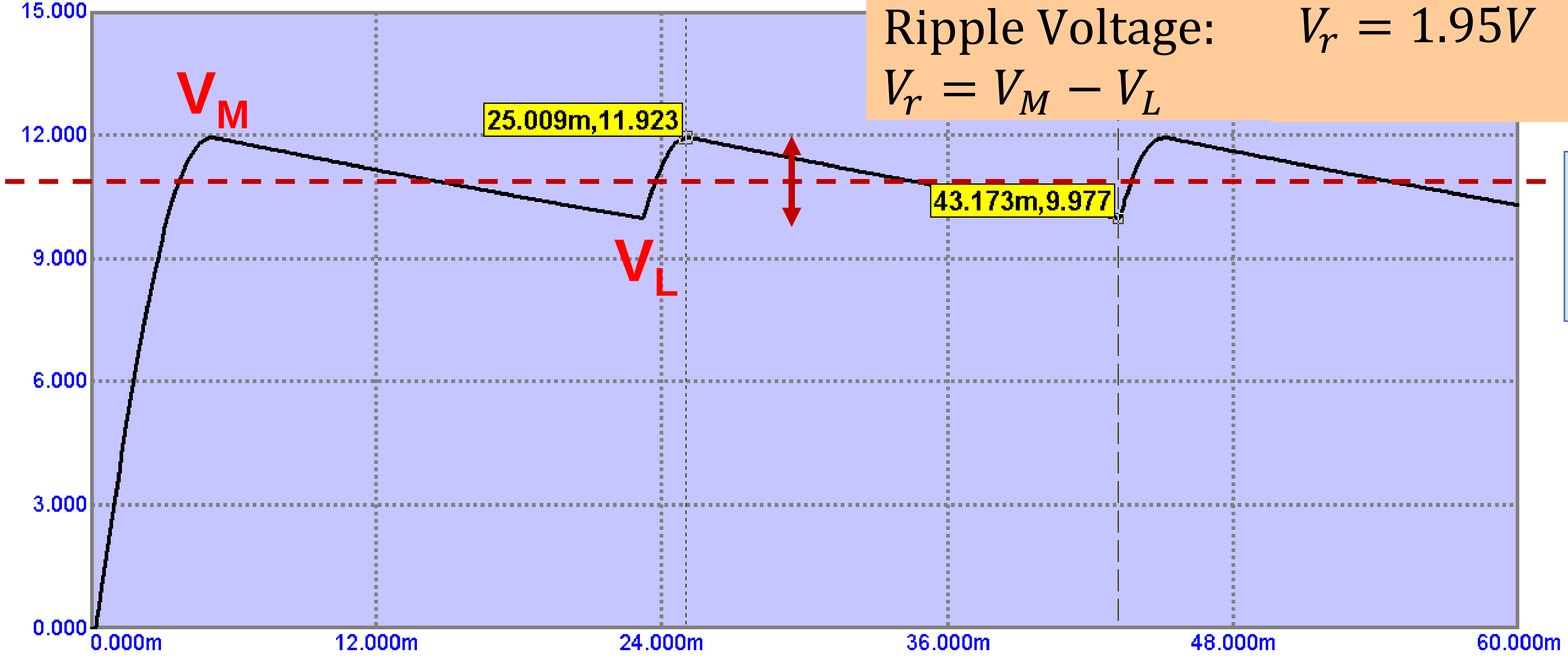


$R_L C$ should be high.

Output has a ripple

Ripple Voltage: $V_r = 1.95V$

$V_r = V_M - V_L$



Average Output Voltage :

$$V_O(avg) \cong V_M - \frac{V_R}{2}$$

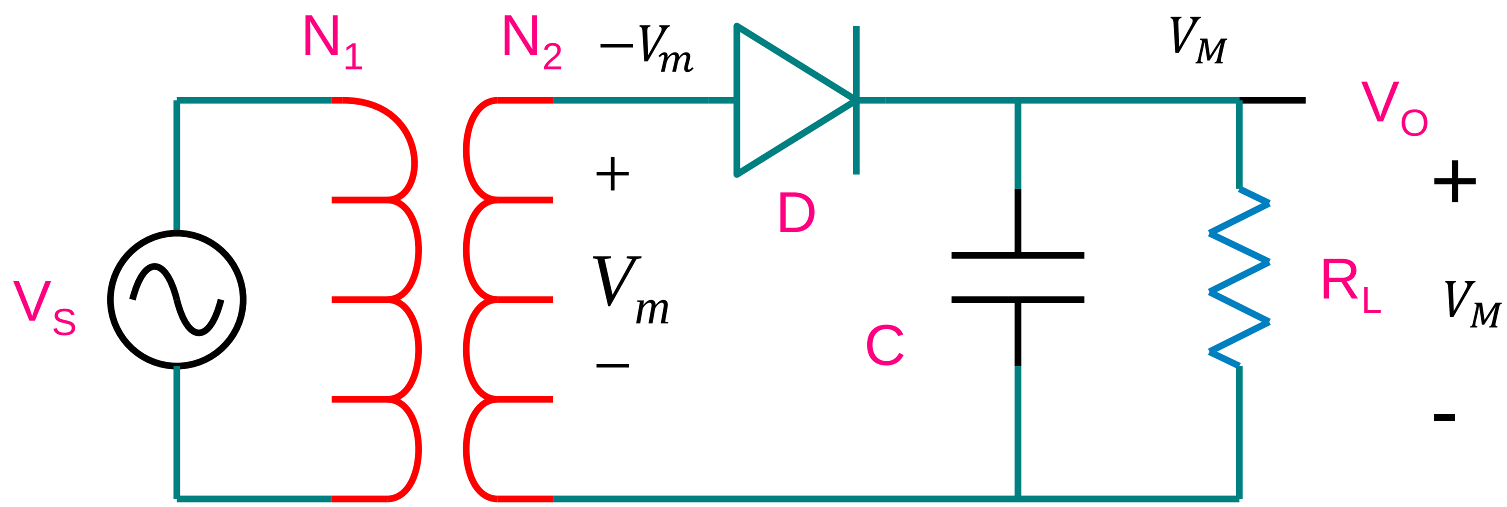
Diode inverse voltage

In practice, we must also look at diode specifications: can the diode tolerate the current and voltage?

Let the input voltage after step-down transformer is

$V_m = 12.7\text{ V}$

$V_\gamma = 0.7\text{ V}$



$V_M = V_m - V_\gamma$

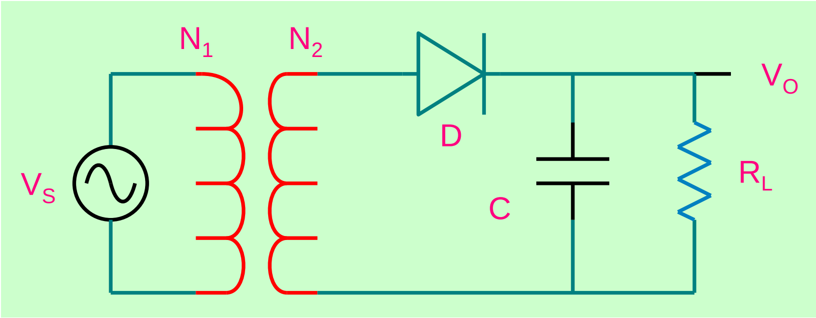
$= 12\ V$

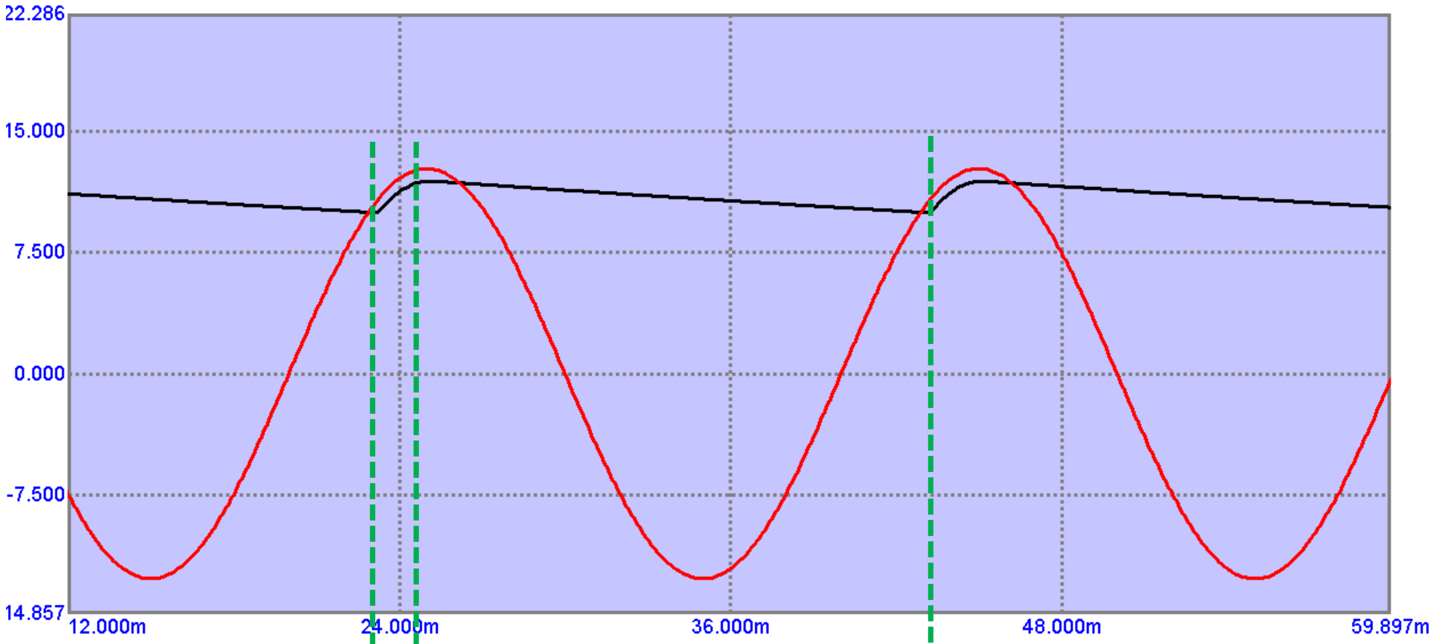
$$\text{PIV} = V_M + V_m$$

$$= 2V_M + V_\gamma$$

=12+12.7 = 24.7 V

DC Power Supply using Half Wave Rectifier





- How much current and voltage diode can handle?
- Let us calculate the maximum diode current in forward bias

