High-performance amplifier for stick-slip piezoelectric motors

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Abstract

The paper presents a low-cost amplifier circuit specifically designed for driving piezoceramic actuators. The amplifier has been integrated as a complete driver supporting the operation of piezoelectric motors in stick-slip mode, and the synchronized or unsynchronized supply to 4 piezoelectric actuators based on programmable waveform.

1 Introduction

Recent developments in the field of micro and nanotechnology demand positioning systems with distinct features such as precision (in the order of 1 nm), extended range (several centimetres) and speed (several mm/s).

In order to meet these needs, stick-slip, inch-worm and ultrasonic piezoelectric motors have been developed and successfully applied to micro positioners, medical equipment and miniature robotics. Piezoelectric motors offer potentially unlimited positioning range while allowing nanometer resolution.

Such actuators require a driver composed of a signal generator and a power amplifier with sufficient bandwidth able to drive capacitive loads with signals varying over hundreds of volts.

This paper presents a high-performance amplifier and its integration as a complete driver for piezoelectric motors.

2 The amplifier

The amplification stage is based on a class AB amplifier as shown in Figure 1. It consists of a circuit using 6 bipolar transistors. This choice allows a lower consumption (η=0.78) and a maximal voltage (85% of the bias) greater than with other possible configurations.

In the design, a critical step is the choice of the two transistors of the final stage. The transistors need a small transconductance and a little depletion region in the p-n junction and thus a small parasitic capacitance. In order to satisfy these requirements, bipolar pnp-npn fast switching transistors BUL3N7 and BUL3P5 supplied by STMicroelectronics [1] were chosen.

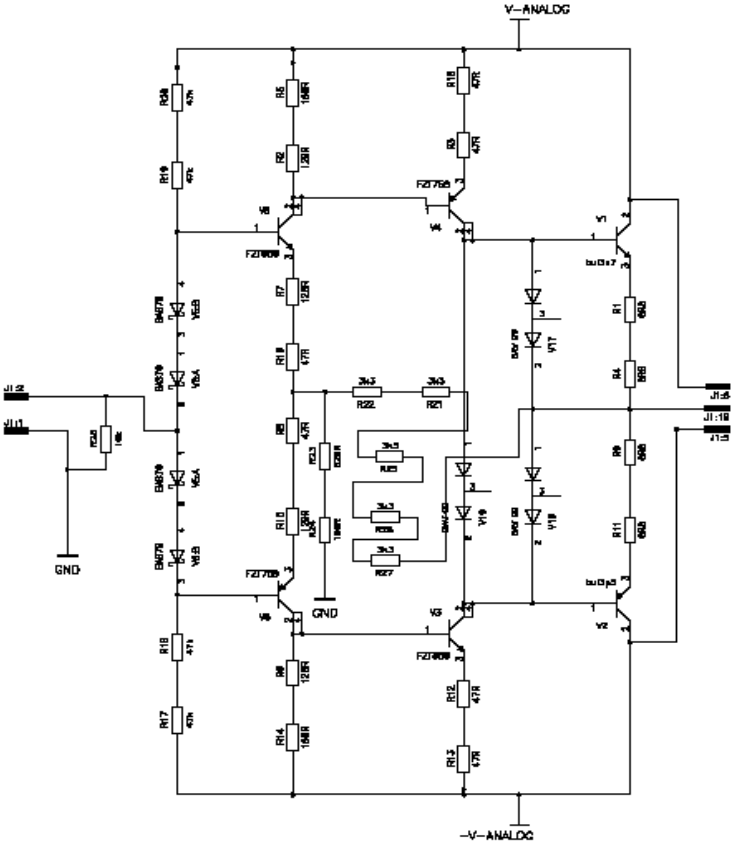

Figure 1: Schematic circuit of the operational amplifier

Commercial amplifiers (i.e. MSK130 manufactured by M.S.Kennedy corp.) are equipped with a final stage composed of field effect transistors (FET), but this solution is not ideal for driving capacitive loads because the channel of the FET creates an additional output capacity.

In order to carry the highest possible load or to obtain the highest possible actuator force for stick-slip piezoactuators, the amplifier design was optimized by maximizing the voltage slew-rate. For capacitive loads of up to 4 nF, the achieved voltage slew-rate was found to be 150 V/µs over a range of almost 400 V. Only low-cost off-the-shelf components were used.

The resulting Bode diagrams for different loads are presented in Figure 2. They show a cut-off frequency of 300 kHz.

