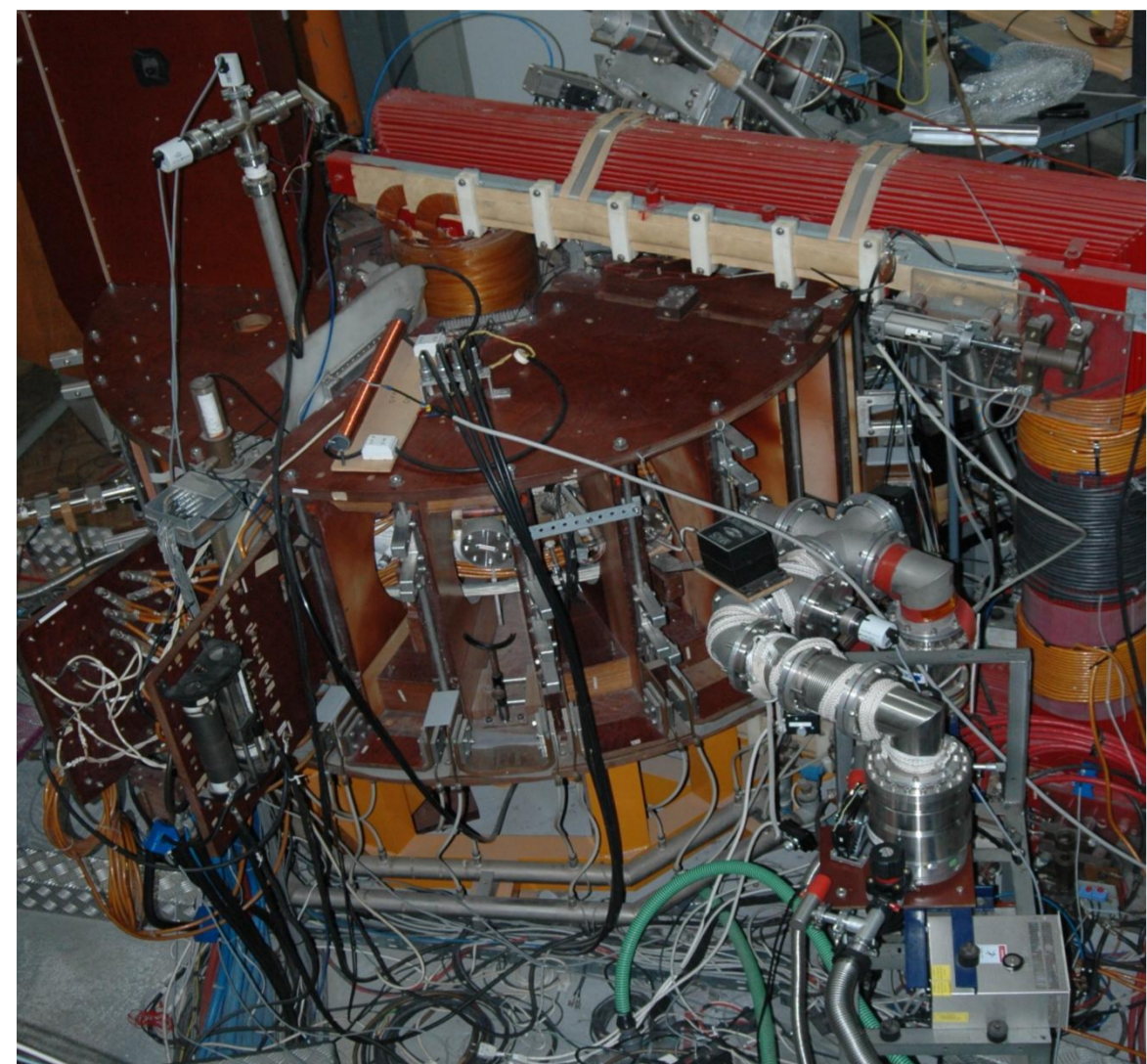


ISTTOK real-time control of AC discharges

I.S. Carvalho*, D.F. Valcárcel, P.J. Carvalho, H. Fernandes, C. Silva, J.C. Fortunato, A.S. Duarte, P. Duarte, A. Neto, T. Pereira, J. Sousa, B.B. Carvalho, A.J.N. Batista
 Associação EURATOM/IST, Instituto de Plasmas e Fusão Nuclear – Laboratório Associado – IST, Av. Rovisco Pais, 1049-001 Lisboa, Portugal
 *E-mail address: ivoc@ipfn.ist.utl.pt

