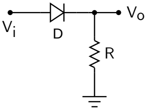
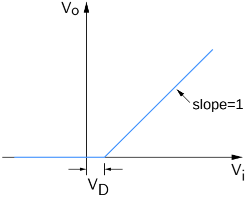
EE101: Op Amp circuits (Part 4)

M. B. Patil
mbpatil@ee.iitb.ac.in

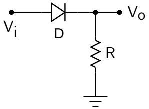
Department of Electrical Engineering
Indian Institute of Technology Bombay

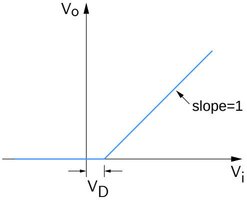
Consider a diode rectifier:





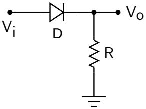
Consider a diode rectifier:

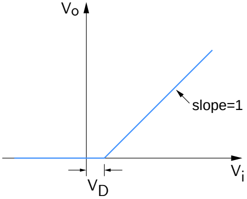




If $V_i \gg V_D$, the diode drop can be ignored.
However, if V_i is small, e.g., $V_i = 0.2 \sin \omega t\ V$, then the circuit does not rectify, and $V_o(t) = 0\,V$.

Consider a diode rectifier:



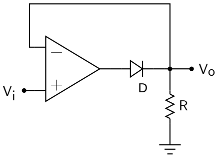


If $V_i \gg V_D$, the diode drop can be ignored.

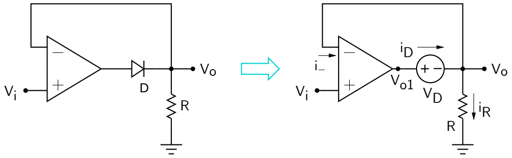
However, if V_i is small, e.g., $V_i = 0.2 \sin \omega t \;\; V$, then the circuit does not rectify, and $V_o(t) = 0 \; V$.

Precision rectifier circuits overcome this drawback.

Half-wave precision rectifier

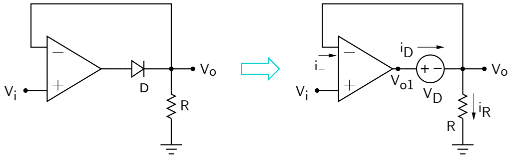


Half-wave precision rectifier



Consider two cases:

(i) D is conducting: The feedback loop is closed, and the circuit looks like (except for the diode drop) the buffer we have seen earlier.

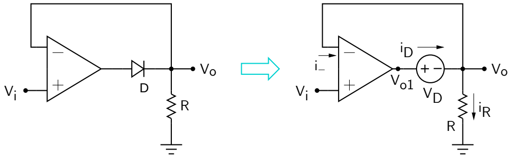


Consider two cases:

(i) D is conducting: The feedback loop is closed, and the circuit looks like (except for the diode drop) the buffer we have seen earlier.

Since the input current $i_- \approx 0$, $i_R = i_D$.

Further, $V_+ - V_- = \dfrac{V_{o1}}{A_V} = \dfrac{V_o + 0.7\ V}{A_V} \approx 0\ V \rightarrow V_o = V_i$.



Consider two cases:

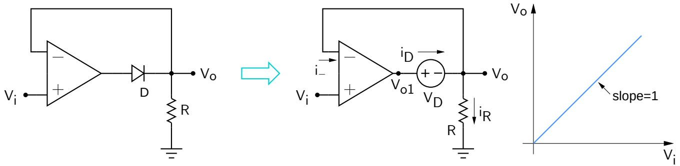
(i) D is conducting: The feedback loop is closed, and the circuit looks like (except for the diode drop) the buffer we have seen earlier.

Since the input current $i_- \approx 0$, $i_R = i_D$.

Further, $V_+ - V_- = \dfrac{V_{o1}}{A_V} = \dfrac{V_o + 0.7\,V}{A_V} \approx 0\,V \rightarrow V_o = V_i$.

This situation arises only if $i_D > 0$ (since the diode can only conduct in the forward direction), i.e., $V_o > 0 \rightarrow V_i = V_o > 0\,V$.

Half-wave precision rectifier



Consider two cases:

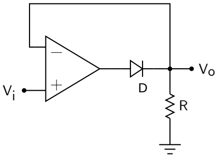
(i) D is conducting: The feedback loop is closed, and the circuit looks like (except for the diode drop) the buffer we have seen earlier.

Since the input current $i_- \approx 0$, $i_R = i_D$.

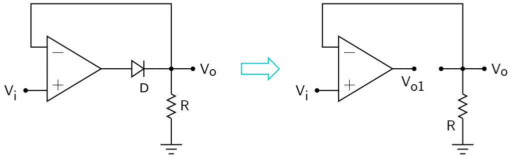
Further, $V_+ - V_- = \dfrac{V_{o1}}{A_V} = \dfrac{V_o + 0.7\,V}{A_V} \approx 0\,V \rightarrow V_o = V_i$.

This situation arises only if $i_D > 0$ (since the diode can only conduct in the forward direction), i.e., $V_o > 0 \rightarrow V_i = V_o > 0\,V$.

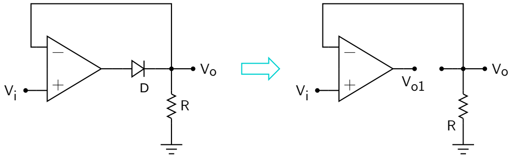
Half-wave precision rectifier



Half-wave precision rectifier



(ii) D is not conducting $\rightarrow V_o = 0\,V$.

