

Using a current monitor to create an elegant precision rectifier design

By Peter Abiodun Bode

Traditionally, precision full wave rectifiers¹ used in a range of instrumentation applications have employed between 7 and 9 discrete circuit components. These are typically 2 op-amps, 2 diodes and 3 to 5 resistors. This article will show that an alternative approach, using a standard current monitor IC, not only reduces the component count to just five, it also greatly simplifies circuit configuration and produces a far more elegant overall solution.

Let's first recap on why a precision rectifier is required. Put simply, since a diode has a forward voltage drop of typically 0.6V, any signal that is not an order of magnitude larger than this will suffer major distortion. The problem is exacerbated for full wave rectification, where the signal must overcome two diode drops.

Even a voltage as 'large' as 10V will suffer significant distortion when full-wave rectified using diodes, with at least 12 percent of the signal being subject to severe distortion. Quite often however, the signal to be rectified is far less than 1 volt and can be as low as a few millivolts.

Illustrated in Figure 1, classic solutions used to address this problem fea-

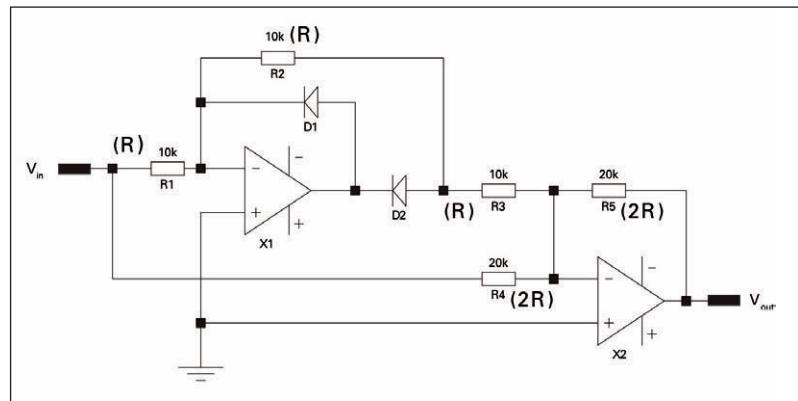


Fig 1: Classic precision full wave rectifier (nine components).

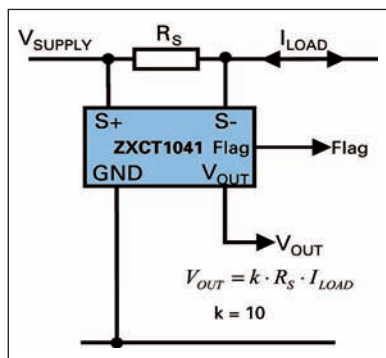


Fig 2: The ZXCT1041 bi-directional current monitor normal use.

ture diodes in the feedback path of an operational amplifier. This effectively changes the normal diodes into near

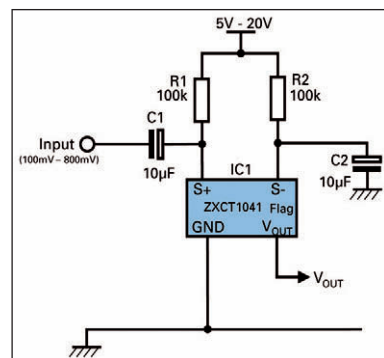


Fig 3: A current monitor based precision full wave rectifier (five components).

perfect diodes, i.e. devices that conduct unidirectionally with zero forward voltage drop.

To better appreciate the advantages offered by the proposed current monitor based design, the operation of the classic precision full wave rectifier shown in Figure 1 is best considered first. A quick inspection shows the following.

For positive inputs, the transfer function is given by:

$$V_{OUT} = +V_{IN} \left(\frac{R2 \cdot R5}{R1 \cdot R3} - \frac{R5}{R4} \right) \quad \text{Equation 1}$$

For negative inputs, the transfer function is given by:

$$V_{OUT} = +V_{IN} \frac{R5}{R4} \quad \text{Equation 2}$$

There is therefore inherent asymmetry in the transfer functions for the two halves of the signal and the circuit can only work qualitatively provided that

$$\frac{R2 \cdot R5}{R1 \cdot R3} = 2 \cdot \frac{R5}{R4} \quad \text{Equation 3}$$

Or
$$\frac{R2 \cdot R4}{R1 \cdot R3} = 2 \quad \text{Equation 4}$$

Equation 4 shows that both the absolute values and ratios of resistors R1 to R4 are critical to satisfactory performance of this circuit. It also shows that there are two ways that the values could be arranged for precision rectification to take place. One way, shown in Figure 1 is to make R1, R2 and R3 the same value (R), and then make R4 and R5 equal to 2R for unity gain. The other way is to make R1, R3, R4 and R5 the same value (R), and then make R2 equal to 2R. This also gives a unity gain. This second option, while it works OK, will have a slightly reduced bandwidth compared to the first and is therefore not the preferred option. The effect of R5 in both cases is to apply an overall gain to the circuit. Its absolute value is not important so long as the condition given by Equation 4 is satisfied. This will only be the case if very close tolerance resistors are used.

