Pre-zero crossing detector improves automotive relay performance

Circuit anticipates transitions based on trajectory, allowing enhanced relay control and reliability

By John Bottrill, Texas Instruments

Relays are used to connect, or disconnect, ring generators to-and-from telephone lines. If the two points are at different potentials, there are high-current transients at the moment of contact. This results in arcing and pitting of the contacts which shortens a relay's life from contact failures and causes expensive repairs.

For these reasons, having the contact "make", or "break", at the moment of zero potential between the two points is desirable. However, relays can take a "long time" in terms of modern electronics to transition from the open-to-closed position or from the closed-to-open position. This paper discusses a method of developing a signal that will close, or open, a relay so that the contacts close, or open, when the ring generator's ring signal is at zero potential.

This discussion includes describing a circuit that provides a simple circuit delivering a pulse for both the negative- and positive-side zero crossing and anticipating the zero crossing by a fixed-time, or the time necessary for the relay to operate.

In a ring generator, the relay's finite operating time is a significant portion of the period of the incoming ring voltage. If switching at the desired voltage is to occur, it's important to have the pulse initiation take place at a defined time preceding the ring signal's desired voltage.

The principal of the circuit is simple. By connecting a capacitor and resistor in series with one end connected to the signal and the other to the ground, it is possible to have the current through the series combination lead the voltage. The phase shift will be a function of the two elements. For instance, a series-connected R/C circuit, where the R is 60 kΩs and the C is 200 nF, will have the current leading the voltage by 33.5 degrees.

Figure 1 below shows a simple R/C circuit and the relationship of the voltage and current through that simple R/C circuit. The current is leading relative to the voltage.

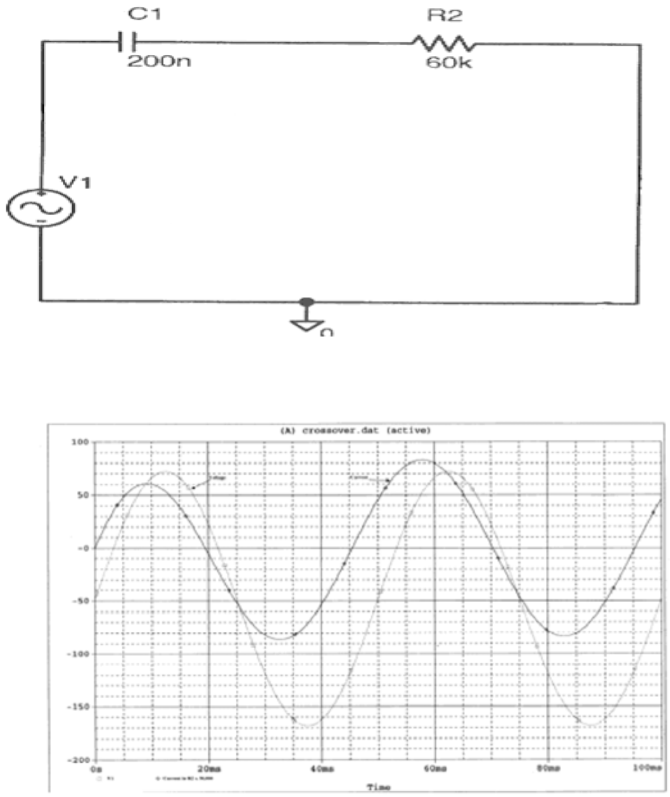

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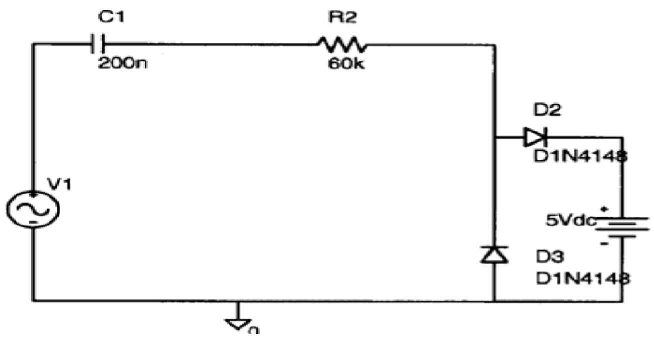
Figure 1: A simple circuit (upper) to generate a leading current and voltage signal and its waveforms (lower)

The sine wave that carries the ring voltage has a dc offset, so the positive-going crossing is at a different angle and slope than the negative-going crossing and neither is at the zero, or the 180-degree, point of the voltage's sine wave.

