Autocorrelator for Analysis of Picosecond Pulses from a Modelocked Laser.

Diploma paper

Jörgen Carlsson
Fredrik Rüter

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Department of Physics
Lund Institute of Technology

CONTENTS

INTRODUCTION

This is a paper dealing with picosecond laser pulses. It is a result of our work at the Department of Physics at Lund Institute of Technology during 1984 and 1985. Our joint diploma work is constituted of the construction of an autocorrelator, an Autocorrelator Manual, and this paper. Dr. Hans Lundberg has been our supervisor during this work.

The paper consists of five chapters. The first three chapters are general, and the two last ones are about our specific autocorrelator construction.

Lund August 1985

Jörgen Carlsson

Fredrik Rüter

CHAPTER 1. MODELOCKING

The method of generating laserpulses in the pico- and the subpicosecond regime is referred to as modelocking. Let us first take a look at the modestructure in a laser-cavity. First let us restrict ourselves to a laser with plane and parallell mirrors. Solving the Maxwell equations gives you an infinite set of solutions, corresponding to standing wave patterns in the cavity. The frequencies of the different possible waves are given by $\nu=n\cdot c/2L$ *where c is the velocity of light in the specific medium, L is the length of the cavity and n is a large integer. These different ways to oscillate are called longitudinal modes. If the mirrors are not plane (most laser cavities do not have plane mirrors, for stability reasons) there turns up another set of possible standing wave patterns, referred to as transversal modes. The transversal modes are not desired and they can also be suppressed by putting a diaphragm at each mirror. The apertures are chosen so that the losses for the transversal modes are too big and the laser "chooses" to oscillate on a set of modes where laser-action is the least counteracted. We have the situation where mathematically a number of frequencies, separated by c/2L, can exist and interfere constructively in the laser cavity.*

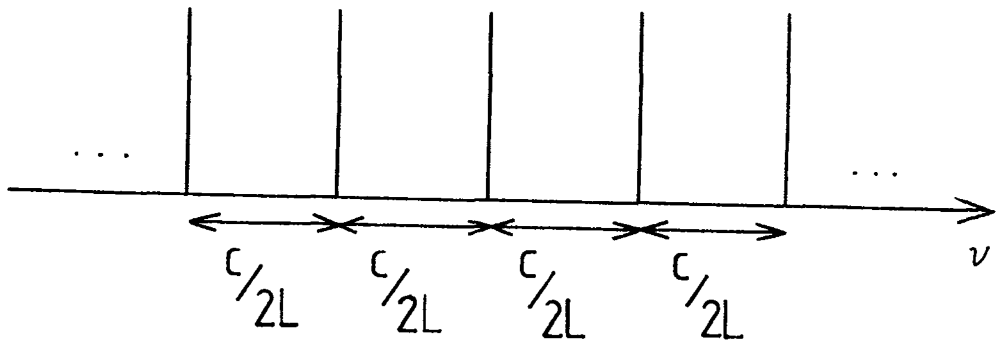
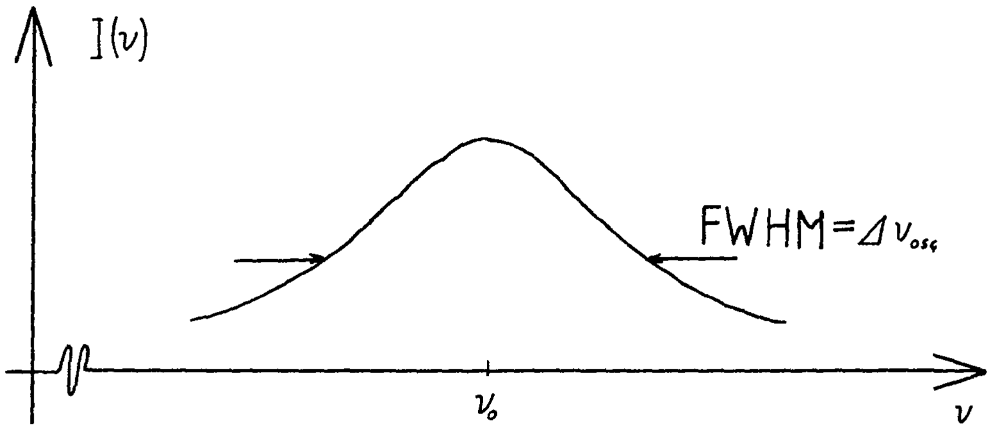


Figure 1. Laser modes in a cavity.

So far we have just discussed the effects of interference in a cavity. In order to get a laser there naturally has to be some kind of medium from where the characteristic laser light originates. Each laser medium has its specific wavelength (or wavelengths). The laser action originates in the stimulated emission of photons between two energy levels where inverted population must be possible to create. The laser line is broadened by different mechanisms, such as broadening by natural bandwidth, collision broadening and Doppler broadening (the latter two being dominant when the laser medium is a gas). We thus do not have one infinite sharp wavelength that can be amplified, but a distribution of wavelengths. Very often this distribution can be considered to be Gaussian in its shape.



$$A(\nu) \sim \exp \cdot \left[-\left(\frac{\nu - \nu(osc)}{\Delta\nu_0 / 2} \right)^2 \cdot \ln 2 \right]$$

Figure 2. Gaussian gainprofile.

This is the so called gain profile of the laser medium. Together with what we said earlier, we now have the situation where a number of modes are allowed to oscillate under the gain profile.

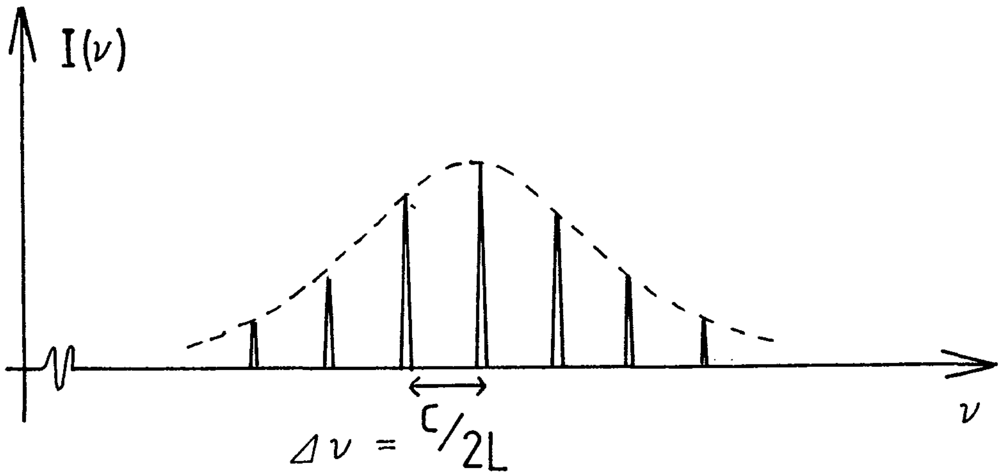


Figure 3. Gainprofile with modestructure.

