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LASER PULSE STRETCHING

VIA ENHANCED CLOSED LOOP CONTROL WITH SLOW Q-SWITCHING

L. Verluyten[1(*)], S. Willocq[2]
Interuniversity Institute for High Energies (ULB-VUB),
B-1050 Brussels, Belgium
and
Fermilab,
Batavia, IL. 60510, USA

G.G. Harigel
CERN,
CH-1211 Geneva 23, Switzerland

J.K. Hawkins, W.M. Smart, W.A. Williams
Fermilab,
Batavia, IL. 60510, USA

M.W. Peters
University of Hawaii,
Honolulu, HI. 96822, USA

H. Akbari[3]
Tufts University,
Medford, MA. 02155, USA

ABSTRACT

A pulse stretching technique in a Q-switched ruby laser oscillator is described. The major improvement to our previously developed pulse stretching circuit consists in a more adequate waveform for the feedforward part. This new system gives fairly flat pulses with adjustable duration up to ~100 μs and good coherence length in excess of 11 m. The cavity is followed by several amplifiers and produces light energies up to 8 J for holographic recording of particle tracks in the Fermilab 15-Foot Bubble Chamber. The considerably increased coherence length will find applications in many fields of pulsed holography and its use with fiber optics is particularly promising.

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1 Also at Universitaire Instelling Antwerpen, B-2610 Wilrijk, Belgium
2 Now at Tufts University, Medford, MA. 02155, USA
3 Now at Johns Hopkins University, Baltimore, MD. 21218, USA
(*) Researcher IIKW, Belgium

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1. INTRODUCTION

1.1 Holography in Big Bubble Chambers

Initial tests of holographic recording of particle tracks in a 35-m^3 cryogenic bubble chamber at CERN (BEBC) with a Q-switched ruby laser were successful [1]. However, the use of the powerful laser in this operation mode produced boiling of the chamber liquid which adversely affected the quality of the conventional photographs taken some 10 ms later. In this first test it was demonstrated that at a given energy (≦5 J), the boiling was suppressed by using a free-lasing pulse (~1 ms) instead of the Q-switched pulse. But the 1-ms operation mode of the laser is unsuitable for holography, due to the absence of the required coherence length and due to bubble movement and size variation during illumination. We therefore had to aim for an intermediate pulse duration, as had been proposed by one of the authors (GGH) [1]. A pulse stretching circuit was developed at Columbia University's Nevis Laboratories for the use in a KORAD Laser oscillator, followed by three amplifiers [2]. It was tested during a technical run of the 15-Foot Bubble Chamber at Fermilab and gave the expected reduction of boiling [3].

It is the aim of this paper to describe our more refined technique, which was applied to a commercial holographic JK Laser System 2000. It reduces the light flux at constant energy by producing now **temporally squared light pulses.** The width of these pulses can be set from tens of nanoseconds to ~100 µs. With a proper choice of pulse duration and laser light energy any boiling, if present at all, is virtually invisible when the conventional photographs are taken.

Parallel approaches to suppress boiling, which are not the subject of this paper, consist of the reduction of the overall energy requirements by the increase of the sensitivity of existing holographic emulsions [4] and the decrease of small impurities, suspended in the liquid, by appropriate filtering methods [5].

1.2 Laser Pulse Stretching Methods

Various methods for obtaining stretched pulses have been reviewed both from the experimental and theoretical point of view [6-9]. Any application requires a specific shape and certain energy of stretched pulses, which may then be obtained with one of the following techniques. Lengthening of the cavity of a Q-switched laser, introducing non-linear materials into its cavity, or use of a feedback loop to control switching of an electro-optic shutter is used to obtain long pulses. The first two methods produce light pulses whose time variation is either almost Gaussian or very asymmetric and fairly short. They will not be considered further, since the pulse for our application must be reasonably flat over at least several microseconds, and the rise and decay times are short compared with the flat-top. Therefore, we pursued only the third method.

The most promising of this kind of active pulse stretching schemes, which used a compound feedback method [9], and had been tested by us [3], suffered from three major problems:

- The extreme stray capacitance limited the response time of this circuit. This resulted usually in a large unwanted spike at the start of the pulse.
- In compound feedback both sides of the Pockels cell were connected through an inductor. The need for steep rise and fall times caused inductive ringing after the stretched pulse. This induced postlasing in the oscillator cavity.
- It did not use a classic closed loop control but rather a feedback loop without any reference input signal. Thus when the laser oscillator conditions changed, this often meant adjusting some parasitic components to stabilize the output laser beam.

