MTCA.4 MODULE FOR CAVITY AND LASER PIEZO OPERATION*

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Abstract

A MicroTCA.4 (MTCA.4) compliant Piezo Driver (DRTM-PZT4) [1] has been developed to drive piezoelectric-based actuators used in accelerator instrumentation applications. More specifically, it is used for superconducting cavities fine tuning, synchronization of pulsed lasers and stabilization of fiber links. This paper briefly presents the designed system requirements and discusses the main hardware issues. The Piezo Driver performance measurements are also discussed. The first results of the prototype hardware usage for laser locking [2] to an external RF source and fiber link stabilization are summarized.

INTRODUCTION

MTCA.4 is a module standard developed on the basis of MTCA.0. It introduces the Rear Transition Modules (RTM) which provide additional space for custom analog and digital functions that cannot be integrated on standard Advanced Mezzanine Cards (AMCs) due to space constraints or the requirement to separate digital and analog components. Compared to the MTCA.0 standard, MTCA.4 doubles the available board space per single slot.

To support partners in the industry as well as high energy physics research facilities, DESY is developing the following components:

- A Module Management Controller (MMC) which provides a template solution to deliver a set of functions that can be easily ported on custom boards.
- Fast Mezzanine Card (FMC) carriers that allow integration of existing components: DAC/ADC cards, I/O extension cards or Small Form-Factor Pluggable (SFP) transceivers into MicroTCA.4 systems.
- Custom-developed RTM cards that are designed according to DESY Zone 3 pin recommendation [3], allowing to integrate complex functions into a single slot.

DRTM-PZT4 OVERVIEW

The DRTM-PZT4 module is an example of the custom RTM cards developed at DESY. The Piezo Driver is in charge of driving and sensing piezoelectric-based actuators and sensors commonly used for:

- Precision object positioning.
- Rapid motion control.
- Laser mirror steering.

The piezoelectric actuators are also applied for accelerator instrumentation applications at DESY, including:

- Fiber link stabilization – a piezo-based fiber stretcher is applied to stabilize an optical pulse stream distributed to parts of the facility via optical fiber links (fine tuning). The fine tuning operating point needs to be found by a coarse tuning procedure that uses step motors.
- Synchronization of pulsed lasers – the laser optics are equipped with a motorized translation stage (course tuning) acting whenever the piezo actuator (fine tuning) comes close to its operating range limits.
- Cavity frequency control - course tuning is supported by a mechanical arm movement introduced by a step motor driver. Fine tuning is done using piezoelectric-based mechanical frames that directly stress the cavity edge. Both tuners are integrated into a single cavity tuner framework and operated at cryogenic temperature.

The Piezo Driver module is compliant with the MTCA.4 standard. The RTM provides high voltage, high current output signals (on-board DAC or external source) which are low-pass filtered and amplified by a power amplifier to drive active piezo elements (capacitance range $0.1\ \mu F \div 6\ \mu F$). The feedback information from piezo sensors is initially conditioned using low noise operational amplifiers, digitized using ADCs and sent to a digital controller located on an AMC card. The piezo actuator and sensor functionality can be swapped remotely for each channel independently.

The DRTM-PZT4 provides several diagnostic signal readings: power amplifier output voltages and currents, high voltage power supply and temperature sensors. The on-board switches allow flexible configurations like power amplifier input source selection and conditioning, programming the analog active filters, changing the actuator and sensor functionality, as well as selecting the output and input voltages range of the DAC and ADC circuits. In order to prevent driving the piezos when the control system is not ready, the interlock signal is provided. Whenever the interlock signal is activated, the output high voltage signal is disconnected from the load and its driving circuits (DAC, external inputs are switched off). The over-temperature condition is also monitored individually for each power amplifier and causes the driving signal to be disconnected if the threshold is reached.

The Piezo Driver module accepts the main +12 V Payload Power (PP) and +3.3 V Management Power (MP) from the AMC card and generates the required voltages. The power amplifiers can be supplied using

