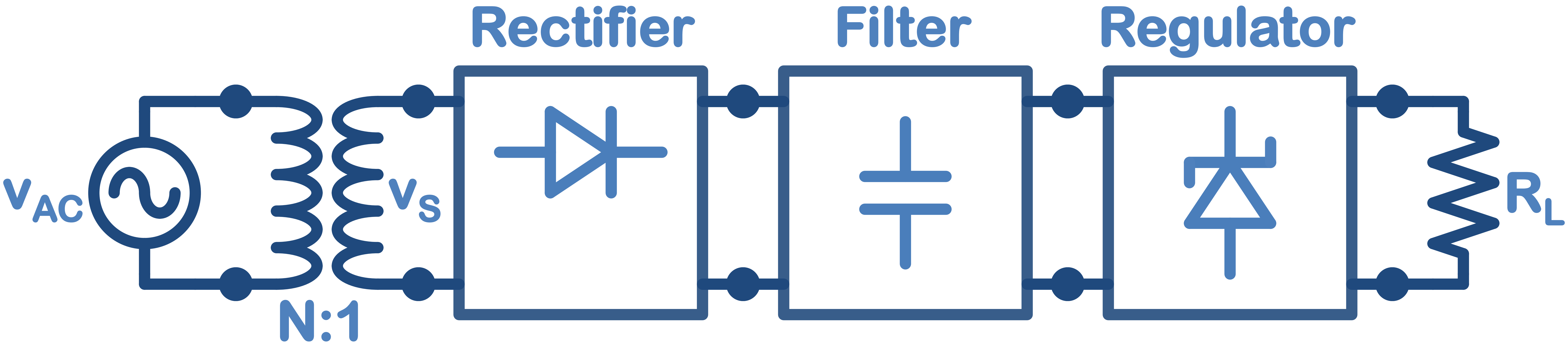
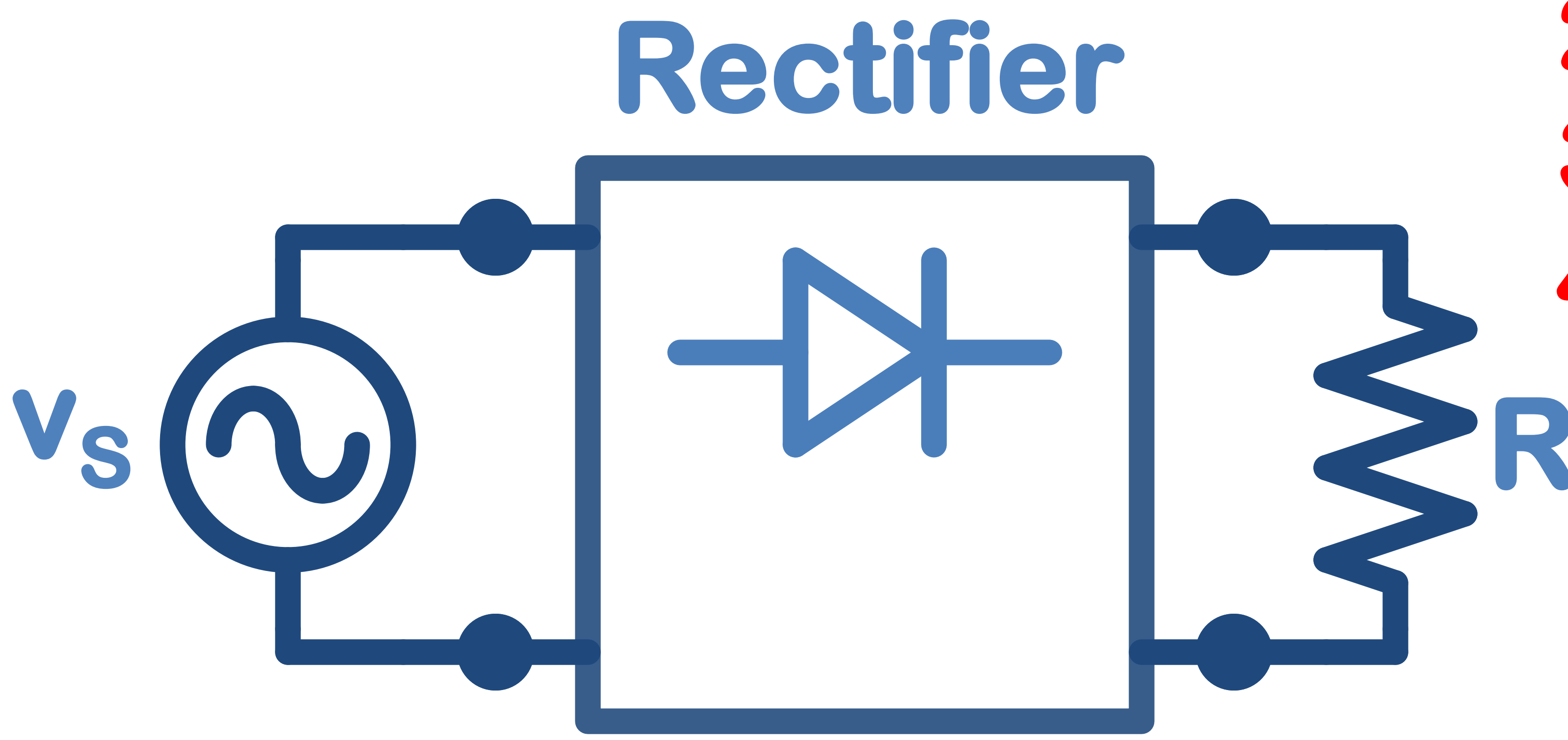
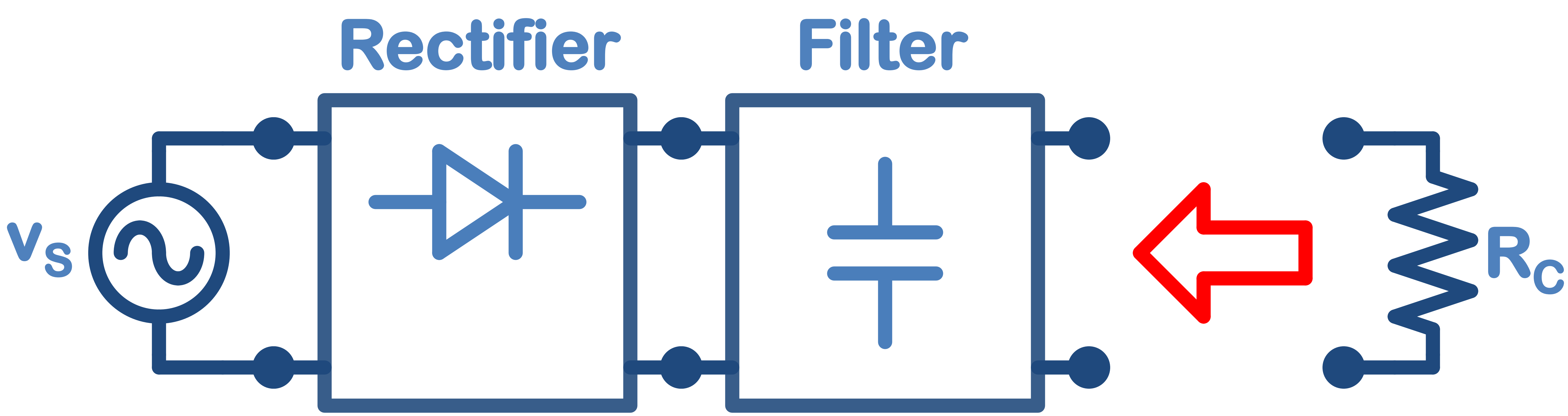
RT1
F2AL250V
C8
R18
C5
U2
105°C(M)
R5
CY3
U5

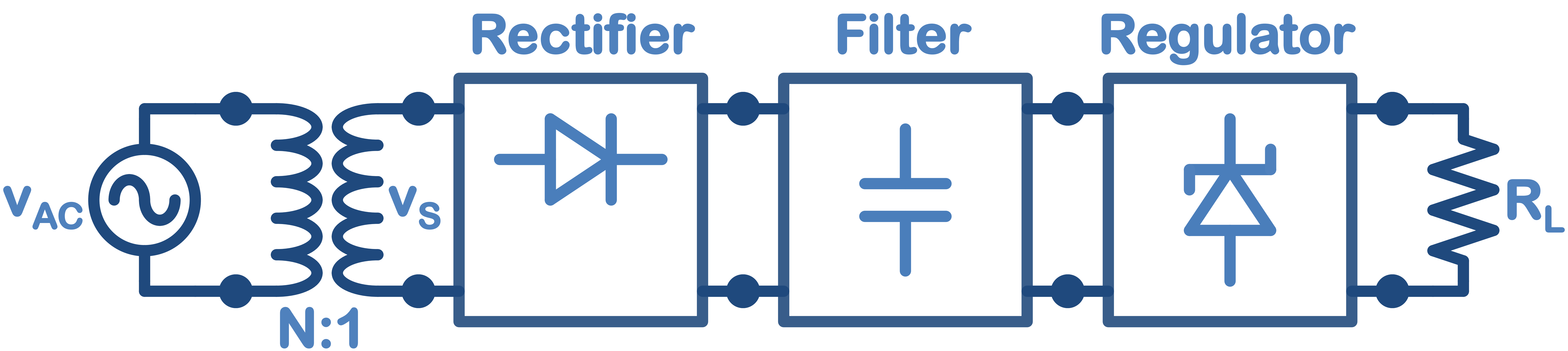


1) Rectifier Circuits w/Resistor.
2) Filter Capacitor.
3) Capacitor & Resistor.
4) Regulator.






PORTER CABLE


Rectifier
Filter
Regulator
V_{AC}
V_S
N:1
R_L

Positive Half Wave Rectifier

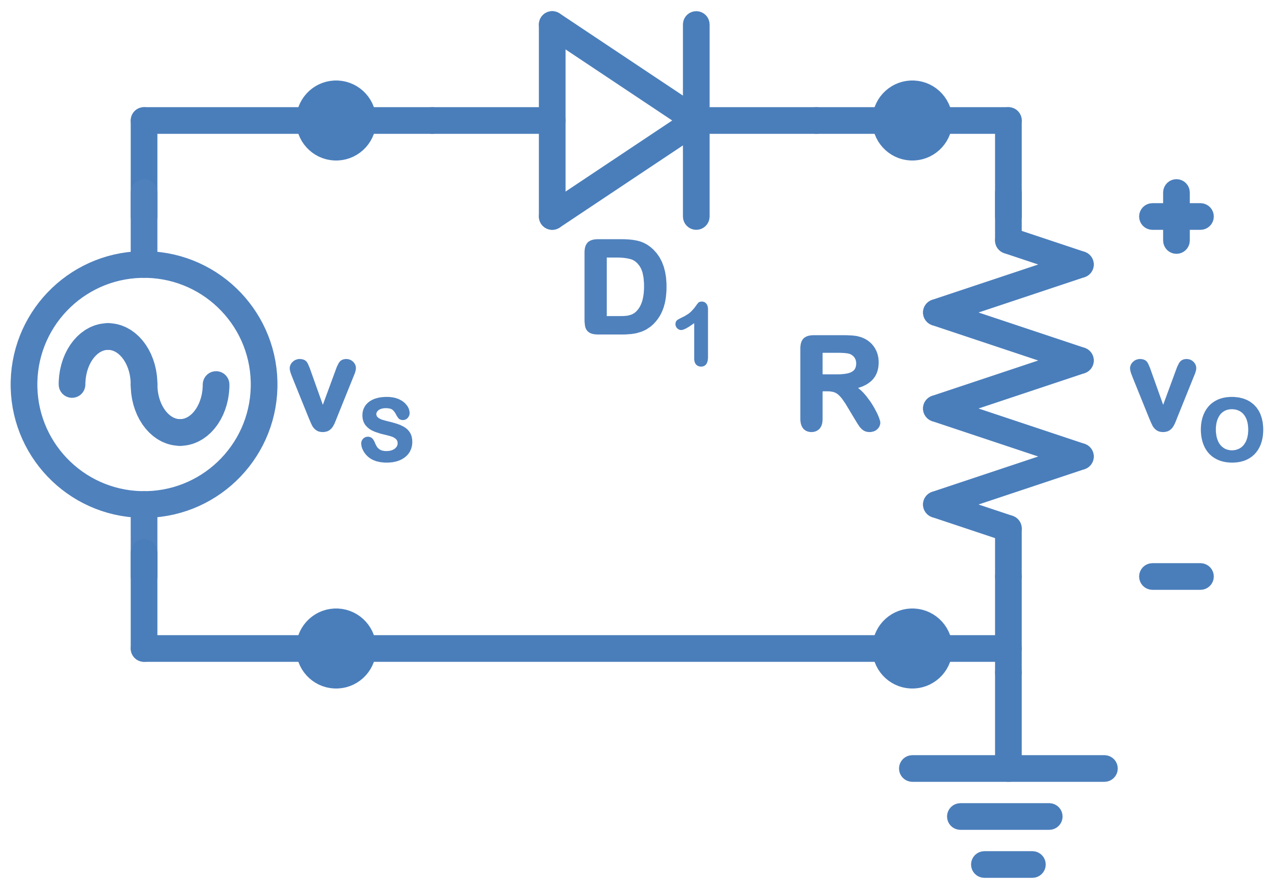
Find the transfer function $v_O(v_S)$

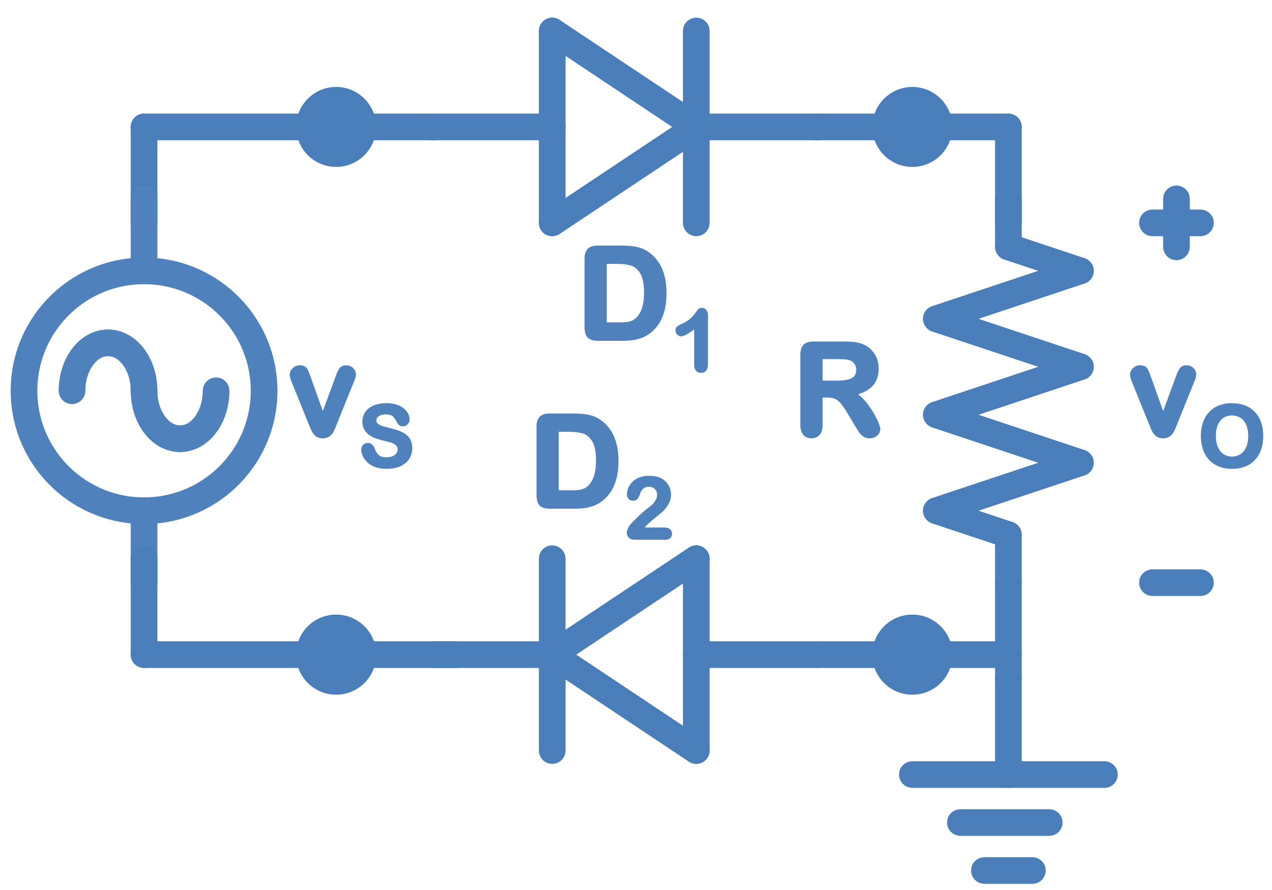
Find the Peak Inverse Voltage

$PIV=\max(-v_D(v_S))$

Plot input & output for a sinusoidal input.

$v_S(t)=V_P\cos(2\pi t/T)$





Positive Half Wave Rectifier

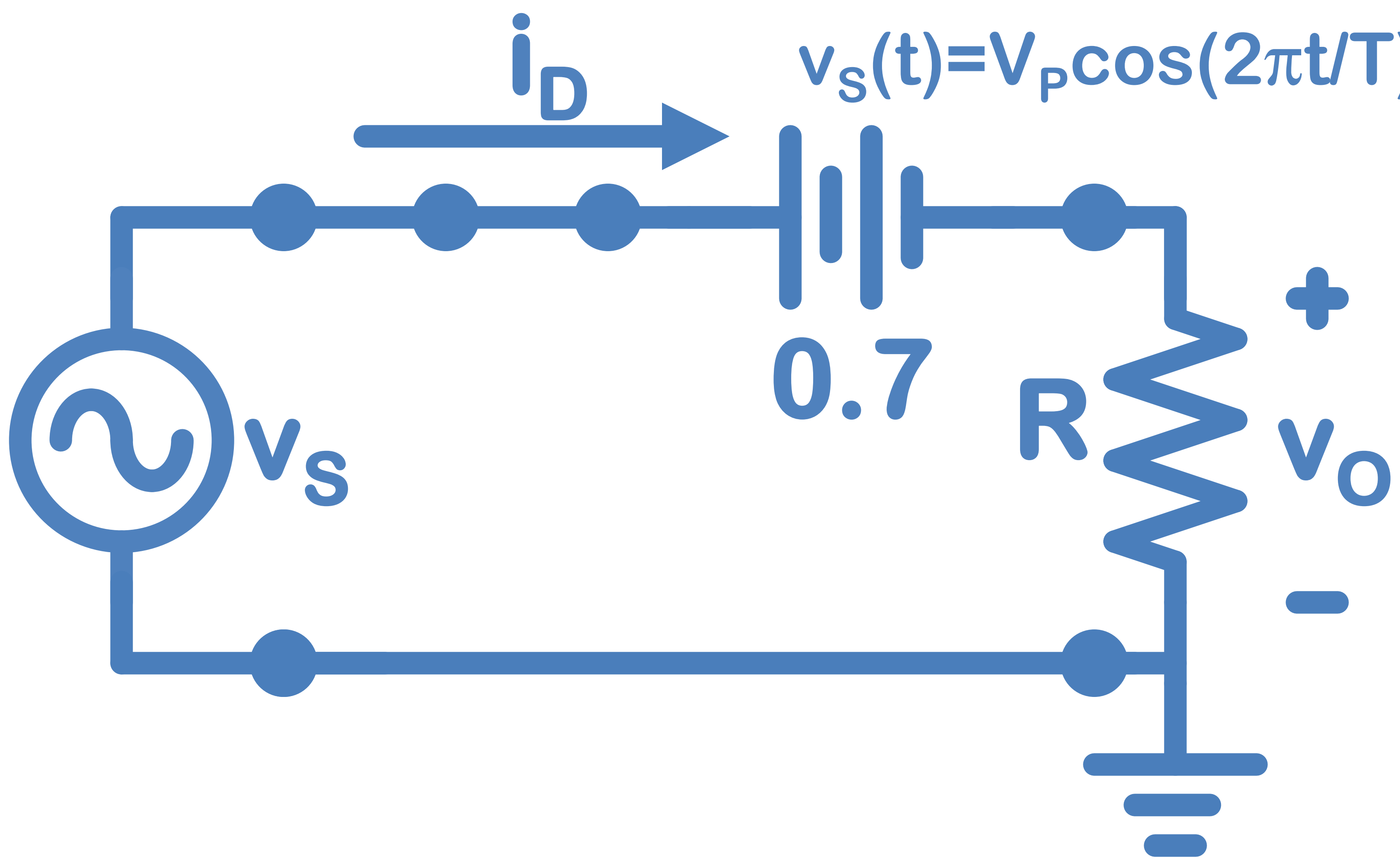
Find the transfer function $v_O(v_S)$

Find the Peak Inverse Voltage

$PIV = \max(-v_D(v_S))$

Plot input & output for a sinusoidal input.

$v_S(t) = V_P \cos(2\pi t/T)$

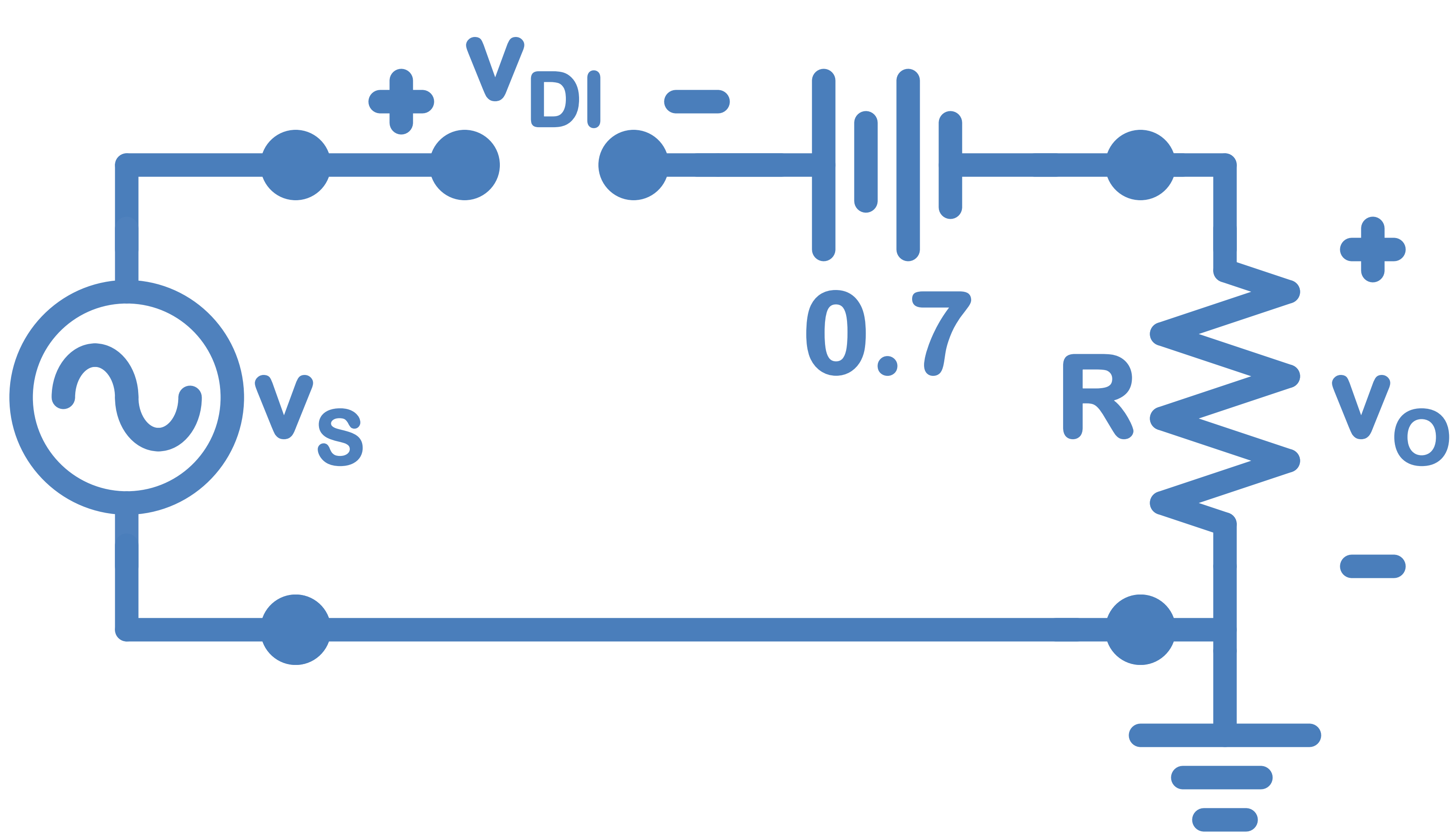


FB: $v_O(v_S) = v_S - 0.7$

$i_D(v_S) = (v_S - 0.7)/R > 0; \; v_S > 0.7$

RB: $v_O(v_S) = 0$

$v_D(v_S) = v_S < 0.7; \; v_S < 0.7$



$v_O(v_S) = v_S - 0.7$ for $v_S > 0.7$

$v_O(v_S) = 0$ for $v_S < 0.7$

PIV: $v_D(v_S) = 0.7$ for $v_S > 0.7$

$v_D(v_S) = v_S$ for $v_S < 0.7$

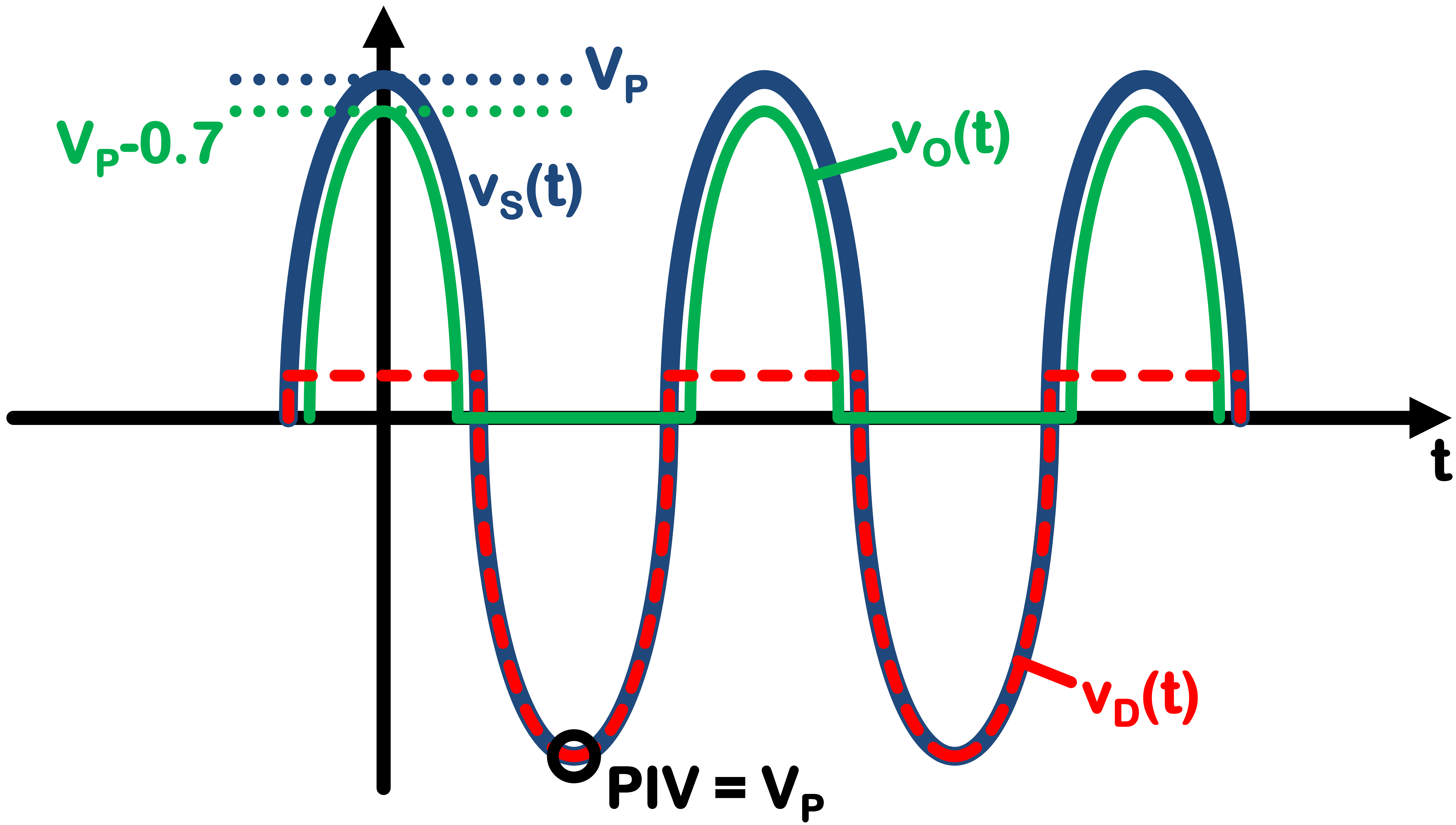
$PIV = \max(-v_D) = V_P$

Positive Half Wave Rectifier (1-Diode)

