The CTF Laser

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This paper reviews the laser activities of 1995 and examines some of the remaining problems which call for system modifications as well as the changes needed to fulfil the CTFII requirements.

1995

The CTF laser system of 1995 is outwardly as described by K.K.Geissler in 1993 and S.Schreiber in 1994 [1]. The shutdown of January - March 1995 was used to replace damaged optical parts, notably the Nd:YLF rod in the Regenerative Amplifier (RA) and some mirrors and their supports. Electro-magnetically shielded Pockels' cells with 50 Ohm drive circuits, developed by I.Kamber, were installed to reduce electrical noise which was perturbing the CTF timing system. The interlock system of the closed circuit cooling water flow was faulty and was replaced with an independent flow-meter and calibrated flow gauge. During the 1994 and 1995 runs the laser frequently stopped with faults on the simmering current circuits, their function is to keep the gas in the flashlamps ionised, which minimises pulse to pulse variations of the lamp output which directly affects the pulse to pulse amplitude variation of the system. The amplifier heads were stripped down and the isolating plate of the Regenerative Amplifier was found to be defective, it was replaced and direct simmering connections were made to all flashlamp housings, no further problems were experienced with the simmering circuits. The laser was carefully aligned and its performance augmented to a level far superior to that of previous years in terms of efficiency, stability and total energy output.

	1993 (29/9)	1994 (16/5)	1995 (7/11)
RA Voltage	896 V	700 V	630 V
Amp. Voltage	825 V	750 V	800 V
UV output, normal	50/250 (209/262 nm)	490 uJ (262 nm)	1000 uJ

The increased performance is due to partly to the removal of losses due to damaged optical parts but also to the installation of diagnostics in the injection path and the RA which permitted a more precise alignment. For the injection, the unused part of the train (train + hole or "missing pulse") is permanently monitored, this allows the observation of the pulse selector Pockels cell (PC3) action, the correct timing and polarisation are easily seen, which separates PC3 and PC1 (injection Pockels cell) operation.

The "axial monitor" on the regenerative amplifier is the leakage through one of the cavity end mirrors, observation of this light by either a fast detector or a ccd camera, allows us to "see" inside the RA cavity during the 50 round trip amplifying cycle. This shows the alignment of the cavity itself, the alignment of the injected seed pulse into the cavity, the amplification achieved per cycle and from that one may choose the optimum extraction time for best stability. It also serves as the most precise monitor of the injection alignment.

The increased energy was put to use during the 1995 run when a vacuum leak occurred in the cathode preparation chamber, a custom bellows had to sent to the UK for repair and there was no spare part. Despite a major adaptation of the remaining chamber, it was not possible to supply cathodes with the required quantum efficiency, the extra energy available from the laser compensated the shortcomings of the cathodes and the CTF run was largely unperturbed.

The pulse to pulse amplitude stability of the laser when correctly aligned is 3% rms., the laser maintains this alignment for a day if there are only small temperature changes, to achieve even this level of stability the regenerative amplifier runs continuously, only being switched off for weekends. The daily fine tuning consists of adjustments to the injection and extraction pockels cells angles and the timing of all three pockels cells, the injection alignment and occasionally the cavity mirrors themselves need to be slightly corrected. The laser system is

therefore highly temperature sensitive, which results in mechanical alignment changes as well as polarisation and timing drifts.
The mechanical changes of the injection alignment may be due in part to poorly held optics. At the start of the year certain mounts were seen to be broken and were changed, possibly one or more of the remaining mounts has the same fault, in which a small brass collar develops a micro-fracture and eventually brakes. A visual inspection has not revealed any faulty components, it is proposed to systematically change all of the suspect type of mounts during 1996 as a precautionary measure.