This is the normal situation in for instance gas- or dye lasers. A remark: the "spikes" separatated c/2L are of course not infinitely sharp, but compared with the laser gain profile they can be considered to be sharp. From here on we assume we have Gaussian gain profile and longitudinal modes only. In the laser we consequently can distinguish a number of different frequencies, all separated by c/2L in frequency. These modes all have different phases, or more correct: the phases, $\phi(k)$, of the modes are uncorrelated. The total electric field $E(t)$ of the electromagnetic wave can be written as

$$E(t)= \sum_{k=-n}^{n} E(k)\cdot \exp(i2\pi(\nu_0+k\cdot\Delta\nu)t+\phi(k))$$

where $E(k)$ is given by the Gaussian distribution, and $2n+1$ is the number of modes that can oscillate under the gain profile. If we could force the $2n+1$ modes to oscillate with a constant difference in phase:

$$\phi(k)-\phi(k-1)=\alpha$$

the electric field will be given by:

$$E(t)=\sum_{k=-n}^{n} E(k)\cdot\exp[i2\pi(\nu_0+k\cdot\Delta\nu)t+k\alpha]$$

if the center frequency is defined to have zero phase. $\Delta\nu$ *is still c/2L. Carrying out the summation we obtain*

$$E(t)=A(t)\cdot\exp(i2\pi\nu_0 t)$$

where

$$A(t)=E(k)\cdot\frac{\sin[(2n+1)(2\pi\Delta\nu t+\alpha)/2]}{\sin[(2\pi\Delta\nu t+\alpha)/2]}$$

As a result of this phase-locking, the modes interfere to produce short light pulses. The pulse maxima occur when the denominator in the expression for A(t) equals zero. From here we can see that two pulse maxima are separated by the time period

$$\tau=1/\Delta\nu=2L/c$$

Since the output power of the laser is proportional to $A^2(t)$ it is interesting to take a look at following figure:

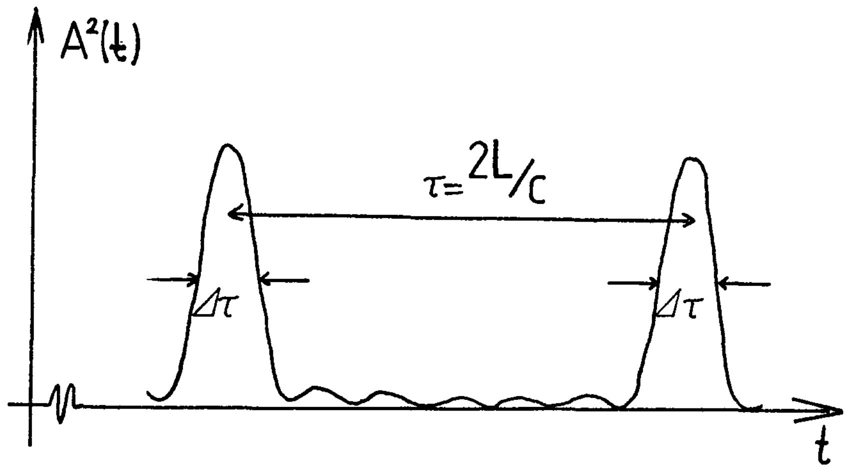


Figure 4. Modestructure in time, modelocked.

It is also possible to deduct that

$$\Delta\tau \approx 2 \cdot \ln 2 \ / \ \pi \cdot \Delta\nu(osc) \approx 0.441 \ / \ \Delta\nu(osc)$$

The last equation is interesting, because it implies that the wider the gain profile of the laser medium is (i.e. the broader the distribution of possible frequencies), the shorter in time laser pulses can you produce. Dye lasers have quite large $\Delta\nu(osc)$, typically some THz (if no wavelength-selective elements are used in the laser) which then would make sub-picosecond pulses possible to create. One can think of modelocking as a way of concentrating the power into short pulses. The intensity of the pulse is for a modelocked laser proportional to $(2n+1)^2 E_0^2$ (where E_0 is the amplitude of the electric field), compared to $(2n+1)E_0^2$ for a non-modelocked laser. This big pulse is alone in the cavity and it bounces back and forth between the *two cavity mirrors. By now it is easy to see why modelocking is desired, but so far we have not mentioned how modelocking is obtained. Lasers can be either actively or passively modelocked.*

1.1. Active modelocking.

The idea of active modelocking is letting an active modulator, driven by an external signal, modulate the laser losses (or gain) at a frequency corresponding to the modeseparation c/2L. Loss modulation modelocking can be obtained by introducing an acousto-optic cell in the cavity. The modulator is driven by an RF source, introducing losses in a loss cycle corresponding to the round trip time for one pulse, 2L/c.

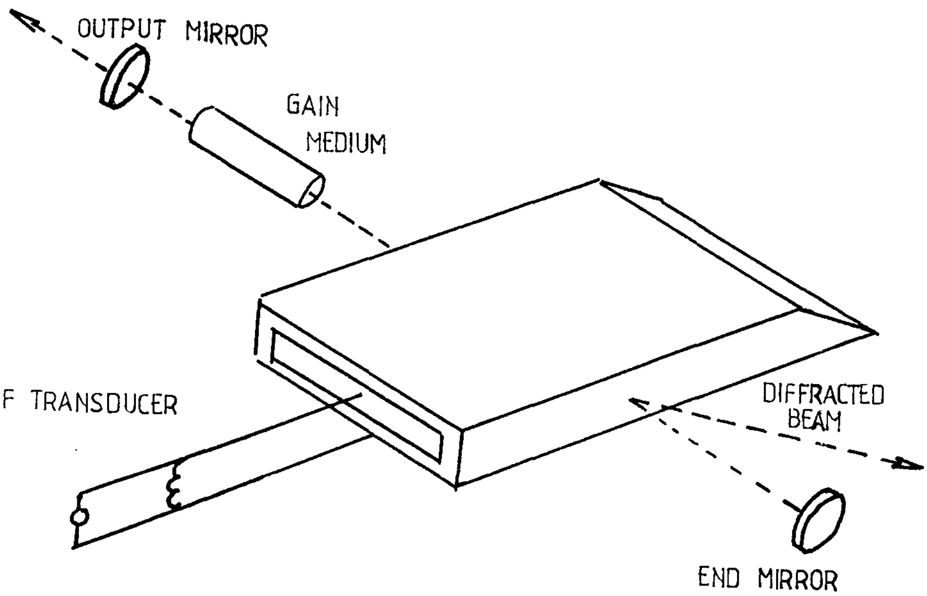


Figure 5. Acousto-optic modulator.

Another technique connected with modelocking is cavity dumping. The mirrors are chosen both to be 100% reflective. By putting another modulating cell in the cavity, one can allow the pulse to gain and grow even greater before it is dumped out of the cavity. This gives more powerful pulses, but it also gives larger time separation between produced laser pulses, a lower repetition rate. Another way of modelocking actively is to modulate the gain in the laser medium. This method is used in dye lasers. The dye laser is pumped by another modelocked laser (an Ar-ion laser for example). The cavity length of the dye laser is matched to correspond with the length of the pumping laser. The pulses in the dye laser that oscillate synchronously with the pulses in the pump laser, experience more gain than if they would oscillate out of phase. Thus the dye laser is modelocked. The dye laser has a wide gain profile which allows it to produce even shorter (in the subpicosecond region) pulses than the pumping laser. An effect of getting the light pulses very short is that they at the same time get quite wide in frequency, which one for instance can understand from the Heisenberg relation $\Delta E \cdot \Delta t \gtrsim h/2\pi$.

1.2. Passive modelocking.

In order to modelock a laser passively, one introduces a thin slab with a saturable absorber in the cavity. The absorber works as a kind of shutter. The light from uncorrelated modes is strongly absorbed, but at high enough intensities the absorber saturates and it bleaches, the shutter is open. The modes in the laser arranges themselves so that oscillation can be maintained, and so modelocking is obtained. The shortest light pulses that have been obtained have been produced in a ring cavity laser, using colliding pulses. The pulses travel around the ring cavity in different directions. Only when they meet in *the absorber, enough bleaching is obtained to allow transmission. By using this technique as short pulses as 65 fs have been produced.*

CHAPTER 2. WHY ULTRASHORT LASER PULSES ?

In order to study a fast movement or a fast process one has to have a light source which can produce light pulses that are shorter than the studied phenomena. Man's curiosity of how nature works has driven physicists onward in the research of finding shorter and shorter light pulses. The cause of the fast development in the past decade can mainly be attributed to the invention of the laser in 1960. Getting lasers to produce as short light pulses as possible is only one direction of laser science, but an important one. The scientists first learned to master Q-switching, which is a technique of producing laser pulses in the nanosecond area with high peakpower. Q-switching was developed on the first working laser, the ruby laser, in order to avoid irregular spiking of the light. In 1965 the first modelocked lasers were built, and the picosecond era was started. The first modelocked laser was a He-Ne laser. Soon modelocking was applied to other kinds of lasers. Today the shortest pulses come from a dye laser, pumped by an Ar- or Kr-ion laser.