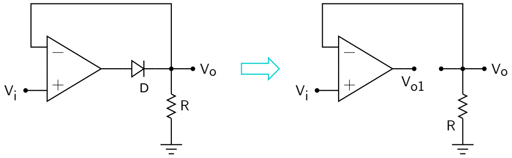


(ii) D is not conducting $\rightarrow V_o = 0\,V$.

What about V_{o1}?

Since the Op Amp is now in the open-loop configuration, a very small V_i is enough to drive it to saturation.

Half-wave precision rectifier

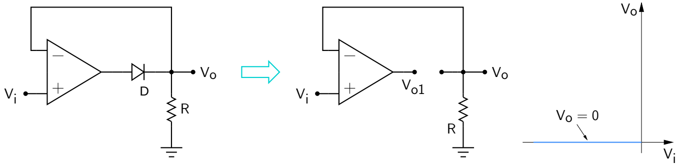


(ii) D is not conducting $\rightarrow V_o = 0\,V$.

What about V_{o1}?

Since the Op Amp is now in the open-loop configuration, a very small V_i is enough to drive it to saturation.

Note that Case (ii) occurs when $V_i < 0\,V$. Since $V_+ - V_- = V_i - 0 = V_i$ is negative, V_{o1} is driven to $-V\mathrm{sat}$.



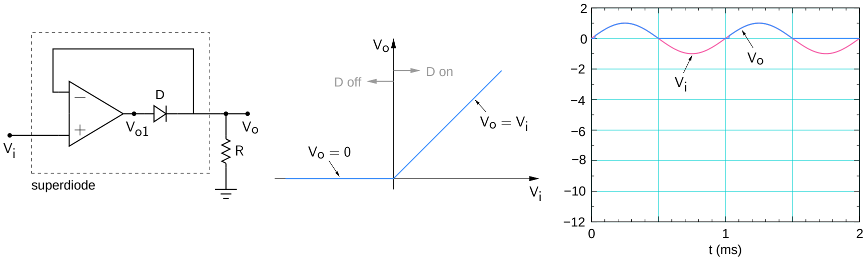
(ii) D is not conducting $\rightarrow V_o = 0\,V$.

What about V_{o1}?

Since the Op Amp is now in the open-loop configuration, a very small V_i is enough to drive it to saturation.

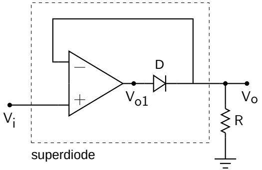
Note that Case (ii) occurs when $V_i < 0\,V$. Since $V_+ - V_- = V_i - 0 = V_i$ is negative, V_{o1} is driven to $-V\text{sat}$.

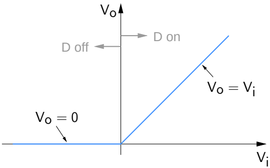
Half-wave precision rectifier

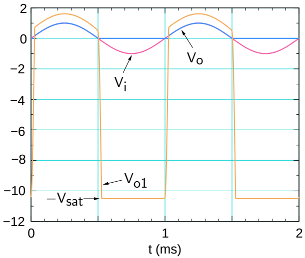


* The circuit is called a “superdiode” (i.e., a diode with zero V_{on}).

Half-wave precision rectifier

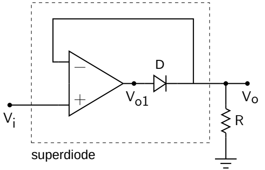


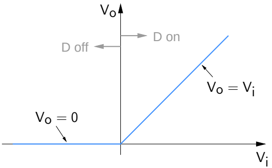


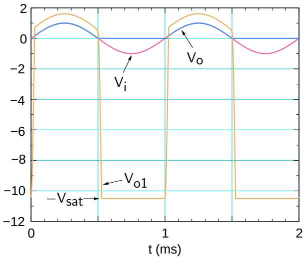


* The circuit is called a "superdiode" (i.e., a diode with zero V_{on}).

Half-wave precision rectifier

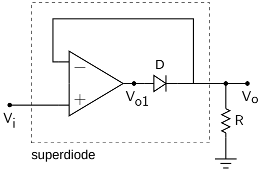


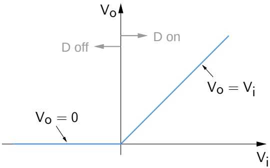


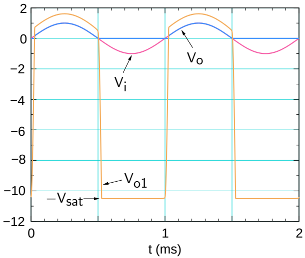


* The circuit is called a "superdiode" (i.e., a diode with zero V_{on}).
* Note that the Op Amp needs to come out of saturation when V_i changes from negative to positive values. This is a relatively slow process, and it limits the speed of this circuit.

Half-wave precision rectifier



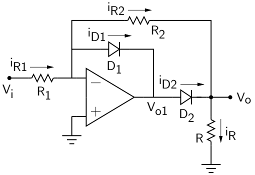




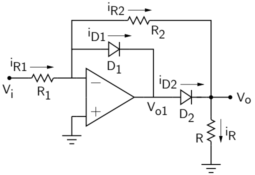
* The circuit is called a "superdiode" (i.e., a diode with zero V_{on}).
* Note that the Op Amp needs to come out of saturation when V_i changes from negative to positive values. This is a relatively slow process, and it limits the speed of this circuit.

