Kentech Instruments Ltd.

Laser pulse too long?

The combination of modern pulse sources and fast Pockels cells now make it possible to consider several techniques for manipulating laser pulses both inside and outside a laser cavity.

Pulse shortening, a common requirement, can be achieved by several methods e.g. mode locking and Brillioun backscattering. In addition short laser pulses are now available from several laser diodes. However, here we discuss the techniques of pulse chopping with Pockels cells.

Pockels cells use bifringence to produce a relative phase lag between ordinary and extraordinary rays in a medium. The Pockels effect is an electrically induced bifringence in which the electric field modifies the refractive indices of the medium. If the phase lag can be made 180° then the polarisation of the emerging light can be made orthogonal to the incident light and a polarisation analyser can be used to block or transmit the light. By manipulating the electric field in time one may change the polarisation in time and consequently use the combination of a Pockels cell and two polarisers as an optical shutter. Note that this is not simple rotation of the plane of polarisation. At intermediate situations the polarisation goes from plane, through elliptical, circular, elliptical and on to orthogonally linear. For true rotation of the plane of polarisation a Faraday rotator should be used.

The transmission of light through a perfect polariser depends upon the $\cos^2$ of the angle between the axis of polarisation of the polariser and the electric field vector of the radiation.

A pockels cell is normally set up so that incident polarised light is split equally between the ordinary and exrtraordinary rays. At the “half wave voltage” ($V_{\lambda/2}$) the relative retardation of these is half a wavelength, so the polarisation emerging is rotated 90°. The transmission in a loss free system is given by $T = \sin^2(V/V_{\lambda/2} \times 90°)$.

Pockels cells are commercially available with response times down to around 50ps. They come in two main configurations, longitudinal and transverse. These names describe the relative angle between the electric field and the direction of propagation of the light.

Transverse devices offer high sensitivity (significant relative phase lag of the two waves with low voltage) but are limited in bandwidth as the velocity of electromagnetic waves is very different for the optical and drive frequencies. This results in a phase mismatch between the two and limits the length of crystal that can be used for a given response time. Shorter crystals limit the interaction length and consequently the sensitivity. These devices are suitable for phase modulation up to around 100MHz, and pulse picking type applications where the required bandwidth is not great. There are lower sensitivity devices available that can be used to around 1ns response time.

Longitudinal cells do not suffer from these limitations but are not so sensitive. They also have the advantage that the relative retardation of the waves is only dependent upon the voltage applied, not on crystal length, although 3 dimensional effects may be significant. These devices are more stable and offer better extinction ratios coupled with higher bandwidth. The relative phase retardation depends linearly on the voltage and inversely with the wavelength.

When considering an application with such a cell it is important to consider how a crystal will respond. Although the capacitance of a crystal may be small enough that the RC time required to charge it up may be small enough for an application, the user should also be aware that the propagation velocity of the electric field in the crystal is considerably slower than light and this may lead to problems getting the field into the crystal. This is the same problem as trying to make a very small capacitance from a very large structure. One has to consider the propagation of the wave inside the capacitor.

The result for Pockels cells is that very fast gating cannot be achieved in large aperture systems. The very fastest cells are around 2.5mm clear aperture whilst at 10mm one may only achieve perhaps 250 to 300ps.

Drivers for Pockels cells

In order to make use of the properties of Pockels cells to their full, fast high voltage drivers are needed. These drivers use fast high voltage switches to produce pulses which are fed to the cell with coaxial cable. There are several types of switches available:- thyratrons, krytrons, vacuum thermionic tubes, bipolar and field effect transistors, avalanche transistors, spark gaps, photoconductive switches (other than spark gaps). All these have their associated advantages and

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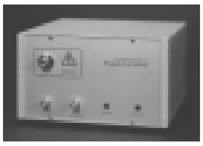
disadvantages. For very fast applications it is generally necessary to have low jitter switches, (jitter is the timing uncertainty with resect to a trigger signal). Also long term reliability is generally very important. These two criteria limit the options to transistors of various types and photoconductive switches. Photoconductive switches generally need a significant amount of energy, and a laser pulse that is already fast to make them switch. The more recent devices that use bulk material breakdown have a limited life at present.