What are the applications where it is important with pico- and subpicosecond pulses? The main interest is in physics, chemistry and biology, where processes occur in the picosecond domain. There are some different approaches in exploring picosecondphenomena. The problem is that there are no electronic devices which can follow the events when they are this fast. Let us first take a look at the experimental arrangements.

2.1. *Experimental arrangements.*

When one wants to study ultrafast relaxation processes or absorption saturation, one often uses the technique of excite and probe. One way of doing this is using an autocorrelator of the same type that we have built.

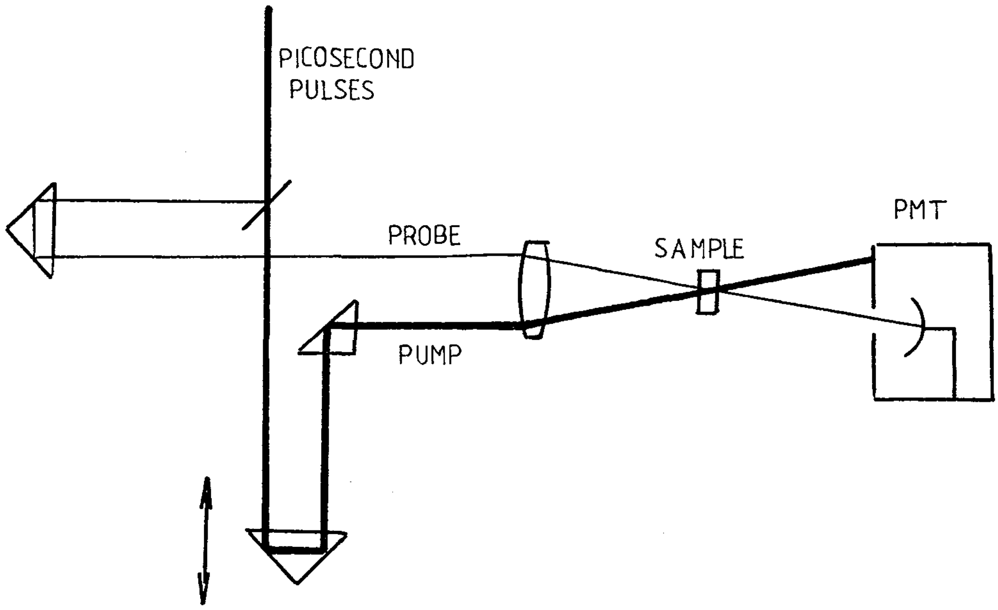


Figure 1. Autocorrelator for pump-probe experiment.

One beam is used to excite the sample, and the other beam probes the sample. The exciting beam should be about ten times stronger than the probe beam. The delay of one of the beams is varied continously.

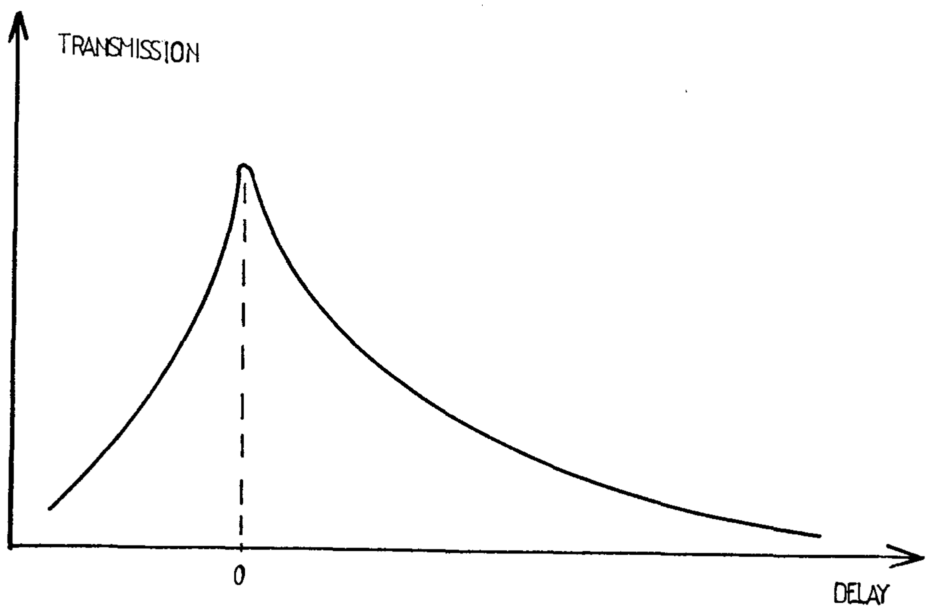


Figure 2. Exponential decay.

Another probe and excite approach is the induced grating method. The two excite beams generate an interference fringe pattern in the sample. A delayed probe pulse which passes through the sample will be diffracted. The induced grating relaxes, which means the intensity of the diffracted part of the probe beam decreases as a function of the delay. We hereby get information on the relaxation time of the sample.

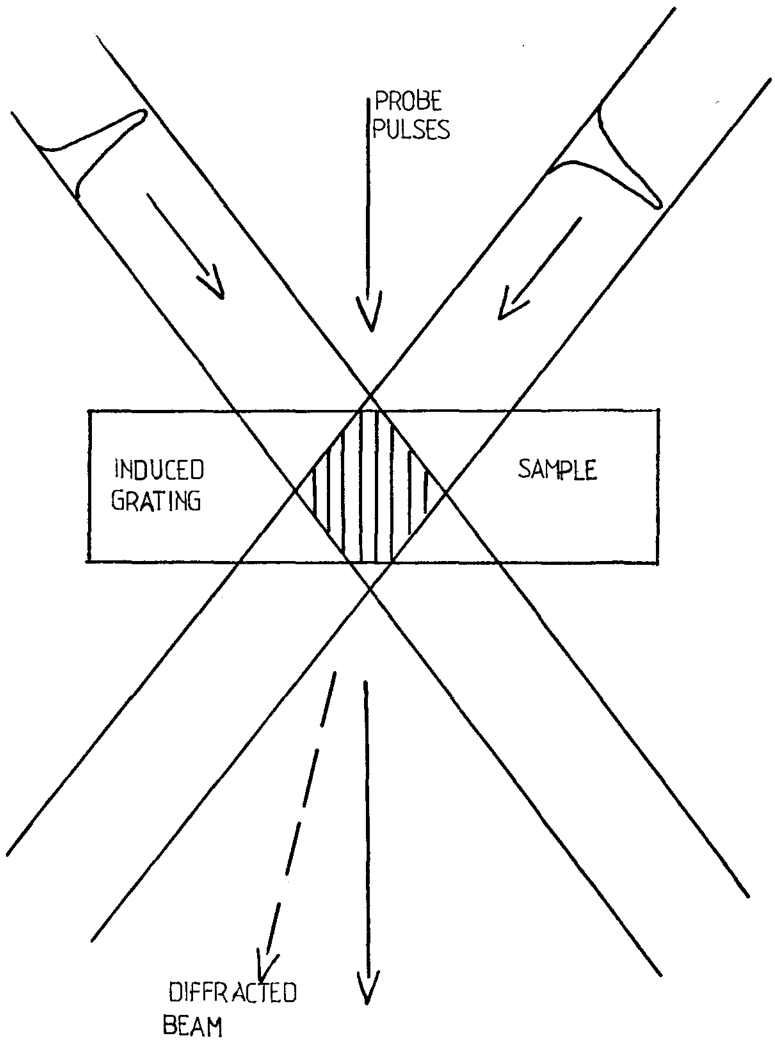


Figure 3. The induced grating method.

When one wishes to study fluorescence decays one normally uses some kind of gating technique. This can be done using optical or electronic gating. Let us take a look at optical gating. It consists of a Kerr cell (a CS_2-filled cell sandwiched between two crossed polarizers). The Kerr cell works as a camera shutter. The shutter pulse must be intense enough, in other words it has to be amplified. Delaying the shutter pulse differently allows you to sample the fluorescence at different times.