$v_O(v_S) = v_S - 0.7$ for $v_S > 0.7$

$v_O(v_S) = 0$ for $v_S < 0.7$

$PIV = V_P$

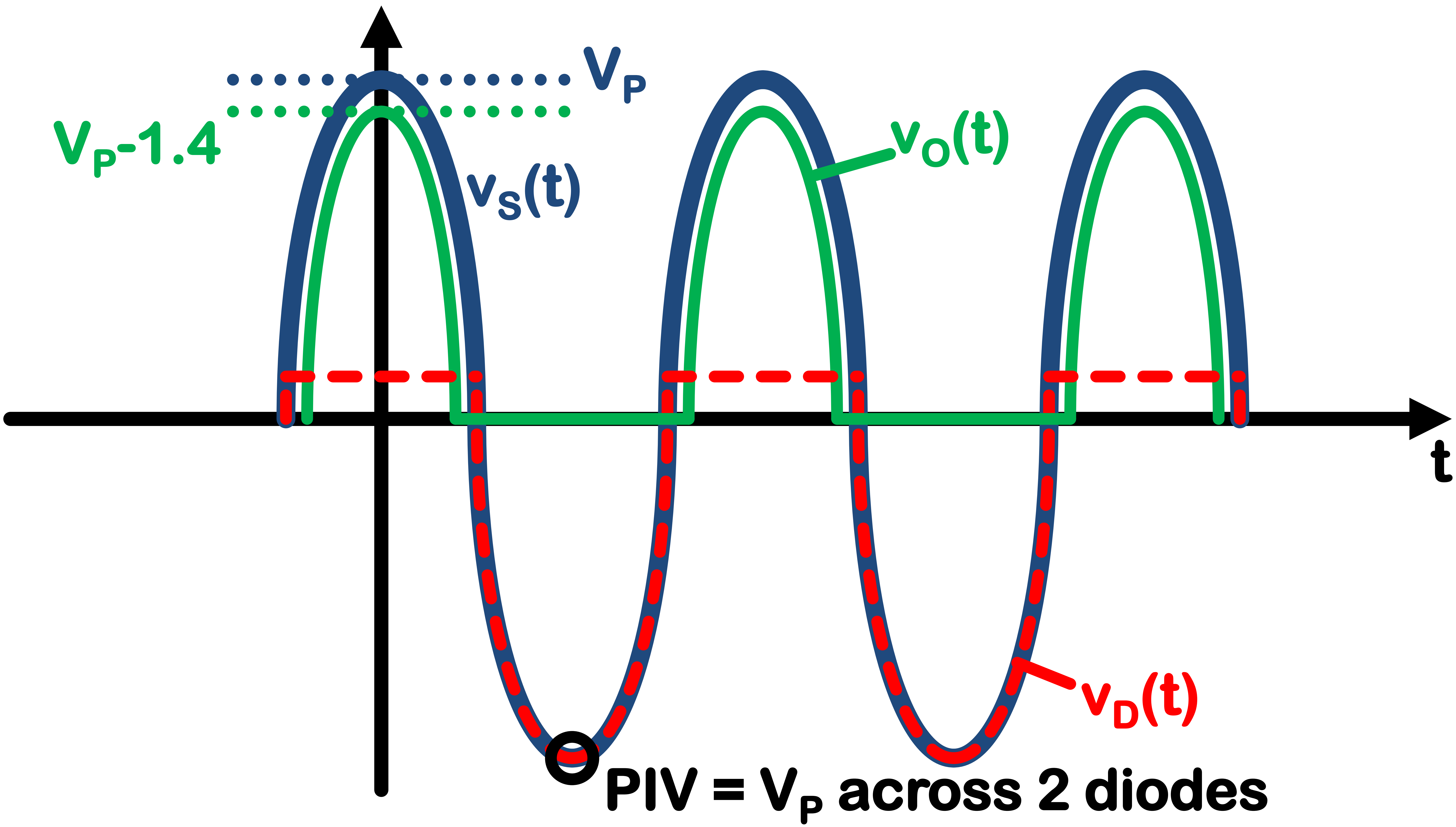


Positive Half Wave Rectifier (2-Diodes)

$v_O(v_S) = v_S - 1.4$ for $v_S > 1.4$

$v_O(v_S) = 0$ for $v_S < 1.4$

PIV = $V_P/2$; half across each diode



Negative Half Wave Rectifier

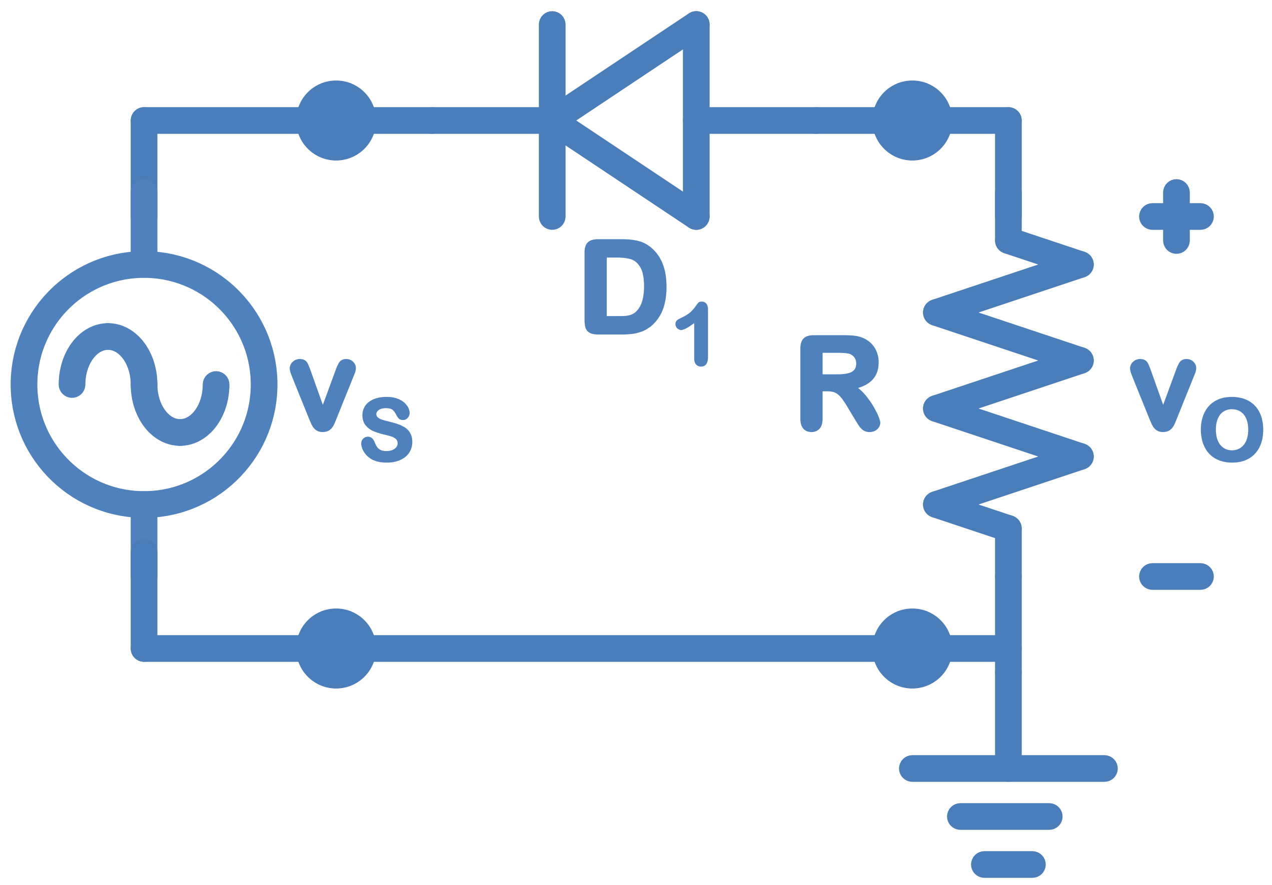
Find the transfer function $v_O(v_S)$

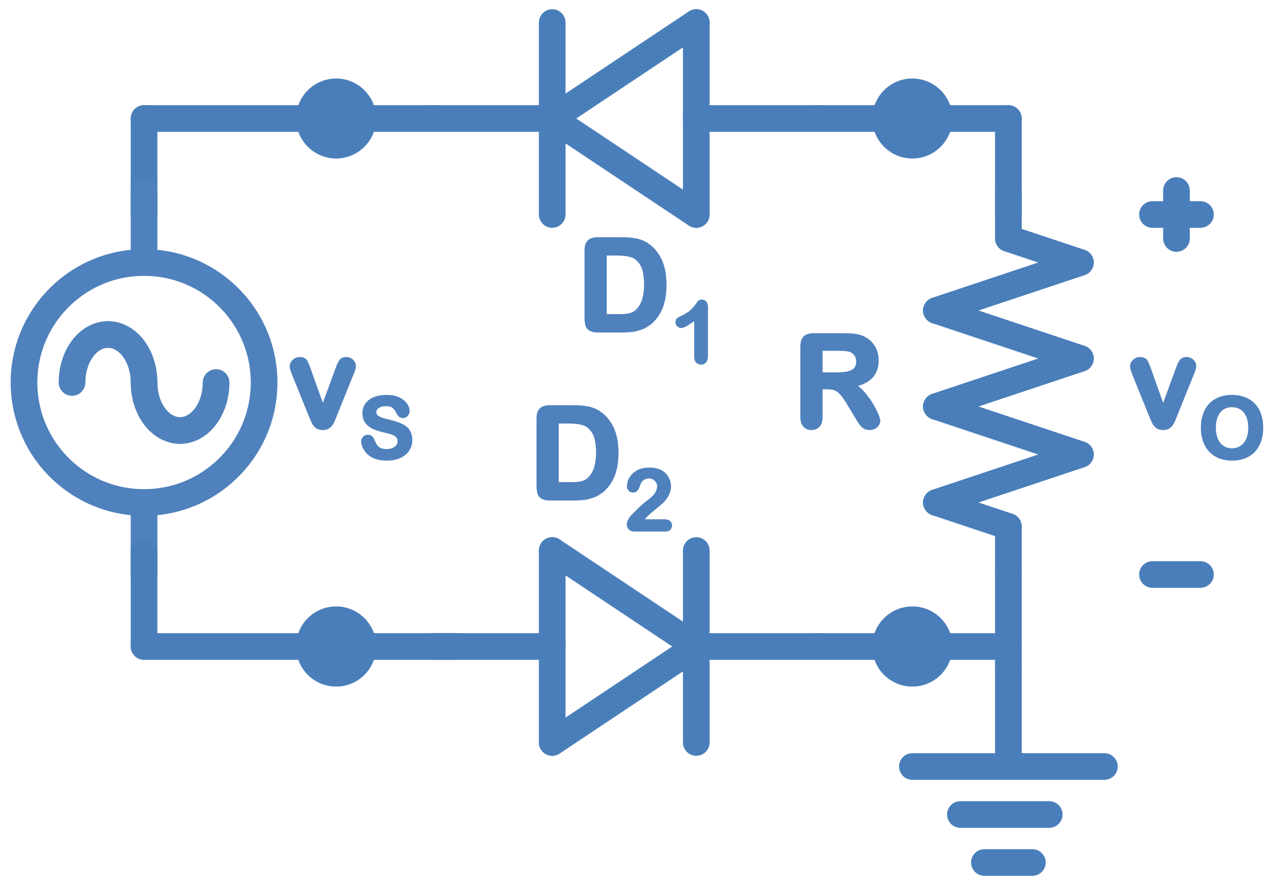
Find the Peak Inverse Voltage

$PIV=max(-v_D(v_S))$

Plot input & output for a sinusoidal input.

$v_S(t)=V_P\cos(2\pi t/T)$





Negative Half Wave Rectifier

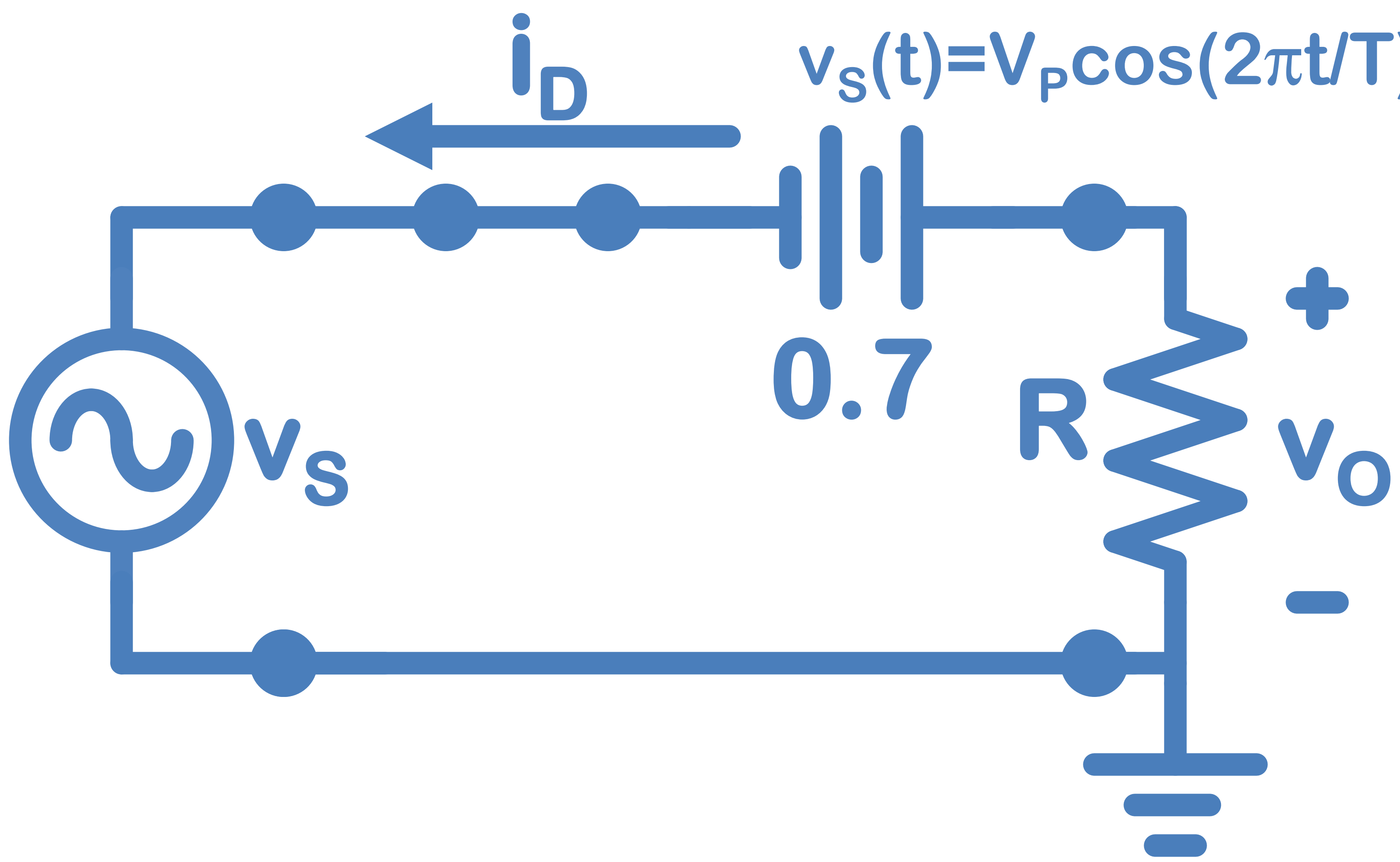
Find the transfer function $v_O(v_S)$

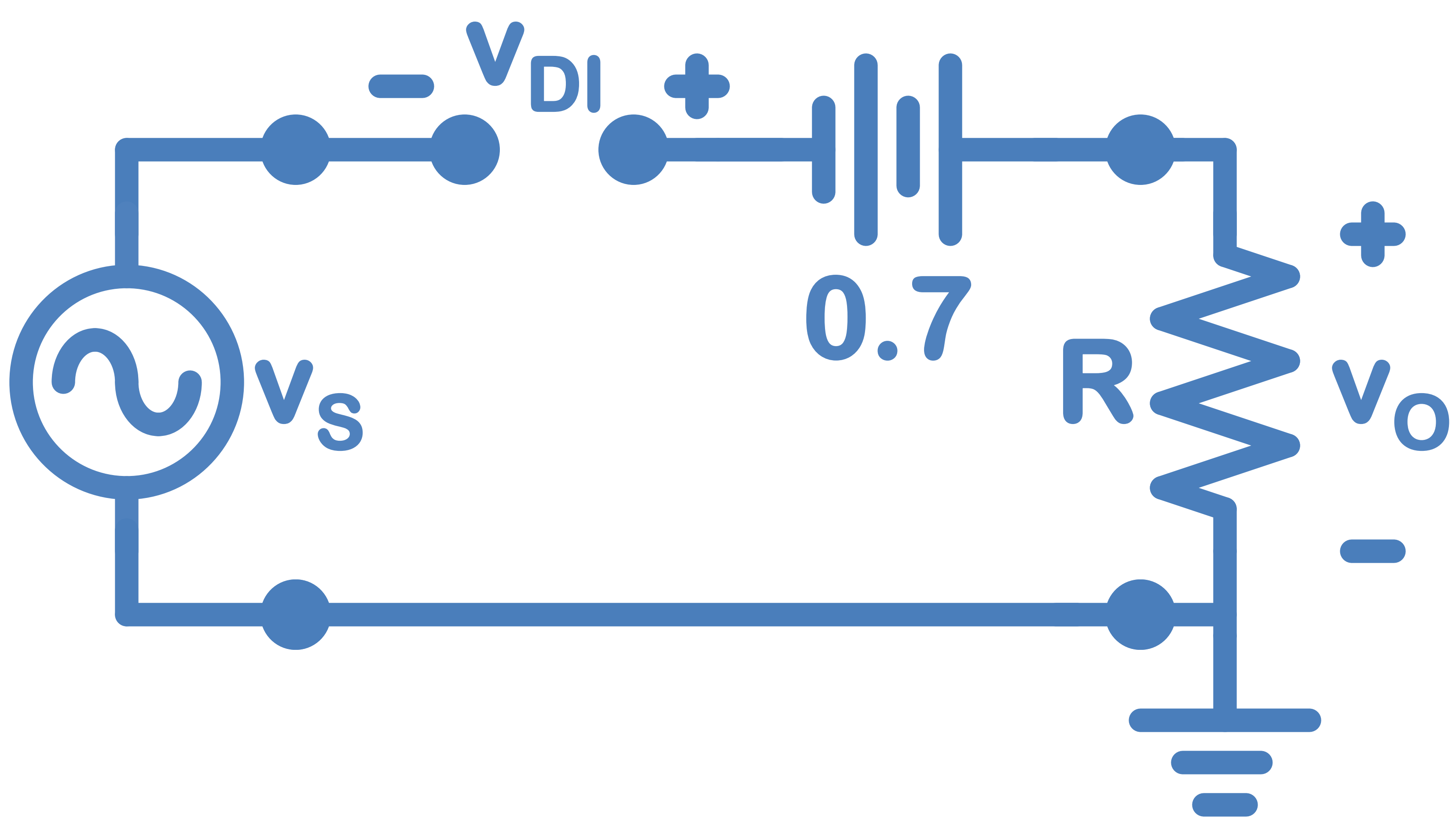
Find the Peak Inverse Voltage

$PIV = \max(-v_D(v_S))$

Plot input & output for a sinusoidal input.

$v_S(t) = V_P \cos(2\pi t/T)$





FB: $v_O(v_S) = v_S + 0.7$

$i_D(v_S) = -(v_S + 0.7)/R > 0;\ v_S < -0.7$

RB: $v_O(v_S) = 0$

$v_D(v_S) = -v_S < 0;\ v_S > -0.7$

$v_O(v_S) = v_S + 0.7$ for $v_S < -0.7$

$v_O(v_S) = 0$ for $v_S > -0.7$

PIV: $v_D(v_S) = 0.7$ for $v_S < -0.7$

$v_D(v_S) = -v_S$ for $v_S > -0.7$

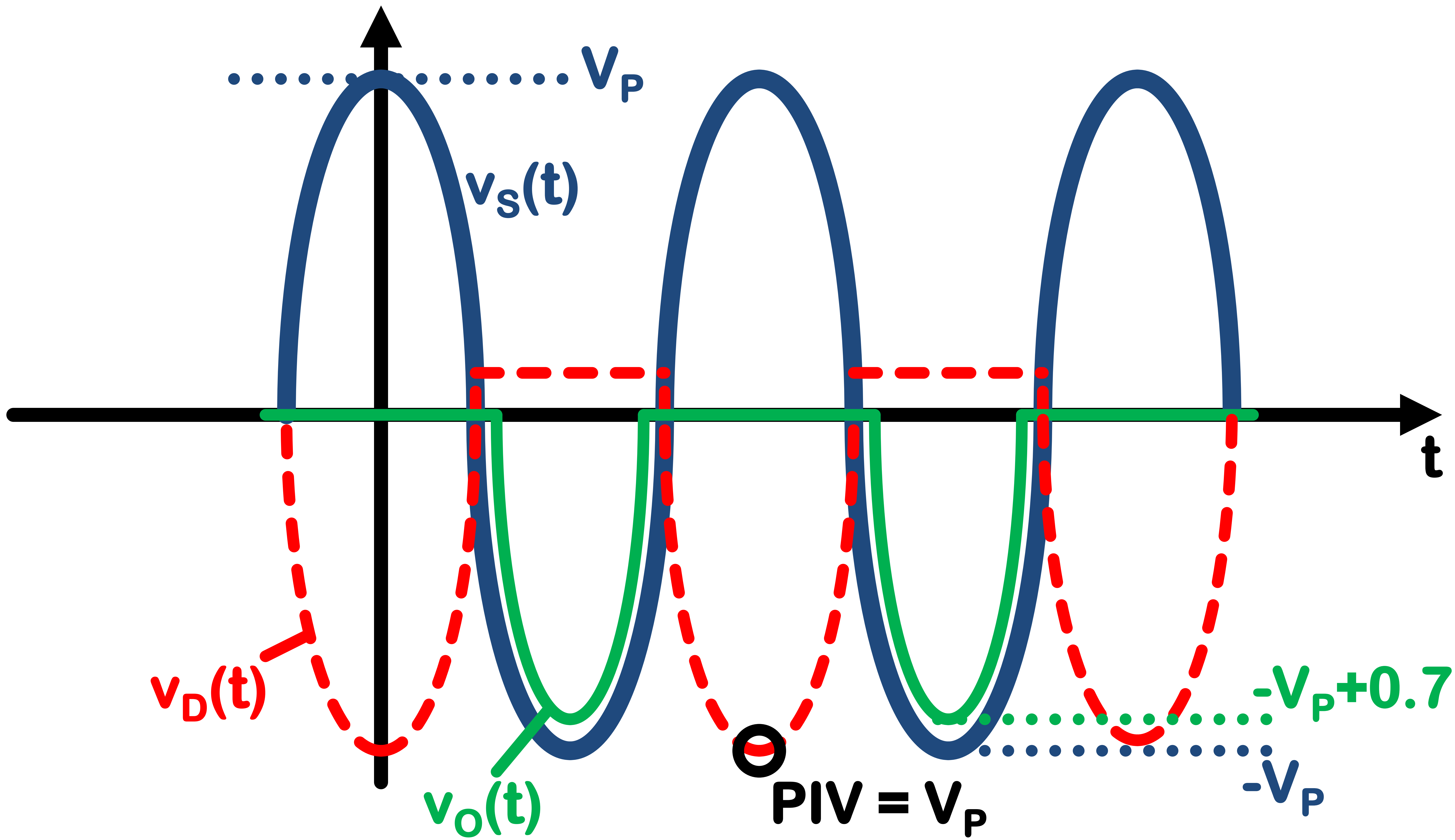
$PIV = \max(-v_D) = V_P$

Negative Half Wave Rectifier (1-Diode)

$v_O(v_S) = v_S + 0.7$ for $v_S < -0.7$

$v_O(v_S) = 0$ for $v_S > -0.7$

$PIV = V_P$

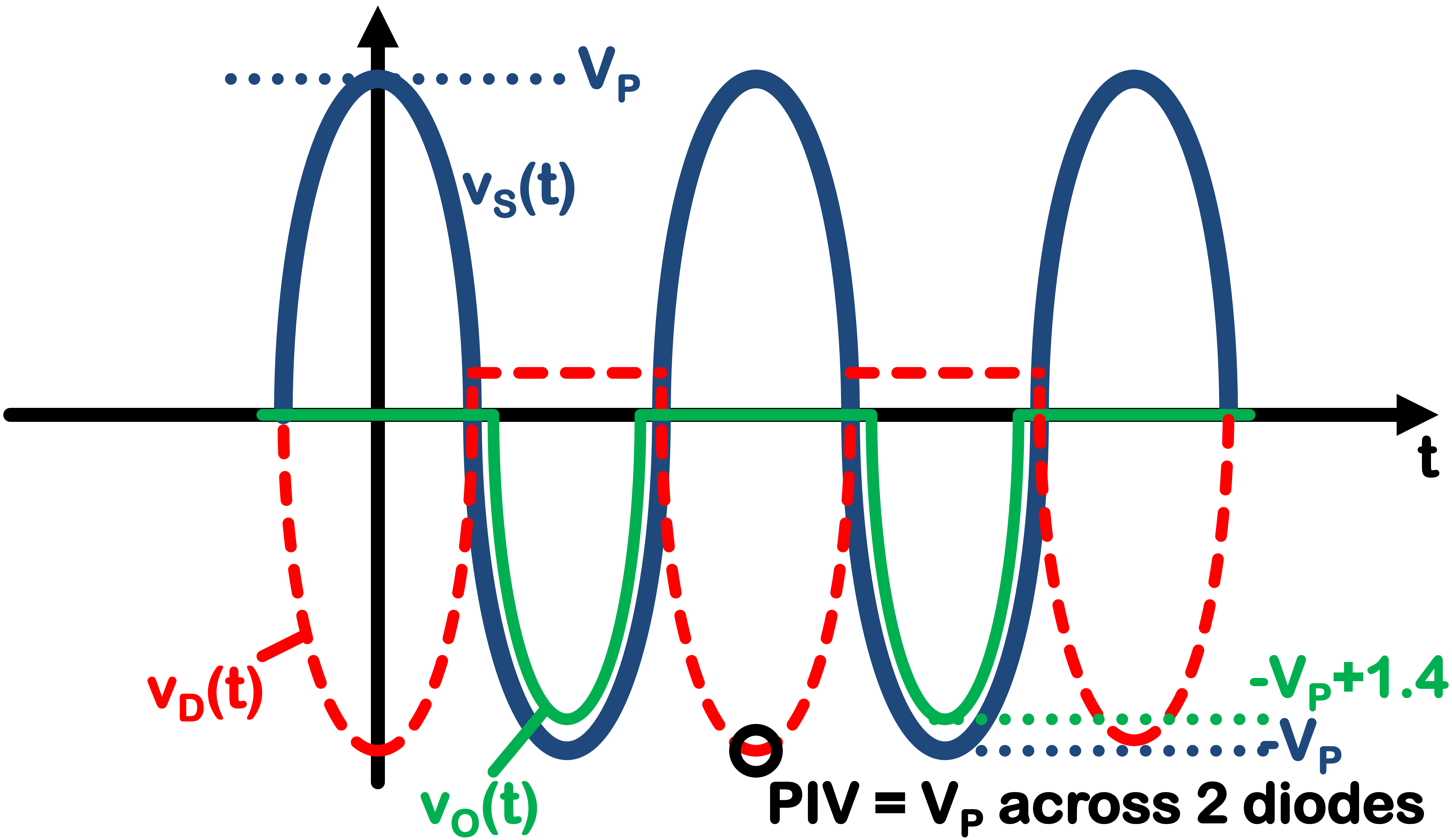


Negative Half Wave Rectifier (2-Diodes)

