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Full Wave Rectifier

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IN THIS MINI TUTORIAL

The full wave rectifier is typically used to create a dc level from an ac input. This rectifier is one of a set of discrete circuits incorporating operational amplifiers (op amps) described in a series of mini tutorials.

The full wave rectifier is typically used to create a dc level from an ac input. This is often used to measure the amplitude of the ac signal. The full wave rectifier is an averaging detector. This is to be differentiated with a rms detector or a peak detector.

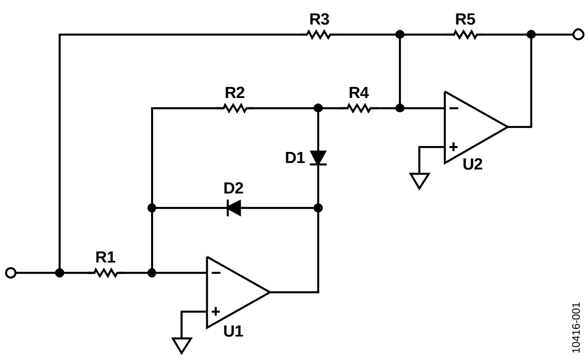

Figure 1. The Full Wave Recifier

The full wave rectifier is an enhancement of the half wave rectifier (see MT-212). Figure 2 illustrates the full wave rectifier as a half wave rectifier summed with the input.

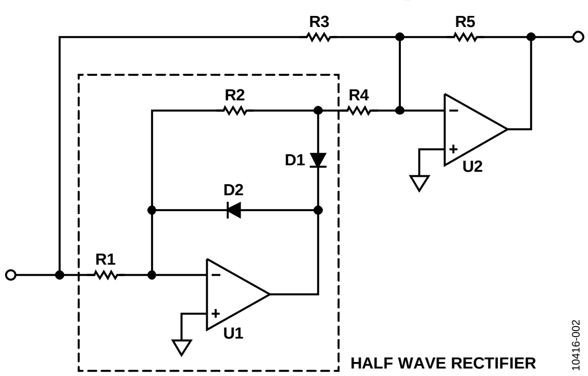

Figure 2. The Full Wave Rectifier as an Enhancement to the Half Wave Rectifier

To understand the operation of the full wave rectifier, assume that the theoretical op amp and diodes have no forward voltage. For negative input voltages, the output of U1 tries to go positive, which turns D1 on and D2 off. Assuming a short for D1 (on in this condition), this holds the output at ground potential, since the action of the op amp (U1) forces the input voltages of the op amp to the same level.

For positive input voltages, the output goes negative, D2 turns on, and D1 turns off. The output of U1 then acts as an inverting amplifier (see MT-213) with gain set by R2/R1. Typically the gain is set to 1, which means R2 = R1.

The result is that the output of U1 follows the negative half cycle of the input (inverted) with an output of 0 V for the positive half cycle. This output then becomes one of the inputs of the second stage (U2) which is summed with the input waveform (see MT-214).

The gain of the first stage, which is a half wave rectifier (see MT-212), has a gain of 2 relative to the input. This means that R3 = 2R4. Thus, the input wave is summed with the reference potential (ground) for the negative half cycle. The result at the output of U2 is a positive gain for the negative half cycle. For the positive half cycle, the inverted wave of the half wave rectifier is summed with the input with a gain for the half wave rectifier of 2. This results in a positive half wave at the output of U2. The result is a full wave rectifier.

The gain of the half wave rectifier section is typically set to 1 (R1 = R2). The ratio matching of R3 and R4 should be fairly tight (the absolute value of the resistor values is relatively unimportant), so that the summing of the input with the output of the half wave rectifier output will sum correctly. Gain can most easily be taken in the circuit by changing the value of R5.

Figure 3 shows the waveforms of the full wave rectifier. The top trace is the input and the bottom trace is the output of the circuit at U2.