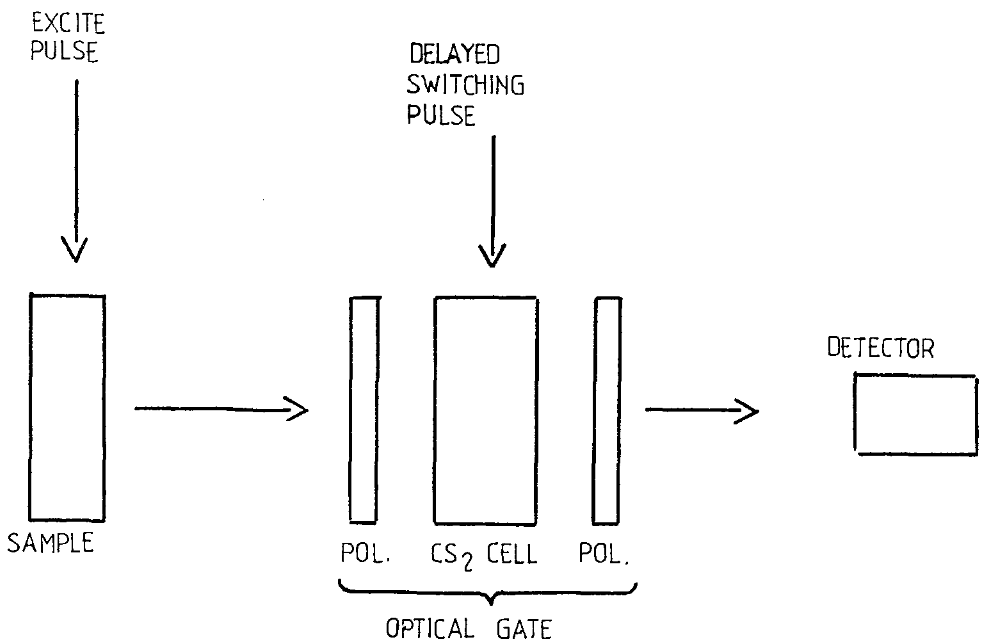


Figure 4. Optical gating.

2.2. Applications.

So far we have just given some examples of how to arrange your experiments when you are looking at picosecond phenomena. Now we are going to take a quick look at some of the interesting experiments using tunable picosecond laser pulses.

2.2.1. Physics.

The fact that picosecond pulses are so short in time gives them at least one desirable property: they have high peak powers but moderate energy. This opens the possibility to study multiphoton interactions, where high light intensities are required, but where longer pulses bring about undesired heating.
Typical times of vibrational relaxation is in the picosecond domain. It is essential to have a mean of excitation and probing in the same time domain.
Studies of the properties of semi-conductors are preferably done with picosecond laser pulses. The high peak power generates dense electron-hole plasma, which gives you the possibility to study the behaviour of charge carriers.
Relaxation processes in semi-conductors are often phonon emission processes. Since these relaxations occur in the picosecond domain and compete with optical emission processes, picosecond studies of these phenomena are interesting.
Another interesting application in semi-conductors, is the generation of picosecond electrical pulses. This is done in a so called strip line arrangement. Using picosecond laser pulses is the only way today to obtain these short electrical pulses. The ultrashort electrical pulses are used to test ultrafast electronic devices at an early stage

of the production.

Ultrashort laser pulses are also used in the study of optical fibres and pulse coded communication applications.

2.2.2. Chemistry.

Many of the relaxation processes in molecules occur in a picosecond time scale. To mention a few of the interesting effects studied:

- *intermolecular energy transfer*
- *rotational relaxation*
- *photo dissociation*
- *electron transfer processes*
- *internal conversion*

2.2.3. Biology.

The study of the photosynthesis process is an important application of picosecond laser pulses. Photosynthesis is a very complex process and many of the intermediate steps of the process need a picosecond light source in order to be resolved. The process of attaching and detaching oxygen molecules to haemoglobin molecules, is of great interest to understand. Here, as in the case of most processes dealing with biological molecules, much of the interesting action takes place in the picosecond time scale. The study of the DNA-molecule has high actuality today. Energy migration along the molecular chain, as well as fluorescent decay of the nucleotides occur in the picosecond time scale.

2.2.4. Fusion energy.

One way of attacking the problem of extracting energy from fusion processes, is the laser-induced fusion technology. Here a plasma of deuterium and tritium is created by a laser pulse with high peak energy and short duration. The highly exothermic process is

$$D + T \rightarrow {}^{4}He + n.$$

It is induced in a small droplet. A number of modelocked (usually Nd:glass) lasers are focused at the small piece of materia, and the picosecond amplified pulses are fired simultaneously. They induce a plasma where the above mentioned reaction takes place, while the droplet is being contained by its own inertia. In the beginning of the 80's one could produce pulses with a peak power of approximately 30 TW, a peak power of about 200 TW is needed for break-even. It is still a long way to go before fusion power plants is a reality.

2.3. Femtosecond pulses.

The race towards shorter and shorter laser pulses goes on. Today the shortest light pulses produced are twelve femtoseconds long (Halbout and Grischkowsky, IBM). During this period of time the light pulse travels 3.6 µm. These short pulses are produced by pulse compression of femtosecond pulses produced by a ring laser using colliding pulse modelocking.

2.3.1. Colliding pulse modelocking.

The principle of colliding pulse modelocking is having two counterpropagating pulses in a ring laser. The pulses precisely overlap in the saturable absorber, but the pulses pass through the gain medium with as big time difference as possible. Only when the extremely short pulses overlap in the absorber is the bleaching of the absorber good enough, and the pulses are transmitted. The saturable absorber is in the form of a very thin (10 μm) jet, and the gain medium is a dye jet (Rhodamine 6G) pumped by a cw Ar-ion laser. This technique has today produced pulses down to 65 fs.

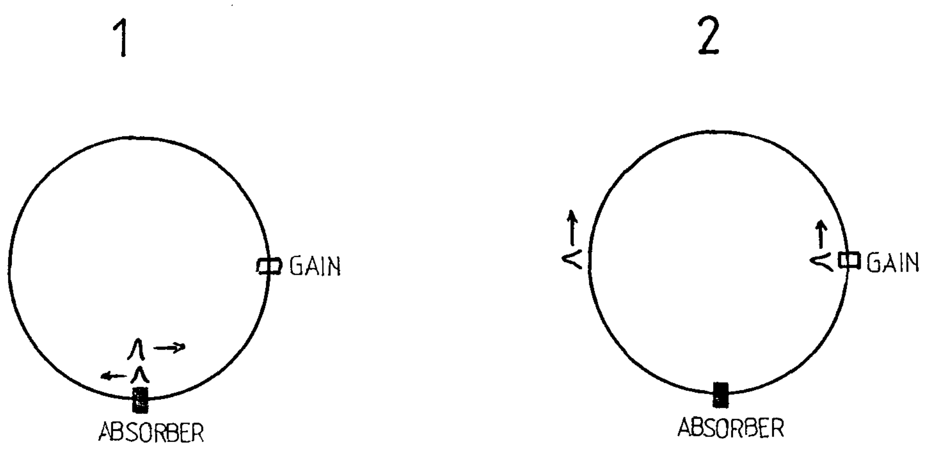


Figure 5. Ring cavity for colliding pulse modelocking

The fact that two pulses saturate the absorber while only one pulse saturates the gain is the secret why the pulses can get so short. The theory for showing this is complex, and we here just establish the fact that it works.

2.3.2. *Pulse compression.*

In order to further bring down the duration of the pulse one uses a pulse compression technique. This technique involves a 15 cm optical single mode fibre, and a pair of gratings. The refractive index of the fibre is a function of intensity and wavelength. The pulse from the ring cavity (app 70 - 100 fs) is amplified. This amplifier can for instance consist of a four-stage dye amplifier pumped by a frequency doubled Nd:YAG laser (Shank, Fork, Yen and Stolen). The amplified pulse is focused into the fibre. The fibre spectrally broadens the pulse, since different frequencies propagate with different speed. After the fibre the outcoming pulse is defocused and passes parallell through a pair of gratings. The red light, which came first out of the fibre, goes a longer way through the pair of gratings, than the blue light. Thus a compressed pulse, constituted by almost white light is created. In this process one has to optimize the intensity of the incoming pulse, the length and the quality of the optical fibre, and of course the quality of the gratings is essential in bringing down pulse times.