Because the capacitor blocks direct current (dc), the current waveform is symmetrical at zero while the voltage that has a -48 volt offset is symmetrical at the -48 volt level. However, the offset means that it is not symmetrical about the ground.

Figure 2 shows a method of generating a simple zero current-crossing detector.



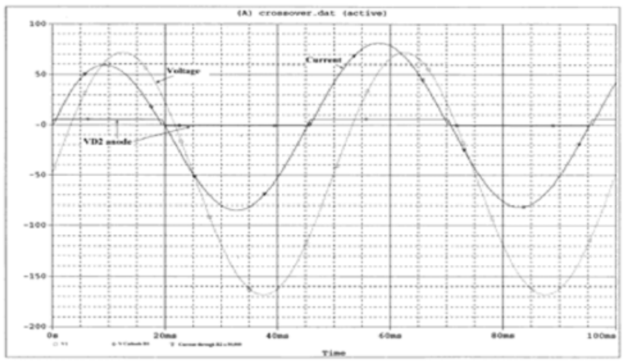


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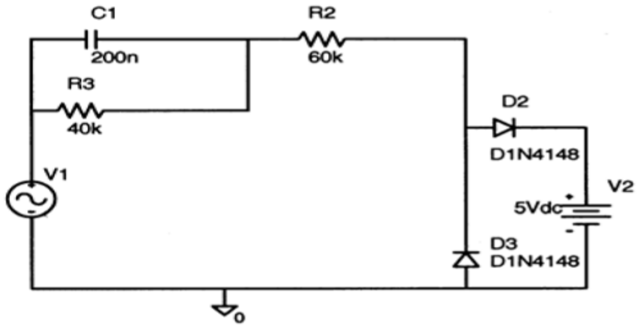
Figure 2: A simple zero-crossing detector (upper) and waveforms (lower)

With this detector and the current leading the voltage, it is possible to generate pulses (see Figure 7, below, for the pulse-generating circuit) prior to the voltage crossing zero.
In Figure 2, the voltage at the anode of D_2 (labeled V_{D2}) goes to one diode drop above five volts for current flowing out of R_2 into the junction with D_2. It then goes one diode drop below ground for current flowing into R_2 from the junction with D_3. This transition signifies a change in the current's polarity.

Deal with non-symmetry
However, as shown in Figure 2 the current is still symmetrical about zero. This results in the two current crossings not proceeding across the voltage crossings by the same amount. There are significant differences caused by the dc-offset of the voltage. These differences can be partially compensated for by the addition of a resistor across the capacitor C_1.

With the addition of a resistor across the capacitor C_1 (**Figure 3**), a dc-component is added to the current similar to that of the voltage which this gives an asymmetrical zero current-crossing.



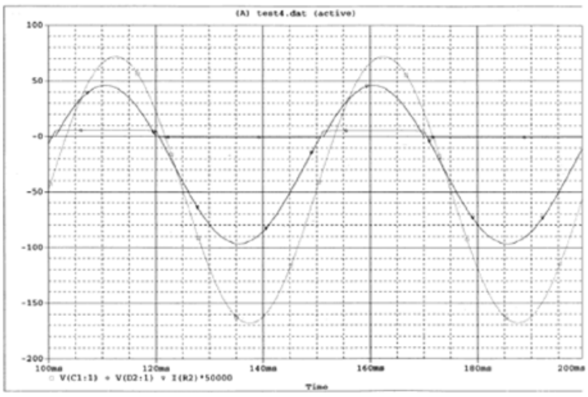


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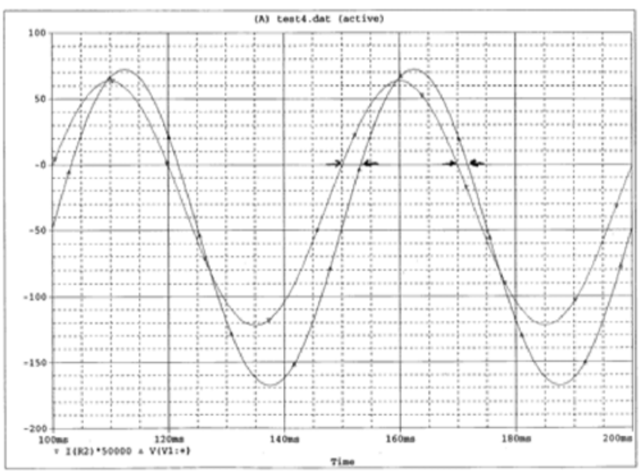
Figure 3: The effects of adding a resistor across the capacitor ; circuit (upper) and waveform (lower)

The current crossover detector voltage (V_{D2} anode) and the sinewave voltage trace are marked with arrows in **Figure 4** showing how close these two waveforms are to crossing the zero point, relative to each other.