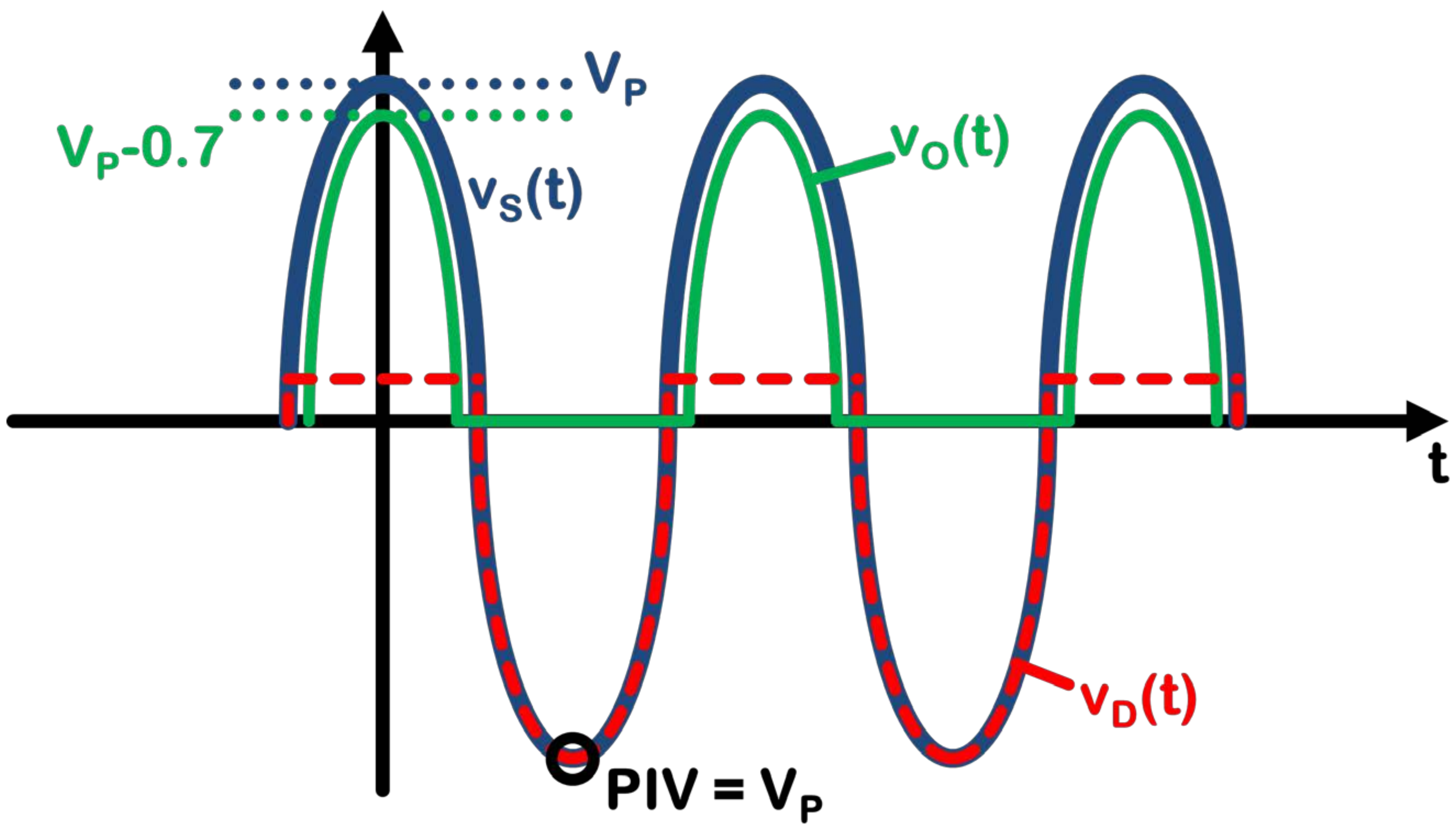
$v_O(v_S) = v_S + 1.4$ for $v_S < -1.4$

$v_O(v_S) = 0$ for $v_S > -1.4$

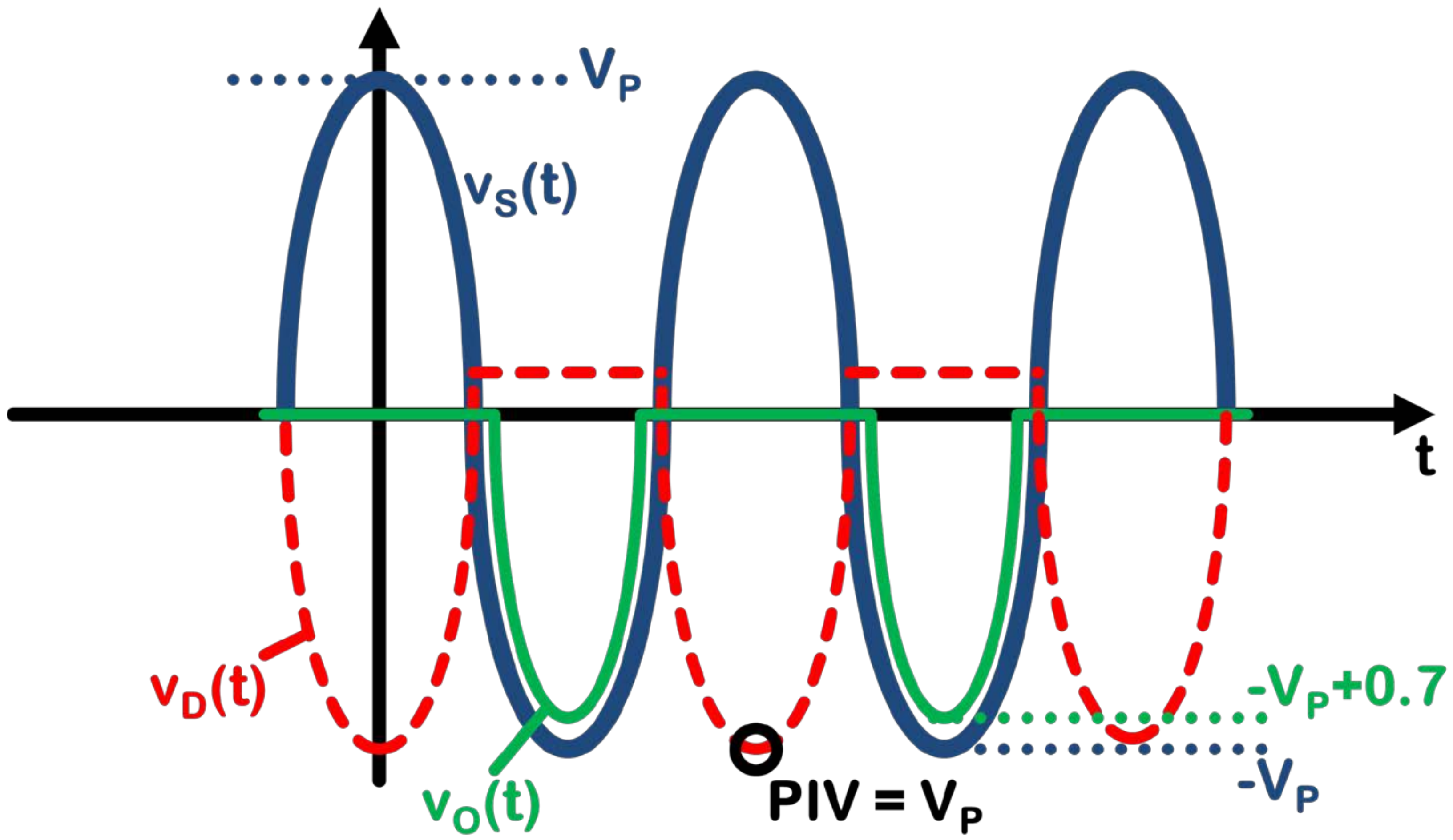
PIV = $V_P/2$; half across each diode



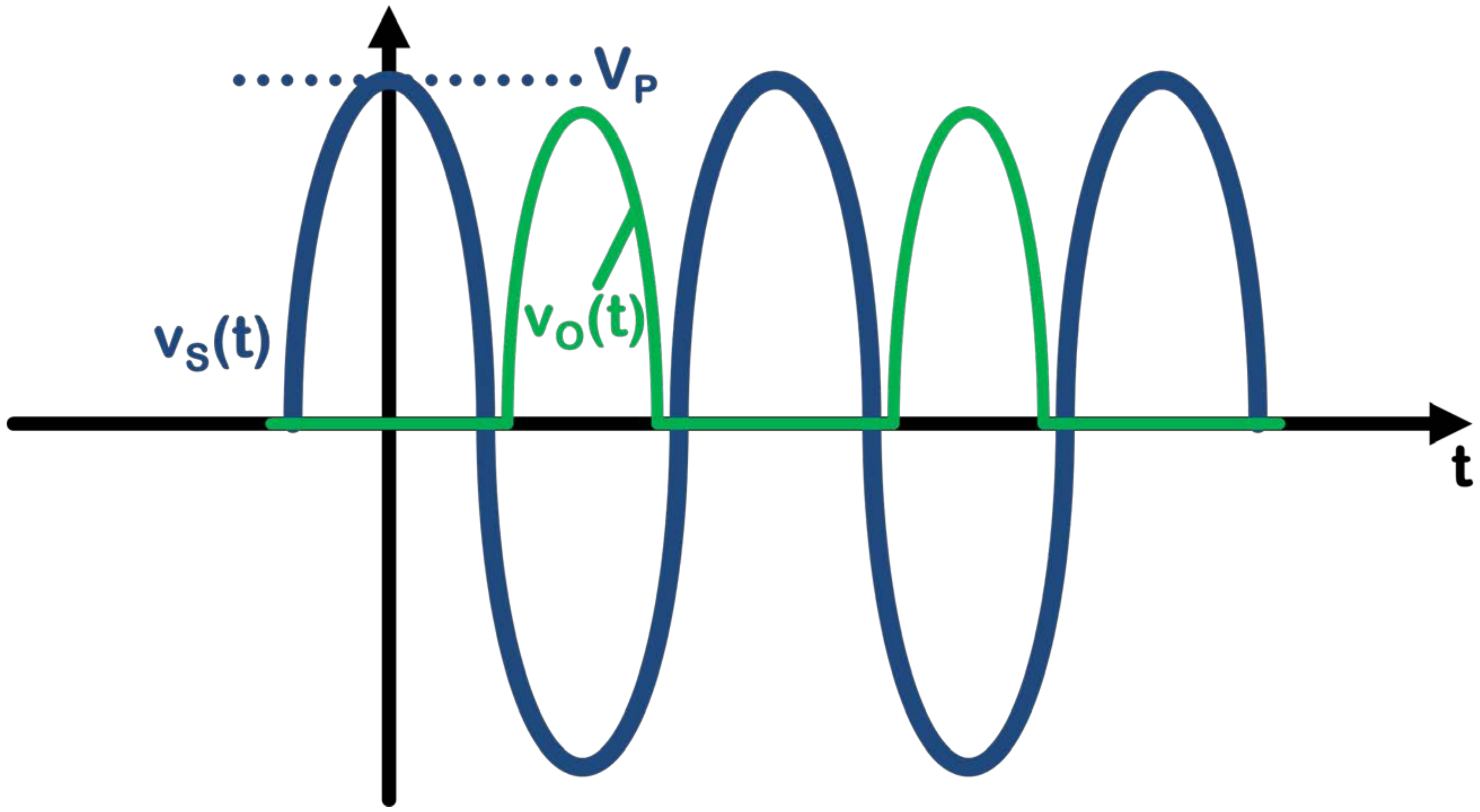
Positive Half Wave



Negative Half Wave



???



Negative Half Wave Rectifier

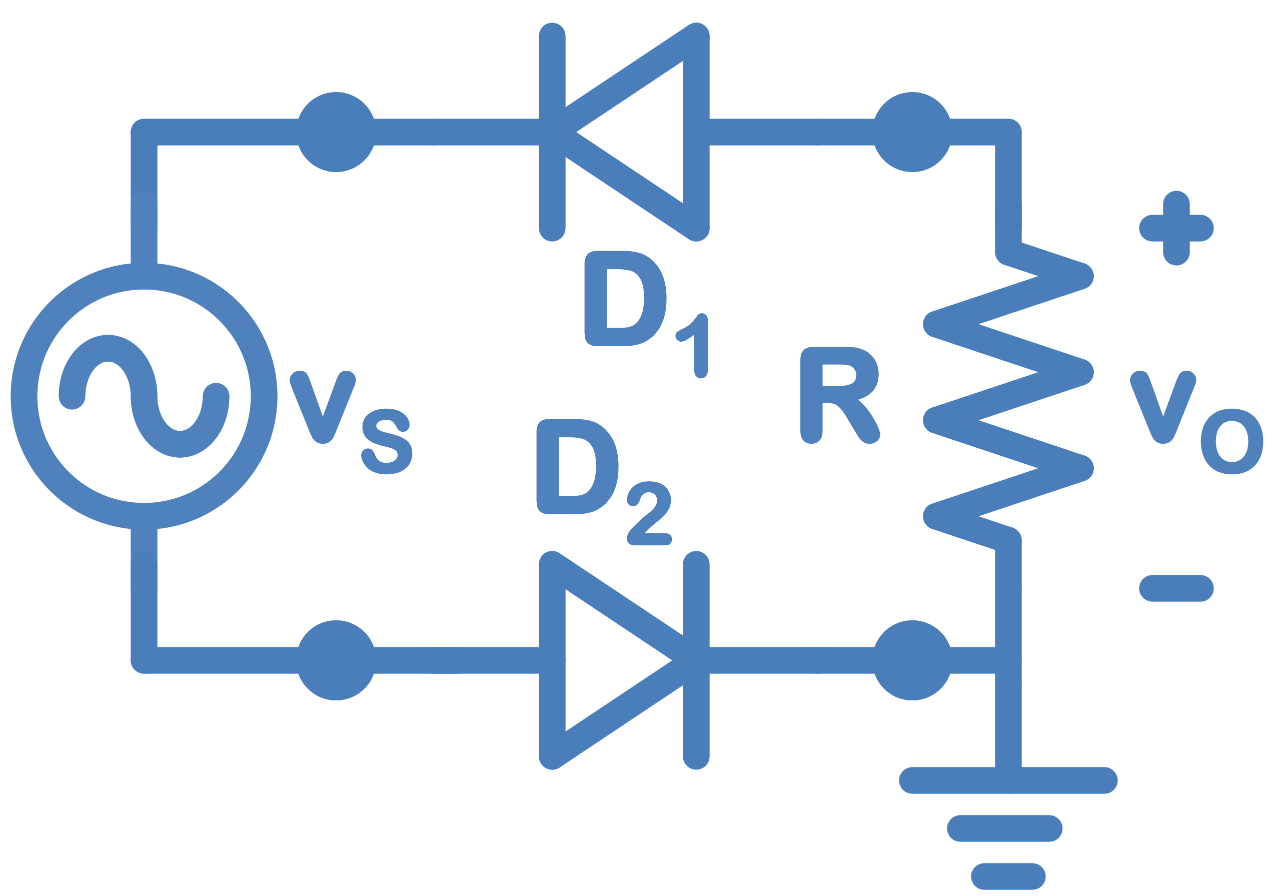
Find the transfer function $v_O(v_S)$

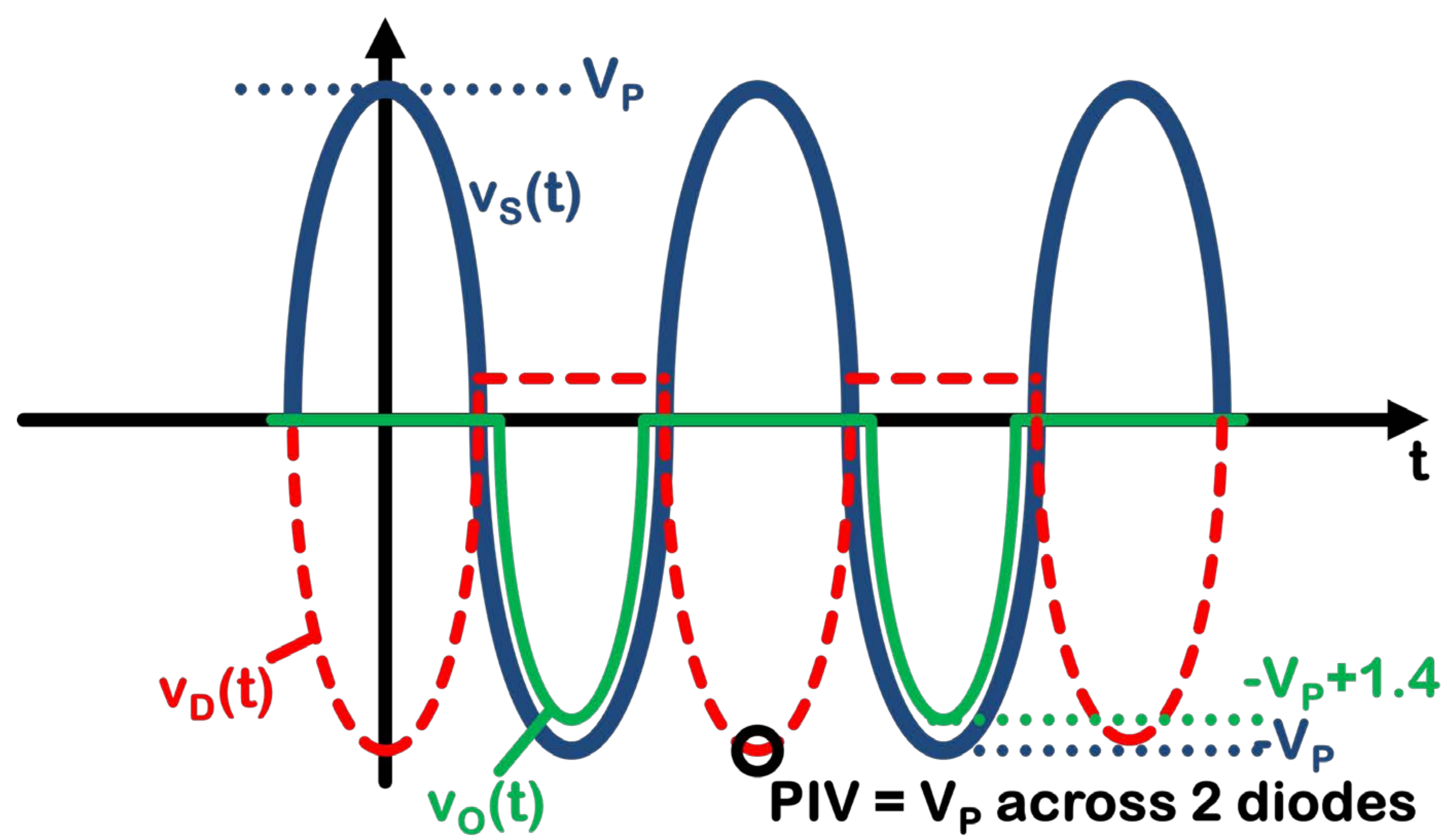
Find the Peak Inverse Voltage

$PIV=max(-v_D(v_S))$

Plot input & output for a sinusoidal input.

$v_S(t)=V_P cos(2\pi t/T)$





Inverting Half Wave Rectifier

Find the transfer function $v_O(v_S)$

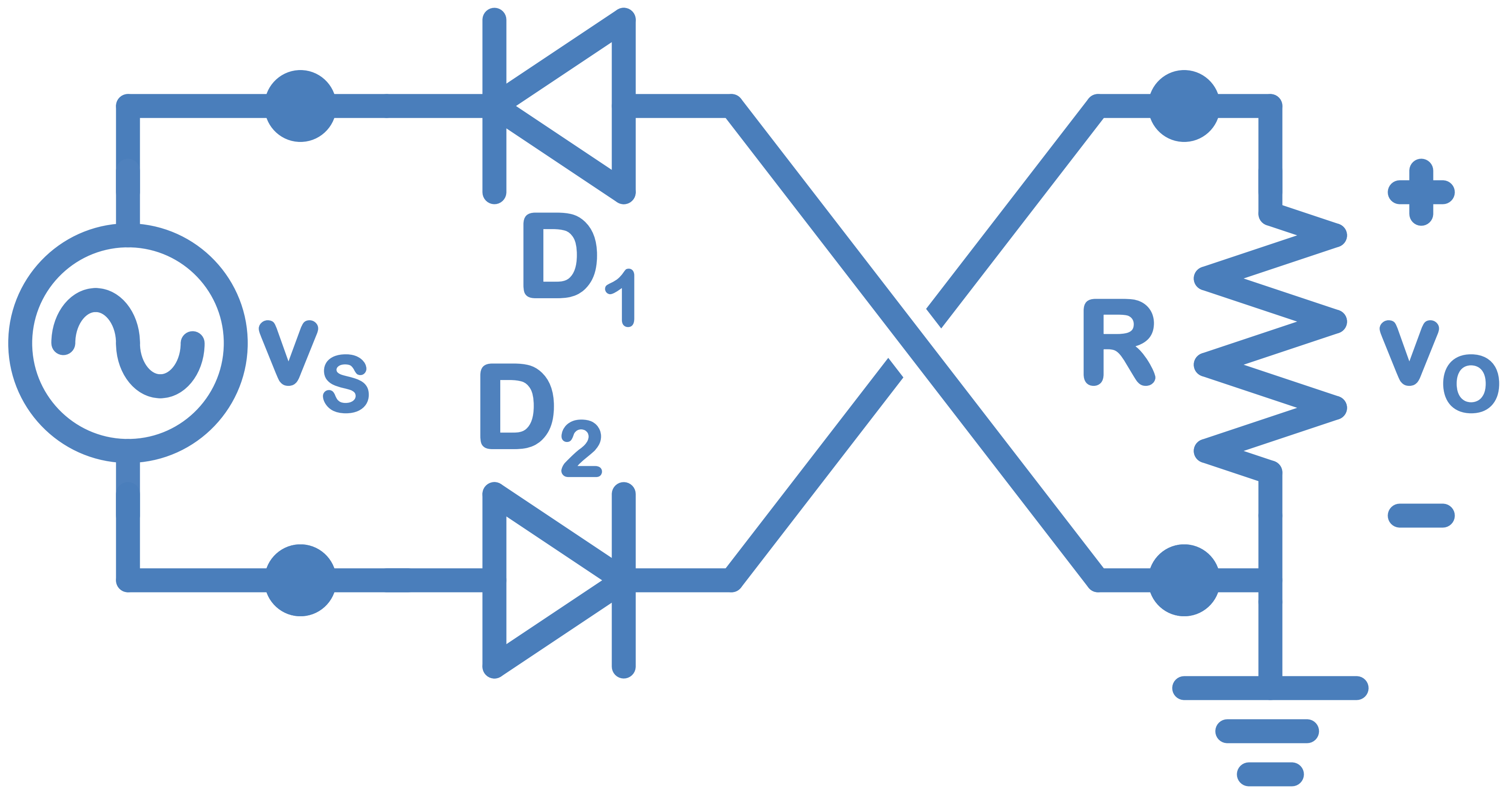
Find the Peak Inverse Voltage

$PIV=max(-v_D(v_S))$

Plot input & output for a sinusoidal input.

$v_S(t)=V_P cos(2\pi t/T)$

Same Analysis as Negative Half Wave with $new(v_O) = -old(v_O)$

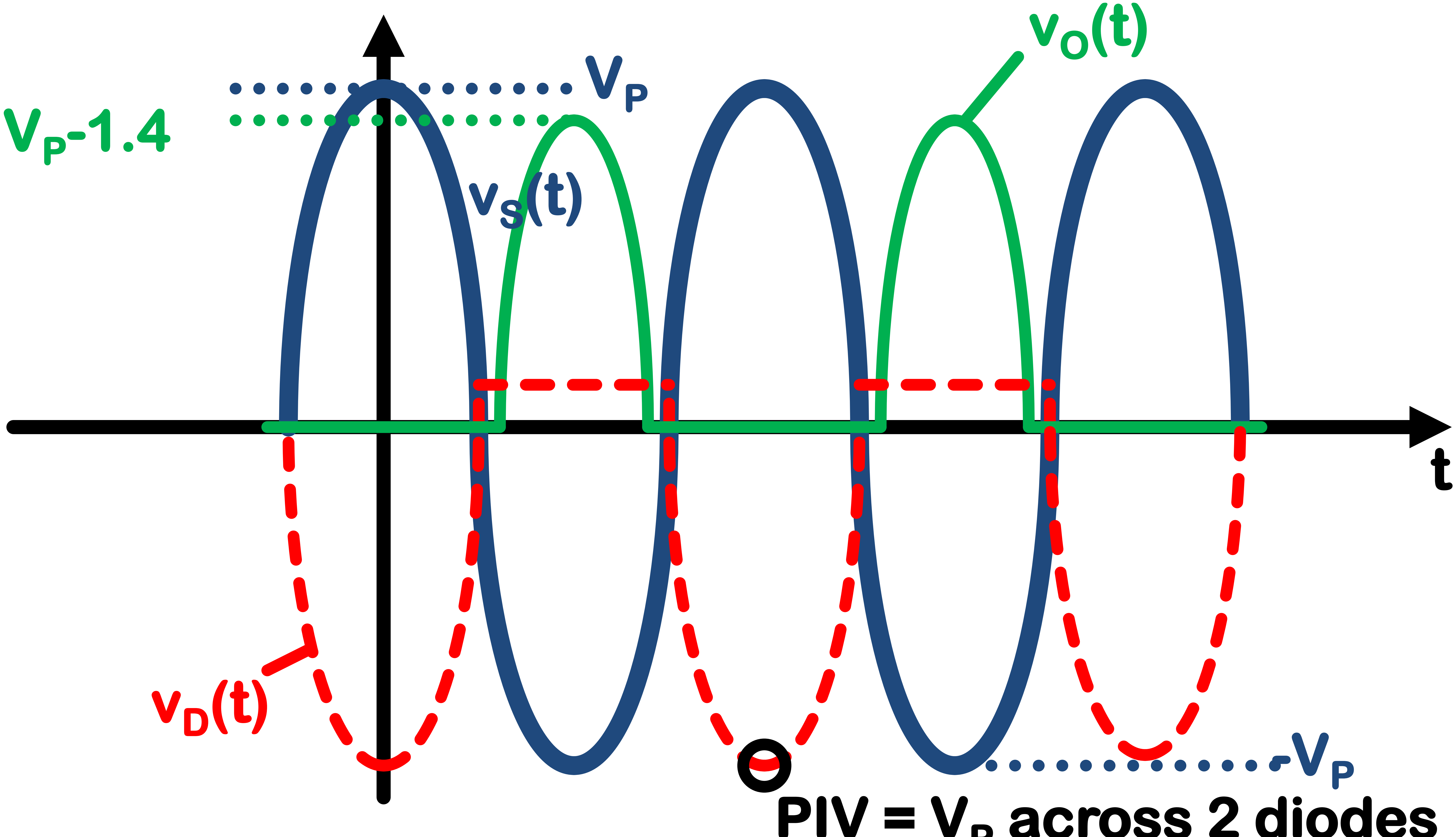


Negative Half Wave Rectifier (2-Diodes)

$v_O(v_S) = -v_S - 1.4$ for $v_S < -1.4$

$v_O(v_S) = 0$ for $v_S > -1.4$

PIV = $V_P/2$; half across each diode



Full Wave "Bridge" Rectifier

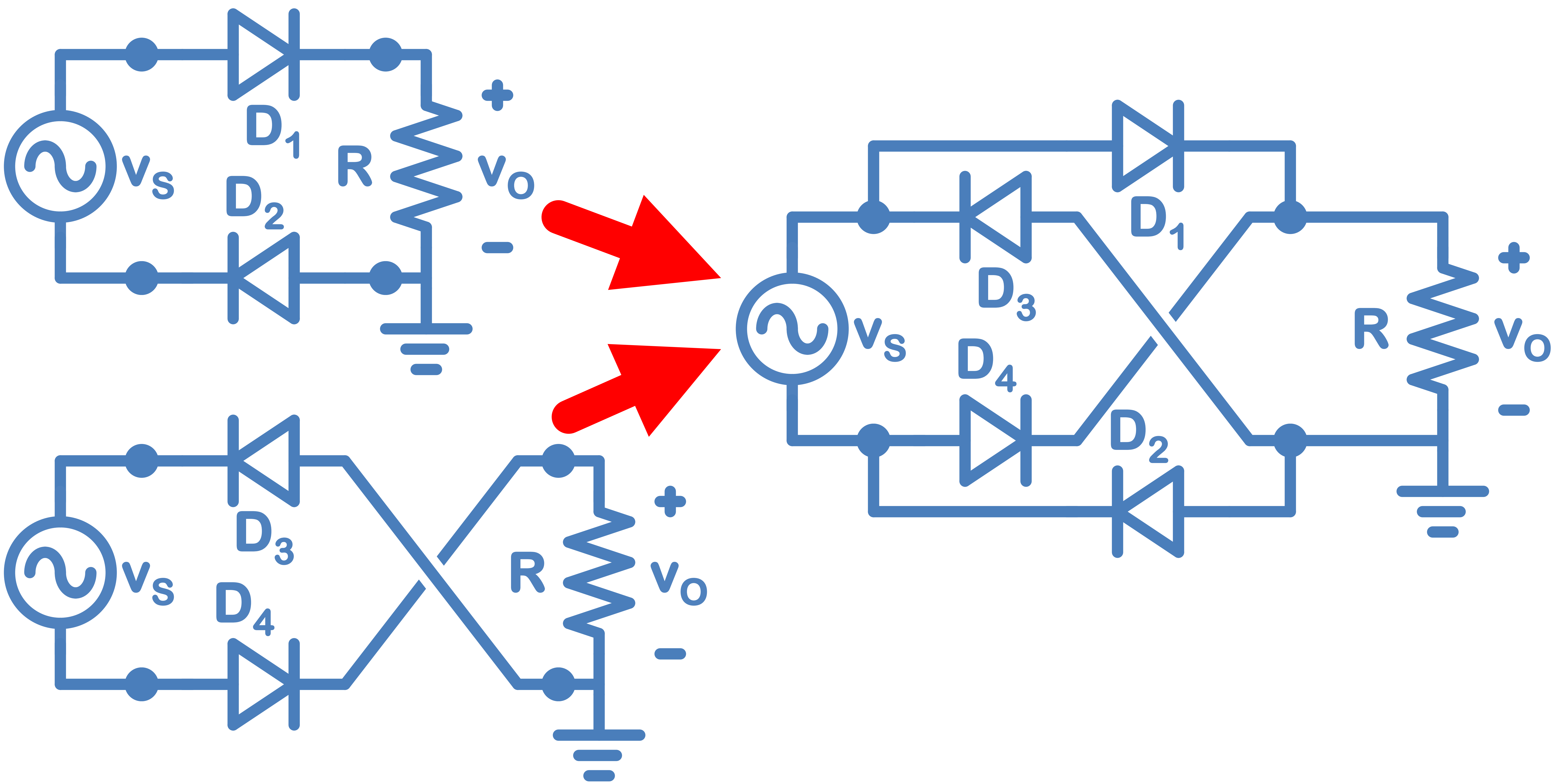
Find the transfer function $v_O(v_S)$

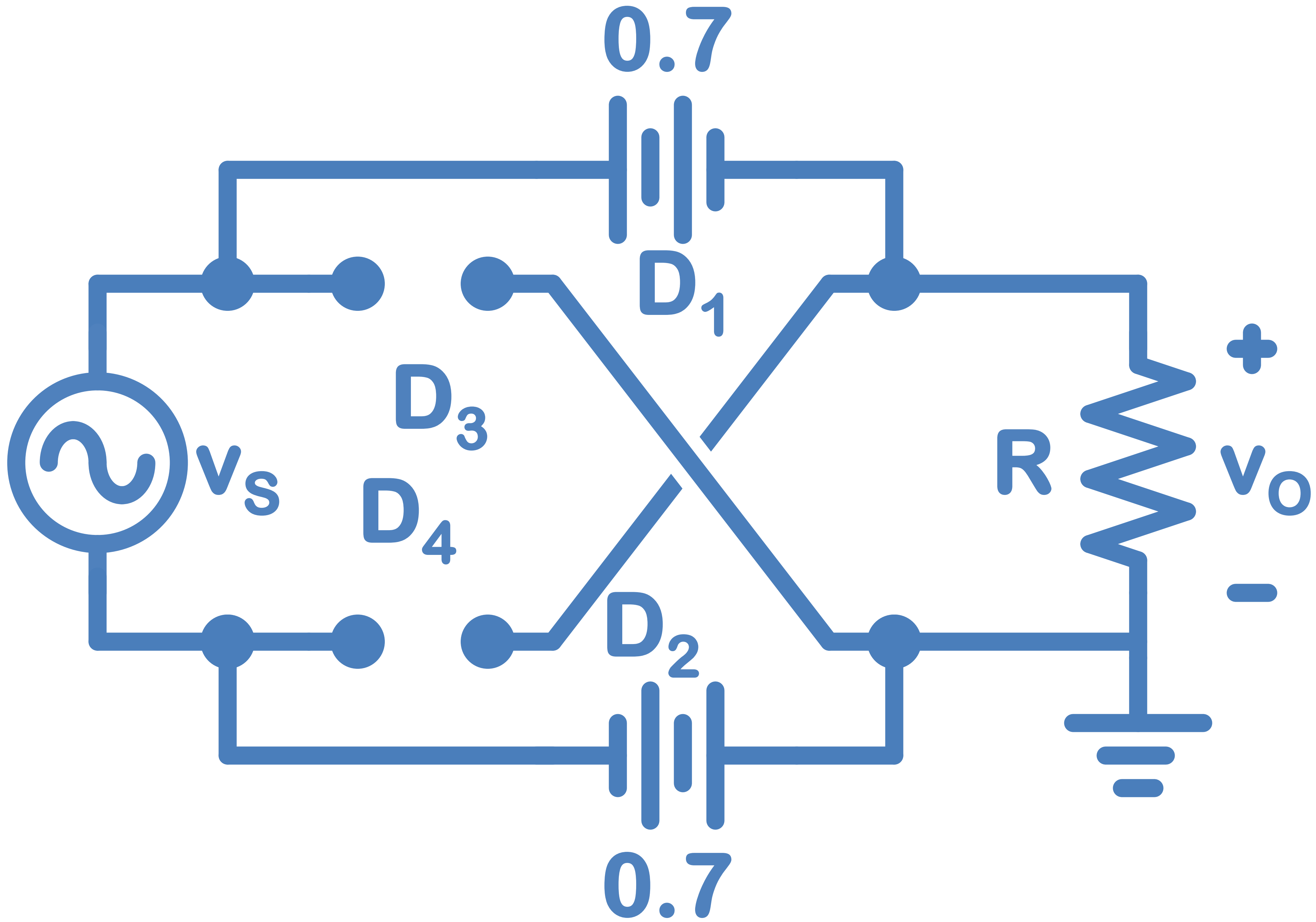
Find the Peak Inverse Voltage

$PIV = \max(-v_D(v_S))$

Plot input & output for a sinusoidal input.

