LOCAL CONTROL OF PIEZOELECTRIC ACTUATORS

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Abstract

Active devices based on piezoelectric actuators are widely used to dump unwanted vibrations in a variety of applications; for instance fast tuners for superconducting RF cavities. In another report (TUPEA44) we describe a low cost modular system of drivers for piezoelectric actuators developed at INFN-Pisa; we show here that the same system can easily be extended, with the inclusion of a simple plug-in board, to include sufficient I/O and computing capability to allow control of the device up to frequencies in the kHz range. This implementation is extremely cost effective and can be used in all situations where a high granularity distributed control system is desirable. We also show our first test results obtained using this system to control a warm single cell 1.3 GHz cavity. The cavity is perturbed using a piezoelectric actuator to generate random noise, while another piezo is used in the control loop to stabilize the resonance frequency. We use the phase of the RF pickup from the cavity as a measure of the deviation from the resonance caused by the perturbation. This simple setup allows to easily test various control algorithms without the need to work at large complex facilities.

OVERVIEW

Recently several researchers of INFN-Pisa have successfully designed and built a driver system for piezo-electric actuators. The design guideline was to have a modular and low-cost system but at the same time a high power and bandwidth to be able to drive and test the largest variety of piezo-actuators used in cavity tuners.
The external control inputs are low voltage DC signals amplified on choice from 20x up to 400x.

A natural extension of the driver system is the inclusion of a digital section enabling the creation of an independent control loop for each channel. In large superconducting Linacs such a system could be used to control the detuning of each cavity. This local control would complement the standard LLRF (Low Level RF) system that typically acts at the one or more cryomodule level. The cavity probe signal could be used as input and of course some intelligence is required.

To implement this functionality we have developed a small board, equipped with two ADC (Analog Digital Converter), two DACs (Digital Analog Converter) and a powerful CPU that can be fitted inside the piezo-driver box.

To test the system we have designed and built a mock up based on a 1.3 GHz single cell cavity. The cavity is mechanically connected to 2 independent piezoelectric actuators: one is used to induce detuning while the other is driven to correct this same detuning. A simple, mixer based, RF circuit is used to generate a DC signal (0 IF) proportional to the cavity detuning.

PIEZO DRIVER

The driver has the following specifications:

- Bipolar voltage rails (-175 V to +175V)
- Full Power Bandwidth: 100 Hz
- Small Signals Bandwidth: 10 kHz
- 3 A max peak current
- Noise on electrical output: <10 mVrms
- Controlled by a DC signal

Each module (Figure 1) hosts two channels and a custom crate has been designed to install up to 5 modules.

Figure 1: Piezo Driver.

DIGITAL CONTROL

The additional digital control for the piezo driver follows the block diagram shown in Figure 2. It is based on a commercial CPU board, named Fox board (Figure 3) plus a custom designed plug-in module (Figure 4) that hosts 2 DACs and a multi-channel ADC.

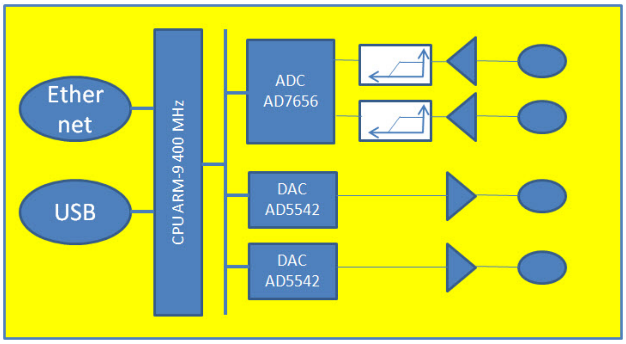

Figure 2: Block diagram of the digital section.