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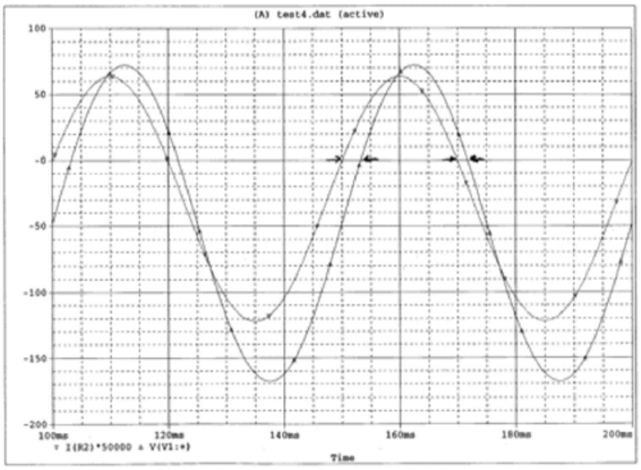

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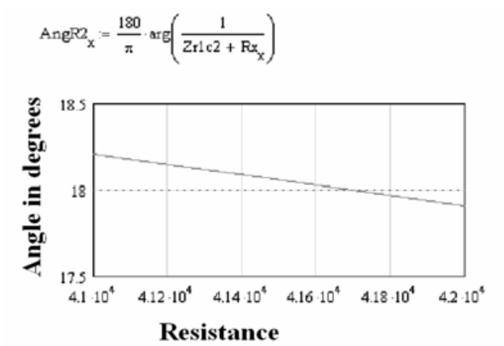
Figure 4: Waveform with R2 set at 41.7 kΩ (upper) and zoomed detail (lower)

Using this phase-shift and the dc-offset that the added resistor causes to the current trace, a lead factor can be programmed into the current so that the current crosses zero at a point prior to the voltage crossing zero in nearly the same amount of time. The relay requires that the coil be energized approximately 2.5 millisecond (msec) prior to the relay's closing.

A time of 2.5 millisecond is the equivalent of an 18-degree angle, for a 20-Hz signal. Using Mathcad and solving the equation for the inverse angle of the impedance where R_2 is allowed to vary results in:



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Graph 1: Angle equation and graph of equation results

From this equation and **Graph 1**, the value of R_2 can be set to 41.7 kΩ.
Unfortunately, the zero crossing of the down slope and the up slope are still not the same pre-determined time, as shown by the arrows in Figure 4 above. Neither meets the requirement as the time from the

current zero crossing to the voltage zero crossing is greater than needed for the upslope and the reverse for the downslope.

By increasing R_2 to 60 kΩ, the upslope time meets the requirement of about 2.5 msec prior to the voltage crossing but the downslope is only about one msec. In the remaining 1.5 msec, the voltage would have dropped by 20 volts, causing a significant voltage to be present at the time the contacts of the relay either “opened” or “closed”, **Figure 5**.