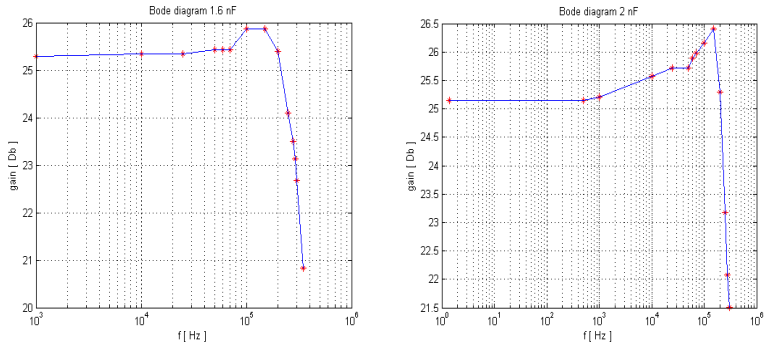

Figure 2: Bode diagrams of the amplifier with a capacitive load of 1.5 nF (left) and 2 nF (right)

Figure 3 shows a comparison between the commercial amplifier MSK130 ([2], price greater than 100 €) and the new amplifier presented here. It is noted that:

- The slew rate (10%-90%) is 150 V/µs for the MSK130 vs. a slew rate of 200 V/µs for the amplifier presented here using a sawtooth signal at 25 kHz

- An achievable voltage range of [-150 V, 150V] for the MSK130 vs. a voltage range of [-200 V, 200 V] for the amplifier presented here.

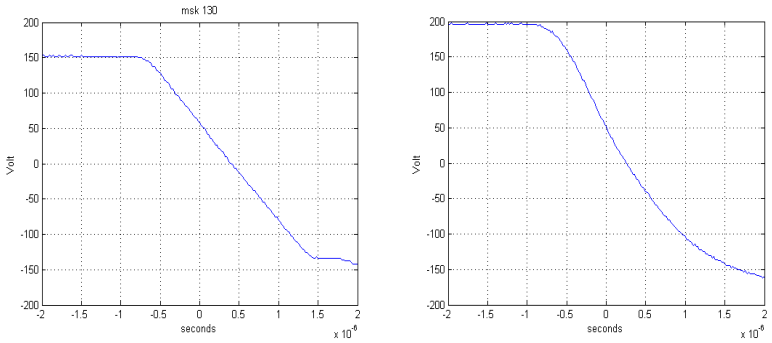

Figure 3: Step response of the new amplifier (right) and a commercial amplifier (left). Both amplifiers are subject to a load of 2nF.

3 A flexible driver

Based on the amplifier, a 4-channel piezoelectric motor driver with multiple-mode operation was developed for the Swiss Federal Institute of Technology in Lausanne (EPFL). The driver supports the operation of piezoelectric motors in stick-slip mode, and the synchronized or unsynchronized supply to 4 piezoelectric actuators based on programmable waveforms. The driver was tested on a 3 degree-of-freedom manipulator with a speed of several mm/s and nanometer resolution.

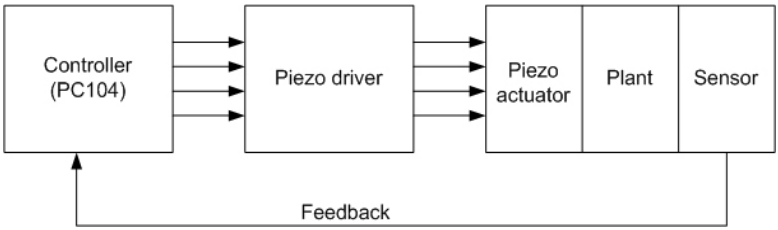

Figure 4: Driver in a typical closed-loop configuration.

The driver can be easily integrated into commercial positioning control systems and used in a configuration like the one shown in Figure 4.

The driver can be parametrized to operate according to different modes which are selectable through external jumpers.

- Generation of sawtooth voltage (±200V) with a logarithmic spaced frequency range from 1 Hz to 25kHz. The frequency depends on an external analog input signal for each channel.
- Generation of 4 sinusoidal voltages, each with 90° shift at a frequency determined by an external analog input signal
- Amplification by a factor of 25 of an external analog input signal for each single channel.
- Other special modes which depend on thresholds of the analog input signals.

With specific software code and the addition of a simple interface, the driver can be used as an autonomous motion controller for precision positioning systems.

4 Conclusions

The presented low-cost, high-bandwidth amplifier is particularly suited for driving capacitive loads such as piezoelectric motors and outperforms general purpose commercially available drivers.
Integrated as a complete driver it offers great flexibility as it supports the operation of piezoelectric motors in stick-slip mode, and the synchronized or unsynchronized supply to 4 piezoelectric actuators based on programmable waveforms.

References:

[1] ST Microelectronics, www.st.com
[2] M.S.Kennedy corp., www.mskennedy.com