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Controls for a 10 Petawatt Class Laser Facility

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Abstract

Computerised controls are vital to the operability and flexibility of large-scale physics facilities (such as accelerators, synchrotrons and high-power lasers) in providing fundamental services, for example: automatic configuring of specialist hardware; motion control; firing of shot sequences; enabling precision trigger distribution; vacuum monitoring and control, data acquisition and analysis.

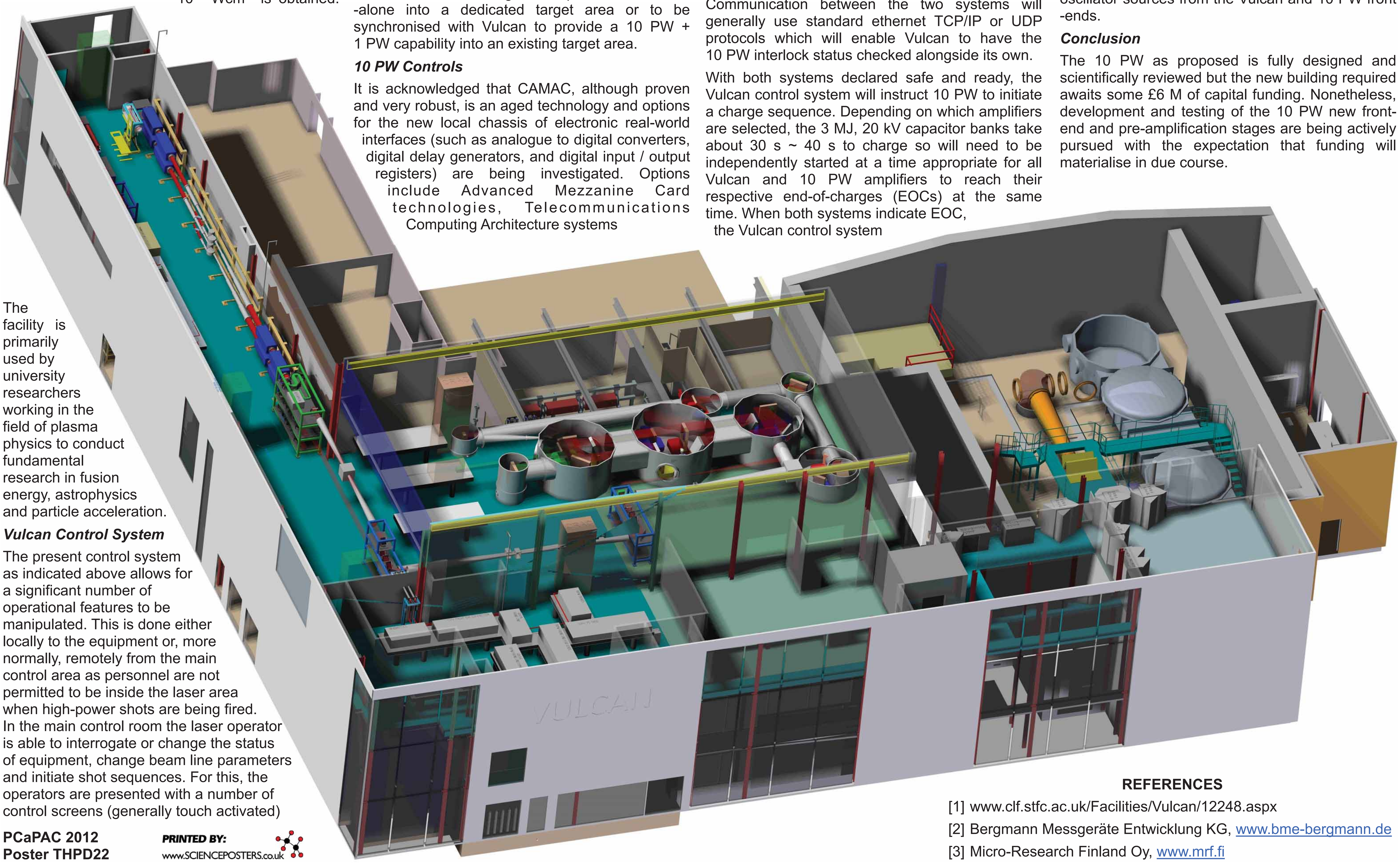
The proposed 10 PW Laser Facility (300 J, 30 fs, 10^{16} W), in line with other major physics facilities around the world, will require a complex computer control system. This is expected to be modelled on the existing Vulcan Laser [1] computer control system and consist of a dozen or so Windows based PCs each of which will be running a separate and dedicated application to control a particular area or function of the facility.