One is left primarily with avalanche transistors and field effect transactors (FETs).

Avalanche transistors are suitable for fast risetimes down to around 100ps but are limited in long pulses to around 15ns. Also in the arrangements needed to produce the high voltages for Pockels cells they can only achieve a few kHz typically.



The pulsers also are not of high fidelity and the voltage may not go completely to zero immediately after the pulse. This can result in poor post pulse extinction ratios. FETs can operate at high repetition rates but for high voltages tend to have risetimes of around a few ns, or slower for large devices. FET pulsers tend to have better fidelity than avalanche pulsers.

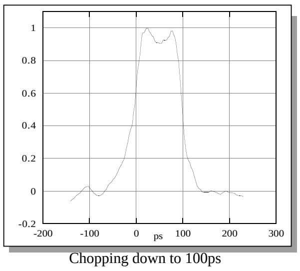
Operational modes

There are many configurations for pulse chopping and some schemes for extra cavity chopping are shown in the figures. The two main regimes to be considered are Extra and Intra cavity chopping. Also for users of mode locked lasers, pulse picking may be necessary

Extra-cavity chopping

For a simple optical shutter one needs to consider the required risetime, the repetition rate, the beam aperture, the extinction ratio, the wavelength and bandwidth, the power, both peak and continuous, the required gate length, the beam divergence.

For example for 1 micron light, with a low divergence and bandwidth and a beam size of less than 2.5mm one may achieve extinction ratios before the gate of 1000:1 and gate widths down to 100ps.



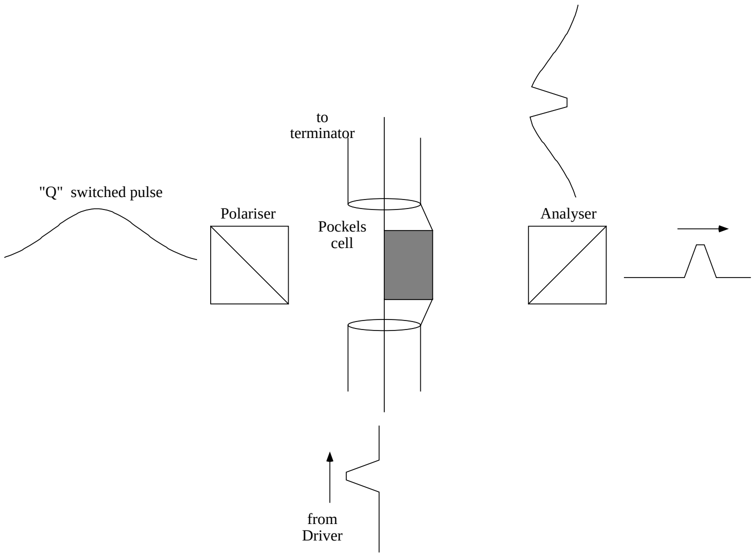
Chopping down to 100ps

Chopping a laser pulse outside a laser cavity obviously reduces the total pulse energy as the brightness is moderately well maintained. This is obviously inefficient compared to other techniques, e.g. Brillioun back scatter in which the pulse is actually compressed. However, it does offer enormous flexibility. It is easy to arrange the system to offer a variety of gate lengths and to operate over a range of incident energies. In addition the gate pulse is available for absolute synchronisation of ancillary equipment to the chopped pulse.