$v_S(t) = V_P \cos(2\pi t/T)$

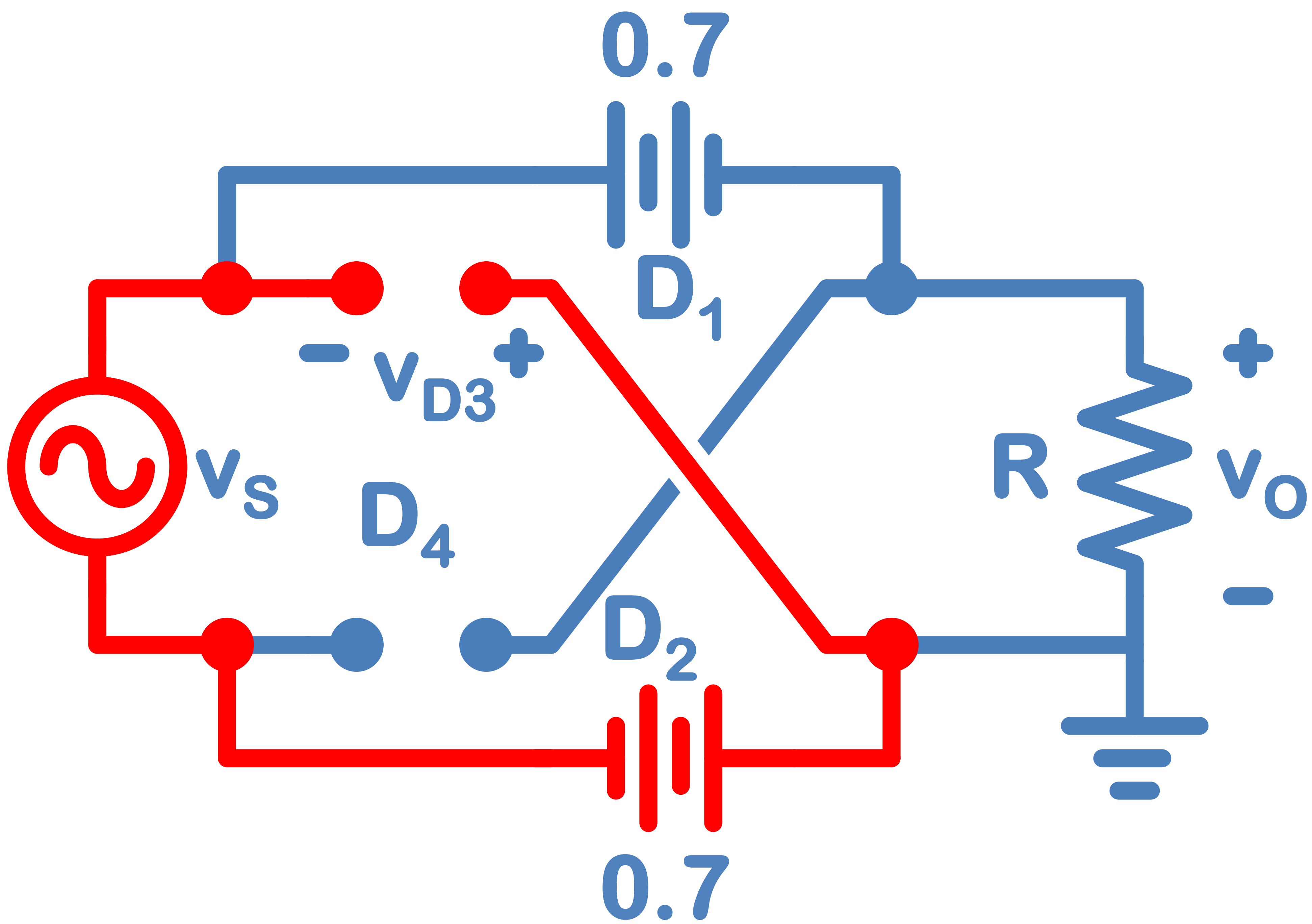




FB,FB,RB,RB:

$$v_O(v_S) = v_S - 1.4$$

$$i_D(v_S) = (v_S - 1.4)/R > 0;\ v_S > 1.4$$

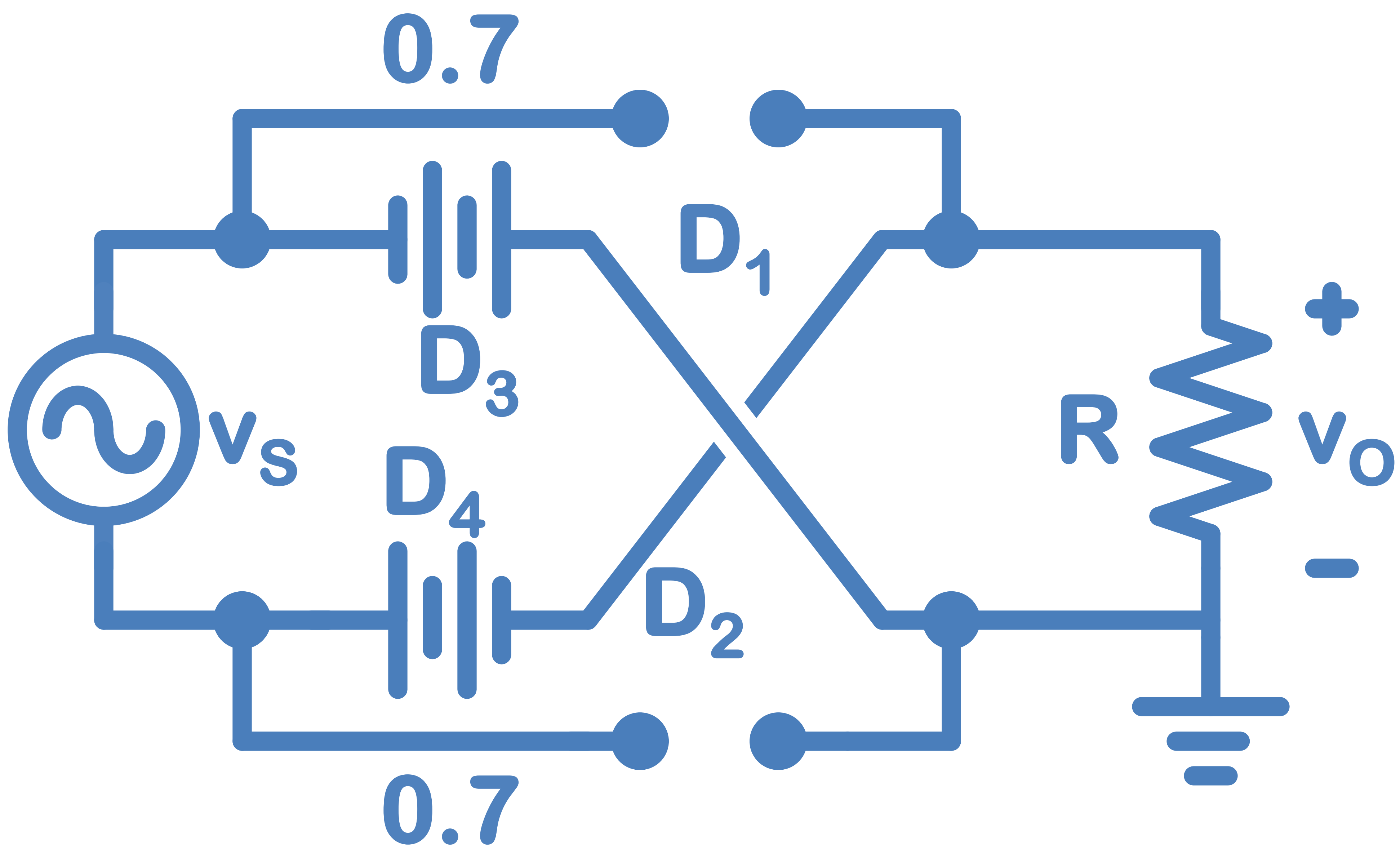


PIV: when $v_S = V_P$

$$-V_P - v_{D3} + 0.7 = 0$$

$$v_{D3} = 0 - (V_P - 0.7)$$

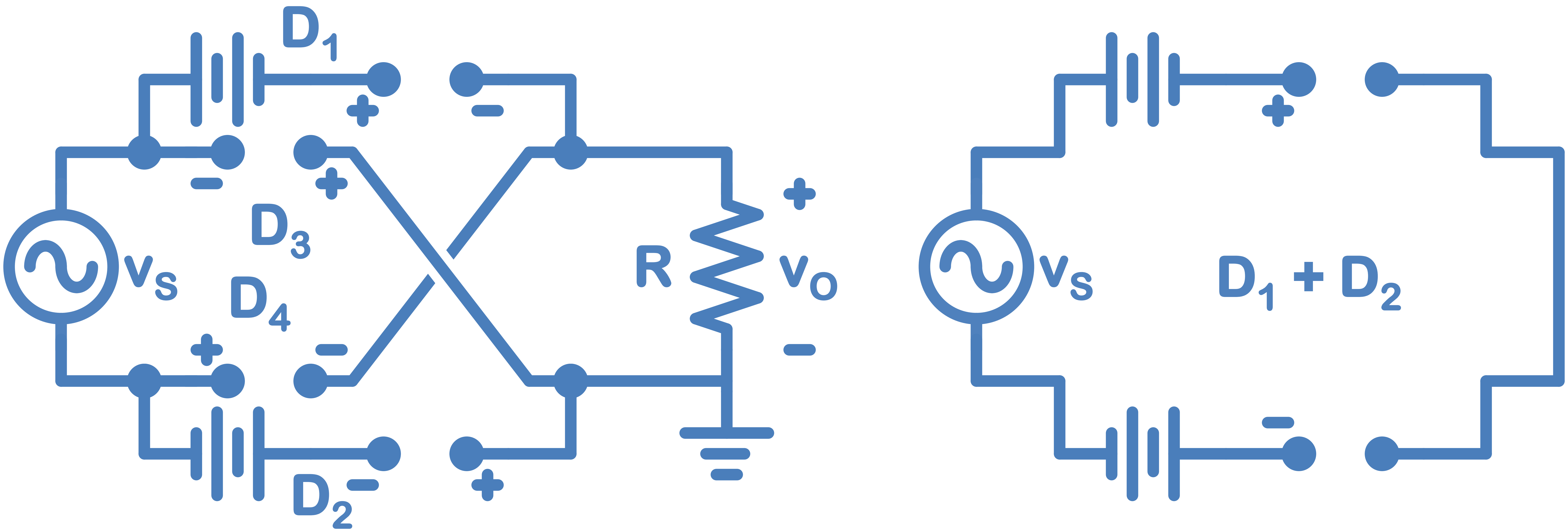
$$PIV = \max(-v_D) = V_P - 0.7$$



RB,RB,FB,FB:

$$v_O(v_S) = -v_S - 1.4$$

$$i_D(v_S) = -(v_S + 1.4)/R > 0;\ v_S < -1.4$$



RB,RB,RB,RB:

$v_O(v_S) = 0$

$v_{D1}+v_{D2} = 2v_D = v_S - 1.4 < 0;\ v_S < 1.4$

Similarly for D3, and D4: $v_S > -1.4$

$v_O(v_S) = 0$ for $-1.4 < v_S < 1.4$

Full Wave "Bridge" Rectifier

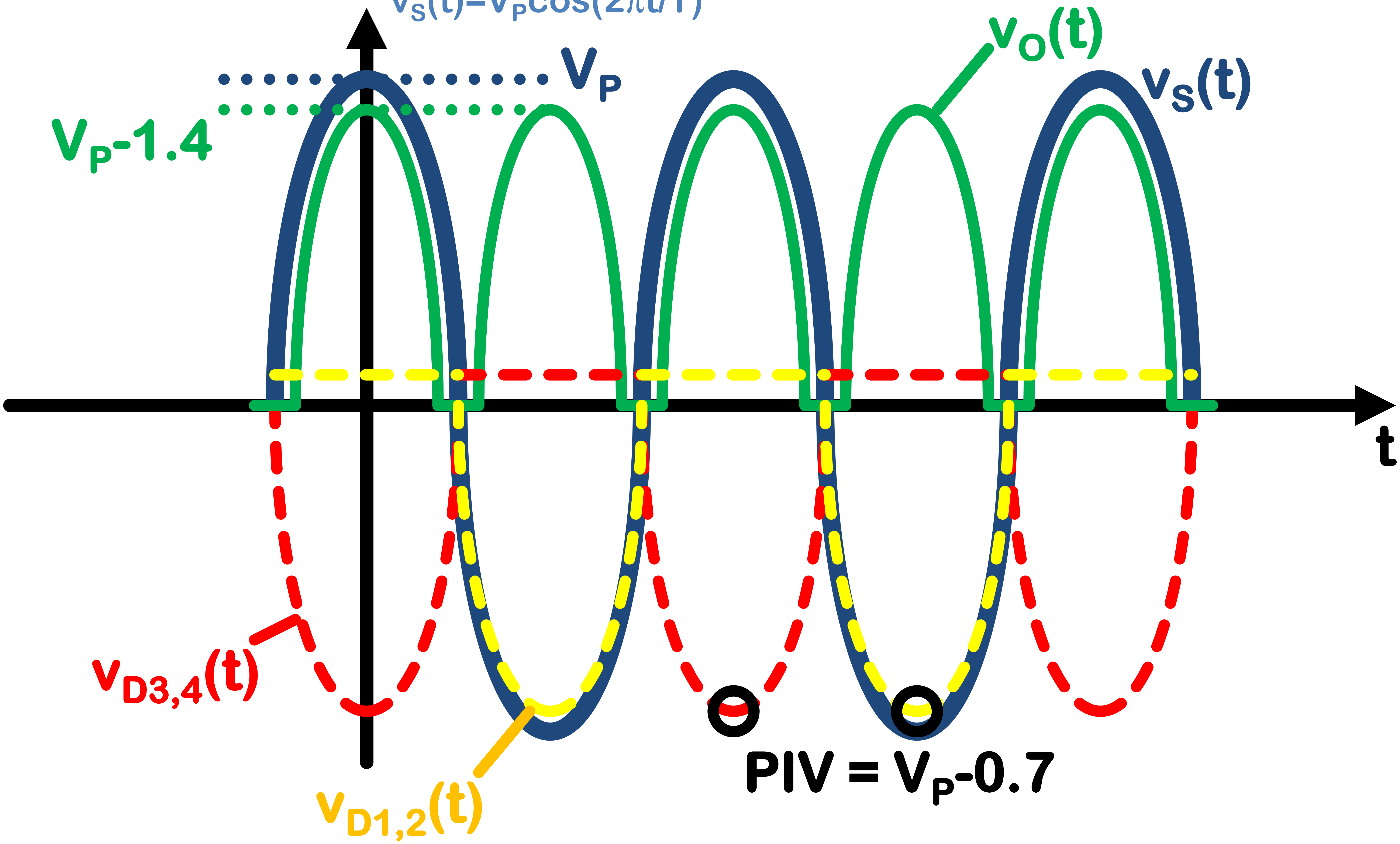
Find the transfer function $v_O(v_S)$

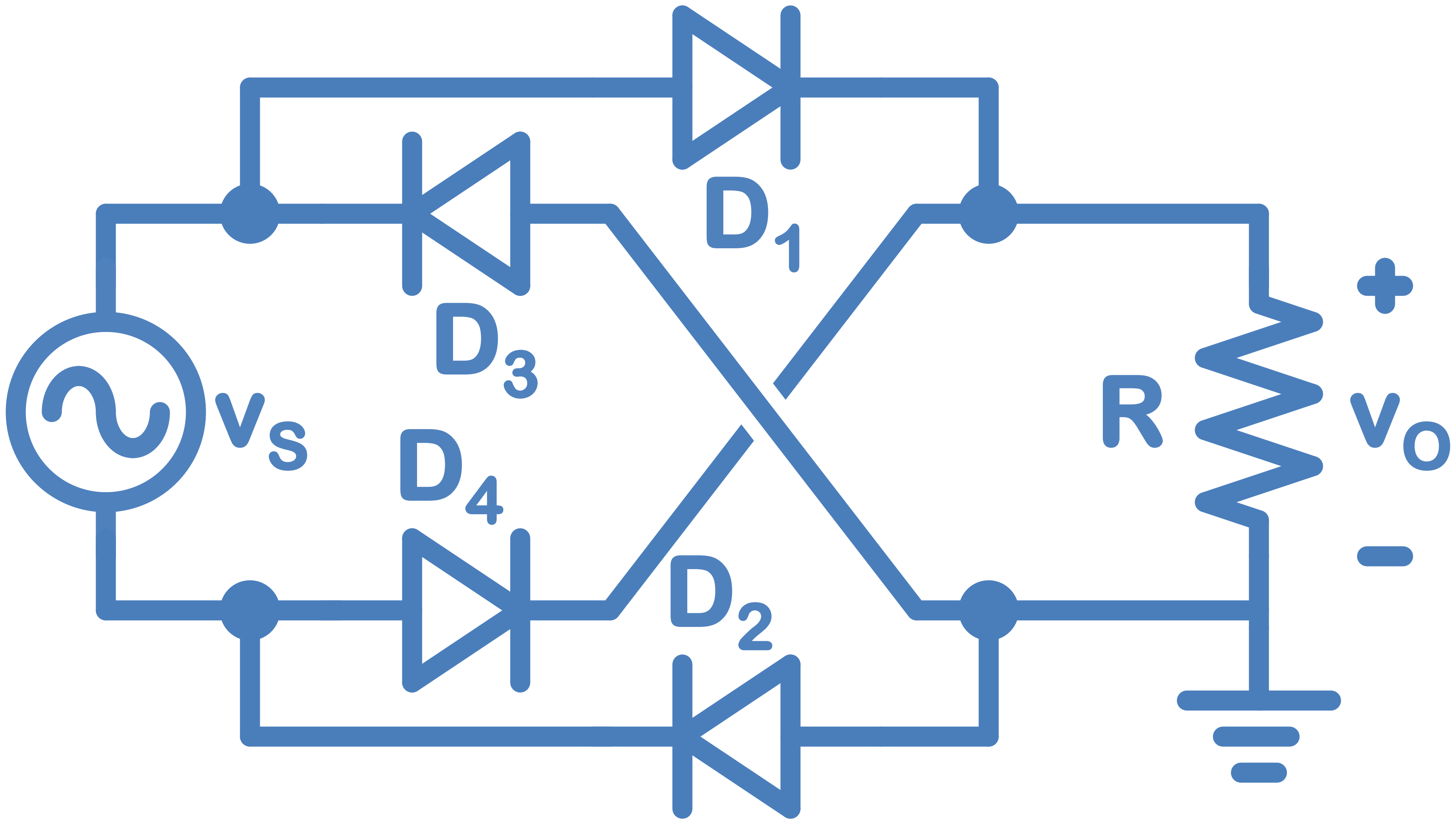
Find the Peak Inverse Voltage

$PIV = \max(-v_D(v_S))$

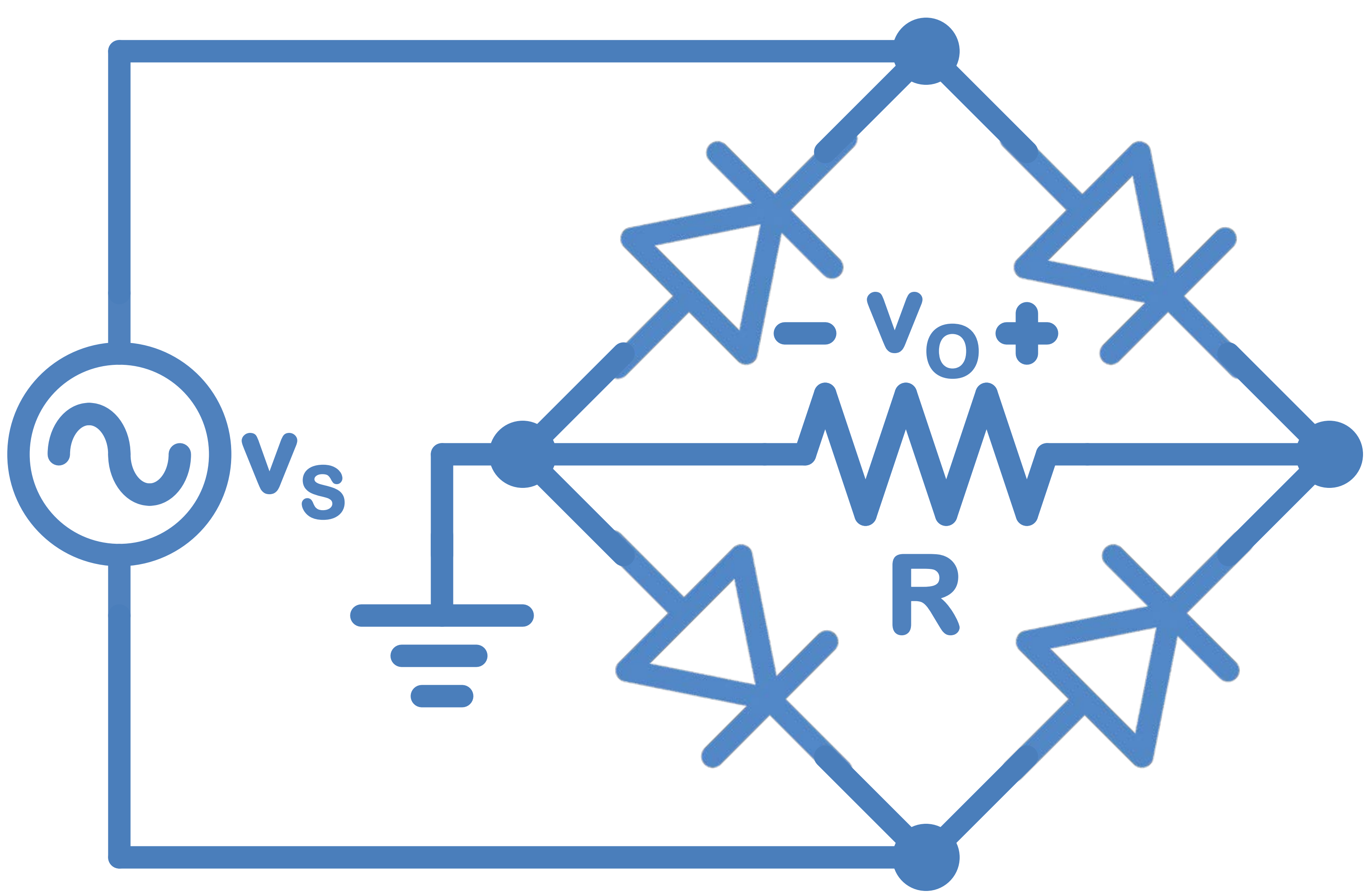
Plot input & output for a sinusoidal input.