This paper will present an overview of the existing Vulcan laser and provide a status report on the development towards the 10 PW which will require the control system to be designed to allow autonomous operation of the 10 PW Facility as well as to be fully integrated with the existing Vulcan laser controls for combined and synchronised 10 PW plus 1 PW operations.

INTRODUCTION

The Vulcan Laser

Vulcan is a high-power Nd:glass near-infrared laser with a physical footprint 75 m by 50 m (about the size of a couple of Olympic-sized swimming pools). It has roughly 250 m of optical beam path from the various laser oscillator sources through the numerous laser amplification stages and on to the target areas. The laser is a multi-beam pulsed system with 'long' pulses of 0.3 ns to 6 ns duration synchronised with 'short' pulses of 500 fs to 20 ps duration. The initial short pulses start at the nJ level with 1 mm ~ 2 mm diameter beams and are amplified up to 500 J at 600 mm beam diameter providing a peak power of 10^{15} W i.e. a Petawatt. Using a large (1 m diameter) off-axis parabola, this beam is then focussed down to 5 microns onto various targets, where an intensity of up to 10^{21} Wcm^{-2} is obtained.



The facility is primarily used by university researchers working in the field of plasma physics to conduct fundamental research in fusion energy, astrophysics and particle acceleration.

Vulcan Control System

The present control system as indicated above allows for a significant number of operational features to be manipulated. This is done either locally to the equipment or, more normally, remotely from the main control area as personnel are not permitted to be inside the laser area when high-power shots are being fired. In the main control room the laser operator is able to interrogate or change the status of equipment, change beam line parameters and initiate shot sequences. For this, the operators are presented with a number of control screens (generally touch activated) which gives them access to a real-time overview and control of the current state of the laser hardware. Figure 1 shows three of the central control interfaces used by the operators. These and other key control applications have been written in-house using Delphi 7 (visual Pascal) a choice that has allowed the development of a very robust and flexible operational system.

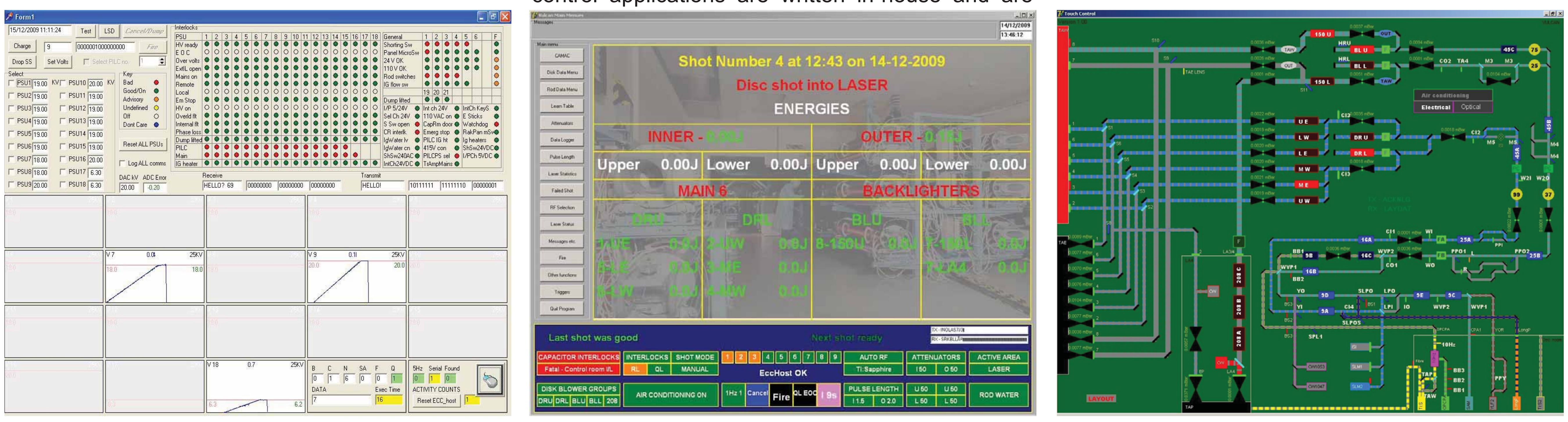


Figure 1: Laser Operators central control screens for (left) the high voltage capacitor bank controls; (middle) the main control, data acquisition and diagnostic interface; and (right) the system schematic showing overall active status of individual components.