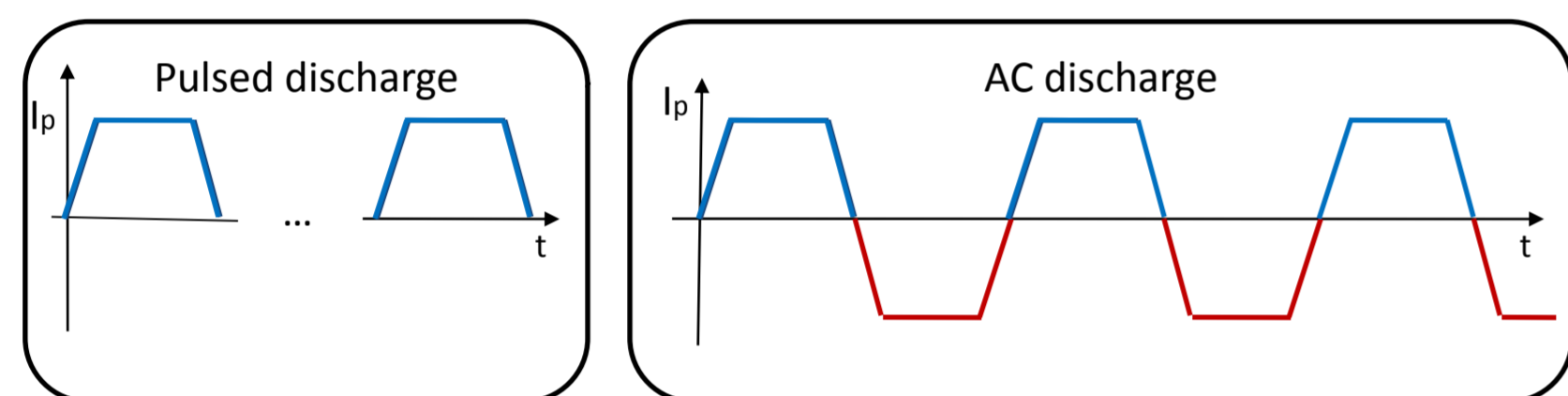
ISTTOK tokamak



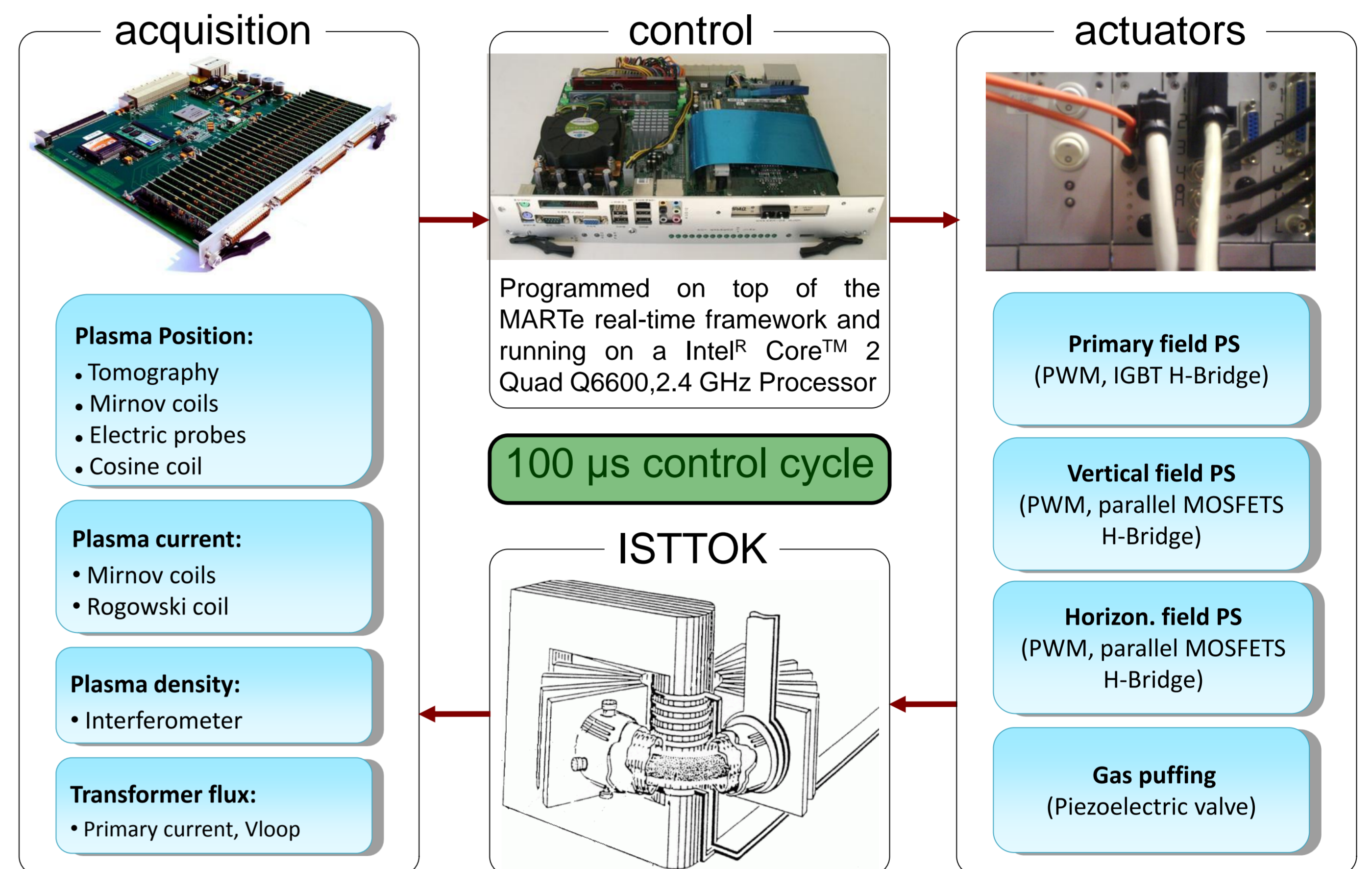
characteristics

Major radius 0.46 m
 Minor radius 0.085 m
 Plasma current < 7 kA
 Toroidal field < 2.8 T
 Discharge duration < 45 ms
 Plasma density < $5 \times 10^{18} \text{ m}^{-3}$
 Electron temperature (center) ~ 120 eV
 Toroidal flux swing = 0.25 Vs
 Energy confinement time ~ 0.8 ms

ISTTOK is one of the few tokamaks that have a regular alternate current (AC) discharges scientific program. In AC discharges, the current reversal should be as short as possible to optimize the plasma performance. However, plasma position becomes very difficult to control during this short period as a result of the low plasma current. In the current reversal the magnetic diagnostics are unreliable due to their low signal and other diagnostics such as the visible tomography have to be used for real-time control.



System description



Several diagnostics were connected to ATCA digitizers to provide real-time information for the control system including: tomography, Mirnov coils, interferometer, electric probes, current in the primary power supply, loop voltage and plasma current.

