

Op Amp Rectifiers, Peak Detectors and Clamps

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INTRODUCTION

This application note covers a wide range of applications, such as half-wave rectifiers, full-wave rectifiers, peak detectors and clamps. Many of the circuits are simple in terms of component count, but they play important roles in overall systems design, such as:

- AC to DC Power Conversion
- Automatic Gain Control Loops
- Power Monitoring Applications
- AM Demodulator

BASIC RECTIFIERS

The basic rectifiers have been designed with diodes. Figure 1 shows such a simple series circuit, driven by an AC source. When the diode is reverse-biased, it acts as a very high impedance device. Figure 1 shows a negative half wave rectifier. It outputs nearly the full input voltage across the diode when reverse biased. A similar circuit in Figure 2 shows a positive half-wave rectifier. If a full-wave rectifier is desired, more diodes must be used to configure a bridge, as shown in Figure 3. The input signal must be larger than the voltage across the diode to ensure that the diode is forward biased.

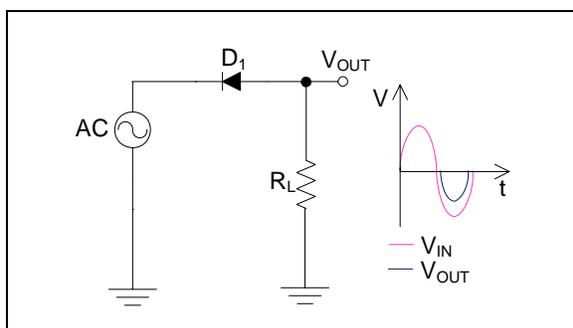


FIGURE 1: Negative Half-Wave Rectifier.

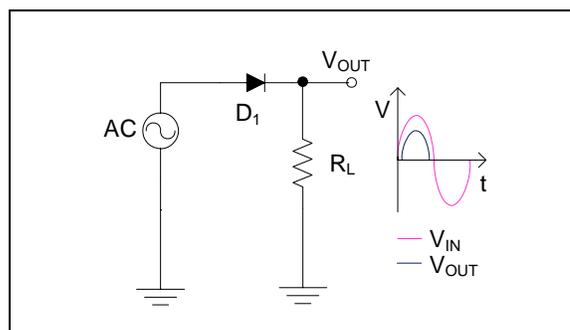


FIGURE 2: Positive Half-Wave Rectifier.

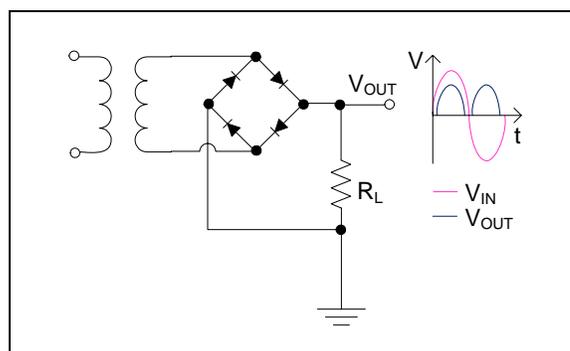


FIGURE 3: Full-Wave Rectifier.

Choosing the Components

SELECTING THE DIODE

When choosing the diode, the most important parameters are the maximum forward current (I_F), and the peak inverse voltage rating (PIV) of the diode. The peak inverse voltage is the maximum voltage the diode can withstand when it is reverse-biased. If this voltage is exceeded, the diode may be destroyed. The diode must have a peak inverse voltage rating that is higher than the maximum voltage applied to it in an application. In many diode data sheets, PIV is referred to as peak reverse voltage (PRV).

The peak inverse voltage of the diode will be equal to:

EQUATION 1:

$$V_{PIV(-rating)} \geq V_{PK(max)} + V_{D(on)}$$

Where:

$$V_{PIV} = \text{Peak inverse voltage}$$

$$V_{PK(max)} = \text{Maximum peak amplitude}$$

$$V_{D(on)} = \text{Diode voltage on when in}$$

Every diode has a parasitic capacitance and, by default, has a time charge storage. This charge storage mechanism is nonlinear, leading to a nonlinear capacitance. This effect is very important because the nonlinearity of the diode can generate harmonics. For example, the output voltage becomes negative for a short time. This period is called reverse recovery time.

During the transition, the diode's parasitic capacitance will interact with the circuit resistors to modify the circuit's behavior.

For most general purpose applications, low power signal diodes such as 1N4148, are adequate. For high accuracy applications, where offset errors and reverse diode leakage current are critical, a low leakage FET transistor can be used as a diode (short Drain and Source together), such as 2N4117A. In applications where speed is important, silicon Schottky barrier diodes are worth considering, since they have a low forward ON voltage of only 0.4V and are fast.

SELECTING THE RESISTOR

The resistor is selected based on the load current.

One limitation is the value of load resistor. The value of the load resistor must be less than the diode resistance when in reverse bias. The parasitic capacitance of the diode interacts with the load resistor causing a time constant. If this constant is large, the output voltage will have a delayed recovery.

Advantages and Disadvantages

The major disadvantage of these circuits is the nonlinearity of the diodes. If the input signal is smaller than the threshold voltage of the diode, the signal cannot be recovered. To reduce the threshold voltage of the diode and improve linearity, we need to include the diode into the feedback loop of the operational amplifier.

Practical Examples

Figures 4 – 6 show practical samples when using the 1N4001 diode and $R_L = 1 \text{ k}\Omega$. The frequency is $f = 1 \text{ kHz}$.

TABLE 1: ADVANTAGES AND DISADVANTAGES OF THE CIRCUIT

Advantages	Disadvantages
- Uses few components	- Poor accuracy
- Simple design	- The rectified voltage depends on the diode voltage threshold

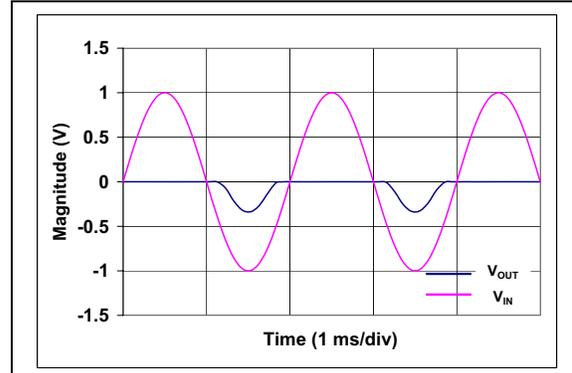


FIGURE 4: Negative Half-Wave Rectifier Sample.

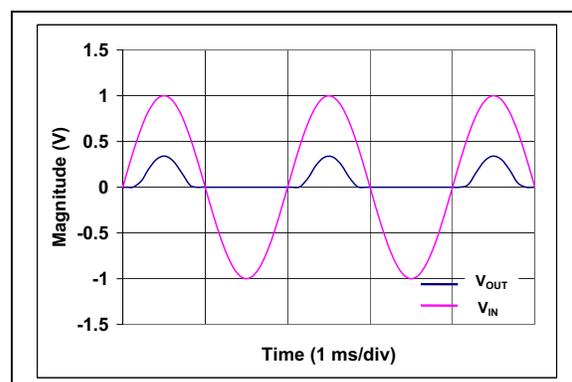


FIGURE 5: Positive Half-Wave Rectifier Sample.

