Close-in Contrast Measurements of the New ps OPCPA Front End

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Introduction

In high intensity laser matter interactions the contrast of the laser pulse can be crucial to the outcome of the physics. In this article we discuss the addition of a picoseconds optical parametric chirped pulse amplification (OPCPA) stage to the Vulcan front end improving the amplified stimulated emission (ASE) by more than 2 orders of magnitude.

The technique of Optical parametric chirped pulse amplification (OPCPA) is becoming increasingly popular as pre-amplifiers for seeding laser systems [1,2] and as potential amplifiers for extremely high peak power systems. This is because they are capable of amplifying a broad bandwidth and can have large gains. Our previous study of the ASE contrast of the Vulcan laser system [3] demonstrated that the parametric fluorescence (PF) generated by the nanosecond OPCPA pre-amplifier acted to seed the rest of the amplification chain.

Picosecond OPCPA Preamplifier

The upgraded front end introduces a single picosecond stretch and then an OPCPA stage to generate a clean high energy seed pulse that is then injected into the Vulcan laser. Unlike other schemes [1], only the seed is stretched. This has a number of advantages that are explained below. Figure 2 shows a schematic of how this is achieved. The output from the Ti: Sapphire oscillator is divided into two with pulses being amplified in a Nd:YLF regenerative amplifier and stretched in a grating stretcher. As the pulses are amplified in the regenerative amplifier gain narrowing occurs that acts to increase their pulse length to 10ps. The output pulses are frequency doubled to 527nm with energies of 700μJ. These form the pump pulses for the picosecond OPCPA. The temporal profile of the output pulse means that the instantaneous small signal gain also varies. Consequently the seed pulses must be stretched to best match the pump pulse profile to extract energy efficiently and ensure close to uniform gain across the spectrum. The pump pulses are imaged into the BBO crystal and demagnified to a beam diameter of 1mm. The seed pulses are stretched to 3ps in a single grating stretcher. The stretcher is comprised of a grating with a line density of 1500 l/mm and an imaging lens as shown in figure 2. A retro-prism is employed to remove the spatial chirp and ensure a uniform beam. The stretcher has the added advantage that the lens and the back mirror are mounted on a single translation stage enabling the pulse length to be tuned. Since the picosecond OPA is degenerate a small ~2mrad non-collinear geometry is employed so that the seed and idler beams can be separated. The picosecond OPA generates pulses that have 70μJ of energy representing a conversion efficiency of 20% and are then injected into the existing nanosecond amplification system.

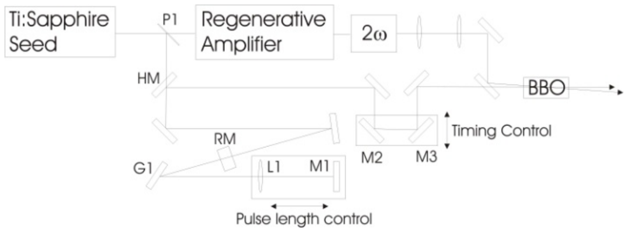

Figure 1: Schematic of picosecond OPCPA preamplifier

Rod Chain and Disk Amplifier Bypass

To examine the close in contrast to ascertain any changes introduced by the initial stretcher stage we have installed a beam line that by-passes the amplifier chain and relays the pulses from the front-end directly to the compressor chamber. This enables the use of a scanning 3rd order device to characterize the contrast. Figure 2 shows part of the bypass installed next to the main six in LA2 and LA3. Vertical propagation was enclosed.