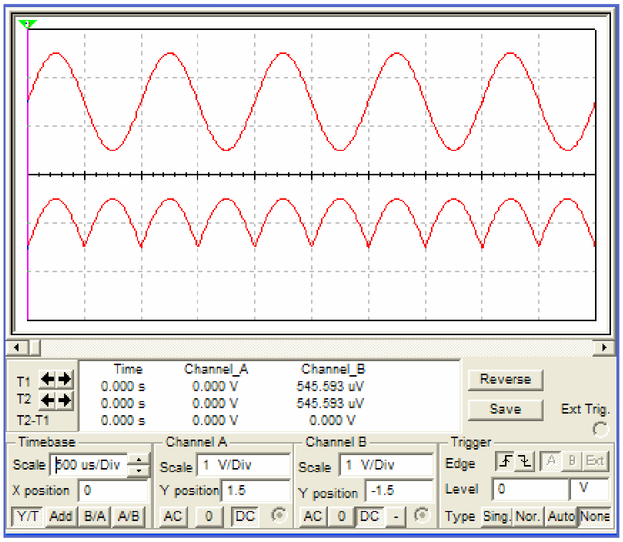

Figure 3. Full Wave Rectifier Waveforms

Figure 4 shows the output of U1 and the output of the half wave rectifier. Note that in a practical circuit the output of U1 is actually running open loop until the forward voltage of D2 is reached. This is shown in the third trace from the top (Channel C). The output of the half wave rectifier is shown as the bottom trace (Channel D). The gain of all the traces in Figure 4 are the same.

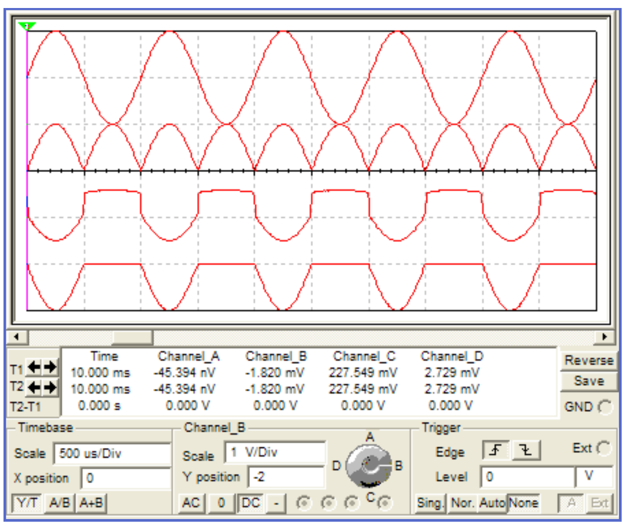

Figure 4. Full Wave Rectifier Waveforms with Half Wave Rectifier Output

The output of the full wave rectifier is often followed by a filter to develop the dc level. The corner frequency of the filter should be set low enough to limit the ac ripple on the output, but high enough not to seriously impact the transient response speed of the circuit.

The output spectrum of the output is shown in Figure 5. An advantage of the full wave rectifier over the half wave rectifier is that the frequency spectrum of the output is multiplied by a factor of 2 due to the doubling of the output lobes due to the rectifier action.

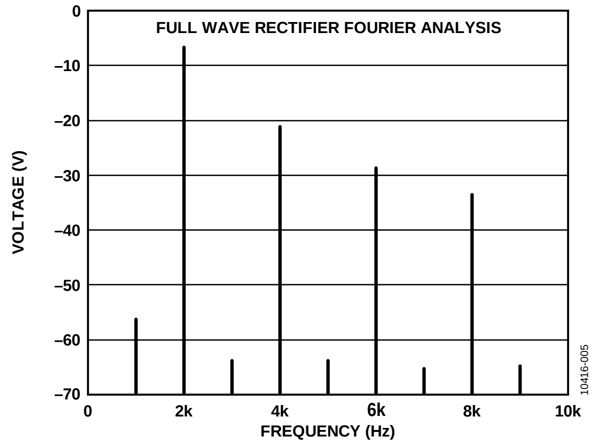

Figure 5. Full Wave Rectifier Output Spectrum

The summer section of the full wave rectifier can be turned into a simple filter by the addition of a capacitor in the feedback network. The corner frequency of the filter is set by the capacitor value and the value of R5 ($F_0 = 1/(2\pi R5C1)$). This is illustrated in Figure 6. In addition, this circuit can be followed by an active filter.

