Accelerator Studies – March 2008
Report of the measurements and achieved results

Subject: Multi-Cavity Complex Controller - MCC
applying SIMCON 3.1 board for ACC1 module driving

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Motivation and goal.

The FPGA based controller supported by MATLAB system was developed to investigate the novel firmware implementation and the optimal control methods for the LLRF system Control algorithm based on feed-forward driving supported by feedback mode was examined for the optimal cavity performance:

driving under the resonance condition during *filling* and field stabilization for *flattop* range.

The concept of the Multi-cavity Complex Controller – MCC

The outline of Low Level RF control system based on the MCC controller is presented in figure 1.

The MCC controller system consists of two coupled subsystems:

1. FPGA hardware layer – actual controller with relatively simple structure as an executor of control algorithms (slave)

2. Low Level Application (LLA) layer – adjacent software part arranging control algorithms and supplementary procedures (master)

The FPGA-based controller executes procedure of feedback driving supported by feed-forward according to prearranged control tables: Feed-Forward, Set-Point and Gain. The 8-channel multiplexer MUX switches ADC or internal Simulator signals respectively to a given mode of operation. The digital processing is performed in I/Q detector for signal of intermediate frequency 250 kHz for 8 channels. The resultant cavity voltage envelope represented by in-phase I and quadrature Q components is calibrated according to given coefficients for scaling and phasing of each channel. The Vector Sum of 8 signals is considered for the actual control processing. Consequently, an average value of the cavities voltage envelope is compared to the reference Set-Point creating an error signal. The error signal is multiplied in the Corrector unit by a complex value of the Gain table. Superposition of a feedback signal and a signal of Feed-Forward table results in a controller output for DAC converter.

The Data Acquisition memory acquires *on-line* data of ten ADC channels and selected internal data from FPGA system.