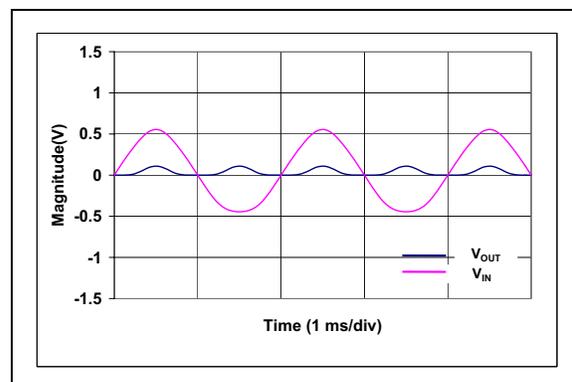


FIGURE 6: Full-Wave Rectifier Sample.

ACTIVE HALF-WAVE RECTIFIER

The simplest op amp half-wave rectifier is shown in [Figure 7](#). When the V_{IN} is positive, the diode is forward biased; the signal can be found on the R_L load. When the V_{IN} is negative, the diode is non-conductive, and the output signal is ground (0V).

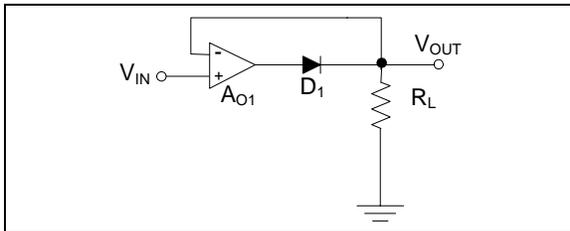


FIGURE 7: Op Amp Half-Wave Rectifier.

The big advantage of this circuit is represented by the small threshold voltage and linearity. This is more convenient than the basic rectifiers, since this circuit is able to rectify signals smaller than the diode threshold voltage.

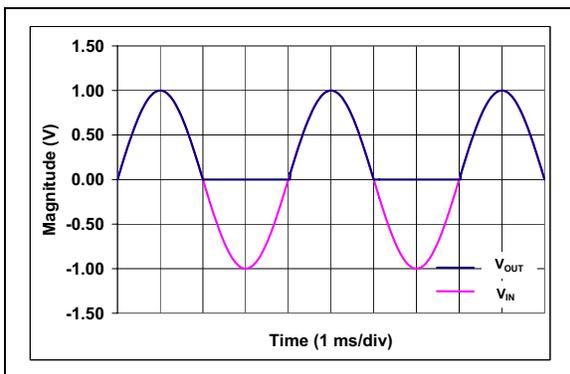


FIGURE 8: Circuit Behavior on Low Frequency.

This circuit has limitations. The rectifier's speed is limited by the op amp bandwidth. This effect is illustrated in [Figure 9](#), where the rectified output signal overlaps the input signal. The maximum frequency that can be rectified is determined by the slew rate of the op amp.

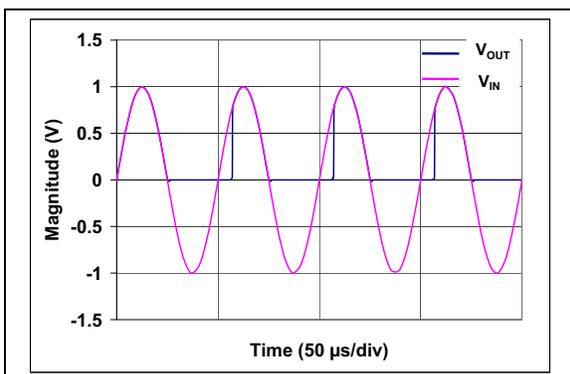


FIGURE 9: Output Limitation on High-Frequency Input Signals.

Choosing the Components

SELECTING THE OP AMP

When selecting the op amp, two important characteristics must be considered:

- Gain Bandwidth Product
- Slew Rate (SR)

The minimum gain bandwidth product requirement can be estimated in [Equation 2](#).

EQUATION 2:

$$f_{GBWP} = 10 \times G \times f_{INPUT}$$

Where:

- f_{GBWP} = Gain bandwidth product
- G = DC gain
- f_{INPUT} = Maximum input frequency

The next parameter that needs to be considered is the slew rate (SR). This is the maximum time rate change at the output of the op amp; it shows how fast the output can follow the input signal. The SR parameter can be found in the selected op amp's data sheet.

The full bandwidth product (FPBW) defines the highest frequency sine wave that will not be distorted by the slew rate limit.

EQUATION 3:

$$SR = \left| \frac{\Delta V_{OUT}}{\Delta T} \right|_{max}$$

$$FPBW = \frac{SR}{\pi \times V_{OUT(p-p)}}$$

SELECTING THE DIODE AND THE RESISTOR

Refer to the sections [Selecting the Diode](#) and [Selecting The Resistor](#), in the [Basic Rectifiers](#) section, for details on choosing the appropriate components.

Advantages and Disadvantages

[Table 2](#) shows the main advantages and disadvantages of a half-wave rectifier.

TABLE 2: ADVANTAGES AND DISADVANTAGES OF THE CIRCUIT

Advantages	Disadvantages
- Uses few components	- Load dependant
- Good linearity	- Limited op amp bandwidth

Practical Example

This example of a half-wave rectifier uses an MBRM110LT3 Schottky diode and the MCP661 op amp with different load resistors. For this example, the value of the load resistor is less than 1 kΩ, to avoid glitches in the negative cycle. The Schottky diode is chosen for higher speed than a small signal silicon diode. Figures 10 and 11 below are examples of a 1 kHz input signal and different load resistors. Note that for the small values of the resistor (i.e. 100Ω), the glitch is smaller.

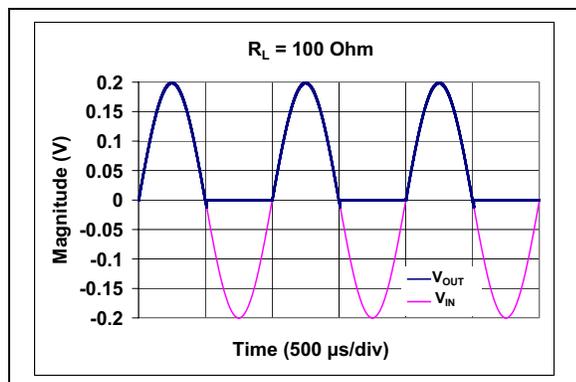


FIGURE 10: Half-Wave Rectifier with $R_L = 100\Omega$.

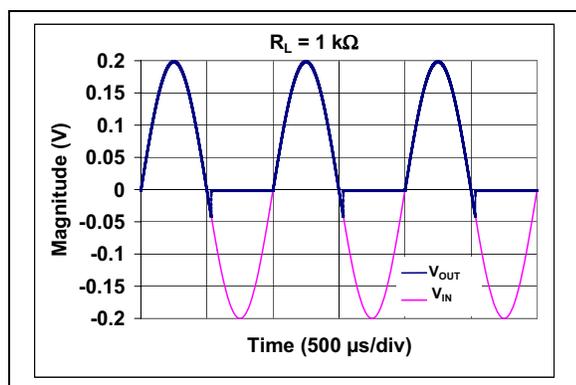


FIGURE 11: Half-Wave Rectifier with $R_L = 1\text{ k}\Omega$.