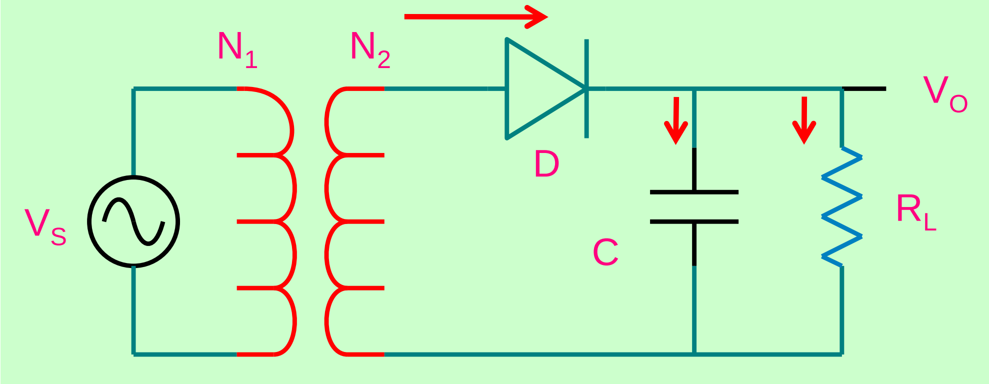
charging period

forward bias

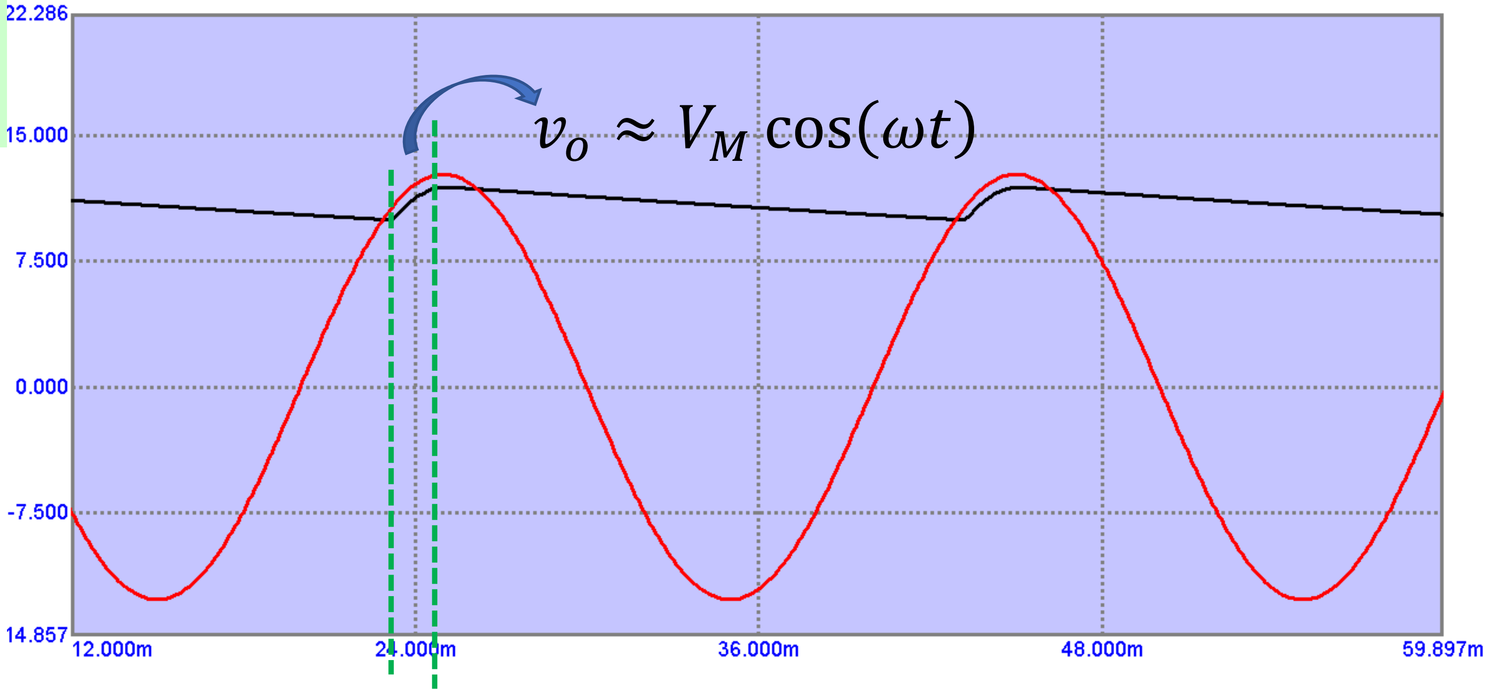
discharging period

reverse bias

Step 1



$$i_D = C \times \frac{dv_O}{dt} + \frac{v_O}{R_L}$$



$t = -\Delta t \quad t = 0$

Charging period
Forward Bias

Approximation:
v_o follows input voltage when D is forward biased

Step 2

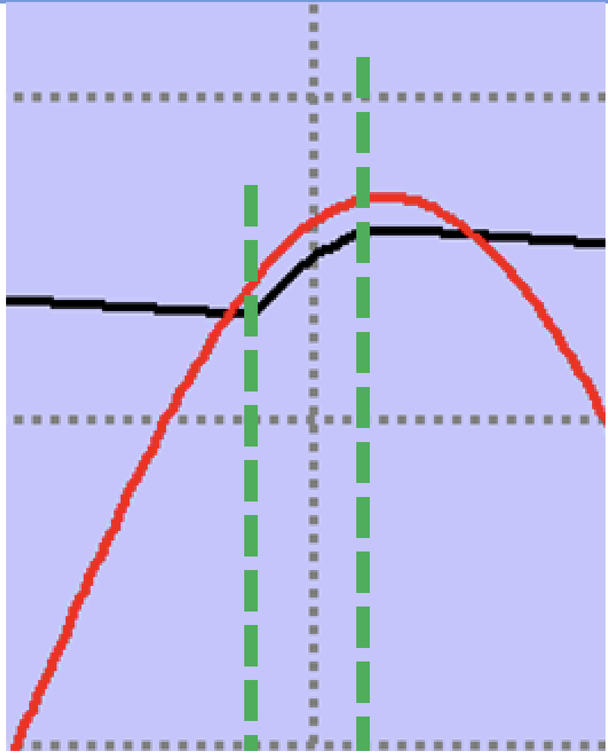
Substituting: $v_o \approx V_M \cos(\omega t)$

$$\boxed{i_D = C \times \frac{dv_O}{dt} + \frac{v_O}{R_L}}$$

$$i_D(t) \approx -CV_M\omega \sin(\omega t) + \frac{V_M \cos(\omega t)}{R_L}$$

Assuming a short ripple,

the charging interval $(-\Delta t, 0)$ is a small interval near $t = 0$.



$t = -\Delta t \quad t = 0$

In this interval, $\sin(\omega t) \approx \ \omega t$, and $\cos(\omega t) \approx 1 - \frac{(\omega t)^2}{2}$

$$i_D(t) \approx -CV_M\omega^2 t + \frac{V_M}{R_L}\left(1 - \frac{(\omega t)^2}{2}\right) \ \approx -CV_M\omega^2 t + \frac{V_M}{R_L}$$

Step 2

$$i_D(t) \approx -CV_M\omega^2 t + \frac{V_M}{R_L}$$

Diode current is maximum near $t = -\Delta t$

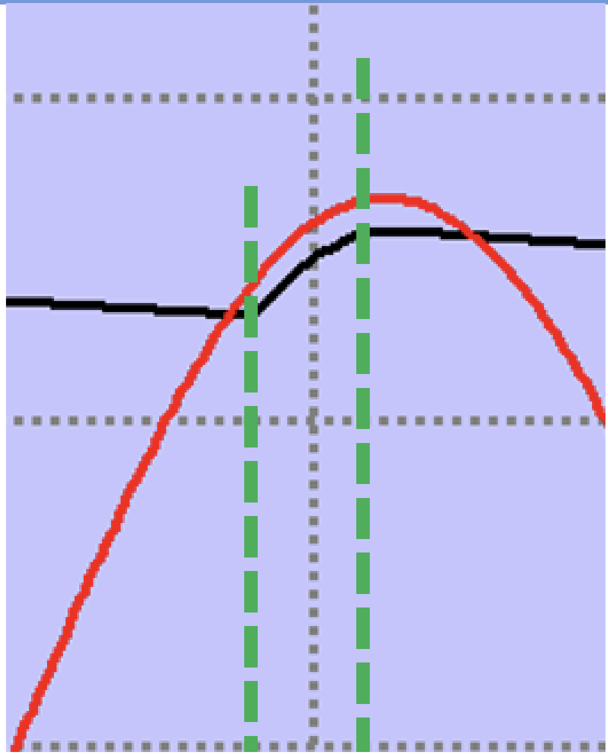
$$i_{D,\max} \approx CV_M\omega^2 \Delta t + \frac{V_M}{R_L}$$

$$i_{D,\max} \approx CV_M\omega\sqrt{\frac{2V_r}{V_M}} + \frac{V_M}{R_L}$$

Recall $v_o \approx V_M \cos(\omega t)$

$$V_L \approx V_M \cos(\omega\Delta t) \approx V_M\left(1 - \frac{(\omega\Delta t)^2}{2}\right)$$

$$\Rightarrow \omega\Delta t = \sqrt{\frac{2(V_M - V_L)}{V_M}} = \sqrt{\frac{2V_r}{V_M}}$$



$t = -\Delta t$ $\quad t = 0$

Step 3

$$i_{D,\max} \approx CV_M\omega\sqrt{\frac{2V_r}{V_M}+\frac{V_M}{R_L}}$$

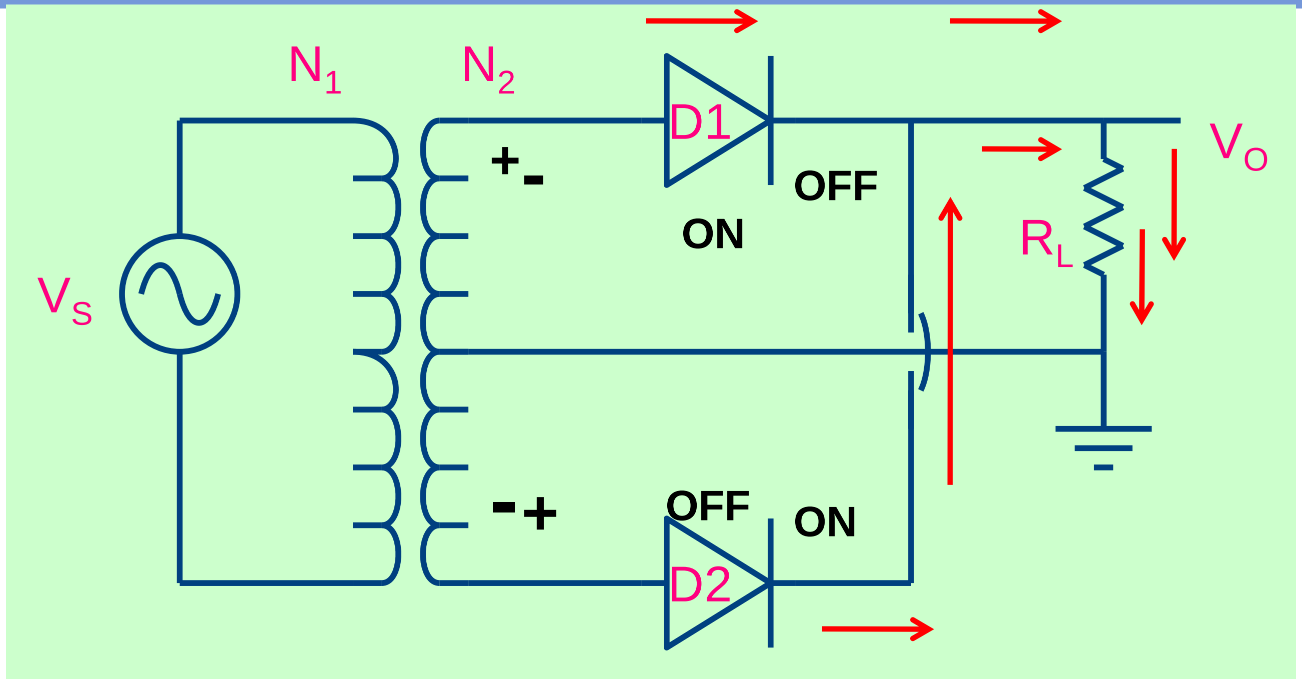
- Recall that $V_r \approx \dfrac{V_M}{fR_LC}$