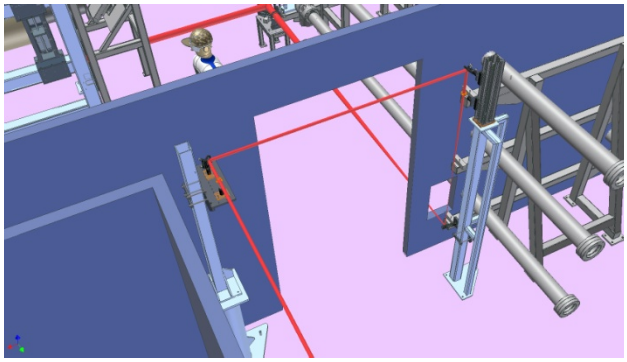

Figure 2: CAD drawing of part of the bypass in LA2 and LA3

TAP Diagnostics Line

The Contrast Monitor and 3rd order cross correlator (Sequoia) were set up on a diagnostics table outside the TAP vacuum chamber. There are several porthole windows that allow beams to be delivered out of the vacuum chamber. The beam must propagate several meters to the diagnostics table, maintaining spatial beam quality and size. The input aperture of the Sequoia is 5 mm and the beam must enter the device without clipping. Image relaying the beam using long focal length lenses ensures the spatial quality of the beam. The beam must be reduced in size by a factor of four in two stages to avoid breakdown of the beam in the air. Figure 2 shows the diagnostics beam line, set up to demagnify and image relay the beam out of the TAP vacuum chamber and on to the diagnostics table. After the compressor, the beam is 600 mm in diameter and focused on to the target centre via an f3 off axis parabola inside the target chamber. The beam is recollimated using a 37.5 mm lens, mounted on the target stage. The target stage is motorized, allowing adjustment of the collimation after the gate value is opened under vacuum. The beam is repointed using two, and it is reduced using a 2:1 telescope which also relays the beam through the window. The beam us collimated as it propagates through the window to avoid picking up aberrations such as astigmatism. The beam is image relayed through a second 2:1 telescope and arrives at the diagnostic table with a diameter of approximately 4 mm.

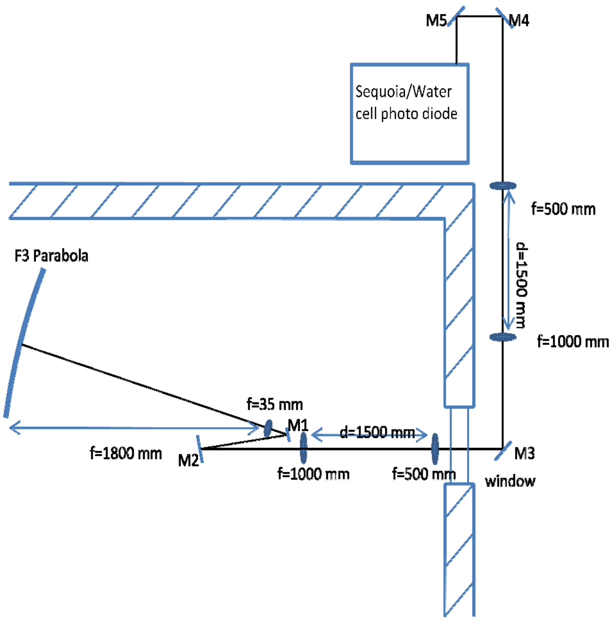

Figure 2: Layout of the TAP diagnostics line

Initially a single shot autocorrelator was used to adjust the ns stretcher to ensure that the 3 ps stretch had been compensated for. This confirmed that the pulse length was 500fs after compression.

Contrast Monitor

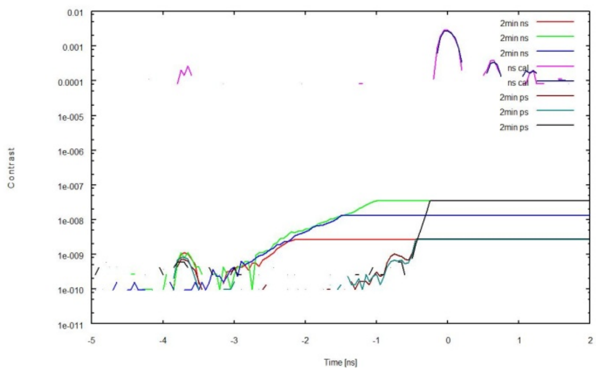

Figure 3: Contrast diode traces

A contrast monitor is a device that has been developed to measure the contrast of high energy, short pulses using a fast diode and a water cell [4]. Figure 3 shows a comparison of the photo-diode traces for the high and low energy seed input configurations. These traces were recorded using only the rod amplifiers and the OPCPAs this is because the damage threshold of the collection optics restricts the amount of energy that can be generated in the laser system. The rod amplifiers act as spectral filters for the PF generated by the OPCPAs limiting the PF's bandwidth to that supported by the rest of the amplifiers in the system. The disk amplifiers have small SSGs (Small Signal Gain) in comparison to the other amplifiers in the system so do not contribute significantly to the ASE level. As can be seen in figure 3 the dynamic range of the diode set-up is 10^{10}. For the low energy seed the ASE starts approximately 3ns ahead of the main pulse. For the high energy seed the ASE starts within 1ns of the peak of the pulse. The dynamic range for the diodes is achieved using an intermediate focus in a water cell to prevent damage to the diode and by using convolution to calculate the under measurement of the peak of the pulse.

3rd Order Cross Correlation

A Sequoia is a commercially available 3rd order cross correlator which is used to measure close in contrast, pulse pedestals and prepulses. It is a multi shot device that temporally scans the pulse. As can be seen from figure 4 the contrast drops to 10^8 at 30ps and corresponds to the dynamic range of the instrument, limited by the scatter or THG on the 2ω arm of the device. The trace shows that there are no significant pre-pulses generated by the front-end within 100ps of the pulse which equates to the scanning range of the instrument. Scans beyond the peak of the pulse also do not show any significant post-pulses that might become pre-pulses during the amplification process due to accumulated non-linear effects.

