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.

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:
- \( V_{PIV} \) = Peak inverse voltage
- \( V_{PK(max)} \) = Maximum peak amplitude
- \( V_{D(on)} \) = 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 \( f = 1 \text{ kHz} \).
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).

![Op Amp Half-Wave Rectifier](image)

**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.

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:**

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

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:**

$$SR = \frac{\Delta V_{OUT}}{\Delta T}$$

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

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**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uses few components</td>
<td>Load dependant</td>
</tr>
<tr>
<td>Good linearity</td>
<td>Limited op amp bandwidth</td>
</tr>
</tbody>
</table>
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 RL = 100Ω.](image1)

![Figure 11: Half-Wave Rectifier with RL = 1 kΩ.](image2)

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, D1 is open and D2 conducts. The output signal is zero because one side of R2 is connected to the virtual ground, with no current through it. When the input is negative, D1 conducts and D2 is open. The output follows the positive input cycle with a gain of \( G = \frac{-R_2}{R_1} \).

![Figure 12: Half-Wave Rectifier Circuit Improvement.](image3)

Choosing the Components

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 R3 shown in Figure 12 is also optional, and is needed only if there is no DC path to ground.

SELECTING THE RESISTORS

The DC gain is determined in Equation 4:

**EQUATION 4:**

\[
G = \frac{-R_2}{R_1}
\]

where \( G = \text{DC gain} \)
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 $1\, \text{k}\Omega$ and $100\, \text{k}\Omega$.
- For a high speed application, the resistor’s value should be between $100\, \Omega$ and $1\, \text{k}\Omega$ (consume more power).
- For portable applications between $1\, \text{M}\Omega$ and $10\, \text{M}\Omega$.

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**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Good linearity</td>
<td>- Uses more components</td>
</tr>
<tr>
<td>- The second diode prevents</td>
<td>- Low impedance because of $R_1$</td>
</tr>
<tr>
<td>the op amp from swinging</td>
<td></td>
</tr>
<tr>
<td>into the negative cycle</td>
<td></td>
</tr>
</tbody>
</table>

**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, $R_L = 1\, \text{k}\Omega$, $R_2 = 10\, \text{k}\Omega$ and $R_1 = 1\, \text{k}\Omega$. The input frequency is $1\, \text{kHz}$.

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

**Figure 14:** Circuit Behavior with $600\, \text{kHz}$ 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 D1 is forward biased, and the output voltage follows the input. When the input signal ($V_{IN}$) is positive, D1 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:

$$EQUATION 6: \quad V_{OUT} = \begin{cases} V_{IN} \times GM & ; \quad V_{IN} < 0 \\ V_{IN} \times GP & ; \quad V_{IN} > 0 \end{cases}$$

Where:

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

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

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:

$$EQUATION 7: \quad R_2 \times (R_1 + R_2 + R_L) = R_1 \times R_L$$

$R_3$ 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>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Uses only one op amp</td>
<td>- Low input resistance</td>
</tr>
<tr>
<td>- Uses a small number of external components</td>
<td>- The source and load resistance affect rectifying</td>
</tr>
<tr>
<td>- Uses a single supply</td>
<td>- A reactive load (capacitor or coil) cannot be tolerated without a buffer</td>
</tr>
<tr>
<td>- Has a low impedance because of $R_1$</td>
<td></td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Resistor</th>
<th>Value (kΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>2</td>
</tr>
<tr>
<td>$R_2$</td>
<td>1</td>
</tr>
<tr>
<td>$R_L$</td>
<td>3</td>
</tr>
</tbody>
</table>

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.
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 $R_5$.

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 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:

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

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

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Very good performance</td>
<td>- Uses two op amps</td>
</tr>
<tr>
<td>- Low output impedance</td>
<td>- Low input resistance</td>
</tr>
<tr>
<td>- Multiple passive components</td>
<td></td>
</tr>
</tbody>
</table>

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](image)

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](image)

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](image)

Choosing the Components

When choosing the resistor, the limits must be considered: \( r_{df} << R_1 << r_{dr} \), 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:

\[
\text{EQUATION 11:} \quad \Delta V = \frac{V_{PEAK}}{f \times \tau_2}
\]

Where:
- \( V_{PEAK} \) = Amplitude maximum value
- \( f \) = Input signal frequency
- \( \tau_2 \) = Discharge time constant

Generally the minimum of \( \tau_2 \) 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:

\[
\text{EQUATION 12:} \quad V_{DROP} = V_{PEAK} \times \exp\left(-\frac{t}{\tau_2}\right)
\]

Where:
- \( \tau_2 \) = time constant

This produces a negative peak clipping that distorts the output. To avoid the negative peak clipping, choose a smaller value for \( \tau_2 \), but to reduce the ripple, \( \tau_2 \) 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>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Uses few components</td>
<td>- The output voltage is one diode drop below the actual output</td>
</tr>
<tr>
<td>- Very low cost</td>
<td>- The input impedance is variable due to the input characteristics of the diode</td>
</tr>
<tr>
<td>- The discharge is very slow due to the leakage current</td>
<td></td>
</tr>
</tbody>
</table>

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, C₁ = 1 µF, R₁ = 100 kΩ and f = 1 kHz.

