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Q-SWITCHED LASER PRELASE DETECTION CIRCUIT

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ABSTRACT

A compact electronic circuit has been developed to detect prelasing in Q-switched pulsed laser systems and once detected to shut down the laser before the next laser pulse occurs. The circuit is small, compact and uses a minimum of components which makes it quite economical, thus readily lending itself to commercial applications. It can easily be incorporated into virtually any Q-switched laser system or can be made into a stand alone auxiliary unit. Use of this detection circuit would improve the reliability of a laser system by reducing a source of possible costly optical damage. This paper will discuss the circuit operation and instrument requirements necessary to incorporated the circuit into a laser system.

INTRODUCTION

In Q-switched laser systems there is a condition referred to as prelasing. This condition is one in which there is some amount of uncontrolled laser output occurring along with the normal laser output. Prelasing occurs when laser light "leaks" out of the laser cavity prematurely. This leakage is due to the inability of the Q-switch to completely hold off the lasing action of the laser cavity. Due to the detrimental effects associated with prelasing the condition is considered to be undesirable and needs to be detected and avoided.

The undesirable effects of prelasing fall into two general categories. The first are those directly related to the optical damage effects on the laser system optics and on the optics of the recipient of the laser system output. This optical damage can be quite costly both to the laser manufacturer and the laser user due to both the financial costs associated with the replacement cost of the optics and the system down time necessary to correct the damage. This repair down time is usually quite inconvenient and annoying. The second category includes those problems not related to optical damage effects but to the effects on the applications of a prelasing laser beam. Detrimental effects on the laser output applications would include those associated with multiple output beams, varying energy per laser pulse, changing average output power and output pulsewidth problems. Reliability of a laser system and that of the results derived from the application of the laser output would be improved by using this detection circuit.

CIRCUIT DESCRIPTION

This circuit was specifically designed to detect prelasing in a commercial Nd:YAG pulsed laser operating at a 10 hertz repetition rate and once detected to then shut down the system before the next occurring laser firing. Operation of the circuit is based on the premise that the desired laser output occurs consistently after the Q-switch operation and that any other signal which is present before that moment is to be considered prelasing. All that is needed to integrate the circuit into the laser system is access to the laser light, the Q-switch trigger pulse and the laser security interlock line.

A simplified circuit diagram is shown in figure 1. The basic circuit consists of six sections. They are the optical detection, comparison, delay, sync input, control and output stages. The optical detection stage converts the optical signal into an electrical signal for the comparison stage to trigger off of. The output of the comparison stage is delayed by the delay stage and then sent to the control stage. The Q-switch signal is sampled by the sync input stage which conditions and provides a variable delay to the sync signal which is also sent to the control stage. The control stage compares the timing of the these signals and generates a signal to control the output stage. The output stage interrupts the laser security line and thereby stops the laser.

Optical Detection Stage

The optical detection stage consists of a high speed small area silicon PIN diode detector operated in the reverse biased mode . This mode of operation provides for very fast detector response times and high signal sensitivity. The associated circuitry contains a power supply noise filter capacitor, a bias voltage current limiting resistor and a 50 ohm output termination resistor for the detector . This whole detection stage can easily be located away from the rest of the circuitry so long as proper transmission line principles are adhered to and thereby simplifying the installation of the circuit with the laser system.

The silicon detector used has an optical response from 350 to 1100 nanometers. In flashlamp pumped or frequency doubled systems there are several different frequency optical signals available . In our application we had available the multi-spectrum pulse from the flashlamp, the 1060 nanometer fundamental and the 532 nanometer doubled laser output pulses. A filter can easily be placed in front of the detector to limit the detector signal to just the desired laser light wavelength, which, in our application was the 532 nanometer output pulse.

The circuit will readily work with detectors used for other wavelengths providing they supply voltage signals that are impedance matched to the rest of the circuit. The speed of the detector selected will determine the maximum speed of the system. This enables the basic circuit to be used with practically any pulsed Q-switched laser system regardless of the operating optical output wavelength.