2. LASER PULSE STRETCHING CONTROL SYSTEM

2.1 Control System Requirements

The pulse stretching control system consists of two major sections which are the output or laser oscillator and the input or Pockels cell controller. A block diagram of the control system is shown in fig. 1. The oscillator section has a non-linear functional relationship between its input, U, and its laser output, Y1. This section also contains more fundamental components like the Pockels cell and the laser cavity with its associated optical elements. The Pockels cell controller is linear and its primary function is to control the laser light output by using the feedback signal B1 to generate the appropriate control signal U. Also, the controller is subdivided into more fundamental components, namely feedback and feedforward, were the feedforward component is functionally independent of the feedback component.

The gain-bandwidth requirements of this system are determined by the dynamics of the laser oscillator. In order to properly control or "stretch" the laser light, the controller section must be able to suppress the random output fluctuations of a solid state laser. Thus, the delay time between the photodiode detector and the Pockels cell shutter must be less than a single random spike width [10]. Since the individual spikes are 50 to 500 ns long, this requires a bandwidth of at least 20 MHz for the feedback component of the Pockels cell controller. Furthermore, since the control system is expected to generate a 1 to 10 µs pulse, which is not a narrowband signal, the input stage should be a wideband device.

The primary feedback signal through block H1 is formed by sampling a portion of the laser light output Y1. However, a simple negative feedback loop will not produce the desired square pulse shape due to the non-linear dynamics of the laser oscillator [9]. Consequently, a feedforward or pulse shaping component will be used to help to generate the control signal U. Since the laser is "slow" Q-switched, the switching time of the feedforward component can be 500 ns.

The signal levels necessary to control the laser cavity via the Pockels cell should range from 0 to 1.0 kV. The control signal U is the voltage difference between the output of the feedback C1 component and the feedforward or pulse shaping component C2. The signal to the feedback amplifier component should range between 1.0 and 3.0 V in amplitude. Its output should vary between 0 and 200 V based on experience with other Pockels cell drivers. Thus, the gain of the feedback component should be about 200. If a normal TTL signal is used to control the pulse shaping component, then its gain should be about 1000 to produce a 1.2 kV output.

2.2 Pockels Controller Circuit

Numerical analysis was done with a fundamental model of the Pockels cell controller composed of two major sections; closed loop feedback control and open loop on feedforward control. These two functions are clearly identified in fig. 1, where the feedback portion applies a voltage to one side of the Pockels cell and the feedforward part to the opposite side of the cell.

The actual implementation of the controller requires the addition of signal conditioning, plus high and low voltage power supplies, and timing or control electronics. These electronics, along with the feedforward and feedback circuits are illustrated in figs 2 and 3. It is apparent from these complete controller schematics that not only can a functional distinction be made between feedback and feedforward controls, but they can be physically mounted on separate printed circuit boards. This is because the Pockels cell effectively isolates the output signals of the feedback and feedforward components.

For the following discussion, a 3554 operational amplifier is wired as a dual input integrator. It provides the desired gate signal, via the 3553 buffer, IC3, to the cascaded FET output stage Qa through d. This output stage is wired to one side of the Pockels cell V_{FF}.

Circuit operation starts when a negative going signal is fed into input V1 which turns off the clamping FET Q1, allowing the integrator to become active. Along with signal V1, a low level positive signal V3 is fed into the positive input of the integrator. Less than a microsecond later, signal V2, a NIM signal, is fed into the integrator's negative input. The overall result as seen at the output of the module (fig 4; upper trace), hence the one side of the Pockels cell, is a rapid drop in voltage (ΔV) followed by a slow ramping down (slope A) of voltage. At some point, the voltage across the Pockels cell drops to such a value so that the Pockels cell can no longer block light from the pumped ruby rod in the oscillator section of the laser system and laser light starts escaping. This light is detected by a fast diode, generating an electrical signal, which is fed into an LC222 pulse generator. This signal is fed into the PC Controller's V4 input where the overall result is to cause the Pockels cell loss term to drop at an even faster rate (slope B), thus extracting most of the light energy from the oscillator. When signal V4 turns off, a gating signal is produced which turns off V1, thus clamping the integrator's output to zero and restoring full blocking voltage to the Pockels cell. This Pockels cell control signal is also divided down and fed into line driver Qe where it provides a monitor signal at the bubble chamber control room.

