EE101: Op Amp circuits (Part 4)

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Department of Electrical Engineering
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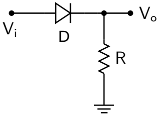
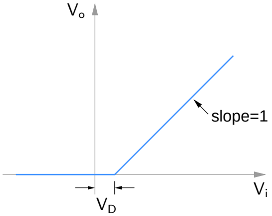
Consider a diode rectifier:





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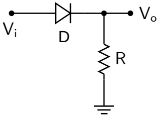

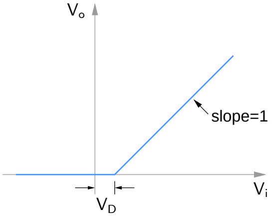

If $V_i \gg V_D$, the diode drop can be ignored.
However, if V_i is small, e.g., $V_i = 0.2 \sin \omega t \ V$, then the circuit does not rectify, and $V_o(t) = 0 \ V$.

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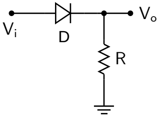

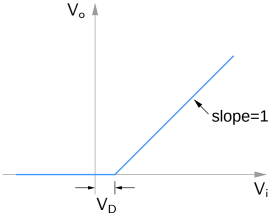

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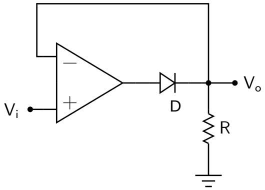
However, if V_i is small, e.g., $V_i = 0.2 \sin \omega t \;\, V$, then the circuit does not rectify, and $V_o(t) = 0\, V$.

Precision rectifier circuits overcome this drawback.

Half-wave precision rectifier



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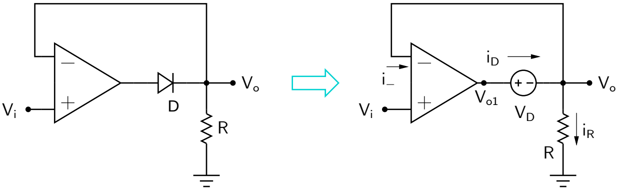
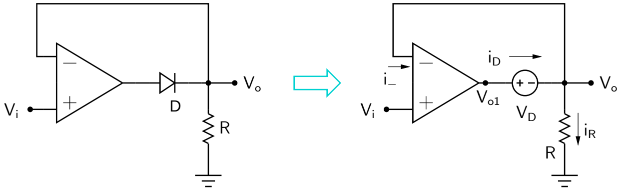


Consider two cases:

(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.



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

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

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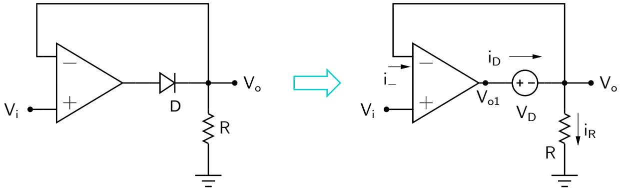

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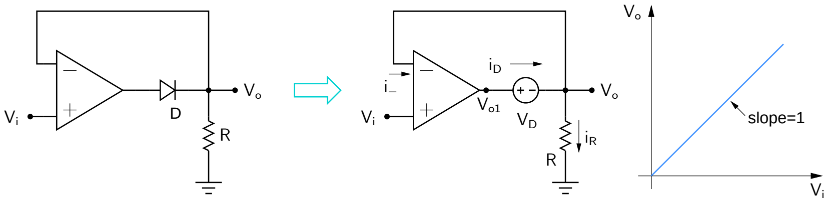

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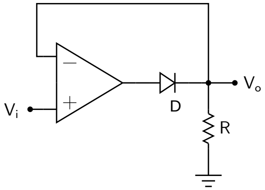

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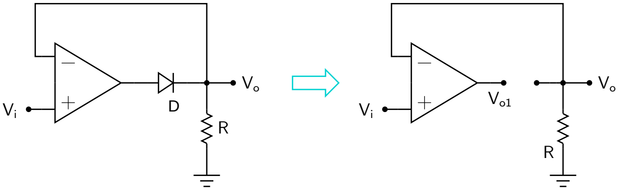

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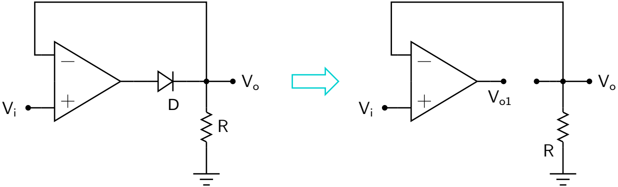
Half-wave precision rectifier



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

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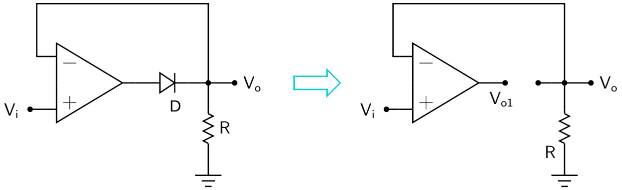