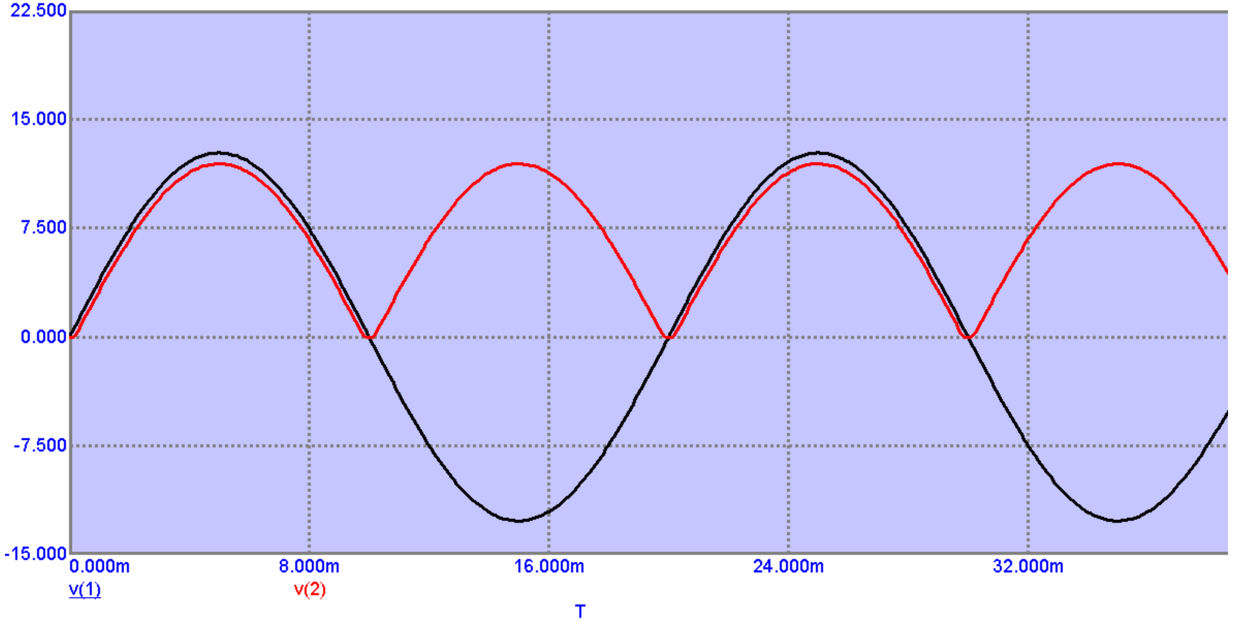
$$i_{D,\max} \approx \frac{V_M}{R_L}\left(1+2\pi\sqrt{2fCR_L}\right)$$

$$i_{D,\max} \approx \frac{V_M}{R_L}\left(1+2\pi\sqrt{\frac{2V_M}{V_r}}\right)$$

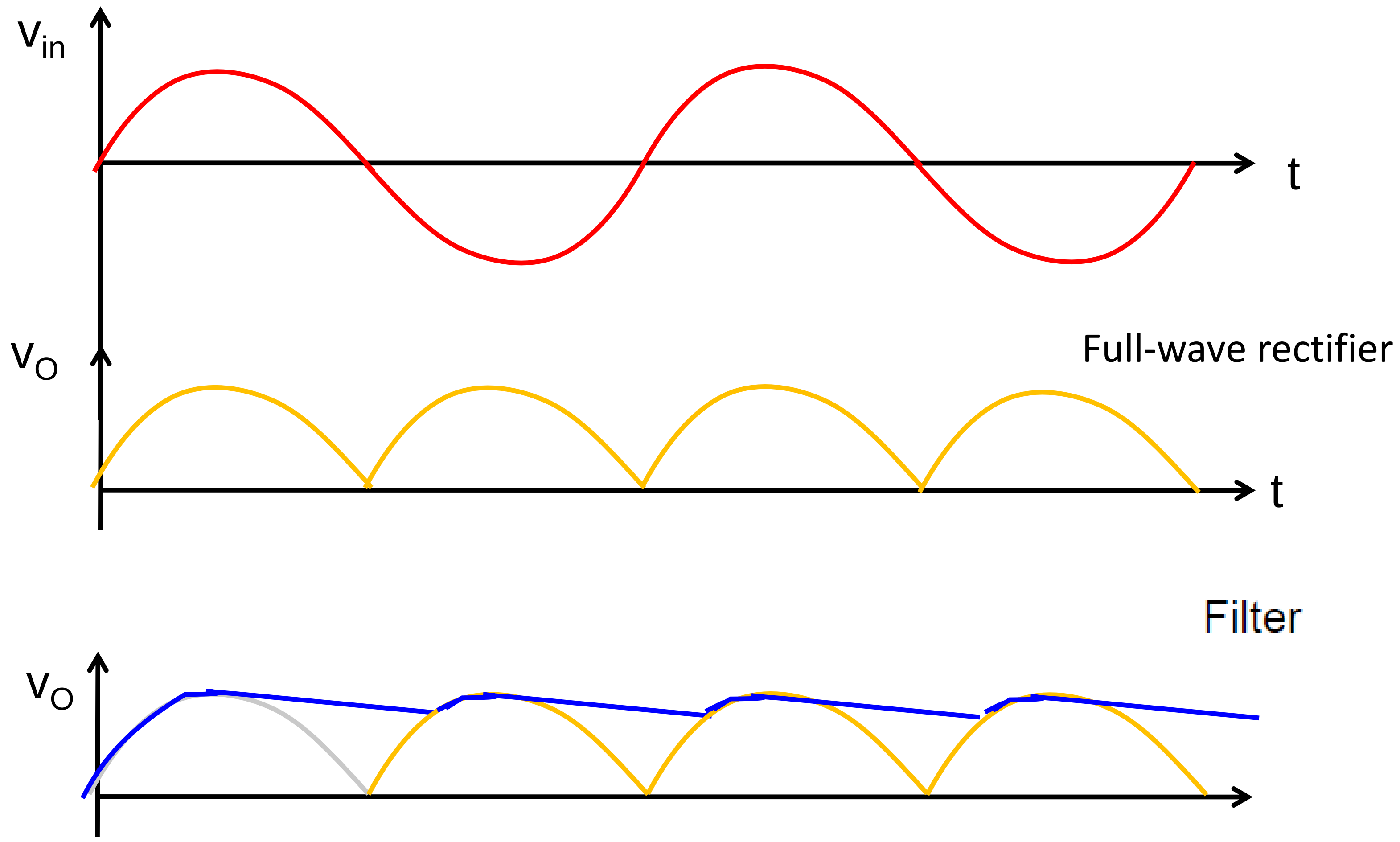
	Ripple Voltage	Max diode current
High Cap	low	high
Low Cap	high	low

Full-wave rectifier

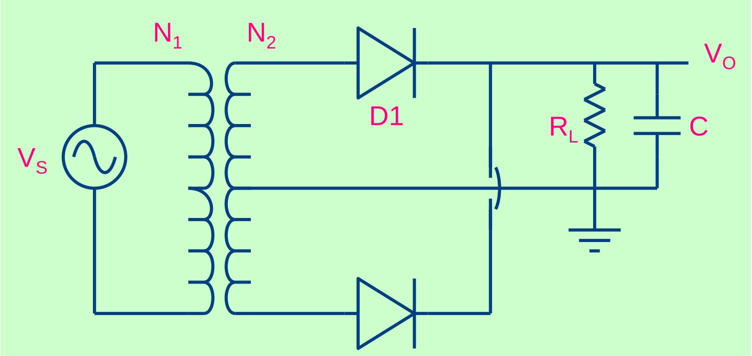




Strategy 2



Ripple Voltage

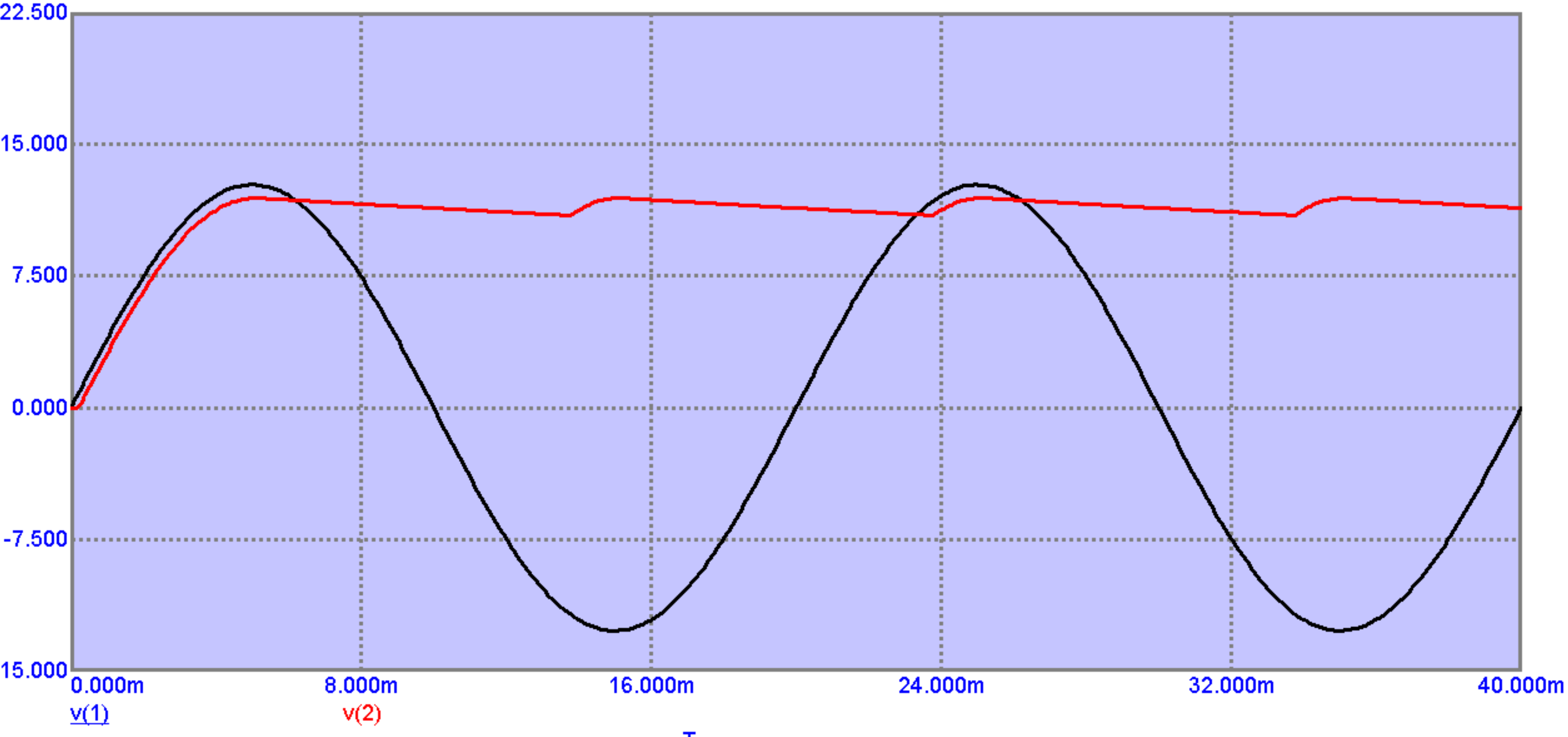


Recall the ripple voltage is

$$V_r = V_M - V_L = V_M \times \left(1 - e^{-\frac{t_1}{R_L C}}\right)$$

$$V_r \cong V_M \times \left(1 - \left(1 - \frac{t_1}{R_L C}\right)\right) = \frac{V_M t_1}{R_L C}$$