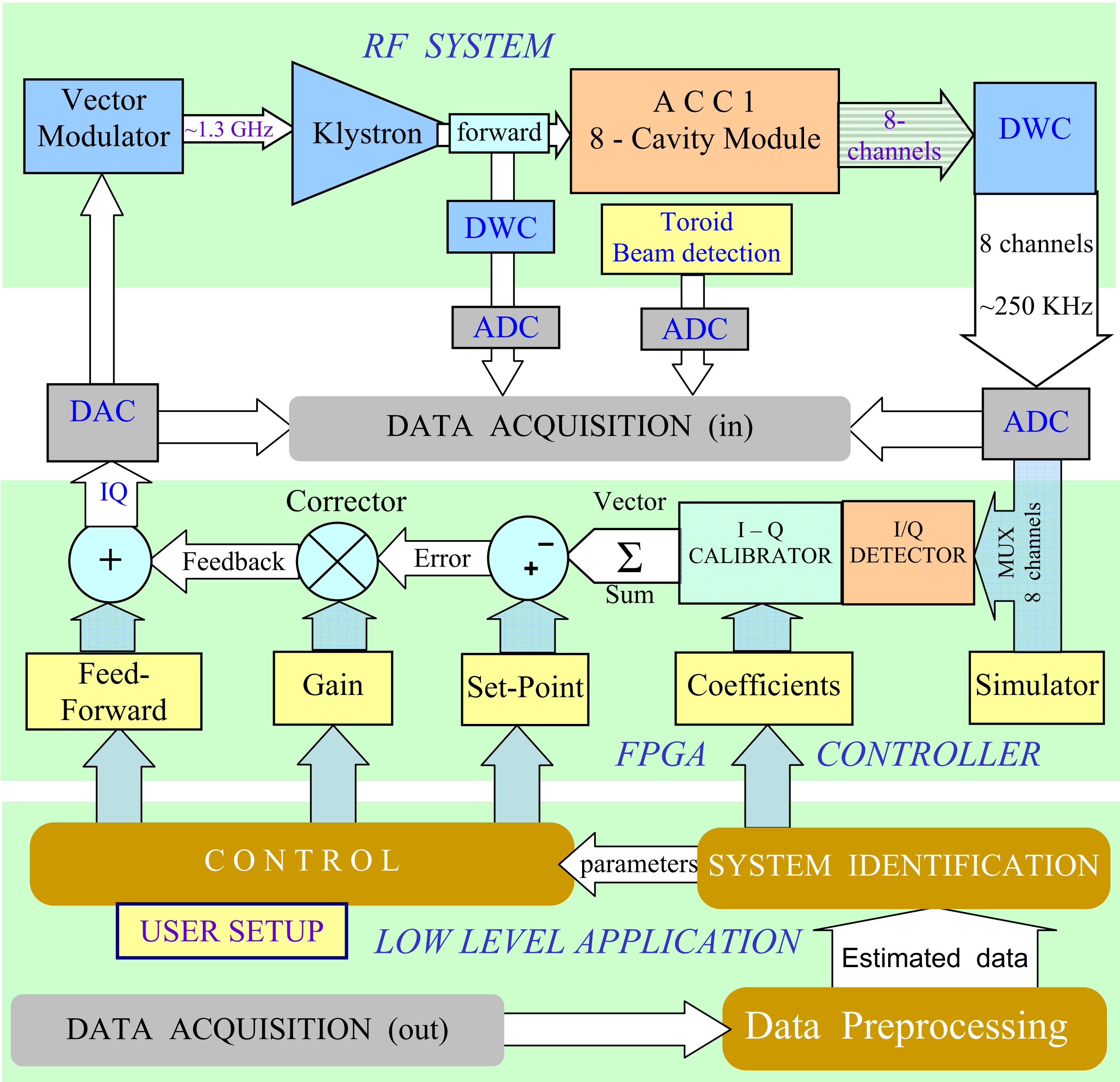

Fig 1. Functional block diagram of LLRF control structure based on Multi-cavity Complex Controller

The data acquired by Data Acquisition system during a pulse are processed by Low Level Application software between pulses.

Two complementary adaptive methods are proposed for control algorithms of LLA:

1. by identification of a given RF system model
2. by feedback based Feed-Forward correction.

Estimated data (after *off-line* preprocessing) related to the controller, klystron and cavities are considered as input and outputs signals respectively for the RF system model. A discrete, linear time-variant model in complex domain is considered for the accelerator cavities system analysis. The multi-cavity model for the vector sum has the same structure like a single cavity. The repetitive process with complex parameters is described by the matrix equation as the input–output relation covering the pulse measurement range. The time varying complex parameters are approximated by set of cubic spline functions. The unknown parameters of the over-determined matrix equation are estimated by the least squares (LS) method. The klystron characteristics, coupling factors cavity bandwidth and detuning are estimated for the given model.

The inverse solution of the recognized process provides required control tables: Feed-Forward, Set-Point and Gain for the desired performance of the cavities module according to the user setup. Nonlinearities and deterministic disturbances are compensated by Feed-Forward table allowing open loop operation. Closed loop correction for feed-back mode is performed by complex gain of the corrector unit. It also includes the klystron linearization.

Stochastic disturbances and discrepancy of the model parameters are compensated by feedback mode. Estimated feedback signal is also apply for correction of the Feed-Forward table improving field stabilization on flattop range. This version of adaptive feed-forward control is dedicated particularly for beam loading compensation.

The experimental results of adaptive control are presented in Fig. 2. as Matlab readouts for feed-forward and feedback driving (loop gain = 5). The cavity is activated with pulse of 0.8 ms duration and repetition of 5 Hz. During the first stage of the operation (~0.5 ms *filling*), the cavity is driven with constant amplitude and modulated phase, so the input signal tracks the time varying resonance frequency of the cavity resulting in an exponential increase of the field under the resonance condition. When the cavity voltage has reached the required final value, the cavity is driven, so the input signal compensates the time varying cavity detuning resulting in stabilization of the field during the *flattop* range (~0.3 ms). Switching off the input signal yields an exponential *decay* of the cavity field.

In the carried out experiment two bunches of beam were injected on the beginning of flattop range. Detected toroid signal can activate the beam loading compensation in the case of long bunches. The beam energy stability measured in the BC2 while operating "on crest" has been tested (Fig. 3).