$v_S(t) = V_P \cos(2\pi t/T)$

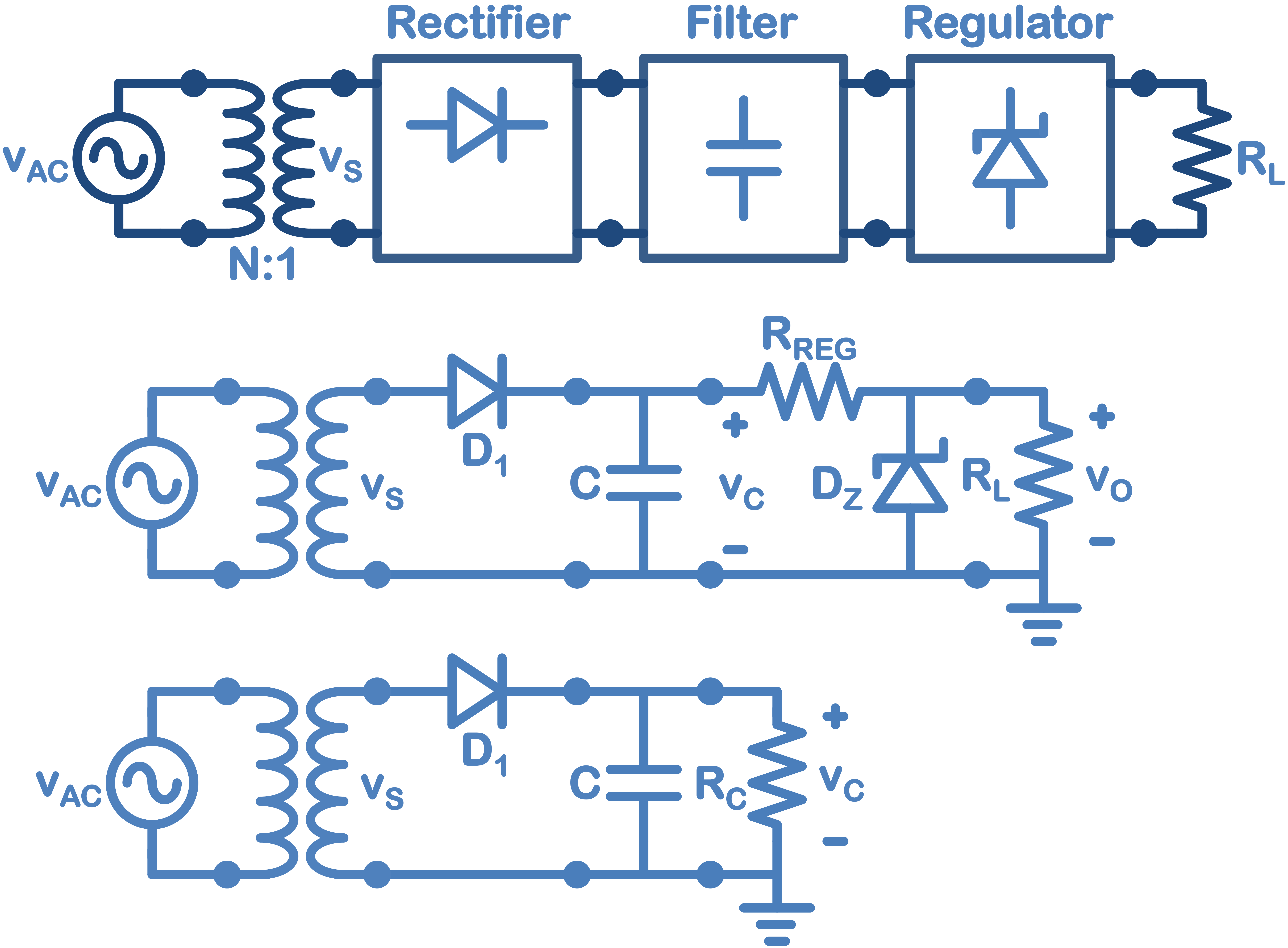


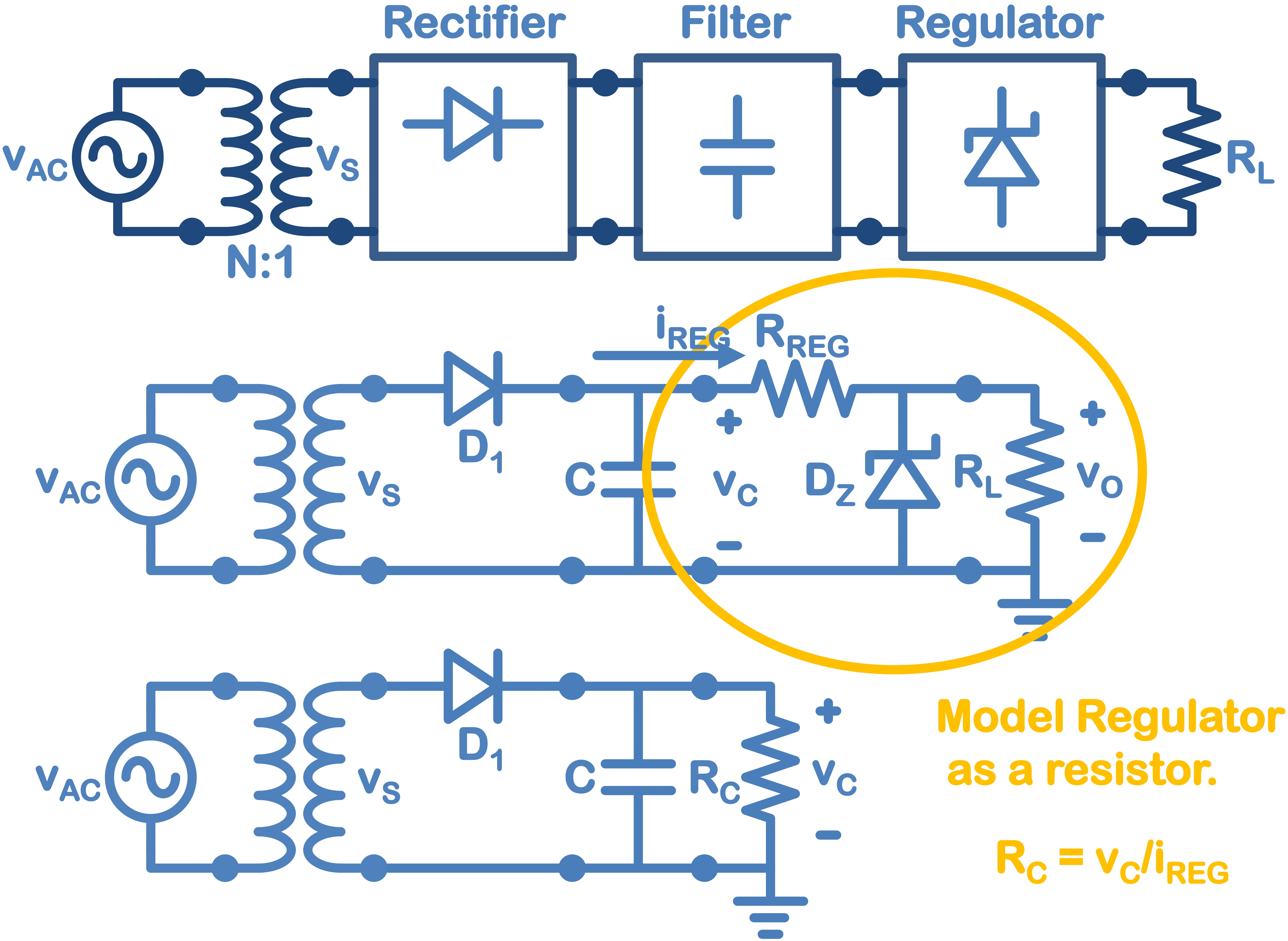


D1
D3
D4
D2
vS
R
+
vO
−



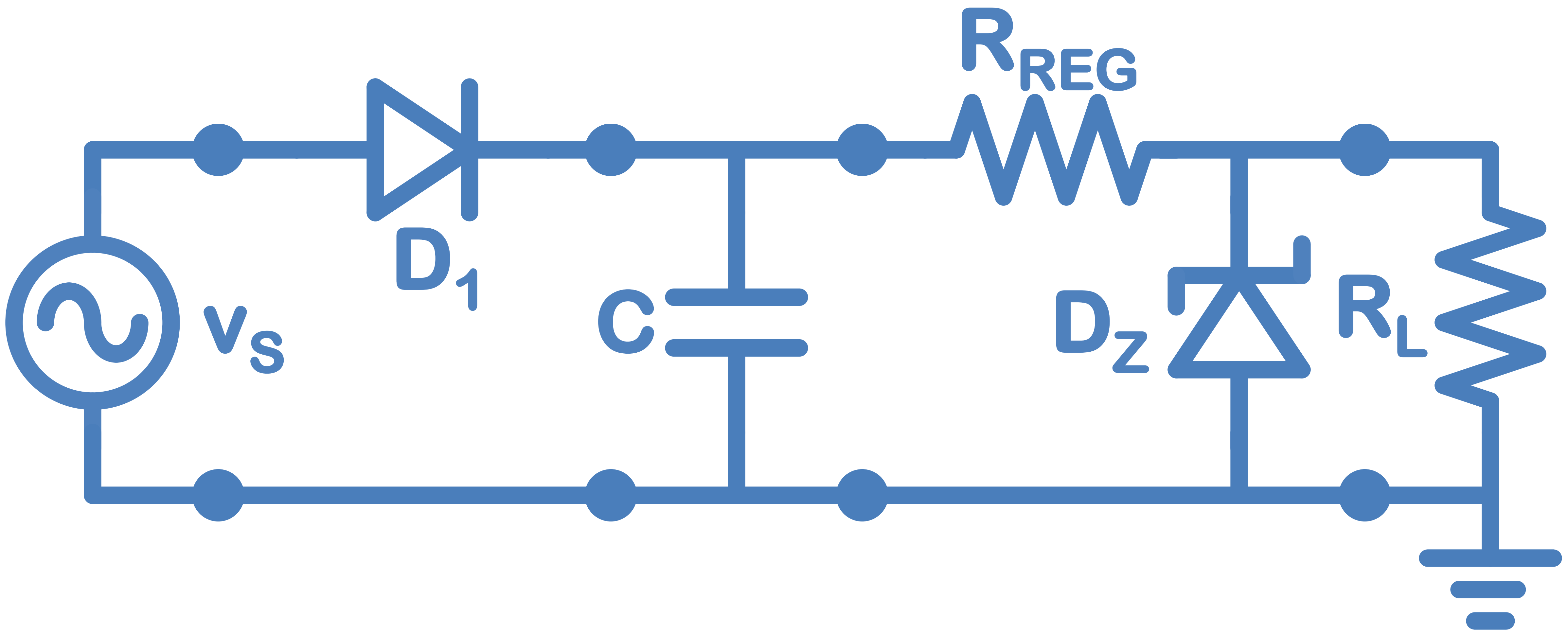
vS
− vO +
R

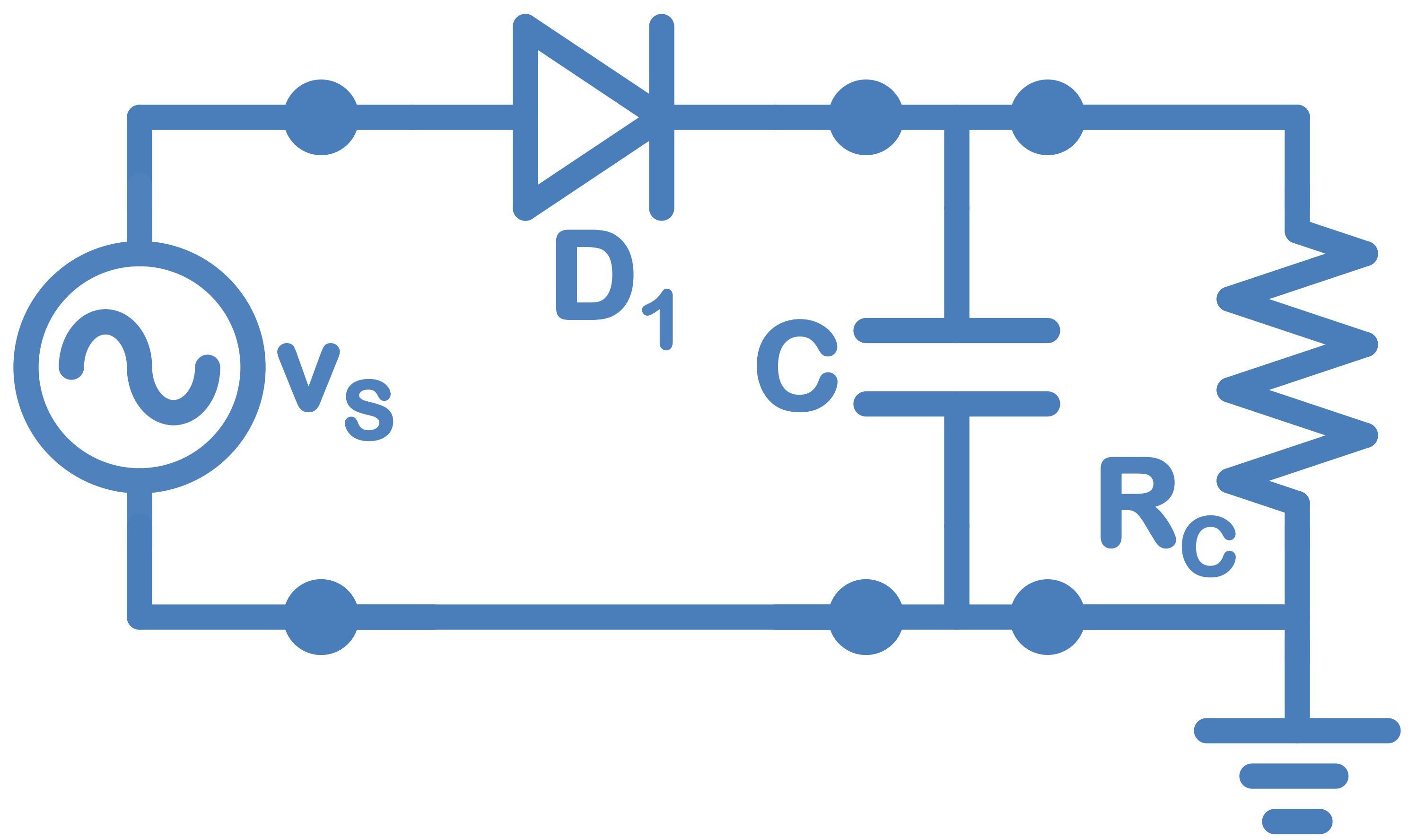

Rectifier
Filter
Regulator
VAC
VS
N:1
RL
RREG
VAC
VS
D1
C
+
VC
−
DZ
RL
+
VO
−
VAC
VS
D1
C
RC
+
VC
−



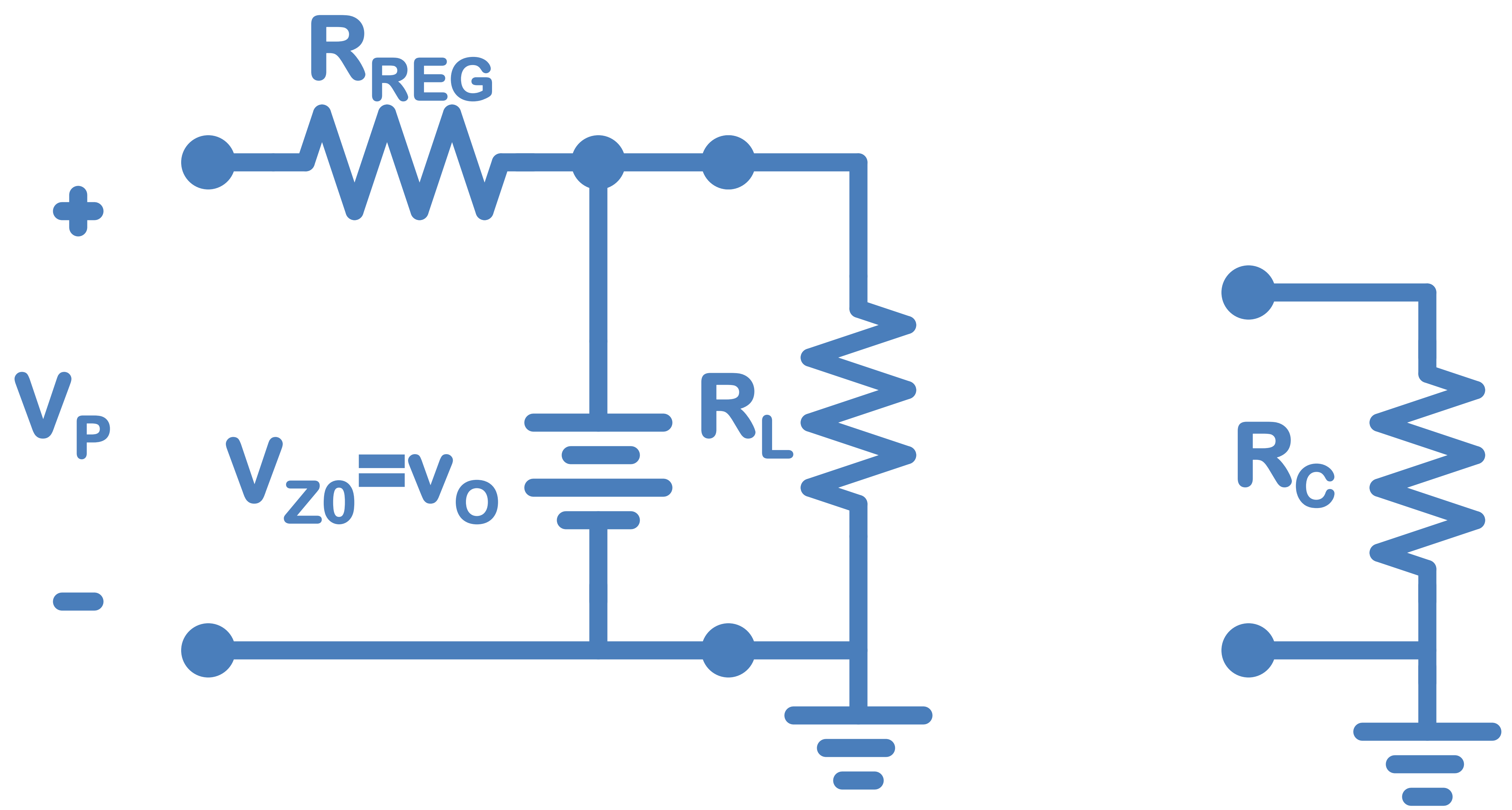
Rectifier
Filter
Regulator
v_AC
v_S
N:1
R_L
i_REG
R_REG
D_1
C
+
v_C
−
D_Z
R_L
+
v_O
−
v_AC
v_S
D_1
C
R_C
+
v_C
−
Model Regulator
as a resistor.
R_C = v_C/i_REG

How can we model the Regulator and Load as a single Resistor, R_C?





How can we model the Regulator and Load as a single Resistor?



V_P is the peak output of the Rectifier.

Use a simple CVD model for the Zener Diode.

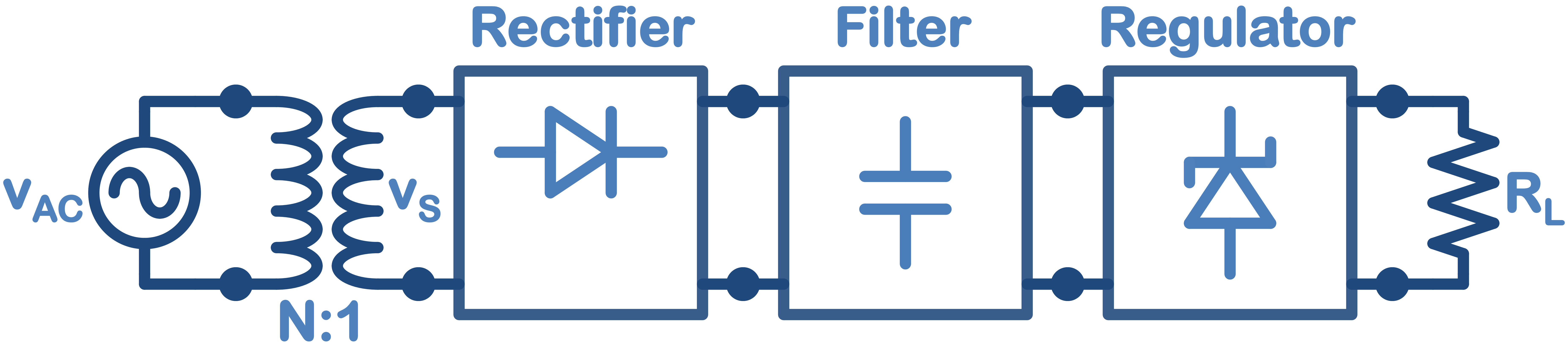
$I_{REG} = (V_P - V_{Z0})/R_{REG}$

The effective resistance that is in parallel with the capacitor filter can be approximated as.

$R_C = V_P/I_{REG} = V_P R_{REG}/(V_P - V_{Z0})$

To ensure FB $I_{REG} > I_L$, or $(V_P - V_{Z0})/R_{REG} > V_{Z0}/R_L$

$R_{REG} < R_L(V_P - V_{Z0})/V_{Z0}$



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2) Filter Capacitor.
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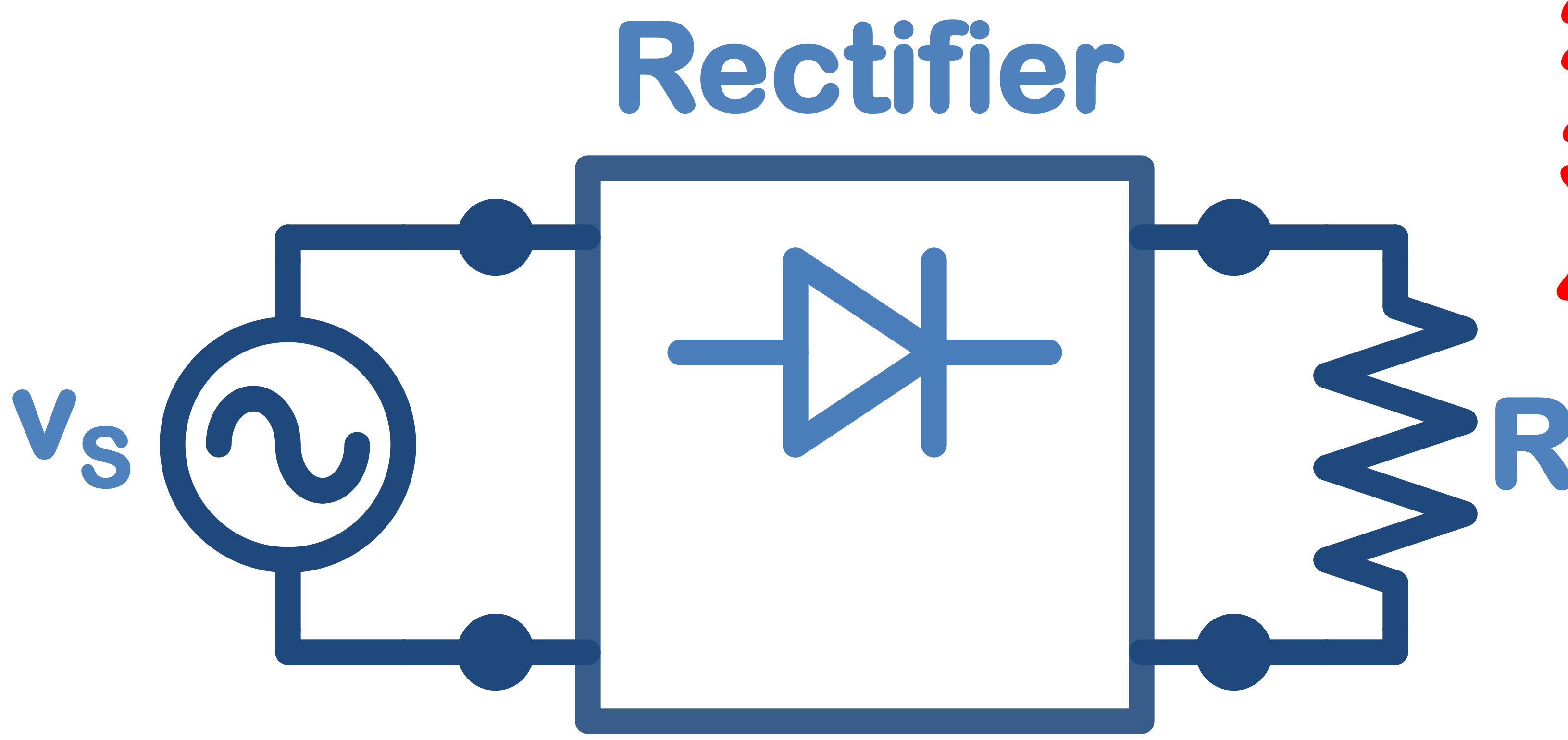
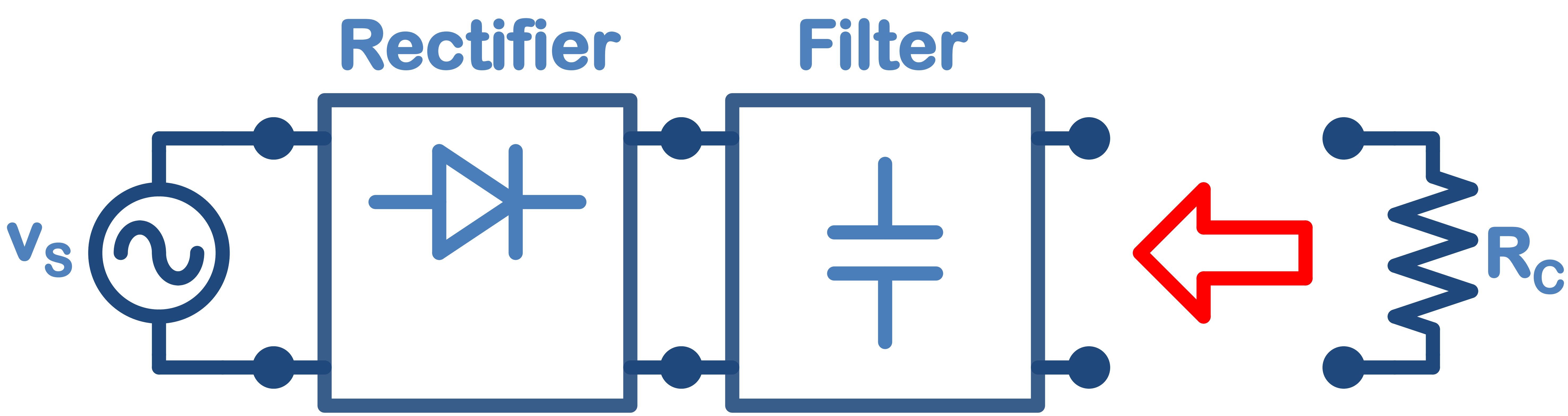
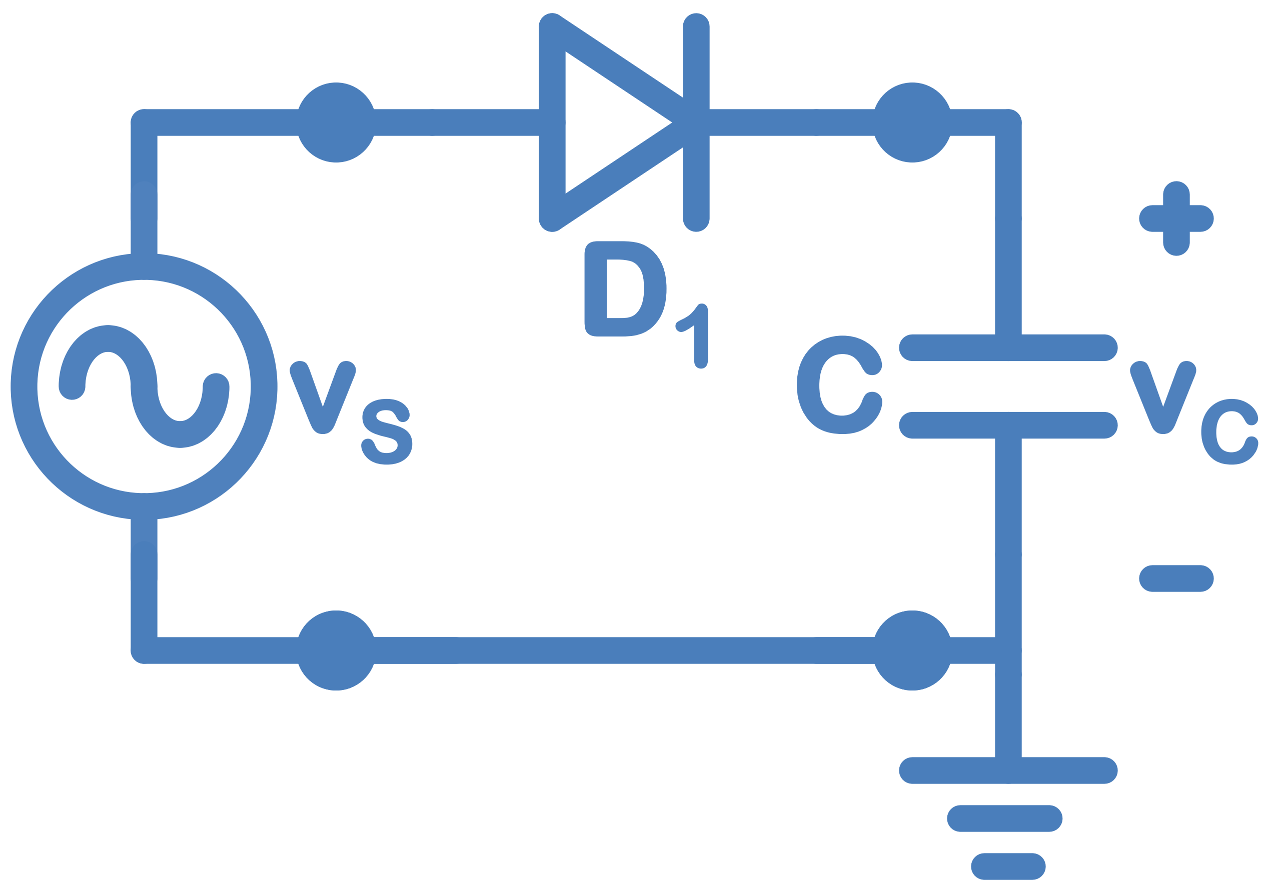




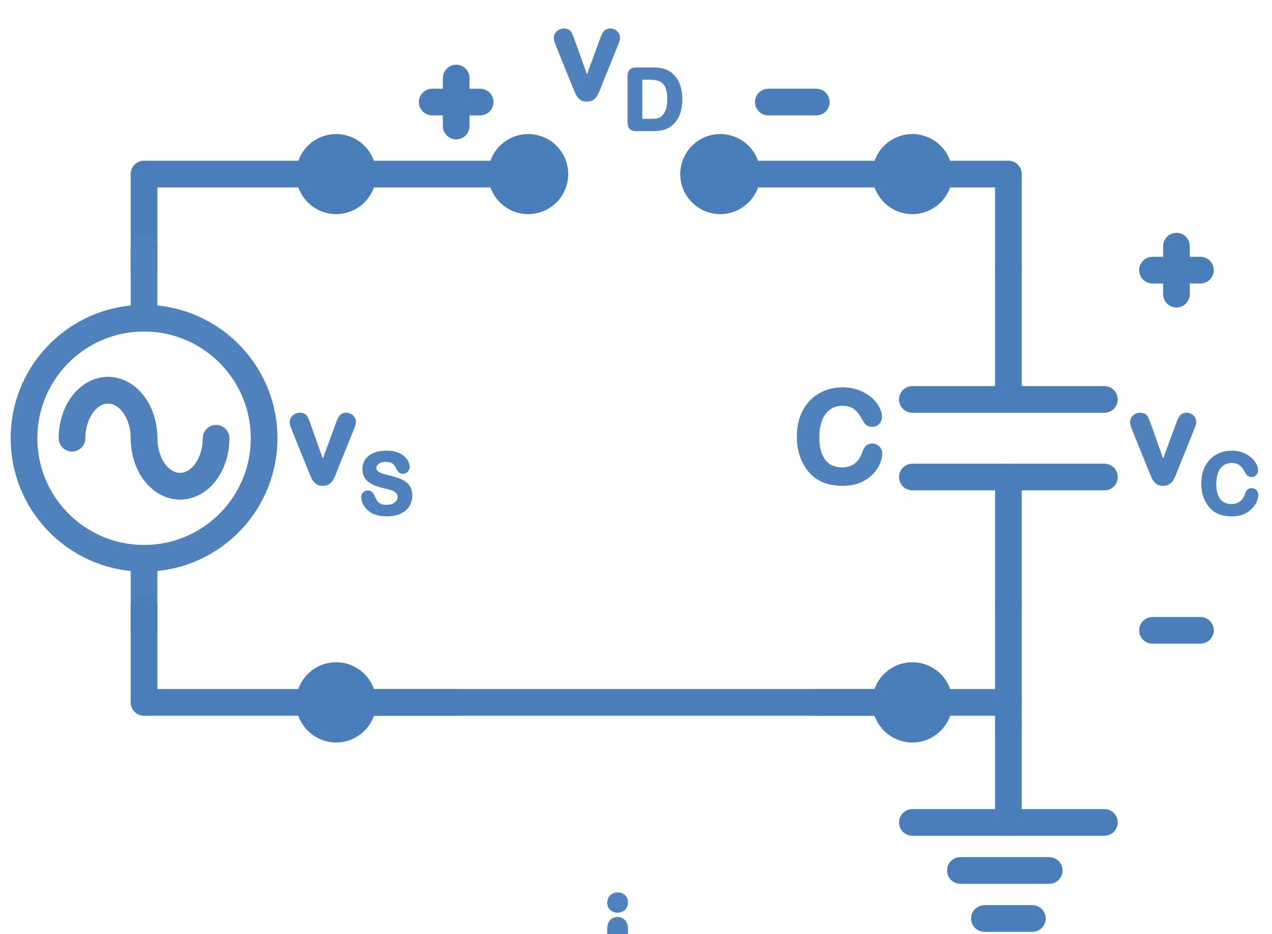
Positive Half Wave Rectifier w Capacitor