In fact , after the detection stage has converted the optical signal to an electrical signal the prelase circuit becomes totally insensitive to the source of the electronic signal which is sent to the comparison stage. Because of this, the circuit timing could be preset before installation into the laser system.

Comparison Stage

The comparison stage is based around a high speed voltage comparator (IC-1) with TTL complementary outputs. The noninverting input signal is supplied by the detection stage , while the inverting signal is derived from an adjustable voltage divider. The voltage divider provides both positive and negative voltage references for the comparator enabling the comparator to trigger off of either voltage polarity signal from the detection stage. This enables the detection stage to be changed at any time without having to modify the rest of the circuit. The voltage reference was designed around a potentiometer mounted on the front of the circuit enclosure. This provides for operator control of the trigger level after installation of the circuit into the laser system . The external adjustment potentiometer could be mounted on the printed circuit board for preset voltage reference applications thereby saving space and cost.

The comparator integrated circuit has two complementary TTL outputs. The inverted output goes to the delay stage while the noninverted TTL output goes to the comparator monitor . The comparator monitor signal is used by the operator when adjusting the voltage reference potentiometer.

Delay Stage

The next stage is the delay stage which consists of a series of CMOS inverters connected in series . This delay stage generates a fixed delay which is necessary to compensate for the differences in the circuit generated delays between the optical monitor signal and the Q-switch monitor signal. While integrated circuit nanosecond delay lines are available for this purpose , the inverters were selected due to their availability and low cost over them. Another advantage of the use of the inverters is the pulsewidth stretching effect inherent with their usage. Although this increase in pulsewidth limits the minimum detection time between the prelase signal and the lasing signal, it consistently ensures adequate pulsewidths for the control stage signals especially when dealing with extremely narrow laser pulses.

At this point the optical signals have been detected , converted to digital voltage levels and delayed. These signals go to the control stage along with the modified Q-switch monitor signal from the sync stage.

Sync Stage

The sync stage consists of two digital logic circuits. The first is a high speed CMOS Schmitt-Trigger inverter with pull-up resistor that is used to sample the Q-switch trigger signal while buffering the circuit from the laser electronics. It's output goes to a CMOS dual non-retriggerable monostable multivibrator integrated circuit (IC-5) whose first multivibrator section is connected to trigger off the inverter's output signal's falling edge . The output pulsewidth of the first multivibrator is controlled by the R/C time constant of a fixed capacitor (C1), fixed resistor (R1) and variable resistor network . The fixed resistor sets the minimum pulsewidth while the variable resistor is used to vary the pulsewidth from that minimum .

The variable pulsewidth output pulse from the first multivibrator is used to trigger the second multivibrator whose output pulsewidth is set by a fixed R/C network (R2,C2). The second multivibrator is designed to trigger off of the trailing edge of the output pulse of the first stage which provides a variable delay from the original Q-switch signal that is equivalent to the variable pulsewidth of the first multivibrator . This fixed pulsewidth output pulse from the second multivibrator goes to the control stage as the Q-switch sync signal.

In this configuration the dual multivibrator chip serves two functions . It provides a trigger signal to the control stage whose pulsewidth is independent of the original Q-switch pulsewidth . Also it provides a variable delay for the trigger signal . It is this variable timing adjustment that is used to set the optimum timing for the control stage.

Now that the Q-switch monitor sync signal has been generated , it along with the previously described optical monitor signal are integrated in the control stage.

Control Stage

The control stage is made up of a CMOS dual J/K flip-flop (IC-4) with preset and clear options. The first flip-flop is connected to toggle off the optical monitor signal with the sync signal acting as a clear control signal. The timing of the sync signal is set just slightly before the normal lasing pulse. Refer to the timing diagram in figure 2. The sync signal holds the clear line of the flip-flop high and as long as the clear line is held high the flip-flop ignores the toggle input from the optical monitor signal. But should a toggle pulse occur before the Q-switch monitor pulse can clear the flip-flop then that signal will toggle the flip-flop generating a square wave output signal pulse. This earlier pulse would be the pulse generated due to prelasing.

