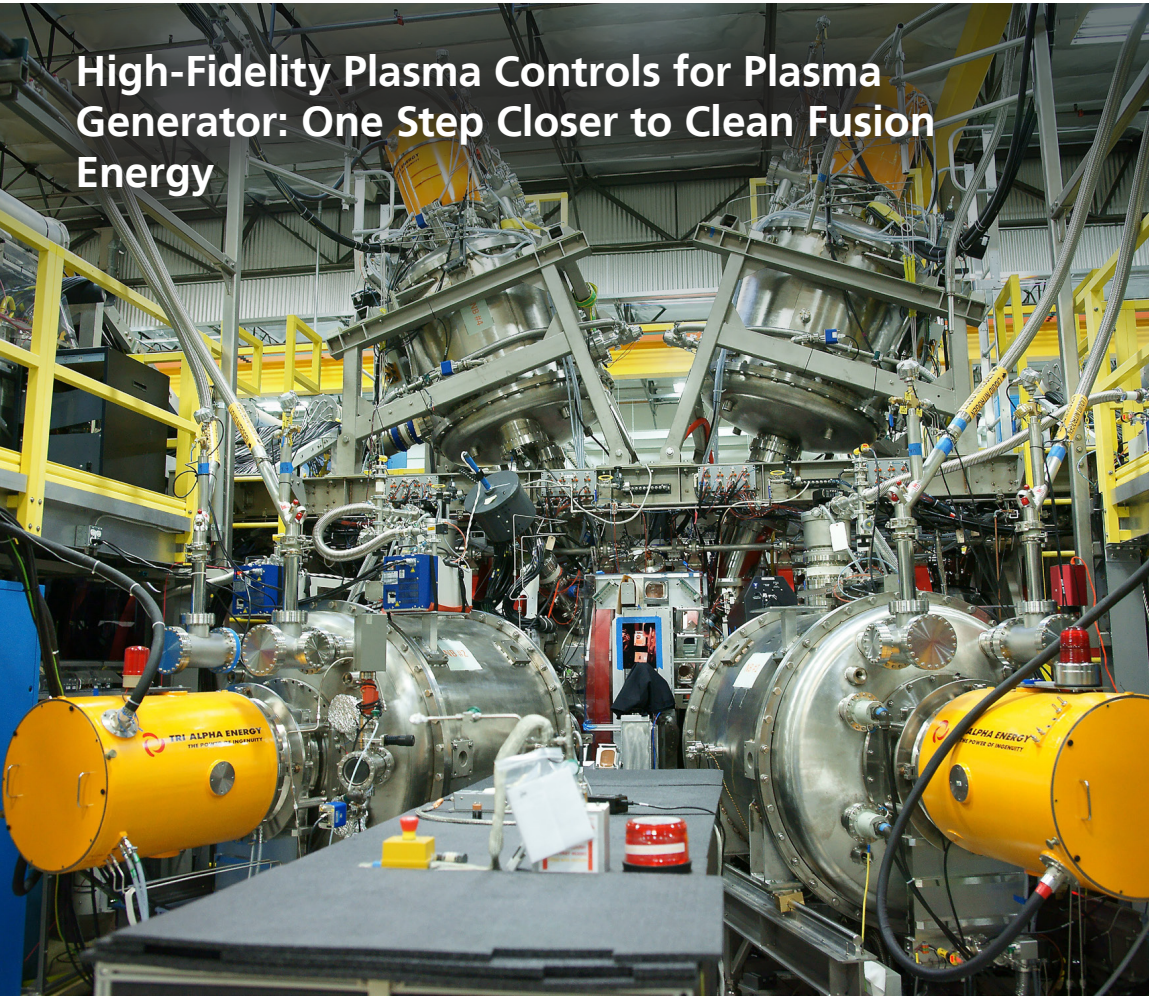
# TAE Technologies

## High-Fidelity Plasma Controls for Plasma Generator: One Step Closer to Clean Fusion Energy




speedgoat
real-time simulation and testing

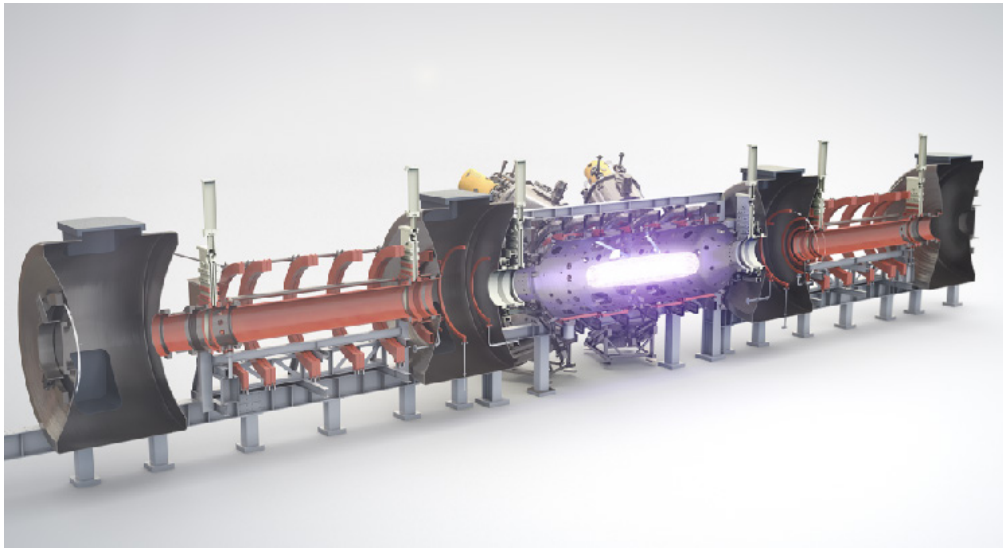


Illustration of the TAE Norman (C2-W) fusion device.

TAE Technologies (TAE) advances fusion research using Speedgoat real-time target machines including over 400 I/O links as distributed high-fidelity and low-latency plasma controllers.

TAE Technologies, the fusion power research company from Foothill Ranch, California is advancing the field of plasma physics with their innovative field-reversed configuration (FRC) plasma generator to create a controlled fusion reaction.

TAE's mission is to create and commercialize fusion energy that is sourced from a clean, safe, and affordable hydrogen-boron solution for a transformational source of electricity widely available in the future.

Their fifth-generation plasma generator, Norman, is ~20 m in length with a central confinement chamber surrounded by two field-reversed formation sources and four biased divertors.

The controlled fusion reaction happens inside the confinement chamber when two FRCs are shot at supersonic speed from either end towards each other.

The resulting collision transforms kinetic energy into thermal energy, merging the two into a single FRC plasma. Neutral beams are then applied to increase plasma performance and temperature.