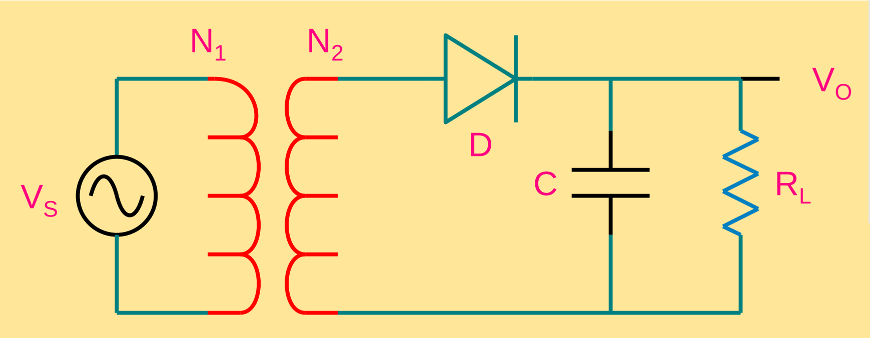
t_1 is the discharging time



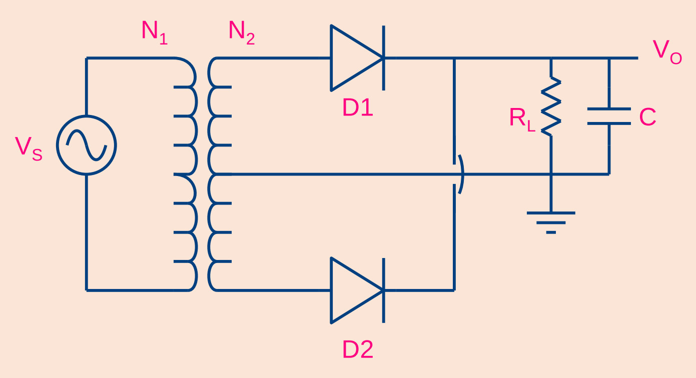
$$t_1 \approx \frac{T}{2}$$

$$V_r = \frac{V_M t_1}{R_L C} \cong \frac{V_M T}{2 R_L C}$$

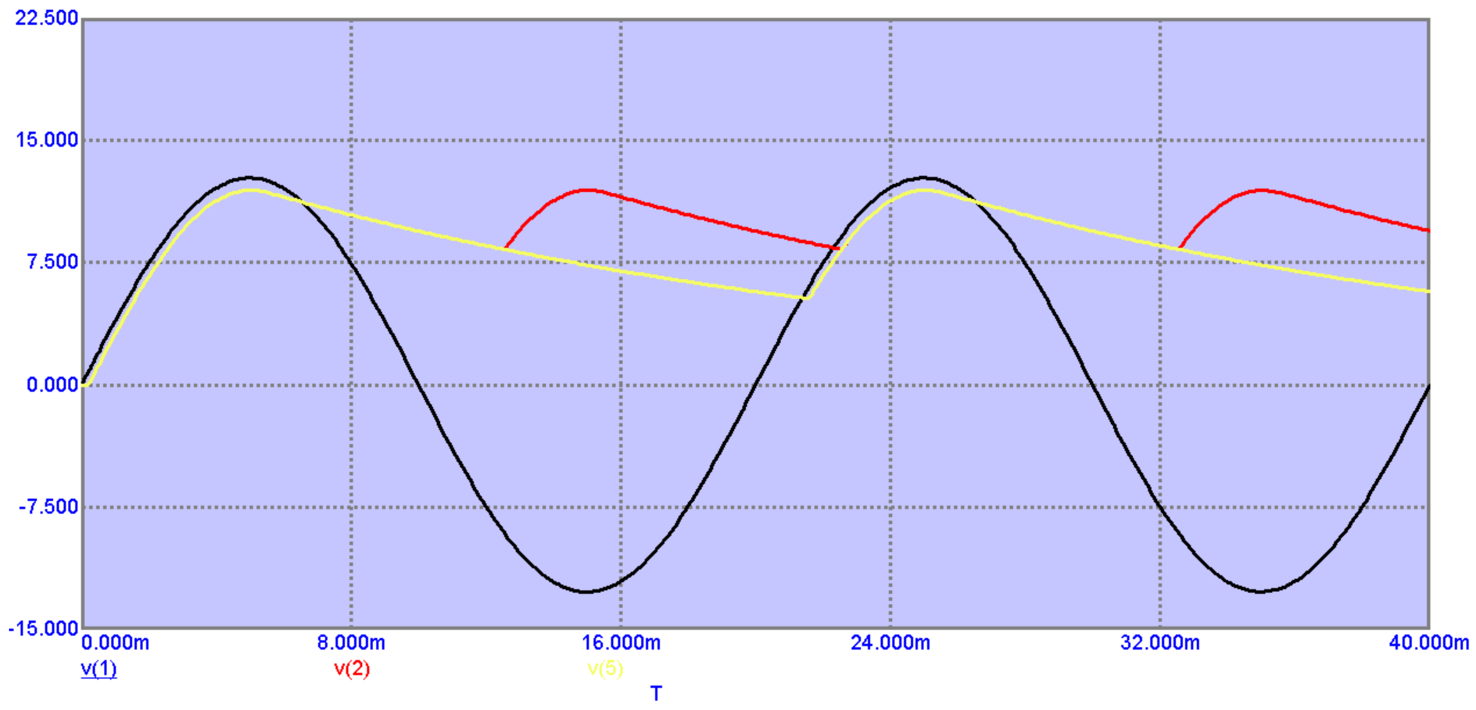
Comparison



$$V_r \cong \frac{V_M}{fR_L C}$$



$$V_r \cong \frac{V_M}{2\,fR_L C}$$



Max. diode current

- All steps of the earlier derivation remain the same

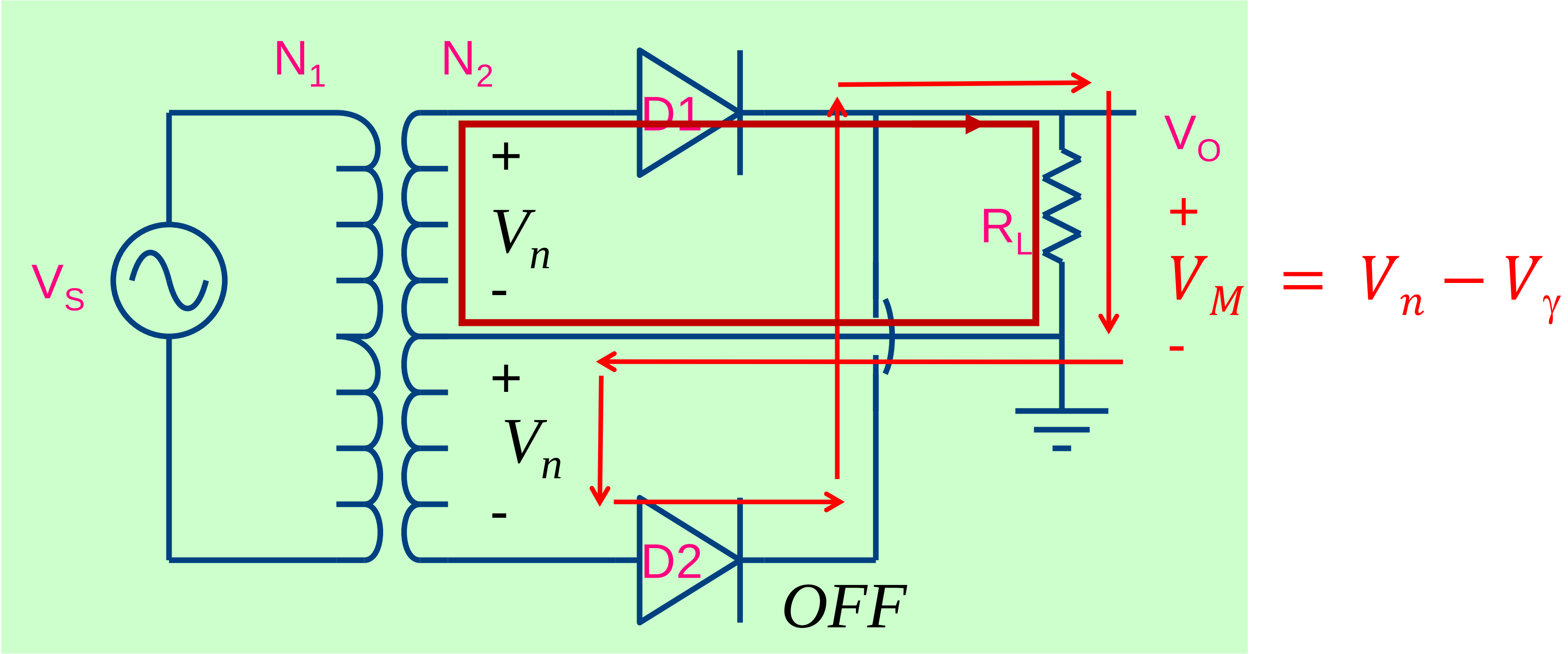
$$\omega \Delta t \approx \sqrt{\frac{2V_r}{V_M}} \qquad i_D(\Delta t) \approx -CV_M\omega^2\Delta t + \frac{V_M}{R_L}$$