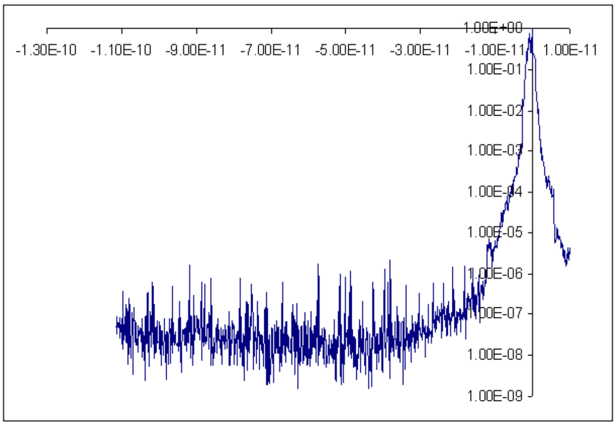

Figure 4: Sequoia temporal scan

Conclusions

In this article we have reported on the development of a novel dual OPCPA pre-amplifier system to seed high energy laser systems. That is sufficiently stable to be injected into the rest of the Vulcan laser system and leads to a direct improvement of the ASE contrast by at least 2 orders of magnitude without degrading the performance of the laser system. The Vulcan Petawatt laser system now has an ASE contrast of 10^{10} at 1ns, at 100ps the contrast is better than 10^8 and the PF caused by the ps OPA starts at 30ps. Further improvements could be achieved by increasing the amount of ps OPCPA pre-amplification, this might be achieved by adding an extra stage of amplification on the ps pump laser.

References

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Vulcan Rod Amplifier Upgrade

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Introduction

The Quantel rod amplifier control system and power supplies have been operating and running successfully on the Vulcan Laser System since the system was inaugurated in 1975.

We report on the programme to replace this control system and capacitor banks.

Reasons for replacement

The original suppliers of the equipment, Quantel SA [1], no longer manufacture or even support the electronics for the rod amplifiers and consequently the equipment has become obsolete. Therefore, it was necessary for the rod amplifier capacitors and control system to be replaced, as it posed a serious risk towards the future operation of Vulcan.

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Figure 1 – Old Quantel units inside the Vulcan Main Control Room.

Figure 2 – Old Quantel rod amplifier racks inside Laser Area 1 that charged the 16mm and 25mm amplifiers.

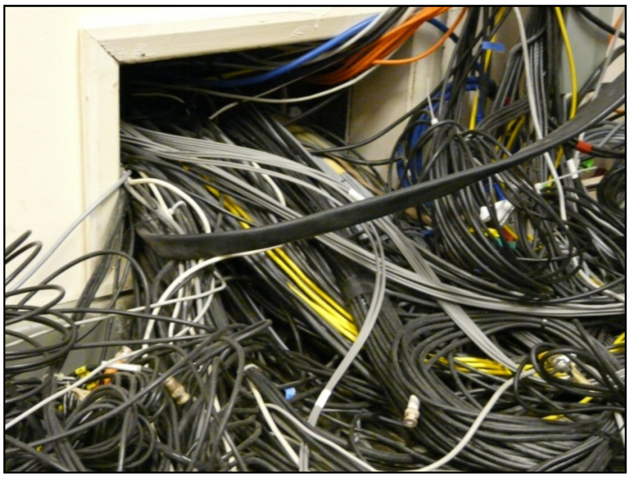

Figure 3. Cables running from the control room to the laser areas.

Figures 1 and 2 show the old Quantel units located in the control room and within the laser area. Figure 3 shows the cluster of cables coming from the only cable ducting in the control room to the laser areas - clearly unmanaged and with little capacity remaining.

Purchasing and preliminary testing

In order to minimize risks, the decision was taken to replace only the electronics (control system, power supplies and capacitor banks), not the amplifier heads since these were designed and built at RAL and could be maintained. Following a competitive tendering process the contract was placed with Quantel SA for replacement of capacitor banks and the hardware was purchased in 2008.

Testing of the new power supplies and control software was performed off line in 2008 proving the successful operation of individual rod amplifiers. An entire rod chain was powered successfully on the Vulcan laser system in April 2009. Operating the rod amplifier chain with the new capacitor banks showed an average (from 10+ shots) of 86.1% +/- 0.4% of the old system (which is run with all amplifiers at 2.2kV). The maximum voltage of the new capacitors is 2.0kV. Operating the complete beamline at this lowered voltage provides sufficient system gain whilst extending component lifetimes.