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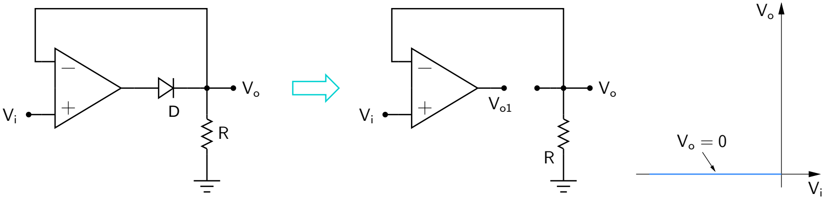

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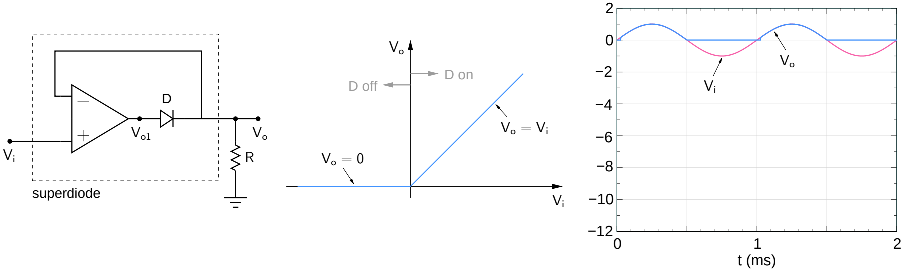

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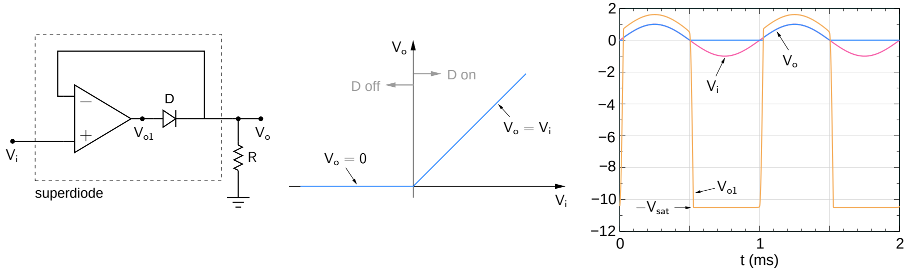
Half-wave precision rectifier



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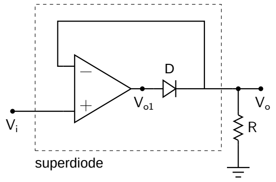

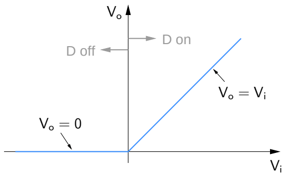

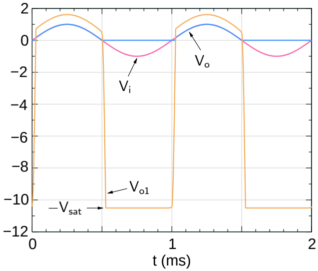

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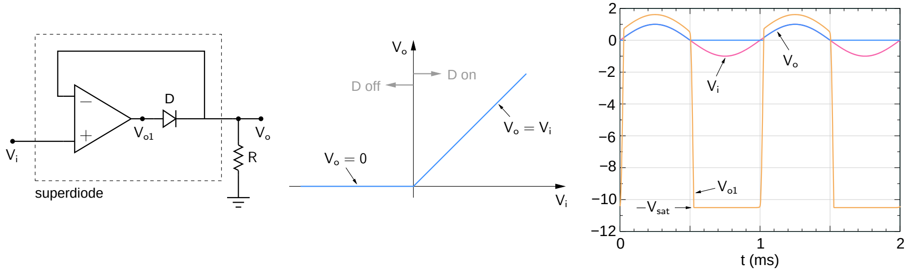

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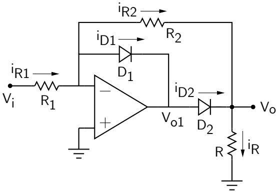
  SEQUEL file: `precision_half_wave_1.sqproj`

Improved half-wave precision rectifier



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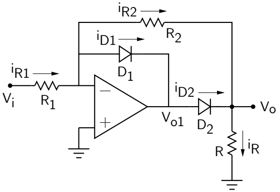

(i) D_1 conducts: $V_- = V_+ = 0\,V$, $V_{o1} = -V_{D1} \approx -0.7\,V$.

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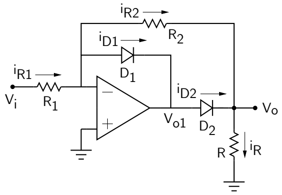

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D_2 cannot conduct (show that, if it did, KCL is not satisfied at V_o).
$\rightarrow i_{R2} = 0$, $V_o = V_- = 0\,V$.

