AN55

ZXCT1041 as a precision full wave rectifier

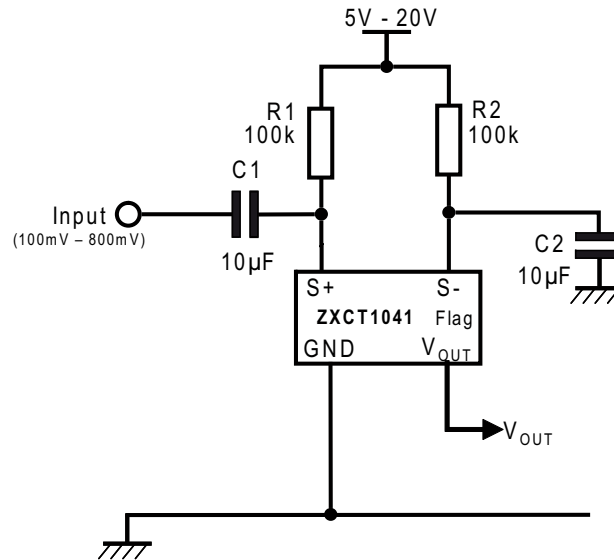**By Peter Abiodun Bode, Snr. Applications Engineer.**

Figure 1 - A very simple full wave precision recifier

Introduction

The ZXCT1041 can be used to make a precision rectifier. This application note shows how to produce a simple precision rectifier using only 4 components and standard resistors.

Two circuits are presented for input voltages above 100mV and below 100mV. The solution is compared with the classic 2-opamp precision rectifier.

Rectifying low level voltages

The precision rectifier is needed because a diode has a forward voltage drop, V_F, of typically 0.6V. Any signal that is not an order of magnitude larger than this will be distorted. The problem is worse for full wave rectification where the signal must overcome two diode drops. Even with a voltage as large as 10V, full wave rectification without significant distortion using only diodes is impossible. At least 12% of the signal will be subject to severe distortion. Often however, the signal to be rectified can be as low as a few millivolts.

The standard solution to this problem is to use diodes in the feedback path of an operational amplifier in order to effectively change these normal diodes into near perfect ones, i.e. devices that conduct unidirectionally with zero forward voltage drop.

There are many such circuits[1] but all share a common feature. They are generally based around

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1. Most of these, though not all, can be found in the book *The Art of Electronics* by Paul Horowitz and Winfield Hill.

- Two op-amps

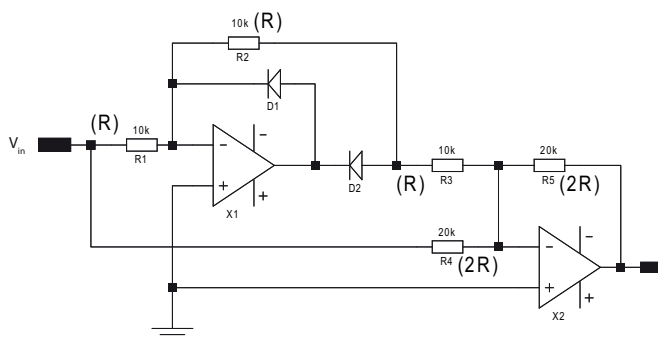- At least one diode, and

- Up to five resistors

Figure 2 - Classic precision full wave rectifier (9 components)

With reference to Figure 2, for positive inputs, the transfer function is given by,,

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

For negative inputs, the transfer function is given by,

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

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

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

Or

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

From Equation 4 above, 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. One of these, shown in Figure 2, is to make R1, R2 and R3 all same value (R), and then make R4 and R5 equal to 2R for unity gain. The other is to make R1, R3, R4 and R5 the same value (R), and then make R2 equal[1] to 2R. This also gives a unity gain. 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.

As elegant as the circuit above is, its drawbacks can be summarised as follows.

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1. This second option, whilst it works fine, will in fact have a slightly reduced bandwidth in comparison with the first option. It is for this reason less preferred.

1.	Component count is relatively high, requiring 9 components
2.	Good performance depends on perfectly getting four resistors in parallel
3.	It requires a double-ended power supply

Table 1 - Shortcomings of classic precision full wave rectifiers

Using the ZXCT1041

The alternative method (shown in Figure 4) is based around the Zetex ZXCT1041 bidirectional current monitor and avoids all the problems outlined above.

The ZXCT1041 is primarily designed for providing bi-directional current monitoring. It is effectively two VOCM's (voltage-output current monitor) in anti-parallel formation within a SOT23-5 package. 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 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.