Find the transfer function $v_C(v_S)$ using ideal Diode



Positive Half Wave Rectifier w Capacitor

Find the transfer function $v_C(v_S)$ using ideal Diode



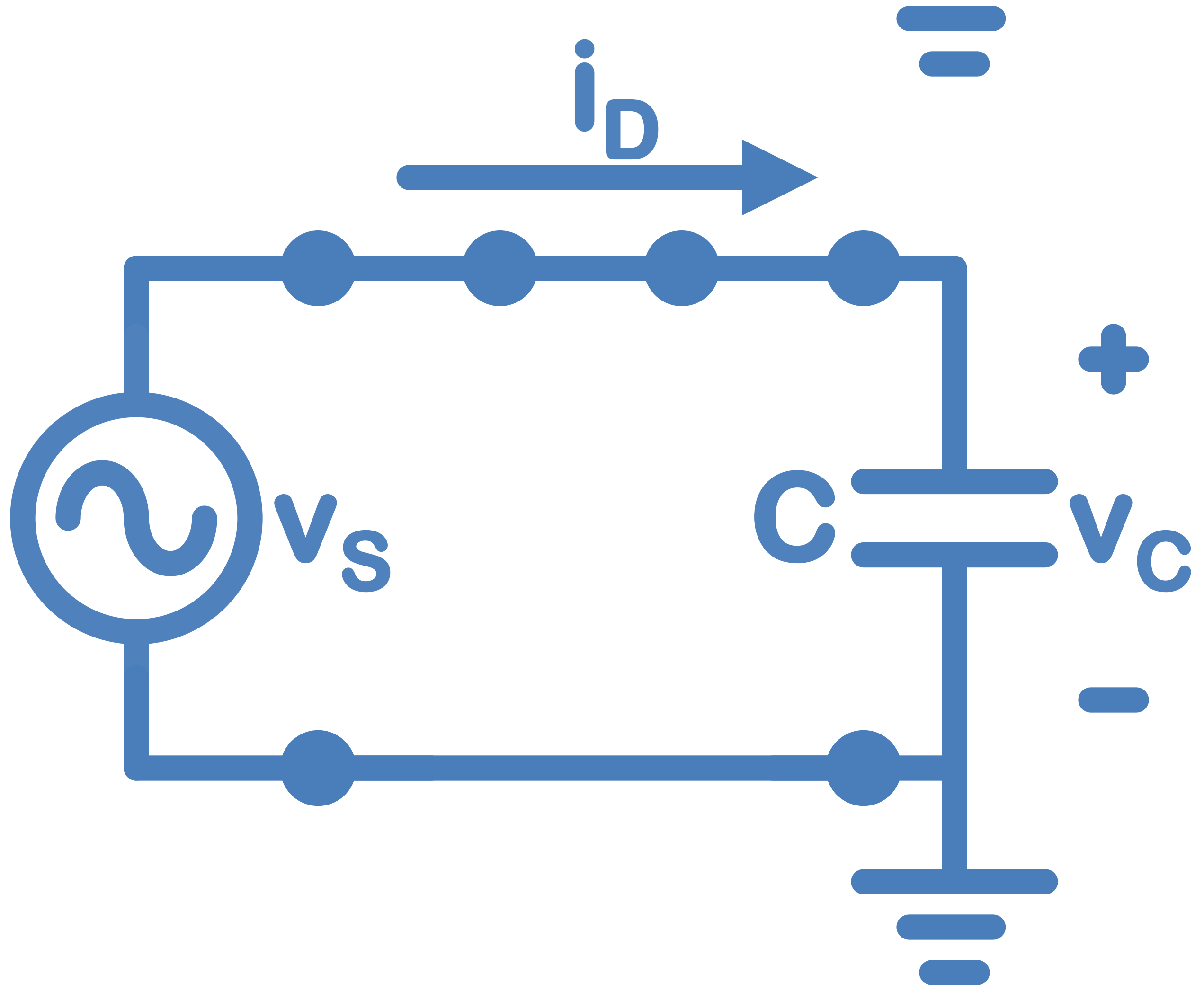
RB: $i_D = i_C = 0$

$i_C = C \cdot v_C'(t) = 0$; $v_C'(t) = 0$

the voltage stays constant

$v_D(v_S) = v_S - v_C < 0$; $v_S < v_C$

as long as $v_S < v_C$, v_C stays constant



FB: $v_C(v_S) = v_S$

$i_D(v_S) = i_C = C \cdot v_C'(t) = C \cdot v_S'(t) > 0$;

$v_S'(t) > 0$; $v_S(t) > v_C$ and increasing

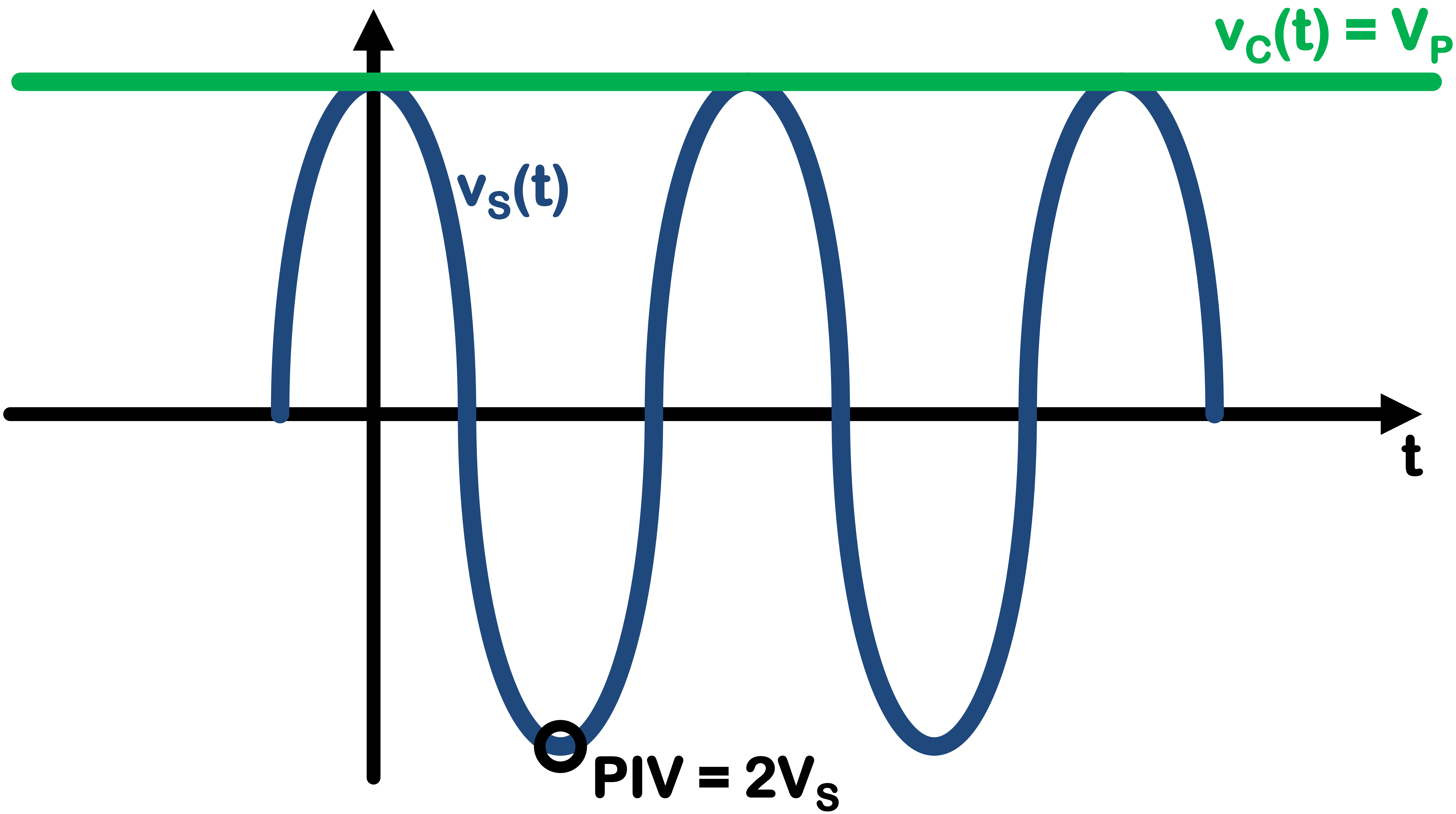
if $v_S > v_C$ and increasing, $v_C = v_S$

Summary

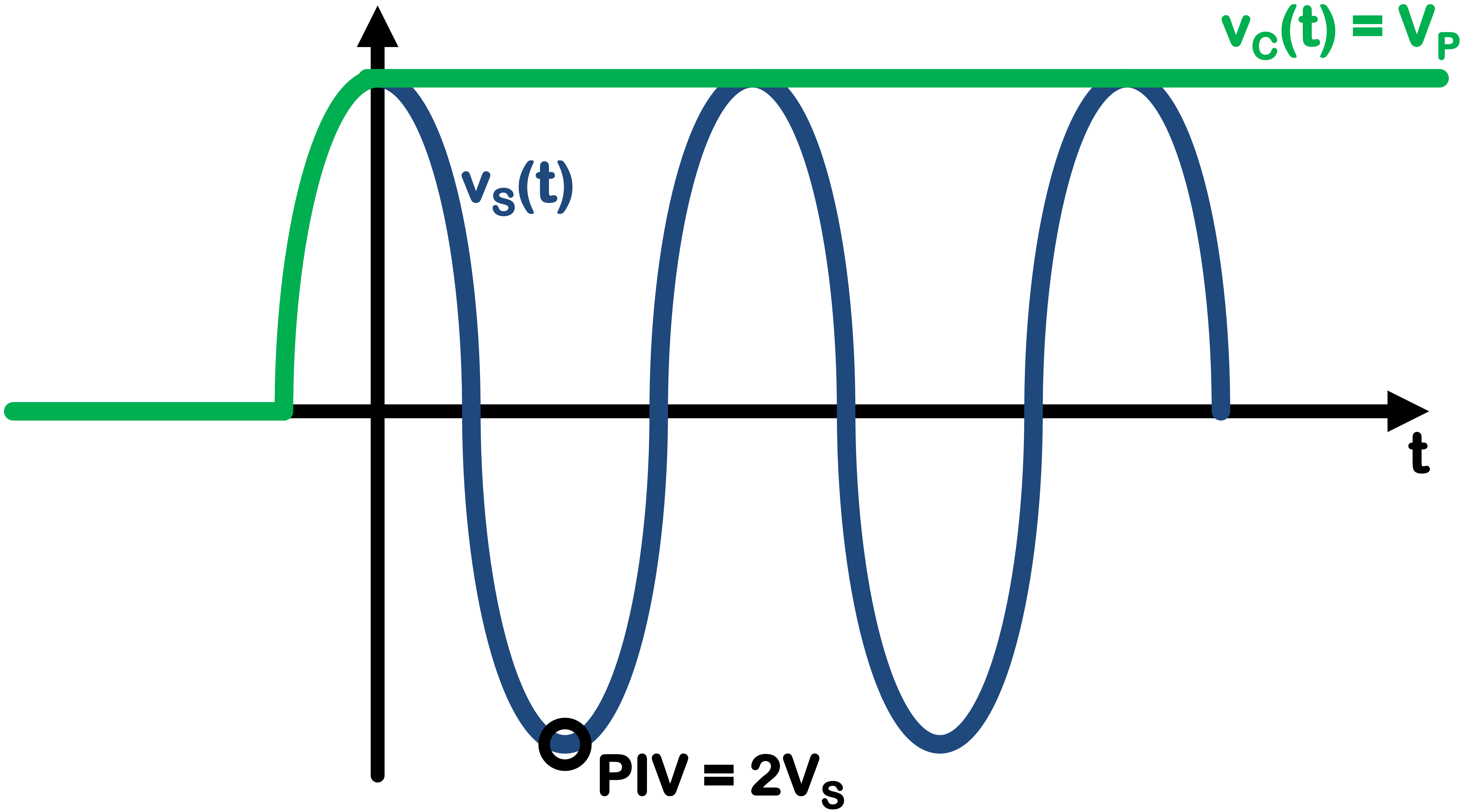
$v_C(t)$ stays constant for $v_S < v_C$

$v_C(t) = v_S(t)$ for $v_S > v_C$ and increasing

Half Wave Rectifier with Capacitor (Ideal)

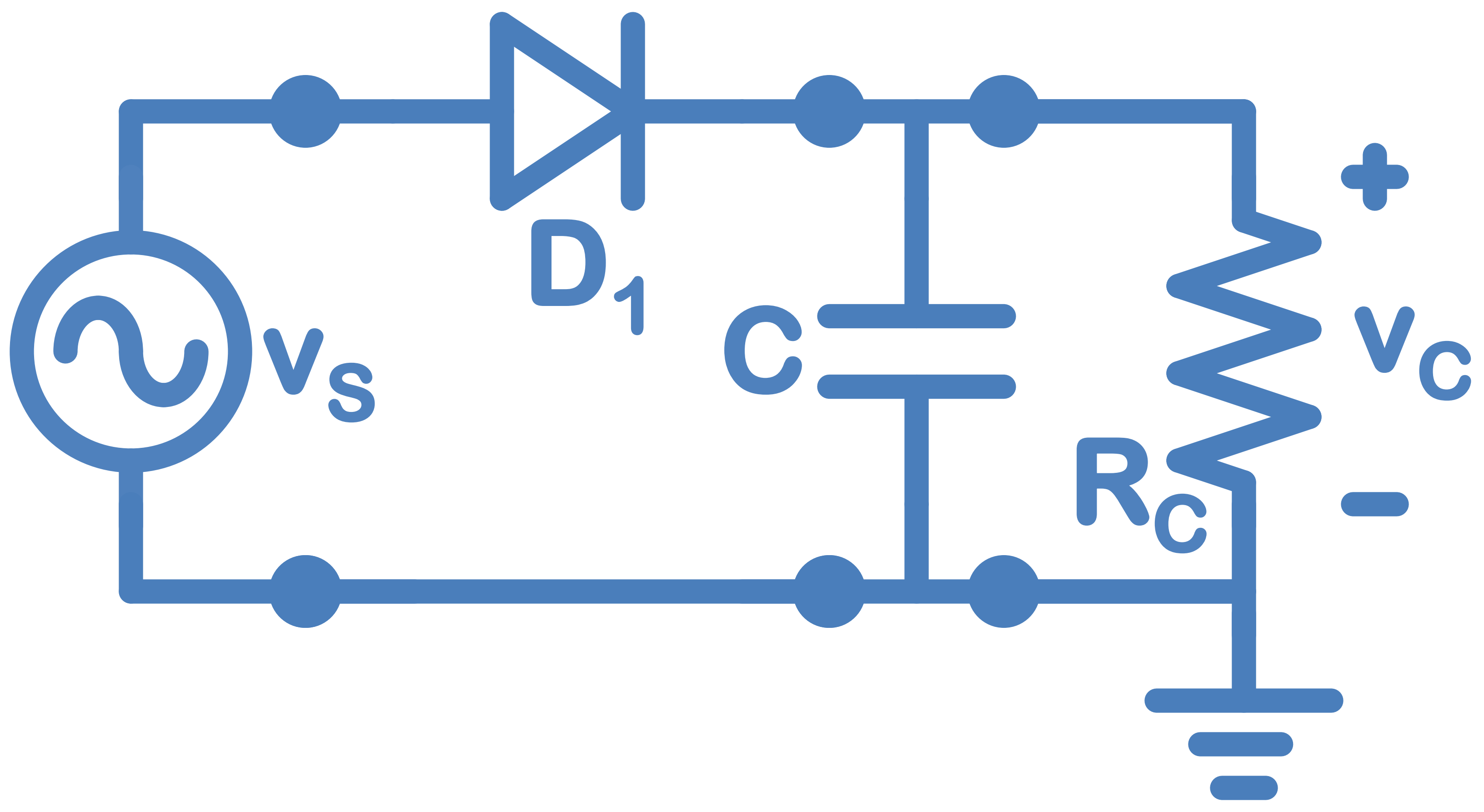


Half Wave Rectifier with Capacitor (Ideal)



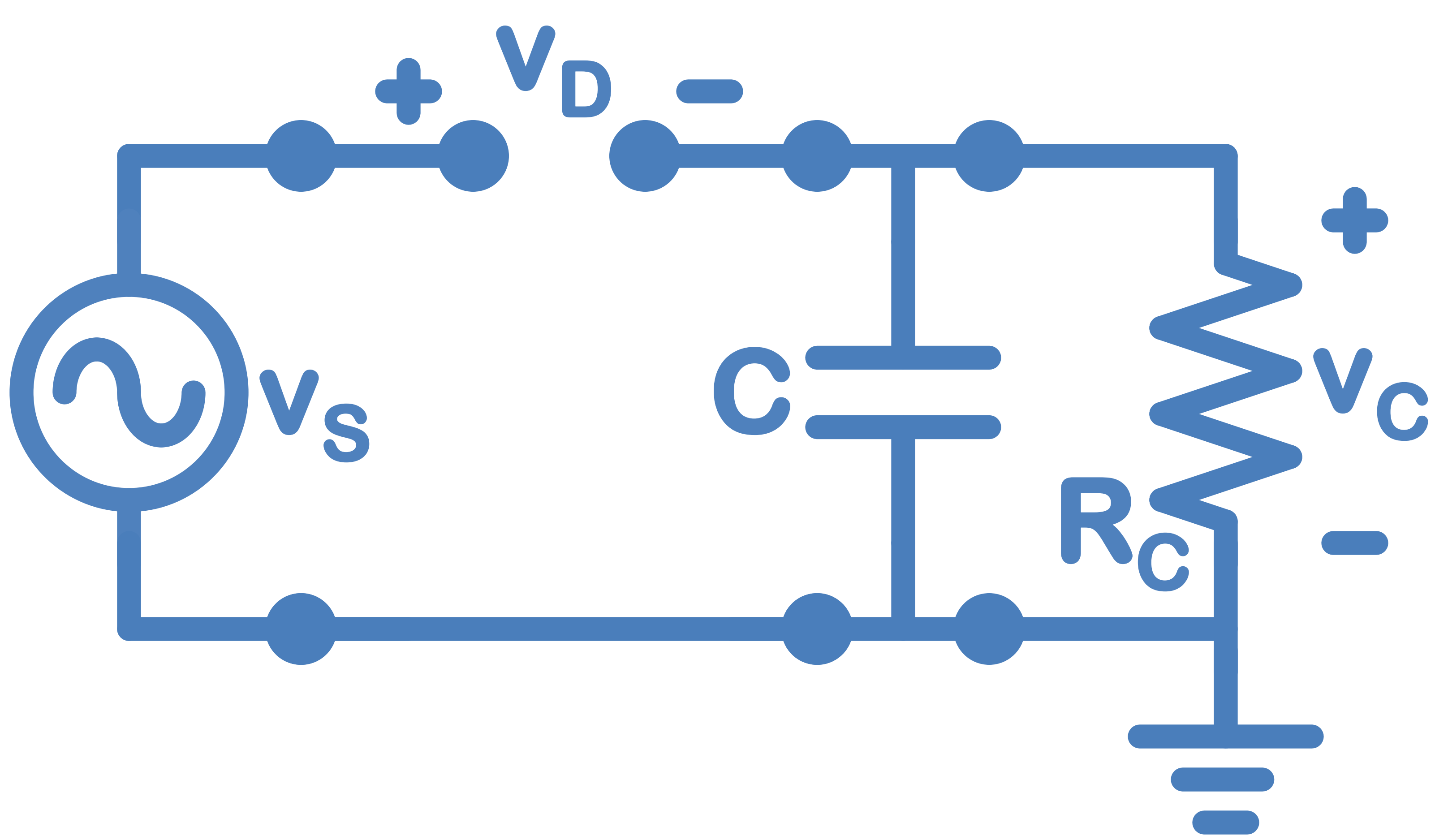
Positive Half Wave Rectifier w Cap & Res

Find the transfer function $v_C(v_S)$ using ideal diode



Positive Half Wave Rectifier w Cap & Res

Find the transfer function $v_C(v_S)$ using ideal diode



RB: $i_D = 0; i_C = -i_R$

$C \cdot v_C'(t) + v_C(t)/R_C = 0$

This is a linear 1st order diff. eq.

$v_C(t) = A\exp(-t/R_C C) + B$

Boundary Conditions

$v_C(\infty) = 0; B = 0; A = v_C(0)$

Assume t=0 is when diode FB to RB.

$v_D = v_S - v_C < 0; v_S < v_C$

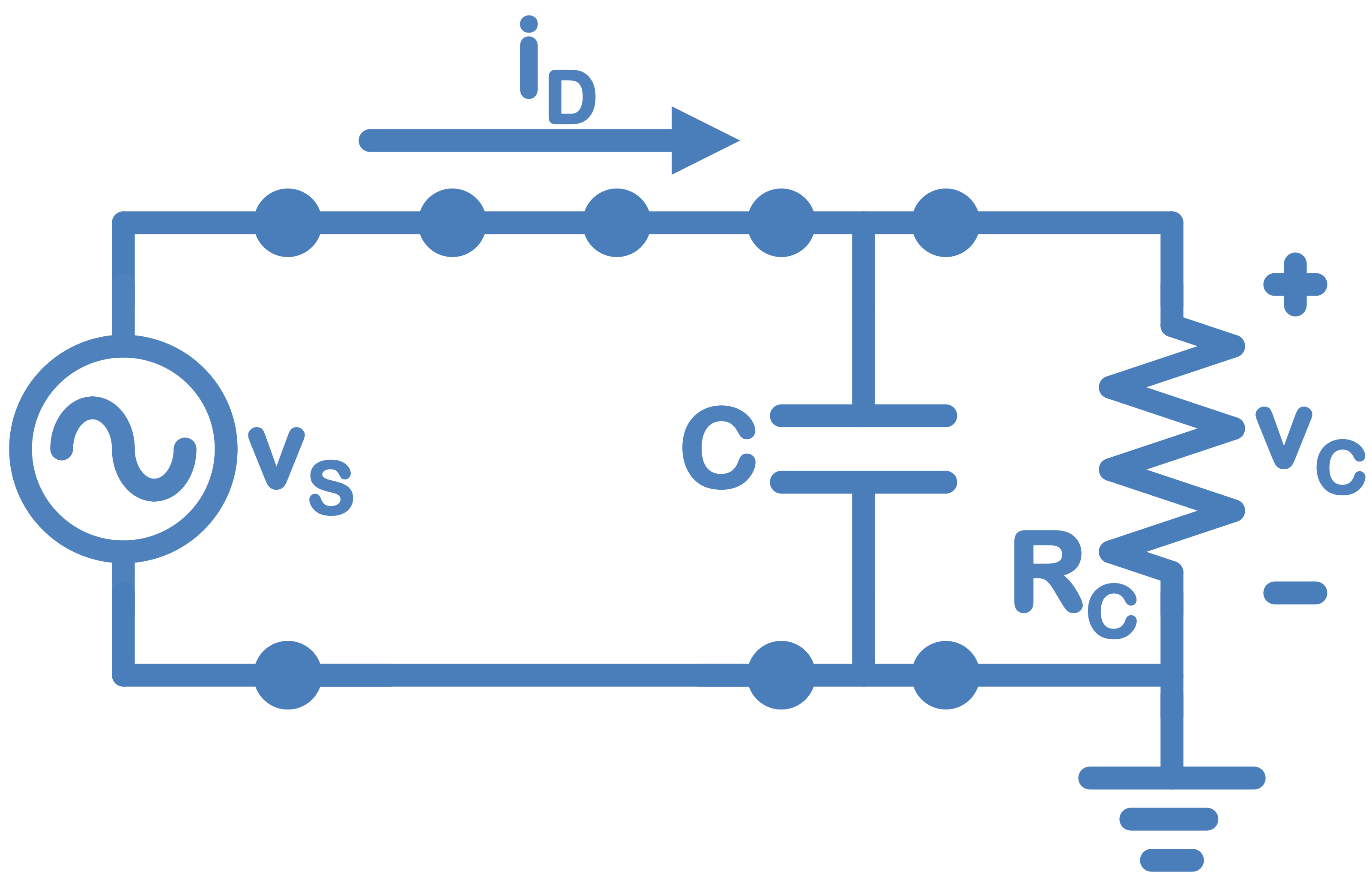
Summary

For diode going FB to RB at t=0.

$v_C(t) = v_C(t=0) \cdot \exp(-t/R_C C)$

Positive Half Wave Rectifier w Cap & Res

Find the transfer function $v_C(v_S)$ using ideal diode



FB: $v_C(t) = v_S(t)$

$i_D(t) = i_R + i_C = v_S(t)/R_C + C \cdot v_S'(t) > 0$

$v_S'(t) > -v_S(t)/R_C C$

*assuming $R_C C >> T=1/f$, this can be approximated as:

$v_S'(t) > 0$

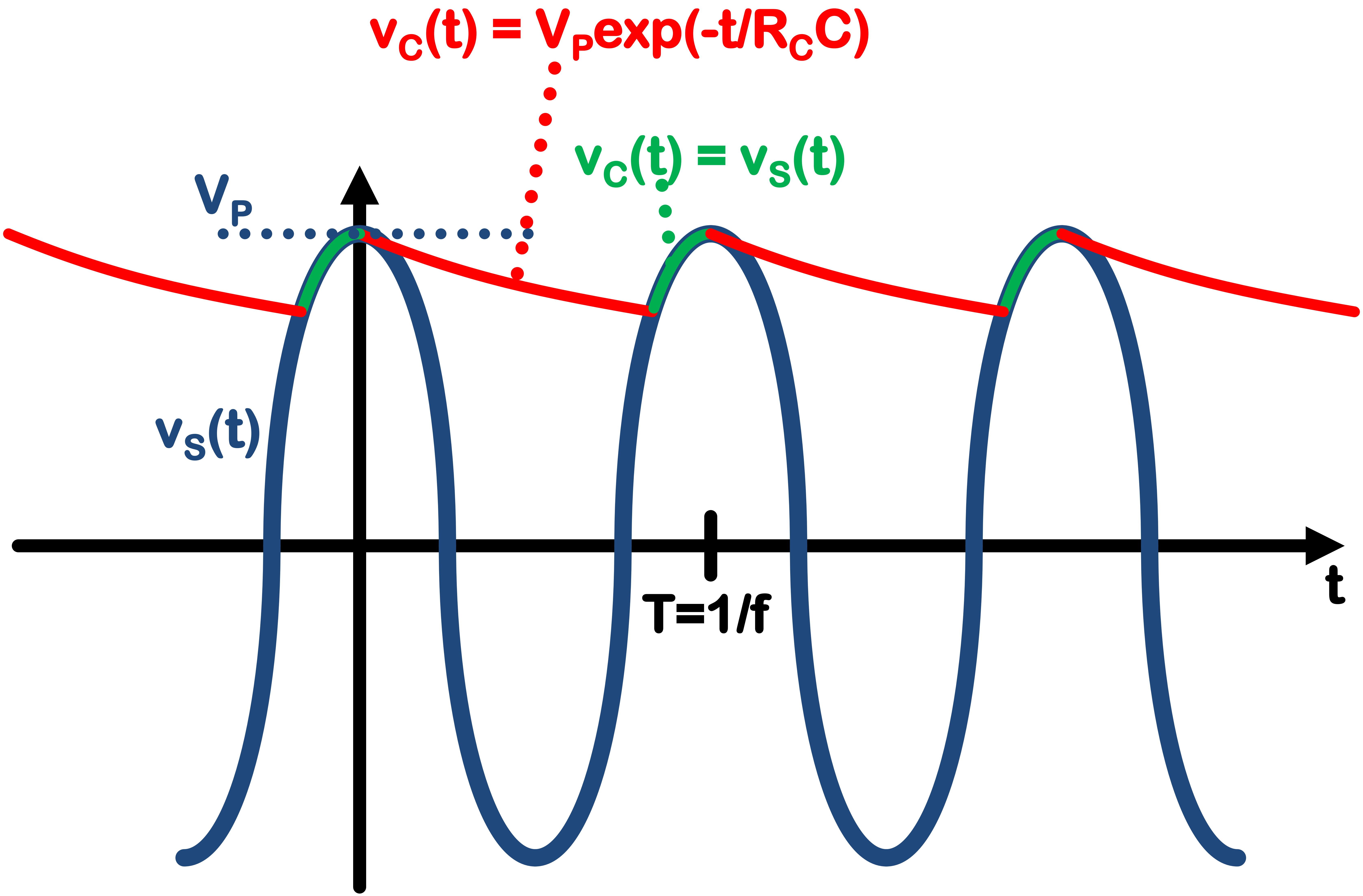
Summaries

FB: $v_C(t) = v_S$

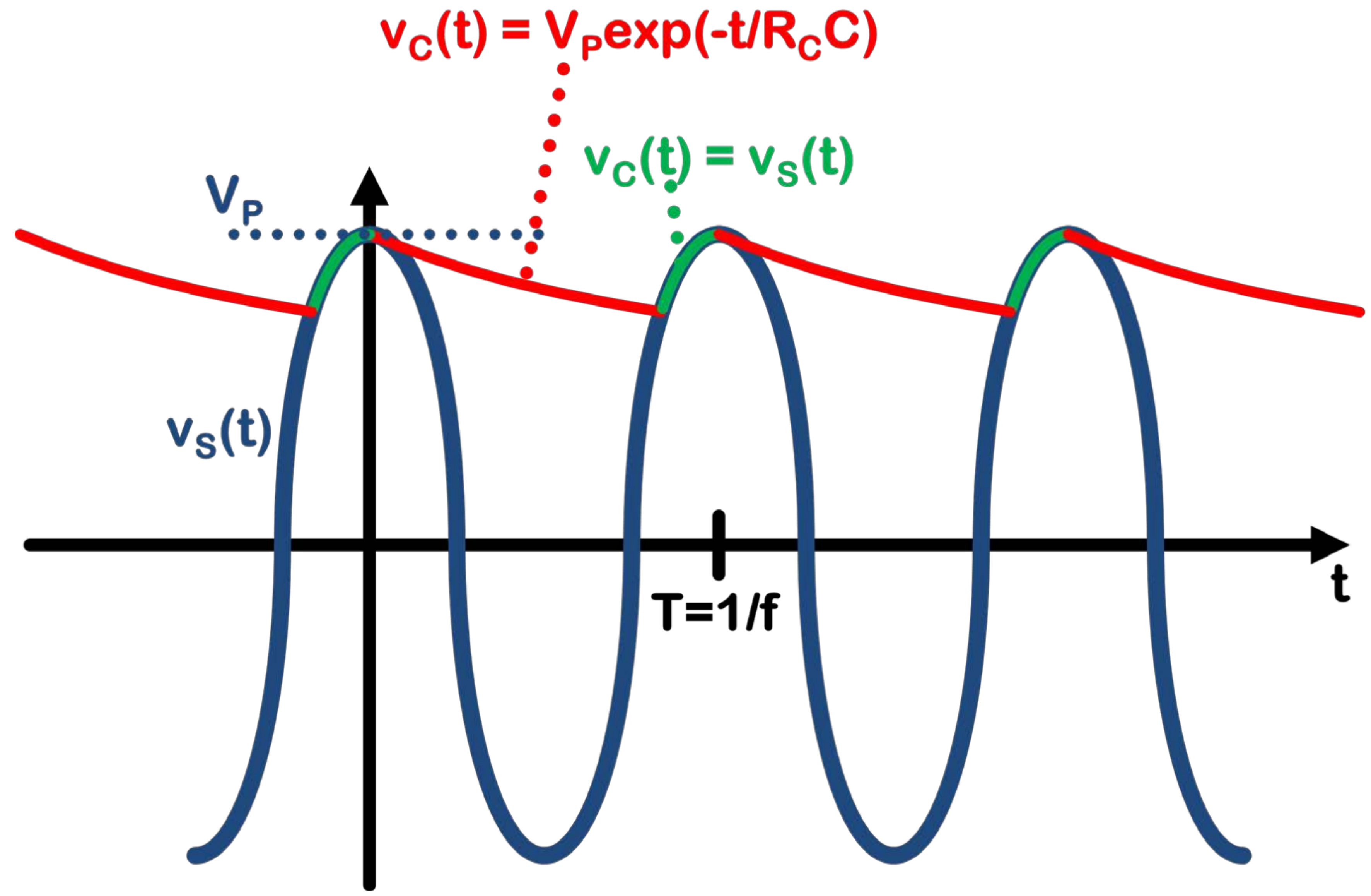
RB: $v_C(t) = v_C(t=0) \cdot \exp(-t/R_C C)$