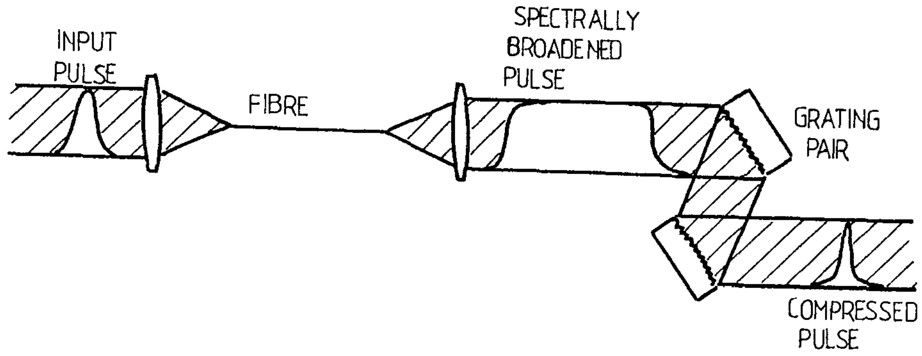


Figure 6. Pulse compression.

2.4. Future.

Today it seems like the way of getting even shorter light pulses is to work on improving the experimental arrangements described above. Trimming the mirrors of the resonator reduced the pulse duration from 90 to 65 fs for Shank, Fork, Yen and Hirlimann for instance. Getting even better gratings and single mode fibres should be able to bring down pulse times further. Constraints in bringing down pulse time is also found in the bandwidth of the gain and absorber media. However, the scientists of today agree that in a couple of years from now 2 fs laser pulses can be produced. This time period is approximately the time of one optical period. This must be the natural limit, and probably the goal for the "racing" scientists.

CHAPTER 3. PULSEWIDTH MEASUREMENTS

3.1. Direct measurement.

3.1.1. The streak-camera.

A streak-camera can make a direct measurement of the intensity-variation in a short light pulse with a best possible time resolution of about 1ps. The construction of a streak-camera is described in figure 1.

The pulse that is to be measured is directed on a photocathode. The photoelectrons then emitted are accelerated and focused on a phosphor screen. The number of electrons is increased by a microchannel plate before the electrons hit the screen. The time resolution is caused by a rapidly rising high voltage on the deflection plates. This means that a light pulse entering the camera will give a trace on the screen. The length of this trace depends on the pulsewidth and the intensity-variation on the screen is the same as in the original pulse. The trace on the screen can be registered on a photographic film or by a multichannel-detector.

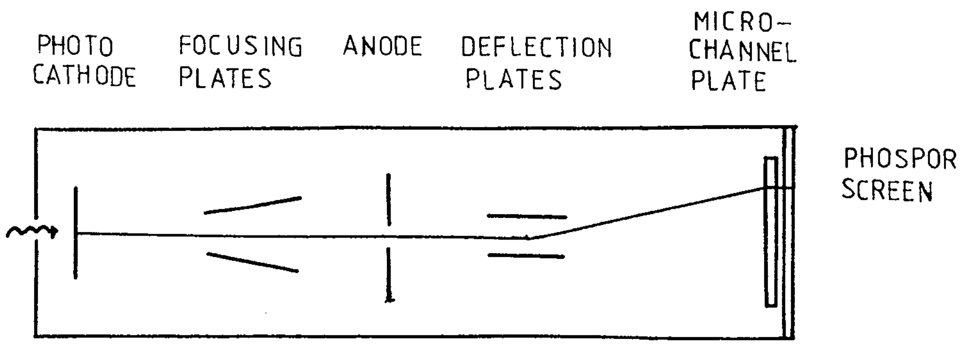


Figure 1. Streak-camera.

3.2. Indirect measurement.

3.2.1. Autocorrelation.

The autocorrelation of a signal $I(t)$ is defined as

$$g(\tau) = \frac{\int_{-\infty}^{\infty} I(t)I(t-\tau)dt}{\int_{-\infty}^{\infty} (I(t))^2 dt} \quad .$$

If we measure the FWHM of the autocorrelationfunction without knowing the shape of the original signal, which is the case when measuring the pulses from a modelocked laser, we will not be able to determine the FWHM of the original signal. Thus, in order to estimate the pulsewidth, we have to assume a pulse-shape. Table 1 gives the ratios of autocorrelationwidth and pulsewidth fore a number of pulse-shapes.

Pulse-shape		$\Delta\tau/\Delta t$
square	$1 \quad (0<t<\Delta t)$	1
Gaussian	$\exp(-t/T)^2$	$\sqrt{2}$
sech^2	$\left(\frac{2}{\exp(t/T)+\exp(-t/T)}\right)^2$	1.55
Lorenzian	$(1+(t/T)^2)^{-1}$	2
single-sided exponential	$\exp(-t/T) \quad (t>0)$	2
double-sided exponential	$\exp(-\mathrm{abs}(t/T))$	2.44

Table 1. Ratios of FWHM of autocorrelation ($\Delta\tau$) and pulse (Δt) for different pulse-shapes.

3.2.2. The autocorrelator.

The construction of the autocorrelator is based on the Michelson-interferometer. The pulses, whose width is to be measured, are each divided in two equal parts by a beamsplitter and the pulses travelling one of the two ways are given a variable delay. The pulses are recombined in a birefringent crystal, such as KDP, in which, if the proper phase-matching condition is fulfilled, frequency-doubled pulses will be created through second-harmonic generation. The way in which the pulses are recombined in the crystal greatly effects the phase-matching condition and the frequency-doubled signal produced.

The non-colinear arrangement in figure 2 with the incoming pulses polarized perpendicular to the optical axis of the crystal, i.e. as ordinary rays, gives a pulse in the direction of the bisector of the angle between the two incoming pulses when the condition $n_2 = n_1 \cos\phi$ *is fulfilled.*

n_2 *is the refractive index for the pulse produced.*

n_1 *is the refractive index for the incoming pulses.*

ϕ *is half the angle between the two incoming pulses.*

This condition is easily deduced from the conservation of momentum when two photons from the incoming pulses with frequency ν *are transformed to one photon of frequency* 2ν *travelling in the direction of the bisector:*

Conservation of momentum perpendicular to the bisector gives that one photon must be taken from each of the incoming pulses.

Conservation of momentum in the direction of the bisector gives

$$(h\nu/c_1 + h\nu/c_1)\cos\phi = h2\nu/c_2$$

$$(1/c_1)\cos\phi = 1/c_2$$

$$n_1\cos\phi = n_2$$

$c_1 = c/n_1$ is the spead of the incoming pulses.

$c_2 = c/n_2$ is the spead of the pulses created.

Due to dispersion n_2 is usually greater than n_1. However, in a birefringent crystal where the extraordinary refractive index is smaller than the ordinary the opposite may be possible if n_2 is an extraordinary refractive index and n_1 is an ordinary.

Phase-matching can be done either by changing ϕ or by changing n_2. The latter is done by turning the crystal so that the refractive index for the pulses created varies between the ordinary value n_0 and the extraordinary value n_e.

If the angle between the bisector and the optical axis is θ, the refractive index n for the pulse created is given by

$$\frac{1}{n^2} = \left(\frac{\cos\theta}{n_0}\right)^2 + \left(\frac{\sin\theta}{n_e}\right)^2$$

or

$$\sin^2\theta = \frac{1/n^2 - 1/n_0^2}{1/n_e^2 - 1/n_0^2}.$$

The intensity of the frequency-doubled light for a delay τ is

$$g(\tau) = C_1\int_{-\infty}^{\infty} I(t)I(t-\tau)dt$$

where C_1 is a constant. This is the autocorrelation of the original pulse-intensity, $I(t)$. This background-free signal is measured by a photomultiplier tube and is displayed on an oscilloscope or a a multichannel analyzer as a function of the delay τ.