Shutdown schedule

The Vulcan laser was shut down for three months from 12th August until 9th November to allow the replacement of the rod amplifier racks from inside the control room and laser areas with six new racks inside Laser Area 1. The timetable was as follows :

- Weeks 1-7 : Old equipment removal, cable labeling and rationalization
- Weeks 8-9 : New Quantel equipment installed in Laser Area 1
- Week 10 : Commissioning new power supplies
- Weeks 11-13 : Re-commissioning Vulcan – beam alignment and timing

Removal of equipment and cabling

Optics inside the laser areas were sheeted down to prevent accidental damage and dust accumulating on their surfaces. There was no direct access to remove racks from the middle of Laser Area 1. A vacuum spatial filter was removed and many low-lying cables were disconnected to allow the old Quantel racks to be moved out of the area; this was a common theme during the project in order to manoeuvre the large cumbersome racks.

The shutdown period was also an opportunity to clean up the Vulcan laser area and control room in general, as an accumulation of cables had built up over the last 30 years. This has led to an increased difficulty when installing new systems when many old systems have not been completely removed from the area, taking up unnecessary space and causing even more confusion in the area.

A total of 400 cables were labeled and documented, and then disconnected in order to facilitate the removal of the existing Quantel power supplies. The control desk was also removed and some of the redundant equipment was donated to Imperial College with documentation. Strict cable management was vital to complete the project on time. This involved keeping an up to date record of all the cables that were disconnected, removed redundant cables, tidying cable runs and salvaging the Quantel rod amplifier cables from the system.

The unmanaged cable situation had built up over the long operating lifetime of Vulcan. The result of improved cable management is that whereas it was previously unmanaged and confusing, tracking systems of cables is now far more streamlined enabling the installation of new hardware.

Installation of new equipment and system commissioning

By mid-October the new power supplies had been installed. A significant visual improvement was achieved with more walkway space available on both sides of the racks (Figures 4 and 5).

Figure 4 – Laser Area 1 with new Quantel hardware installed.

Many redundant systems have been removed, reducing confusion amongst staff and mess in Vulcan. Approximately a thousand cables were disturbed during the shutdown. If one of these were a working cable in the system and was not correctly reconnected the system would not function properly. A few trigger cables for cameras were found to be not reconnected properly during the start-up, which were quickly diagnosed and fixed.

Software issues became apparent during testing, which were eventually resolved. The new rod amplifier electronics were commissioned with very few problems, and the project overran by only three days. The first shot after the shutdown achieved the required energy with the new Quantel rod amplifier racks.

Figure 5 – New Quantel racks, located on north wall of Laser Area 1, to power the 45mm rod amplifiers and control processing and power of both rod chains.

Refurbishment of the main control room

The Vulcan Main Control Room is intended to become the focal point for visitors to the CLF. Once the new Quantel racks were installed, a new space had become available in the room for a larger Vulcan controls and diagnostics desk; allowing more monitors, PCs, communications and working space. Along with this new operations desk, new display furniture has been installed for improved operations. In addition, the new control room allows for more effective communications during external visits to the CLF.

Conclusion

The upgrade was successfully completed three days overdue and user experiments commenced on Monday 9th November 2009.

Although the project as a whole was a success, there were potential pitfalls that could have caused the project to fall far behind schedule, such as lack of staff co-ordination and available expertise. The experience gained from this project will aid the future success of the upcoming six-year 10 Petawatt upgrade project.

Reference

1. Quantel SA, 2 Bis Avenue du Pacifique BP23 91 941 Les Ulis cedex, France. www.quantel-laser.com.

Vulcan Computer Control System Upgrade

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Introduction

Apart from the obvious need for significant numbers of laser optics and components, the successful operation of the Vulcan high-power laser over the past several decades has been heavily dependent upon sophisticated electronics, high voltage pulsed-power units and computerized control systems. This paper reports recent major changes to the computer control systems.

Historical Background

The computer controls on Vulcan originated (in the late 1970's) with a GEC 4080 "mini" computer but in the mid 1980's this was removed in favour of a pair of IBM 286 DOS-based PC's. Over the following decades the network gradually grew in size and complexity with (by the late 1990's) some peripheral PC's running Windows NT / 2000 but with the core fundamental laser control PC's remaining DOS.

As for the two rod amplifier chains, although these had seen a number of mechanical and optical re-designs, the essential pulsed power of capacitor banks, charging units and electronic control units have remained those as originally supplied from Quantel, France, over 30 years ago.

With loss of key people with their knowledge and experience as well as deteriorating serviceability of the respective software and hardware, both the main Vulcan computer and the Quantel control systems were ripe for replacement.