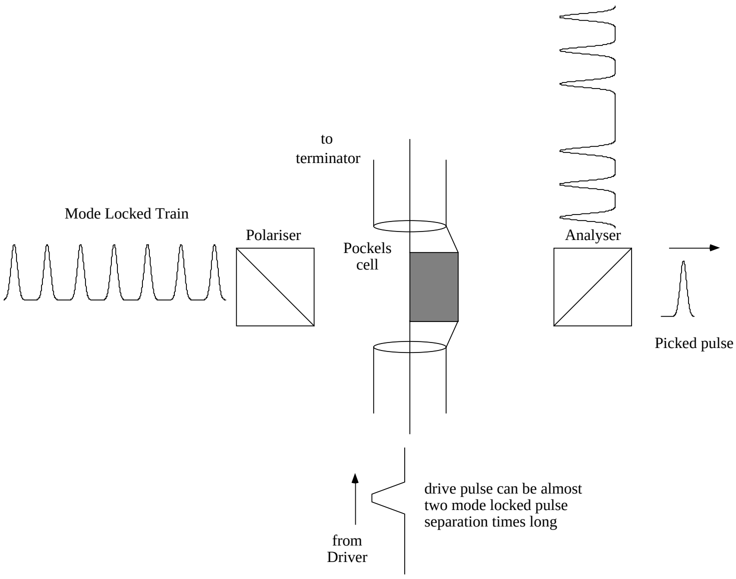
Intra-cavity chopping

Intra-cavity chopping involves modulating the pulse before it leaves the laser cavity. In a typical “Q” switched laser cavity the pulse length is a function of the net cavity gain and length, etc. One can construct cavity dumping schemes in which the pulse length is determined by the cavity length alone but in order to obtain short pulses the cavity length must be small, a problem in many systems. Modulating the gain in a cavity is like mode locking and a cavity dumped mode locked laser can produce very short pulses. The intermediate stage is to modulate the laser pulse inside the cavity just once during the build up phase using a Pockels cell and is a self seeding type of technique. This shortened pulse will then extract most of the available energy from the gain medium and can be dumped. In this way the dumped pulse can be shorter than the round trip time and yet the complications of mode locking are avoided. This technique was published by Charlton & Ewart (Opt. Comm. 50,4, p241, 1984). They used a krytron to drive a Pockels cell and dump most of the energy in a “Q” switched pulse during the build up phase. Obviously most of the energy is extracted from the gain medium in the last few round trips of the cavity, so the shortened pulse can still extract most of the energy. With a modern avalanche pulser one may dump a larger fraction of the pulse length leaving a significantly shorter pulse inside the cavity. By using variable pulse length drivers one may control the pulse length of the exit pulse. In addition the dumping may be achieved using the same pulse and this pulse is then available for absolute synchronisation with other equipment.

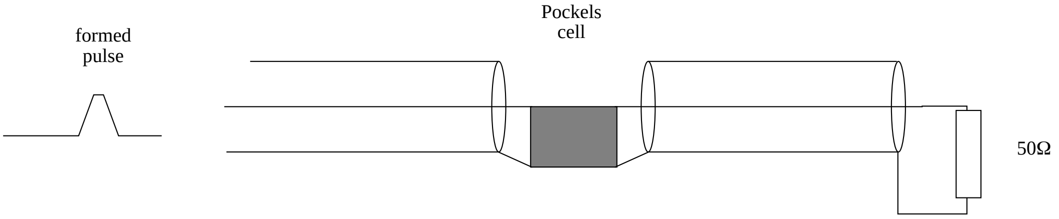
The scheme shown here uses a double passed Pockels cell, however, using a single pass cell and twice the voltage or a two crystal device one may achieve faster edges to the pulse and consequently shorter pulses.



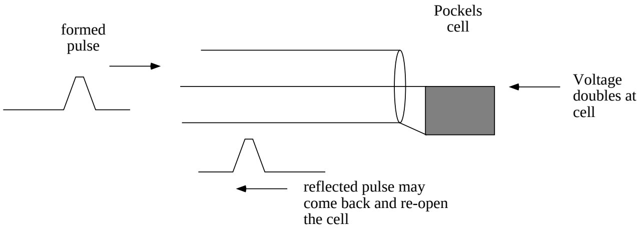
The basic pulse slicing arrangement. This is shown being used to slice a section out of a typical “Q” Switched pulse.