The daily changes to the two Pockels' cells in the laser may reflect two problems, of alignment and of temperature coefficients of the polarising optics [2]. The mounts for these cells are being changed for a more solid construction which will be better able to support the mass of the solid copper housing and the pull of the semi-rigid cables which are used to power the cells. Changing the alignment of the pockels cell alters the polarisation change that they apply to the beam, it is possible that the polarisation in the laser changes with temperature causing lower gain and that this is then compensated by a fine change in the pockels cell angle. One possible source of temperature sensitivity is the lambda/2 waveplate which is used in the regenerative amplifier, this is a multiple order 1064nm design, a commercially available standard product. The phase retardation that this waveplate generates at 1047nm will be more than the half-wavelength required which results in a loss in the cavity on each round-trip, being multiple order it has a temperature sensitivity of 0.1-1 optical degrees/degree C which when multiplied by the 100 transits represents a considerable depolarisation. Special zero-order waveplates for 1047nm have been made with temperature coefficients of only 0.01 optical degree/deg.C, we hope by this action that an improvement of the temperature sensitivity will be seen.

The last of the regular adjustments is the fine timing of the Pockels' cells, PC3 is the most critical as the 0 to 100% risetime of the HV pulser is 4ns (see fig.1), this must be placed exactly between two pulses in the 250 MHz optical pulse train from the LWE laser which have a spacing of 4ns. The normal HV timing jitter is 3-400 ps, the width of the flat top of the pulse of 500ps, the optical pulse must make two passes through the cell to achieve polarisation rotation, the time of flight from the Pockels' cell to the mirror and back is 600ps, so that the two passes "straddle" the peak.(fig.2)

First pass position — old, new
Second pass position — new, old

fig.1 PC3 HV pulse and timing jitter

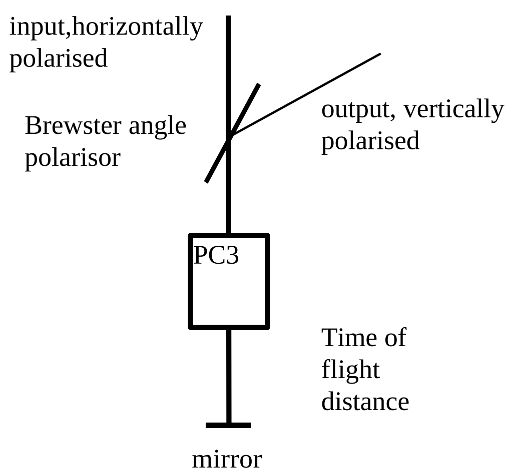


fig.2 Pockels' cell 3 (single pulse selector) layout

There is a timing drift, which may be due, in part, to temperature changes, so that adjustments of +/- 0.5 ps are needed daily to keep the peak of the HV pulse exactly on the

pulse to be selected. When the timing is off by 0.5ns the Pockels cell rejects some of the wanted pulse and passes part of the leading or trailing pulses, this results in amplitude variations and can lead to unwanted satellite pulses.
The jitter of the HV pulse has two origins, one is the timing system uncertainty and the second is from the HV switches themselves. The new timing system should be more stable but this may still be masked by the HV switches which have an internal delay of 200us.
To attempt to accommodate this problem the time-of flight delay of the two passages through the Pockels' cell has been minimised to 350ps, the length of time that the timing setting is correct should be prolonged by this action.

The position of the laser spot on the cathode was also noticed to move vertically by up to 2 mm during the day, this position would revert to normal overnight if uncorrected. This movement may come from the laser, a mirror in the beam path, the x-y-scan stage or the building itself. It is unlike the beam alignment problems experienced with the PTG as the movement is always vertical and always reverts back to the nominal position. Other positions in the beam path will be monitored by CCD cameras as they become available during the 1996 run, this will help to identify the source of this movement.

Several times during 1995 the laser system developed faults which could be characterised as "drop-outs", "unstable and extremely jittery" and "satellite pulses" at these times none of the normal adjustments had any positive effect.