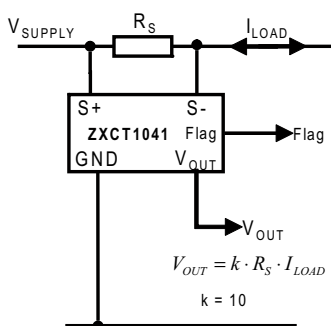$$V_{OUT} = k \cdot R_S \cdot I_{LOAD}$$

k = 10

Figure 3 - ZXCT1041 bi-directional current monitor - normal application
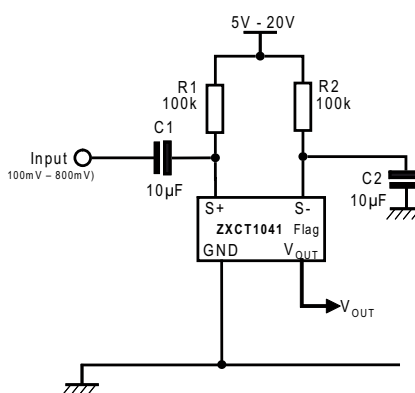
Figure 4 - Precision full wave rectifier using ZXCT1041

Circuit description

Using the ZXCT1041, the solution to the three problems in Table 1 are solved.

With reference to Figure 4, resistors R1 and R2 provide DC bias for 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 ZXCT1041 which produces a unipolar output. It is therefore an amplified full wave rectification of the AC component of the input voltage.

This solution offers an inherent advantage of blocking DC components in the signal. If DC blocking is a requirement, the conventional method would require an additional capacitor to achieve this which adds to the component count. This circuit is not usable for DC signals. If low frequency response is not required, the values of capacitors C1 and C2 can be correspondingly reduced. A value of 0.1µF, for example, is quite adequate for a signal of 1kHz.

Testing

The circuit above was constructed and tested for performance. The graphs below (Figure 5 to Figure 10) show how well it works. The circuit was tested with a range of signal amplitude from 100mV up to 500mV and frequency ranging from 50 Hz up to 25 kHz.
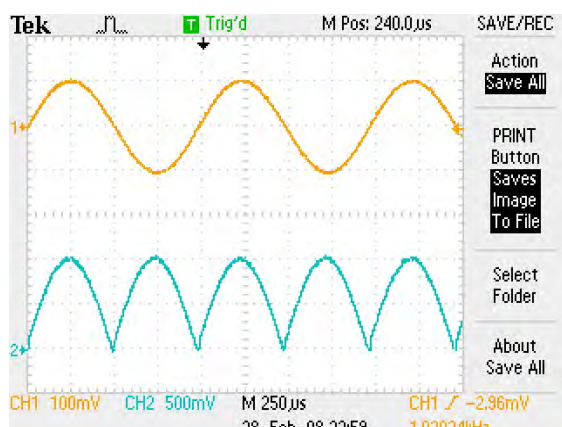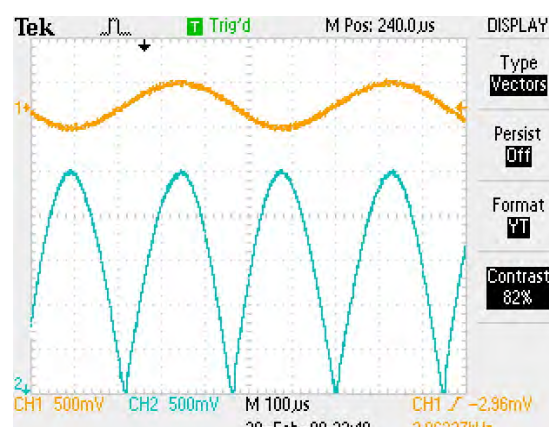

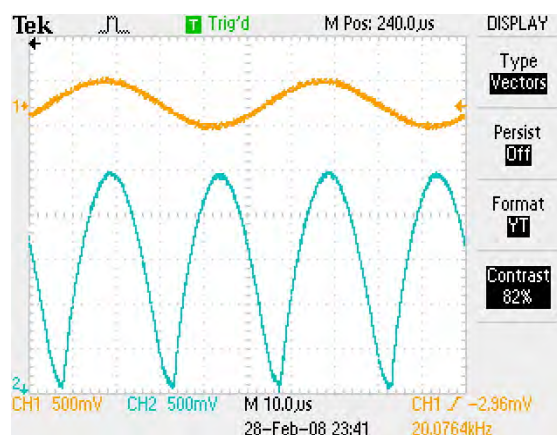Figure 5 - 100mV input at 1kHz

Figure 6 250mV input at 2kHz

Figure 7 250mV at 20kHz

Very low level signals

Signals as low as 10mV can also be precision rectified by the circuit. There are however some limitations that need to be addressed.