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, A₀₁, R₁, R₂, D₁, R₅ and C₁ represent the first stage, while A₀₂, R₃ and R₄ is the second stage. A₀₁ charges the capacitor up to the peak value, and A₀₂ acts as an output buffer. A₀₁ removes the variability of the input impedance, while A₀₂ removes the variability of the output impedance.

The time constant for charging C₁ is very short, and primarily consists of the C₁ and the forward resistance of the diode. Thus, C₁ charges almost instantly to the peak output of the input signal (Vᵢₙ). When Vᵢₙ goes below the output signal (Vₒᵤₜ), diode D₁ becomes reverse-biased. The only discharge path for C₁ is through R₅, via leakage or op amp bias currents. The discharge time constant is much longer than the charge time constant, so C₁ holds its charge and presents a steady input voltage to A₀₂ that is equal to the peak amplitude of the input signal. A₀₂ is a buffer amplifier that prevents unintentional discharging of the C₁, caused by the loading impedance of the following circuit. If the R₅C₁ time constant is too short, then the voltage on C₁ will not be constant, and will have a high value of ripple. On the other hand, if the R₅C₁ 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):

\[
 f₀ = \frac{1}{R₅ C₁ \times ln \left( \frac{V - Vₒ}{V - Vₐ} \right)}
\]

Where:
- V = Capacitor’s discharge voltage
- Vₐ = Minimum allowable voltage on the capacitor
- Vₒ = Initial charge of the capacitor

The response time describes how quickly C₁ 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 \( \text{AO}_2 \) when power is disconnected from the circuit. Without this resistor, the \( \text{AO}_2 \) may be damaged as \( C_1 \) discharges through it. For capacitors smaller than 1 \( \mu \)F, \( R_3 \) can normally be omitted. Resistor \( R_4 \) minimizes the effects of the bias currents in \( \text{AO}_2 \). Resistor \( R_2 \) limits the current into the negative input of \( \text{AO}_1 \) 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, \( R_5 = 100 \text{ k} \Omega \) and \( C_1 = 1 \mu \text{F} \). Input signal has the frequency equal to 1 kHz.

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

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

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) \( V_{\text{REF}} \). Reversing the diode creates a positive clamp.

Practical Example

Figure 27 shows a simulation for the above schematic with \( V_{\text{REF}} = 2V, \, C_1 = 1 \text{ n} \mu \text{F} \) and diode 1N4148. The input signal has the frequency equal to 500 Hz.
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 D1 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 C1 is charged with the difference of potential between VIN and VREF. This effectively disconnects the op amp from the circuit so the output will be the same as VIN plus C1’s voltage. The capacitor has no rapid discharge path and will act as a DC source, providing the clamping action.

Choose 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 C1 decreases and lowers the input impedance.

Usually, R1 gives the input impedance, so the chosen resistance should be the minimum of the desired impedance.

The value of C1 is shown in 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 AO1
- $R_(+)$ = Input resistance on the positive terminal of AO1 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>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Uses only one op amp</td>
<td>- The input impedance varies with the input frequency</td>
</tr>
<tr>
<td>- Few external components</td>
<td>- The output impedance varies with the input frequency</td>
</tr>
<tr>
<td>- Adjustable level for voltage reference</td>
<td>- Uses a potentiometer</td>
</tr>
<tr>
<td>- Uses a positive and a negative voltage reference</td>
<td></td>
</tr>
</tbody>
</table>

Practical Example

This example uses the MCP6021 device, a 1N4148 diode, C1 = 150 nF, R1 = 1.2 kΩ, R2 = 43 kΩ, R3 = 47 kΩ, VREF = 0.7V. 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\text{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 R2, which causes the output to droop. Diode D2 provides the local feedback around AO1, once a peak has been detected. This prevents AO1 from saturating during the peak hold mode and decreases the peak acquisition time. You can omit D2, but the circuit will be slower when detecting peaks.

FIGURE 37: Peak Detector Rectifier 1.

For Figure 38, VOUT is positive. Reversing the diode creates a negative rectifier.

FIGURE 38: Peak Detector Rectifier 2.

For Figure 39, VOUT 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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