"Drop-outs" or missing pulses are thought to be a forerunner to a Pockels' cell termination resistor failure. These 50 Ohm terminations are part if the integrator made by I.Kamber which is used at the end of the transmission line driving the cell, they must absorb the 3400V pulses from the Belke switches. It seems that in this application they have limited lifetime, as they approach failure they occasionally go open circuit which stops the appropriate Pockels cell from completing its function. Pending an improved design some spare pieces are required to minimise down time.

"Satellite pulses" were found to be present at 580ps from the normal pulse, this fault highlighted the lack of diagnostic instruments available in the IR part of the laser. One inconclusive measurement showed an extremely small satellite at the output of the LWE oscillator, it was clearly present at the RA output giving two pulses of equal intensity. We have since found that the two Pockels' cells were both damaged, this may have been a contributing factor, since their replacement the satellite pulses are no longer observed.

"Unstable and extremely jittery" operation occurred even when the alignment into the RA was optimised, the RA itself was correctly aligned and all the timing and HV monitoring signals were normal. Under these conditions the only real suspect was the LWE oscillator. This previously intermittent condition re-appeared in tests during March 1996, and required a service visit by K.Wiengarten, the LWE European representative. The problem was found to be an accumulation of dust on some of the internal optics and a slight misalignment of the cavity. These together were found to allow modes higher than the required TEM00, to develop in the cavity, which then drastically perturbed the lasers operation. Cleaning the internal optics and reducing the diode pumping power has solved this problem at the expense of a small drop in output power which is now 120mW (from 130mW). The laser system has been run with the new lower level of input and has the same stability as in normal operation in 1995, sigma=1% or 3% rms.

Relative humidity and atmospheric pressure variations have been investigated as sources of instabilities in modelocked lasers [3], the change of the refractive index of air in the cavity causing an effective change of the cavity length. We now monitor the atmospheric pressure in an attempt to correlate this with troublesome operation of the Lightwave laser.

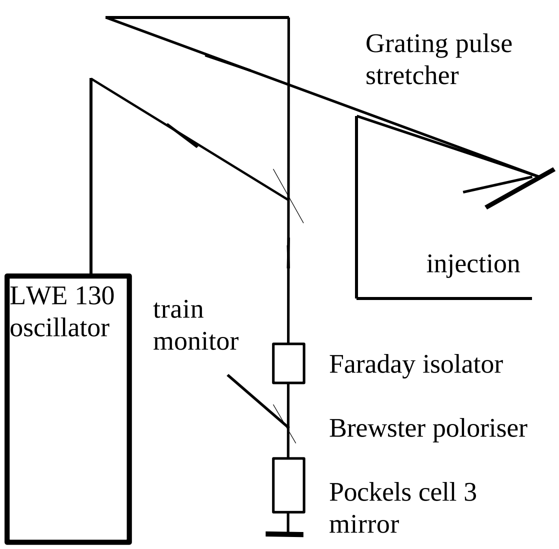
The injection line.
The current arrangement of the Lightwave oscillator-pulse stretcher-pulse selector limits the range of measurements which can be made on the seed pulse before it enters the regenerative amplifier, if more was known about its state, it may be possible to improve the laser performance.

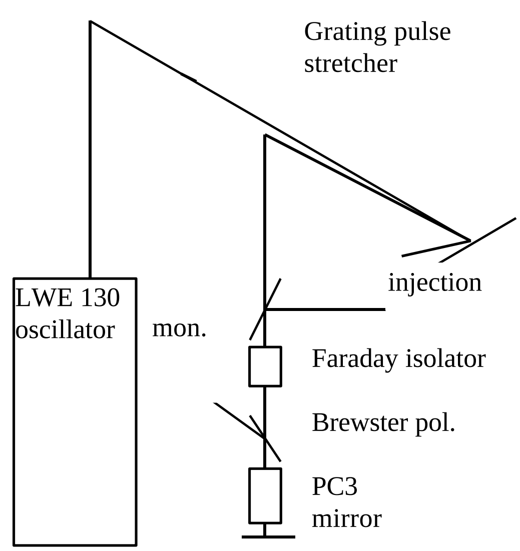
For most stable operation the injected (seed) signal should be as large as possible to minimise the amount of amplification that then required from the laser, ideally the number of round-trips could then be reduced, as each passage through the amplifier adds a small amount of wavefront distortion which reduces the quality of the beams' transverse profiles.

