# Compact, Efficient Drive Circuit for a Piezoelectric Pump

## Piezoelectric actuators are charged in a time much shorter than the pump cycle.

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Figure 1 depicts a switching circuit that drives a piezoelectric pump at a high voltage with a polarity that alternates at the desired mechanical pump frequency. This circuit offers advantages of (1) high energy efficiency relative to conventional direct-drive circuits and (2) compactness relative to conventional resonant drive circuits.

Conventional direct-drive circuits are inefficient because the piezoelectric actuators in the pump behave electrically as large capacitors and consume only a small part of the energy supplied to them during each pump cycle. Conventional resonant drive circuits are more efficient, but they must include inductive coils, which can be unacceptably large.

The present switching drive circuit includes inductive coils, but they are small and not used to resonate the actuator capacitance; instead, the charging of the actuator capacitances and the exchanges of energy among inductive and capacitive circuit elements are accomplished (by design) in times much shorter than the mechanical pump cycle. In other words, this drive circuit rapidly charges the actuator capacitance and turns itself off until the actuators reach their maximum mechanical expansion or contraction. Some time after the actuators reach their maximum mechanical expansion or contraction, the circuit turns itself back on to charge the actuator capacitance in the opposite polarity; as it does so, it replenishes the energy lost since the previous charge.

When power is first turned on, the capacitance of the piezoelectric actuators (C2 in Figure 1) is first charged to a potential of +450 V via transistor Q2. The charging current and, hence, charging time are determined by the characteristics of the dc-to-dc converter and the characteristics of the piezoelectric films. Inductor L1 is used to reduce the initial current spike during each recharge cycle, and C1 is used to stabilize the output voltage of the converter as well as reduce the peak output current demand on the dc-to-dc converter. Inductor L2 is the main energy-storage inductor; it is used to exchange energy with C2 for switching polarity, as described in more detail below.

The timing signals that govern the operation of this circuit are transistor/ transistor-logic (TTL)-level pulses with a duration of 5 ms and a repetition frequency equal to the desired pump frequency (20 Hz in the original design). The short pulse duration is necessary in order to enable the triac (Q2) to turn itself off when the current in inductor L2 reaches zero. The timing signal is generated by timing/control oscillator U6, which supplies

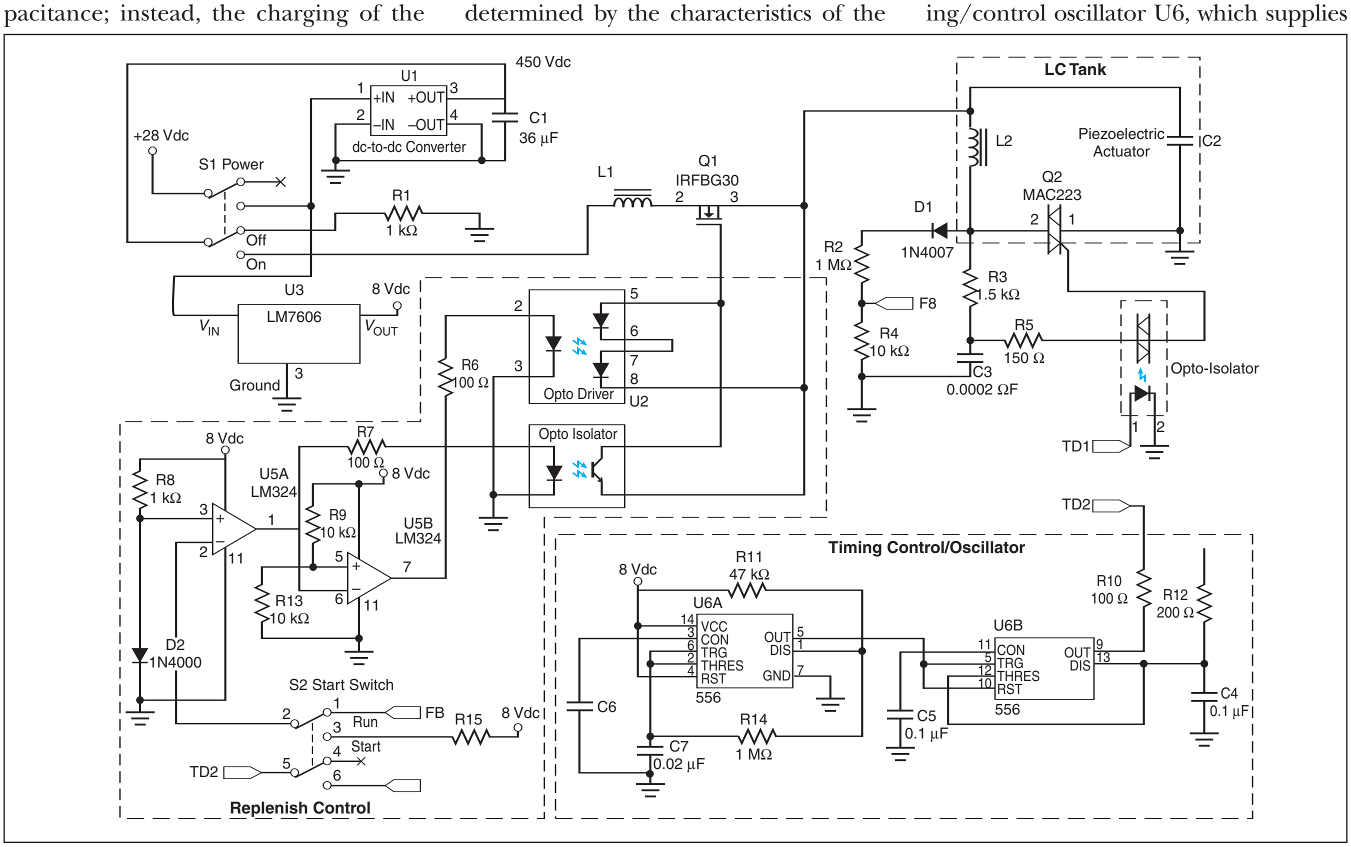


Figure 1. This **Circuit Operates at High Efficiency** in driving a piezoelectric pump at a frequency of 20 Hz. High efficiency is achieved by use of nonresonating inductor L2 to recycle the charge on the piezoelectric-actuator capacitance C2.