The Conversion

The project to rewrite the sophisticated computer control system, converting everything to windows XP, turned out to be more complex than originally thought and became a four year project. The bulk of the development for this took pace offline with the final windows controls being tested during the normal inter-experimental maintenance periods, a process which ensured minimal operational downtime.

The new windows control software was installed in parallel with the existing DOS controls so that, as far as was possible, online testing could be facilitated and the control functions switched between the two systems fairly quickly.

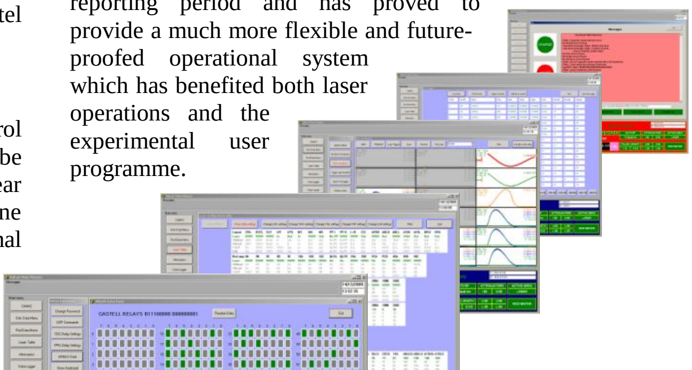
The DOS was "switched off" in June 2009 and (after a successful operational period using the new system) was finally removed during the September - November shutdown.

The full laser control network now comprises of a dozen PCs running Windows XP and with around 80,000 lines of code (predominately Delphi and LabVIEW). The three main (and independent) touch-control screens are depicted in figure 1 below with (left) the disk amplifier / capacitor bank control screen; (middle) the main control screen with many control functions and diagnostic report forms and (right) a layout diagram showing the schematic of the laser.

In addition there are many diagnostic PC's which are sent various commands during operations to facilitate shot sequencing, data capture and archiving.

Conclusions

The system has been operational for the bulk of this past reporting period and has proved to provide a much more flexible and future-proofed operational system which has benefited both laser operations and the experimental user programme.



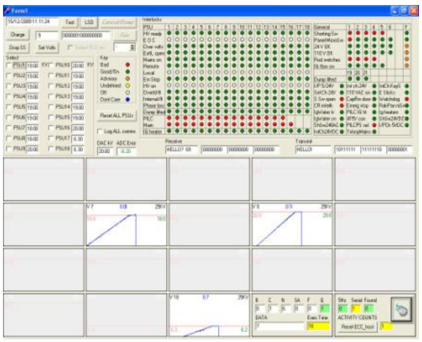


Figure 1a - Disk amplifier control and diagnostic screen showing capacitor bank interlocks and high-voltage charging graphs.

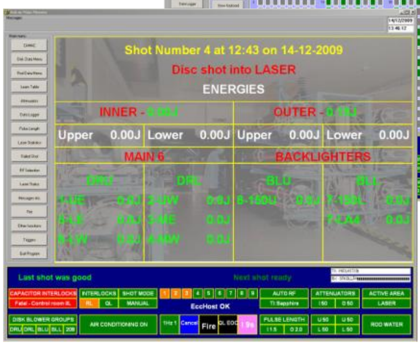


Figure 1b - Main control screen giving access to prime control functions and diagnostic data such as the shot firing sequence and waveform displays.

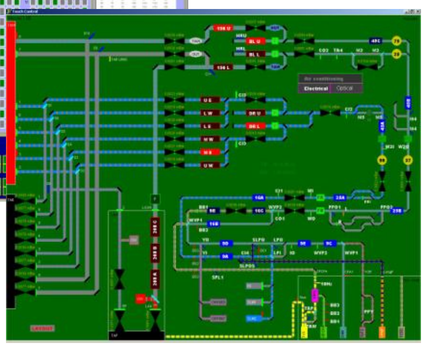


Figure 1c - Schematic of the laser providing direct control of components via the touch screen interface.

The Vulcan 10PW project – Building Design

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Introduction

A key aspect of the Vulcan 10 PW project is the new building that will house the large amount of equipment required for the 10 PW laser facility. A basic conceptual design was developed during phase one of this project [1)]. This design extends the current building (R1) to maximise the available space within the limited surrounding land at RAL.

In preparation for the start of phase two of the project a team consisting of STFC staff and external consultants has been working hard for the past six months to develop the Vulcan 10PW building design.

During this period the design brief has been agreed, initial surveys conducted, risks reviewed, the layout developed to incorporate operational requirements, disabled access, fire strategies etc, and the structural design and services outlined. A value engineering exercise has also been conducted to prioritise the various design elements against the available budget.

The 10PW management team have now agreed a conceptual design for the building that has been costed to a level adequate for the project to proceed to the building detail design, ready for anticipated tender action in the Autumn of 2010. This article describes the agreed building design concept.