Spontaneous emission in the laser medium creates a situation analogous to a poor signal to noise ratio in an RF amplifier, this unwanted light will be amplified, this would not be so important if the aim was to amplify a short or "Dirac-like" pulse where the noise could be considered as extra signal, but the pulse to be amplified in the regenerative amplifier has been carefully "chirped" when is was stretched to 50ps length, there is an exact relation between the temporal position in the pulse and the wavelength (or phase) at that point [4]. Without this the pulse cannot be re-compressed, any "noise" signal will be amplified but it will not have the required phase/time relationship, when the pulse is compressed the noise component may form a "pedestal" or base to the shortened pulse[5], the leading edge of this base may be preferentially amplified in any following amplifier stages, stretching the final pulse. In our system the pedestal should be lost in the harmonic generating stages, due to their non-linear action, the low peak intensity parasite signal produces almost no UV light. It follows therefore that increasing level of the injected seed pulse should help to maintain shorter UV output pulses.

There are some losses in the line between the LWE and the RA which must therefore be eliminated, these stem from the use of waveplates designed for use at 1064nm, the Nd:YAG wavelength, at our 1047nm the polarisation advance is incorrect giving a linearly polarised beam which is not aligned to the required vertical or horizontal planes, when the light passes through a polarisor, the non-vertical (or horizontal) proportion is lost. These waveplates will be replaced with new ones which are designed for use at the correct wavelength.

Diagnostics of the injection are currently limited to the observation of the unused part of the train- the "train + hole" where the action of the pulse selector can be monitored, the current configuration places the pulse selector before the pulse stretcher the energy of the selected pulse is so low that no further measurements can be made on it. This situation has meant that no data is available on the length of the stretched pulse, the efficiency (transmission) of the grating system or the spectral characteristics of the injected pulse. A comparison of the spectra of the injected pulse and that of the output from the RA would indicate the optimum settings for the RA, as the bandwidth of the YLF rod changes with the pumping energy and pulse intensity[6].





The "old" injection layout

New injection layout

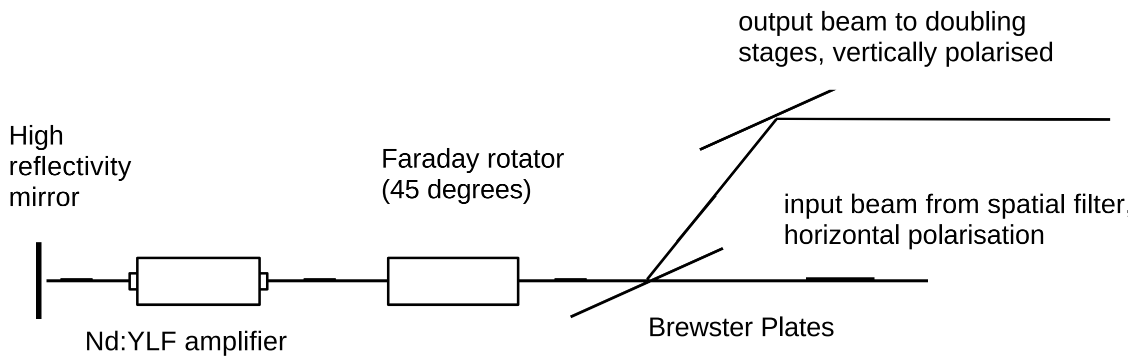
As a start on this path of optimisation, the injection path will be modified so that the pulse selector is the last element in the injection chain, this will provide the same “train + hole” monitor as at present, and also give the possibility of monitoring the efficiency, pulselength and spectrum from the grating. The problem of the detection of these parameters will be addressed during the 1996 run, a simple spectrometer may be produced by a grating and CCD camera, for the pulse length measurement a fast and sensitive IR detector is required, it is possible that our existing 50 GHz detector could measure the pulse length directly.