The feedback module circuit is built on a printed circuit card located as close to the Pockels cell as practical. It consists of FETs Qa and Qb wired in cascade. They receive part of the signal generated by laser light, producing a signal to the opposite side of the Pockels cell V_{FB}, the speed of which matches that of the laser light variations. The phase of this signal is such so as to increase the Pockels cell loss term thereby retarding light transmission. Thus, with proper gain settings and circuit responses, the output of the laser oscillator can be controlled in both amplitude and length.

Also located on the feedback card are gain control, bias adjusting components, fast diode circuit components, power supply filters, and a line driving buffer, Qf. Qf provides the bubble chamber control room with a faithful reproduction of the feedback signal.

2.3 Laser Pulse Stretching Performance

The Pockels cell controller was installed in a commercial holographic ruby JK Laser System 2000, equipped with 3 (instead of 2) amplifiers. The laser system was capable of producing a 30-J Q-switched pulse of 30 ns fwhm. The oscillator stage of the JK System was altered by using an 80% rear mirror (instead of the supplied 100% mirror), and by replacing its Pockels cell by one from Lasermetrics (type 1042) which has a quarterwave voltage of 1.15 kV.

Laser light from the ruby oscillator stage will suffer spatial beam profile alterations and temporary pulse distortions after the passage through the amplifiers. Effects of alterations on the spatial beam profile are discussed in detail in [10]. Temporal pulse distortions are caused by self-oscillation of the amplifiers and by back reflections from optical elements located downstream the laser system. These effects can be solved by optically isolating the oscillator stage, as shown in [5].

The JK Laser oscillator flashlamp voltage was set to 1.8 kV where 1.7 kV is the threshold for lasing. Laser light output was monitored by a second photo diode whose output was then input to a Tektronix 374 oscilloscope. Also, the feedforward voltage was monitored via a second input on the same scope. Thus, a voltage waveform and the laser light time structure could be observed simultaneously.

Initially, the gain of the feedback loop was set to zero. This was done by simply turning off the high voltage across the fast photo diode called V(photo). The laser was fired by using the Pockels cell sync pulse from the JK Laser controls to trigger the feedforward voltage V_{FF}. The slow Q-switch of the V_{FF} waveform induced free lasing as expected. Further, laser firing produced similar results, thus indicating that the feedforward circuit was working as anticipated.

The feedforward voltage, V_{FF}, was adjusted such that the pulse stretching occurs, but since the feedback voltage V_{FB} was set to zero, the light pulses appeared highly modulated with the leading edge spikes. Next the feedback loop was turned on by setting the V(photo) voltage to 2.4 kV as indicated by its response curve characteristics. Adjusting the gain of the V_{FB} signal eliminated the leading edge spikes and greatly reduced the instantaneous energy fluctuations during the stretched pulse as seen in figs 4 and 5.

Stretched light pulses of 1–10 µs duration are easily generated by changing the width of the trigger pulse to the feedforward card. Longer pulse widths require controller gain adjustments. Typical stretcher performance characteristics are:

(1)	Average pulse width variation	$\leqq$ 1%
(2)	Average pulse energy variation	= 10%
	Maximum pulse energy variation	= 25%
(3)	Average pulse modulation	= 30%
(4)	Coherence length	> 4.0 meters

This information represents the output after three amplifier stages. Consequently, the stretched pulse has more modulation and energy variation than the output of the oscillator stage only. This pulse stretching circuit has been extensively used with light pulses between 2 and 16 µs.

CONCLUSIONS

It has been shown that controllable stretched pulses with adjustable duration up to 16 µs in the TEM_{00}–mode can be obtained from a ruby oscillator stage, which is equipped with a closed loop control system. This increase in pulse length from 200 ns (Q–switched) to 16 µs at the energy level of a few joules suppressed boiling in the bubble chamber liquid.

A remarkable asset of these stretched pulses is a four–fold increase in the coherence length, as compared with the Q–switched operation (1 – 2 m). Apparently, the mechanism for this is the prevention of the high gain laser cavity latching on to several modes at the onset of the pulse [2, 11]. Also, since the power density of the stretched pulse is much less than a Q–switched one, stretched pulses are more desirable for transporting high energy laser light through mono– or multi–mode optical fibers [3]. Thus, stretched pulses could be used for the holography of volumes larger than previously possible with a Q–switched ruby laser. One future application might be in a two–beam holography technique for large bubble chambers [12].