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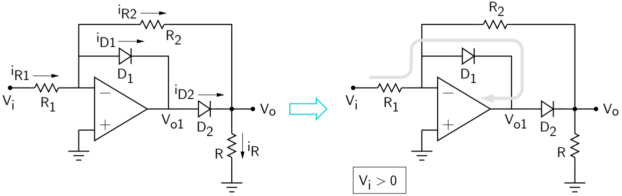

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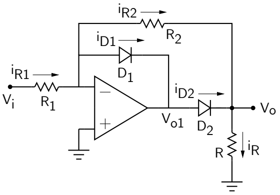

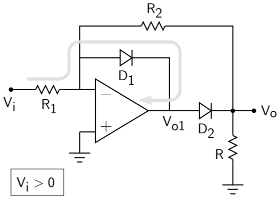

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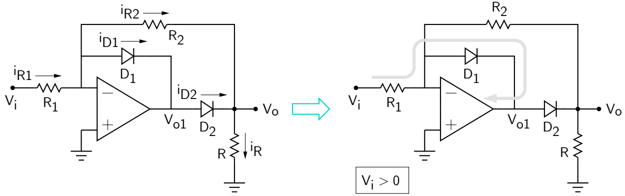

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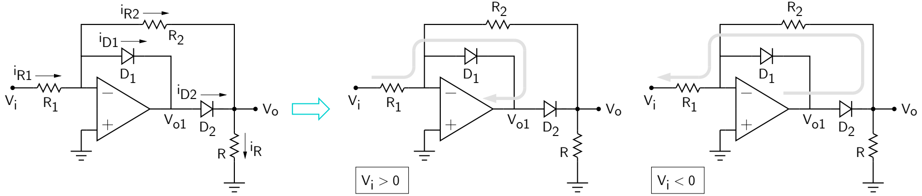

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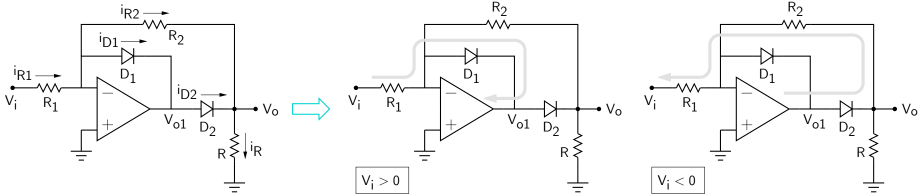

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$$V_o = V_- + i_{R2} R_2 = 0 + \left(\frac{0 - V_i}{R_1}\right) R_2 = -\frac{R_2}{R_1} V_i \,.$$

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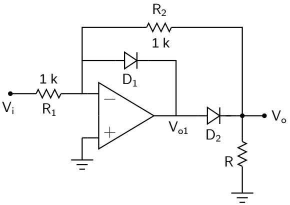

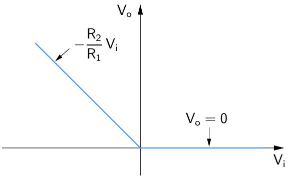

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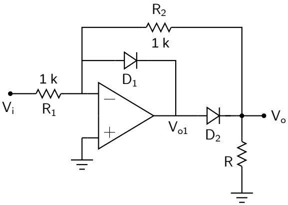

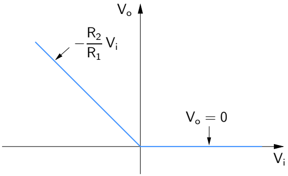

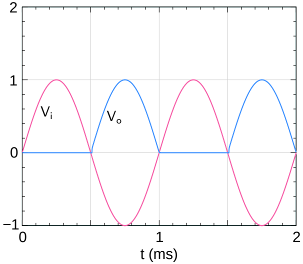

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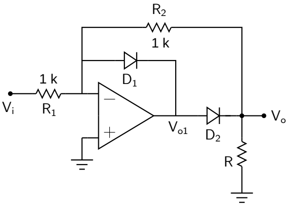

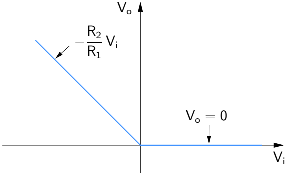

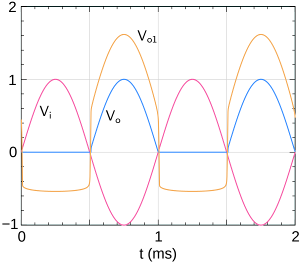

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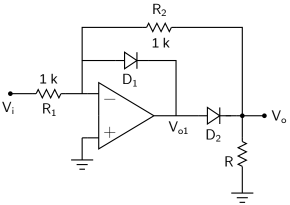

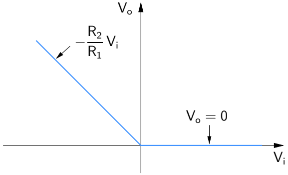

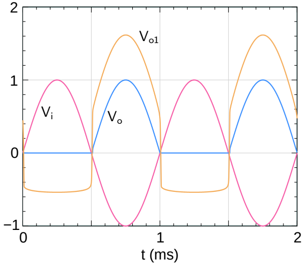

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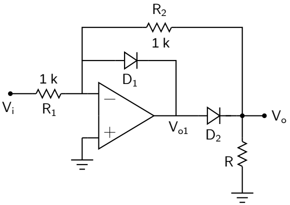