Improved Op Amp Half-Wave Rectifier

Figure 12 shows a half-wave rectifier circuit with improved performance. The additional diode prevents the op amp's output from swinging to the negative supply rail. The low level linearity is also improved. Although the op amp still operates in open-loop at the point where the input swings from positive to negative or vice versa, the range is limited by the diode and the load resistor.

When the input signal is positive, D_1 is open and D_2 conducts. The output signal is zero because one side of R_2 is connected to the virtual ground, with no current through it. When the input is negative, D_1 conducts and D_2 is open. The output follows the positive input cycle with a gain of $G = -R_2/R_1$.

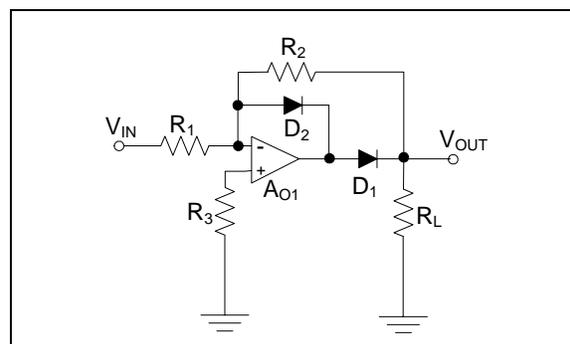


FIGURE 12: Have-Wave Rectifier Circuit Improvement.

This type of circuit also has limitations. The input impedance is determined by the input resistor. It must be driven from a low-impedance source. Likewise, the input resistor R_3 shown in Figure 12 is also optional, and is needed only if there is no DC path to ground.

Choosing the Components

Refer to the section [Selecting the Op Amp](#) in the [Active Half-Wave Rectifier](#) section, and to the section [Selecting the Diode](#) in the section [Basic Rectifiers](#), for details on choosing the appropriate components.

SELECTING THE RESISTORS

The DC gain is determined in [Equation 4](#):

EQUATION 4:

$$G = -\frac{R_2}{R_1}$$

where G = DC gain

Resistors R_1 and R_2 are selected based on the application design:

- For a general purpose application, the resistor's value should be between 1 k Ω and 100 k Ω .
- For a high speed application, the resistor's value should be between 100 Ω and 1 k Ω (consume more power)
- For portable applications between 1 M Ω and 10 M Ω .

The R_3 is added to minimize the error caused by the input bias current.

EQUATION 5:

$$R_3 = \frac{R_1 \times R_2}{R_1 + R_2}$$

Advantages and Disadvantages

Table 3 shows the main advantages and disadvantages of an improved half-wave rectifier.

TABLE 3: ADVANTAGES AND DISADVANTAGES OF THE CIRCUIT

Advantages	Disadvantages
- Good linearity	- Uses more components
- The second diode prevents the op amp from swinging into the negative cycle	- Low impedance because of R_1

Practical Example

The example in Figure 13 is based on the circuit in Figure 12, and uses the MCP661 op amp, two MBRM110LT3 Schottky diodes, $R_L = 1$ k Ω , $R_2 = 10$ k Ω and $R_1 = 1$ k Ω . The input frequency is 1 kHz.

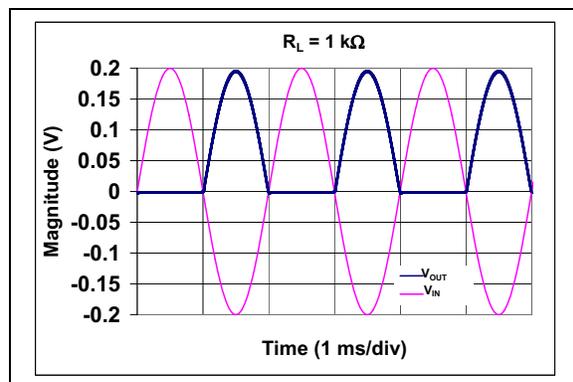


FIGURE 13: Improved Half-Wave Rectifier with $R_L = 1$ K Ω .

For an input frequency under 600 kHz, the circuit performs properly. For frequencies larger than this value, the output signal is distorted.

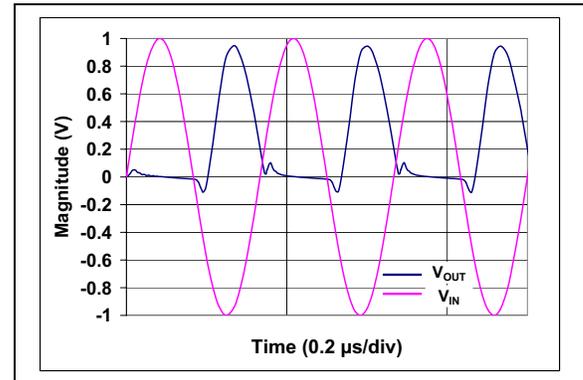


FIGURE 14: Circuit Behavior with 600 kHz Input Frequency.

To design a negative half-wave rectifier using the same components, we only have to invert the diodes, as shown in the circuit in Figure 15.

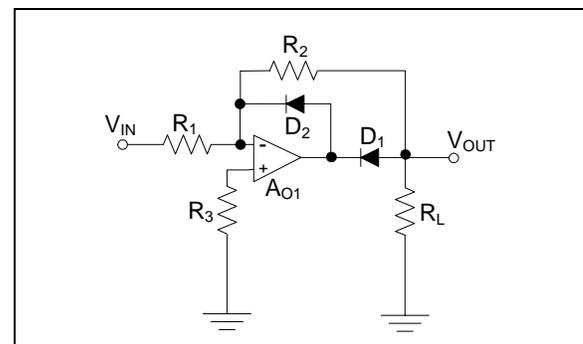


FIGURE 15: Negative Half-Wave Rectifier.

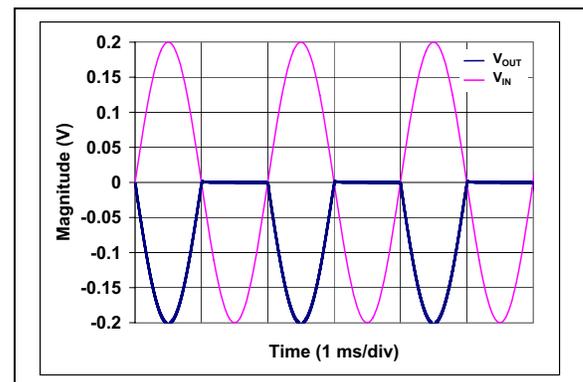


FIGURE 16: Negative Cycle Rectifier Sample.

ACTIVE FULL-WAVE RECTIFIER

Full-wave rectifiers are more complex, compared to the half-wave circuits. Full-wave rectifiers output one polarity of the input signal and invert the other. A circuit for a full-wave rectifier is illustrated in Figure 17.