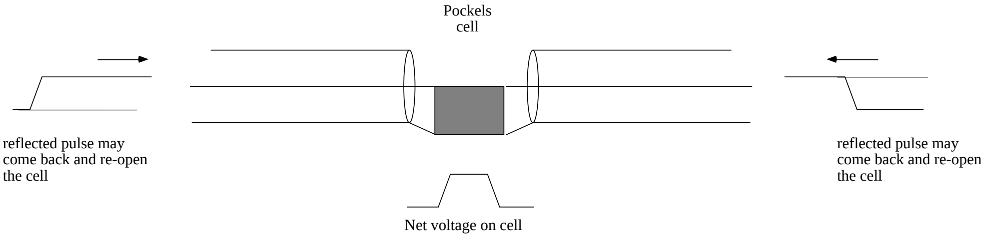
A similar arrangement being used to pulse pick. Driver requirements are somewhat different. The pulse must go from zero to zero in less than two mode locked cycles. If the laser is “Q” switched and mode locked then late time reflections are not important. For CW mode locked lasers there must be no post pulse signals.



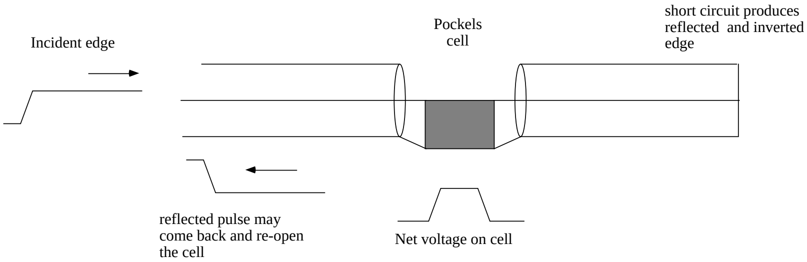
Simplest pulse drive circuit. Can be fast but requires a lot of pulser power. Hard to adjust the pulse length below 500ps but fixed lengths can go to 100ps.



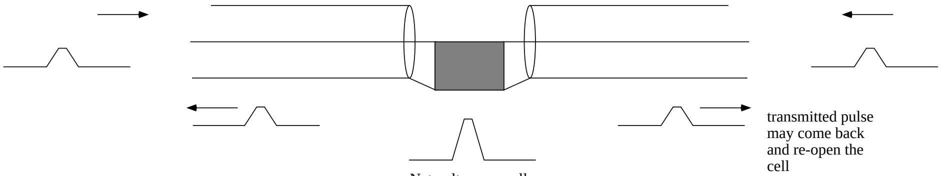
An unterminated system requires half the pulse power but the response is 2 times slower than above. If this is fast enough then one also has to allow for reflections of the pulse from the driver after a round trip time of the cables.



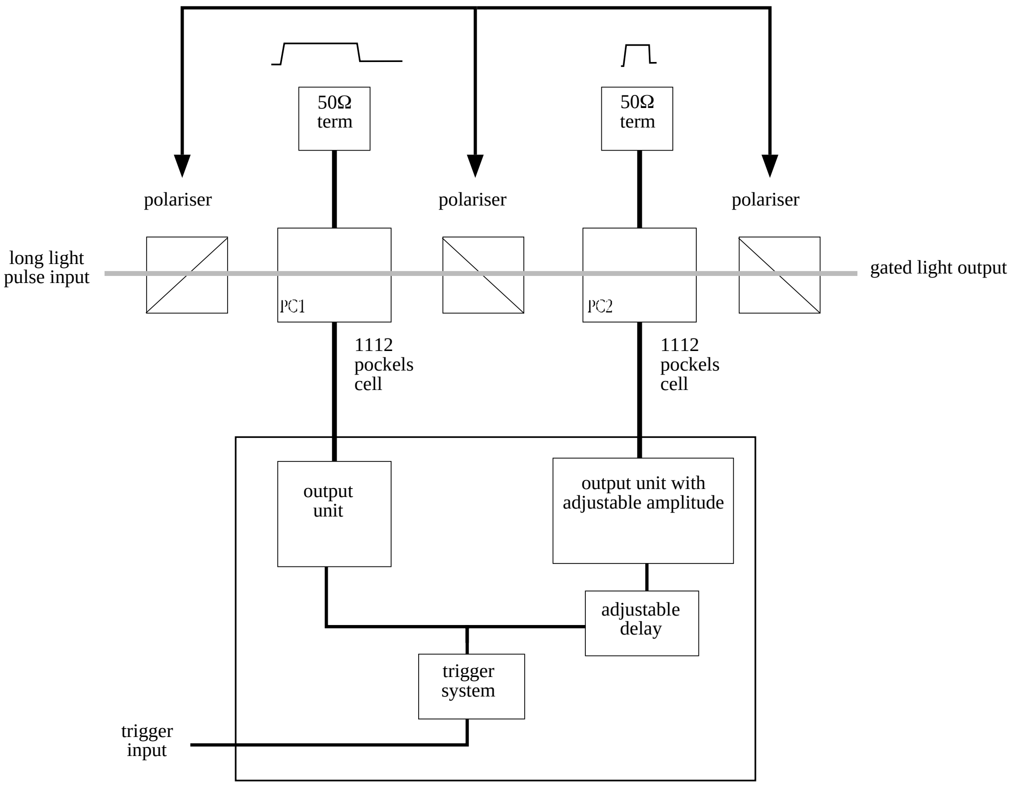
A pulse edge colliding system. The edges can be very fast so that full adjustment down to 100ps is possible. The edges decay in a few ns so this is not good for long pulses. The edges also reflect from the driver after a round trip time of the cables.