The major drawbacks of this classic precision rectifier design can therefore be summarized as follows:

1. Component count is relatively high.
2. Good performance depends on getting four resistors in perfect balance.
3. It requires a double-ended power supply.

In contrast, the proposed alternative method based around a current monitor IC avoids all of the problems outlined above. Shown in Figure 2, the current monitor is normally used to provide bi-directional current monitoring. It produces an amplified output (gain = 10) that is always positive regardless of the polarity of the voltage across its S+ and S- terminals (sense voltage or

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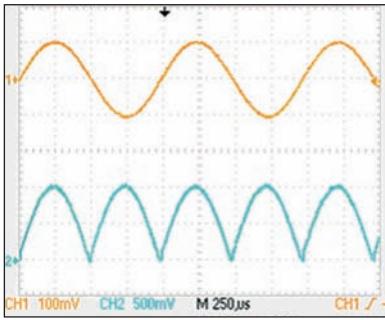


Fig 4: Circuit testing: 100mV input at 1kHz.

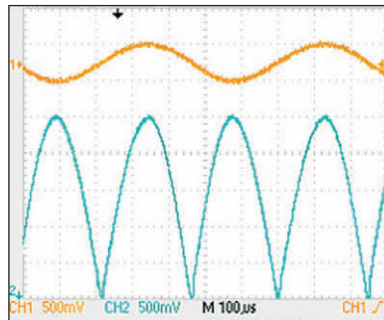


Fig 5: Circuit testing: 250mV input at 2kHz.

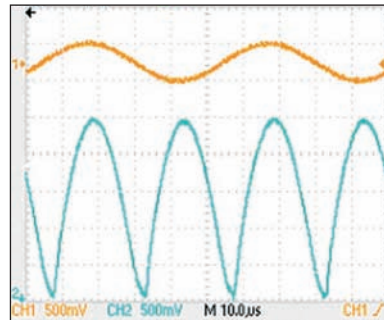


Fig 6: Circuit testing: 250mV input at 20kHz.

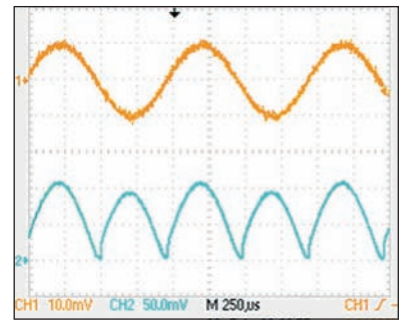


Fig 8: Circuit testing: 10mV input at 1kHz – no offset trimming.

V_{SENSE}). This sense voltage is normally derived by using a sense resistor (R_s) in series with a load in order to make V_{SENSE} proportional to the load current.

Consider now the current monitor's use in the alternative precision full wave rectifier circuit shown in Figure 3. Here, resistors R1 and R2 provide dc bias for IC pins S+ and S- respectively. Pin S- is decoupled by C2, effectively making it an ac ground. This means that any signal that is coupled onto pin S+ will appear across pins S+ and S- as sense voltage. This voltage is then amplified by the current monitor which also produces a unipolar output. It is therefore an amplified full wave rectification of the ac component of the input voltage.

The oscilloscope traces of Figures 4, 5 and 6 show just how well the rectifier works. The circuit was tested with a range of signal amplitudes from 100mV up to 500mV and frequencies ranging from 50Hz up to 25kHz.

Signals as low as 10mV or less can also be precision rectified by the circuit. There are however some limitations that need to be considered. Figure 8 shows the circuit being tested with an input signal of only 10mV. Two factors limiting performance are evident.

The less important of these is the differential input offset voltage of the device. This is the net difference between the input offset voltage in the forward and reverse direction. This difference is added to the rectified signal in one direction and subtracted in the other.