- Except the value of V_r is halved

$$i_{D,\max} \approx \frac{V_M}{R_L}\left(1 + 2\pi\sqrt{fCR_L}\right)$$

- Therefore a reduction in $i_{D,\max}$

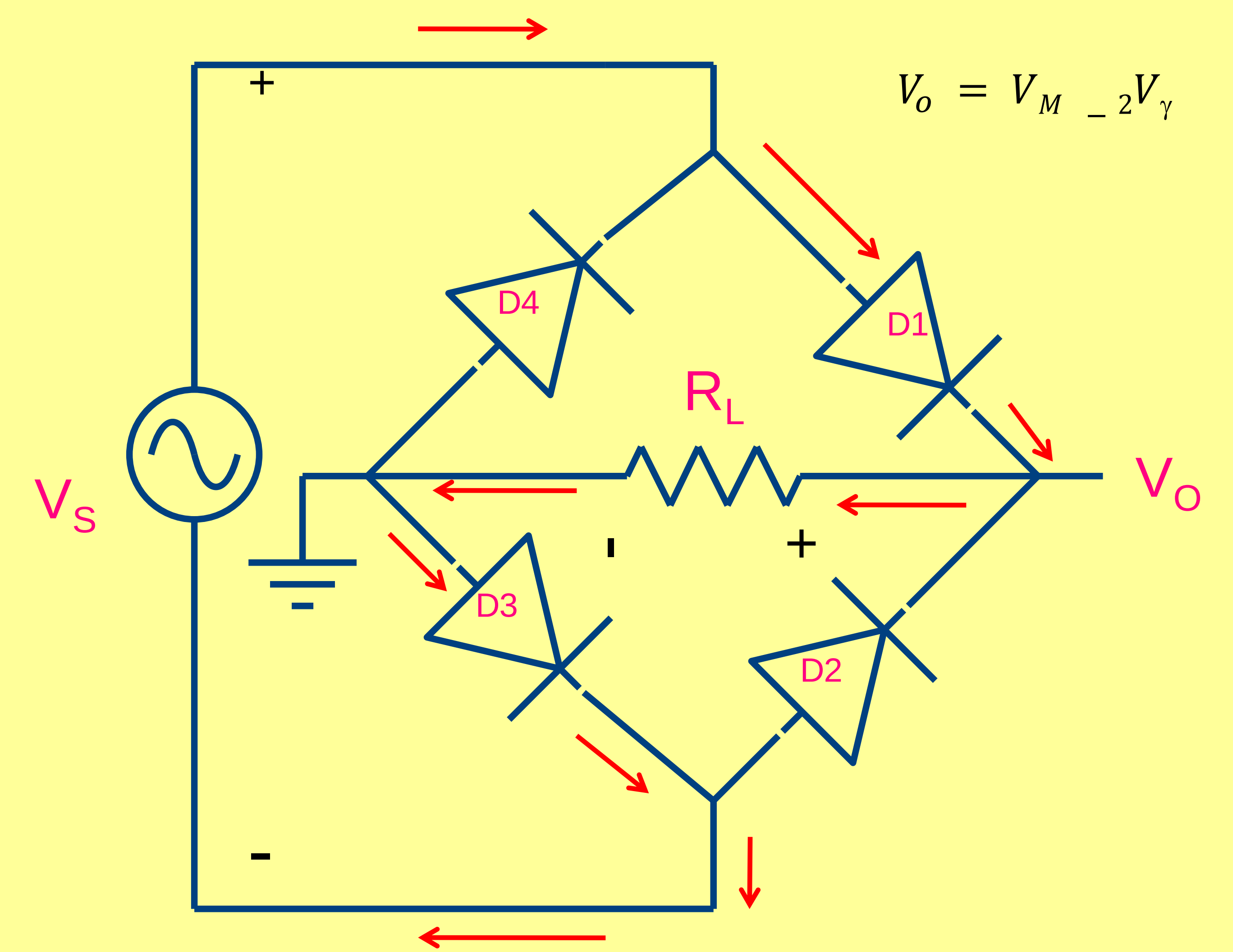
Peak inverse voltage



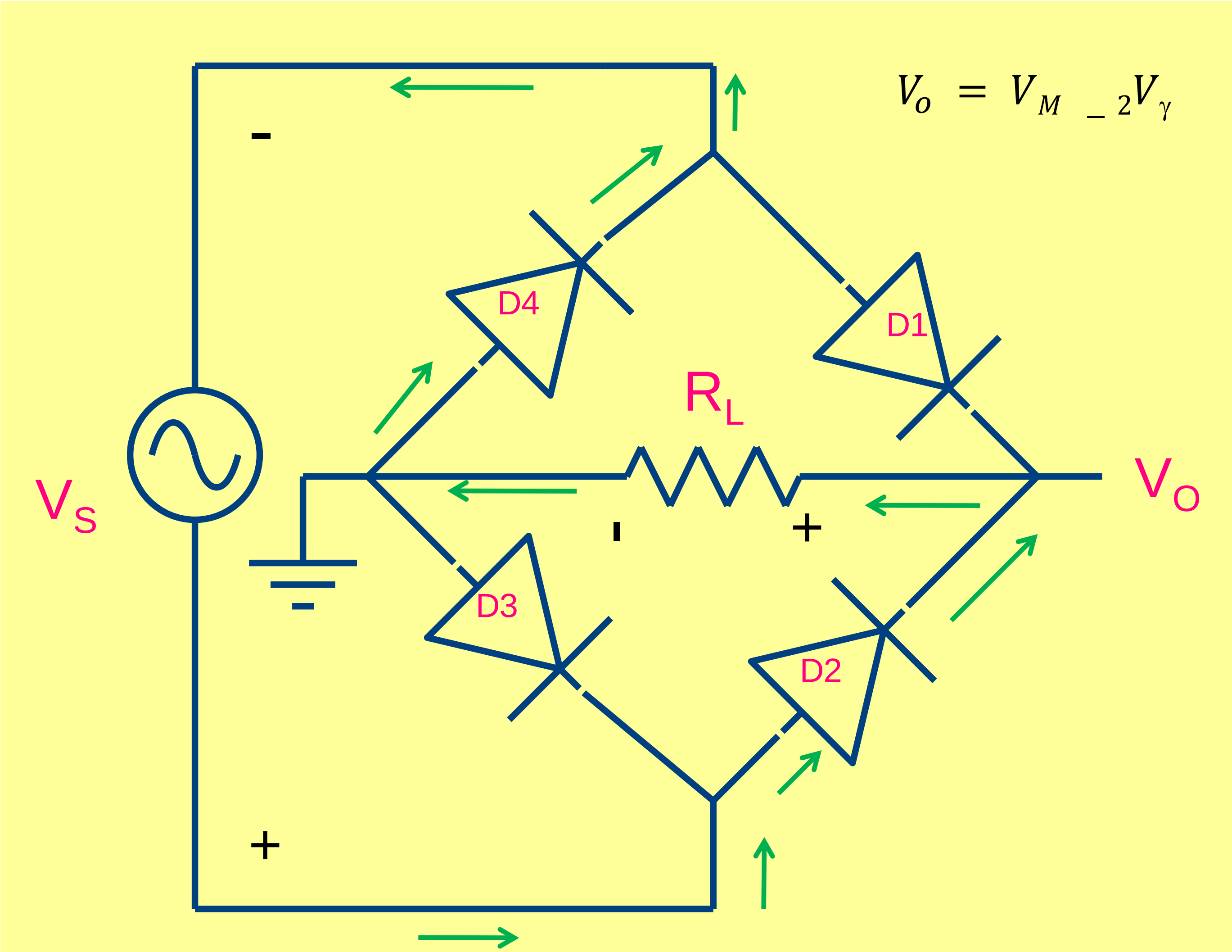
$$V_n \ +VD \ +V_n - V_\gamma \ = \ 0$$

$$\mathrm{PIV} = 2V_n - V_\gamma$$

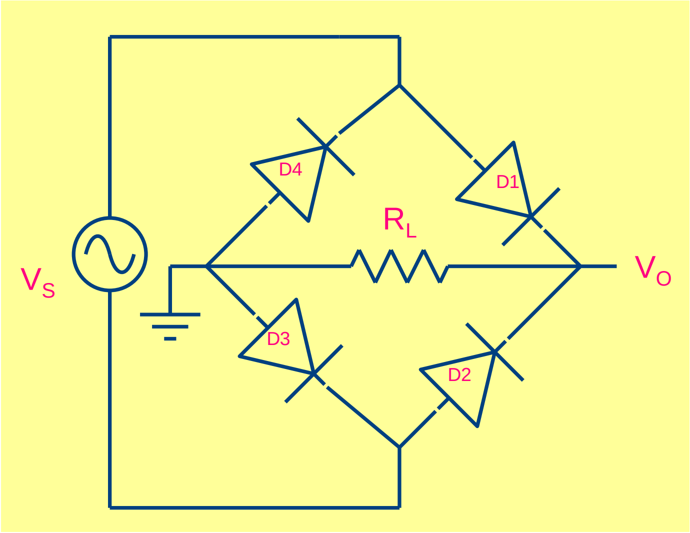
Bridge rectifier

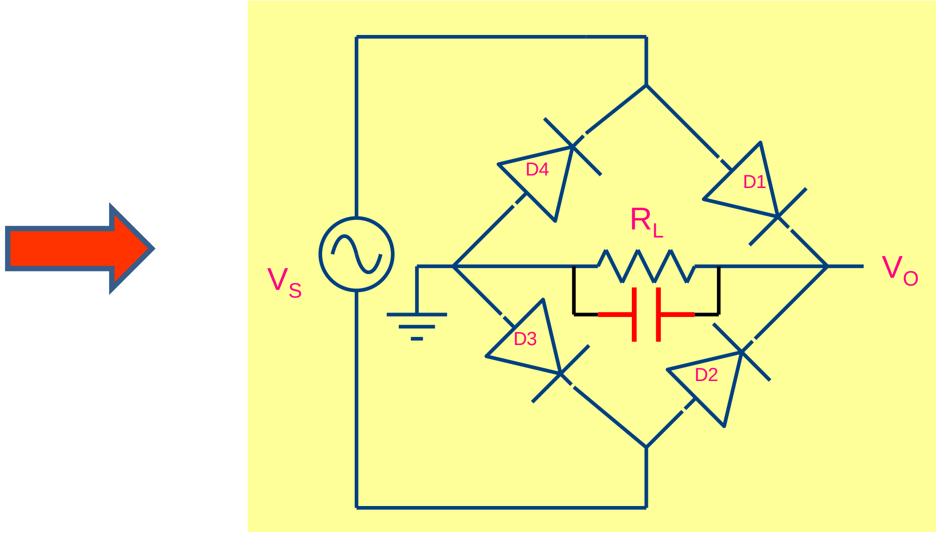


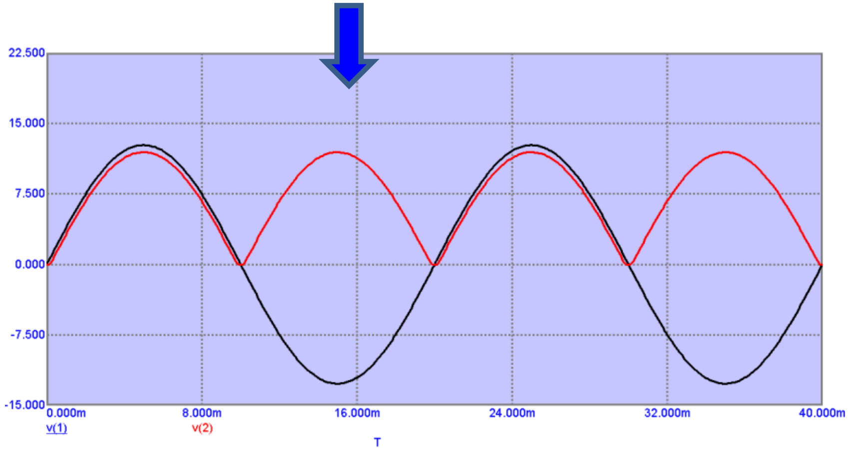
Bridge rectifier

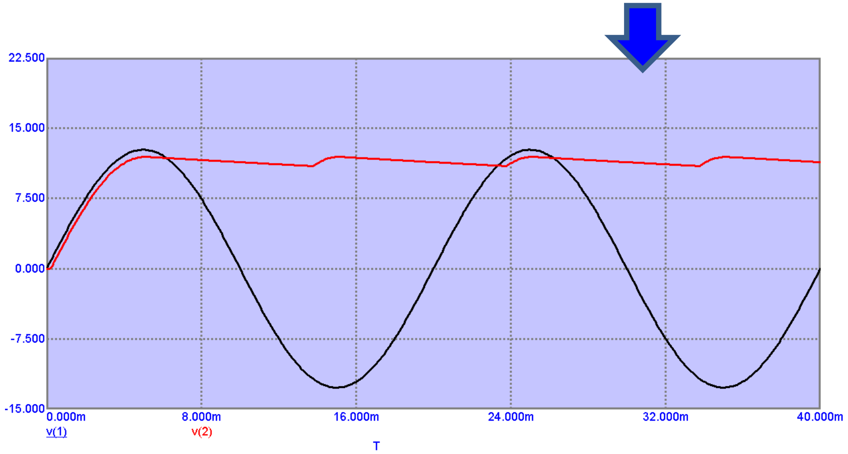


Power supply using full wave Bridge Rectifier



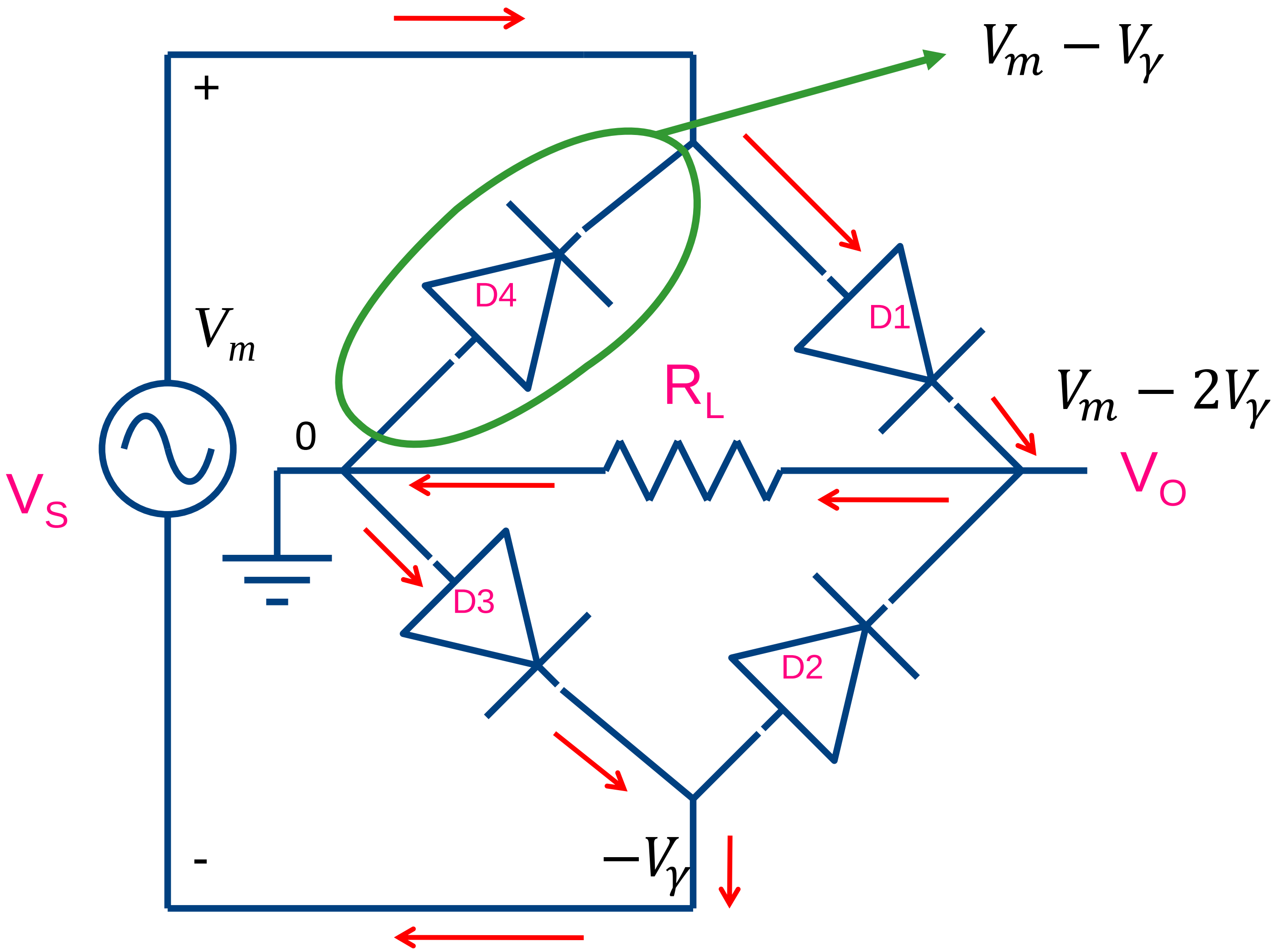




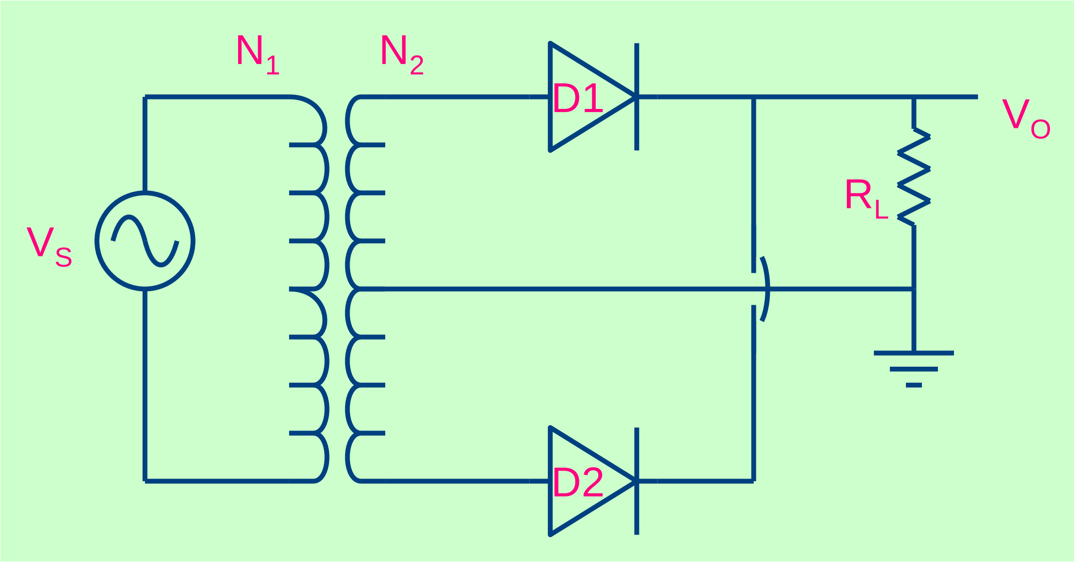