  SEQUEL file: `precision_half_wave_1.sqproj`

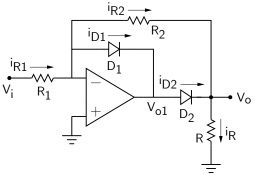
Improved half-wave precision rectifier



Improved half-wave precision rectifier



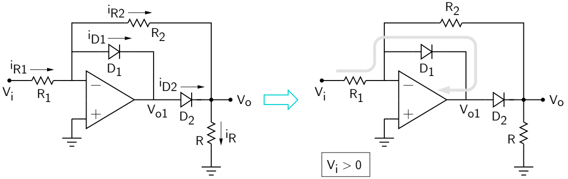
(i) D_1 conducts: $V_- = V_+ = 0\,V$, $V_{o1} = -V_{D1} \approx -0.7\,V$.



(i) D_1 conducts: $V_- = V_+ = 0\,V$, $V_{o1} = -V_{D1} \approx -0.7\,V$.

D_2 cannot conduct (show that, if it did, KCL is not satisfied at V_o).
$\rightarrow i_{R2} = 0$, $V_o = V_- = 0\,V$.

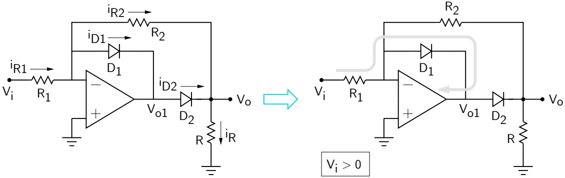
Improved half-wave precision rectifier



(i) D_1 conducts: $V_- = V_+ = 0\,V$, $V_{o1} = -V_{D1} \approx -0.7\,V$.

D_2 cannot conduct (show that, if it did, KCL is not satisfied at V_o).
$\rightarrow i_{R2} = 0$, $V_o = V_- = 0\,V$.

Improved half-wave precision rectifier

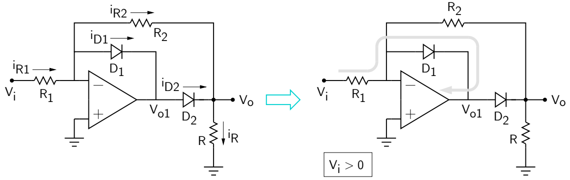


(i) D_1 conducts: $V_- = V_+ = 0\,V$, $V_{o1} = -V_{D1} \approx -0.7\,V$.

D_2 cannot conduct (show that, if it did, KCL is not satisfied at V_o).
$\rightarrow i_{R2} = 0$, $V_o = V_- = 0\,V$.

$i_{R1} = i_{D1}$ which can only be positive $\Rightarrow V_i > 0\,V$.

Improved half-wave precision rectifier



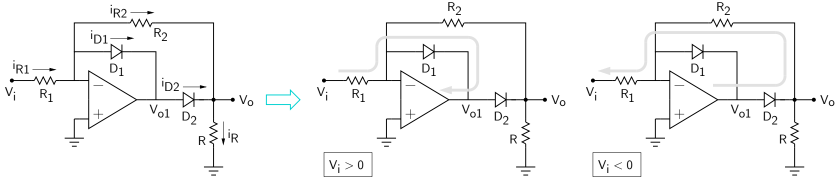
(i) D_1 conducts: $V_- = V_+ = 0\,V$, $V_{o1} = -V_{D1} \approx -0.7\,V$.

D_2 cannot conduct (show that, if it did, KCL is not satisfied at V_o).
$\rightarrow i_{R2} = 0$, $V_o = V_- = 0\,V$.

$i_{R1} = i_{D1}$ which can only be positive $\Rightarrow V_i > 0\,V$.

(ii) D_1 is off; this will happen when $V_i < 0\,V$.

Improved half-wave precision rectifier



(i) D_1 conducts: $V_- = V_+ = 0\,V$, $V_{o1} = -V_{D1} \approx -0.7\,V$.

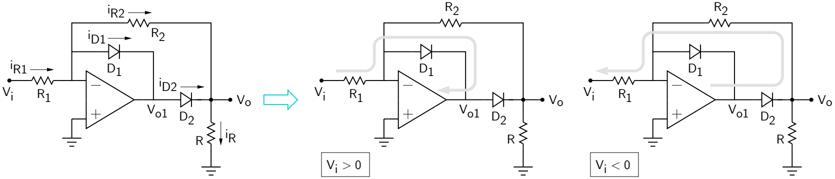
D_2 cannot conduct (show that, if it did, KCL is not satisfied at V_o).
$\rightarrow i_{R2} = 0$, $V_o = V_- = 0\,V$.

$i_{R1} = i_{D1}$ which can only be positive $\Rightarrow V_i > 0\,V$.

(ii) D_1 is off; this will happen when $V_i < 0\,V$.

In this case, D_2 conducts and closes the feedback loop through R_2.

Improved half-wave precision rectifier



(i) D_1 conducts: $V_- = V_+ = 0\,V$, $V_{o1} = -V_{D1} \approx -0.7\,V$.

D_2 cannot conduct (show that, if it did, KCL is not satisfied at V_o).
$\rightarrow i_{R2} = 0$, $V_o = V_- = 0\,V$.

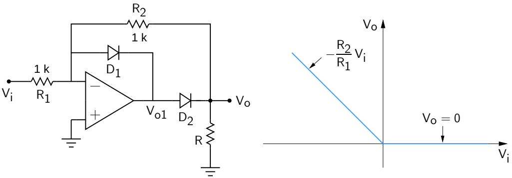
$i_{R1} = i_{D1}$ which can only be positive $\Rightarrow V_i > 0\,V$.