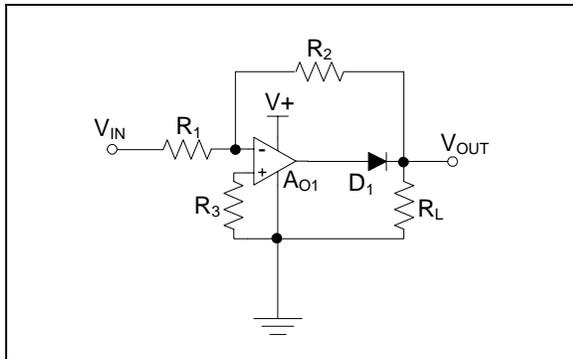


FIGURE 17: Full-Wave Rectifier Circuit.

When in the negative cycle of the input signal, diode D_1 is forward biased, and the output voltage follows the input. When the input signal (V_{IN}) is positive, D_1 is non-conductive and the input signal passes through the feedback resistor (R_2), which forms a voltage divider with R_1 and R_L . Equation 6 shows the calculation for the output voltage:

EQUATION 6:

$$V_{OUT} = V_{IN} \times GM; \quad V_{IN} < 0$$

$$V_{OUT} = V_{IN} \times GP; \quad V_{IN} > 0$$

Where:

$$GM = \frac{-R_2}{R_1}$$

$$GP = \frac{R_L}{R_1 + R_2 + R_L}$$

When $-GM = GP$, the full-wave output is symmetric. Note that the output is not buffered, so it should be connected only to a circuit with high impedance, much higher than R_L .

Choosing the Components

Refer to the section [Selecting the Diode](#) in the section [Basic Rectifiers](#), and to the section [Selecting the Op Amp](#) in the section [Active Half-Wave Rectifier](#), for details on choosing the appropriate components.

SELECTING THE RESISTORS

When selecting the resistors for the circuit in Figure 17, $-GM$ must be equal to GP . The result is shown in Equation 7:

EQUATION 7:

$$R_2 \times (R_1 + R_2 + R_L) = R_1 \times R_L$$

R_3 is added to minimize the error caused by the input bias current. Refer to the section [Selecting the Resistors](#), in the section [Improved Op Amp Half-Wave Rectifier](#), for details on the selection of the resistor.

Advantages and Disadvantages

TABLE 4: ADVANTAGES AND DISADVANTAGES OF THE CIRCUIT

Advantages	Disadvantages
- Uses only one op amp	- Low input resistance
- Uses a small number of external components	- The source and load resistance affect rectifying
- Uses a single supply	- A reactive load (capacitor or coil) cannot be tolerated without a buffer
	- Has a low impedance because of R_1

Practical Example

This design uses an MCP661 and a general purpose diode rectifier 1N4148. The input frequency is 1 kHz.

Table 5 shows the resistor values recommended to obtain the same amplitude with each input cycle:

TABLE 5: VALUES FOR RECTIFIED, EQUAL AMPLITUDE

Resistor	Value (kΩ)
R_1	2
R_2	1
R_L	3

The values of the resistors can be scaled depending on the application: high speed, portable or general purpose. For more details, refer to the section [Selecting the Resistors](#), in the section [Improved Op Amp Half-Wave Rectifier](#). Figure 18 shows the result of the full-wave rectifier circuit simulation.

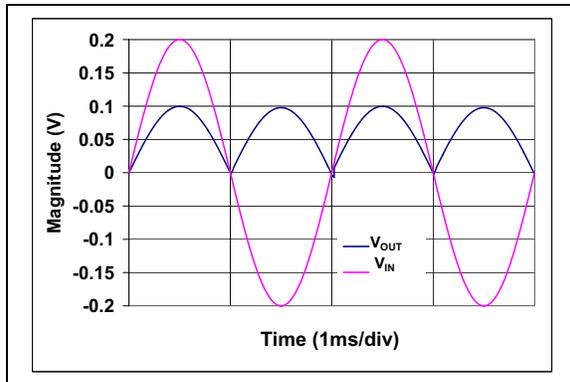


FIGURE 18: Full-Wave Rectifier Circuit Simulation with the Recommended Values of the Resistors.

TWO STAGE OP AMP FULL-WAVE RECTIFIER

Another full-wave rectifier can be obtained by including an adder to the single-wave rectifier, which subtracts V_{IN} from the rectified signal. The rectifier stage consists of A_{O1} , R_1 , R_2 , D_1 and D_2 , while the adder stage consists of A_{O2} , R_3 , R_4 and R_5 .

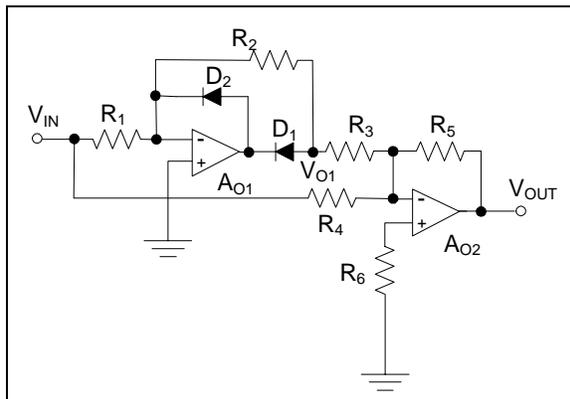


FIGURE 19: Two Stage Op Amp Full-Wave Rectifier Circuit.

When V_{IN} is positive, D_1 is forward-biased and D_2 is reverse-biased, while when V_{IN} is negative, D_2 is forward-biased and D_1 is reverse-biased. The second stage adds V_{IN} and V_{O1} and inverts the polarity of the resulting signal. The output voltage for the positive cycle of the input voltage is calculated in Equation 8.

For the negative cycle of the input voltage (V_{IN}), D_1 blocks the signal, while D_2 conducts the whole current coming from the input. In this case, the output voltage for the first stage is $V_{O1} = 0V$.

For the positive cycle of the input signal, V_{O1} is negative and, in this case, the adder stage combines the input signals with equal amplitudes, one positive and one negative.

EQUATION 8:

$$V_{O1} = V_{IN} \times G, \text{ when } V_{IN} > 0$$

Where:

$$G = \frac{-R_1}{R_2}$$

$$V_{O1} = 0, \text{ when } V_{IN} < 0$$

Equation 9 calculates the output voltage:

EQUATION 9:

$$V_{OUT} = -\frac{R_5 \times V_{O1}}{R_3} - \frac{R_5 \times V_{IN}}{R_4}$$

Choosing the Components

To obtain a good performance for the two stage circuit, the tolerance of resistors R_1 to R_5 should be 1%, or better; this makes the gains (for negative and positive V_{IN}) match well. The circuit in Figure 19 has a good linearity, down to a couple of mV at low frequencies, but the high-frequency response is limited by the op amp bandwidth.

Refer to the section [Selecting the Diode](#) in the section [Basic Rectifiers](#), and to the section [Selecting the Op Amp](#) in the section [Active Half-Wave Rectifier](#), for details on choosing the appropriate components.

SELECTING THE RESISTORS

R_1 and R_2 give the gain for the first stage; R_3 and R_5 for the second stage.

To get the same amplitude for both cycles, choose $R_1 = R_3 = R_4$ and $R_2 = R_5 = 2 \times R_1$.

EQUATION 10:

$$V_{OUT} = -\frac{R_5 \times (V_{O1} + V_{IN})}{R_1}$$

R_6 is added to minimize the error caused by the input bias current. Refer to the section [Selecting the Resistors](#), in the section [Improved Op Amp Half-Wave Rectifier](#), for details on choosing the appropriate components.

