AN55

ZXCT1041 as a precision full wave rectifier (low component count)

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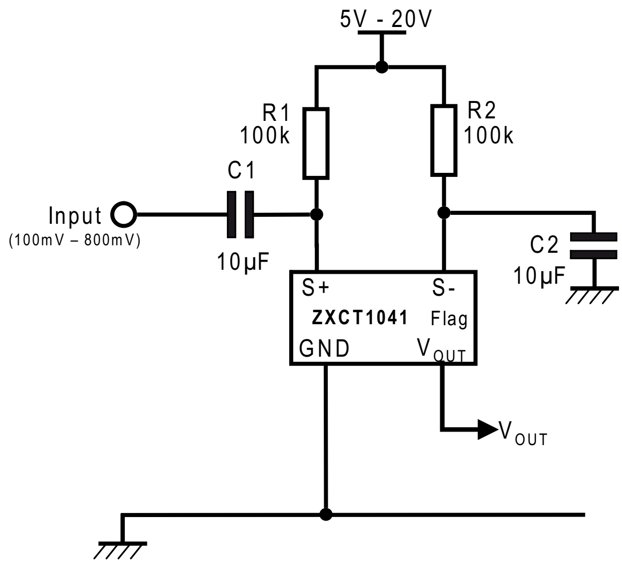

Figure 1 A very simple full wave precision recifier

Introduction

Precision rectification is a subject that has been around for a long time and has been covered in many articles and publications by several authors over the years. It is therefore not the intention of this applications note to provide a general coverage but to present an alternative method of achieving precision rectification which offers unique advantages.

The advantages of this proposed alternative is that it uses less number of components thus offering a significant saving on PCB real estate (at least 50%), reduced component value criticality and requiring only a single-ended power supply.

It is appropriate to briefly discuss the need for precision rectification and the problem with standard methods of implementing it.

Rectifying low level voltages

The requirement for a precision rectifier is not difficult to appreciate. With a diode having a forward voltage drop, V_F, of typically 0.6V, it is obvious that any signal that is not an order of magnitude larger than this will suffer major distortion. The problem is worse for full wave rectification where the signal must overcome two diode drops. Even with a voltage as large as 10V (going by signal standards), full wave rectifying it without significant distortion using only diodes will be an impossible task. At least 12% of the signal will be subject to severe distortion.

Quite often however, the signal to be rectified is far less than 1 volt and can be even 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

- Two op-amps
- At least one diode, and
- Anything from three to five resistors

Most precision full wave rectifiers are based on between seven and nine components (2 op-amps, 2 diodes and 3 to 5 resistors).

To better appreciate the advantages offered by this design based on the ZXCT1041, it is helpful to consider the classic precision full wave rectifier shown in Figure 2.

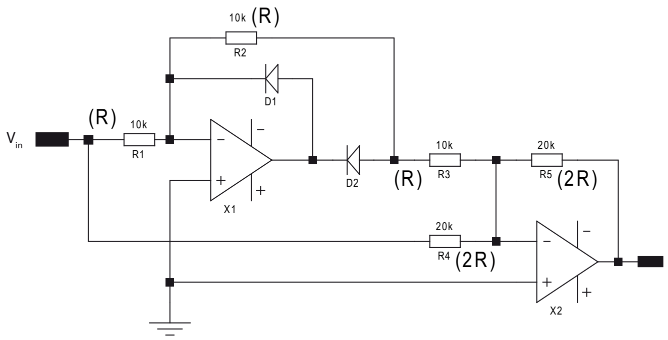

Figure 2 Classic precision full wave rectifier (9 components)

A quick inspection will show the following:
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 therefore inherent asymmetry in the transfer functions for the two halves of the signal and the circuit can only work qualitatively provided that

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

Or

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

It can be seen from Equation 4 above that 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 of these, which is the one shown in Figure 1, 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 to 2R[2]. This also gives a unity gain. The effect of R5 in both cases is to apply an overall gain to the circuit and 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 now be summarised as follows.

