

An ultra-low noise, high-voltage piezo driver

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We present an ultra-low noise, high voltage driver suited for use with piezoelectric actuators and other low-current applications. The architecture leverages a commercially available, small-form-factor integrated circuit (IC) for generating high voltage outputs. The IC uses a flyback configuration switching regulator to generate up to 250V in our design (but up to 1kV or more with small modification), and a high slew-rate op-amp capacitively coupled to the output compensates for the switching noise. A low-voltage (± 10 V), high bandwidth modulation input is capable of summing small voltage corrections onto the output, making the driver well suited for use in closed-loop feedback applications.

I. INTRODUCTION

Many instrumentation applications in the modern laboratory require agile, low-noise voltage sources that can supply hundreds of volts or more. Such high-voltage amplifiers are useful for micro-positioning applications, driving piezo-actuated mirrors (e.g., in a scanning Fabry-Perot cavity) or diffraction gratings (such as in extended-cavity diode lasers). Precision high voltage sources can also be used to bias low-noise, high-bandwidth photodiodes [details?], Other applications...? biophysics? medical devices? Often, these applications are operated in a closed feedback loop, where small voltage changes on top of a large DC voltage are necessary to correct for some disturbance to the system.

Traditionally, laboratory electronics capable of supplying high voltages fall under one of two architectural umbrellas: switching converters, and “linear” amplifiers. DC-DC converters are efficient and can work at very high voltages, but suffer from switching noise and limited control bandwidths. Linear-type devices are typically constructed from a high-voltage operational amplifier (op-amp), powered either from a high voltage linear regulator or more typically from a secondary switching converter. While the op-amp provides 100 dB or more of power-supply noise rejection, a high-voltage op-amp require substantially more power than an equivalent switching circuit. In either case, the output voltage V_{out} is typically given by

$$V_{\text{out}} = G_p(V_{\text{DC}} + V_{\text{mod}}), \quad (1)$$

where G_p is the piezo amplifier gain (typically $G_p \approx 10 - 20$ or more), V_{DC} is a DC setpoint, and V_{mod} is a modulation input used for closed-loop control.

It is often the case, however, that in closed-loop feedback applications we do not need and often do not want the modulation control to have a high gain. Because the closed loop gain cannot be increased without limit, $G_p V_{\text{mod}} \gg 1$ means the servo gain G must be proportionally smaller to keep the lock stable. Because noise

added by the servo is suppressed by $1/|G|$ in the large gain limit, if G is limited to achieve a stable lock it is no longer as effective at servoing its own noise.

To avoid this problem, we desire a high voltage amplifier which separates the “setpoint” gain G_p from the modulation gain, G_m . That is,

$$V_{\text{out}} = G_p V_{\text{DC}} + G_m V_{\text{mod}}, \quad (2)$$

where now we can make $G_m \approx 1$.

II. CIRCUIT DESIGN

The design is based on the newly-available Texas Instruments DRV2700 piezo driver.¹ This single-chip integrated circuit (IC) can be operated as a boost converter to drive an on-chip differential amplifier up to 100 V, or as a flyback converter up to 1 kV. In flyback configuration, the internal-boost switch of the DRV2700 drives a step-up transformer. When the switch is closed, current flows through the primary coil of the transformer and induces a corresponding voltage across the secondary coil, which charges a capacitor at the output (C_{HV} in Fig. 1). When the switch opens, a negative voltage appears across the secondary coil of the transformer, but a diode prevents the capacitor from discharging. One key benefit of this topology is the galvanically isolated output. By sensing the output voltage across a resistive divider, we servo the floating ground from the flyback converter to remove switching noise and stabilize the high voltage output; see Fig. 1.

In isolation, the DRV2700 is not suited for low-noise laboratory instrumentation. The output ripple, even after heavy filtering, can be as high as a few volts, and standard filtering techniques to reduce this noise simultaneously reduces the modulation control bandwidth. Even if this were not the case, it remains unlikely that the RMS noise could be brought below 1 mV, which is the operating regime we require for certain low-noise applications in the laboratory. Despite this drawback, the flyback converter requires very little current to operate and leverages a compact IC to generate very high voltages, making it versatile and easy to deploy in the lab.