If the angle between the two incoming pulses is zero, as in figure 3, and they again are polarized perpendicular to the optical axis, the phase-matching condition is reduced to $n_2 = n_1$ *which usually can be fulfilled in larger ranges of wavelengts than the condition involving* $\cos\phi$. *However, the pulses being colinear removes the condition that one photon must be taken from each pulse. This means that the intensity-autocorrelation will be superimposed on a constant background, giving the signal*

$$h(\tau) = g(\tau)+g(0)/2$$

which has a peak to background ratio of 3:1. When using colinear pulses it is necessary to remove the light with the original frequency with a filter before measuring the signal.

A background-free signal can be produced in a colinear autocorrelator if one of the two pulses recombined in the crystal is an extraordinary ray and the other is an ordinary. This gives a signal when the condition $n_{1o}+n_{1e} = 2n_{2e}$ *is fulfilled. This method requires that the polarization of the pulses travelling one of the two ways is changed and, compared to the methods described earlier, phase-matching can be obtained only in very limited ranges of wavelength.*

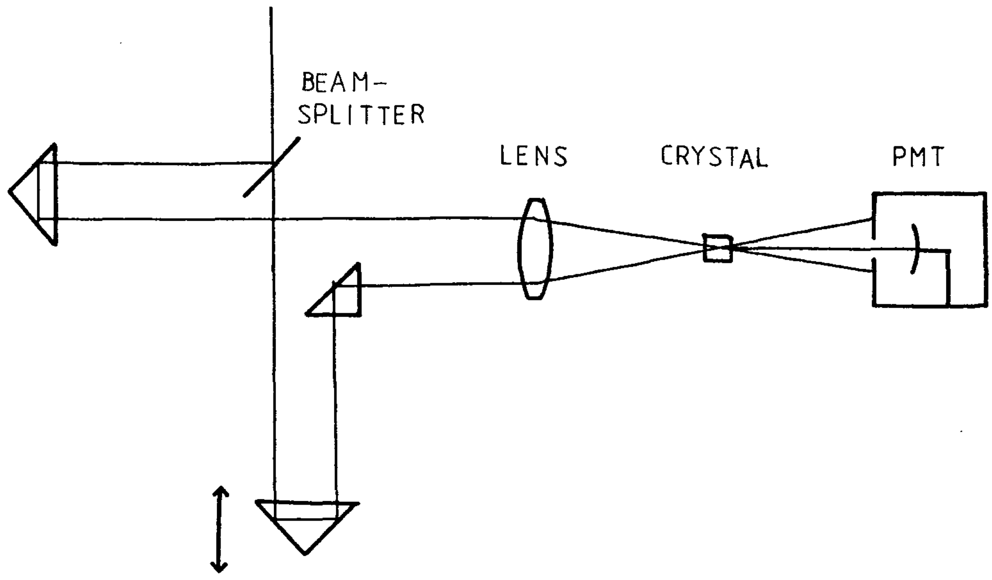


Figure 2. Non-colinear autocorrelator.

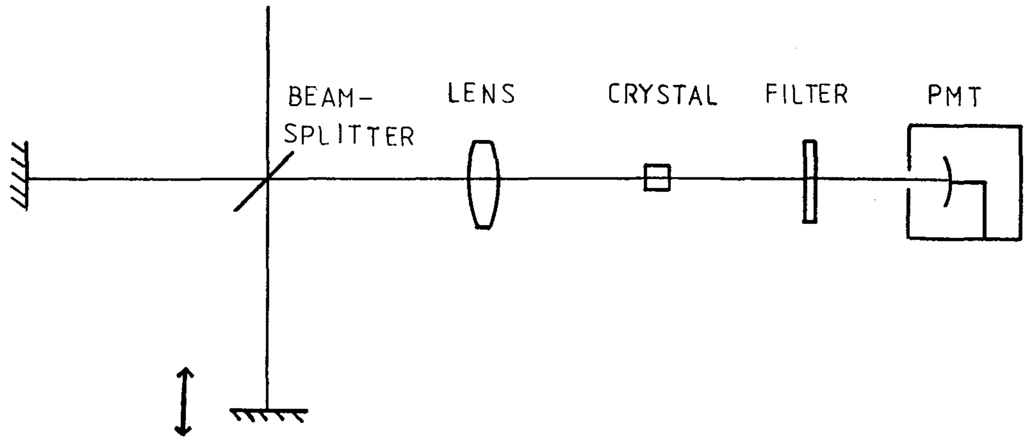


Figure 3. Colinear autocorrelator.

3.2.3. Two-photon fluorescence.

The intensity-autocorrelation of a pulse can also be obtained with the set-up described in figure 4. The pulse is divided in two equal parts by a beamsplitter. The two pulses then pass through a dye in opposite directiones but in the same trace so that they overlap in the dye. The dye is chosen so that light can be absorbed only by two-photon *absorption. The intensity of the fluorescence following this absorption, measured along the trace, will be*

$$h(\tau) = C_2\left(\int_{-\infty}^{\infty}(I(t))^2dt+2\int_{-\infty}^{\infty}I(t)I(t-\tau)dt\right)$$

with $\tau = 2nx/c$.

C_2 *is a constant.*

$I(t)$ *is the original pulse-intensity.*

n *is the refractive index of the dye.*

x *is the distance along the trace from the point where the pulse-maxima overlap.*

This signal, with a constant background, is the same that can be obtained from an autocorrelator.

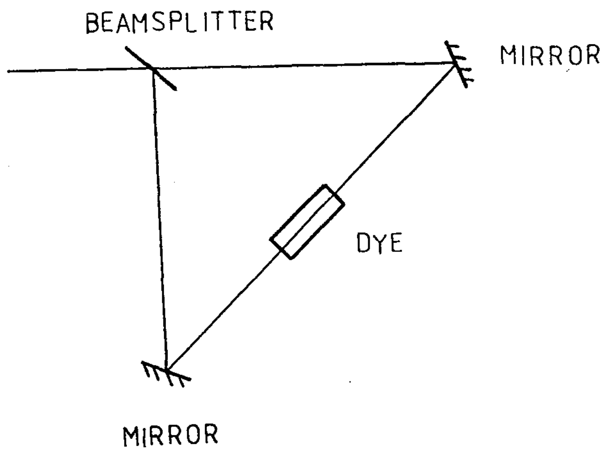


Figure 4. Autocorrelation-measurement by two-photon fluorescence.

CHAPTER 4. THE AUTOCORRELATOR CONSTRUCTED

The autocorrelator constructed by us is of the non-colinear type previously described in 3.2.2. It gives a background-free signal which is the autocorrelation of the incoming pulse-intensity.

4.1. Optical and mechanical construction.

The autocorrelator is described in figure 1. All objects are mounted on a 78cm•51cm baseplate.