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

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

[2]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 to be less preferred.

Using the ZXCT1041

The alternative method (shown in Figure 3) 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 housed in a SOT23-5 package (refer to ZXCT1041 datasheet which may be downloaded from the Zetex web site at www.zetex.com). 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.

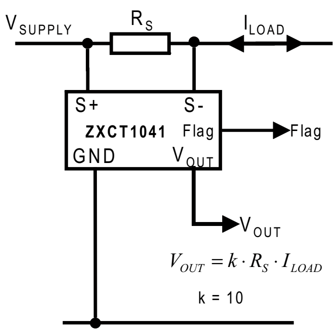

Figure 3 ZXCT1041 bi-directional current monitor - normal application

Circuit description

Using the ZXCT1041, the solution to the three problems highlighted earlier is surprisingly simple.

With reference to Figure 3, 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.

Testing

The circuit above was constructed and tested for performance. The graphs below (Figure 4 to Figure 9) show how very 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.

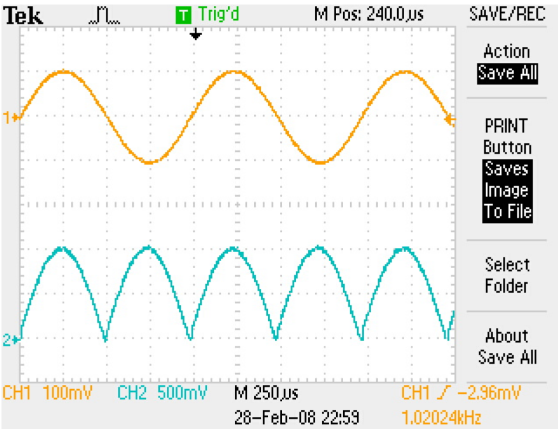

Figure 4 100mV input at 1kHz

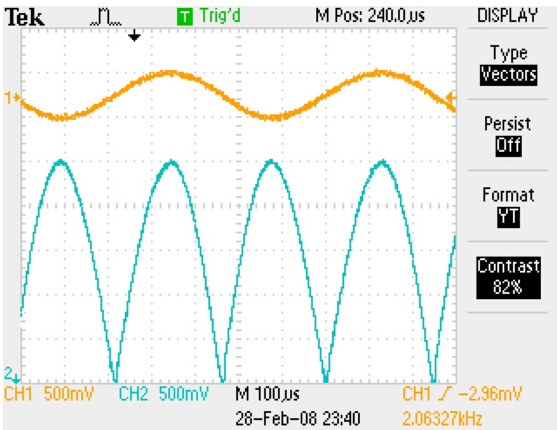

Figure 5 250mV input at 2kHz

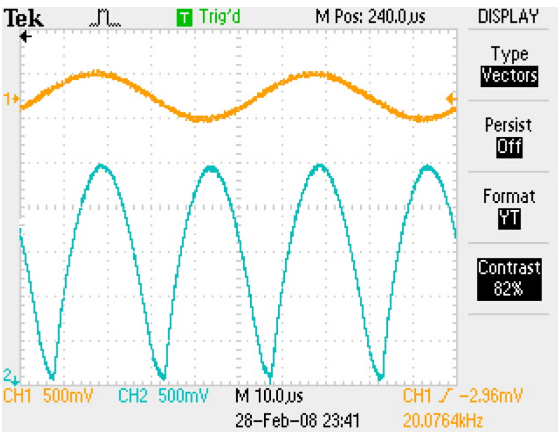

Figure 6 250mV at 20kHz

Very low level signals

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

Figure 8 shows the circuit being tested with an input signal of only 10mV. Two factors limiting performance are clearly visible. The less important of these factors is that of 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 clearly seen in Figure 8 where alternate peaks are elevated whilst alternate peaks are depressed. It is termed less important for two reasons. One, the net effect of this distortion on the average value of the signal is nil. Second, the effect is quite easily cancelled out by simple input offset trimming as shown in Figure 7. Figure 9 shows the much improved waveform after offset trimming.