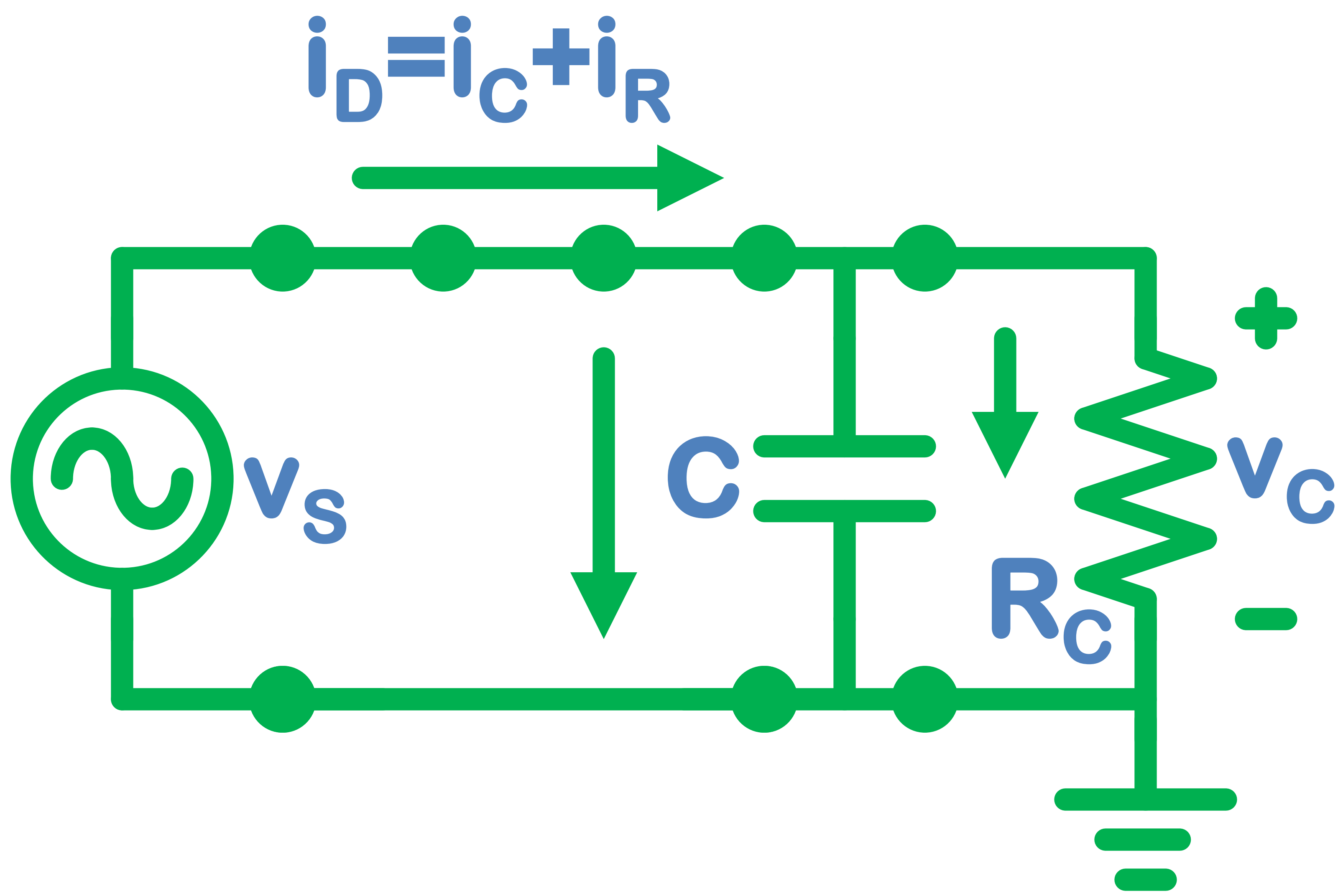
Switches between FB and RB when $v_S'(t)$ goes from pos to neg (peak) assume this happens at t=0

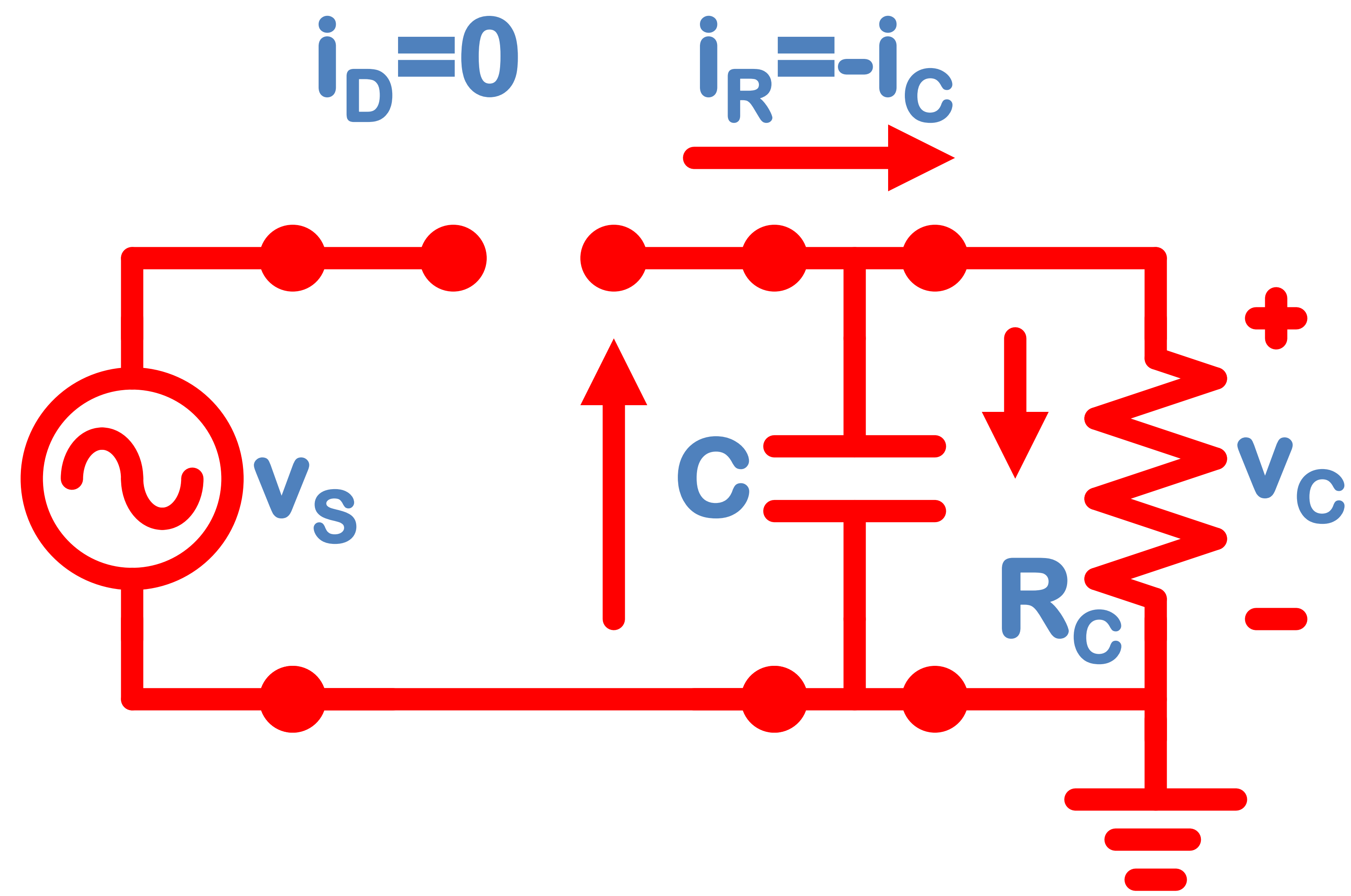
Half Wave Rectifier with Capacitor And Resistor (Ideal)



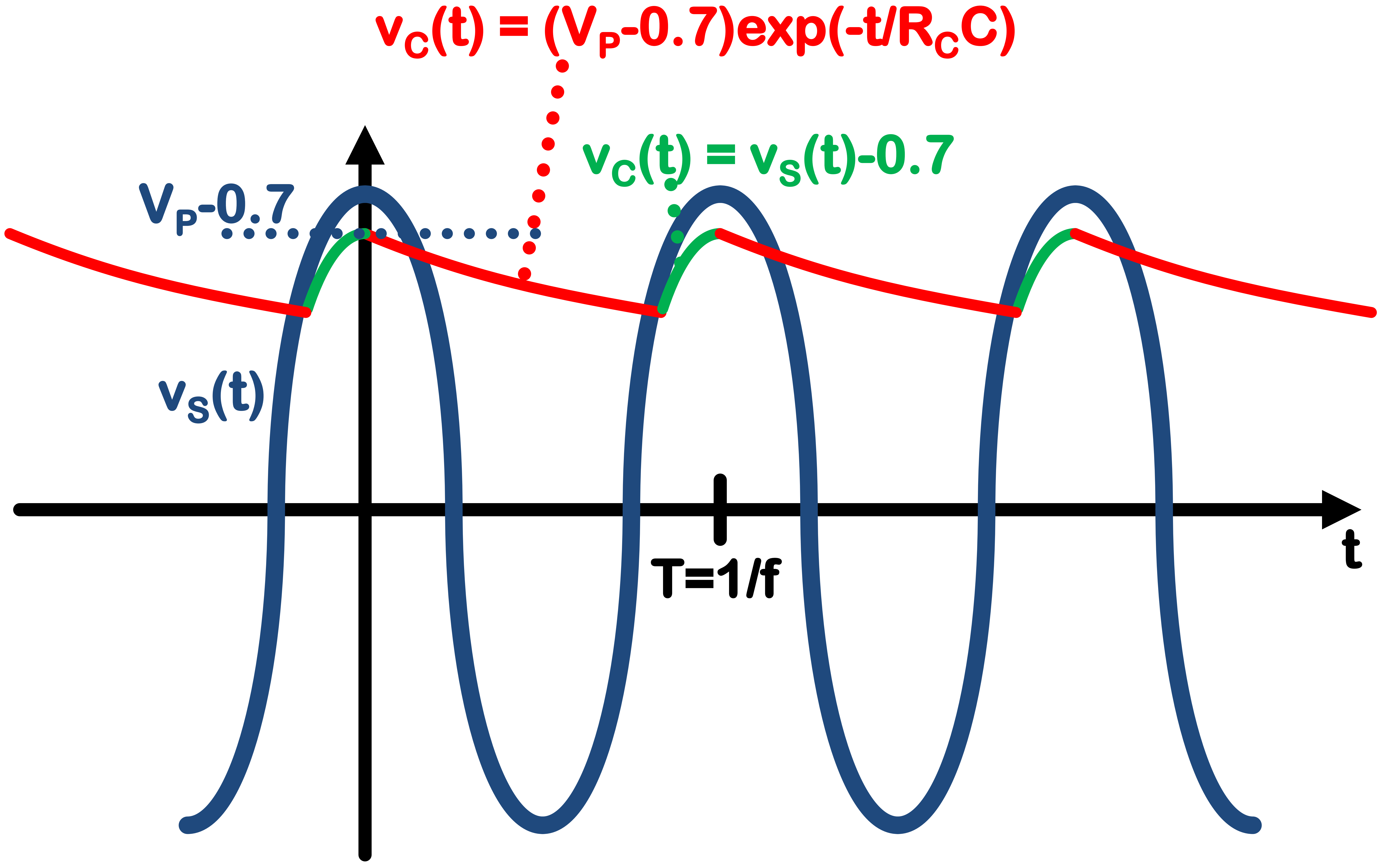
Half Wave Rectifier with Capacitor And Resistor (Ideal)



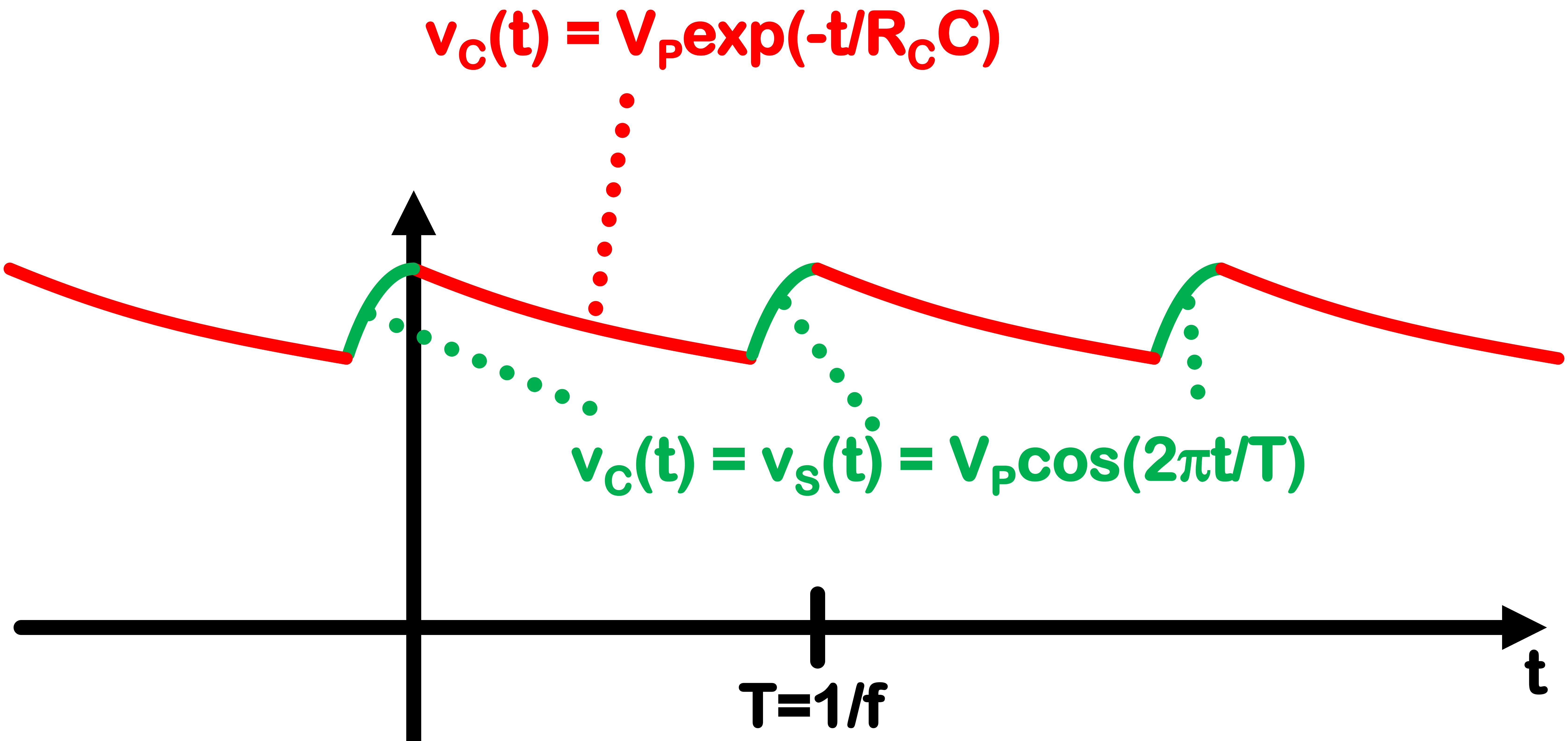




Half Wave Rectifier with Capacitor And Resistor (CVD)



Half Wave Rectifier with Capacitor And Resistor (Ideal)



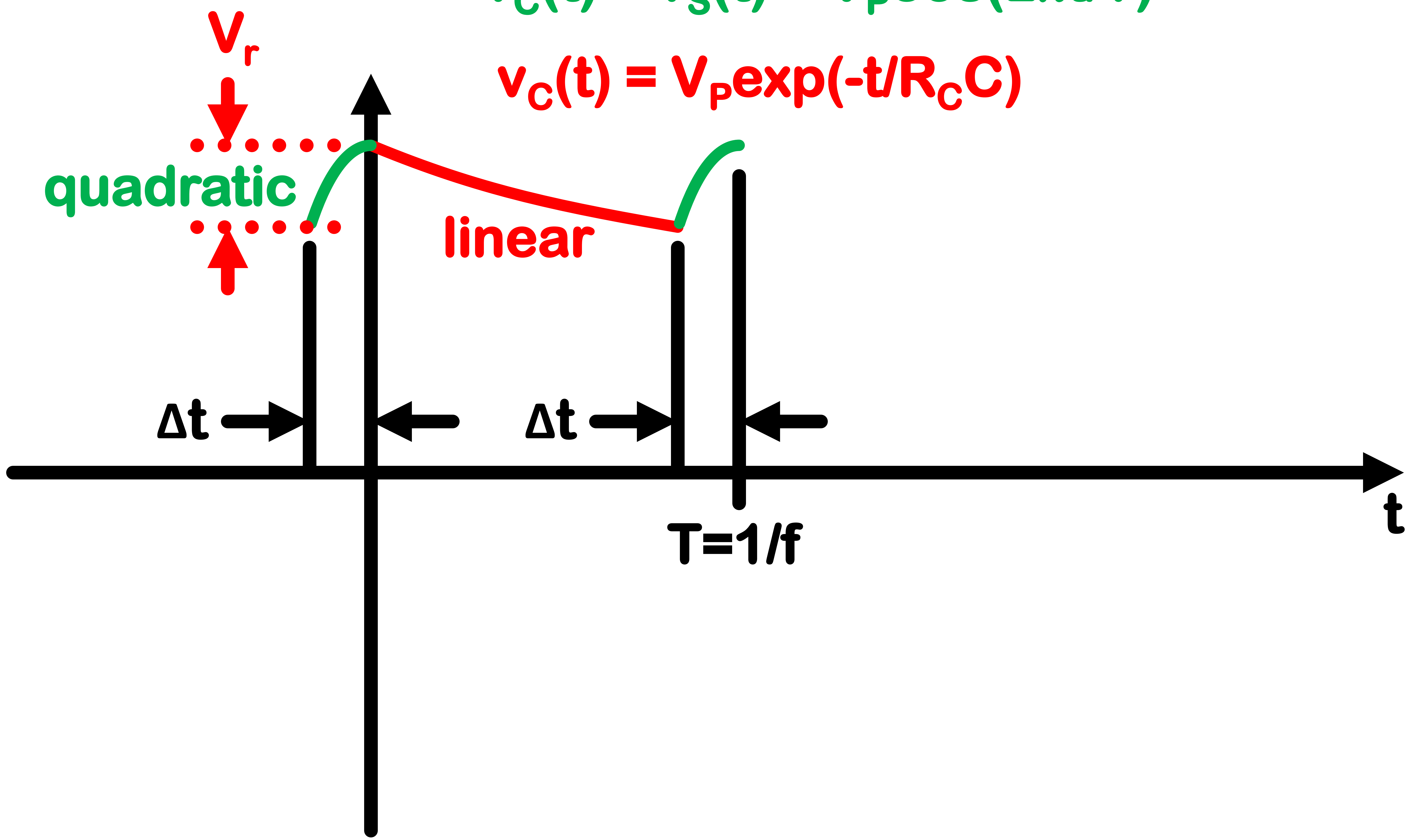
What is the Ripple Level ($v_{C:MAX} - v_{C:MIN}$)?
What percentage of time is it FB?
What is the average and max diode current?

Half Wave Rectifier with Capacitor And Resistor (Ideal)

What is the Ripple Level ($v_{C:MAX} - v_{C:MIN}$)?

$$v_C(t) = v_S(t) = V_P\cos(2\pi t/T)$$

$$v_C(t) = V_P\exp(-t/R_C C)$$

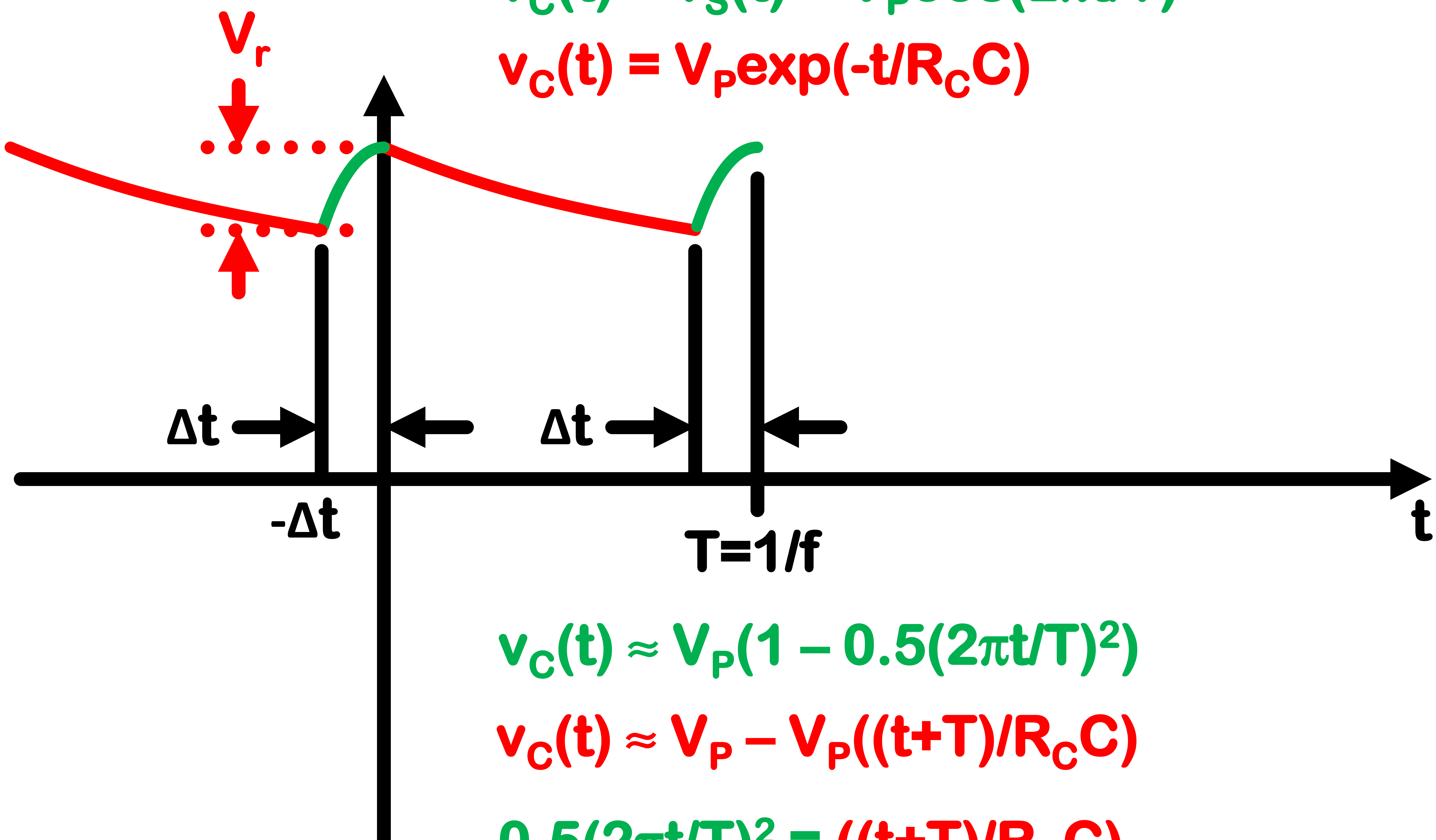


Half Wave Rectifier with Capacitor And Resistor (Ideal)

What is the Ripple Level ($v_{C:MAX} - v_{C:MIN}$)?

$$v_C(t) = v_S(t) = V_P\cos(2\pi t/T)$$

$$v_C(t) = V_P\exp(-t/R_C C)$$



$$v_C(t) \approx V_P(1 - 0.5(2\pi t/T)^2)$$

$$v_C(t) \approx V_P - V_P((t+T)/R_C C)$$

$$0.5(2\pi t/T)^2 = ((t+T)/R_C C)$$

Half Wave Rectifier with Capacitor And Resistor (Ideal)

What is the Ripple Level ($v_{C:MAX} - v_{C:MIN}$)?

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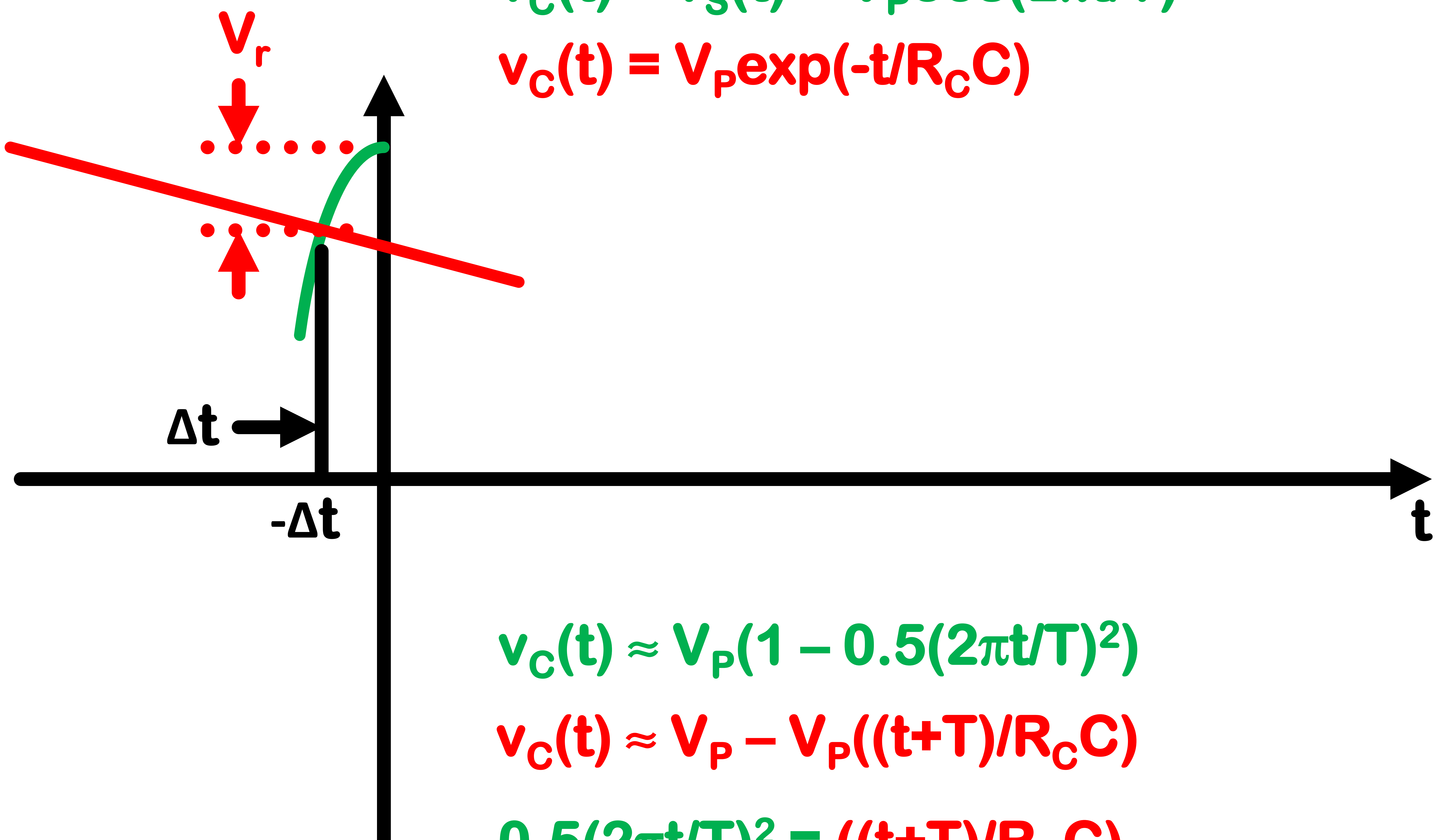


$v_C(t) \approx V_P(1 - 0.5(2\pi t/T)^2)$

$v_C(t) \approx V_P - V_P((t+T)/R_C C)$

$0.5(2\pi t/T)^2 = ((t+T)/R_C C)$

$$2\pi^2(t/T)^2 - (T/R_CC)(t/T) - (T/R_CC) = 0$$

$$\frac{t}{T} = \frac{\frac{T}{R_cC} - \sqrt{\left(\frac{T}{R_cC}\right)^2 + 4 \cdot 2\pi^2 \cdot \left(\frac{T}{R_cC}\right)}}{4\pi^2}$$

$$\frac{t}{T} = \frac{-\sqrt{2\left(\frac{T}{R_cC}\right)}}{2\pi}$$

$$\Delta t = \frac{T}{2\pi}\sqrt{\left(\frac{2T}{R_cC}\right)}$$

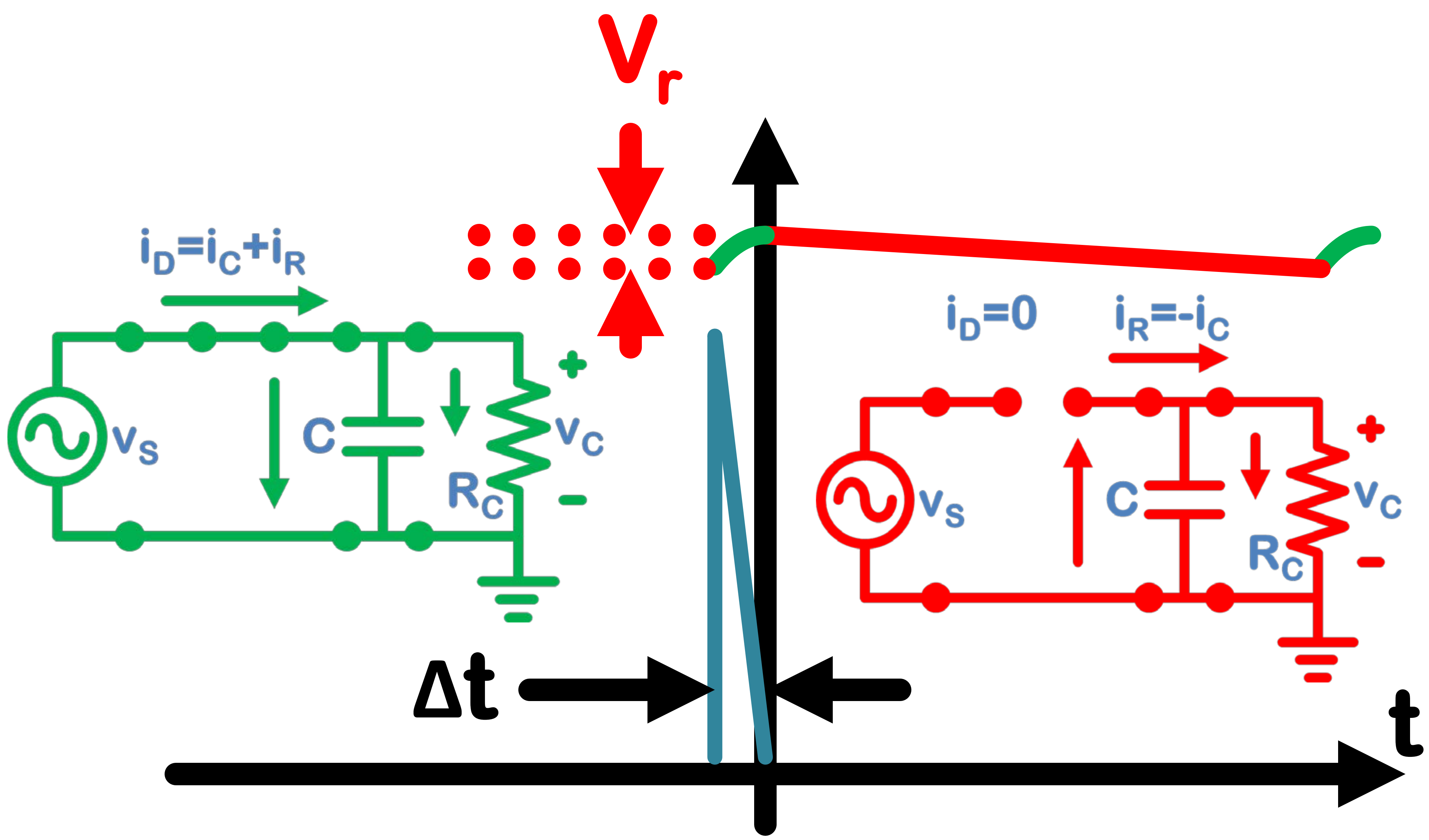
$$v_C(\Delta t) \approx V_P(1 - 2\pi^2\, 2\, (T/R_CC)/4\pi^2$$

$$v_C(\Delta t) \approx V_P(1 - T/(R_CC))$$

$$V_r = V_P - V_P + V_PT/(R_CC) = V_P/(fR_CC)$$

Half Wave Rectifier with Capacitor And Resistor (Ideal)

What is the average and max diode current?



