# Piezo driver for spoke and elliptical cavities of ESS project linac production and installation status

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## Abstract

The MTCA.4 based piezo driver has been proposed and developed by the LUT-DMCS engineers as a Polish in-kind to the ESS project. The driver is capable to drive two independent channels dedicated to a single piezo tuner in a single cavity. It has been designed to work for elliptical resonators (M-Beta and H-Beta) with 0 to 200 V output voltage range. Additionally, it can be reconfigured to work in any bipolar or asymmetric range between -190 to 190 V. That is why it will be installed also for the spoke accelerating structures of the same linac. The current contribution presents the latest status of the piezo driver production and installation in the ESS accelerator. Results from the hardware evaluation and initial tuning performance achieved at the Test Stand 2 facility are discussed too.

## Piezo Driver Design and parameters

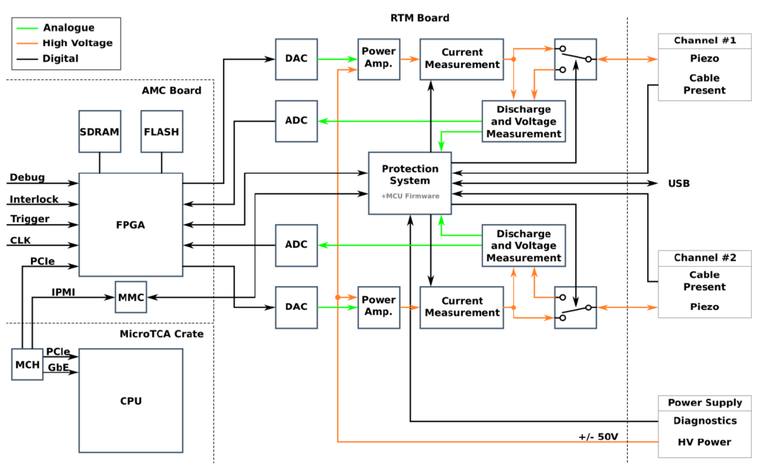


Figure 1: Piezo driver implementation diagram

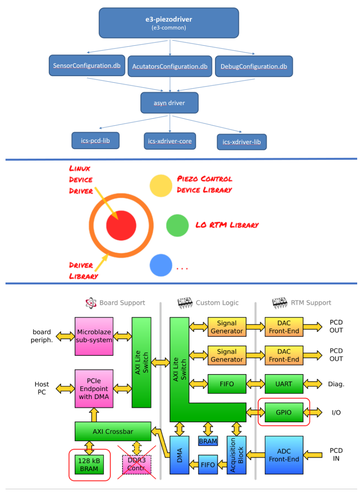


Figure 2: SW/FW diagram

Main features:

- 2 independent channels operation,
- operation as an actuator or a sensor,
- suitable for all kind of cavities in the cold linac,
- synchronization with the linac timing,
- remote reconfiguration accessible,
- MTCA.4 compatible,
- separated Piezo Power Supply Module with integrated diagnostics and control,
- health status and diagnostics integrated on the RTM module and accessible from the AMC side.

Parameters :

- output voltage range: 0 to +200V (-40 to 160V - for spokes),
- controller bandwidth DC-1kHz,
- repetition rate - 14 Hz,
- Max. power - 30W,
- PowerSupply voltage -/+ 100V,
- Actuator: sampling freq. 1MHz, No of samples: 30k, resolution 16 bits,
- Sensor: sampling freq. 1MHz, No of samples: 30k, resolution 16 bits, input voltage -/+1V, impedance: 10kOhm,
- piezo capacitance (room temp.) 6.6 to 11 uF.

## Piezo Driver evaluation with elliptical cavities

- Piezo Driver prototypes evaluated @FREIA laboratory with the spoke prototypes cavities
  - first tests with the AMC proof of concept prototype with one carrier and 3 daughter boards,
  - operation with 2 channels and -/+80V voltage range
  - first full-scale (RTM board and external PS) prototype used for spoke and H-Beta prototype testing
- Final prototype installed and evaluated @ESS-TestStand2
  - Single piezo-driver for full cryo-module operation (4 cavs.),
  - channels configuration (single/two cavities operation) possible thanks to the piezo split-box,
  - operation with full 0 to 200V or asymmetric configuration possible,
  - full integration with the HW infrastructure and control system (IOC installed and running)
  - in everyday use by the TS2 operators.