The other limiting factor to the low input threshold is more difficult to counter. This is the crossover distortion which is introduced when the ZXCT1041 transits 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 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 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 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.

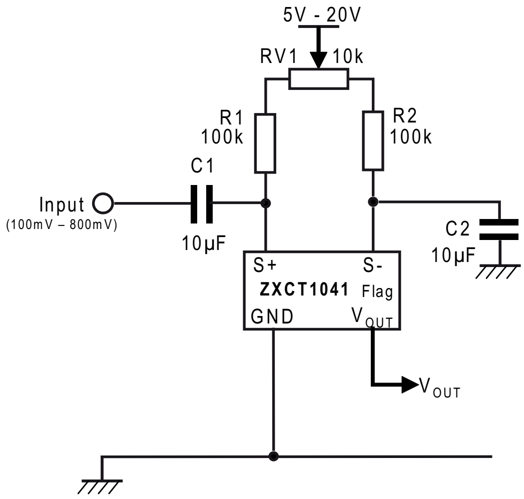

Figure 7 Compensating for input offset voltage effect

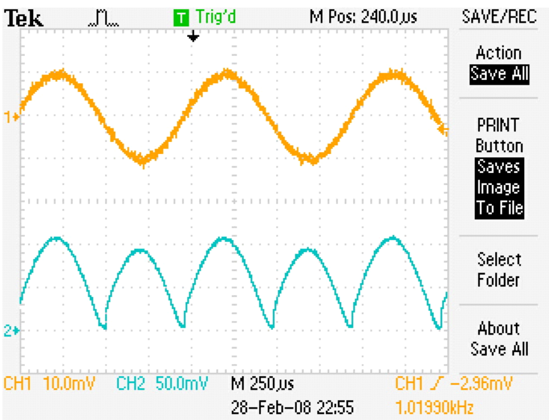

Figure 8 10mV input at 1kHz - no offset trimming

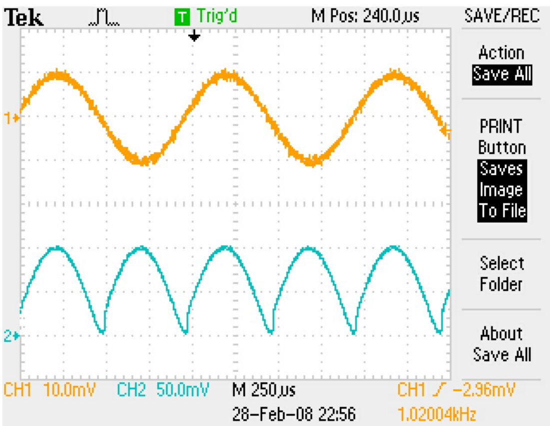

Figure 9 10mV input at 1kHz - with offset trimming

Conclusion

It has been demonstrated that a precision full wave rectifier can be implemented using the ZXCT1041. It offers the advantage of a reduced components count over the conventional two op-amp methods as only 5 components are required. The saving in PCB real estate is even greater because the single active element (ZXCT1041) is housed in a SOT23-5 package compared with the much bigger SO-8 package for a dual op-amp.

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, as said above (in paragraph "*Very low level signals*") any mismatch does not generate an absolute error but rather 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.

Lastly there is the added advantage that the proposed scheme offers an inherent ability to block DC components in the signal. If DC blocking is a requirement, the conventional method would require an additional capacitor to achieve this thus increasing the component count further. This circuit will, of course, not be usable if it is intended to also rectify DC signals unless it is used in a chopping scheme. 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.

Recommended further reading

1. AN39 - Current Measurement Applications Handbook.
2. Datasheet ZXCT1041

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