(ii) D_1 is off; this will happen when $V_i < 0\,V$.

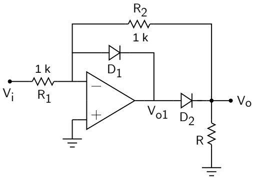
In this case, D_2 conducts and closes the feedback loop through R_2.

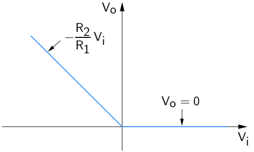
$$V_o = V_- + i_{R2}R_2 = 0 + \left(\frac{0 - V_i}{R_1}\right) R_2 = -\frac{R_2}{R_1} V_i \,.$$

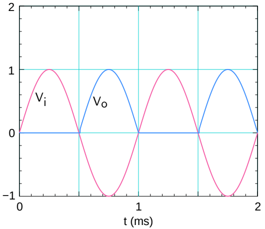
Improved half-wave precision rectifier



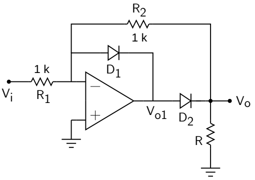
Improved half-wave precision rectifier

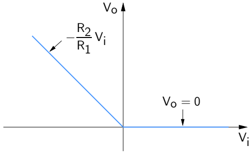


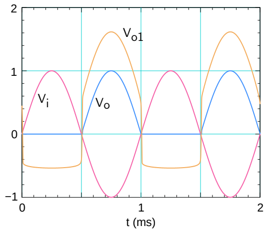




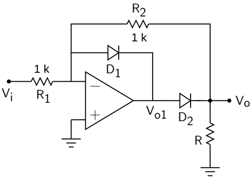
Improved half-wave precision rectifier

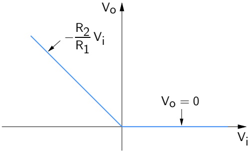


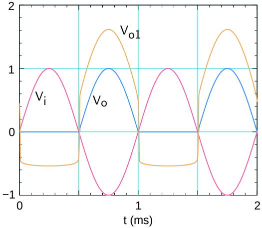




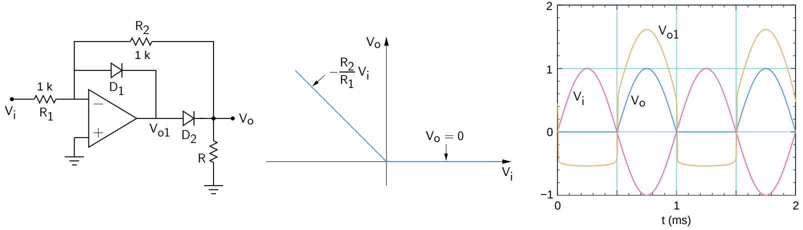
Improved half-wave precision rectifier







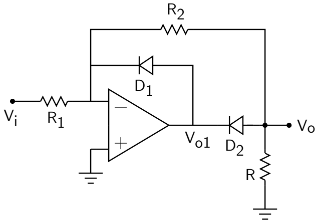
* Note that the Op Amp does not enter saturation since a feedback path is available for $V_i > 0\,V$ and $V_i < 0\,V$.

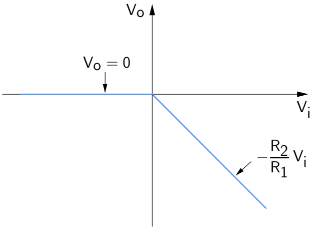


* Note that the Op Amp does not enter saturation since a feedback path is available for $V_i > 0\,V$ and $V_i < 0\,V$.

  SEQUEL file: `precision_half_wave.sqproj`

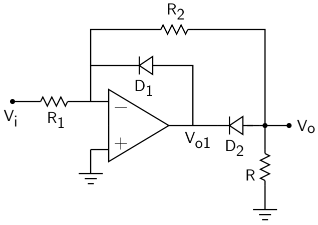
Improved half-wave precision rectifier

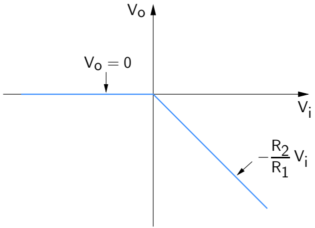




The diodes are now reversed.

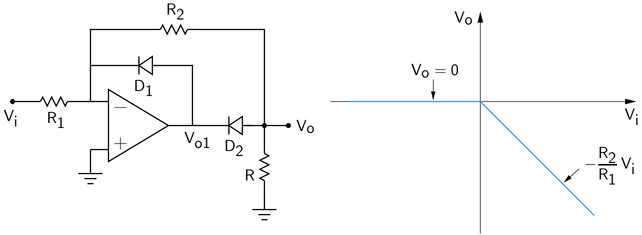
Improved half-wave precision rectifier





The diodes are now reversed.

By considering two cases: (i) D_1 on, (ii) D_1 off, the V_o versus V_i relationship shown in the figure is obtained (show this).

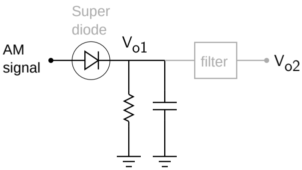


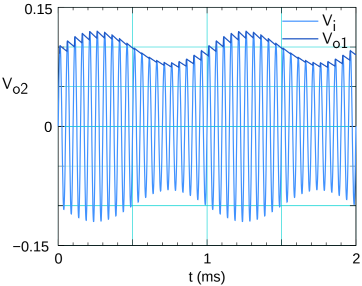
The diodes are now reversed.