Figure 9 shows the circuit being tested with an input signal of only 10mV. One factor limiting performance 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 becomes additive to the rectified signal in one direction and subtractive to it in the other direction. The effect is seen in Figure 9 where alternate peaks are raised and lowered. It is a fairly harmless factor for two reasons. One, the net effect of this distortion on the average value of the signal is nil. Second, the effect is easily cancelled out by input offset trimming as shown in Figure 8. Figure 10 shows the much improved waveform after offset trimming.

Another limiting factor to the low input threshold is crossover distortion. This is introduced when the ZXCT1041 changes from conducting in one direction to conducting in the opposite direction. Two phenomena contribute to this distortion as next discussed. Effect of input offset voltage on crossover distortion

Effect of input offset voltage on crossover distortion

The first is the input offset voltage of the amplifiers within the ZXCT1041. 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, since the input offset voltage is quite small (of the order of 0.9mV to 5mV), the effect is largely indiscernible except at the very low input voltages such as is being considered in Figure 9.

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 datasheet 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) but less conspicuous at higher input voltages (higher than 100mV). Together, they impose a limit on the bandwidth that is achievable by the circuit. Although, the ZXCT1041, when operated in the unipolar mode with suitable DC bias, is capable of a bandwidth of 300kHz, the achievable bandwidth in this experiment has been limited to about 25kHz due to these outlined factors.
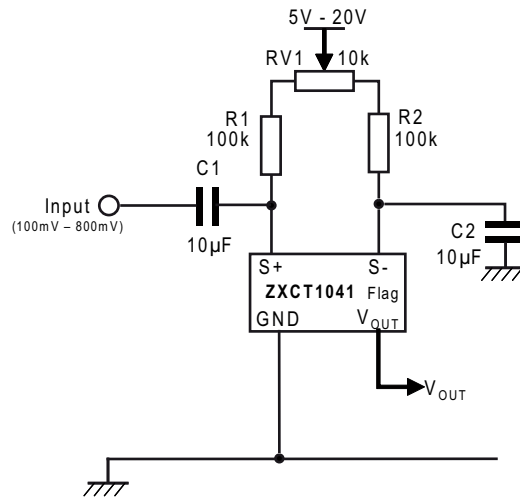
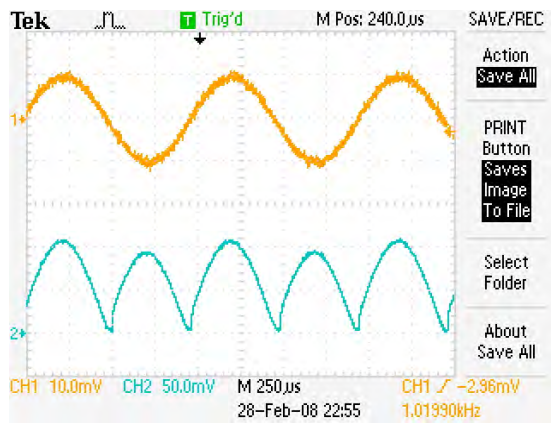Figure 8 - Compensating for input offset voltage effect
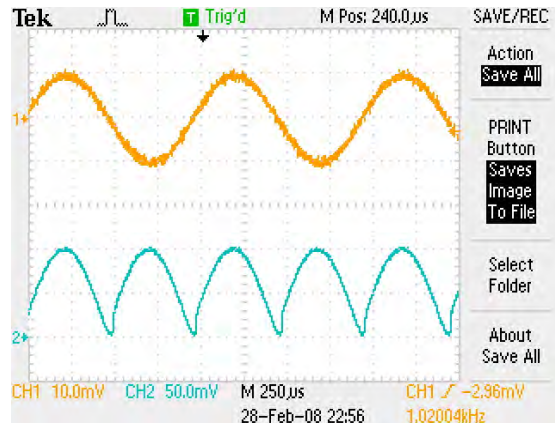

Figure 9 -10mV input at 1kHz - no offset trimming

Figure 10 -10mV input at 1kHz - with offset trimming

Conclusion

A precision full wave rectifier can be implemented using the ZXCT1041. It offers the advantage of a reduced component count over the conventional two op-amp methods.

It uses only two resistors and two capacitors and its performance is not adversely affected by the absolute values of any of these. A good match is still recommended for the two resistors as any mismatch translates to input offset and output offset voltages. However, for *very low level signals*, any mismatch does not generate an absolute error but a shift in relative amplitudes of each half of the signal.

Unlike the classic circuit that requires both a positive and negative supply, this one only uses a positive power supply.

Recommended further reading

1. AN39 - Current Measurement Applications Handbook.

2. Datasheet ZXCT1041

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