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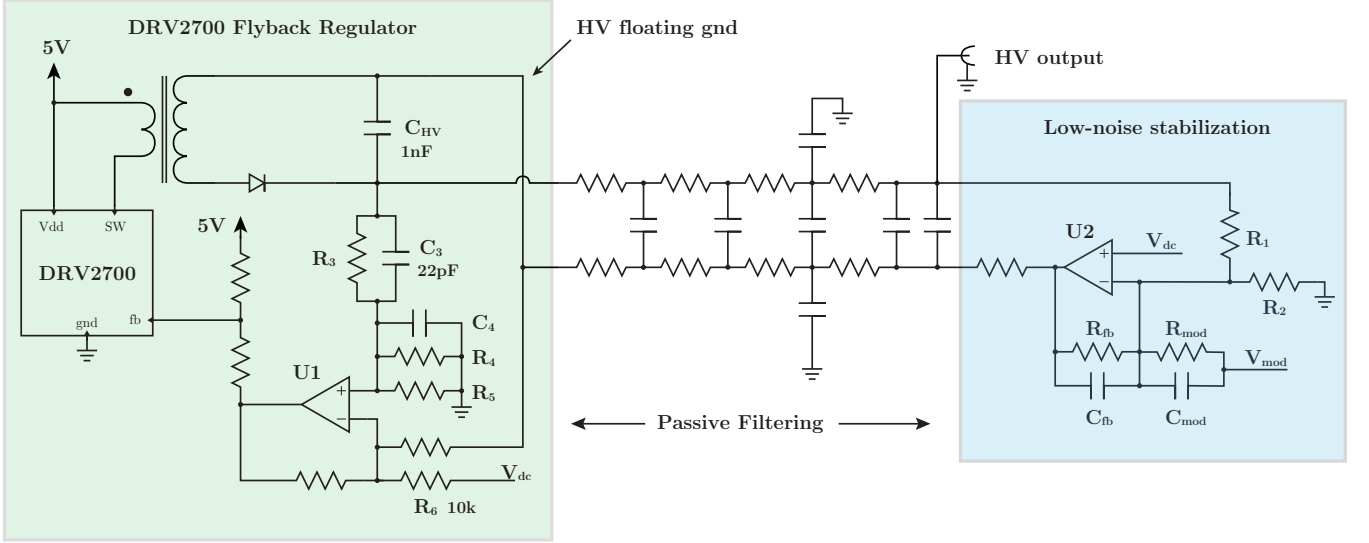


FIG. 1. Schematic of the high voltage stabilization. The voltage HV is generated using a Texas Instruments DRV2700 high voltage driver in flyback configuration (see Fig. ??). A fast, very high slew-rate op-amp senses the output voltage across R_1 and R_2 , and servos it by modulating the node at “HV floating gnd”. The V_{DC} gain is set by $(1 + R_1/R_2)$, while the modulation gain is set by $-R_{mod}/R_{fb}$. The capacitor linking the floating ground node to the output allows the op-amp to remove residual switching noise and stabilize the DC output according to the transfer function given in Eq. (2).

The motivation behind our hybrid architecture is twofold. First, to make a switching converter useful for low-noise laboratory instrumentation, we need a way to remove the output ripple and residual switching noise. Second, we want to take advantage of low-noise op-amps that only work up to tens of volts to provide a unity gain (DC-coupled) feedback path to the high voltage output. The architecture shown in Fig. 1 does just this; a low-noise, high-slew rate op-amp (U2) adjusts the floating ground node of the transformer output to cancel switching noise and sum in an offset given by V_{mod} , while the flyback regulator works close to DC to impose the high voltage across the HV - floating ground output. We now explain the operation of each sub-block, and draw attention to important design details.

IV. CONCLUSION

A. DRV2700 flyback regulator

B. Low-noise stabilization

C. Digital control and auxiliary design features

III. RESULTS

Noise analysis, bandwidth, (DC) stability, etc.

¹The identification of commercial products is for information only and does not imply recommendation or endorsement by the National Institute of Standards and Technology.