This is like the edge colliding system but the turn off edge is just the turn on edge reflected from a short circuit. The nearest proximity of the short circuit sets the shortest gate obtainable.



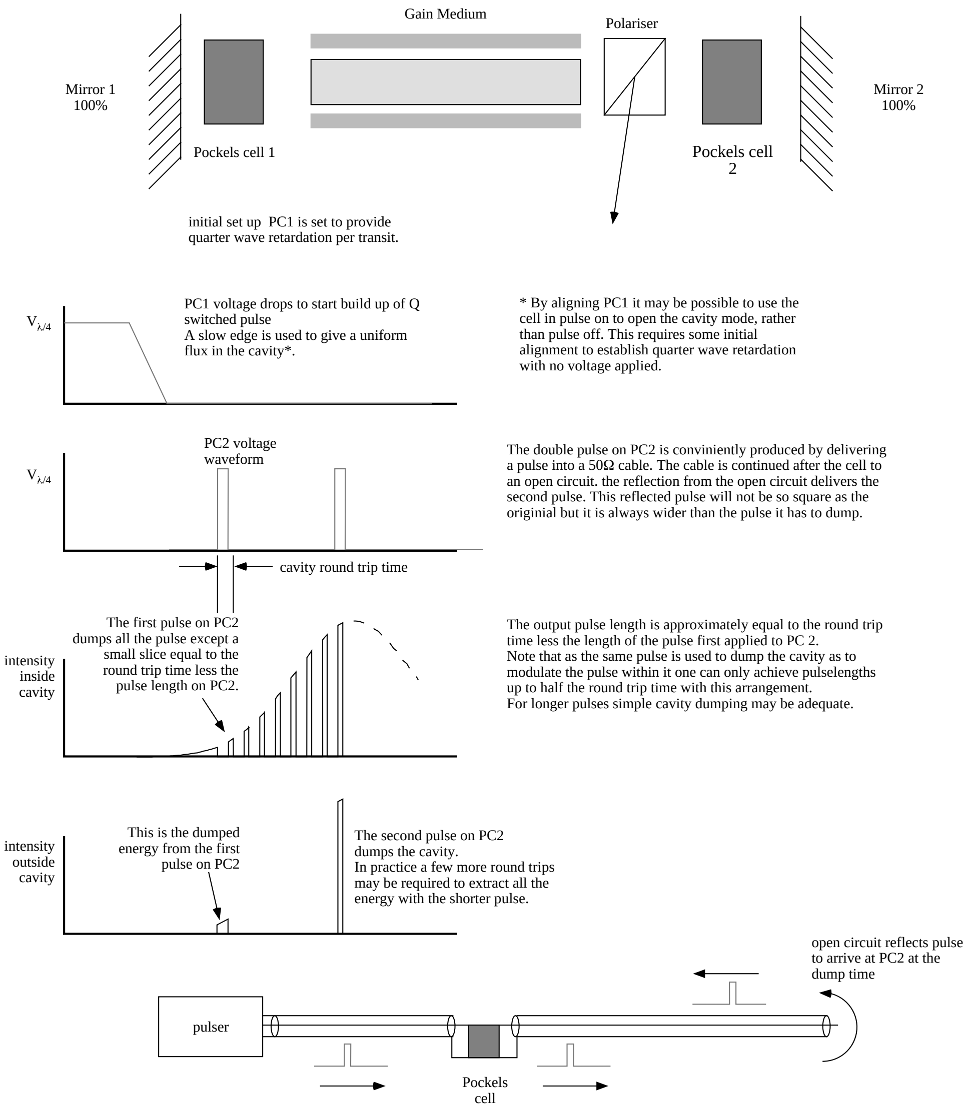
A pulse combining system using two lower voltage pulses. This requires less pulsed power than a single pulse. Although this has a better risetime than a single sided drive it gives rise to reflections at the round trip time of the cabling.