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FIGURE CAPTIONS

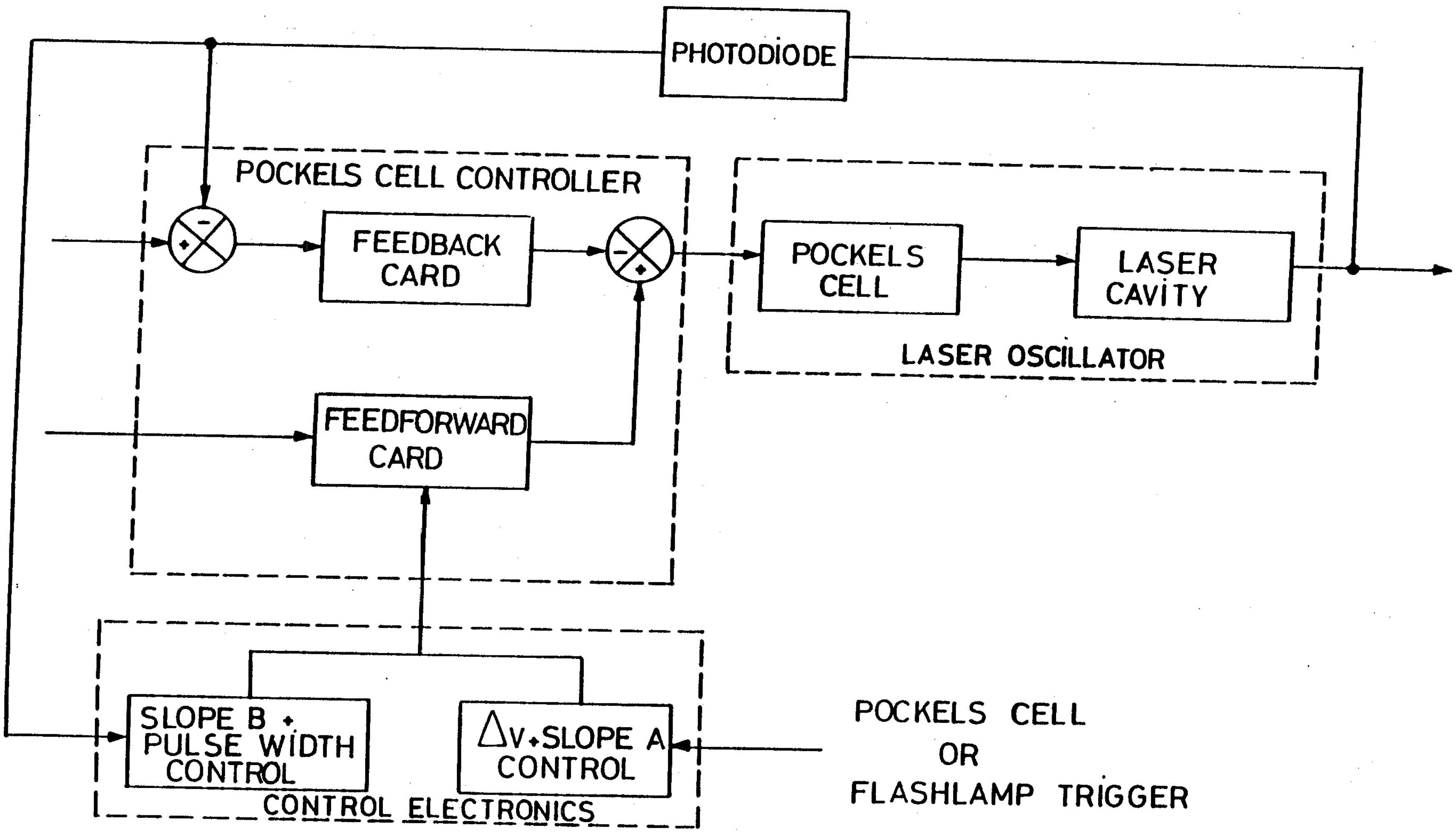
Fig. 1 A block diagram of the control system with the Pockels cell controller and laser oscillator.

Fig. 2 Circuit schematic of the Pockels cell controller feedforward section.