Building Objectives

The primary building objectives were:

- To provide a building that is fit for purpose in relation to the occupants and equipment that it will accommodate.
- To provide a building that caters for the installation, and possible future removal, of major items of equipment.
- To meet the financial constraints of the project. The current building project budget is £5m (excluding contingency).
- To meet the project timescales. The current 10PW project program schedules handover of the building in the Autumn of 2012 .
- To provide a design which can be built with minimal impact upon ongoing CLF (and other departments) activities in the existing and nearby buildings.

Overview of areas

The area that the 10PW building extension will occupy is shown by the red lines in figure 1 and by the yellow shaded area in figure 2. The building will comprise of:

• New HIA (High Intensity Area) combining current TAE (Target Area East) and South Control Room extended to the south.

Figure 1. Location for 10PW building extension.

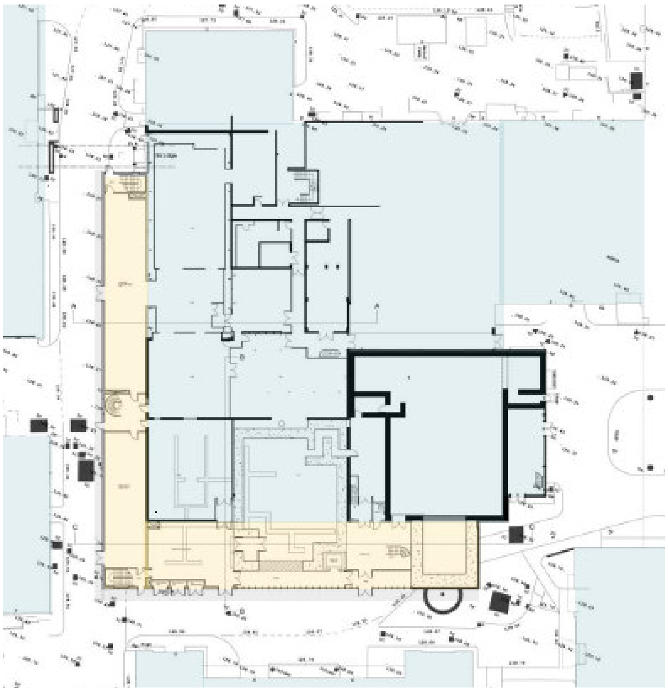

Figure 2: Site Plan showing extent of 10PW building extension

• New Target Area Control Room (combined for TAW & HIA) to the south of TAW (Target Area West).

• New Optical Parametric Chirped Pulse Amplification (OPCPA) Compressor and Diagnostics Area (Laser Area 7) above the current TAW & new HIA.

• New OPCPA long pulse amplification laser area (Laser Area LA6) to the west.

• New OPCPA front end laser area

• New OPCPA laser control room

• New laser amplification area (Laser Area 5) to the west for possible additional long pulse beams.

• An extension of TAP (Target Area Pettawatt) to the south with a shielded Electron Beam Dump Area.

• New Pulsed Power Area to the west.

• New entrance/atrium for the Vulcan facility.

• New building and CLF plant services areas.

Image

The design team developed a number of key words and phrases that attempt to encapsulate the image that the CLF wishes to portray in the design and detail of the facility:

• Open and interactive

• Modern and impressive facade

• Progressive

• Light and airy

• Excellence

• Safe and healthy

• Accessible to all

• Conscious of the environment

Primary Design Determinants

The primary design determinants are as follows:

The CLF attaches great importance to the design quality of all installations and this must be continued in the design and delivery of this facility.

The design proposals should provide opportunities to encourage interaction between staff.

Security arrangements must allow 24hour, 7 days per week access for designated staff and users. CCTV supervision for security of the new facility will not be incorporated however CCTV between control rooms and target/laser/ancillary areas is required for safety reasons.

Where possible the design should seek to utilise environmentally friendly, low carbon, sustainable solutions and energy efficient features. The use of natural daylight will be considered as well as the appropriate use of materials and M&E technologies.

Comfort, air quality and environmental stability for equipment and apparatus must achieve best practice for such an installation.

Design proposals will take full cognisance and support the implementation of CLF logistical and safety requirements.

Statutory regulations, including Building Regulations and the Disability Discrimination Act (DDA) require that proper provision be made for people with disabilities, though exemptions may be sought where the nature and severity of the disability is inherently incompatible with good health and safety practice. The new visitor access areas will comply with DDA.

Systems should be as simple as possible with adequate, safe, easy access provided to all parts of the installations. They should also be designed taking into account the limited resources available to the STFC for operating the plant. It is important that M&E systems are designed so that they can be repaired, maintained, inspected and extended with minimal disruption to the building user. Maintenance access to the rooftop of the new facility will be provided if necessary for servicing of building plant.