Fox Board

The "Fox board" is a commercial card developed by the Italian company ACME Systems, it runs the Linux operating system and has been chosen mostly for its small dimensions (66 x 72 mm)
Main characteristics are:

- 400 MHz ARM-9 CPU
- 64 Mb RAM
- 8 Mb flash
- Linux based
- 4 Serial ports
- 1 SPI (Serial Peripheral Interface)
- Ethernet + USB

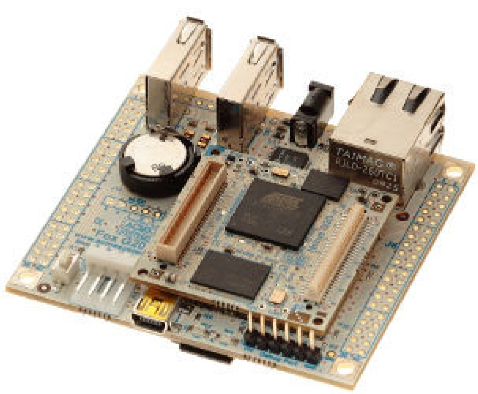

Figure 3: Fox board.

Custom plug-in

This small board follows the same form factor of the Fox board and fits exactly on its bottom side.
The converters are all connected to the CPU through the SPI bus.
In detail the main parts are:

- ADC: AD7656 16 bits, bipolar, up to 150 KHz conversion rate. It provides 6 input channels simultaneously sampled but only 2 are used.
- DAC: 2 AD5542, 16 bits bipolar
- Analog inputs are low pass filtered and amplified before reaching the ADC
- 2 digital inputs are used as triggers if feed-forward controls are required.
- 8 layers PCB

The conversion rates of both ADCs and DACs are defined on the firmware to about 1 KHz, which seems suitable to track almost in real time the cavity detuning.

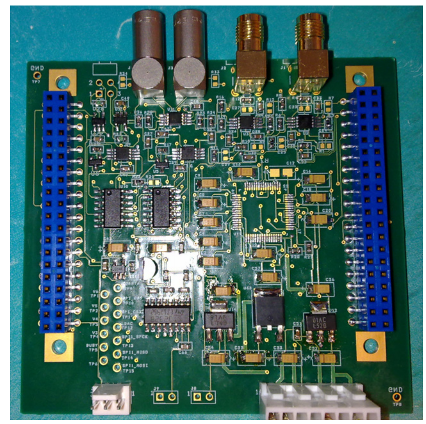

Figure 4: Converters plug-in.

TEST SYSTEM

To test the system (piezo driver plus digital control) and to perform studies on control algorithms we designed a mechanical mock up that includes a single cell 1.3 GHz niobium cavity (used in warm conditions) and two piezo actuators (Figure 5 and 6)

One side of the cavity is strongly anchored to one of the lateral sides while the other can be compressed by one of the piezos. The other piezo is mounted on a fork that acts as a displacement amplifier and again is able to compress one of the cavity sides.

The actuators are made by PI, model P-880.90 and are rated for a 30 micron displacement at 100 volts. They can be powered from -20 to 120 volts.

One actuator is used to perturb the cavity and the other one to correct the detuning. To power the disturb piezo we use one of the two channels of the piezo- driver. On the software side two independent processes run in parallel, one drives the disturb piezo, while the other uses the cavity probe detuning signal and the other DAC analog signal to form a closed loop control system.

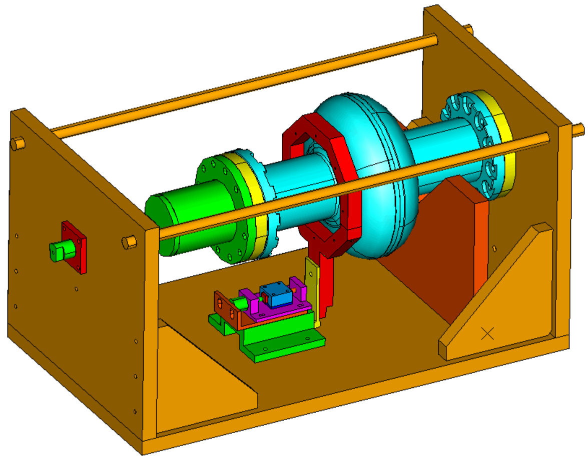

Figure 5: Mechanical structure.