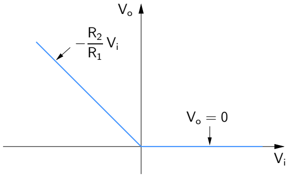

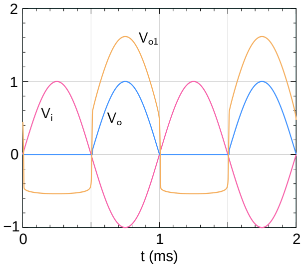

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  SEQUEL file: `precision_half_wave.sqproj`

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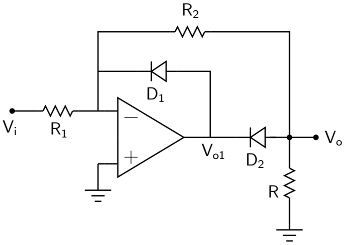
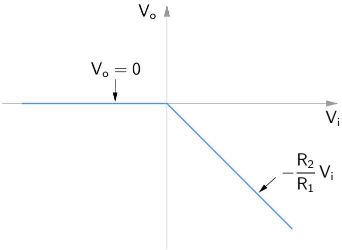
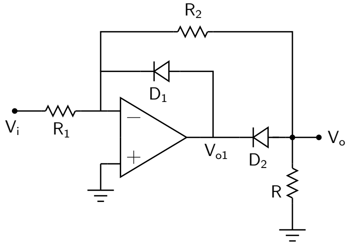
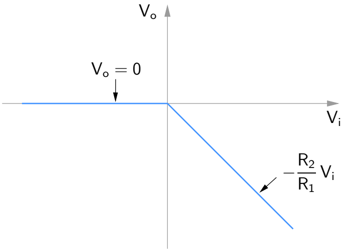




The diodes are now reversed.

Improved half-wave precision rectifier





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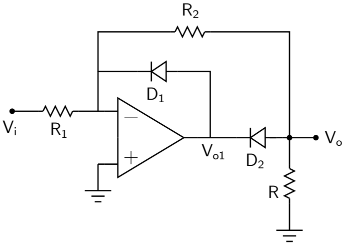

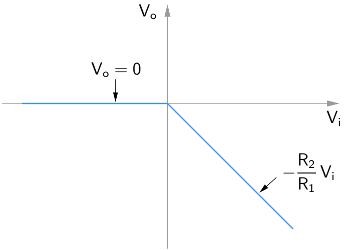

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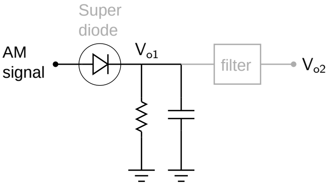
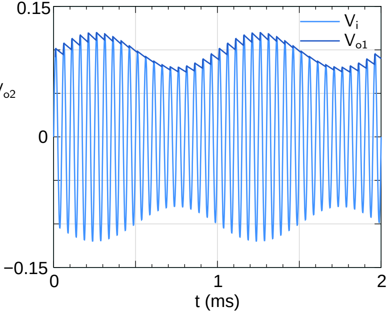
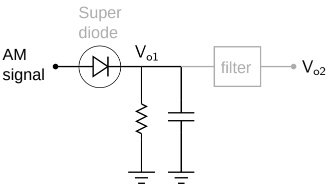
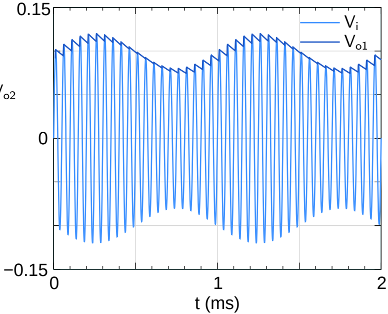
SEQUEL file: `precision_half_wave_2.sqproj`

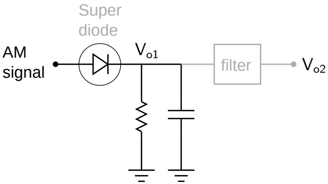

Super
diode
AM
signal
V_{o1}
filter
V_{o2}

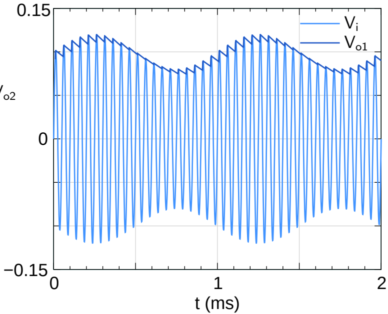

0.15
0
−0.15
0
1
2
t (ms)
V_i
V_{o1}



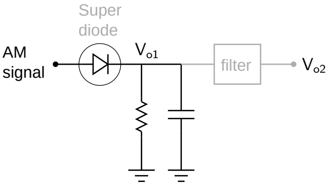


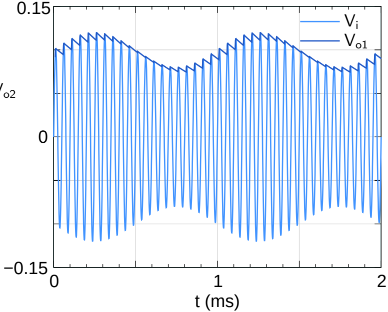
* charging through superdiode, discharging through resistor