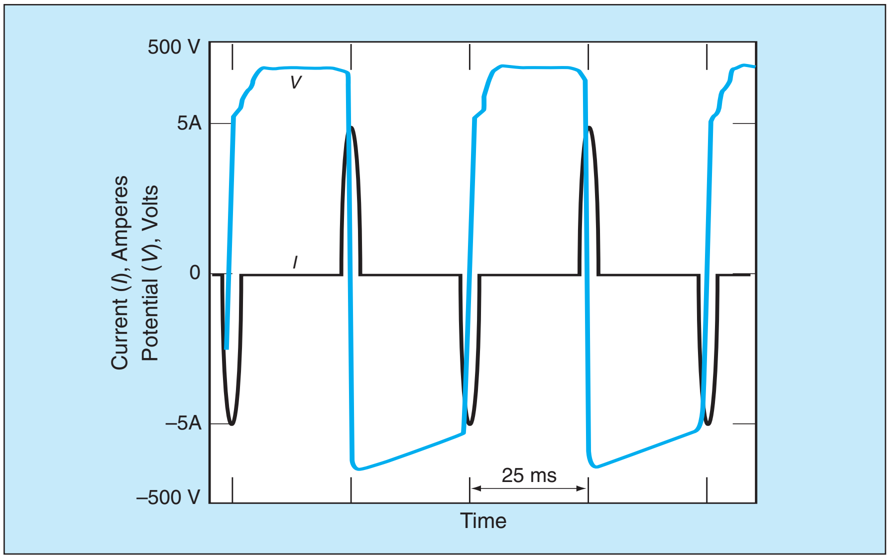


Figure 2. These **Voltage and Current Waveforms** occur at the terminals of the piezoelectric actuators.

timing drive current to opto-isolator U4, which, in turn, provides the switch-on signal for the triac gate.

Figure 2 illustrates the voltage and current waveforms at the terminals of the piezoelectric actuators. Suppose that C2 has been initially charged. At the beginning of the first half cycle, when a timing pulse occurs, the triac is turned on and current begins to flow from C2 through the triac and L2. When the magnitude of the current increases above the minimum hold current, the triac becomes latched on. The triac then continues to conduct until the current drops below the minimum hold current, which is essentially zero for the purpose of this application. The minimum hold current is reached and the triac turns off when the voltage on C2 reaches a negative peak near –450 V. The reversal of polarity is provided by L2. The precise magnitude of the peak reverse voltage is slightly less than |450 V| by an amount that depends on the energy lost in the various exchanges of energy involved in the reversal of polarity. While the triac remains off, C2 remains in its negatively charged state, in which only parasitic dielectric losses slowly reduce the magnitude of the voltage on C2.

At the beginning of the second half cycle, when the next timing pulse arrives, the process described in the preceding paragraph is repeated, except that the currents and voltages applied to C2 are reversed. Again, the difference between |450 V| and the magnitude of the peak voltage depends on the energy lost.

If the operation as described thus far were allowed to continue, the voltages would continue to decay and operation would halt after a number of cycles. To enable continuous operation, it is necessary to replenish the energy lost. This is accomplished as follows: After the completion of the polarity reversal of the second half cycle and before the arrival of the next timing pulse, the replenish-control subcircuit senses the triac cutoff and turns on Q1 to recharge C2 to 450 V. At the chosen 20-Hz pump frequency, the triac-off time is long enough to enable C2 to be recharged to 450 V by use of relatively low charging current, provided that the energy lost is relatively low.

Because recharging is done only during the positive half cycle, a dc offset is induced in C2; however, this offset is typically a small fraction of the peak drive voltage and does not adversely affect the operation of the piezoelectric actuators. The advantage of recharging only during positive half cycle is that the circuit can be less complex and contain fewer components than would be needed for recharging during both half cycles.

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*Title to this invention has been waived under the provisions of the National Aeronautics and Space Act {42 U.S.C. 2457(f)} to Oceaneering Space Systems. Inquiries concerning licenses for its commercial development should be addressed to:*

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# Dual Common Planes for Time Multiplexing of Dual-Color QWIPs

## With external control, commercial single-color readout integrated circuits could be used.

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A proposed improved method of externally controlled time multiplexing of the readouts of focal-plane arrays of pairs of stacked quantum-well infrared photodetectors (QWIPs) that operate in different wavelength bands is based on a dual-detector-common-plane circuit configuration. The method would be implemented in a QWIP integrated-circuit chip hybridized with a readout integrated-circuit (ROIC) chip.

There are alternative methods of multicolor readout, but they involve more on-chip circuitry and the attendant disadvantages of greater size, power dissipation, number of control signals, and complexity of circuitry on the QWIP and ROIC chips. To minimize size of, and power dissipation in, a multicolor pixel, one must minimize the number of transistors and control signals; this can be achieved only by time multiplexing of colors in each pixel. The time multiplexing can be controlled by signals from external or internal circuitry. The proposed reliance on external control for time multiplexing would make it possible to use a commercial single-color ROIC with only minor modifications in the form of extra metallization for an additional detector common plane and for clocking bias potentials. (If, instead, one were to rely on internally controlled