By considering two cases: (i) D_1 on, (ii) D_1 off, the V_o versus V_i relationship shown in the figure is obtained (show this).

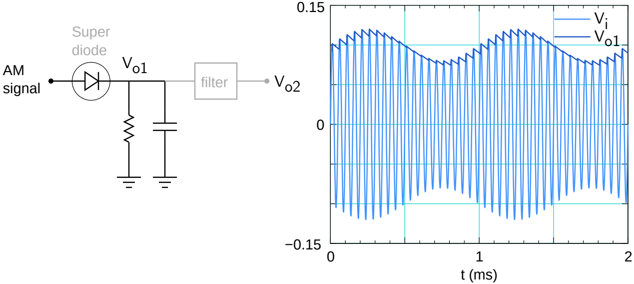
SEQUEL file: `precision_half_wave_2.sqproj`

AM demodulation using a peak detector



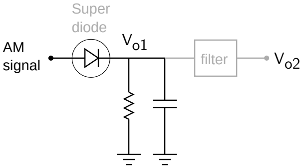


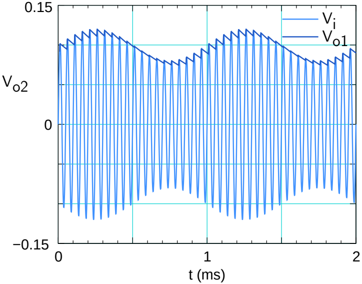
AM demodulation using a peak detector



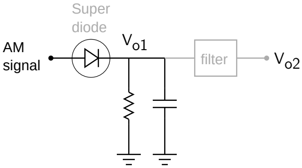
* charging through superdiode, discharging through resistor

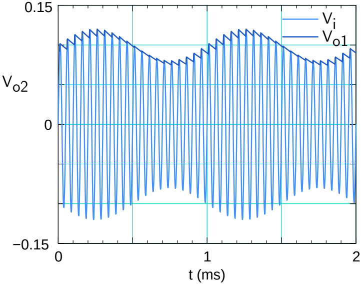
AM demodulation using a peak detector





* charging through superdiode, discharging through resistor
* The time constant (RC) needs to be carefully selected.

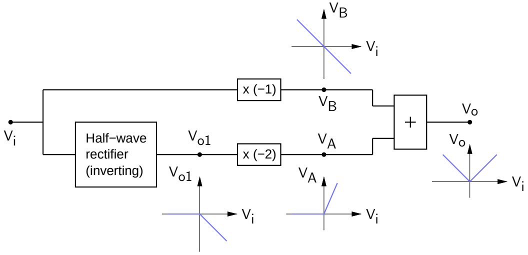




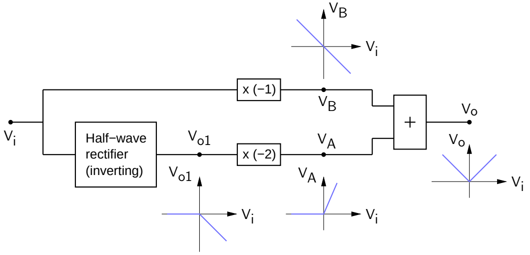
* charging through superdiode, discharging through resistor
* The time constant (RC) needs to be carefully selected.

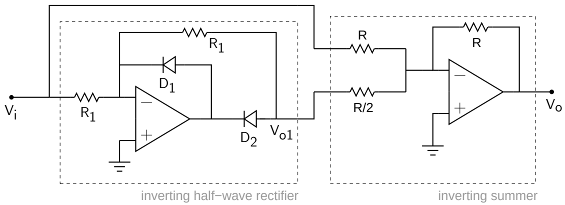
  SEQUEL file: `super_diode.sqproj`

Full-wave precision rectifier



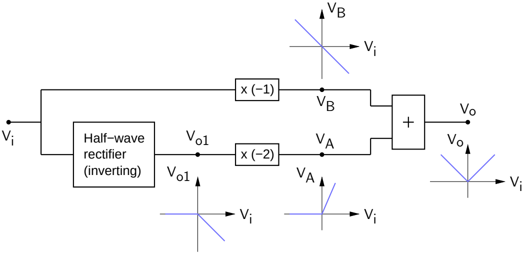
Full-wave precision rectifier

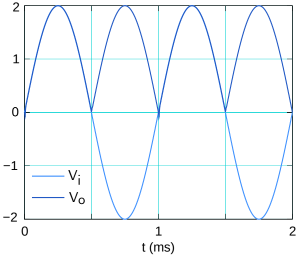


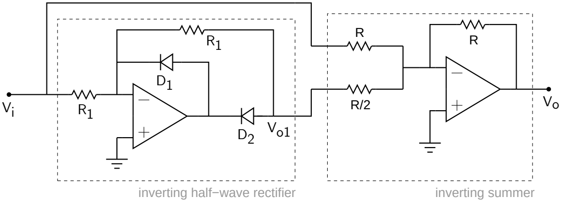


(SEQUEL file: precision_full_wave.sqproj)

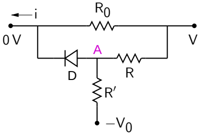
Full-wave precision rectifier



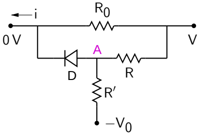


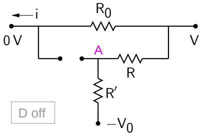


(SEQUEL file: precision_full_wave.sqproj)