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

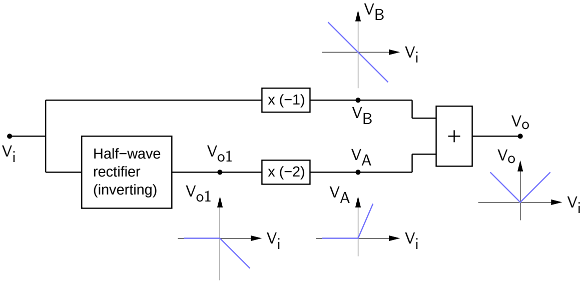




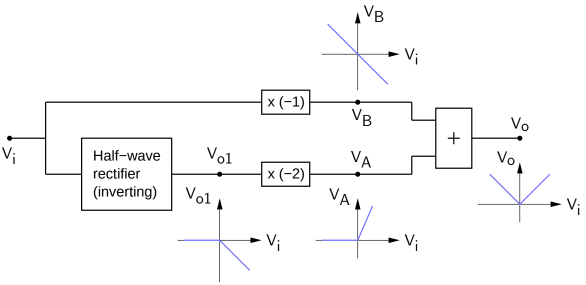
* charging through superdiode, discharging through resistor
* The time constant (RC) needs to be carefully selected.

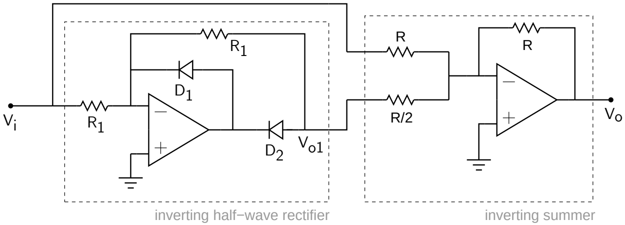
  SEQUEL file: `super_diode.sqproj`

Full-wave precision rectifier



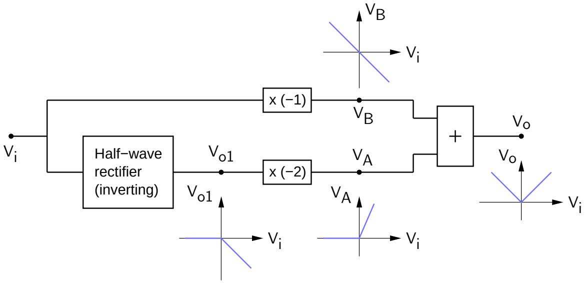
Full-wave precision rectifier

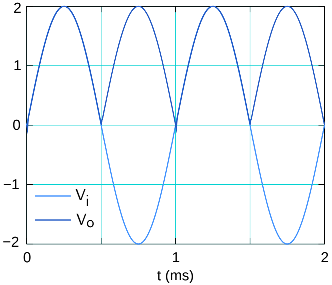


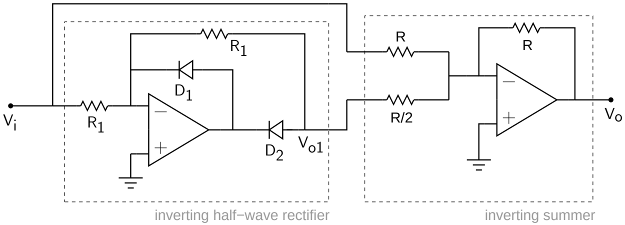


(SEQUEL file: precision_full_wave.sqproj)

Full-wave precision rectifier

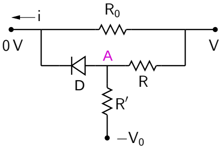




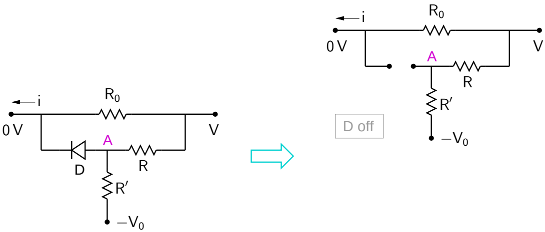


(SEQUEL file: precision_full_wave.sqproj)