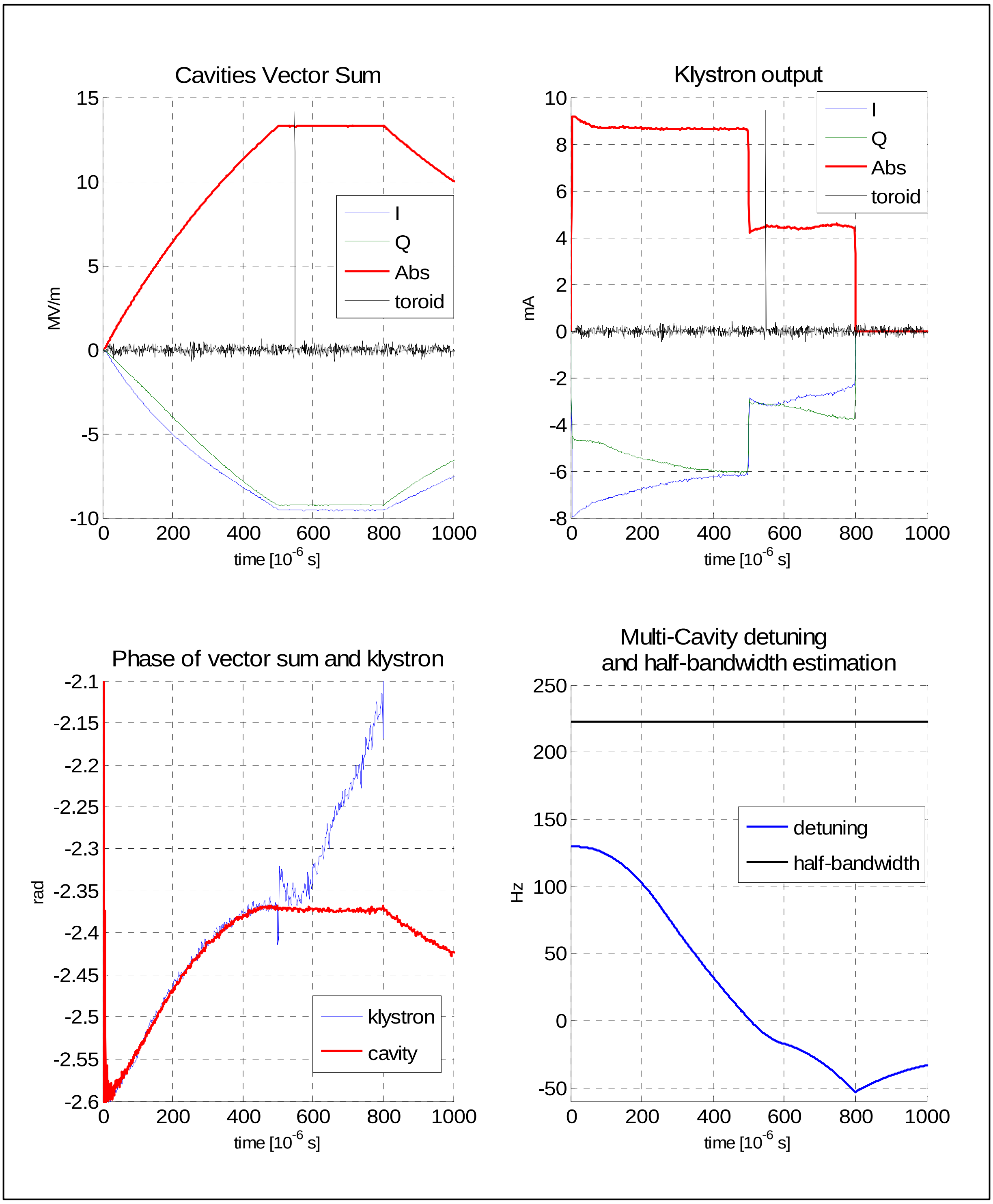

Figure 2. Matlab readouts of vector sum control for feed-forward and feedback driving (loop gain = 5).