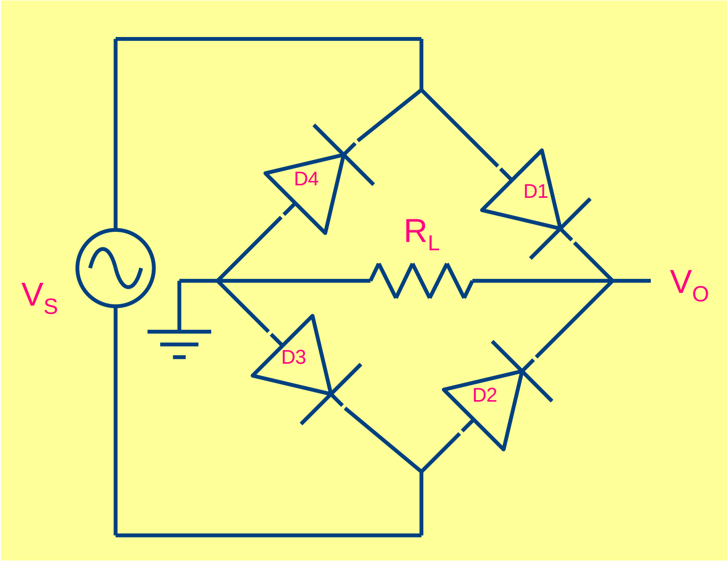
$$V_r \cong \frac{V_M}{2fR_LC}$$

Peak Inverse Voltage



Advantage: lower PIV

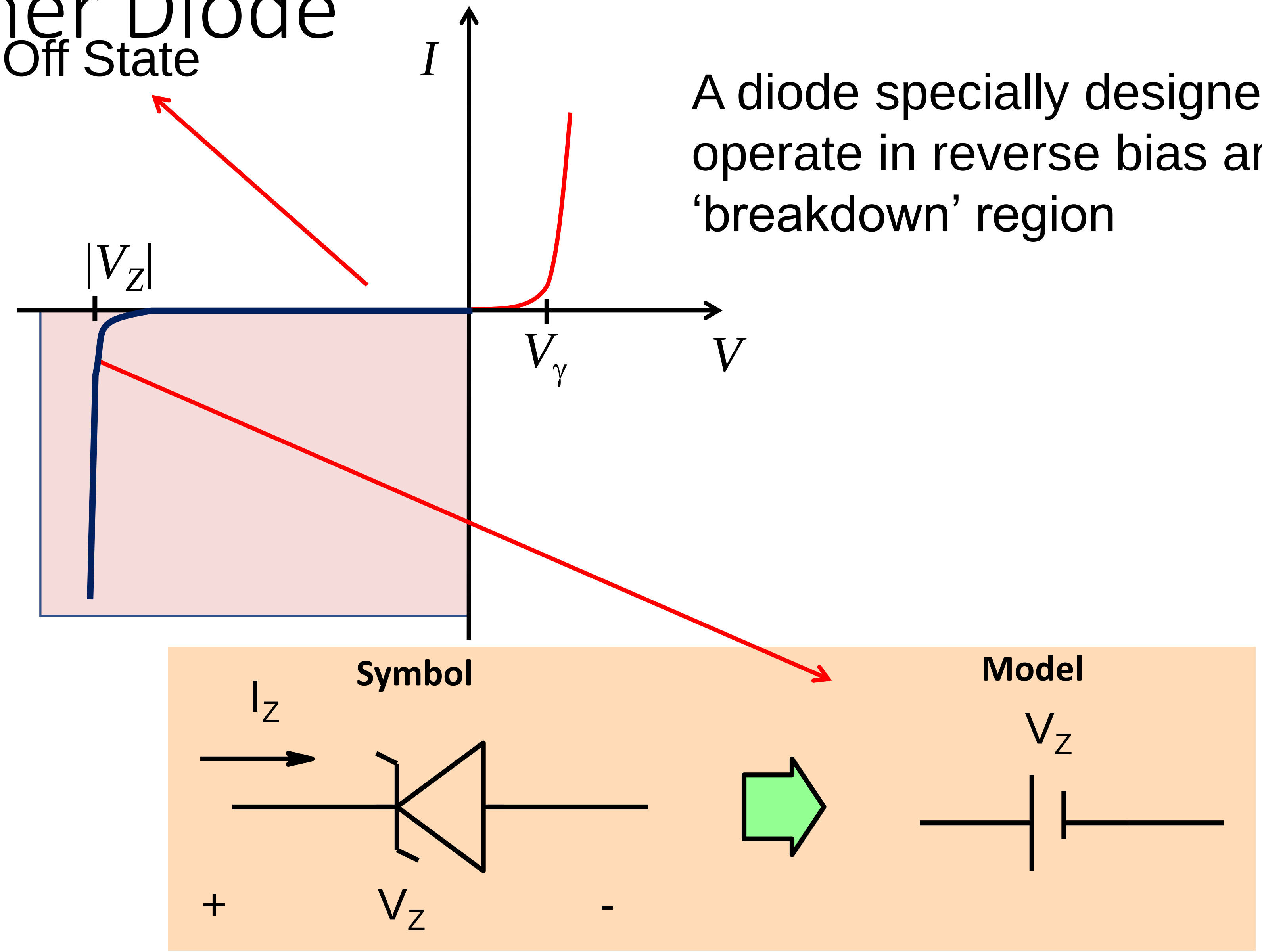




$$\text{PIV} = 2V_m - V_\gamma$$

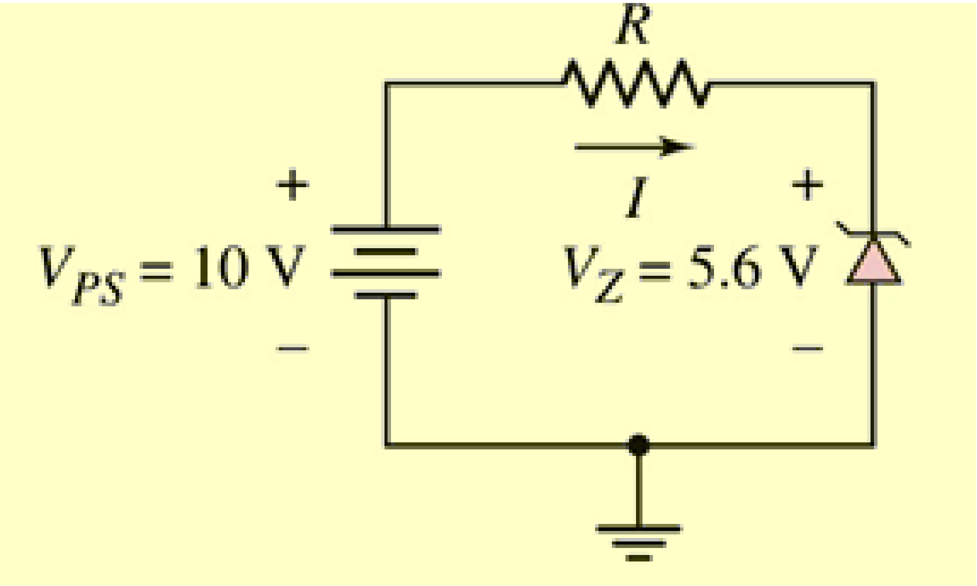
$$\text{PIV} = V_m - V_\gamma$$

Zener Diode



A diode specially designed to operate in reverse bias and in 'breakdown' region

Example

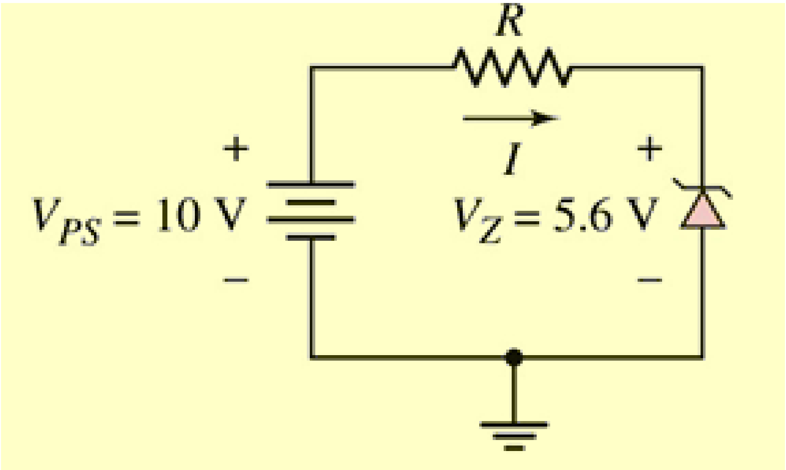


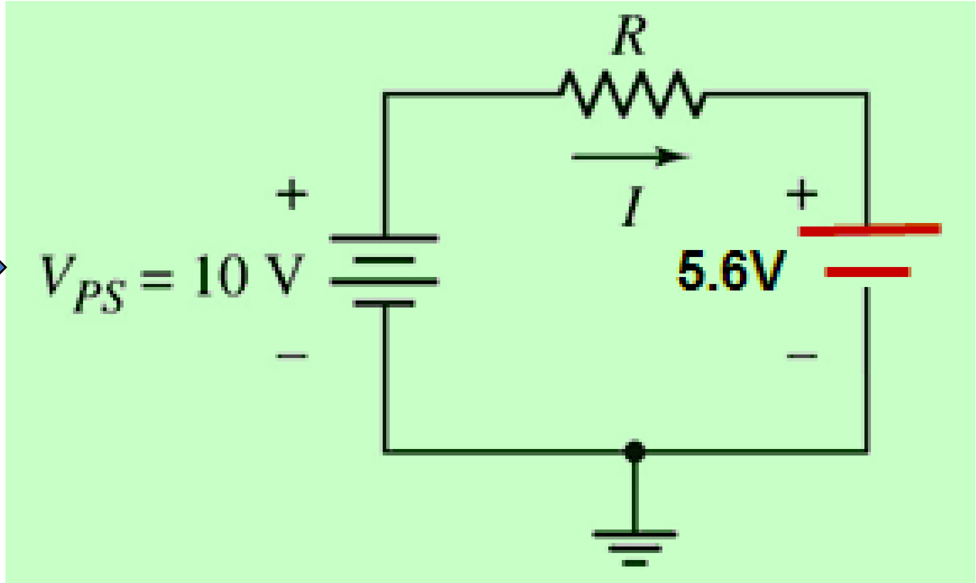
Given $V_Z = 5.6V$

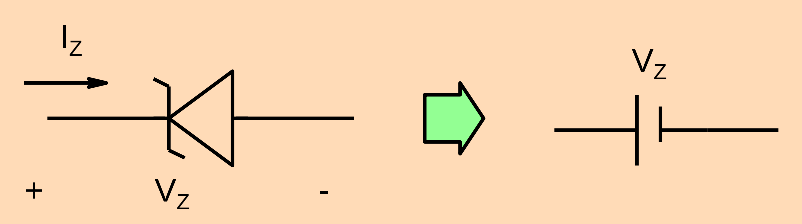
$r_Z = 0\Omega$

Find a value for R such that the current through the diode is limited to 3mA

Example (continued)