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AMC PP or an external power supply. The external power supply connection can be provided using standard laboratory power supply or a dedicated high voltage RTM power module pluggable to Power Supply Carrier. The RTM card is closed inside a metal housing for EMI purposes and user protection against touching the high voltage elements. The block diagram of the Piezo Driver is shown in Fig. 1.
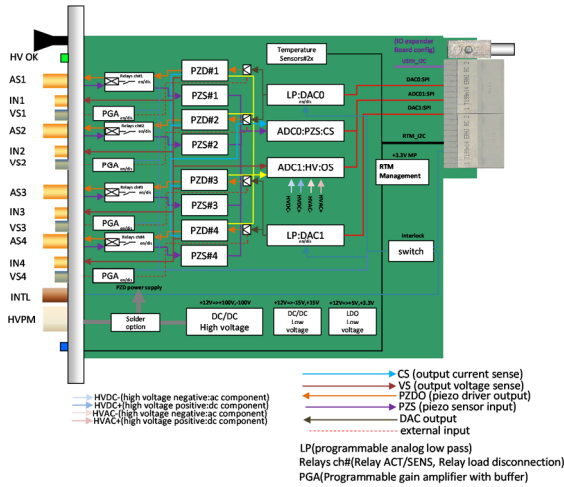

Figure 1: Block diagram of DRTM-PZT4 module.

LABOAROTORY MEASUREMENTS

There are three use cases for the PZT4 module:

- Fiber link stabilization - driving signal range 5 V_{pp}, operational bandwidth max. 20 kHz, capacitance load max. 100 nF.
- Synchronization of the pulsed lasers - driving signal range 0.5 V_{pp}, operational bandwidth <50 kHz, capacitance load <1 µF.
- Cavity tuner – driving signal range 160 V_{pp}, operational bandwidth 300 Hz, capacitance load <6 µF.

To fulfill the following use cases requirements the power amplifier circuit that drives the pure capacitance load needs to be adjusted. The solid-state power amplifiers can be compensated using strip programmable pins (C_C) and, if that's not sufficient, by applying in-loop (C_F small capacitance in parallel with feedback resistor) and out-of-loop (R_S small resistance in series with output capacitance load) circuits (see Table 1).

Table 1: Booster Setup (total gain 10 V/V, 4.7 µF load)

Compensation	Value	Output voltage
C_C; C_F; R_S	0 pF; 0 pF; 0 Ω	not stable
C_C; C_F; R_S	22 pF; 22 pF; 5 Ω	oscillate
C_C; C_F; R_S	22 pF; 4.7 pF; 5 Ω	stable

The VSA HP89410 transfer function measurement with a periodic chirp source was used to characterize the PZT4

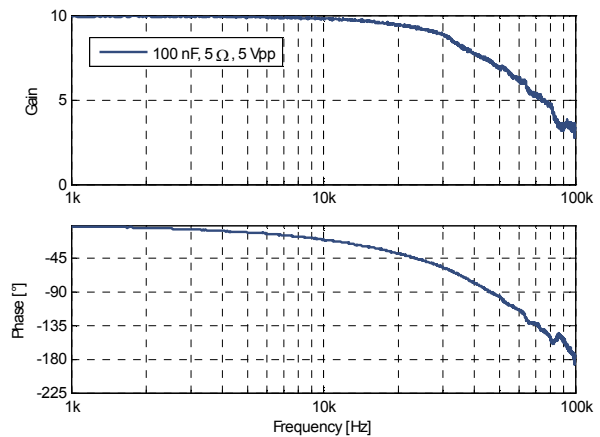module. The Piezo Driver characterization for the Fiber link stretcher control is shown in Fig. 2.

Figure 2: Bode plots of bandwidth measurements for Fiber link stabilization application.

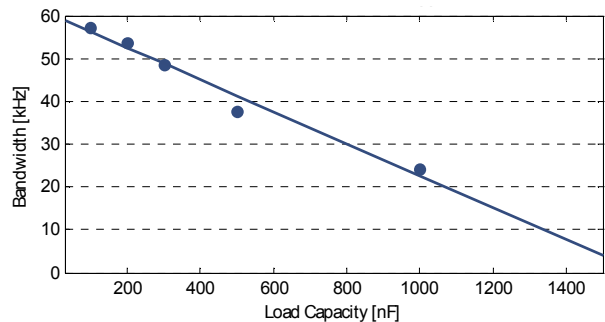The performance measurements for synchronization of pulsed lasers are shown in Fig. 3.

Figure 3: Bandwidth measurements for the laser synchronization application.

For the parameters of the Fiber link stabilization the requirements are fulfilled since the bandwidth is about 50 kHz. The Laser synchronization use case is not well defined as the piezo actuators cover a larger range of capacity values. With the linear fit shown in Fig. 3 it is possible to estimate the achievable bandwidth dependent of this parameter.