## The Challenge

A well-known challenge of fusion is keeping the plasma well centered and away from the confinement vessel walls long enough to release sufficient amounts of harvestable fusion energy.

Early FRCs in the field achieved lifetimes of no more than a millisecond. However, with Speedgoat's contribution alongside others, TAE's Norman fusion device has achieved a steady state operation of hot FRC plasma (~ 30 Million degrees Celsius) for as long as the neutral beam power input lasts (~ 30ms).

The single FRC is stabilized using state of the art feedback control techniques. This requires the plasma shape and position to be inferred with low latency (<10 µs) from hundreds of magnetic field sensors located outside the plasma.

The device settings of the Norman fusion device are further optimized between consecutive experiments using the Optometrist Algorithm, a joint research partnership between TAE and Google.

## The Solution

Speedgoat delivered the core functionality and overall acquisition and control system setup, including implementation, for TAE's Norman.

The use of the Simulink® and HDL Coder™ workflow enables a quick and easy transition from model-based designs to hardware, thereby utilizing multi-gigabit transceivers and the Xilinx® Aurora protocol.

Magnetic sensors are connected over an integrator circuit to the differential analog inputs located inside of 4 x acquisition systems from Speedgoat. This modular setup accommodates up to 384 sensors, with allowance to expand if required.

Each acquisition setup is also equipped with a Simulink programmable FPGA I/O module to act as a local control.