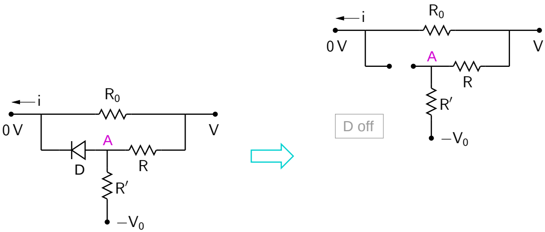
Wave shaping with diodes



Wave shaping with diodes



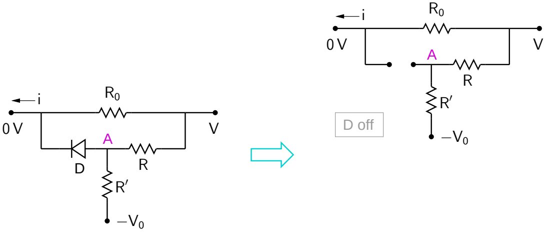
Wave shaping with diodes



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

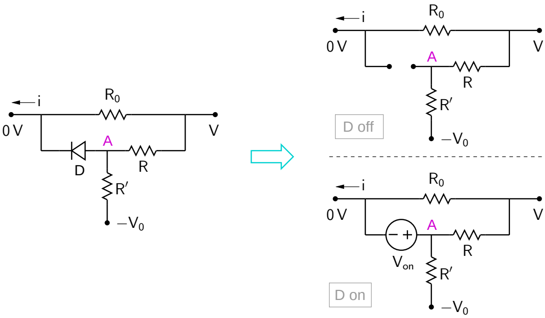


When D is off, V_A is (by superposition),

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

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



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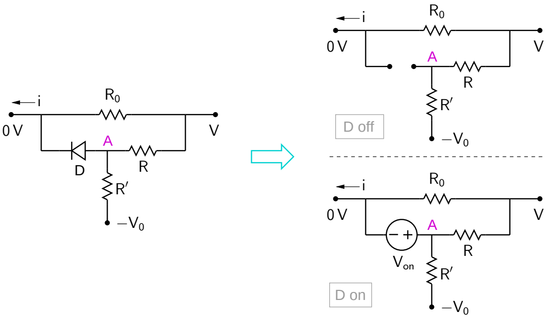
Wave shaping with diodes



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

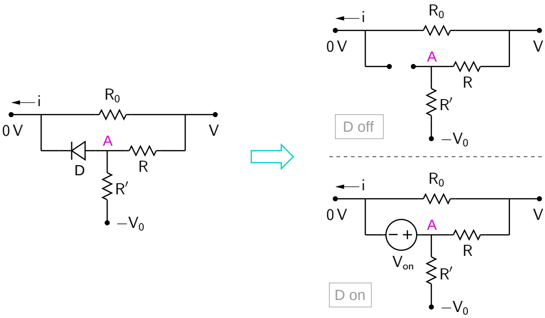
$$V_A = V \frac{R'}{R+R'} - V_0 \frac{R}{R+R'} \, .$$

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

When D is on,

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

Wave shaping with diodes



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

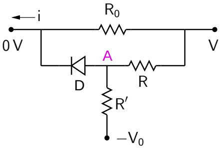
$$V_A = V \frac{R'}{R+R'} - V_0 \frac{R}{R+R'} \, .$$

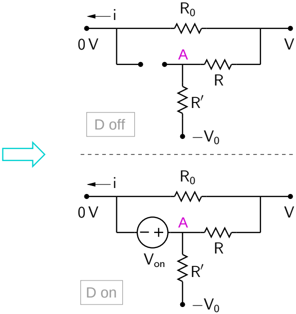
For D to turn on, $V_A = V_{\rm on} \approx 0.7\,V \rightarrow V \equiv V_{\rm break} = \dfrac{R}{R'}\,(V_0 + V_{\rm on}) + V_{\rm on}$.

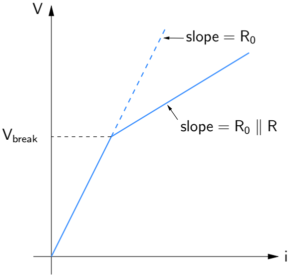
When D is on,

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

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







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

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

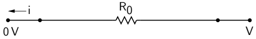
For D to turn on, $V_A = V_{on} \approx 0.7\,V \rightarrow V \equiv V_{break} = \dfrac{R}{R'}\,(V_0 + V_{on}) + V_{on}\,.$

When D is on,

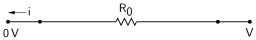
$$\begin{aligned} i &= \frac{V}{R_0} + \frac{V - V_{on}}{R} + \frac{-V_0 - V_{on}}{R'} \\ &= V \left[\frac{1}{R_0} + \frac{1}{R} \right] + (\text{constant}) \end{aligned}$$

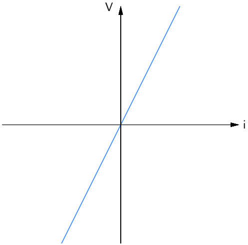
i.e., $V = (R_0 \parallel R)\, i + (\text{constant})\,.$