Figure 3: Piezo driver installation in the rack

Figure 4: TS2 bunker with the CM03

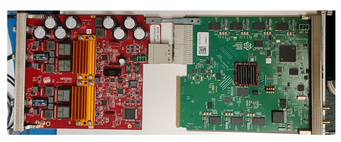

Figure 5: Piezo controller HW for TS2 installation

## Cavities parameters evaluation

Thanks to the integrated acquisition system, following studies are being performed :

- main cavity mechanical mode determination from the RF pulse excitation response,
- various mechanical modes o fthe system determination with dedicated mechanical excitation patterns,
- piezo capacitance measurement,
- piezo tuning range and hysteresis,

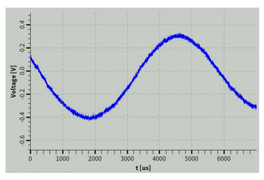


Figure 6: Cavity (M-Beta) oscillations registered by the piezo sensor during open loop operation

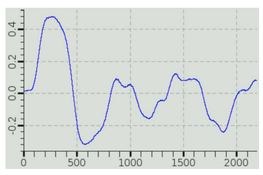

Figure 7: Cavity (M-Beta) free oscillations other module

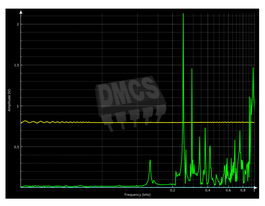


Figure 8: Spoke cavity mechanical response measured by sensor (chirp signal)

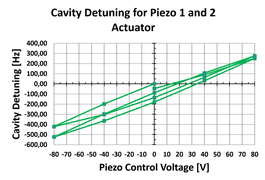


Figure 9: Tuning range measured for spoke cav.

## Piezo Driver and PPSM production

- The mass production consisted of 2 pre-production pieces and 118 pieces of final production,
- The 2 pre-production modules have been used for the production quality check and possible corrections and improvements report preparation,
- The final production has been released after pre-production verification and corrections/improvements report acceptance,
- Post-production testing included four phases: visual inspection, management power test, thermal pads and shielding installation, verification in local dedicated test stand,
- Imperfections spotted in each phase resulted in vendor actions to remove error,
- PPSM modules assembled in-house,
- dedicated internal PCB designed for the power supply control and various sensors monitoring,
- 120 pcs completed and tested,
- due to the semiconductor crisis - two versions have been designed verified and produced,
- post-production testing performed on the dedicated test-stand,
- dedicated inventory for HW - provided.

Figure 10: Piezo driver RTM board - mass production version

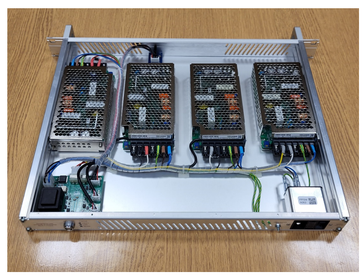

Figure 11: Piezo Power Supply Module top-view (without cover)

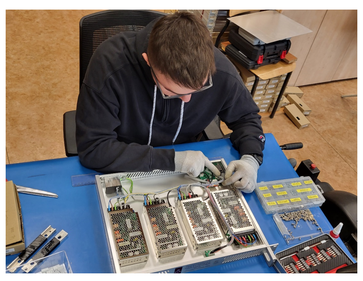

Figure 12: PPSM assembly

## Piezo driver installation

Piezo driver installation scope:

- Delivery of 120 pcs of the piezo driver RTM module to ESS,
- Delivery of 120 pcs of the piezo driver external power supply module to ESS,
- Delivery of 120 RTM to PS connection cables to ESS,
- Hardware installation for the M-Beta LLRF systems (36 pcs),
- Hardware installation for the H-Beta LLRF systems (20 pcs),
- Hardware installation for the Spoke LLRF systems (26 pcs) – outside current IK scope,
- Verification of the installed systems:
  - Visual inspection,
  - Test of the AC and DC excitation readouts from the driver,
  - Both channels signal output test with cavity simulator.