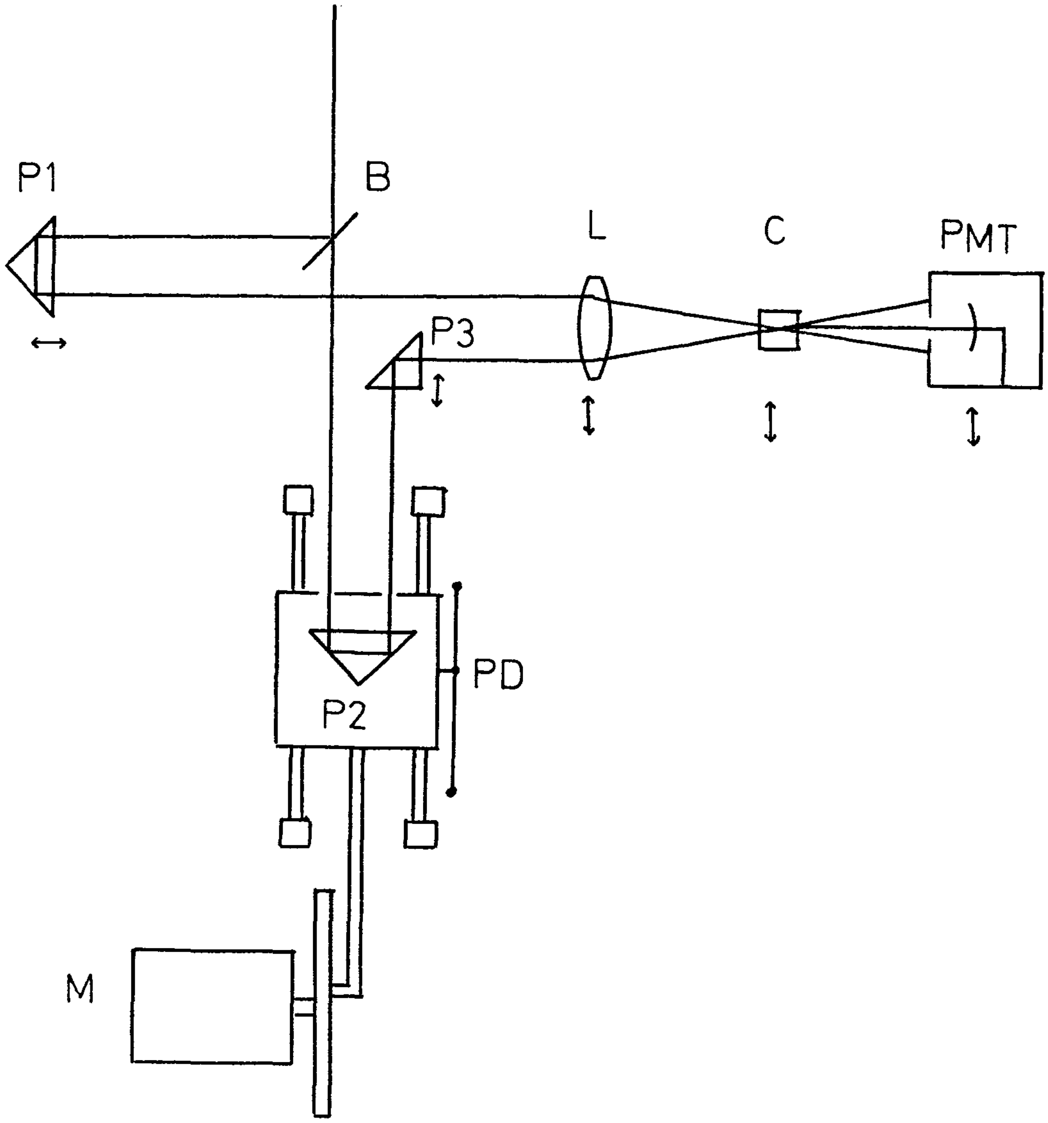


Figure 1. The autocorrelator. Arrows showing the direction in which the objects can be translated on the baseplate.

B : 50% beamsplitter.

P1,P2 : 25mm corner prisms of quartz.

P3 : 15mm corner prism of quartz.

L : f = 200mm, 50mm diameter lens of quartz.

C : Birefringent crystal. Exchangeable to match the wavelength used.

PMT : RCA 1P28 photomultiplier tube with RCA PF1043 power supply.

M : 24V DC-motor. 250 rpm.

B, P1, P3 and C are set on mounts with adjustmentscrews. The mounts for P1, P3, L and C can be translated on the baseplate. The photomultiplier tube and power supply are contained in a housing which the light enters through a 2mm hole. The hole is covered by a 2mm thick Schott UG5 filter with high transmission between 2500 and 3500Å. The housing can be translated on the baseplate. P2 is mounted on a carriage which moves on two axles and is driven by a rod, the other end of which is attached to a plate fastened on the motor-axle. The rod can be fastened to the plate at a radius from the motor-axle of 5, 15, 25, 35 or 45 mm. PD is a position-detector in the form of a 10cm long, 0.10mm diameter kanthal-wire with a resistance of 10Ω over which lies a voltage of 1.0V. A trailing-contact mounted on the carriage is moving along the wire, thus giving a voltage proportional to the displacement of P2.

4.2. Electrical construction.

The circuits described in this section are designed and built by Åke Bergquist.

The photomultiplier tube power supply requires a DC-voltage variable between 0 and 9V to give a high voltage between 0 and 1250V.

The motor requires 24V DC.

The position-detector requires 1.0V DC.

These requirements are met by the circuits in figure 2. These also provide a variable amplification of the signal from the position-detector and a variable off-set to the voltage over the kanthal-wire.

All electrical controls are placed on the autocorrelators front panel, a picture of which is shown in figure 3.

To display the autocorrelationfunction, the signal from the photo-multiplier tube can be shown as a function of the signal from the position-detector on an oscilloscope.

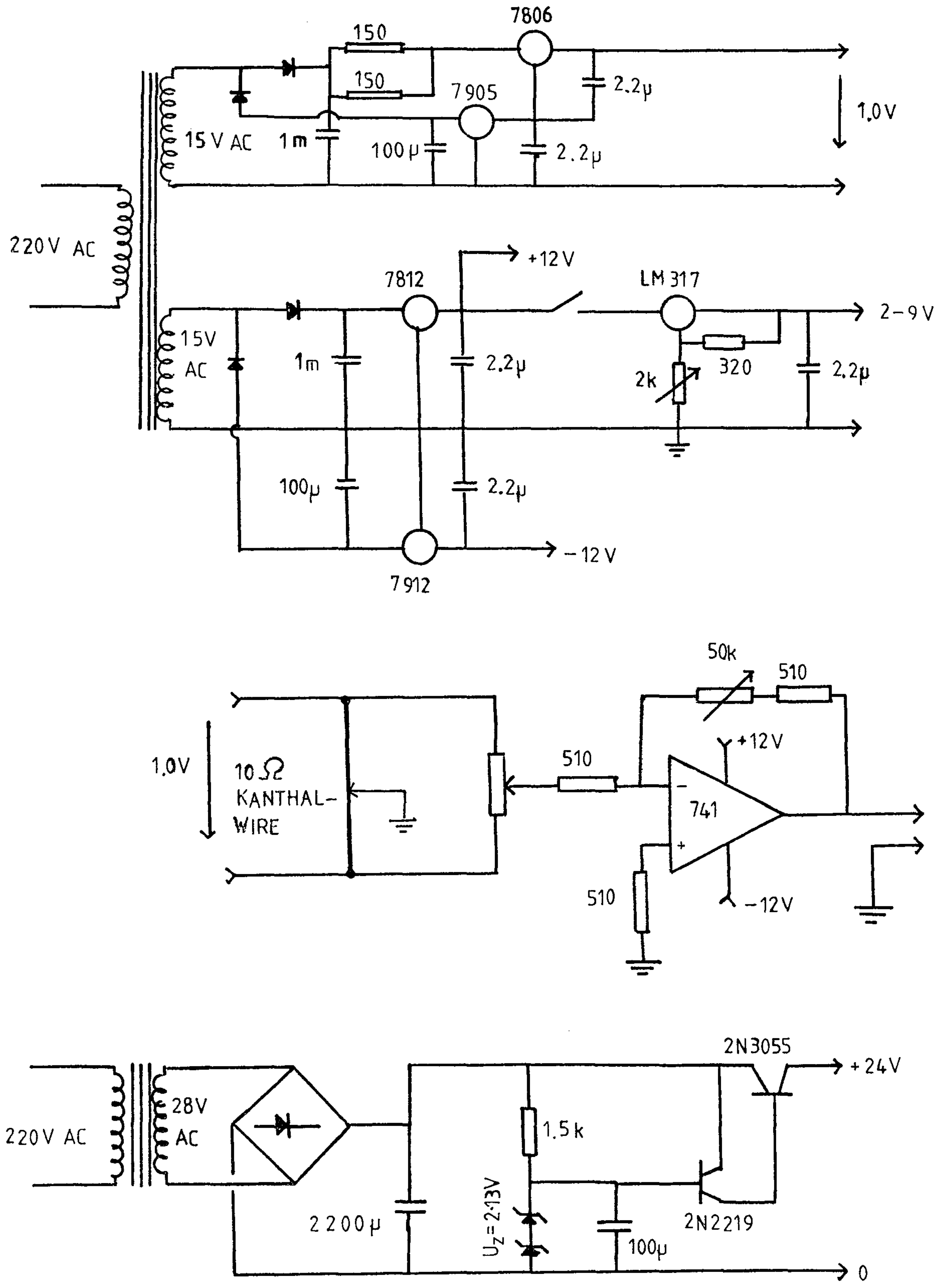


Figure 2. Electronic circuits used in the autocorrelator.