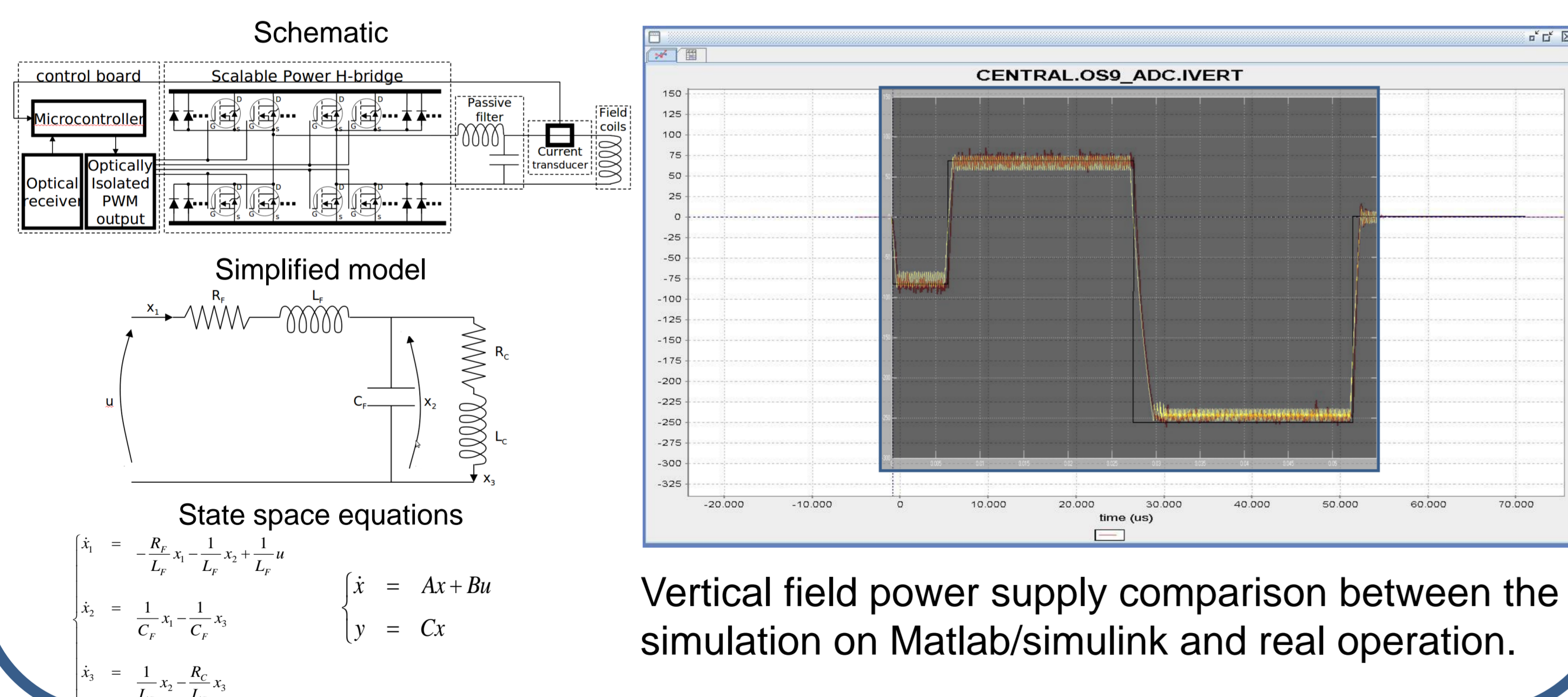
Actuators upgrade

ISTTOK tokamak actuators (vertical field power supply, horizontal field power supply, primary field power supply and gas puffing) were upgraded to be able to communicate with the ATCA control system.

Power supply	Com. speed	Control cycle	Voltage	current/control
Primary field PS	none	none	350 V	±200A, no control
Vertical field PS	781 kbps	20,48 μs	24 V	±230A, on/off + PID
Horizontal field PS	781 kbps	20,48 μs	24 V	±200A, PID

actuator	Com. speed	Control cycle	Voltage	current/control
Primary field PS	921.6 kbps	34,72 μs	350 V	±200A, PID or ATCA controlled
Vertical field PS	921.6 kbps	17,36 μs	60 V	±450A, PID or ATCA controlled
Horizontal field PS	921.6 kbps	17,36 μs	24 V	±200A, PID or ATCA controlled
Puffing	-	100 μs	-	ATCA controlled

Modeling of the new vertical field power supply



Schematic

control board: Microcontroller, Scalable Power H-bridge, Passive filter, Field coils, Current transformer, Optically Isolated PWM output, Optical receiver.