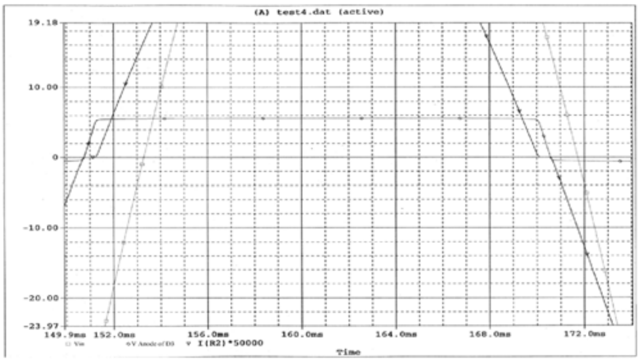

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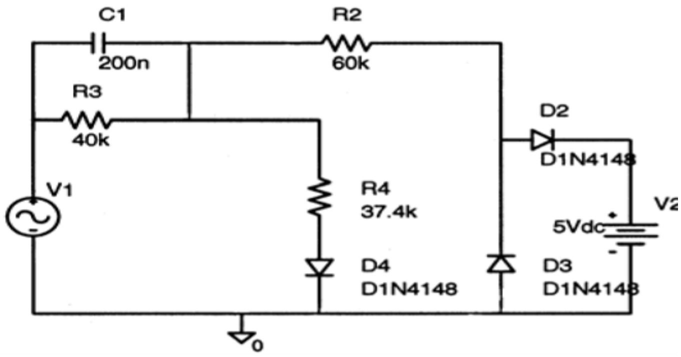
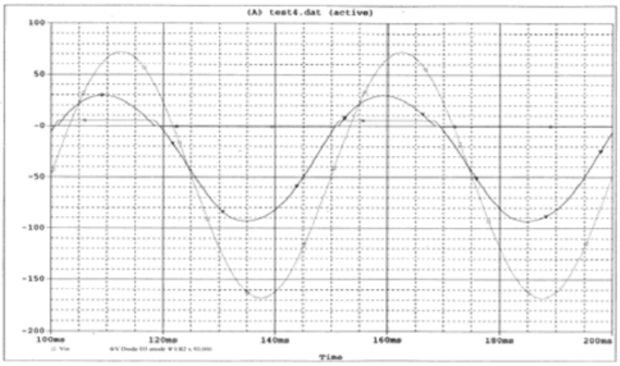
Figure 5: The voltage and current at the cross-over for the circuit in Figure 3.

If there is an additional resistor and diode added from the capacitor to ground (D_4 and R_4 in **Figure 6**), it will affect only one polarity of the current.





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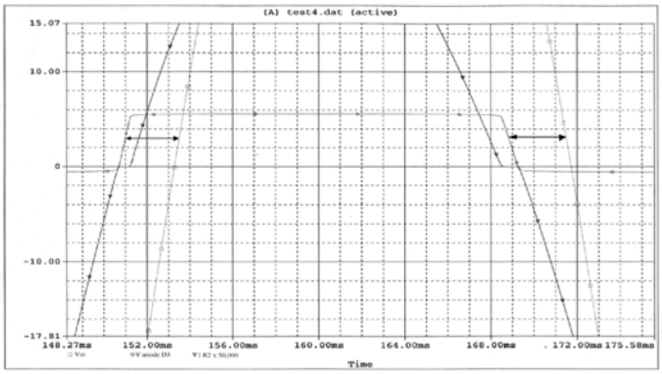

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Figure 6: Final circuit (upper) and resultant waveforms (middle); expanded part of waveform showing both transitions (lower)

With the configuration shown, the change in timing of the positive current is the only parameter that is being affected by the new components.

Putting it all together

Using this complete circuit and the zero-current detector, it is possible to generate a pulse that indicates a pre-determined time ahead of the voltage crossings. At this point, the relay was "triggered" to close at the time of the zero-voltage crossing.

As can be seen from Figure 6, the detector pulse for both the positive-and-negative crossing precedes the actual crossing by approximately the same amount. This addition allowed the use of the same circuit shown in **Figure 7** for detecting both the positive and negative pre-crossover points.

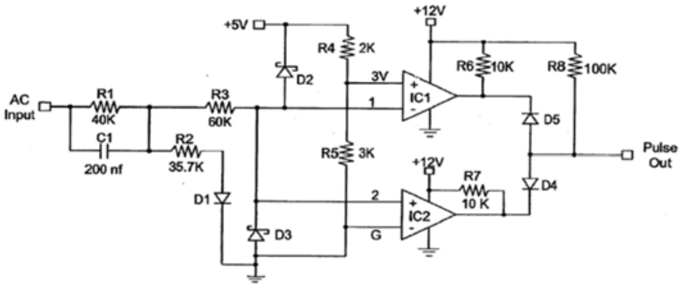

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Figure 7: Pre-crossover detector and pulse-generator schematic

This pulse also allowed the circuit to trigger the relay so that the contacts closed at the zero-voltage crossing. The results: longer contact life and higher product reliability.

The circuit was built and tested with a UCC3570 ring generator controller (**Figure 8**) generating the “ring” signal.