The Laser

The conversion efficiencies for the generation of the 262 nm UV light required for operation of CsTe photocathodes, are over 50% for the 1047 to 524 nm 2nd harmonic generator and 25% for the 524 to 262 nm 4th harmonic generator, this gives a maximum UV output of 1.2 mJ for the nominal 10mJ of IR energy. Although this level can be maintained without damage for week-long periods it requires that all elements in the laser system be kept perfectly aligned and the slightest temperature variation be compensated by constant adjustments. A more comfortable long term operating level for the current system is 800uJ (UV) at which level the laser requires minimal attention.
Some changes are foreseen for CTFII operation in 1996, to improve the mechanical and optical stability the pockels cells will be mounted on more solid, adjustable bases as the present mounts have required frequent correction which was not foreseen. Several waveplates will also be changed as those presently in use are low-order waveplates designed for 1064 nm, the correct polarisation advance being achieved by their use at an angle to the incident light, this technique is acceptable in a laboratory and permits the use of far cheaper components, but the temperature coefficient of the polarisation is 10-20 times higher than with a zero-order waveplate of the correct wavelength properly installed. The largest loss in the Regenerative amplifier may be due to incorrect polarisation control, the monitor signal of the cavity output shows that over 5% of the pulse in the cavity is lost per cycle, this loss is compensated by driving the flashlamps at a higher level, but without this loss fewer cycles would be required and possibly the Amplifier could be driven at a lower level, giving the chance of finding shorter pulses as well as better short and long term stability.

The available energy will also be increased by changing the second amplifier from single to double pass, the advantages are those of increased energy, pulse to pulse stability and an improved transverse profile. In a single passage amplifier the light pulse cannot extract all of the available stored energy, a gain of 10 is currently achieved, but this is the linear gain value, if the input is reduced the output follows in proportion. If it were possible to operate the amplifier in saturated gain, pulse to pulse amplitude variations from the regenerative amplifier could be reduced, the output level would be mainly dependant on the stored energy in the amplifier which is in turn accurately determined by the voltage on the capacitor banks [5,6,7]. If the pulse were amplified in this way its transverse profile would also be made more useful, as it would change from a Gaussian towards a “flat top” distribution, which makes more efficient use of the photocathode surface.

To achieve double pass operation in Nd:YLF requires that both passages through the material are of the same polarisation, as the material is birefringent and for the two polarisations operates at two different wavelengths. To separate the input and output beams either an off-axis scheme or a polarisation selection must be used, the off axis scheme would limit the available aperture and therefore the available energy, so polarisation selection must be used.