An arrangement for producing an adjustable pulse length from around 120ps to 6ns with both fast rise and fall edges. PC1 delivers the fast rising edge to the light pulse and the long term extinction. PC2 delivers the fast falling edge and reasonable extinction until the pulse drive to PC1 falls and increases the extinction. PC2 cannot maintain good extinction because the extinction is held by the pulse voltage which cannot be stable enough long term.

The turn on is slightly slower than other systems as it is hard to obtain the fastest risetimes with a shaped pulse

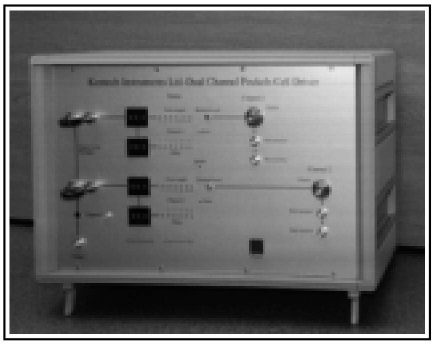
Intra-cavity switching



Intra-cavity switching offers significantly increased efficiency over extra-cavity switching but is not so simple to set up or use. It is also less flexible. However, it can obviate the need for further amplification and for fixed configurations can offer a cost effective solution to short pulse generation.

Some examples

This is a two channel 3.5kV device with pulse lengths from 200ps to 12.7ns with fast risetime and only slightly slower fall times. This is used for extra-cavity pulse chopping at 1.053μm producing two synchonised laser beams chopped to individual lengths. It is based on avalanche transistor technology and has several fail safe features to prevent accidental long pulse generation in the event of a component failure. It has remote control of the pulse length, independently for each channel. The channel to channel jitter is around 2ps and the overall jitter is around 10ps rms, 20ps peak to peak.



This unit is designed as a Q switch driver, although it may be used for many other applications and has been used for pulse picking. It is based on FET technology and can switch up to 8.5kV to ground in < 5ns via a 50Ω cable. It will run at up to 200Hz into low capacitance loads. This technology is easily scaled up to higher repetition rates.

This unit is designed as a pulse slice driver. Two pockels cells and three polariser are used to obtain fast rise and fall times with pulse width adjustment in the range 130ps to 6ns.

HMP2 Special Solid State Pulser

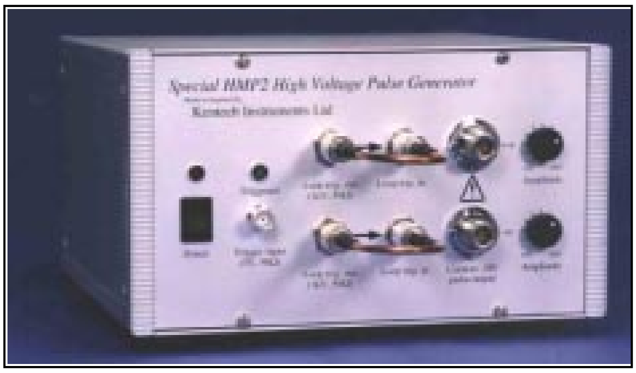
The HMP2 Special provides two ultrafast kilovolt pulse outputs of identical or opposite polarity from a single TTL trigger input. Each output has an amplitude of >4kV into a 50Ω load. The waveform is a fast rising edge with a 10 to 90% risetime of <100ps, and a slower exponential decay with a time constant of ~5ns. Various shaped output waveforms including rectangular pulses down to 100ps fwhm can be provided.