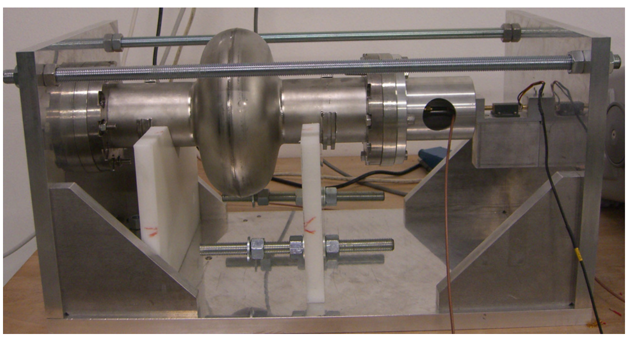

Figure 6: The cavity and piezo-actuators.

RF SYSTEM

The cavity resonates at about 1.3 GHz. To generate a signal proportional to the detuning we use the 0 IF method that although very simple is quite sensitive.
The RF circuit is summarized in Figure 7.

An Agilent 8648B generates an RF signal (11 dBm power) which is split by a 0 degree splitter. Half power is sent to the cavity while the other is sent to the LO (Local Oscillator) input of a Mini-circuits mixer. The generator power was chosen to inject 7 dBm power at the LO mixer input. The RF input of the mixer is connected to the cavity probe. A programmable delay line is inserted in the LO signal path. The mixer multiplies these two signals of the same frequency, so at the IF (Intermediate Frequency) output we get a DC signal proportional to the relative phase of the LO and RF signals. The multiplication produces also a 2.6 GHz signal that is filtered away. The delay line is calibrated so that at the steady state (piezo actuator off) the relative phase is null and so the measured IF signal is 0 mV. Compressing the cavity with a piezo actuator we change its resonant frequency and of course also the relative phase of the cavity input and cavity probe signals, obtaining a non null signal at the mixer IF output.

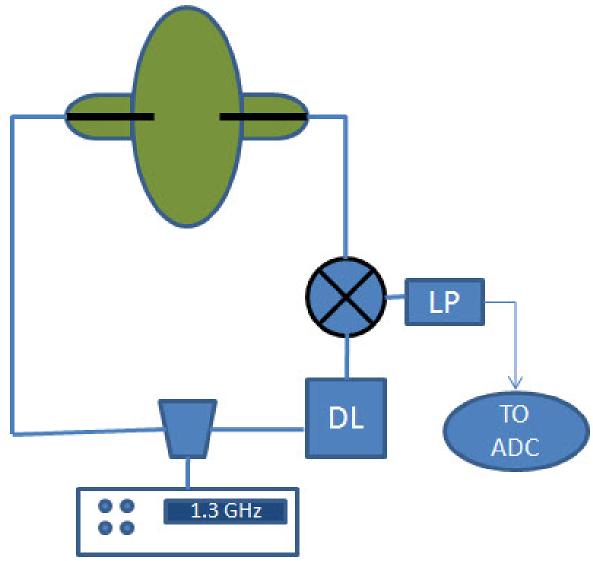

Figure 7: RF system.

CONCLUSIONS

The digital interface and the mock up were completed only recently so we are still doing the final adjustment of the whole system and making the first preliminary measurements to assess the basic performance parameters. One of the main concerns was the sensitivity of such a system at room temperature. We find a very clean mixer output at the 10 mV level when we drive the piezo at the maximum voltage. This is adequate for our purposes. We expect first result on the local control loop very soon.

REFERENCES

[1] M. Liepe, W.D. Moeller, S.N. Simrock, "Dynamic Lorentz Force Compensation with a Fast Piezoelectric Tuner", Proceedings of the 2001 Particle Accelerator Conference, Chicago, p. 1074-1076