| Aisle | System | HPD ID | RTM Carrier ID | PPSM ID | Tested DC/AC | Tested Cav Sim test | Visual inspection | Comments |
|---|---|---|---|---|---|---|---|---|
| MBL-010 | E01 | B011 | 478 | v1.57 | A002 | OK | Ok | piezo cables not connected |
| | E02 | B013 | 490 | v1.57 | A003 | - | Ok | |
| | E03 | B014 | 477 | v1.58 | A001 | OK | Ok | |
| | E04 | B015 | 474 | v1.57 | A004 | OK | REF | Ok |
| MBL-020 | E01 | B016 | 494 | v1.57 | A014 | OK | OK | Ok | no labels for HPD-PPSM cable |
| | E02 | B017 | 471 | v1.57 | A013 | OK | OK | Ok | no labels for HPD-PPSM cable |
| | E03 | B018 | 499 | v1.57 | A015 | OK | OK | Ok | no labels for HPD-PPSM cable |
| | E04 | B019 | 495 | v1.57 | A012 | OK | OK | Ok | no labels for HPD-PPSM cable |
| MBL-030 | E01 | B020 | 483 | v1.57 | A009 | OK | ERR, no RF | Ok | no labels for HPD-PPSM cable |
| | E02 | B022 | 496 | v1.57 | A010 | OK | OK | Ok | no labels for HPD-PPSM cable |
| | E03 | B023 | 492 | v1.57 | A011 | OK | OK | Ok | no labels for HPD-PPSM cable |
| | E04 | B024 | 484 | v1.57 | A008 | OK | OK | Ok | no labels for HPD-PPSM cable |
| MBL-040 | E01 | B025 | 485 | v1.58 | A018 | OK | REF | Ok | |
| | E02 | B026 | 472 | v1.57 | A016 | OK | OK | Ok | |
| | E03 | B027 | 493 | v1.57 | A112 | | In operation | Ok | in operation |
| | E04 | B028 | 497 | v1.57 | A017 | OK | OK | Ok | |
| MBL-050 | E01 | B029 | 479 | v1.57 | A019 | OK | REF | Ok, | piezo cables not connected |
| | E02 | B030 | 491 | v1.57 | A020 | OK | In operation | Ok | |
| | E03 | B031 | 473 | v1.57 | A023 | OK | OK | Ok | |
| | E04 | B032 | 501 | v1.57 | A024 | OK | OK | Ok | |
| MBL-060 | E01 | B033 | 481 | v1.57 | A025 | OK | | Ok | piezo cables not connected |
| | E02 | B034 | 489 | v1.57 | A026 | OK | | Ok | |
| | E03 | B035 | 475 | v1.57 | A027 | OK | | Ok | |
| | E04 | B036 | 488 | v1.57 | A028 | OK | | Ok | |
| MBL-070 | E01 | B037 | 480 | v1.58 | A029 | OK | | Ok | piezo cables not connected |
| | E02 | B038 | | | A030 | OK | | Ok | |

Figure 13: M-Beta installation results table

Final result: Success

RTM_HW_ID: 472
HPD_HD_ID: B026
PPSM_HW_ID: A016
ESS_LOCATION_ID: MBL040E02
STACK: A

| Piezo parameters | |
|---|---|
| Name | Value |
| Sensitivity | 3.58 Hz/V |
| Polarity | Positive [-] |
| Range | 869.23 Hz |
| Hysteresis | 0.0 V |

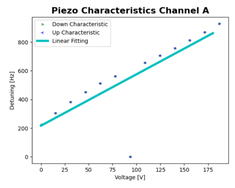


Figure 14: Exemplary report from cavity simulator based DC scan test

- The installation for Spoke (352 MHz) cavities LLRF systems has been completed,
- The installation for M-Beta (704MHz) cavities LLRF systems has been completed,
- The installation for first 20 H-Beta cavities LLRF systems has been completed,
- All installed systems pass visual verification,
- The local excitation/readout tests have been performed for all installed entities,
- Local tests revealed problems with one driver and 2 PPSM - replaced and repaired at DMCS,
- Tests of the DC scan and AC pulse with cavity simulator are in progress and will be concluded in Q1.2024

## Summary

- PD prototypes tested with all types of superconducting cavities (for ESS),
- Support in the piezo control algorithm implementation
- Software preparation for piezo/cavity automatic parameters identification
- Mass production of the Spoke/Medium Beta/High Beta finish despite semiconductor crisis impact (approx. one year delay),
- Successful installation in the ESS accelerator gallery with initial verification
- ongoing tests with the cavity simulator - last verification step.

## References

D. Makowski, A. Mielczarek , et. all, (2019). *Piezo Control Device In Kind Contribution of PEG Consortium*. ESS-ERIC submodule specification.

W. Cichalewski, G. Jablonski, K. Klys, D. Makowski, A. Mielczarek, A. Napieralski, P. Perek, P. Plewinski, A. Abramowicz, K. Czuba, M. Grzegrzolka, K. Oliwa, I. Rutkowski, W. Wierba, P. Bartoszek, K. Chmielewski, Z. Golebiewski, K. Kostrzewa, T. Kowalski, D. Rybka, M. Sitek, J. Szewinski, Z. Wojciechowski, M. Jensen, A. Svensson, A. Johansson (2022). *PEG Contribution to the LLRF System for Superconducting Elliptical Cavities of ESS Accelerator Linac*. IPAC 2022, TUPOST017, Bangkok, Thailand.

## Acknowledgments

Work supported by Polish Ministry of Education and Science, agreement number 2021/WK/04