Viewing locations for high profile areas such as laser and target areas will need to be provided.

The functional areas will need to be located and linked in a cost effective and operationally practical and safe way.

The preferred strategy for moving major items of laser equipment into and out of the building is via the west elevation at each level and into the HIA from the South. The lifting and transportation of large heavy equipment can be achieved using specialist hired equipment and contractors and via temporary access routes if necessary. Fixed cranes will be provided within LA7, the HIA and the TAP electron beam dump area to move the equipment.

A lift will also be used for moving smaller items of equipment between floors.

There are a large number of below ground site services to the south and west of the current building and these will need to be moved/accommodated in the final design.

TAW will be temporarily closed during the build phase and then will be brought back operational again. To minimise the down time of the current Vulcan facility during the build phase, the CLF currently proposes not to strip out all the equipment from TAW.

The TAP area will not be operational during the build phase.

The current liquid Nitrogen tank will need to be relocated and the required capacity of the CLF nitrogen system will need to be assessed.

The design will be reviewed during the development stages to assess the impact upon CLF and other departments operations i.e. all CLF lasers particularly the Astra Gemini laser in the adjacent R7 building, SSTD in R25 and ISIS in R2 and R3.

The current HVAC, vacuum infrastructure, Nitrogen tanks and gases associated with TAW will need to be relocated/replaced.

The new facility will incorporate a new front entrance for staff, users and visitors. The front entrance should be welcoming and project the image that the CLF wishes to portray to the outside world. It should be light and airy.

The design life of the building, as defined in BS 7543, should be 60 years.

The components, assemblies, and installations, that are to be specified shall have a design life, as defined in BS 7543, of not less than 15/20 years.

All design will be undertaken in accordance with the Building Regulations and the appropriate British Standard Codes of Practice and other specific guidance notes relating to the particular installation.

Layouts

The ground, 1st and 2nd floor layout of the 10PW laser building are shown in more detail in figures 3, 4 and 5 respectively. The yellow shaded area indicates the extent of the new build.

Working from top to bottom and left to right of figure 3, the ground floor accommodates: space for additional long pulse beamlines, a capacitor bank, a TAW/HIA target area control room, the new HIA target area, an entrance area and the TAP electron beam dump area.

Likewise figure 4 shows the first floor which includes: main building air conditioning plant room, double height capacitor bank, target area services room, double height HIA, entrance landing and double height TAP electron beam dump area.

Figure 5 shows the second floor which houses: the OPCPA pump laser area, the OPCPA amplification and compression laser area, the OPCPA front end room, the 10PW laser control room and the laser area services room.

Finally figure 6 shows several elevations and cross sections of the building extension and figure 7 and artist’s impression of how the building may look when completed.