Fig. 3 Circuit schematic of the Pockels cell controller feedback section.

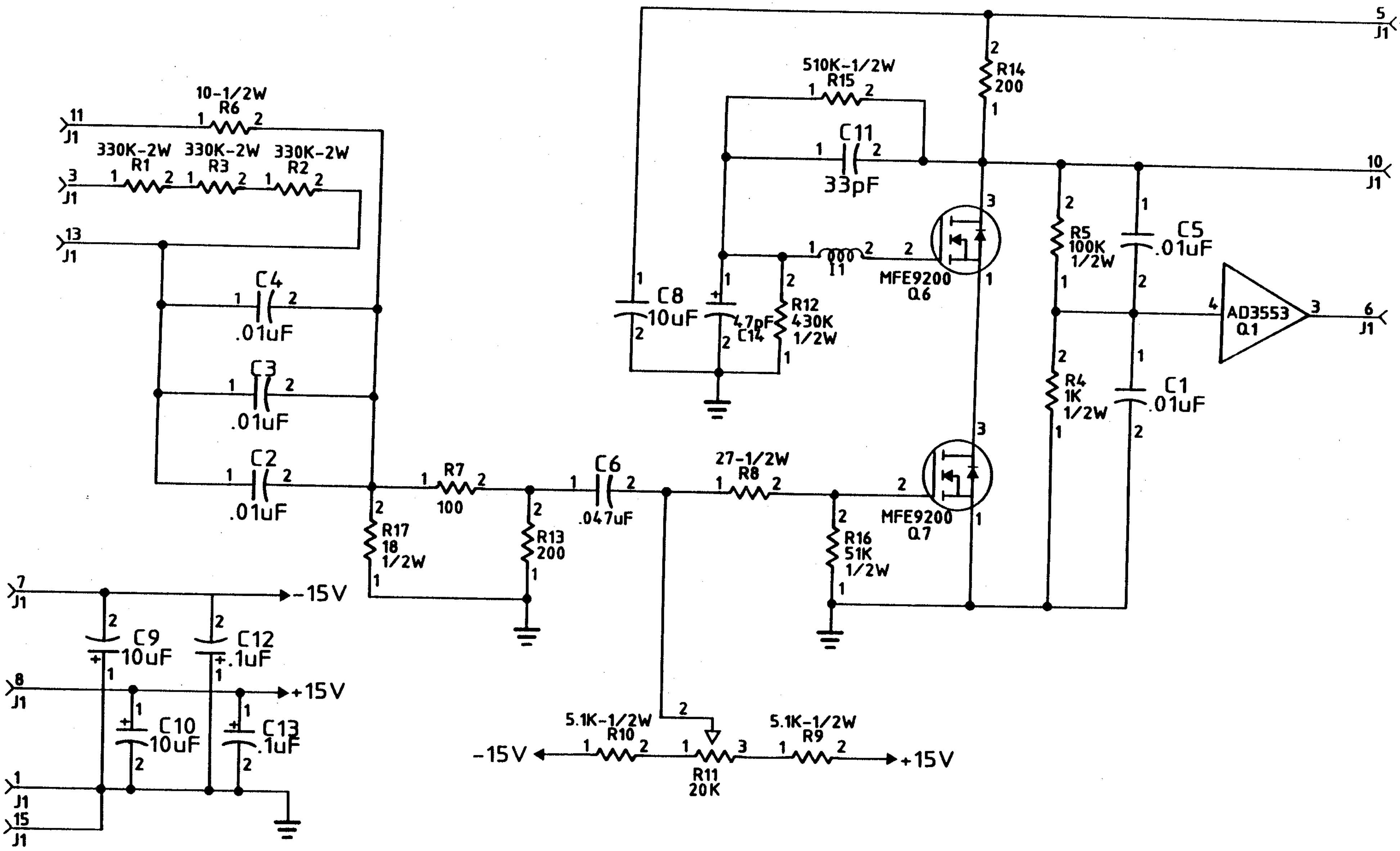
Fig. 4 Feedforward voltage V_{FF} (top) and laser light output (bottom). Time base 2 μs/div.

Fig. 5 Feedback voltage V_{FB} (top) and laser light output (bottom). Time base 2 μs/div.



Blockdiagram of the pulse stretcher for the JK Laser.