The effect is visible in Figure 8 where alternate peaks are elevated and low-

ered. It is the less important factor for two reasons:

1. The net effect of this distortion on the average value of the signal is nil.
2. The effect is quite easily cancelled out by simple input offset trimming as shown in Figure 7. Figure 9 shows the much improved waveform that results.

The more important limiting factor is more difficult to solve. This is the crossover distortion which is introduced when the current monitor IC changes from conducting in one direction to conducting in the opposite direction. Two phenomena contribute to this distortion.

Effect of input offset voltage on crossover distortion: the first is the input offset voltage of the amplifiers within the IC. The effect of these input offset voltages is analogous to the forward voltage drop of a diode in that the signal must first overcome it before the amplifier begins to respond. However, the input offset voltage is quite small and

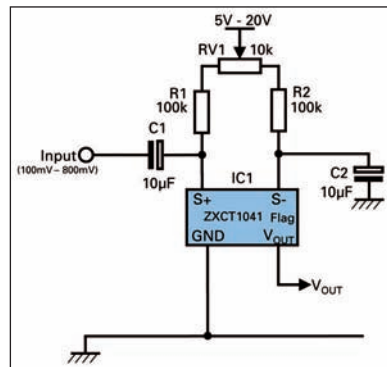


Fig 7: Compensating for input offset voltage effect.

only affects signal levels that are comparable in amplitude to it, as shown in Figure 8.

Effect of zero crossing delay on crossover distortion: a far more dominant phenomenon contributing to crossover distortion is the zero crossing delay of the device. This is the delay between one amplifier switching off and the other taking over when the input changes polarity. It is quantified on the current monitor's datasheet² with graphs showing typical delays for small and large signals. This delay can be as long as 8µs including the effects of output slew rate.

In general all these effects are more dominant and visible only at very low input voltages (less than 100mV). They are less conspicuous at higher input voltages (higher than 100mV). Together, they impose a limit on the bandwidth that is achievable by the circuit. When operated in the unipolar mode with suitable dc bias, this device is capable of a bandwidth of 300 kHz. However, the achievable bandwidth in this case has been limited to about 25 kHz due to the factors outlined here.

A precision full wave rectifier can be readily implemented using a bi-directional current monitor. Requiring five components, it offers the advantage of a significantly reduced component count over classic two op-amp methods. The saving in PCB real estate is even greater because the single active element, the current monitor IC, is housed in a SOT23-5 package compared with the much bigger SO-8 package often used for dual op-amps.

The circuit uses only two resistors

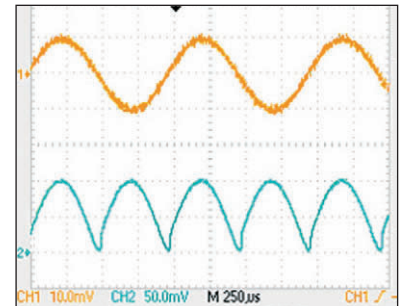


Fig 9: Circuit testing: 10mV input at 1kHz – with offset trimming.

and two capacitors and its performance is not adversely affected by the absolute values of these components. A good match is still recommended for the two resistors, though 1 percent tolerance resistors are sufficient for this purpose; costly precision components are not required. Unlike the classic circuit that requires both a positive and negative supply, this circuit only uses a positive power supply.

Lastly there is the added advantage that the proposed current monitor based rectifier offers an inherent ability to block dc components in the signal. The classic approach requires yet another component, a capacitor, to achieve blocking. ■

References

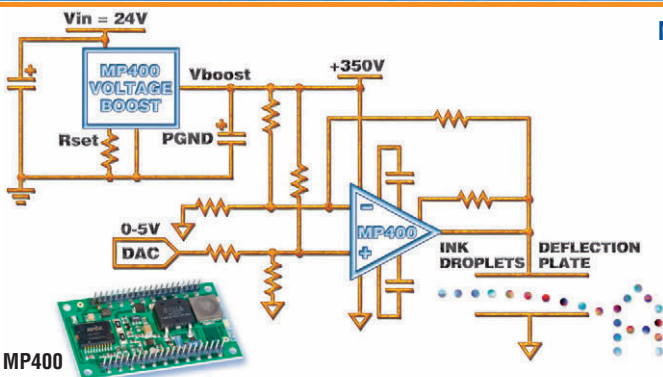
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2. Zetex Semiconductors Application Note 39 (AN39) – Current Measurement Applications Handbook. Zetex Semiconductors Datasheet ZXCT1041.

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