Control and Excitation of Ultrasonic Motors Using a Test-Bench

Introduction

The movement of ultrasonic motors is based on the transfer of vibration energy from a mechanical resonator to a suitably guided surface over frictional contact, Fig. 1.

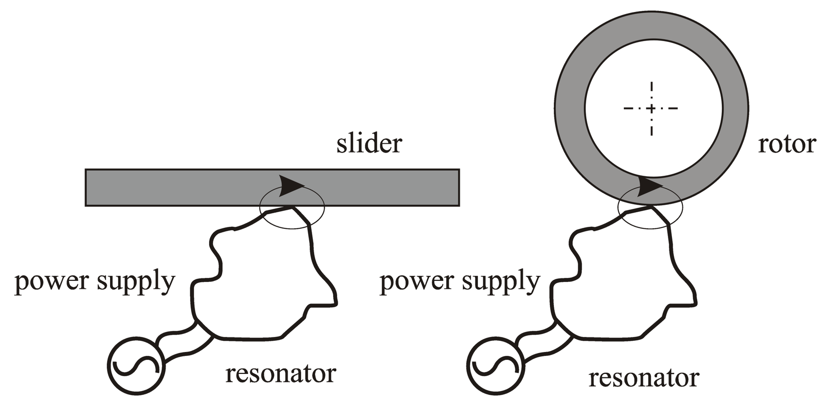

Fig. 1: Stator Vibrator

The vibration is excited at frequencies in the ultrasonic range (>20 kHz) using the inverse piezoelectric effect (1) that describes the generation of mechanical strain S from a mechanical stress T and an applied electric field E. The effect is reversible (2) and can be used equally to generate dielectric displacement D and electrical energy from mechanical stress.

$$S = s_E \cdot T + d^t \cdot E \quad (1)$$

$$D = d \cdot T + \varepsilon_T \cdot E \quad (2)$$

Ultrasonic motors operate silently due to their high excitation frequency and show some special characteristics that in certain cases offer advantages over conventional actuators, e.g. a high holding force in the power off state.

Driving Ultrasonic Motors

Piezoelectric resonators can be driven with amplifiers or with switched inverters using output filters and transformers.

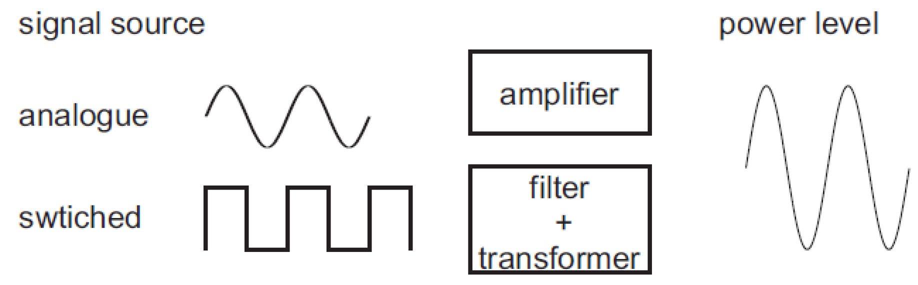

Fig. 2: supply options

The availability of amplifiers for piezoelectric loads, however, is limited and they usually operate from a source signal generated with function generators with slow interfaces. A versatile workstation must be faster in order to implement motion control and must be capable to drive single and multiple phase resonators. For lab use, controller boards as offered from dSPACE, are a suitable approach. However, due to the high frequencies the board-based generation of excitation signals is excluded, and it is necessary to design circuits that generate the excitation signals and connect to dSPACEto be able to use the board .

Control System Design

The design goal is to build electronic circuits with a fast dSPACE interface. In the first step a function generator for amplifier control and in the second step a switched inverter for direct excitation is built. Fig. 3 shows the underlying system design. The DS1103 sends variables to a 16 bit microcontroller using an 8 bit wide parallel interface. The workload is shared between the DS1103 processor and the microcontroller, a PIC24. The DS1103 computes the actuating variables while the PIC24 controls the output according to the transferred data.