Fig. 1



J1 5
J1 10
J1 6
J1 11
J1 3
J1 13
J1 7
J1 8
J1 1
J1 15
10-1/2W R6
330K-2W R1
330K-2W R3
330K-2W R2
C4 .01uF
C3 .01uF
C2 .01uF
R7 100
R17 18 1/2W
R13 200
C6 .047uF
27-1/2W R8
R16 51K 1/2W
510K-1/2W R15
C11 33pF
R14 200
C8 10uF
C14 4.7pF
R12 430K 1/2W
I1
MFE9200 Q6
MFE9200 Q7
R5 100K 1/2W
C5 .01uF
R4 1K 1/2W
C1 .01uF
AD3553 Q1
C9 10uF
C12 .1uF
C10 10uF
C13 .1uF
-15V
+15V
5.1K-1/2W R10
R11 20K
5.1K-1/2W R9

Fig. 2

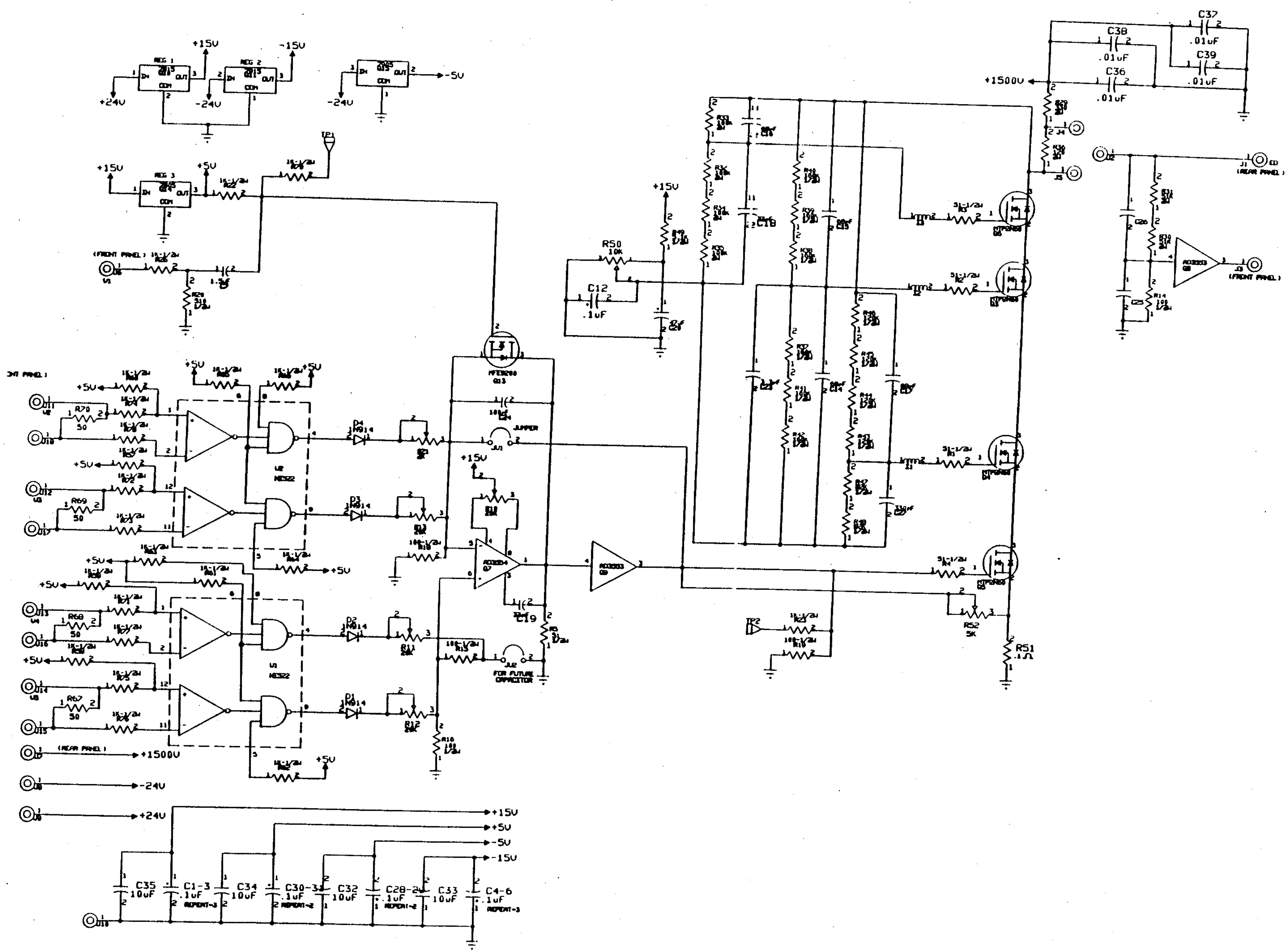

+15V
-15V
-5V
+24V
-24V
+5V
+1500V
C37
C38
C39
C36
.01uF
R50
10K
C12
.1uF
C18
C19
R70
R69
R68
R67
50
JUMPER
FOR FUTURE CAPACITOR
R51
R52
5K
C35
10uF
C1-3
.1uF
C34
C30-32
C32
C28-29
C33
C4-6
(FRONT PANEL)
(REAR PANEL)