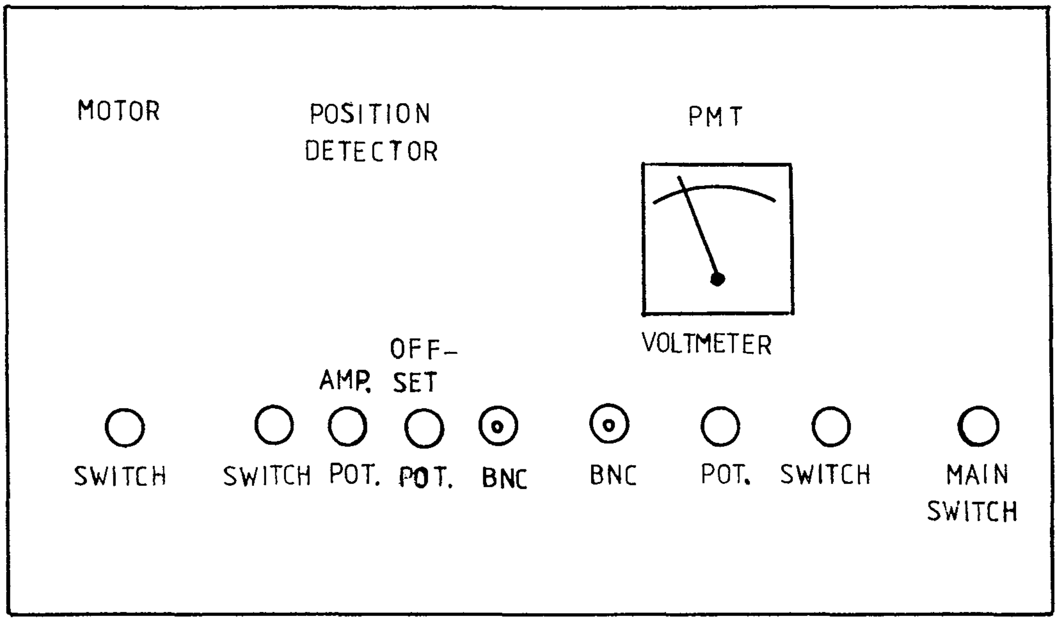


Figure 3. Front panel of the autocorrelator.

CHAPTER 5. MEASUREMENTS WITH THE AUTOCORRELATOR

The autocorrelator has been used to measure the pulses from a Coherent CR 599-04 dye laser, synchronously pumped by a Coherent Innova Ar-ion laser with a Coherent 468-AS modelocker.

5.1. Modelocking of the Ar-ion laser.

The modelocker consists of a frequency-synthesizer and a modelocker head. The frequency-synthesizer is tuned to a frequency with a half period-time equal to the round trip time of the laser. The modelocker head replaces the ordinary high reflector mirror and contains a high reflector mirror and a silica prism to which a piezoelectric transducer is attached. The signal from the synthesizer is applied to the transducer from which an acoustic wave with the same frequency is sent into the prism. The length of the prism is an integer number of half wavelengths which causes a standing wave pattern to be created. This wave causes a variation in pressure and thus in refractive index along its direction of propagation. The light, which is passing through the prism perpendicular to the acoustic wave, will be diffracted by these variations in refractive index, except, of course, when the amplitude of the standing wave is zero, which happens with a frequency twice that of the synthesizer.
This means that one short pulse will be travelling inside the laser cavity, all other light being suppressed by the diffraction in the prism.

5.2. *Modelocking of the dye laser.*

As described in 2.1 synchronous pumping requires that the cavity-lengths are matched. As the dye laser is normally much shorter than the Ar-ion laser, a delay-line is inserted in the dye laser giving a cavity as described in figure 1.

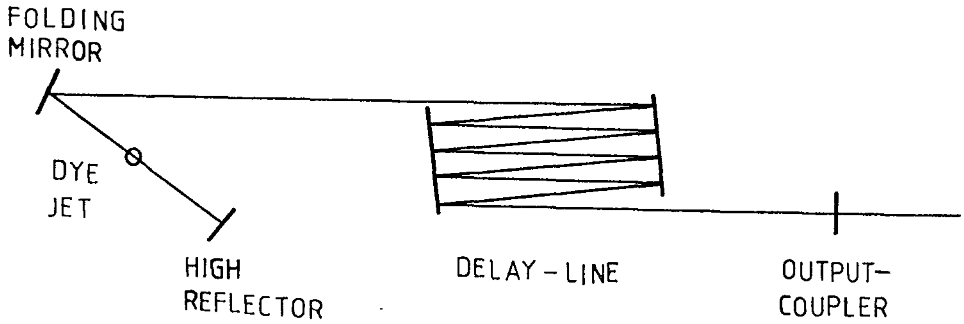


Figure 1. Dye laser cavity.

5.3. *Measurements.*

The Ar-ion laser was operated at 5145 Å.

The dye used in the dye laser was rhodamine 6G in ethylene glycol. The crystal used for frequency-doubling in the autocorrelator was an 8mm thick KDP-crystal.

The mean power from the Ar-ion laser was 0.7W and from the dye laser 45mW.

The synthesizer-frequency was 37.5307MHz giving a pulse repetition-rate of 75.06MHz.

Under these conditions, with matched cavity-lengths and the dye laser tuned to 6000Å the autocorrelation of the pulses from the dye laser was measured. A photograph of the oscilloscope-trace is given in figure 2. The horizontal scale is 20ps/division. The FWHM of the *autocorrelation is 20ps which gives a FWHM of the pulse-intensity of 14ps assuming a Gaussian pulse-shape.*

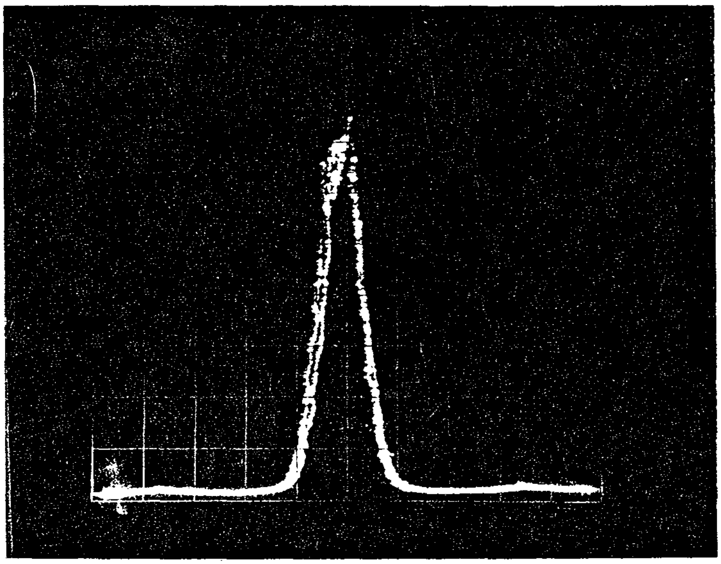


Figure 2. Autocorrelation of the dye laser pulses.

Obviously the light in the dye laser can travel in two directions from the dye jet. This means that two pulses will be travelling inside the dye laser, separated by twice the distance between the dye jet and the high reflector mirror. The light from the dye laser is consequently pairs of pulses, the two pulses in a pair being separated, in this case, 9cm.

If the pulses travelling one of the two ways in the autocorrelator are delayed a time equal to the separation of the pulses in a pair coming from the laser, a crosscorrelation is obtained. Figure 3 is a photograph of an oscilloscope-trace showing the autocorrelation to the left and a crosscorrelation to the right. The horizontal scale is 47ps/division. The separation between the two maxima, and also between

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