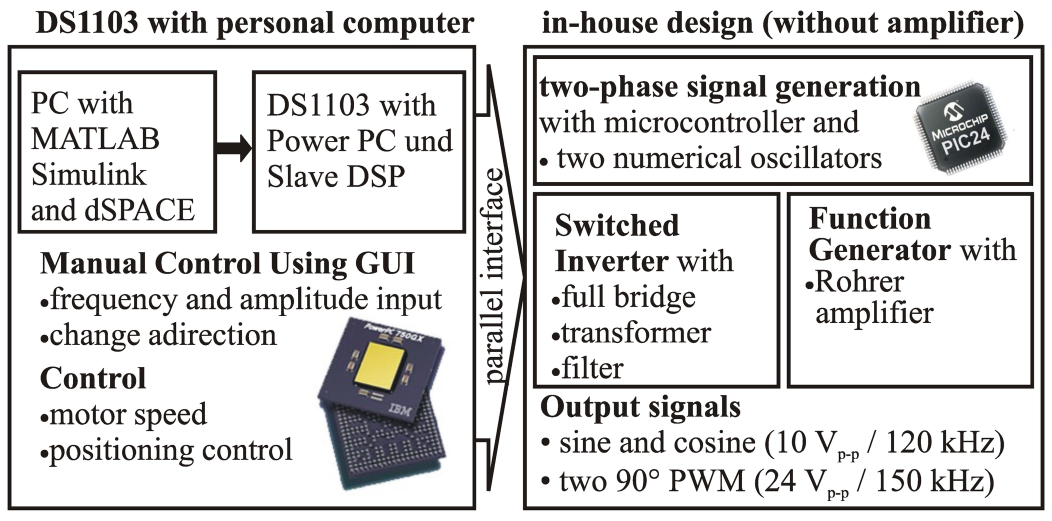

Fig. 3: Prototype system configuration

The electronics is suited for standalone operation. In detail the system allows:

- frequency control from 20 kHz to 100 kHz
- single phase or two phase excitation
- fast arbitrary programmable phase changes
- amplitude or dutycycle control for the function generator or the switched inverter

Signal Generation

Signal generation is based on the numerically controlled oscillator (NCO) AD9833 with programmable frequency and phase angle and sine wave and triangle wave output, Fig. 4.

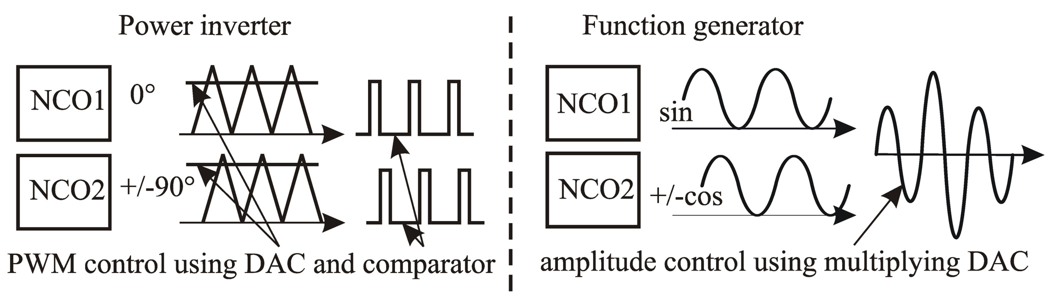

Fig. 4: Prototype system configuration

For the switched inverter a digital-analog-converter (DAC) is used to generate a control voltage and with a comparator a symmetrical PWM-signal. Thus, the phase angle for two-phase operation is sustained when the duty cycle is changed. In case of the function generator a multiplying DAC (AD7837) delivers a programmable attenuation of the amplified NCO output signal for amplifier control.

Function Generator

Fig. 5 shows the basic structure of the sine wave generator.