If a greater sensitivity and high frequency is desired, it is recommended to use lower resistance value, high speed diodes and faster op amps.

Advantages and Disadvantages

Table 6 shows the advantages and disadvantages of a two stage op amp full-wave rectifier.

TABLE 6: ADVANTAGES AND DISADVANTAGES OF THE CIRCUIT

Advantages	Disadvantages
- Very good performance	- Uses two op amps
- Low output impedance	- Low input resistance
	- Multiple passive components

Practical Example

This example uses the MCP6021 device, two 1N4148 diodes, $R_1 = 1\text{ k}\Omega$, $R_2 = 2\text{ k}\Omega$, $R_3 = 1\text{ k}\Omega$, $R_4 = 1\text{ k}\Omega$, and $R_5 = 2\text{ k}\Omega$. The input signal frequency is $f = 1\text{ kHz}$.

Figure 20 shows the result of the simulation for the full-wave rectifier shown in Figure 19:

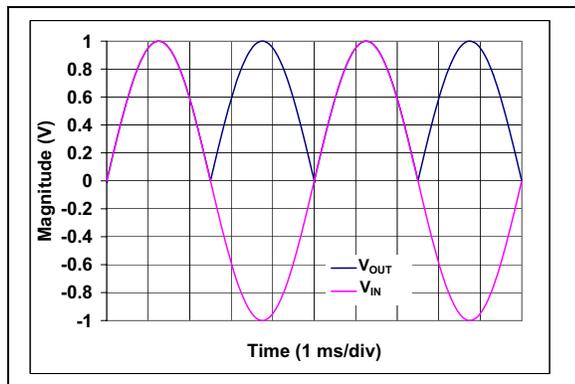


FIGURE 20: Full-Wave Rectifier Circuit Simulation.

For more topologies of the full-wave rectifier, refer to the Appendix section.

Figure 21 shows the behavior of the circuit at the maximum frequency tolerated.

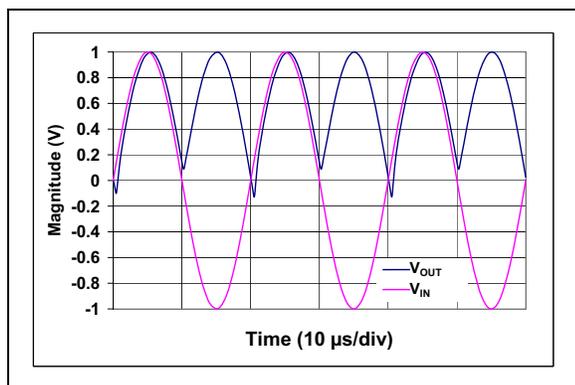


FIGURE 21: Circuit Behavior when Input Frequency = 100 kHz.

BASIC PEAK DETECTORS

The purpose of this circuit is to detect the maximum magnitude of a signal over a period of time. The operation of a peak detector can be illustrated using a simple diode and capacitor, as shown in Figure 22.

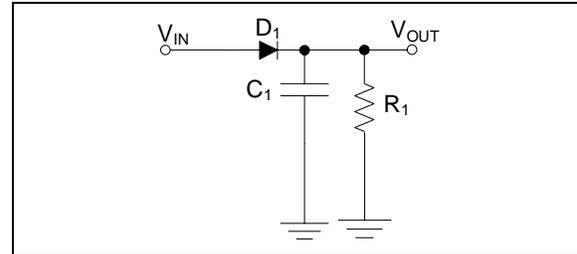


FIGURE 22: Basic Peak Detector Operation.

Choosing the Components

When choosing the resistor, the limits must be considered: $r_{df} \ll R_1 \ll r_{dr}$, where r_{df} is the resistance of the diode when forward biased, and r_{dr} is the resistance of the diode when reverse biased.

The capacitor is charged with the time constant $\tau_1 = r_{df} \times C_1$, and will be discharged with the time constant $\tau_2 = R_1 \times C_1$.

The variation of output voltage will be:

EQUATION 11:

$$\Delta V = \frac{V_{PEAK}}{f \times \tau_2}$$

Where:

- V_{PEAK} = Amplitude maximum value
- f = Input signal frequency
- τ_2 = Discharge time constant

Generally the minimum of τ_2 is $\tau_2 = 10/f$.

This is the case for a sine signal, but we may need to detect the peak for other types of signals, such as square waves, sensors or modulated signals.

For example, on an amplitude modulated signal, the capacitor voltage discharges according to:

EQUATION 12:

$$V_{DROP} = V_{PEAK} \times \exp\left(-\frac{t}{\tau_2}\right)$$

Where: τ_2 = time constant

This produces a negative peak clipping that distorts the output. To avoid the negative peak clipping, choose a smaller value for τ_2 , but to reduce the ripple, τ_2 must be as large as possible. In practice we choose a value between: $1/f_m \gg \tau_2 \gg 1/f_c$, where f_m is the modulation frequency and f_c is the carrier frequency.

Advantages and Disadvantages

Table 7 identifies some of the advantages and disadvantages of the peak detectors.

TABLE 7: ADVANTAGES AND DISADVANTAGES OF THE CIRCUIT

Advantages	Disadvantages
- Uses few components	- The output voltage is one diode drop below the actual output
- Very low cost	- The input impedance is variable due to the input characteristics of the diode
	- The discharge is very slow due to the leakage current

Practical Example

The simulation in Figure 23 shows that this circuit does not reach the peak amplitude of the input signal, but is good for quickly following sudden changes in the signal's amplitude. However, it has significant ripple. This example uses a 1N4148 diode, $C_1 = 1 \mu\text{F}$, $R_1 = 100 \text{ k}\Omega$ and $f = 1 \text{ kHz}$.

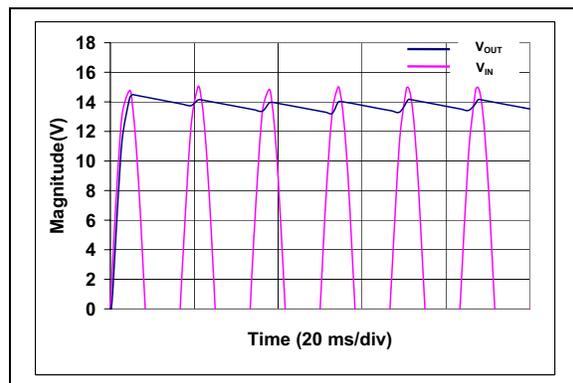


FIGURE 23: Peak Detector Simulation.

Two-Stage Active Peak Detector

In many applications, the voltage drop is not desired. To avoid this, we need to include a diode into the loop of the op amp, as shown in Figure 24.

A two-stage peak detector is shown in Figure 24. In this circuit, A_{O1} , R_1 , R_2 , D_1 , R_5 and C_1 represent the first stage, while A_{O2} , R_3 and R_4 is the second stage. A_{O1} charges the capacitor up to the peak value, and A_{O2} acts as an output buffer. A_{O1} removes the variability of the input impedance, while A_{O2} removes the variability of the output impedance.