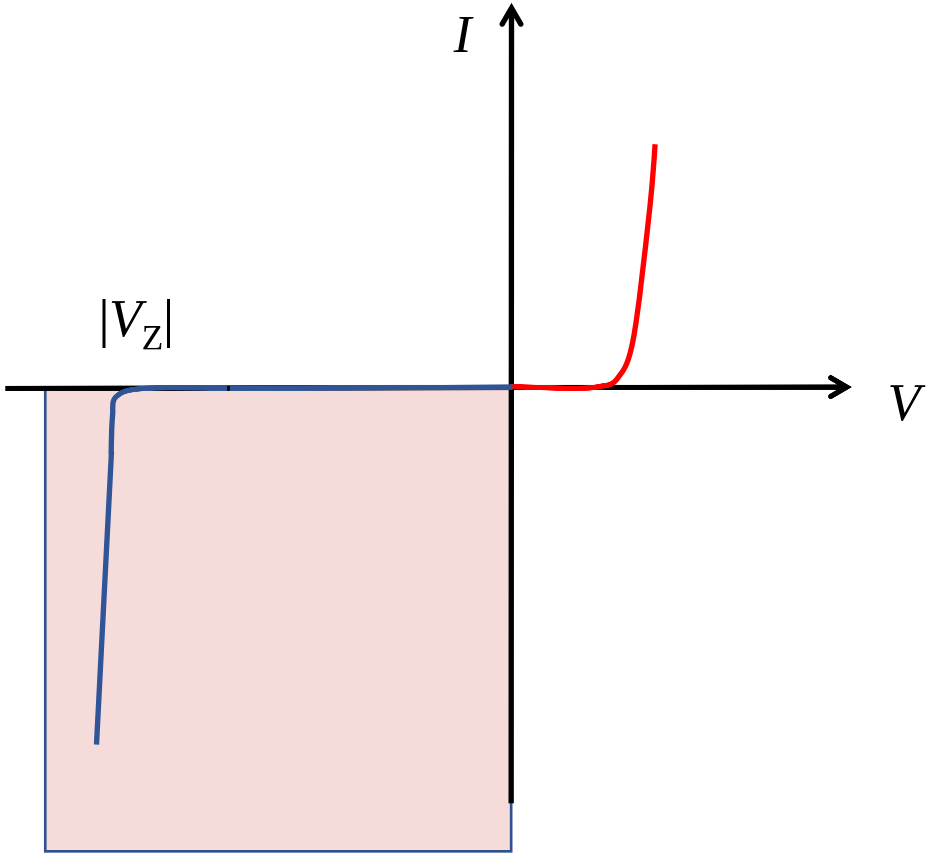




$$I = \frac{V_{PS} - V_Z}{R}$$

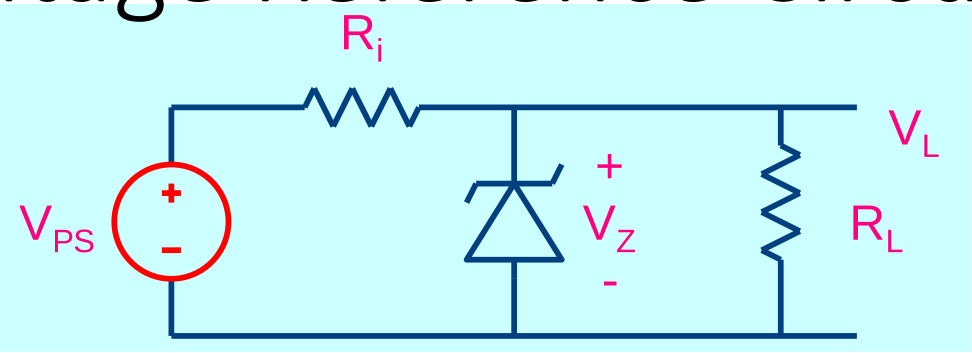
$$R = \frac{V_{PS} - V_Z}{I} = \frac{10V - 5.6V}{3mA} = 1.47k\Omega$$

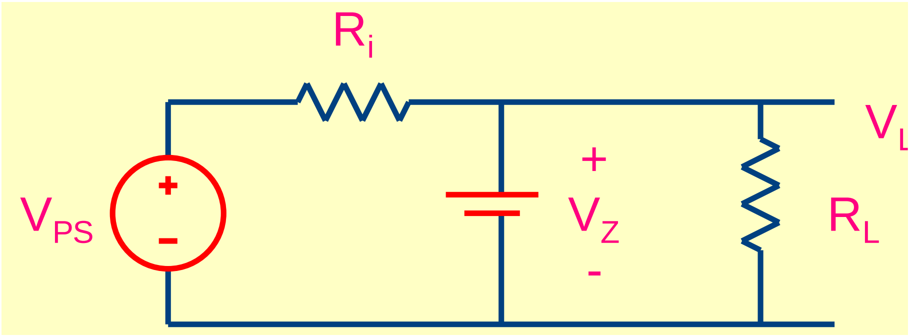
Zener diode: Important Characteristics

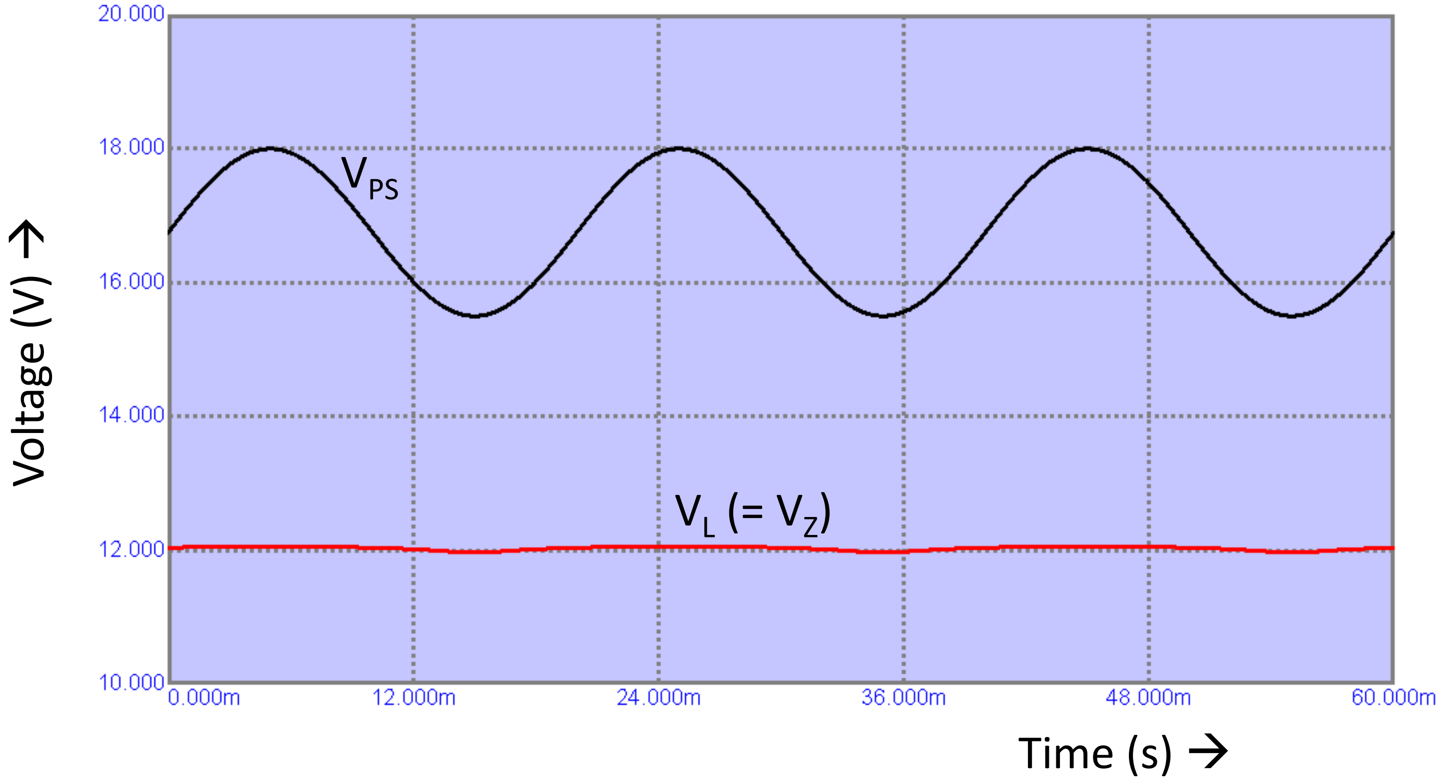


V_Z	Zener voltage → a good reference
$I_Z(\text{max.})$	Maximum current →to safeguard diode
$I_Z(\text{min.})$	Minimum current →to ensure V_Z
P_Z	Maximum Power →to safeguard diode