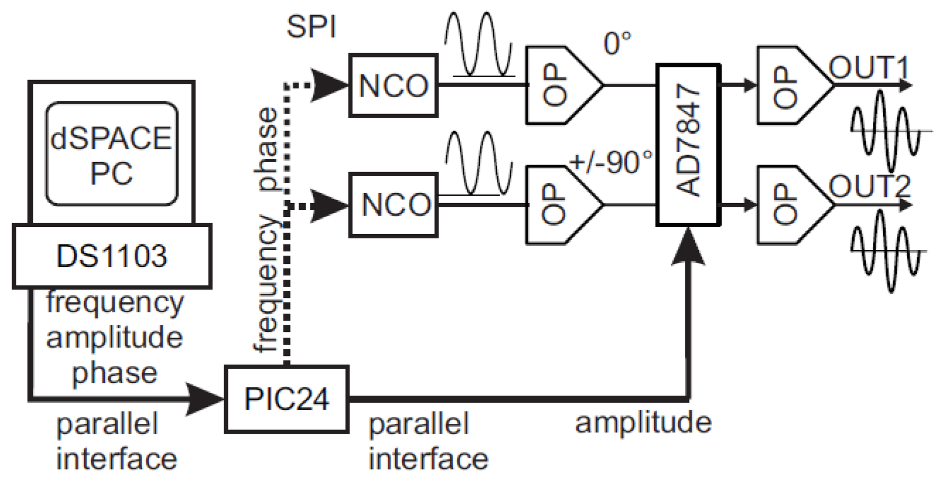

Fig. 5: Prototype sine wave generator

The DDS ICs generate only 0.6 V unipolar output voltage and are not suited to drive the inputs of the four quadrant amplifiers.

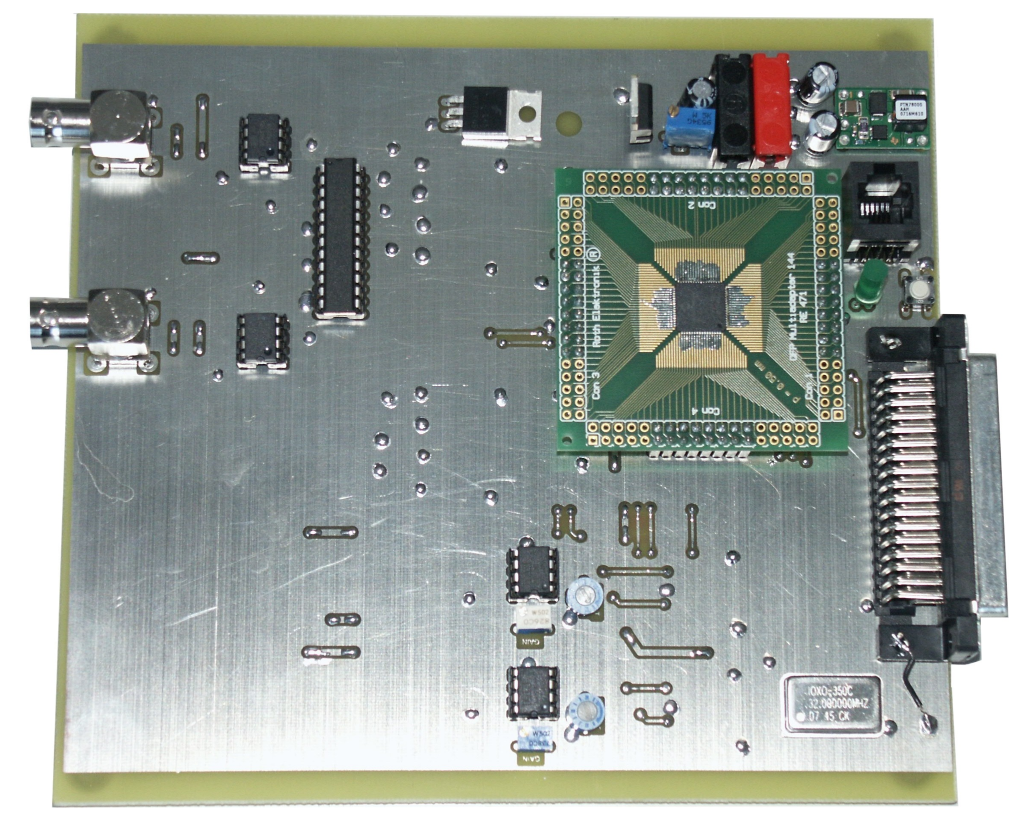

Fig. 6: Prototype function generator

The DDS signal is first amplified then level shifted and finally amplitude control is implemented using the multiplying DAC. The output amplifier generates the current to drive the 50 Ohm amplifier inputs to maximum modulation. Fig 6 shows the circuit board. A D-Sub connector joins the circuit to the DS1103. The device operates from a single supply source. The maximum frequency is 120 kHz which suits a wide range of ultrasonic resonators.

Square Wave Inverter

Square wave inverters are the standard devices for ultrasonic resonators. They are built as full bridge or half bridge inverters using PWM-control. As opposed to a regular amplifier switched inverters are comparatively low cost. Fig. 7 shows the block diagram of a two-phase inverter with +/-90 degrees phase shift.