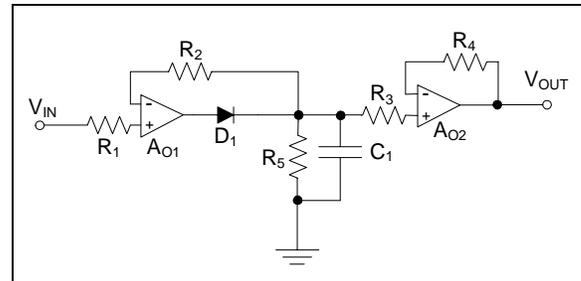


FIGURE 24: Two-Stage Peak Detector Circuit.

The time constant for charging C_1 is very short, and primarily consists of the C_1 and the forward resistance of the diode. Thus, C_1 charges almost instantly to the peak output of the input signal (V_{IN}). When V_{IN} goes below the output signal (V_{OUT}), diode D_1 becomes reverse-biased. The only discharge path for C_1 is through R_5 , via leakage or op amp bias currents. The discharge time constant is much longer than the charge time constant, so C_1 holds its charge and presents a steady input voltage to A_{O2} that is equal to the peak amplitude of the input signal. A_{O2} is a buffer amplifier that prevents unintentional discharging of the C_1 , caused by the loading impedance of the following circuit. If the R_5C_1 time constant is too short, then the voltage on C_1 will not be constant, and will have a high value of ripple. On the other hand, if the R_5C_1 time constant is too long, the circuit cannot respond quickly to the changes in the input amplitude.

The lower frequency limit is the frequency that causes the ripple voltage to exceed the maximum allowable level. It can be estimated by applying the basic discharge equation for capacitors (Equation 13):

EQUATION 13:

$$f_O = \frac{1}{R_5 \times C_1 \times \ln \left[\frac{V - V_o}{V - V_c} \right]}$$

Where:

- V = Capacitor's discharge voltage
- V_C = Minimum allowable voltage on the capacitor
- V_O = Initial charge of the capacitor

The response time describes how quickly C_1 can respond to the decreases in the magnitude of the input signal. This can be computed from the basic discharge equation. However, if we assume that the capacitor is charged to peak and discharges towards an eventual value of 0, we can use the simplified form (Equation 14).

EQUATION 14:

$$t_R = R_5 \times C_1 \times \ln \left[\frac{V_{PK(old)}}{V_{PK(new)}} \right]$$

Where:

$V_{PK(old)}$ = Peak input signal amplitude before the decrease

$V_{PK(new)}$ = Peak input signal amplitude after the decrease

Choosing the Components

Refer to the section [Selecting the Diode](#) in the section [Basic Rectifiers](#), and to the section [Selecting the Op Amp](#), in the section [Active Half-Wave Rectifier](#), for details on choosing the appropriate components.

SELECTING THE RESISTORS

R_3 limits the current into the positive input of the A_{O2} when power is disconnected from the circuit. Without this resistor, the A_{O2} may be damaged as C_1 discharges through it. For capacitors smaller than 1 μ F, resistor R_3 can normally be omitted. Resistor R_4 minimizes the effects of the bias currents in A_{O2} . Resistor R_2 limits the current into the negative input of A_{O1} when power is removed from the circuit.

There are two conflicting circuit parameters that affect the choice of the values for R_5 and C_1 : allowable ripple voltage across C_1 and response time. In general, a faster response time leads to greater ripple.

Refer to the section [Selecting the Resistors](#), in the section [Improved Op Amp Half-Wave Rectifier](#), for details on choosing the appropriate components.

Practical Example

Figure 25 illustrates the simulation result for one peak detector, realized with MCP661 device, diode 1N4148, $R_5 = 100$ k Ω and $C_1 = 1$ μ F. Input signal has the frequency equal to 1 kHz.

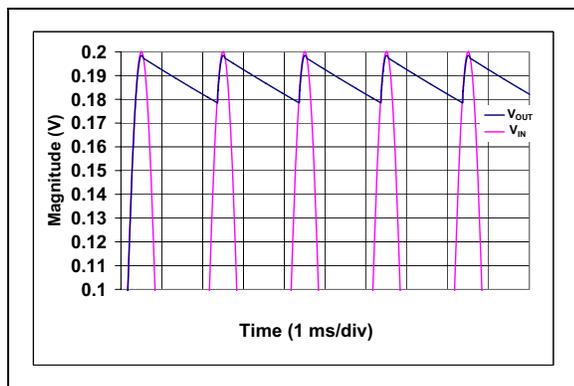


FIGURE 25: One Peak Detector Simulation Results.

For more topologies on the peak detectors, refer to the [Appendix](#).

BASIC CLAMP

A clamp is used to shift the DC reference level of the input signal. Figure 26 shows a basic diode clamp. Its purpose is to shift the average or the DC level of the input signal without altering the wave shape.

When $V_{OUT} > V_{REF}$ and the input signal is fast, D_1 is off, C_1 acts like a short circuit, and V_{OUT} looks like the input. With slow signals, C_1 acts like an open circuit and V_{OUT} will exponentially decay towards V_{REF} .

When $V_{OUT} < V_{REF}$, V_{OUT} becomes $V_{REF} - V_{D(on)}$, D_1 turns on and C_1 is forced to accept a new voltage that shifts the input to the desired minimum V_{OUT} .

For low-amplitude signals, the diode drop becomes significant. In fact, the circuit cannot be used at all if the peak input signal is below the diode threshold, since the diode cannot be forward-biased. An active clamp is needed for signals with an amplitude of millivolts.

Figure 26 shows a negative clamp; it clamps the negative extreme of the signal to (near) V_{REF} . Reversing the diode creates a positive clamp.

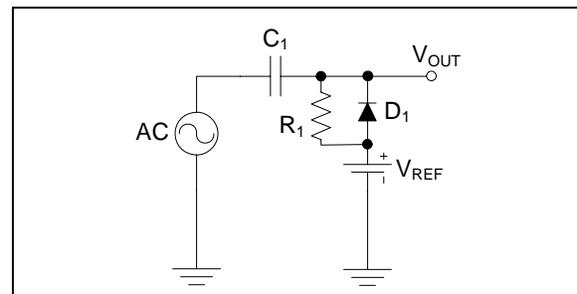


FIGURE 26: Basic Diode Negative Clamp.

Practical Example

Figure 27 shows a simulation for the above schematic with $V_{REF} = 2$ V, $C_1 = 1$ nF and diode 1N4148. The input signal has the frequency equal to 500 Hz.

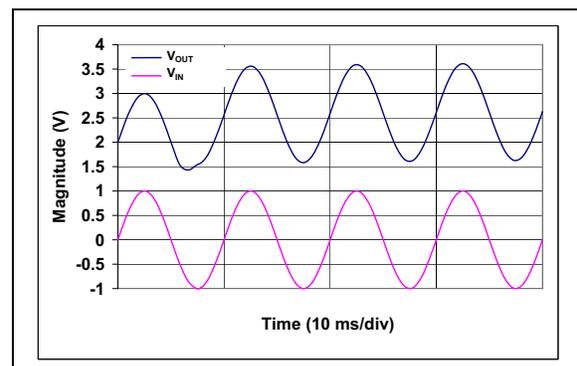


FIGURE 27: Basic Diode Clamp – Circuit Simulation.

Active Clamp

To reduce the threshold voltage of the diode, and for linearization, the circuit needs a diode in the feedback loop of the operational amplifier.