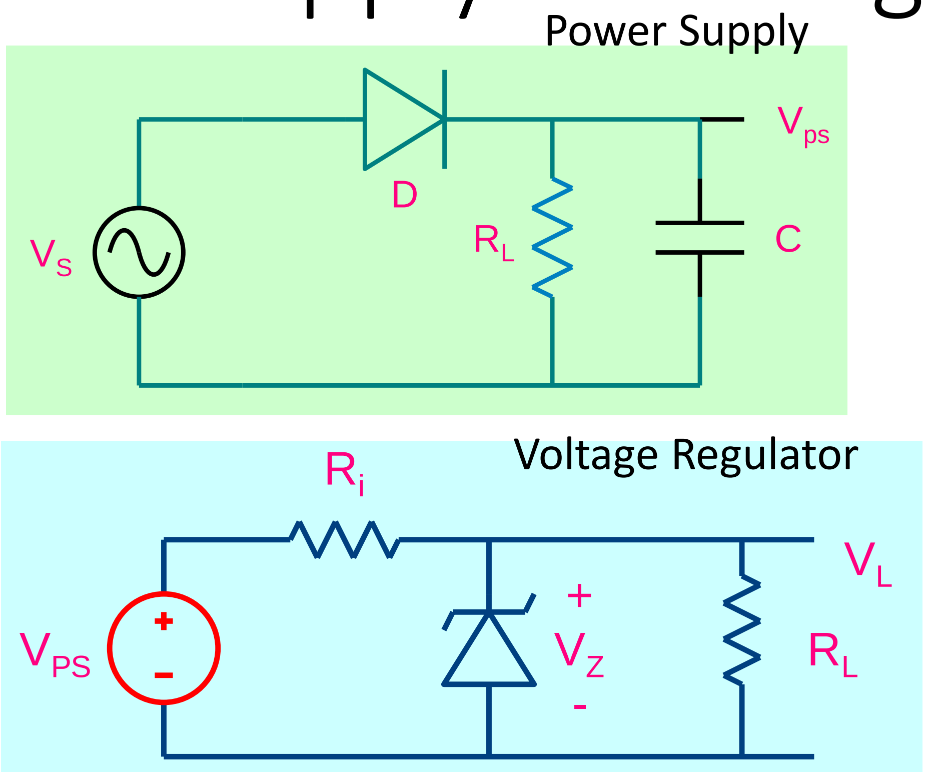
Voltage Reference Circuit

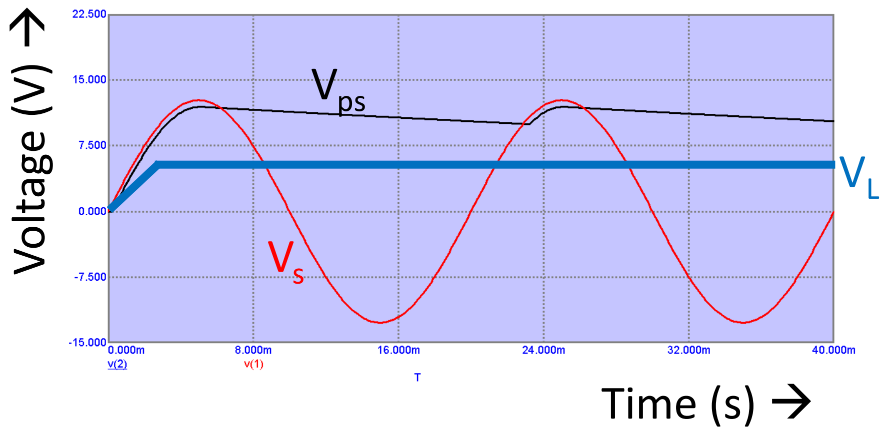




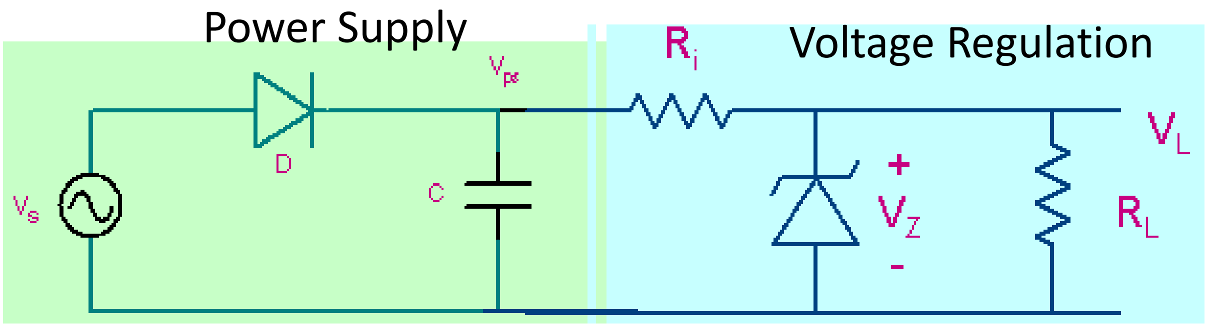


Power Supply with Regulator

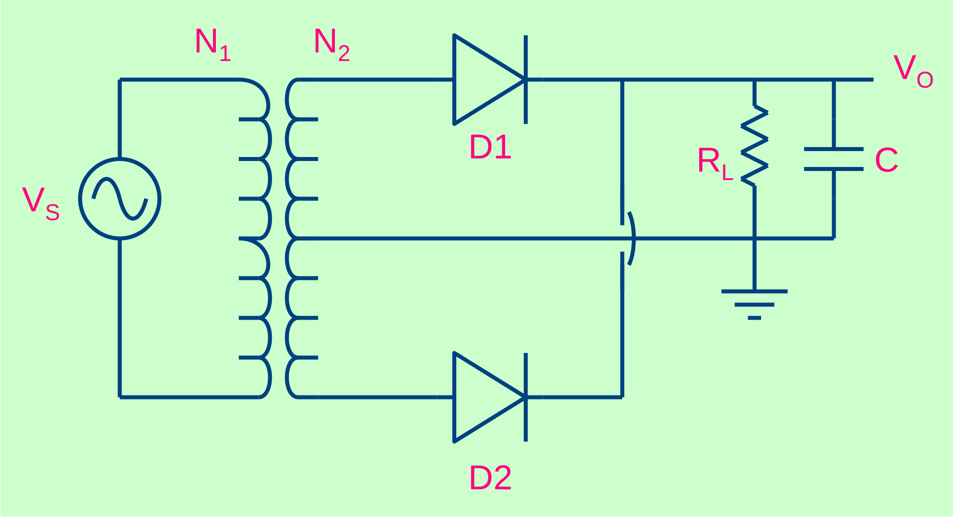




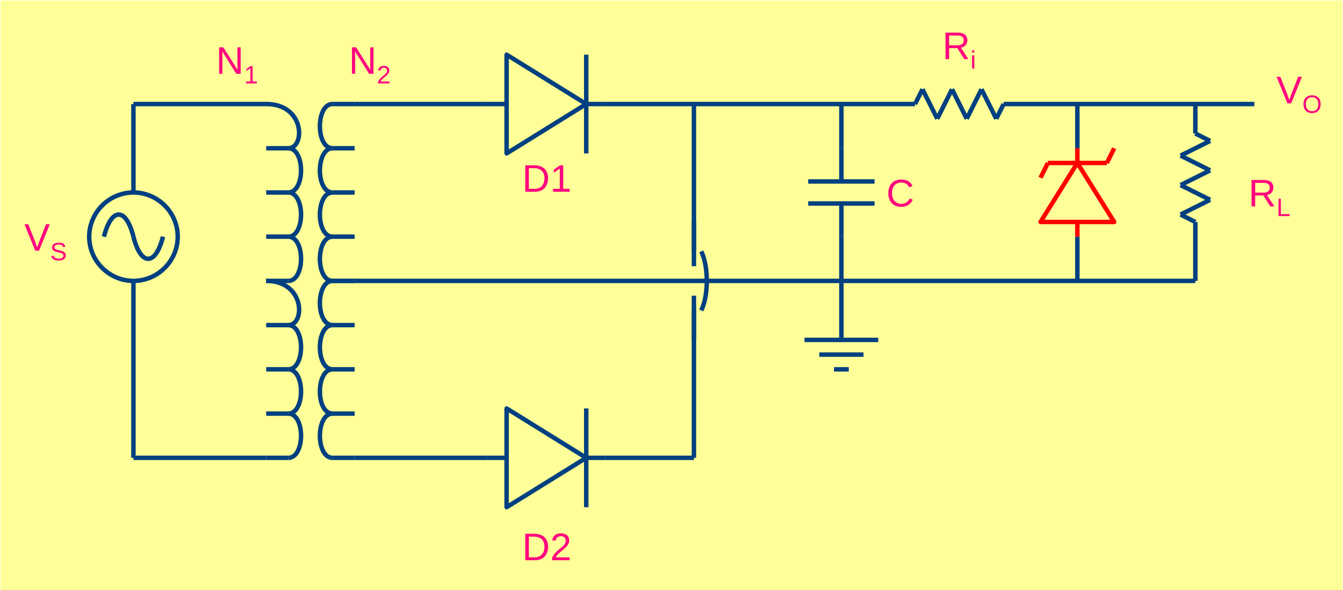
Combine:
Power Supply and Voltage Regulator



Zener Diode as Voltage Regulator

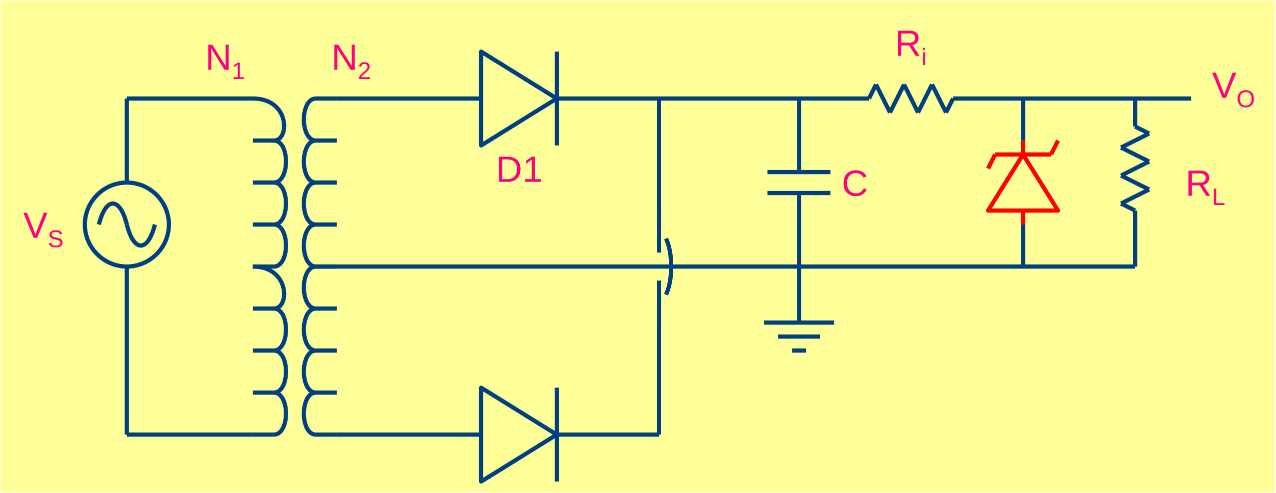


Earlier circuit without Zener

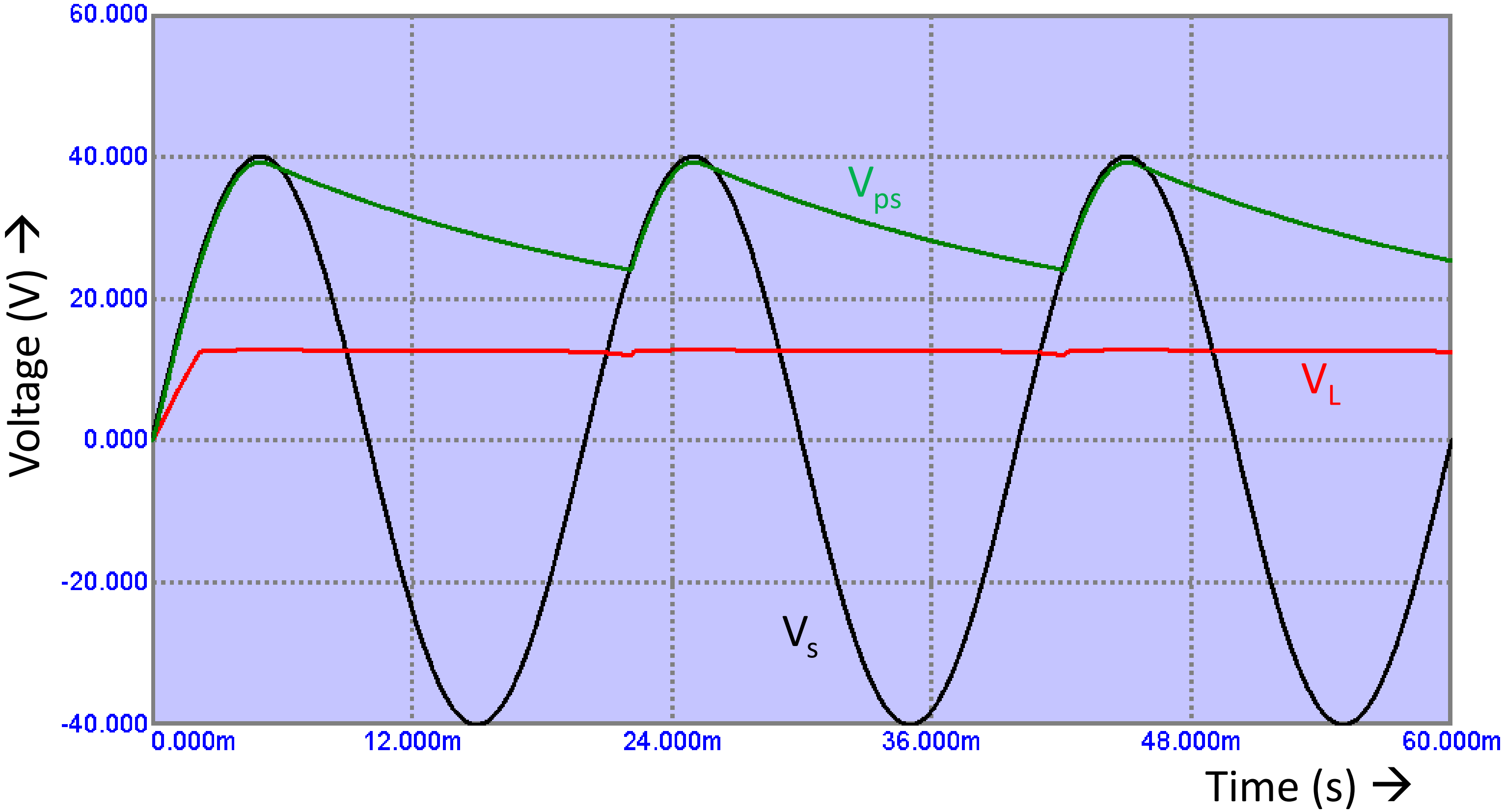


Regulated supply

Zener diode regulates supply



N1
N2
D1
Ri
VO
VS
C
RL



60.000
40.000
20.000
0.000
-20.000
-40.000
Voltage (V) →
Vps
VL
Vs
0.000m
12.000m
24.000m
36.000m
48.000m
60.000m
Time (s) →