The cavity tuner application doesn't cover the high frequency range signals (max. 300 Hz). The cavity fine tuning is mainly applied for the short time duration of the RF pulse which is 1.3 ms at DESY FLASH facility. The repetition rate of the excitation is limited to high power klystron parameters and typically equal to 100 ms. Nevertheless, the output voltage of the Piezo Driver, applied to a 4 µF capacitance, can reach up to 160 V_{pp}. It means that much more current is needed to be pumped to the output capacitance. The current delivered to the piezo can affect channel-to-channel crosstalk parameter. A special printed circuit board (PCB) layout technique has been applied (split planes separated with ground planes, vias stitching around the high voltage paths) in order to

minimize this parameter. The measured channels crosstalk is summarized in Table 2.

Table 2: PZT4 Channels Crosstalk (C_{load} = 4.7 µF)

Aggressor /victim	Ch#1	Ch#2	Ch#3	Ch#4
Ch#1	160 V_{pp}	25 mV	31 mV	32 mV
Ch#2	20 mV	160 V_{pp}	22 mV	23 mV
Ch#3	21 mV	28 mV	160 V_{pp}	24 mV
Ch#4	24 mV	35 mV	23 mV	160 V_{pp}

REAL APPLICATION TESTS

The DRTM-PZT4 module has been applied for Laser synchronization and Fiber links stabilization test stands. For the Laser synchronization application the conventional method using RF technique was applied. The phase (jitter) has been measured in the baseband using analog class RTM card (DWC) and applied to a AMC based digital feedback controller (SIS3800-L) [4]. The correction signal has been amplified by the Piezo Driver (loop filter) and used to drive the optics of the laser subsystem in one dimension. The measured latency of the digital feedback controller didn't exceed 5 µs. The corner frequency of the Piezo Driver low-pass filter has been programmed for 20 kHz. The example results taken for reference 1.3 GHz RF signal are shown in Fig. 4.
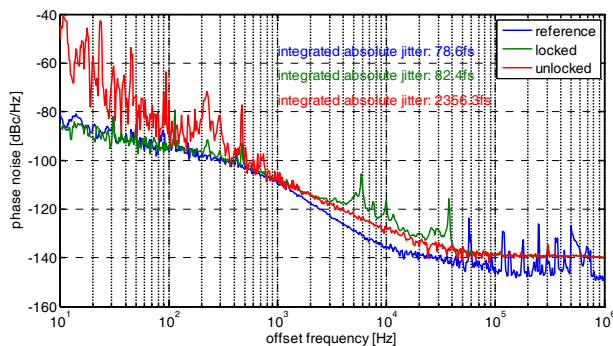

Figure 4: Laser synchronization at 28f test stand.

For the Fiber link stabilization test stand, the output signal from an optical cross-correlator has been connected to an RTM feed-through card (SIS8900) to allow analog signal digitizing using an AMC (SIS3800-L) card. The calculated correction signal has been sent to RTM Piezo Driver module using point to point serial link connection between AMC modules. The sampling frequency of the digitizer has been set to 81 MSPS. The Piezo Driver output signal has been down-sampled to 500 kSPS. The Piezo Driver has been connected to Piezo-stretcher for stabilizing 300 m fiber link. The fiber link lock results are presented in Fig. 5. The digital feedback controller parameters have been not optimized.
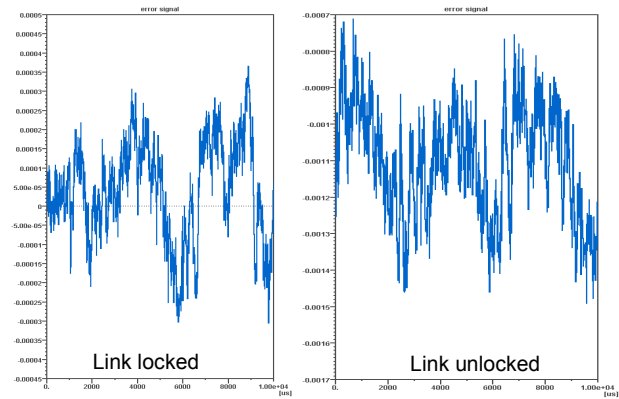

Figure 5: Fiber link stabilization at 26A. On the horizontal axis it is time in µs. On the vertical axis it is voltage in V.

CONCLUSIONS

The DRTM-PZT4 module has been designed, laboratory tested and used in several applications. The performance has been confirmed during long term Laser or Fiber link lock measurements in a laboratory environment. The cavity tuner control demonstration is planned to be done first at DESY using existing test facilities (CMTB, AMTF) and next it will be applied for the European Spallation Source (ESS) experiment where the RF pulse duration is 2.8 ms with a repetition rate up to 14 Hz.

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