Wave shaping with diodes

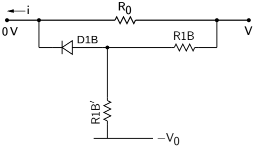


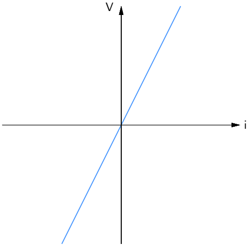
Wave shaping with diodes



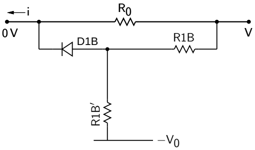


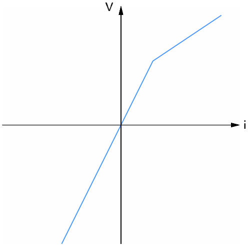
Wave shaping with diodes



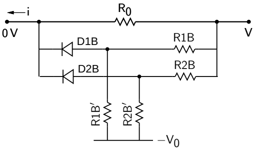


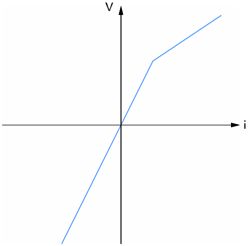
Wave shaping with diodes



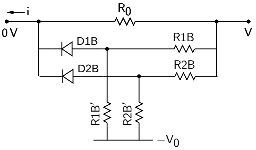


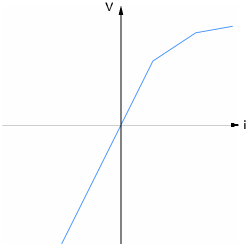
Wave shaping with diodes



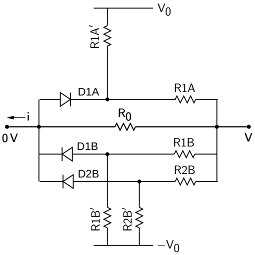


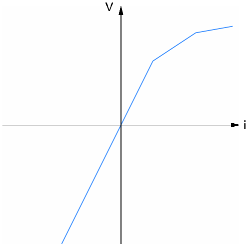
Wave shaping with diodes



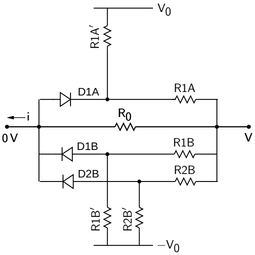


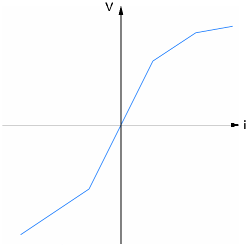
Wave shaping with diodes



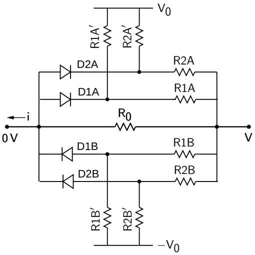


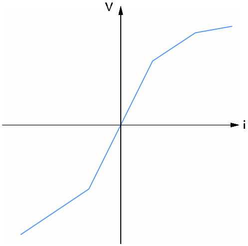
Wave shaping with diodes



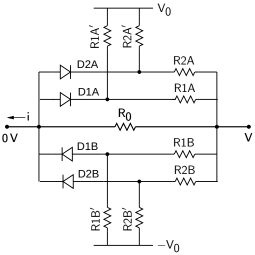


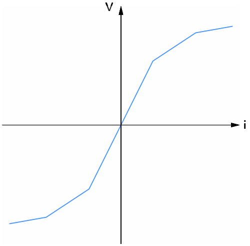
Wave shaping with diodes





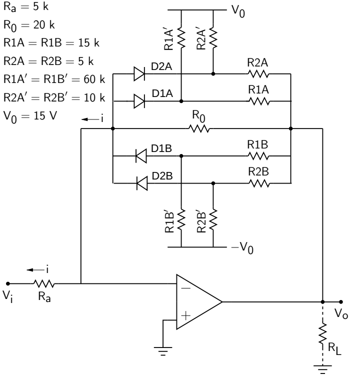
Wave shaping with diodes

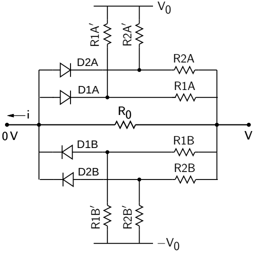


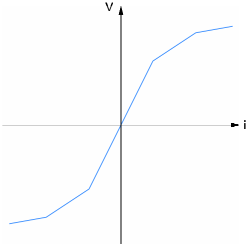


Wave shaping with diodes

$R_a = 5$ 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

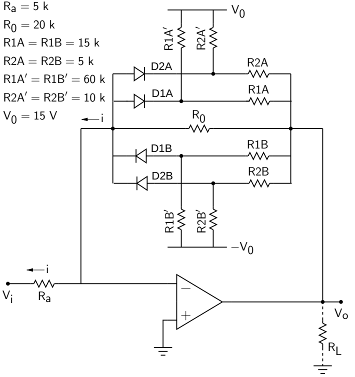


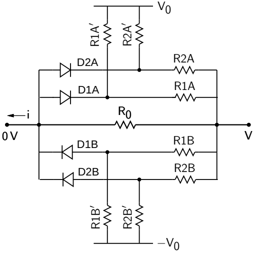


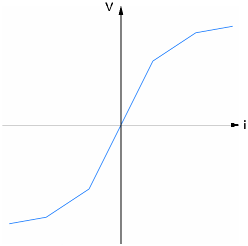


Wave shaping with diodes

$R_a = 5$ 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



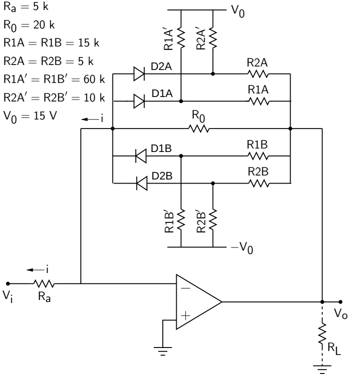


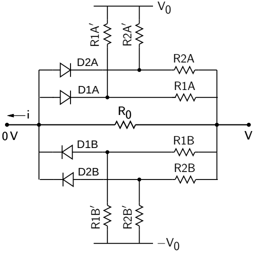


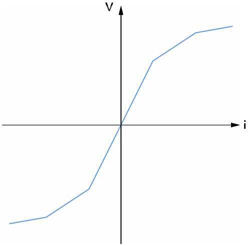
Since $V_i = -R_a i$, the V_o versus V_i plot is similar to the V versus i plot, except for the $(-R_a)$ factor.