The trigger to pulse out timing jitter is <10ps rms, and the timing jitter between the two outputs is <10ps peak to peak. The timing delay between the outputs may be varied by up to +/-10ns by changing timing cables or using an external delay generator. Maximum repetition rate is 1kHz. The unit is fully CE compatible.

The device is well suited to many electro-optic applications requiring pulse collision or differential driving techniques. The architecture is easily extendable to 16 or more channels for building into arbitrary waveform generators for laser pulse shaping.

Specifications

Amplitude	≥ 4kV into 50Ω load on two channels
PRF	1kHz 500Hz (for longer pulses)
Amplitude jitter, shot to shot	< 5%, 1% typical , shot to shot
Trigger to Pulse output Delay	< 30ns
Timing jitter	< 10ps rms
Trigger input	5 to 20 volts, τ_r in < 5ns, 50Ω
Rise time	< 100ps (10 to 90%) typical
Pulse Shape	Fast rise followed by decay over a few ns. The decay can be modified at the factory but faster decays will be necessary for high repetiton rates.
Power requirements	120/240 volts ac, 50/60 Hz
Lifetime	> 10^{10} shots
Operating temperature	10° to 35°C non condensing.



Three Electrode Pockels Cell and Driver for Regenerative Amplifiers

In a regenerative amplifier it is necessary to trap a laser pulse in a cavity for up to a microsecond and then send it into the rest of the laser system. In some systems, particularly those that have a gain medium with a long energy storage time, it is necessary to switch a pockels cell to $V_{\lambda/2}$, hold it there for 1µs and then switch it off again. For high contrast the transitions may have to be fast, e.g. ~1ns, and well synchronised, i.e. better than 1ns accuracy.

It is hard to make pulse generators that can achieve this performance and until recently only hard valve devices could offer this. Alternative systems with more than one pockels cell could do the job but degrade the cavity because of the many surfaces involved.

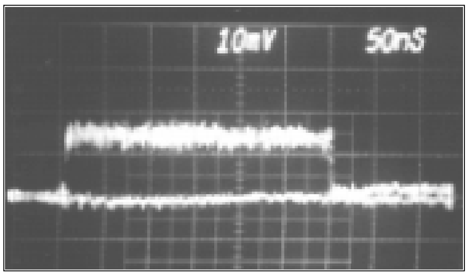
Using a single crystal double pockels cell and a pair of avalanche pulsers we can build a suitable alternative. A single crystal 5mm in diameter with three electrodes is used as a series pair of pockels cells.

The centre electrode is grounded and the two ends of the crystal are switched to the $V_{\lambda/2}$ voltage at relevant but completely independently determined times.

The pulsers which drive each end of the crystal only have to charge up each end of the cell quickly and then hold the charge there for longer than the required cavity opening time. The centre ground electrode helps to isolate the pulser systems from each other.

A schematic of the system is shown. Pulser 1 opens the cavity and then at some time later pulser 2 closes the cavity. As the two events are independent it should be possible to monitor the laser pulse build up in the cavity and switch it out when it has reached the required amplitude, subject to the total delay being less than about 1µs. We have yet to build such a system.

The pockels effect has several factors contributing to it which operate over different time scales. It is found that the voltage required to achieve $\lambda/2$ switching falls gradually over about 1µs. The pulsers have discharge circuits which, to first order, match this behaviour so that the transmission of a pockels cell and polarisers is maintained over the full 1µs.



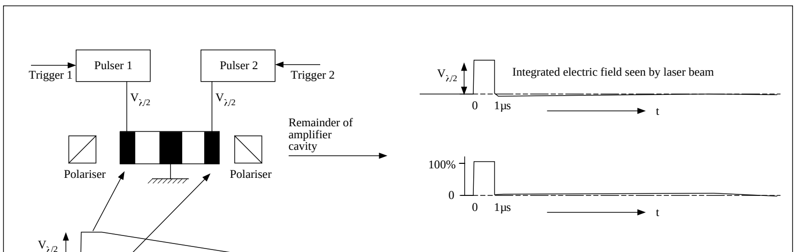
A 300ns pulse chopped from a 2mW CW laser diode beam. The noisy signal is due to the low light level and short itegration time (<1ns).