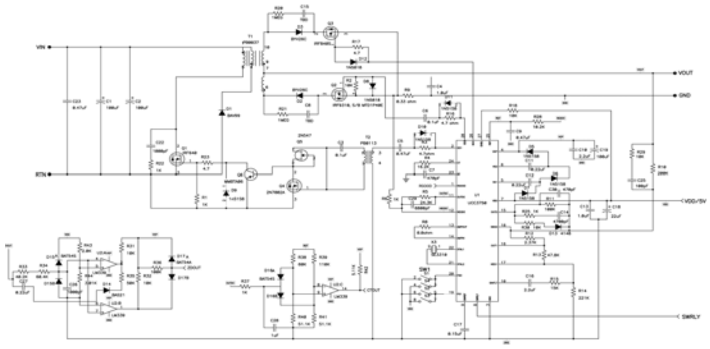

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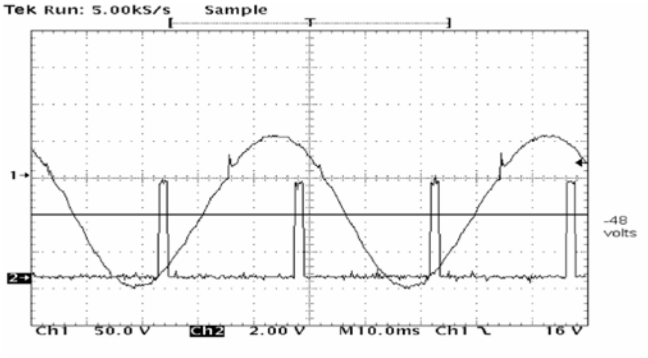
Figure 8: UCC3570 evaluation model with pre-zero crossing detector

Those results are shown in the scope waveforms (**Figure 9a**).



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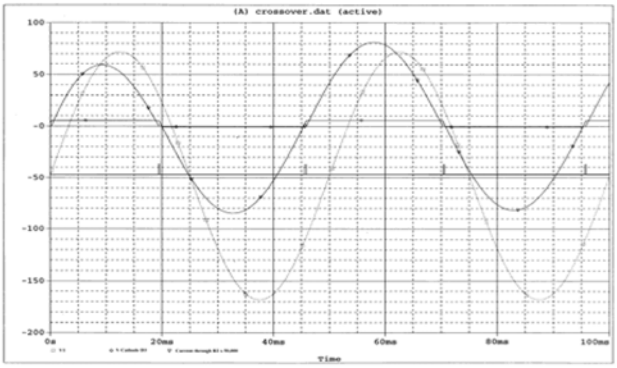

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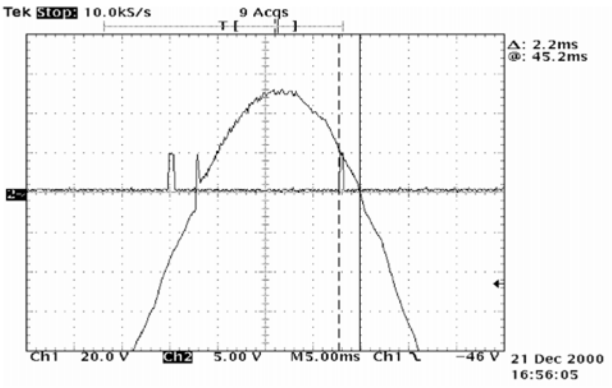
Figure 9: Measured results (upper) compared to simulated results (lower) for the circuit in Figures 6 and 8

The test used the circuit from Figure 8 to generate zero-current crossing pulses. There was good correspondence between the simulated results and the actual measured results as can be seen below in Figure 9 which shows measured against simulated.

In **Figure 10**, both the measured and calculated results are shown for comparison purposes.



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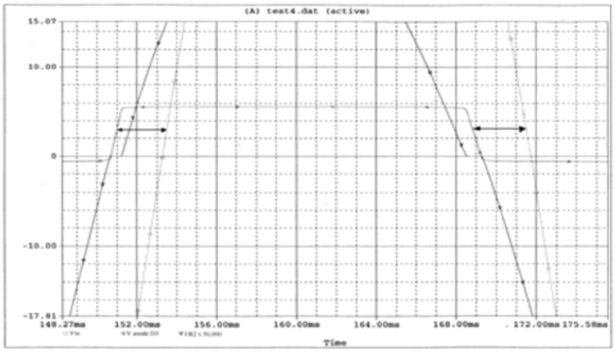

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Figure 10: Measured results (upper) versus calculated results (lower) for the circuit of figure 7

The scaling is increased so that measurements could be taken. The current transition, and hence the trigger pulse, occurs approximately 2.5 ms before the actual voltage zero voltage crossover.

Conclusion

This circuit provides a programmable anticipation of the zero-voltage crossing of the voltage waveform. By anticipating when the zero crossing will occur and starting the relay's action early to take the time of operation into account, the relay closure can occur at the zero-voltage crossing. This results in the contacts being protected from damage due to arcing and increases the life of the relay thus reducing the maintenance cost and increasing the total unit's MTBF (Mean Time Between Failure).

About the author

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