During FB i_D is initially large and then tapers to zero. We can model it as a triangle. If

$i_{Dav} = I_R \cdot (1+T/\Delta t)$

Then

$i_{Dmax} = 2 \cdot I_R \cdot (1+T/\Delta t)$

The resistor is always conducting a constant:

$I_R = V_P/R_C$

During RB the capacitor is supplying this current.

During FB the capacitor needs to recover the lost charge from the source, $v_S(t)$

$$Q_R = I_R T = V_P T/R_C$$

During FB, Cap recovers:

$$Q_C = i_{Cav}\Delta t = Q_R$$

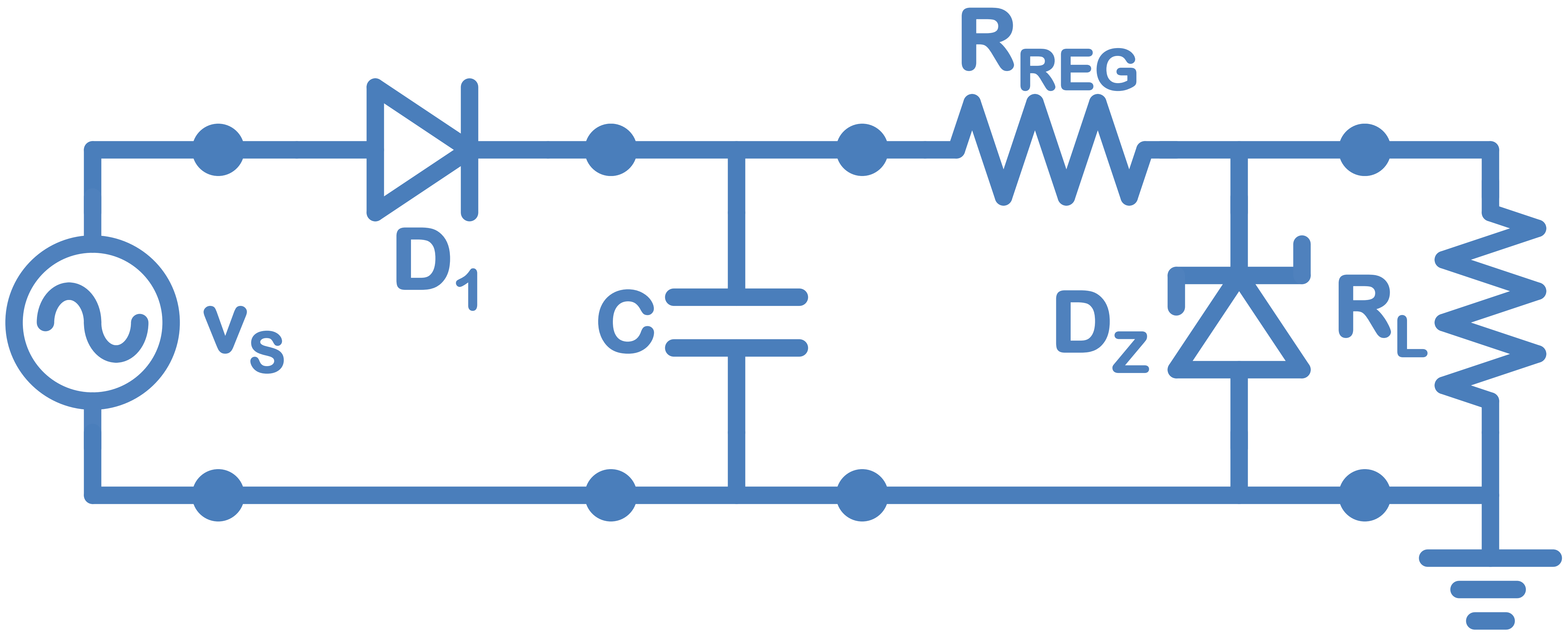
During FB,

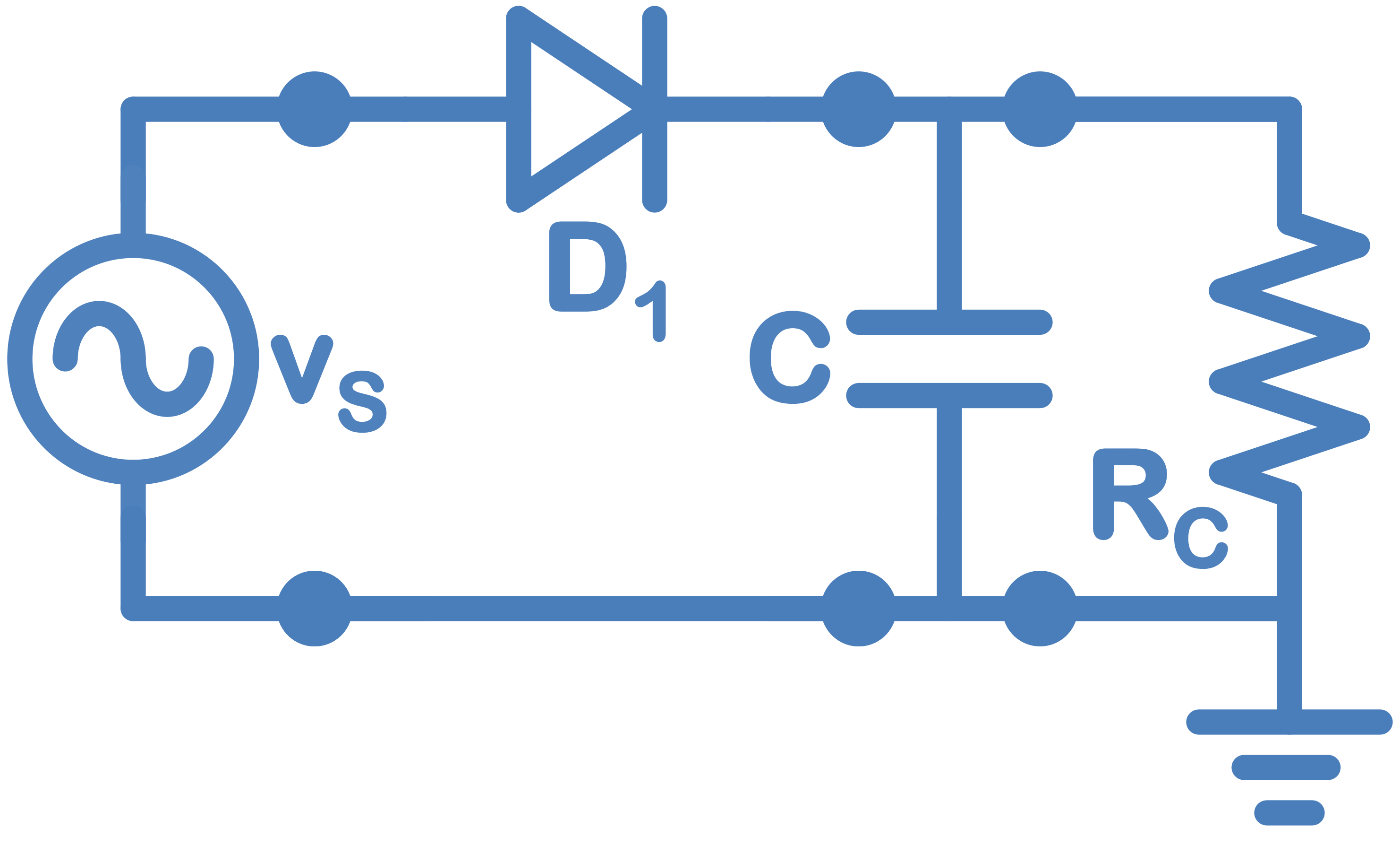
$$i_{Cav} = I_R \cdot (T/\Delta t)$$

$$i_{Dav} = i_{Cav} + I_R$$

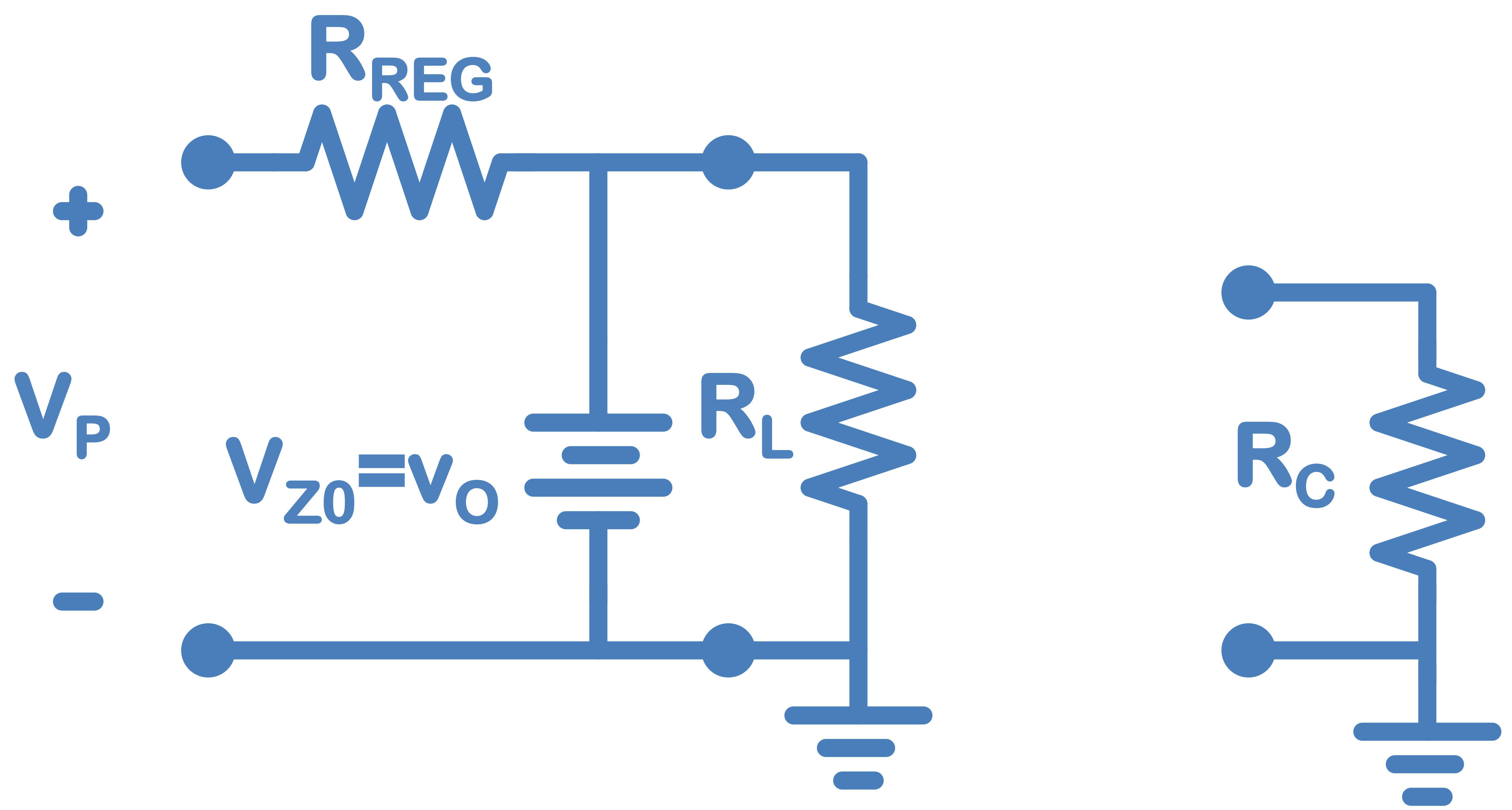
$$i_{Dav} = I_R \cdot (1+T/\Delta t)$$

How can we model the Regulator and Load as a single Resistor, R_C?





How can we model the Regulator and Load as a single Resistor?



V_P is the peak output of the Rectifier.

Use a simple CVD model for the Zener Diode.

$I_{REG} = (V_P – V_{Z0})/R_{REG}$

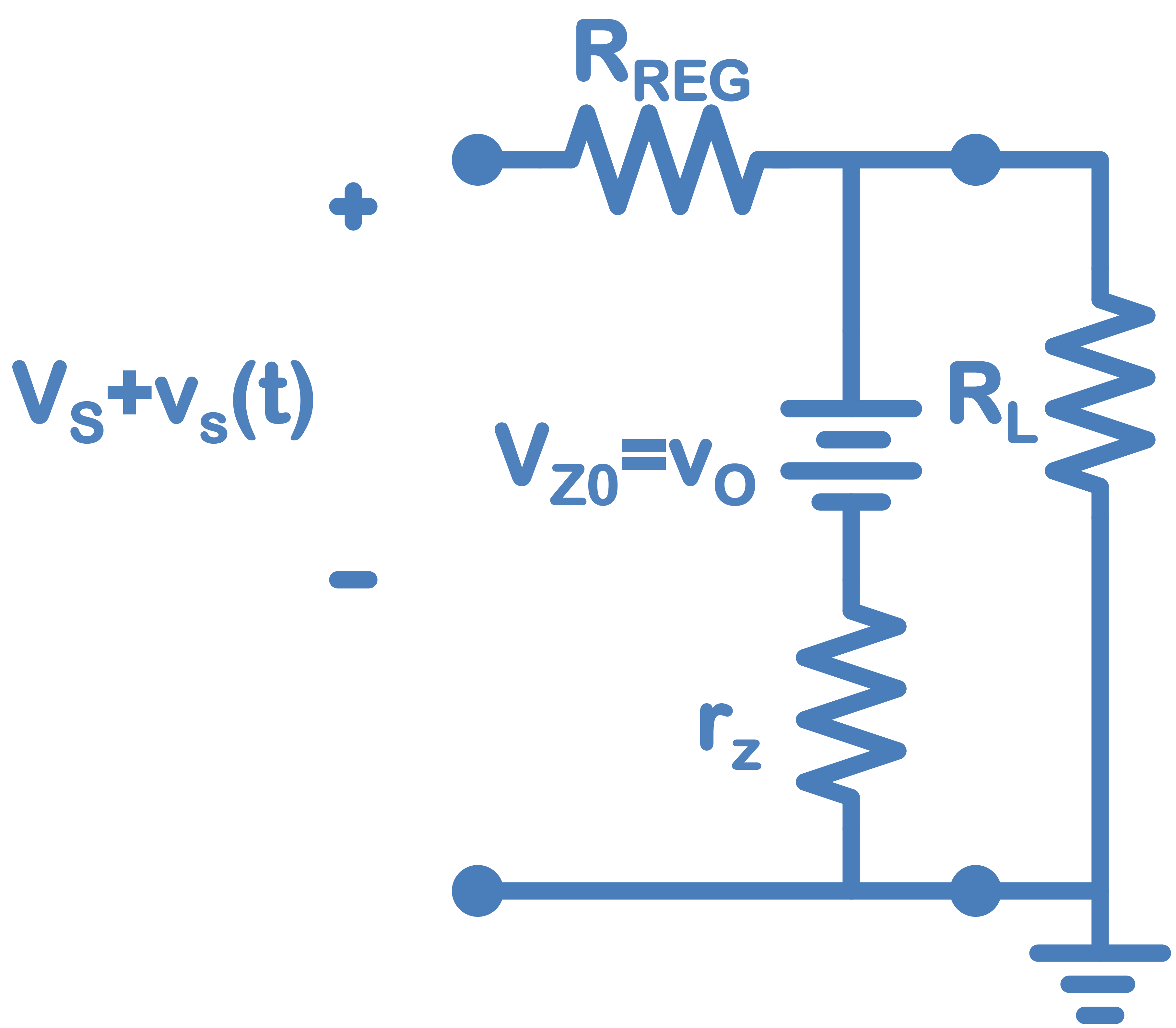
The effective resistance that is in parallel with the capacitor filter can be approximated as.

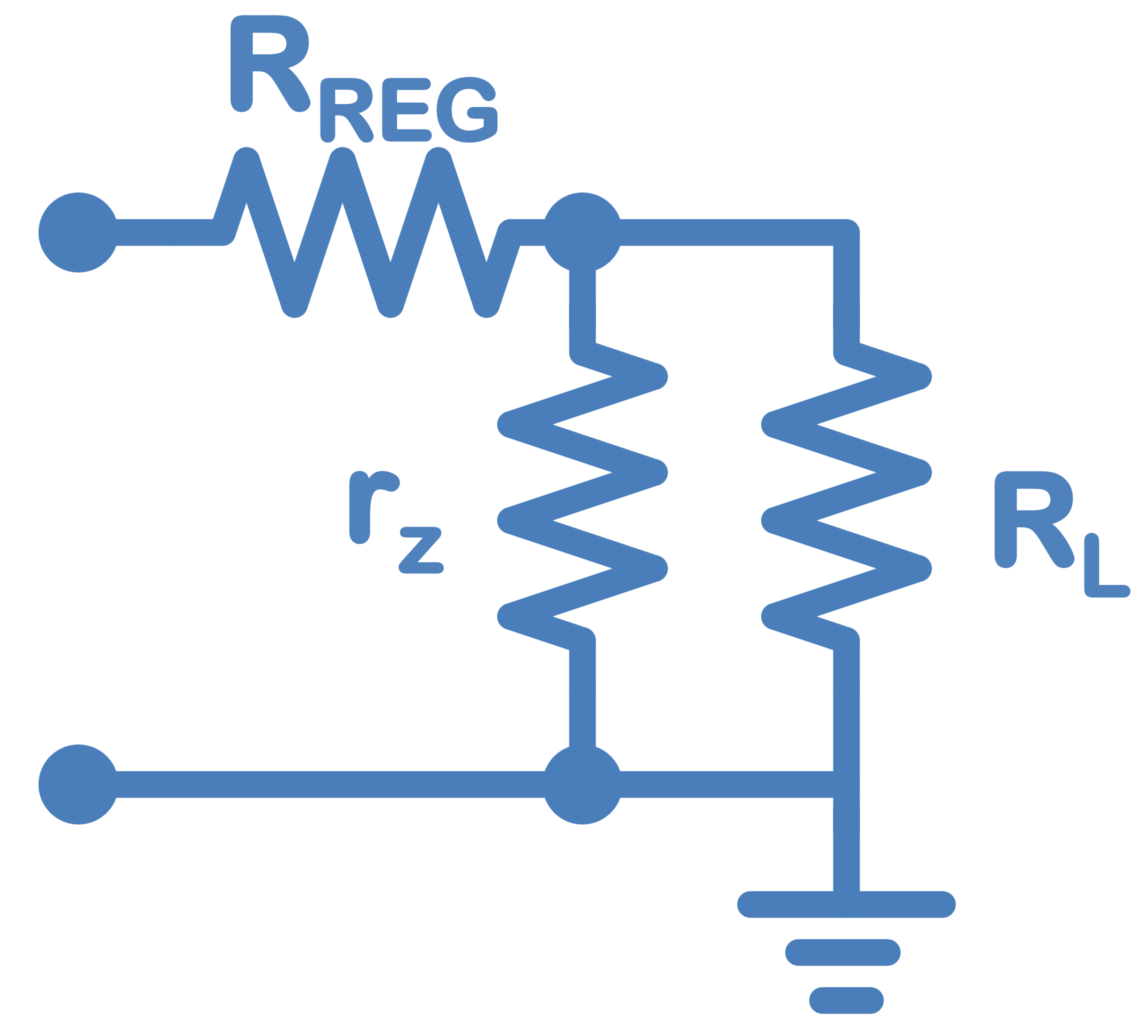
$R_C = V_P/I_{REG} = V_P R_{REG}/(V_P – V_{Z0})$

To ensure FB $I_{REG} > I_L$, or $(V_P – V_{Z0})/R_{REG} > V_{Z0}/R_L$

$R_{REG} < R_L(V_P – V_{Z0})/V_{Z0}$

Remember line regulation

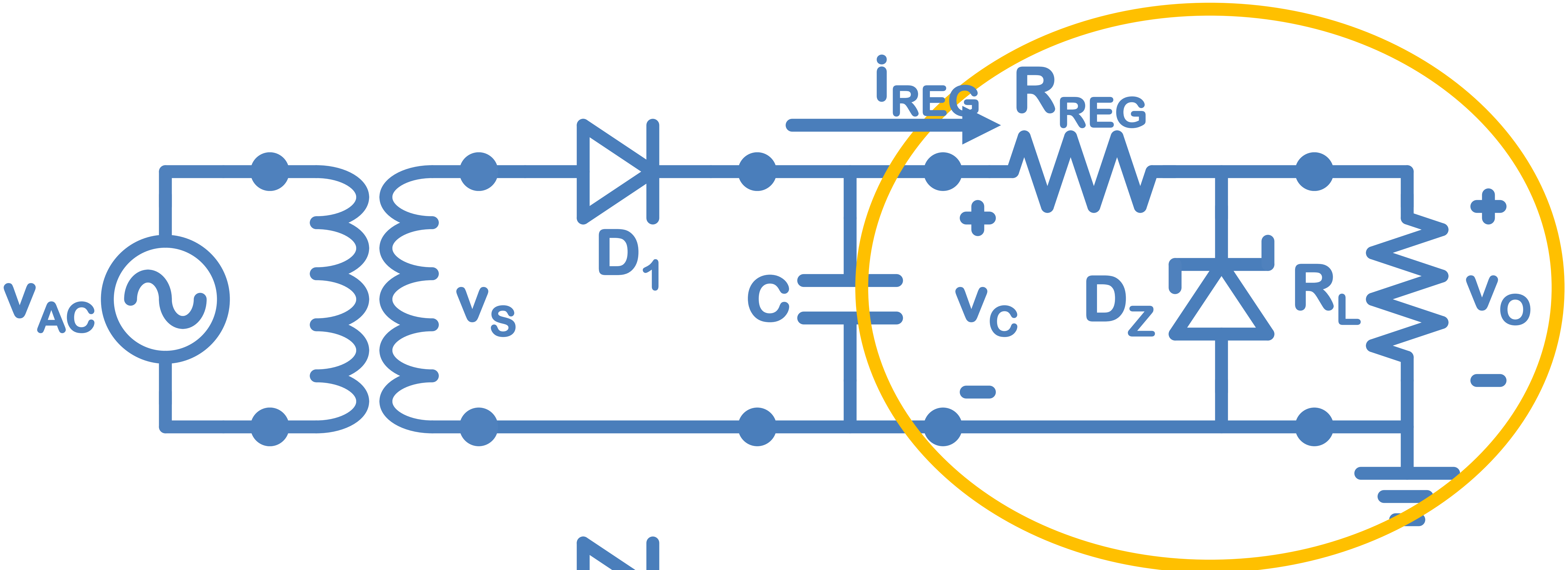


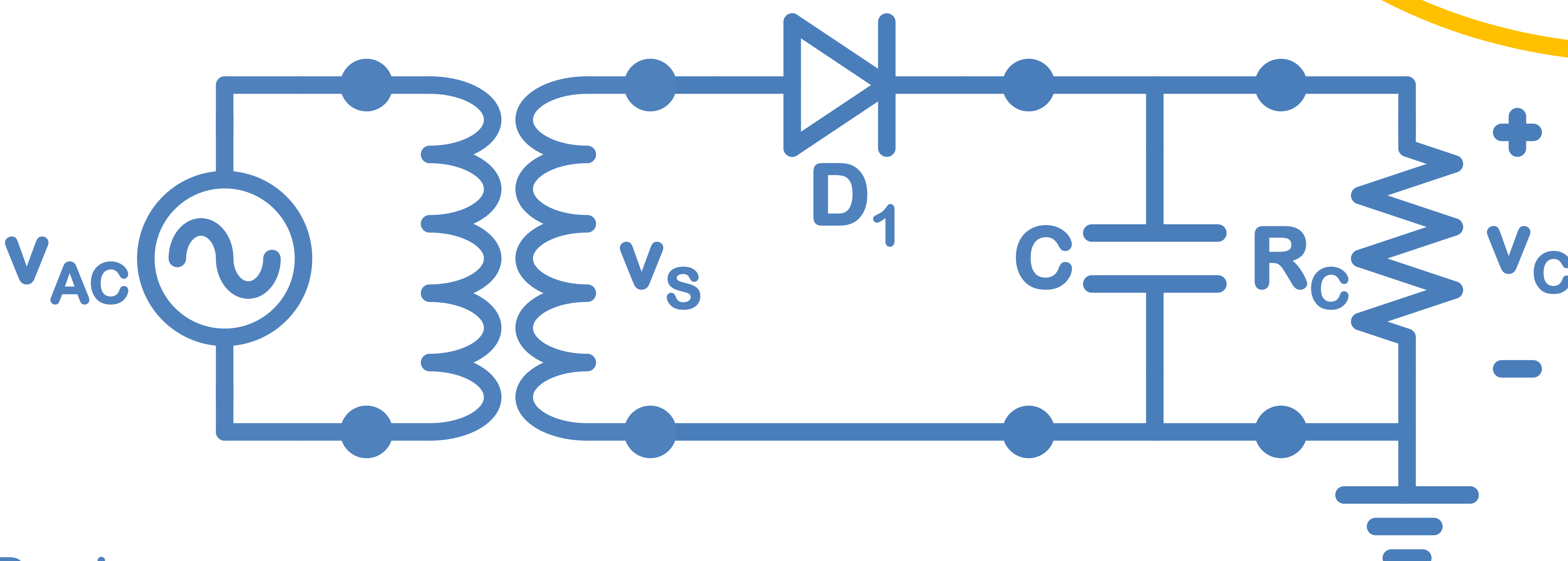


V_S=~V_P is the peak output of the Rectifier (DC component).

$v_s(t)$ is the time varying component which has a peak to peak value corresponding to the ripple voltage (discussed later).

line reg = $v_{out}(t)/v_s(t) = (r_z||r_L)/(r_z||R_L + R_{REG})$





Model Regulator as a resistor.

$R_C = v_C/i_{REG}$

Design

R_L is fixed by the device we supply power to.

R_{REG} is determined by peak output of the rectifier and R_L.

The amount of ripple at the output, Δv_{out}, of the regulator is a design requirement.

The amount of ripple at the output of the rectifier is $V_r = \Delta v_{out}$/(line regulation).

The R_C is determined from i_{REG} and R_{REG}.

The value of the filter capacitor is determined by V_r, V_P, R_C, and frequency.

Waveforms