This system has distinct advantages over others, namely:-

- fast rise and fall times (~1ns).
- half or quarter wave drive systems available.
- same number of optical surfaces as a single cell system.
- independent control, via two trigger inputs, over open and close times (up to 1µs).
- completely solid state drivers with jitter of ~20ps and lifetime of around 10^{10} shots or more.
- no degradation of the pulser with ageing.
- possibility of interface to computer for control of amplitude, delay and system diagnosis.
- correction for fall in $V_{\lambda/2}$ over long time scales

The transmission characteristics of such a system have been obtained with a cw laser diode and a sampling system. Results are shown above. The measurements indicate that rise and fall times of ~1ns are achievable for pulse durations from zero to >1µs.

In laser systems that use a gain medium with a short storage time the pockels cell can be driven by two short pulses separated by the time the pulse is trapped in the cavity. The three electrode cell system offers the possibility of separate control of the two events with no problems of cross talk between the pulse sources and yet only as many optical surfaces as a single pockels cell.



A typical configuratiopn: one pulser charges each end of the crytstal, eachat programmed times to give optical gate lengths from 1ns to 1µs. Half wave system shown.

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HIGH VOLTAGE PULSER SUMMARY

Pulser	Amplitude	T_{rise}/PW	PRF	RMS Jitter	Features	Options
APG1	>100V	150ps/150ps	10kHz	10ps	S/D	
ASG1	>200V	100ps/8ns step	1kHz	10ps	St/D	
SPSV	>1kV	0.7ns/1,2,4,8,10 & 12ns	100Hz	10ps	S/D	
CPS1	>2kV	150ps/2ns decay	1kHz	20ps		/S
CPS2	>4kV	150ps/2ns decay	100Hz	20ps		/S
CPS3	>6kV	150ps/2ns decay	10Hz	20ps		/S
HMP1	>4kV	100ps/5ns	100Hz	10ps		S/D/Q/V/F
HMP2	>4kV x 2	100ps/5ns	100Hz	10ps		S/D/Q/V/F
PBG1	>6.5kV	100ps/5ns	100Hz	10ps		S/D/V/F
PBG2	>8.5kV	100ps/5ns	100Hz	10ps		S/D/V/F
PBG3	>12.5kV	100ps/5ns	100Hz	10ps		S/D/V/F
PBG5	>24kV	150ps/3ns	1kHz	20ps		S/D/V/F/B
PBG7	> 45kV	150ps/3ns	500Hz	20ps		/B

Features and Options
S Shaped pulse
St Step pulse
D Internal switchable delay, rate generator, trigger indicator, auxiliary low level outputs
Q Fast rise time (quick) down to 90ps on some units
V Variable output (approximately 60% to 100%)
F 1kHz repetition rate (some pulsers can achieve this without this option, consult factory)
B Balanced outputs
Units are available with multiple synchronous outputs,
e.g. a PBG5 will drive sixteen 50Ω outputs to 6.4kV

Voltages are into 50Ω, both positive and negative outputs are available.

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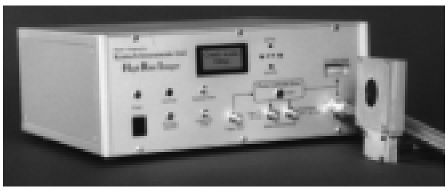
From small to very large; custom built pulsers are available for a wide range of applications.

Kentech Instruments Ltd. manufactures a large range of pulse generators and builds systems to customer specification. If you do not see a suitable instrument listed here please consult the factory to discuss your requirements.

Kentech Instruments Ltd. also make a range of time resolving and imaging devices for both X-ray and Optical wavelengths. In particular we manufacture gated optical image intensifier systems with gate widths down to 50ps and high repetition rate systems with bandwidths to GHz.

For X-rays we can offer gated imager and streak cameras.



The Kentech HRI (High Rate Imager)
Optical image modulation to 1GHz,
gate widths to 300ps at 110MHz
repetition rate