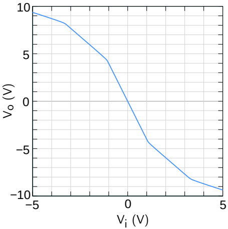
Wave shaping with diodes

$R_a = 5$ 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









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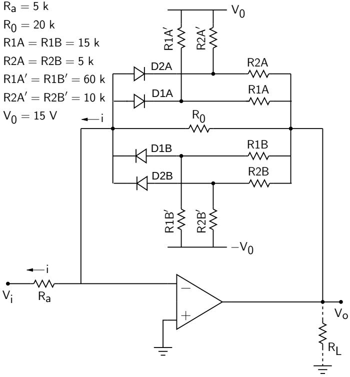
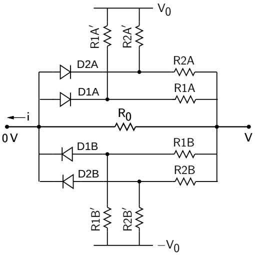
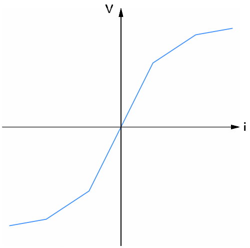
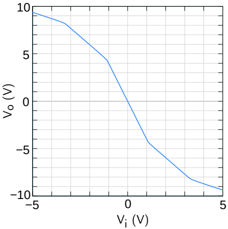
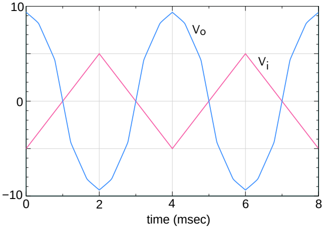
$R_a = 5$ k
$R_0 = 20$ k
$R1A = R1B = 15$ k
$R2A = R2B = 5$ k
$R1A' = R1B' = 60$ k
$R2A' = R2B' = 10$ k
$V_0 = 15$ V







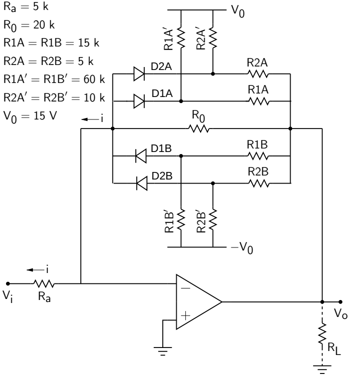


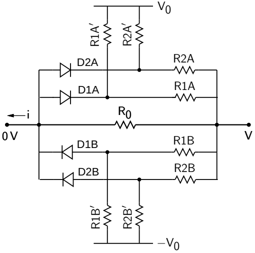


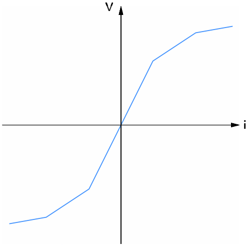
Since $V_i = -R_a i$, the V_o versus V_i plot is similar to the V versus i plot, except for the $(-R_a)$ factor.

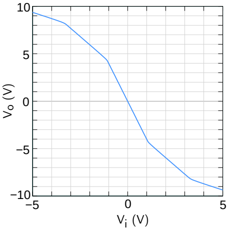
Wave shaping with diodes

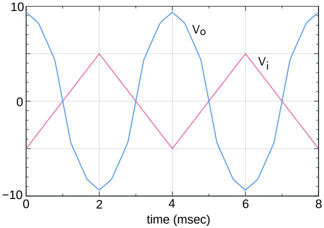
$R_a = 5$ k
$R_0 = 20$ k
$R1A = R1B = 15$ k
$R2A = R2B = 5$ k
$R1A' = R1B' = 60$ k
$R2A' = R2B' = 10$ k
$V_0 = 15$ V







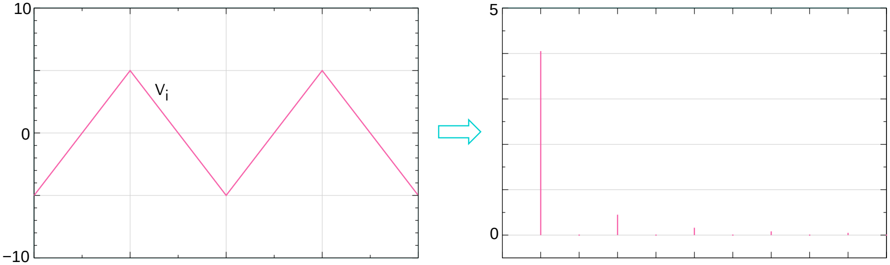




Since $V_i = -R_a i$, the V_o versus V_i plot is similar to the V versus i plot, except for the $(-R_a)$ factor.

SEQUEL file: `ee101_wave_shaper.sqproj`

Wave shaping with diodes: spectrum



Wave shaping with diodes: spectrum