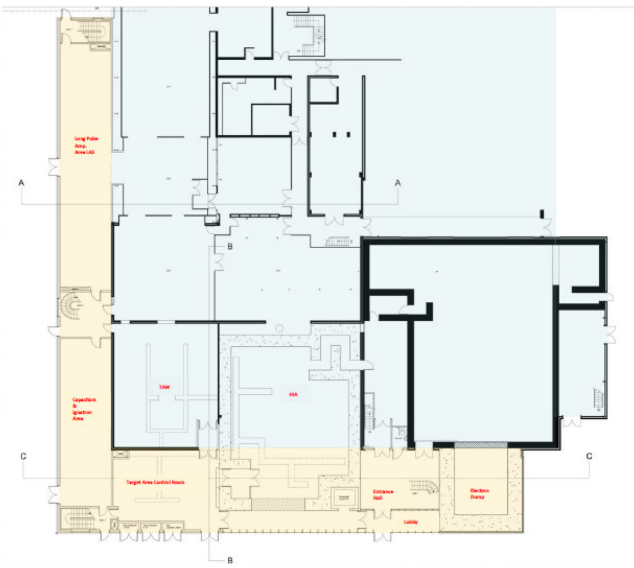

Figure 3: Ground Floor Plan

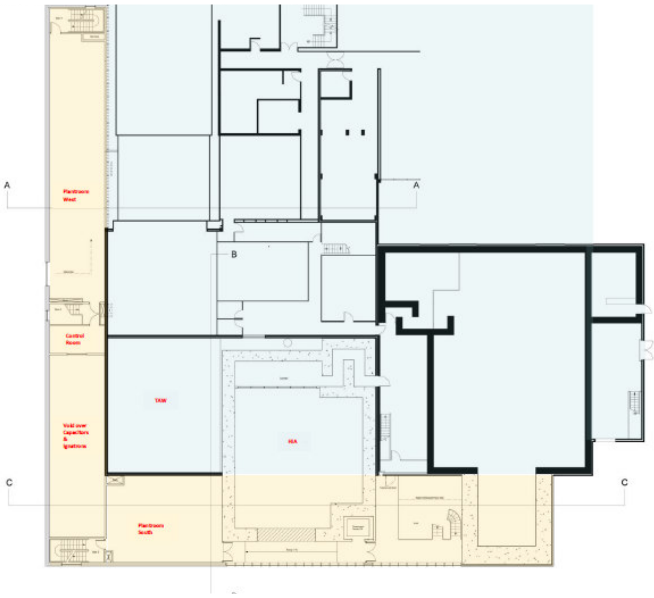

Figure 4: First Floor Plan

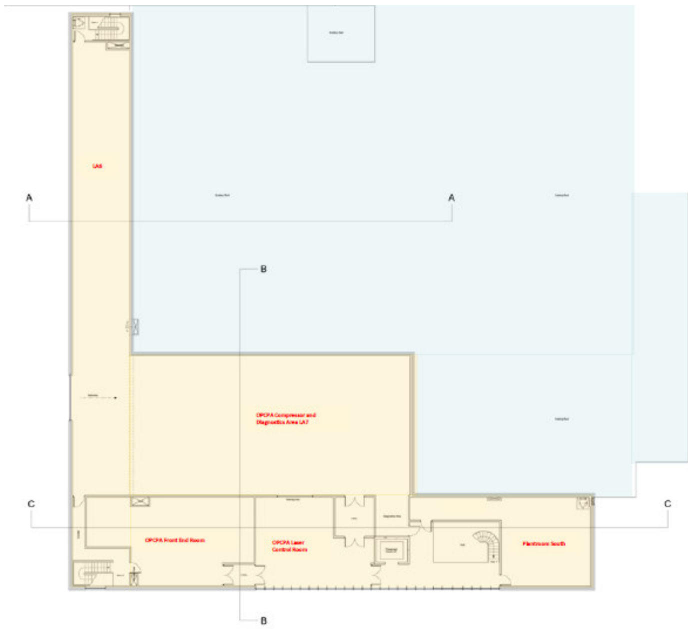

Figure 5: Second Floor Plan

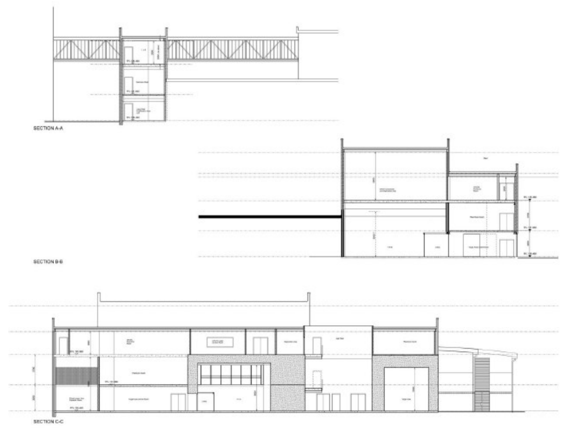

Figure 6: Elevations and sections

Figure 7: Artist Impression of building from South West corner

Programme

The proposed building project programme is shown below The programme, and the procurement and contract strategy which it incorporates, are based upon the following assumptions:-

• Internal consultations required by the Client's organisation can be undertaken to comply with the timescales shown in the Programme.

• Client approvals can be provided to comply with the timescales shown in the programme.

• Design, manufacture, testing and commissioning of the new laser equipment will be progressing in parallel with delivery of the building.

• CLF will be able to provide sufficient details of its proposals for fit out of the building such that the interface with the building design can be co-ordinated during Stages 2 and 3.

• Funds will not be available for any site works to commence until the start of the 2011/2012 financial year.

• CLF operations within Building R1 will stop in 2011 such that site works can commence at the start of the 2011/2012 financial year.

The key dates for the project, as depicted by the programme, are:

Milestone :	**Date:**
Stage 2 Commencement	May 2010
Submit planning application	August 2010
Issue tender documents	November 2010
Contract award	April 2011
R1 Vacant Possession	April 2011
Site works commencement	May 2011
Site works completion	August 2012
Client Fit-out commencement	September 2012

Conclusions

This article has outlined the current design status of the 10 PW building.

Over the next few months much work will be ongoing to develop a more detailed design ready for tender action. A series of client review and value engineering stages will ensure that it will remain a functional, and affordable building which will meet the requirements of the laser and target area equipment to be installed in it and to ensure that it can be built to the project's timescales.

References

1. C. Hernandez-Gomez et al., "The Vulcan 10 PW project", CLF Annual Report 2008-2009 pg 267