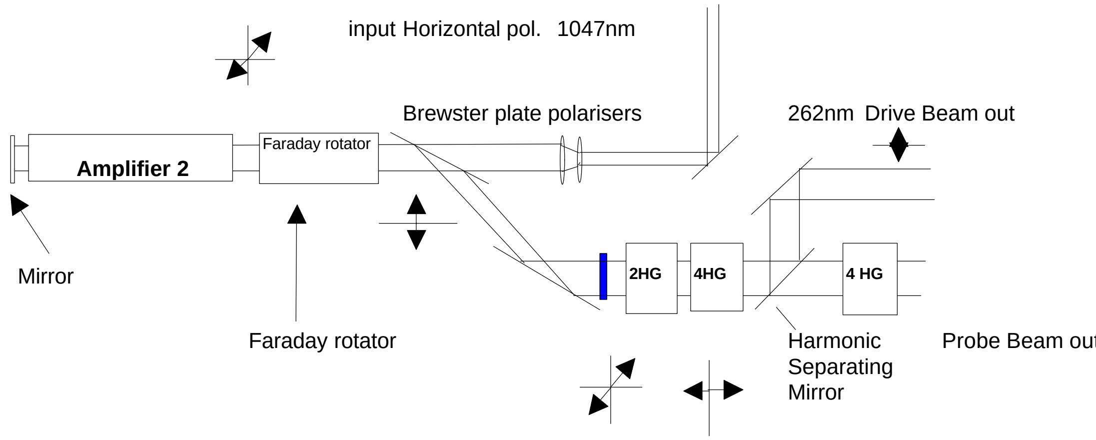
In this configuration, a Brewster plate is used to enter the amplifier, this is immediately followed by a Faraday rotator which advances the polarisation angle by 45 deg. at each passage, the Nd:YLF rod also has to be rotated to this angle, the incoming beam is then amplified through the rod, is reflected off the end mirror, and passes a second time with the same polarisation angle through the amplifier rod. On the second pass through the Faraday rotator the polarisation is rotated by a further 45 degrees to become vertically polarised which is reflected from the two Brewster plates, the second of which simply corrects the orthogonality of the beam.
The vertical polarisation of the output beam in this configuration is not a problem as there is a lambda/2 waveplate before the KDP doubling crystal to rotate the beam polarisation by 45 degrees for Type II harmonic generation.

the probe beam
The aim of CTFII is to demonstrate the two-beam principle of using a powerful train of electron bunches to generate the 30 GHz power required to accelerate the probe beam pulse. To create the probe beam a separate RF gun will be used, it has been decided to use CsI+Ge photocathodes as a vacuum transfer chamber as used for the drive beam is not available for the probe beam. The expected quantum efficiency will only be 0.01%, the required electron charge is 5nC so that a UV energy of 40uJ will be required.

In the harmonic conversion process, it is very difficult to achieve the perfect phase matching condition for all of the incident pulse due to the limited acceptance angle of the converting crystal material [5,8].
The extra energy required for the probe beam will be generated without reducing that of the Drive beam by passing the “unused” 524 nm light at the output of the 4th harmonic generator through a separate 4th harmonic BBO crystal.

	1047 nm	524 nm	262 nm
laser generates	10 mJ		
2nd HG		5 mJ	
4 HG			1.2 mJ
residual outputs	1 mJ	1 mJ	
Probe beam 4th HG			0.25 mJ

CTFII: 2-pass Amplifier, Harmonic generation and Probe Beam



The UV light for the Probe beam will be generated by a second 4th harmonic conversion on the remaining 2nd Harmonic green light. This beam will also require spatial filtering, a motorised attenuator, fine phase adjustment and the generation of a second pulse with variable delay, by polarisation splitting and recombined to be on the same axis. As the laser will normally be working in its 2-pulse mode, two UV pulses would be produced for the probe beam, at a fixed separation of 4ns, making four probe pulses. The foreseen instrumentation for the probe beam would be perturbed by this second pulse, therefore one pulse will have to be suppressed, a Pockels cell would be able to switch the polarisation between the two pulses with a spacing of 4ns as is done for the PC3 pulse selector. This would be most effectively done at the second harmonic where the cells have good transmission and have a half-wave voltage of 3400V as opposed to the IR pockels cells quarter wave voltage of 3300V, this would allow either a faster switch of 1700V in a 2-pass configuration or a single pass 3400V in-line switch. A complete solution to this problem will be devised during the 1996 run, the eventual system must take account of the possible use of an IR mini-train of four pulses which may be produced in the laser.