The sampled magnetic field A/D data are:

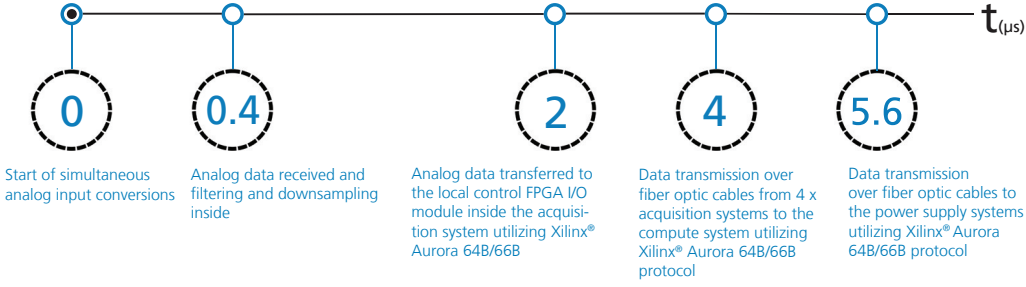
- logged and stored at a 2.5 MHz sample rate
- filtered and downsampled and transferred to the local control FPGA I/O module at 166kHz
- forwarded to the compute system utilizing Xilinx® Aurora protocol and copper cables.

The central control system includes:

- 2 x Simulink-programmable FPGA I/O modules running multiple state-space models used for inference and control, with ~10µs computation time and optimal resource optimization
- 8 x QSFP ports to send new control values to power supplies
- 2x FireFly ports for inter-module data transfer and communication.

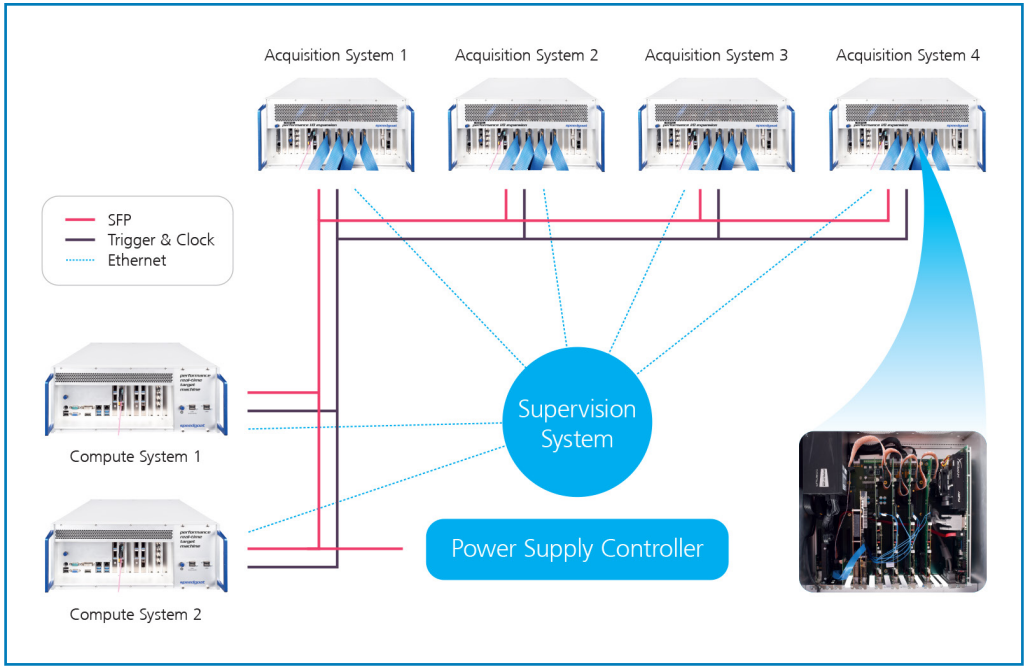
## The Results

The following timeline illustrates the achieved data paths and latencies:




"The Speedgoat solution provides a unique combination of high throughput, low latency I/O and a high-level programming workflow using MATLAB® scripts, Simulink® and HDL Coder™, which is ideal for TAE's fast paced research environment."

Jesús Antonio Romero, Lead Scientist, TAE Technologies




Acquisition and compute systems setup using multiple Performance real-time target machines, I/O modules and communication protocols for the Norman.

**Utilized Speedgoat products:**

» 7 x Performance real-time target machines
» Simulink-programmable FPGA I/O modules with analog and digital I/O and Xilinx® Aurora 64B/66B protocol support

**Utilized MathWorks products:**

» MATLAB®
» Simulink®
» MATLAB Coder™
» Simulink Coder™
» Simulink Real-Time™
» HDL Coder™
» Signal Processing Toolbox™
» Fixed-Point Designer™
» Stateflow®

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