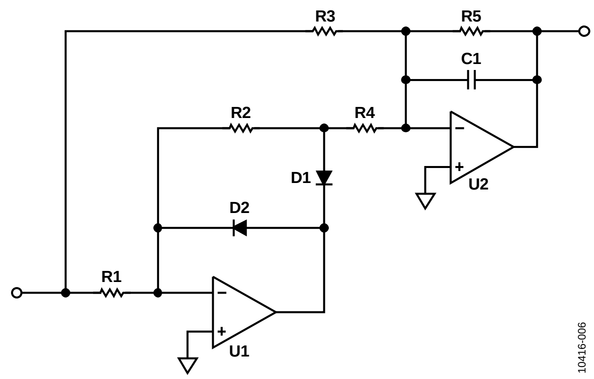

Figure 6. The Addition of a Capacitor in the Feedback Loop Converts the Output of the Full Wave Rectifier to a DC Level

The polarity of the output can be changed to a negative going by reversing both of the diodes.

Error terms for the full wave rectifier are the same as for the inverting amplifier (see MT-213). Most significant is the offset term. The frequency response of the circuit is set primarily by the open-loop gain of the op amp. The shunt capacitance of the diodes and the diode turn on/ turn off time can also affect the frequency response, but their effect is typically much less than that of the frequency response of the op amp.

For operation with a single power supply voltage, the non-inverting input is biased to a reference voltage, typically at ½ the supply voltage. The zero input signal output is then at the reference voltage. Figure 7 shows a single supply half wave rectifier with a reference voltage (the voltage at the noninverting input to the op amp) at +4 V. On the display, ground is at the bottom.

The input is still ground referenced, so the input must be ac coupled using a series capacitor. The low end of the frequency is determined by the RC time constant set by the input coupling capacitor and the input Resistor R1. With bipolar supplies, the circuit response is to dc. Alternatively, if the preceding circuit is referenced to the same reference voltage, the input may be dc coupled. Care should be taken if gain is taken in the circuit, since the reference level as well as the signal is amplified.

The frequency response requirements on the op amp are determined by the maximum signal input frequency. There must be enough open-loop gain for the diodes to be biased. In addition, there is a doubling of frequency due to the summing action. Thus, apply the rule of thumb that the bandwidth of the op amp should be at least 20 dB at twice the maximum frequency of the input signal.

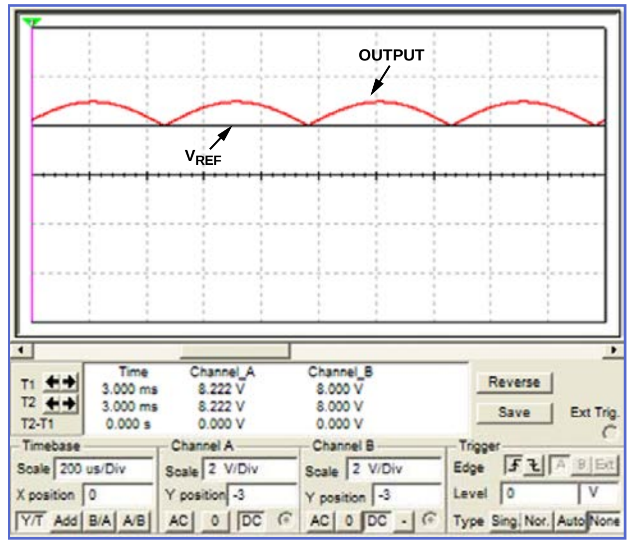

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Figure 7. Single Supply Half Wave Rectifier Waveforms

REVISION HISTORY

2/13—Rev. 0 to Rev. A

Changes to Figure 1 and Figure 2 1
Changes to Figure 6 2

4/12—Revision 0: Initial Version