options for more energy later

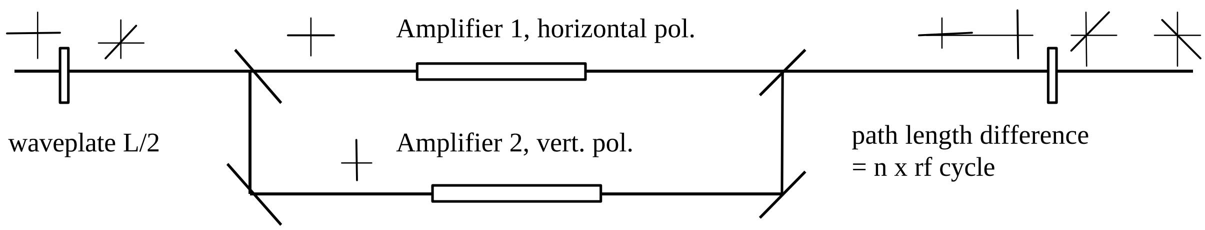
The damage threshold for optical coatings and components is not precisely known for any material, wavelength or pulselength, being dependant on surface effects where microscopic inclusions, polishing marks or scratches can locally enhance the electric field generated by the laser beam [9]. Dust particles are attracted to the very point of danger by static electric fields which develop on the dielectric surfaces during operation. Measurements differ from theoretical values by a factor of 5- in both directions, but a typical value would be 4-8GW/cm^2, given our pulselength, which would encompass the Nd:YLF rods, the anti-reflection coatings, the waveplates, Faraday isolators and harmonic generating crystals. As our pulse length is fixed at about 10 ps the maximum single pulse energy is therefore determined by its size at the last amplifier and through the harmonic generation chain where it has a 6mm diameter due to the dimension of the amplifier rod. This leads to a maximum single pulse energy of 20 mJ at 1047nm which would yield 2mJ per pulse at 262nm, saturation effects having slightly reduced the efficiency of the harmonic generating crystals. It is prudent to operate at a lower level than this, as we require the laser system to function for long periods of time without interruptions, the laser will produce two pulses separated by 4ns, each of 10mJ when the 2-pass amplifier is installed.

There are several possibilities if it is necessary to exceed this value, however they all require considerable development and modifications to the existing system. The simplest idea is to use two amplifiers in parallel, the output pulses generated have opposite polarisations, but

Type II harmonic generation (as currently used) requires only that two equal, orthogonal polarisations are present.

The system can be extended to produce an amplifying train generator, the ultimate limit would be the investment in power supplies, amplifier rods and housings, each pulse of the train could have an IR energy of 20mJ if the current 6.35mm diameter Nd:YLF rods are used. The use of waveplates allows accurate splitting ratios to be achieved, so that the resulting train would be balanced, 45 degree polarisation splitters allow the path length difference to be continuously adjustable so that simple beam loading compensation schemes could be realised.