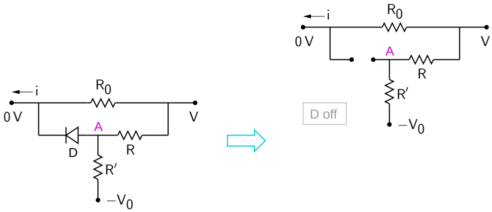

i
R_0
0 V
V
A
D
R
R′
$-V_0$

Wave shaping with diodes





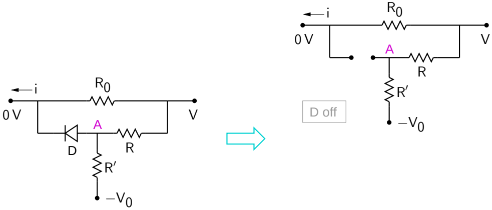
Wave shaping with diodes



When D is off, V_A is (by superposition),

$$V_A = V \frac{R'}{R+R'} - V_0 \frac{R}{R+R'} \, .$$

Wave shaping with diodes

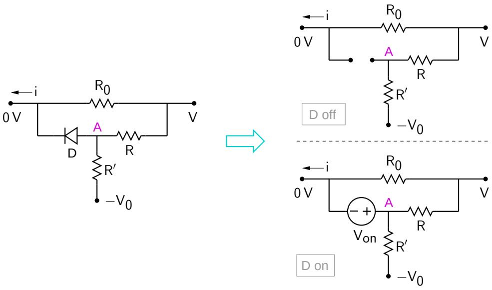


When D is off, V_A is (by superposition),

$$V_A = V\frac{R'}{R+R'} - V_0\frac{R}{R+R'}\ .$$

For D to turn on, $V_A = V_{\text{on}} \approx 0.7\,V \rightarrow V \equiv V_{\text{break}} = \dfrac{R}{R'}\,(V_0 + V_{\text{on}}) + V_{\text{on}}\ .$

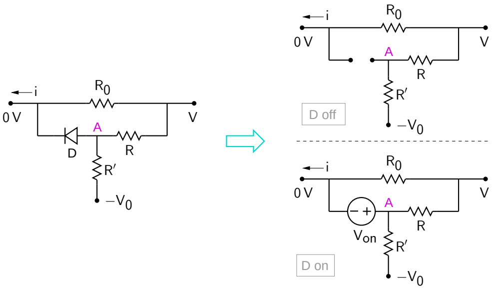
Wave shaping with diodes



When D is off, V_A is (by superposition),

$$V_A = V \frac{R'}{R+R'} - V_0 \frac{R}{R+R'} \, .$$

For D to turn on, $V_A = V_{on} \approx 0.7\, V \rightarrow V \equiv V_{break} = \dfrac{R}{R'} \left(V_0 + V_{on}\right) + V_{on} \, .$



When D is off, V_A is (by superposition),

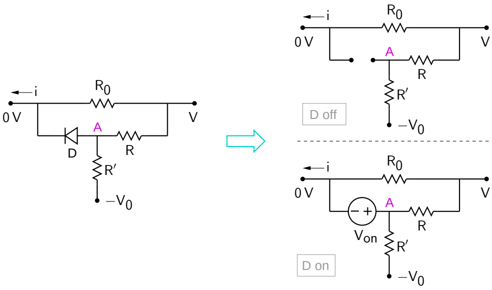
$$V_A = V\,\frac{R'}{R+R'} - V_0\,\frac{R}{R+R'}\ .$$

For D to turn on, $V_A = V_{on} \approx 0.7\ V \rightarrow V \equiv V_{break} = \dfrac{R}{R'}\,(V_0 + V_{on}) + V_{on}\ .$

When D is on,

$$\begin{aligned} i &= \frac{V}{R_0} + \frac{V - V_{on}}{R} + \frac{-V_0 - V_{on}}{R'} \\ &= V\left[\frac{1}{R_0} + \frac{1}{R}\right] + (\text{constant}) \end{aligned}$$

Wave shaping with diodes



When D is off, V_A is (by superposition),

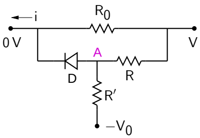
$$V_A = V\,\frac{R'}{R+R'} - V_0\,\frac{R}{R+R'}\,.$$

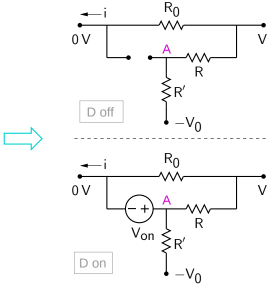
For D to turn on, $V_A = V_{on} \approx 0.7\,V \rightarrow V \equiv V_{break} = \dfrac{R}{R'}\,(V_0 + V_{on}) + V_{on}\,.$

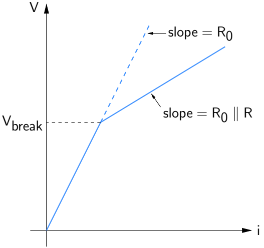
When D is on,

$$\begin{aligned} i &= \frac{V}{R_0} + \frac{V - V_{on}}{R} + \frac{-V_0 - V_{on}}{R'} \\ &= V\left[\frac{1}{R_0} + \frac{1}{R}\right] + (\text{constant}) \end{aligned}$$

i.e., $V = (R_0 \parallel R)\,i + (\text{constant})\,.$







When D is off, V_A is (by superposition),

$$V_A = V\,\frac{R'}{R+R'} - V_0\,\frac{R}{R+R'}\,.$$

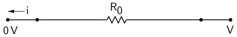
For D to turn on, $V_A = V_{\text{on}} \approx 0.7\,V \rightarrow V \equiv V_{\text{break}} = \dfrac{R}{R'}\,(V_0 + V_{\text{on}}) + V_{\text{on}}\,.$