Fig. 3

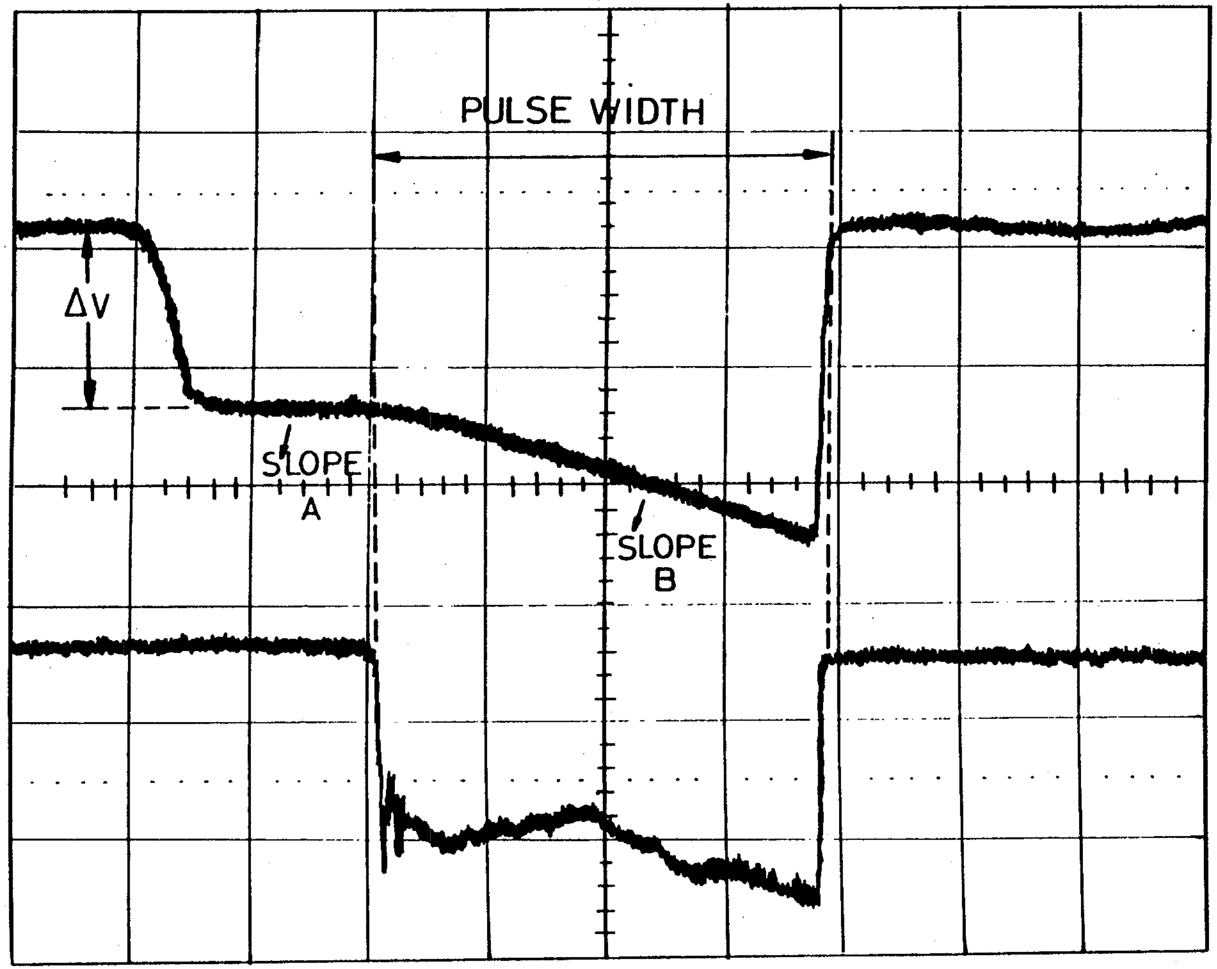