Figure 28 shows an op amp clamp where the input signal is positive and D_1 is forward-biased. The diode converts the circuit into a voltage follower with reference to the positive input. This means that the output of the op amp has approximately the same voltage as the reference voltage. When the input signal is negative, the diode is reversed-biased. The op amp will also be at the reference voltage level. Capacitor C_1 is charged with the difference of potential between V_{IN} and V_{REF} . This effectively disconnects the op amp from the circuit so the output will be the same as V_{IN} plus C_1 's voltage. The capacitor has no rapid discharge path and will act as a DC source, providing the clamping action.

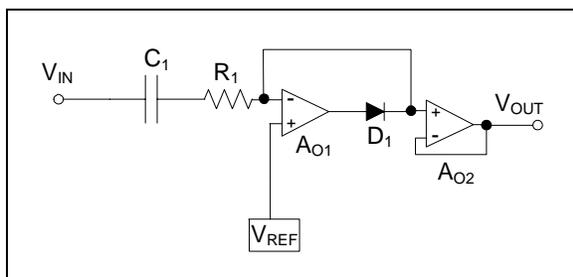


FIGURE 28: Op Amp Clamp.

Choosing the Components

Refer to the section [Selecting the Diode](#), in the section [Basic Rectifiers](#), and to the section [Selecting the Op Amp](#), in the section [Active Half-Wave Rectifier](#), for details on choosing the appropriate components.

SELECTING THE RESISTANCE AND THE CAPACITOR

The input impedance of the circuit varies with the input frequency and with the state of the circuit. As frequency increases, the reactance of C_1 decreases and lowers the input impedance.

Usually, R_1 gives the input impedance, so the chosen resistance should be the minimum of the desired impedance.

The value of C_1 is shown in [Equation 15](#):

EQUATION 15:

$$C_1 = \frac{16.7}{R \times f_{low}}$$

Where:

f_{low} = minimum frequency desired

$$R = r_{dr} \parallel R_{(-)} \parallel R_{(+)}$$

Where:

r_{dr} = Reversed diode resistance

$R_{(-)}$ = Input resistance on the negative terminal of A_{O1}

$R_{(+)}$ = Input resistance on the positive terminal of A_{O1} for voltage follower

$R_{(-)}$ and $R_{(+)}$ are calculated as a ratio between the maximum voltage allowed by the circuit on the input terminal and the maximum input bias current.

Advantages and Disadvantages

Table 8 shows the main advantages and disadvantages of the clamp circuit.

TABLE 8: ADVANTAGES AND DISADVANTAGES OF THE CIRCUIT

Advantages	Disadvantages
- Uses only one op amp	- The input impedance varies with the input frequency
- Few external components	- The output impedance varies with the input frequency
- Adjustable level for voltage reference	- Uses a potentiometer
	- Uses a positive and a negative voltage reference

Practical Example

This example uses the MCP6021 device, a 1N4148 diode, $C_1 = 150$ nF, $R_1 = 1.2$ k Ω , $R_2 = 43$ k Ω , $R_3 = 47$ k Ω , $V_{REF} = 0.7$ V. The input frequency is 10 kHz. [Figure 29](#) shows the simulation result for this example.

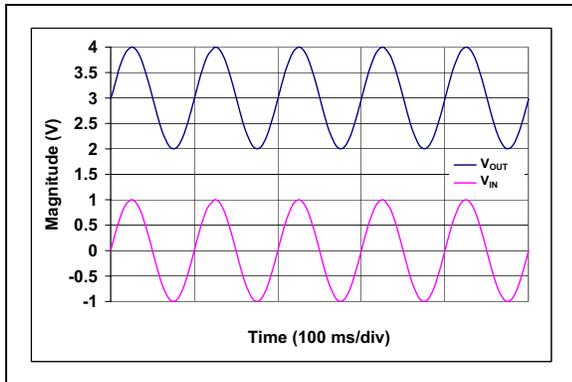


FIGURE 29: *Op Amp Clamp Circuit Simulation Result.*

CONCLUSION

This application note examined the circuits that can rectify the amplitude signal, detect the peak signal and change the DC level of waveforms. The op amp-based solutions bring improvements to the basic solutions, such as operating with millivolt signals or isolating the output and input impedance. The applications proposed are based on low cost op amps, and offer circuits with few peripheral components, giving designers simple, but effective solutions to their problems.

APPENDIX

This Appendix includes schematics for additional half and full-wave rectifiers, peak detectors and clamps. Each of these can be implemented using the rules presented in this application note.

Half-Wave Rectifiers

Figures 30 – 33 show more half-wave rectifiers with their DC transfer functions.

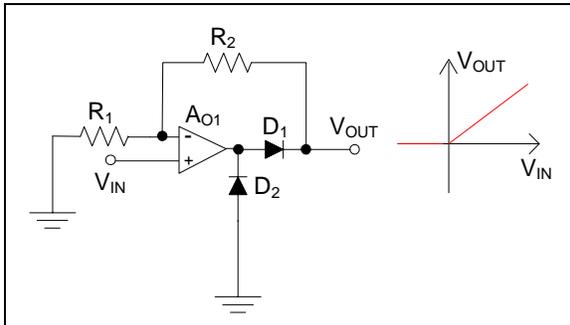


FIGURE 30: Positive Half-Wave Rectifier 1.

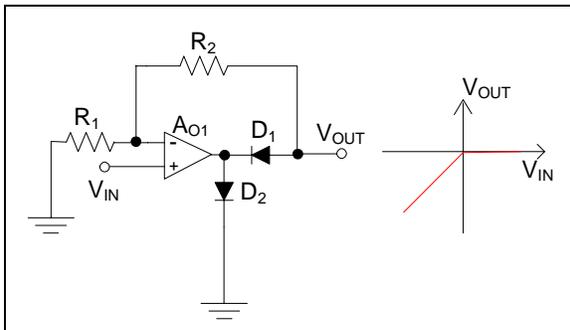


FIGURE 31: Negative Half-Wave Rectifier 1.

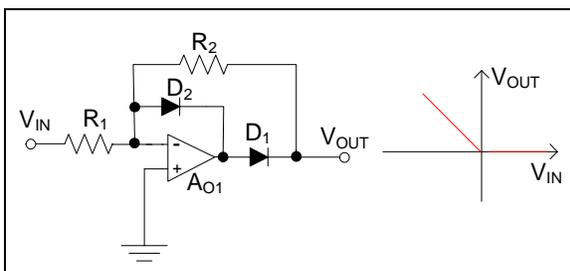


FIGURE 32: Positive Half-Wave Rectifier 2.

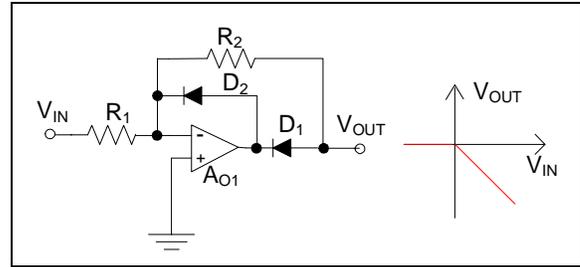


FIGURE 33: Negative Half-Wave Rectifier 2.