When D is on,

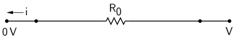
$$\begin{aligned} i &= \frac{V}{R_0} + \frac{V - V_{\text{on}}}{R} + \frac{-V_0 - V_{\text{on}}}{R'} \\ &= V\left[\frac{1}{R_0} + \frac{1}{R}\right] + (\text{constant}) \end{aligned}$$

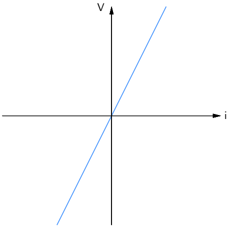
i.e., $V = (R_0 \parallel R)\,i + (\text{constant})\,.$

Wave shaping with diodes

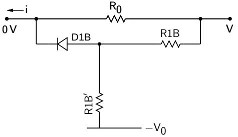


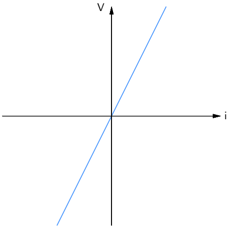
Wave shaping with diodes



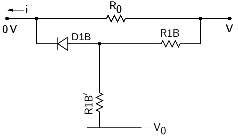


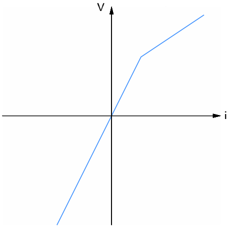
Wave shaping with diodes



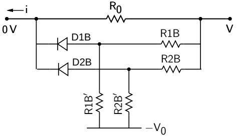


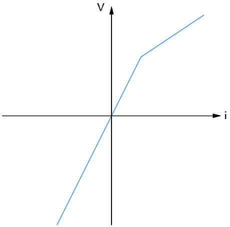
Wave shaping with diodes



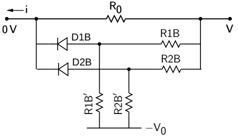


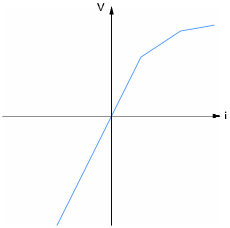
Wave shaping with diodes



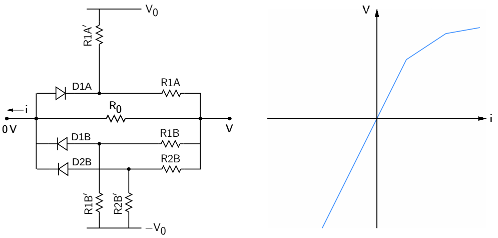


Wave shaping with diodes

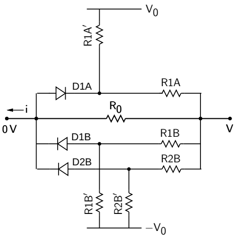


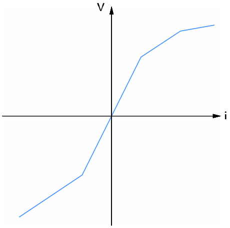


Wave shaping with diodes

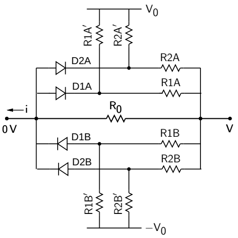


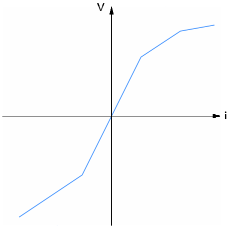
Wave shaping with diodes



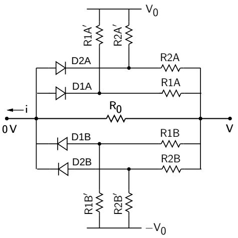


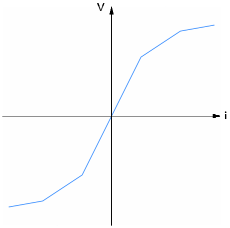
Wave shaping with diodes





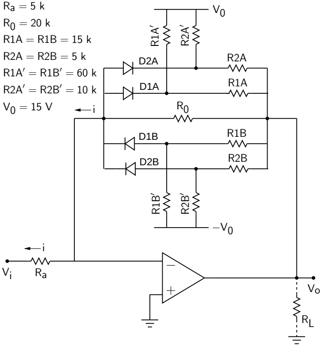
Wave shaping with diodes

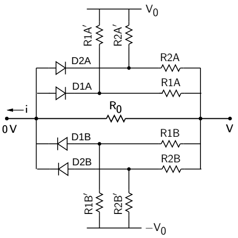


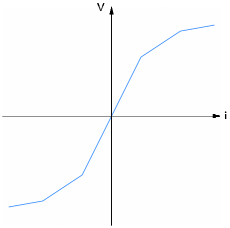


Wave shaping with diodes

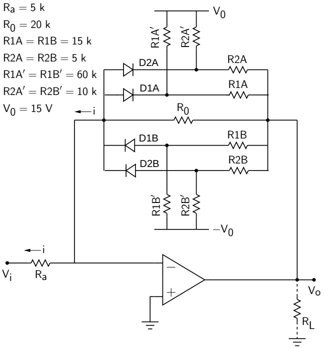
$R_a = 5$ k
$R_0 = 20$ k
$R1A = R1B = 15$ k
$R2A = R2B = 5$ k
$R1A' = R1B' = 60$ k
$R2A' = R2B' = 10$ k
$V_0 = 15$ V