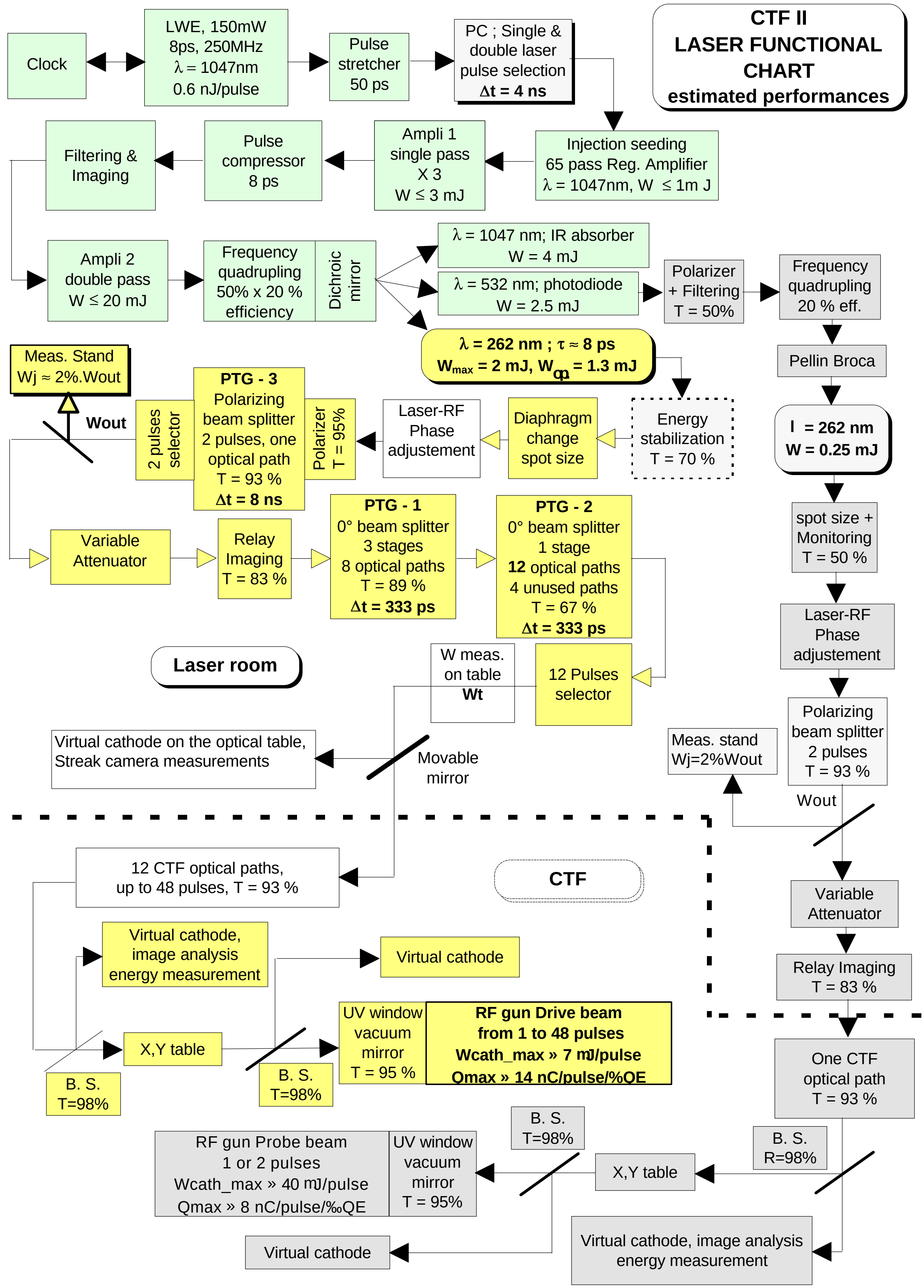
A cell of the amplifying train generator



This technique could be extended to the generation of a high power “mini train” with 4 or 8 pulses separated by one or two 3GHz RF cycles. The use of polarisation splitting avoids the problem of guaranteeing that each pulse in a train is amplified to the same level as it passes through an amplifier, in such a situation the first pulse in the train “sees” the highest stored energy in the amplifier medium and extracts the most also, leaving less for the following pulses, which leads to a decreasing series of pulses if the energy extracted per pulse is a significant fraction of the total stored energy. In this scheme the earlier pulses would be made smaller to compensate for this effect.

Bibliography

[1] S.Schreiber, The Sychro Laser System for CTF,CLIC Note 245
[2] Halbo optics,South Woodham Ferrers,UK.Technical Data
[3] S.Benson & M.Shinn, “Development...Photocathode Drive Laser at CEBAF”
[4] J.Herrmann & B.Wilhelmi, Lasers for ultrashort light pulses, North-Holland
[5] W.Koechner, Solid-State laser engineering, Springer
[6] W.Rudolph & B.Wilhelmi, Light pulse compression, Harwood
[7] O.Svelto, Principles of lasers,Plenum
[8] M.Young, Optics and lasers, Springer
[9] R.Wood, Laser Damage in Optical Materials, Adam Hilger



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