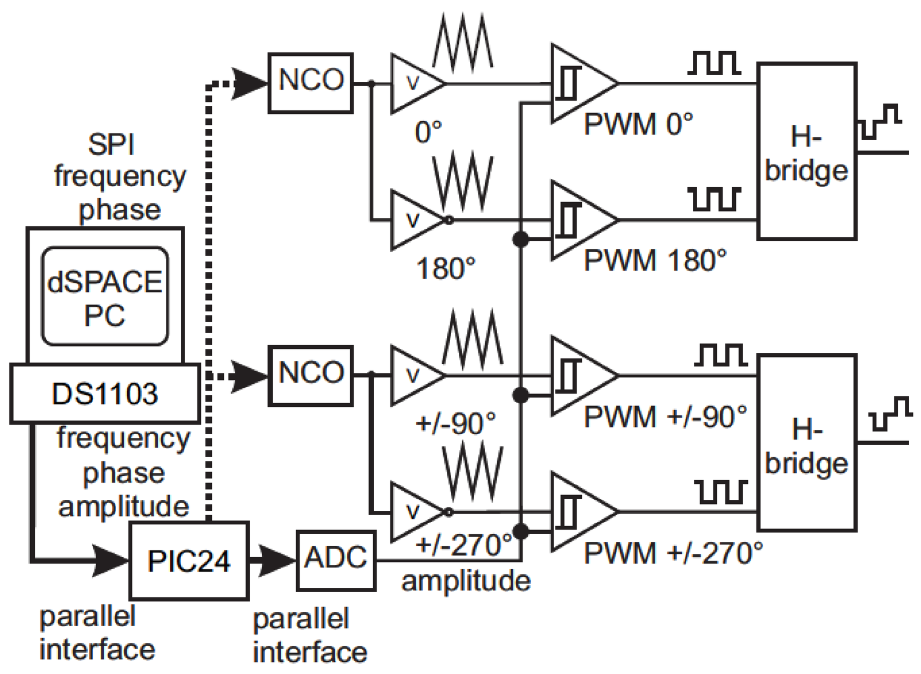

Fig. 7: Prototype square wave inverter

The inverter produces single or dual-phase PWM outputs with a maximum duty cycle of 50%. Fig. 8 shows the prototype of the printed circuit board with no filter components attached. The design has been tested to operate up to 150 kHz.

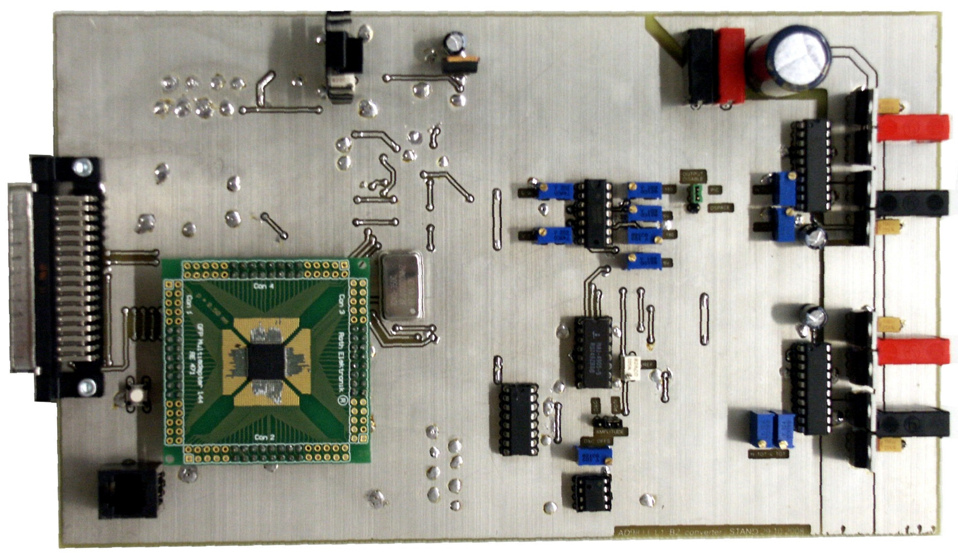

Fig. 8: Prototype power inverter

Dead Times

Both circuits use similar interfaces and achieve comparable time lag from a new input in dSPACE to a measurable output. Amplitude changes are completed in less than 15 µs and phase changes in less than 10 µs. A frequency change is slower due to the higher data volume to reprogram the NCOs and takes 22 µs to complete.

Conclusion

The presented system is a tool for ultrasonic motor design. Actuator operation without dSPACE is possible after extending the use of the microcontroller. Full system performance remains to be evaluated but simple motor control has been tested successfully.

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