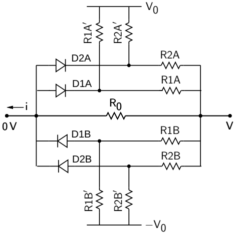


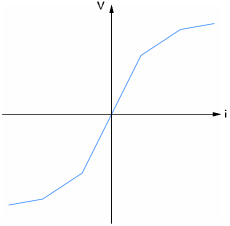




Wave shaping with diodes

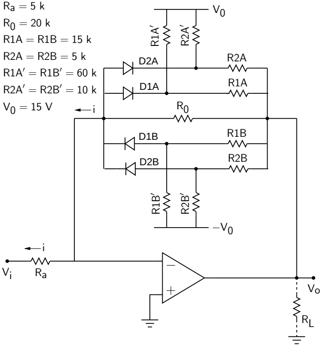


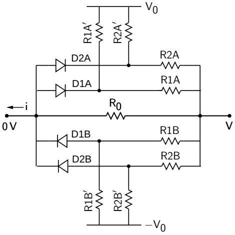


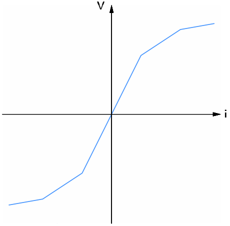


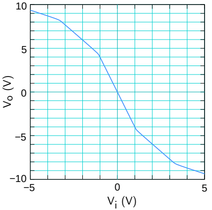
Since $V_i = -R_a i$, the V_o versus V_i plot is similar to the V versus i plot, except for the $(-R_a)$ factor.

Wave shaping with diodes





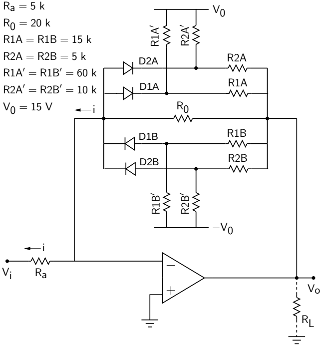


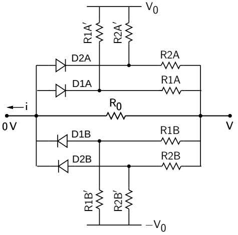


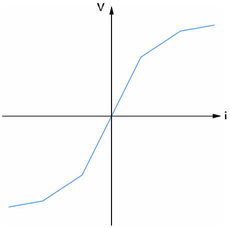
Since $V_i = -R_a i$, the V_o versus V_i plot is similar to the V versus i plot, except for the $(-R_a)$ factor.

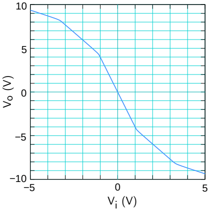
Wave shaping with diodes

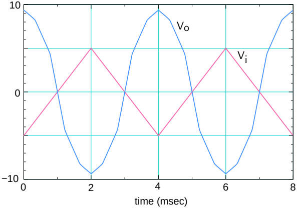
$R_a = 5$ k
$R_0 = 20$ k
$R1A = R1B = 15$ k
$R2A = R2B = 5$ k
$R1A' = R1B' = 60$ k
$R2A' = R2B' = 10$ k
$V_0 = 15$ V





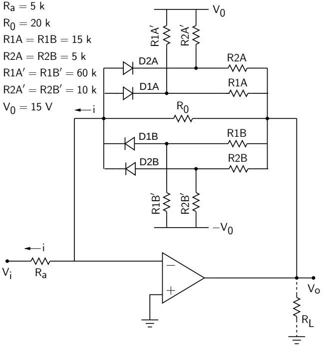


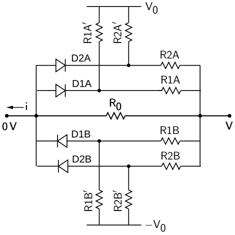


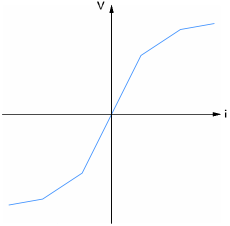


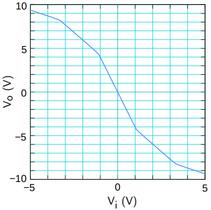
Since $V_i = -R_a i$, the V_o versus V_i plot is similar to the V versus i plot, except for the $(-R_a)$ factor.

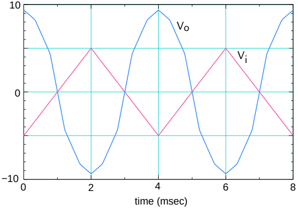
Wave shaping with diodes







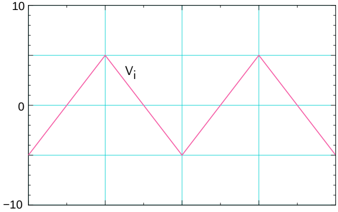


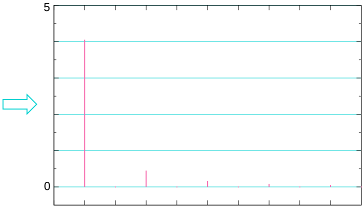


Since $V_i = -R_a i$, the V_o versus V_i plot is similar to the V versus i plot, except for the $(-R_a)$ factor.

SEQUEL file: `ee101_wave_shaper.sqproj`

Wave shaping with diodes: spectrum





Wave shaping with diodes: spectrum