Behind the screens is a private, isolated Ethernet network with a distribution of thirteen PCs and nine CAMAC crates. These are variously populated with analogue and digital electronics to drive, for example, pneumatic slides and oscillator timing controls or, to capture flashlamp discharge waveforms and provide interlock monitoring.

10 PW DEVELOPMENT

Overview

Physically the 10 PW will be another large-scale laser system and it is proposed to be built as a major extension alongside the existing Vulcan system. The 10 PW will be driven with a new front-end oscillator to generate the much shorter optical pulse length of 30 fs but for the main amplification to 300 J it will use flashlamp-pumped Nd:glass amplifier technology similar to that already used in Vulcan.

The 10 PW will be designed to operate either stand -alone into a dedicated target area or to be synchronised with Vulcan to provide a 10 PW + 1 PW capability into an existing target area.

10 PW Controls

It is acknowledged that CAMAC, although proven and very robust, is an aged technology and options for the new local chassis of electronic real-world interfaces (such as analogue to digital converters, digital delay generators, and digital input / output registers) are being investigated. Options include Advanced Mezzanine Card technologies, Telecommunications Computing Architecture systems (such as Advanced TCA or µTCA), PCI extensions for Instrumentation (PXI), compact PCI (cPCI) crates and Industry Pack modules.

Because of the close proximity, similarities and linkage between the two systems the 10 PW could be seen 'simply' as an extension of Vulcan, so far as the controls are concerned. As the Vulcan control applications are written in-house and are somewhat modular in form the 10 PW computer controls are expected in principal to be copied from Vulcan and modified to suit the new hardware.

Keeping the same modules allows integration between the two laser systems to be readily achieved. Keeping the same forms of display also allows for an easier operational integration with Vulcan as display screen familiarity will have an impact on minimising training needs.

Control Synchronisation

In the tandem operational mode where Vulcan and the 10 PW laser systems are required to fire together, it will be important to have the shot sequencing of both systems operating in parallel at the same time. It also is expected that the 10 PW in this mode will be operated remotely from the Vulcan control area. This will need the Vulcan control system operating as a master controller and the 10 PW running as a slave system. Communication between the two systems will generally use standard ethernet TCP/IP or UDP protocols which will enable Vulcan to have the 10 PW interlock status checked alongside its own.

With both systems declared safe and ready, the Vulcan control system will instruct 10 PW to initiate a charge sequence. Depending on which amplifiers are selected, the 3 MJ, 20 kV capacitor banks take about 30 s ~ 40 s to charge so will need to be independently started at a time appropriate for all Vulcan and 10 PW amplifiers to reach their respective end-of-charges (EOCs) at the same time. When both systems indicate EOC, the Vulcan control system will initiate a cascade of electrical triggers for both Vulcan and 10 PW shot usage.

Trigger Requirements

A range of diagnostic and data acquisition systems will require specifically timed triggers. Triggers one second early can easily be provided programmatically as part of the shot sequence but later or more precise triggers will require separate hardware. Triggers 10's of millisecond early can be readily created through the use of digital delay generators whether these are stand-alone units or part of the chassis electronics; nanosecond triggers will need more sophisticated hardware (such as the use of precision delay generators from Bergmann [2], or Micro-Research [3]) which allows for a master trigger cascade to be produced synchronous to an RF cycle derived from the optical pulse train output of the 80MHz source laser oscillator.

Optical Synchronisation

For the combined operation of Vulcan with 10 PW there will need to be precise temporal synchronisation at the target of both the 500 fs pulse from Vulcan and the 30 fs pulse from 10 PW. This will be a challenge and will require extremely finely tuned optical phase-locking together of the oscillator sources from the Vulcan and 10 PW front -ends.

Conclusion

The 10 PW as proposed is fully designed and scientifically reviewed but the new building required awaits some £6 M of capital funding. Nonetheless, development and testing of the 10 PW new front-end and pre-amplification stages are being actively pursued with the expectation that funding will materialise in due course.

REFERENCES

[1] www.clf.stfc.ac.uk/Facilities/Vulcan/12248.aspx

[2] Bergmann Messgeräte Entwicklung KG, www.bme-bergmann.de

[3] Micro-Research Finland Oy, www.mrf.fi