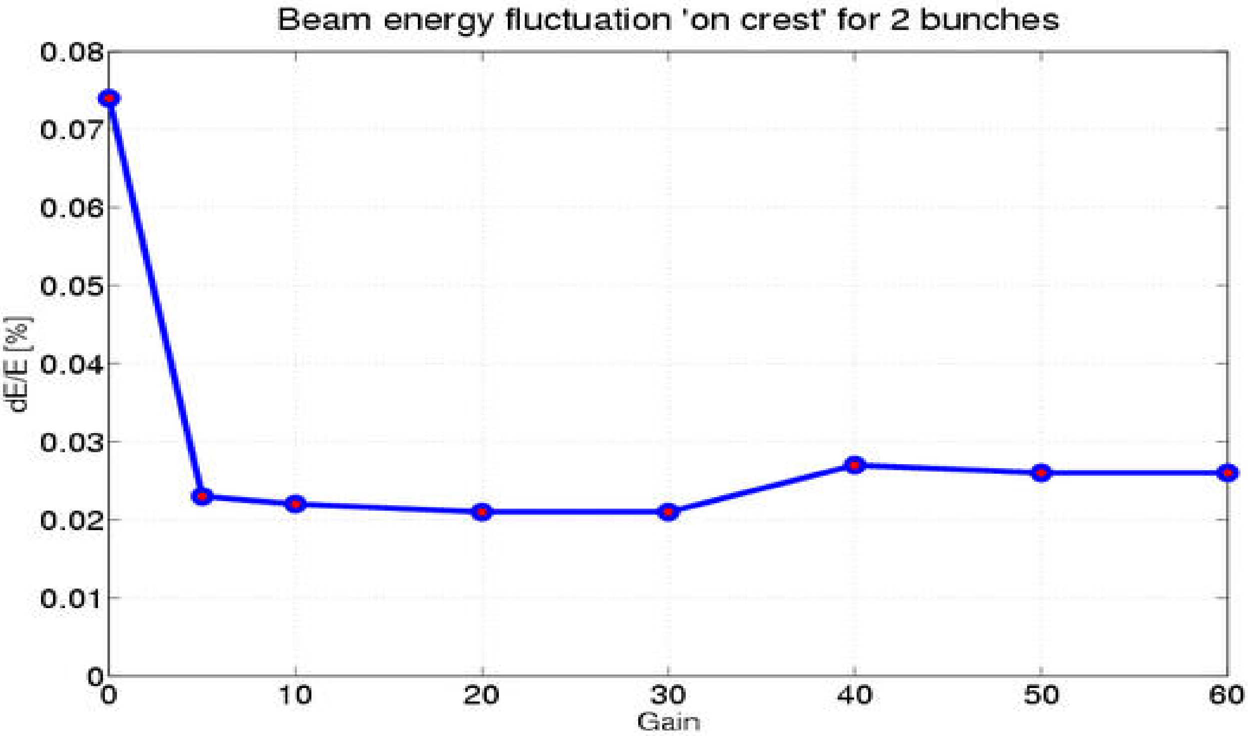

Fig. 3 ISE controller testing (DESY   19.03.2008)

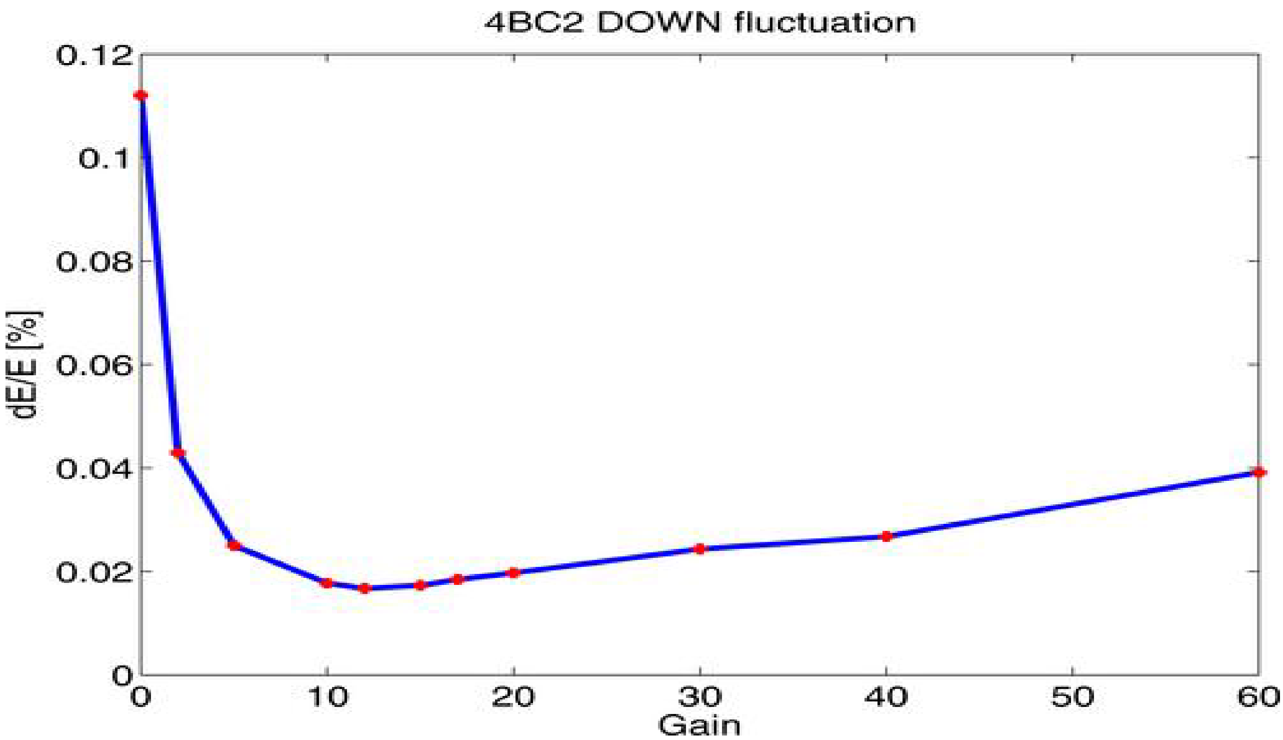

Fig 4. DMCS controller testing with new down-converter (DESY   17.03.2008)

Conclusion

The adaptive control procedure based on system model identification and feedback based feed-forward has been verified for the required cavity performance, i.e. driving on resonance during *filling* and field stabilization during *flattop* range.

The first measurements of beam energy stability has been performed. The comparison of achieved results is presented on figures 3 and 4 for two controllers: ISE and DMCS. The results seems to be comparable, however MCC controller has more flat characteristic with less dependence on gain factor.

The proposed controller has much simpler hardware structure managed by more sophisticated software LLA part. This solution is independent on the environment (e.g. klystron characteristics), as it adapts to the particular repetitive condition. It is more flexible, due dependence on the software LLA which is responsible for arrangement of the control algorithms by the control tables optimization.

References

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