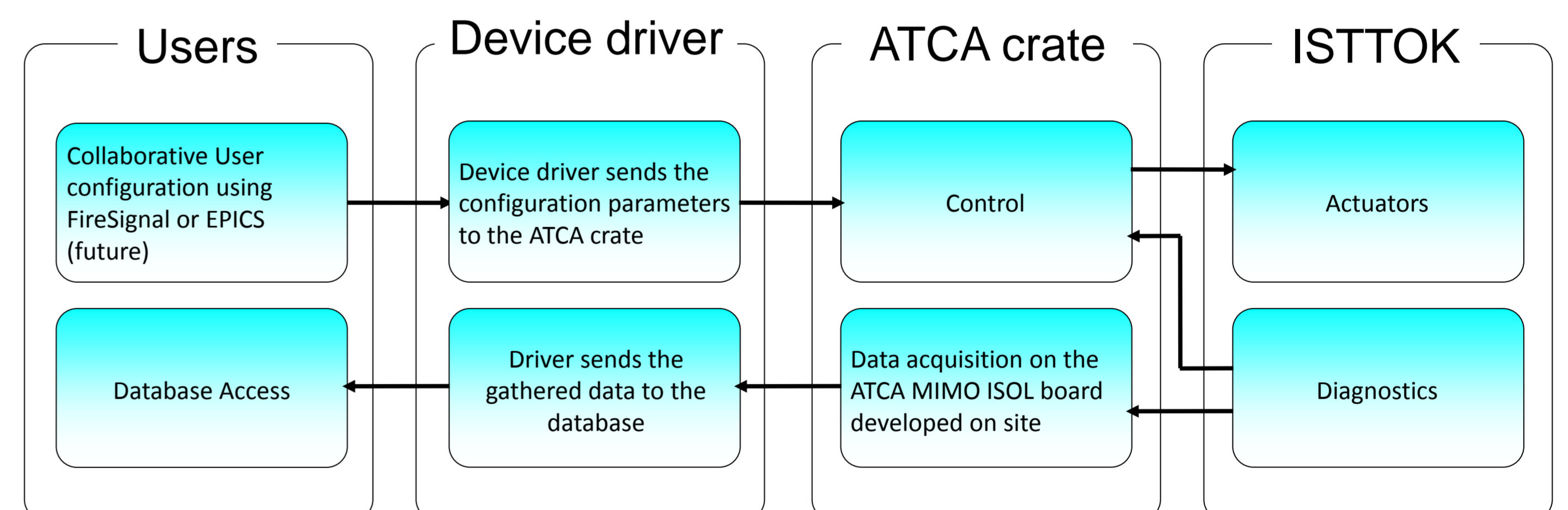
Simplified model

State space equations

$$\begin{cases} \dot{x}_1 = -\frac{R_p}{L_p} x_1 + \frac{1}{L_p} x_2 + \frac{1}{L_p} u \\ \dot{x}_2 = \frac{1}{C_p} x_1 - \frac{1}{C_p} x_2 \\ \dot{x}_3 = \frac{1}{L_c} x_3 - \frac{R_c}{L_c} x_3 \end{cases} \begin{cases} \dot{x} = Ax + Bu \\ y = Cx \end{cases}$$

Vertical field power supply comparison between the simulation on Matlab/simulink and real operation.

Operation



Operation modes

The system has a control cycle of 100 μs and operates in four different modes; (i) automatic mode, (ii) hybrid mode, (iii) single pulse discharge mode and (iv) preprogrammed manual mode.

The usual mode of operation is the automatic mode (i), where system controls all the plasma parameters in order to obtain the desired plasma current, monitoring the flux saturation of the iron core and inverting the current whenever this flux becomes saturated, the maximum runtime of the discharge is selected by the operator. In the other modes, the operator can pre-program a part (ii) (iii) or the entire (iv) discharge procedures, with the system always monitoring the safety limits.

Real-time implementation

The first layer of control was implemented on a ATCA system with the following characteristics:

- several blades with 32 ADC each (18-bit @ 20 kSample/s for control and 2MSample/s for data acquisition).
- Intel® Core™ 2 Quad Q6600 @ 2.4 GHz Processor.
- Fast serial optic communications (921.6 kbaud) with power supplies.

The control thread runs in an isolated CPU core at once every 100 μs using the Multi-threaded Application Real-Time executor (MARTe) framework. Each part of the control algorithm is implemented in C++ inside a well defined block of software, named Generic Application Module (GAM).

Synopsis

The new control system for ISTTOK is being commissioned in order to improve the stability of the plasma discharges, it will allow the machine operator to operate in several different regimes in a controlled environment with machine protection assured by the control system. Until now, only the plasma position was controlled with feedback on one of the available diagnostics. At the present time all the diagnostics are being integrated in order to control not only the plasma position but also the plasma current and gas puffing.

Next steps:

- Integration of all components.
- Extensive testing with regular plasma discharges.
- Multiple-Input Multiple-Output (MIMO) control.