Every one of these circuits can be used to design full-wave rectifiers by adding an op amp adder. This method is illustrated in Figure 19.

Full-Wave Rectifiers

The circuits shown in this section are based on half-wave rectifiers. For example, the circuit in Figure 36 contains two half-wave rectifiers, one for the positive cycle, the other for the negative cycle, and one difference (or adder) amplifier.

For Figures 34 – 36, V_{OUT} is positive. Reversing the diodes creates a negative rectifier.

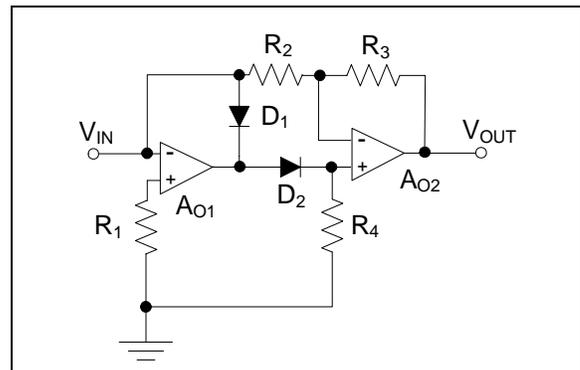


FIGURE 34: Two Stage Full-Wave Rectifier 1.

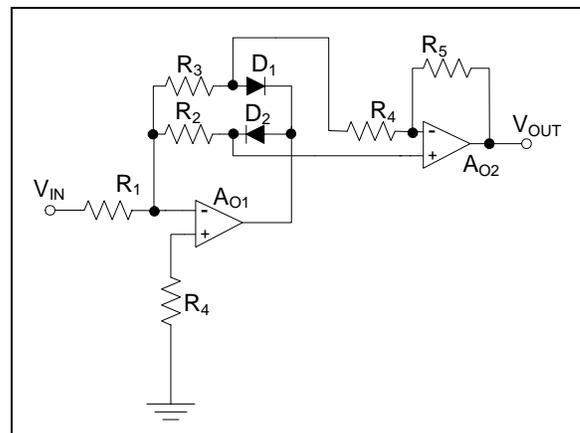


FIGURE 35: Two Stage Full-Wave Rectifier 2.

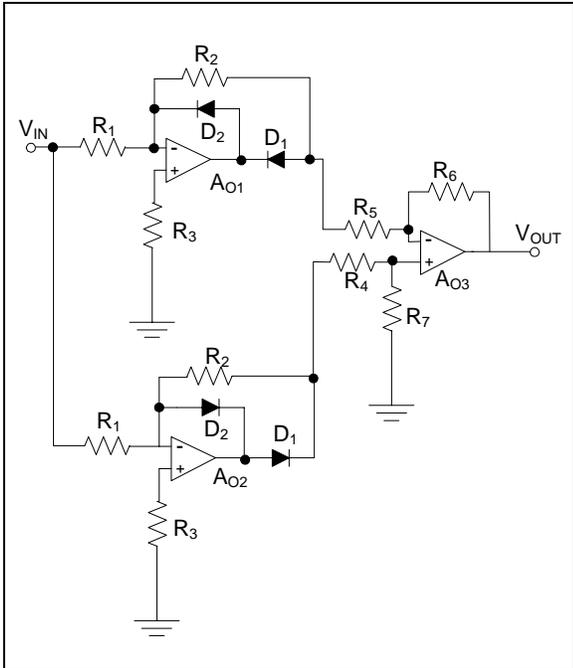


FIGURE 36: Three Stage Full-Wave Rectifier.

Peak Detectors

The circuit in [Figure 37](#) has the capacitor discharge through R_2 , which causes the output to droop. Diode D_2 provides the local feedback around A_{O1} , once a peak has been detected. This prevents A_{O1} from saturating during the peak hold mode and decreases the peak acquisition time. You can omit D_2 , but the circuit will be slower when detecting peaks.

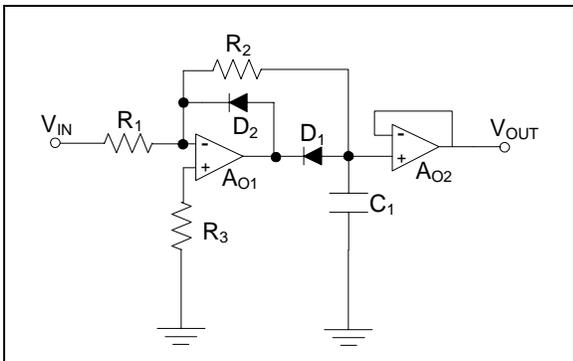


FIGURE 37: Peak Detector Rectifier 1.

For [Figure 38](#), V_{OUT} is positive. Reversing the diode creates a negative rectifier.

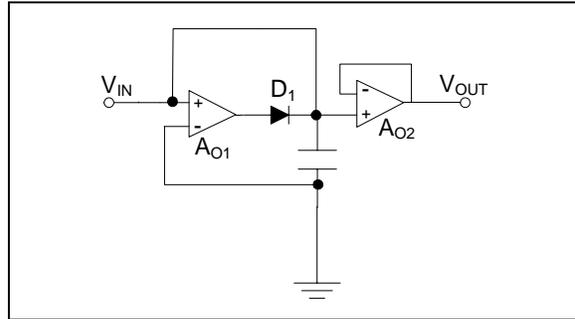


FIGURE 38: Peak Detector Rectifier 2.

For [Figure 39](#), V_{OUT} is positive. Reversing the diodes creates a negative rectifier. To reset this circuit, we can use a relay reed, or a transistor with a low leakage current.

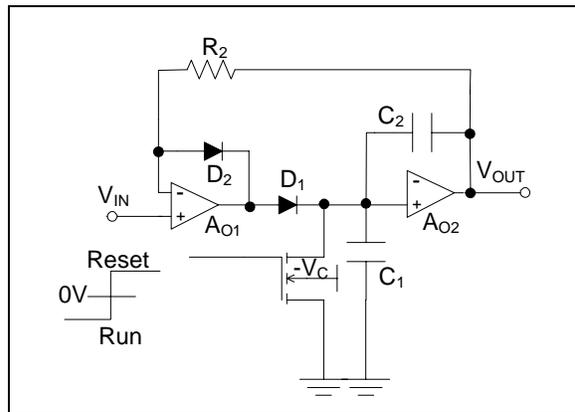


FIGURE 39: Peak Detector Rectifier 3.

Clamp

[Figure 40](#) shows another positive active clamp where the reference voltage can be adjusted. If the diode is inverted, a negative active clamp will result.

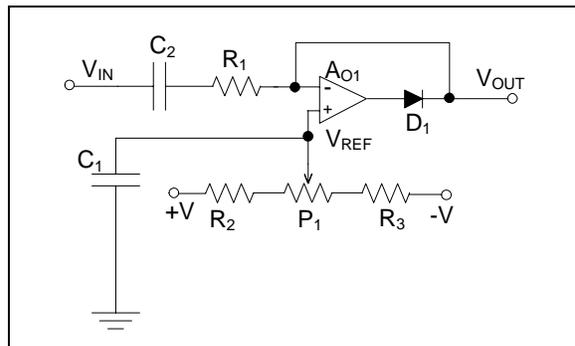


FIGURE 40: Active Clamp Sample.

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