Fig. 4

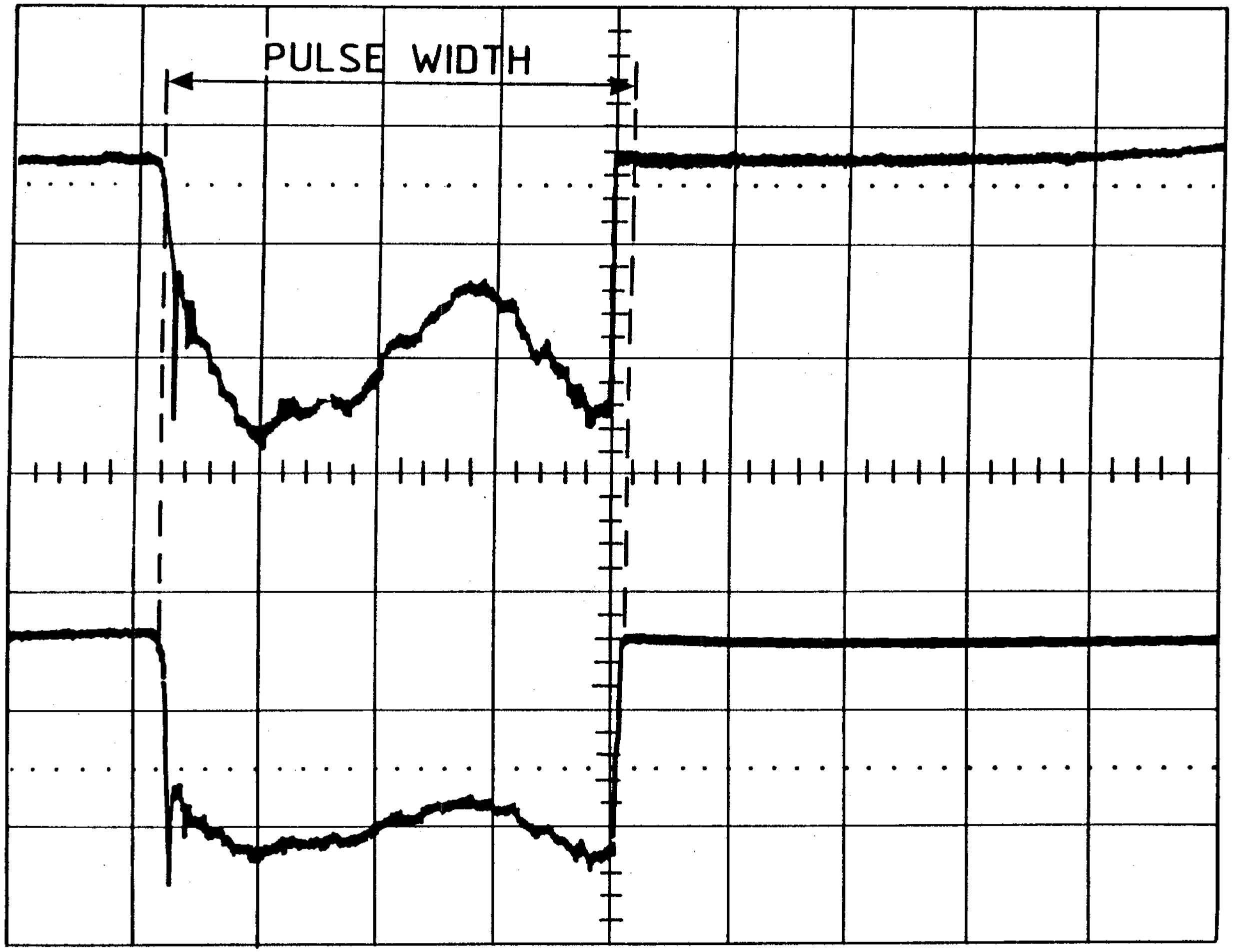


Fig. 5