During normal lasing the first flip-flop generates no output signals while during prelasing it generates a pulse whose pulsewidth varies as a function of the time between the prelase pulse and the Q-switch sync monitor.

This output pulse acts as a toggle signal for the second flip-flop. Like the first, the second flip-flop is also connected in the toggle mode except that once toggled the flip-flop must be manually reset before its output will change . The clear command of the second flip-flop is controlled from a three position switch (on-off-momentary) whose functions are run , by-pass and reset.

In the run mode the clear function is held inactive so that the flip-flop output toggles normally on command . The by-pass mode holds the clear function activated so that the output of the flip-flop never changes state regardless of its input . The reset mode provides a manual clear command to reset the output of the flip-flop after being toggled in the run mode .

A resistor (R3) and capacitor (C3) make up a R/C network which is connected to the clear command of the second flip-flop to provide a start up delay for the clear line. This ensures that the flip-flop is always in the deactivated mode after being powered up.

A trigger monitor signal and a triggered indicator are provided by an inverter and LED respectively. The monitor signal from the inverter is used by the operator in setting up the timing relationship of the signal monitor and Q-switch sync signals to the flip-flops. During normal operation, the LED provides an indication to the laser operator why the laser has shut down.

Output Stage

The output of the second flip-flop goes to the output stage which consists of a DIP relay (IC-7) which opens up the laser security line when energized and thereby shutting down the laser.

SETUP AND ALIGNMENT

The degree of circuit sensitivity is dependent on the trigger level and placement of the detector. The detector sensitivity is extremely high and can easily become saturated resulting in distorted output pulses. Care must be taken in the placement of the detector to avoid this.

Alignment of the detector is not very difficult and is done with the control switch in the bypass mode and the laser operating normally. The output of the detector, which is connected to the circuit, is monitored on a scope during its positioning. The operator ensures that the detector is not saturated and that there is ample signal for the circuit. Another channel of the oscilliscope is then connected to the comparator monitor. The trigger level is adjusted until a signal is detected from the comparator monitor.

Next the circuit timing is adjusted. The timing monitor signal is observed on an oscilloscope which is triggered on the laser Q-switch sync signal. The delay potentiometer is adjusted so that a square wave pulse is observed on the oscilloscope. When the laser is not prelasing an output pulse on the timing monitor indicates that the variable Q-switch sync signal is resetting the control stage after the normal lasing pulse occurs. The operator simply adjusts the delay potentiometer. As the timing approaches the desired position the pulsewidth of the timing monitor signal will reduce. At the point where the timing monitor pulse disappears the correct timing relationship between the control stage signals has been achieved. The flip-flop is being reset by the sync signal pulse before the lasing pulse can trigger the circuit. The operator switches the control switch to the run mode and removes the oscilloscope connections.

PERFORMANCE SUMMARY

This prelasing detection circuit has been tested on a commercial Nd:Yag whose output was frequency doubled to 532 nanometers and also on a Nd:YLF research laser. Testing to determine the timing relationship parameters was done electrically in order to prevent possible optical component damage to the laser system. This was done by injecting electrical signals from a signal generator into the optical signal input to simulate the lasing and prelasing signals from the detection stage. The prototype circuit was able to reliably trigger off of input signals to the comparator that were 10 nanoseconds wide and separated by 80 nanoseconds. This separation time was longer than expected from the integrated circuit data sheets and is attributed to inadequate circuit board construction techniques. A circuit board designed with proper high frequency considerations should improve the circuit response and result in faster trigger times (shorter pulse separation). Suggestions for improved speed would include conversion to faster digital integrated circuit logic, the use of nanosecond delay lines and better circuit board construction techniques than those used for the prototype. Minimum separation times between the lasing and prelasing pulses of 20-25 nanoseconds would be expected.

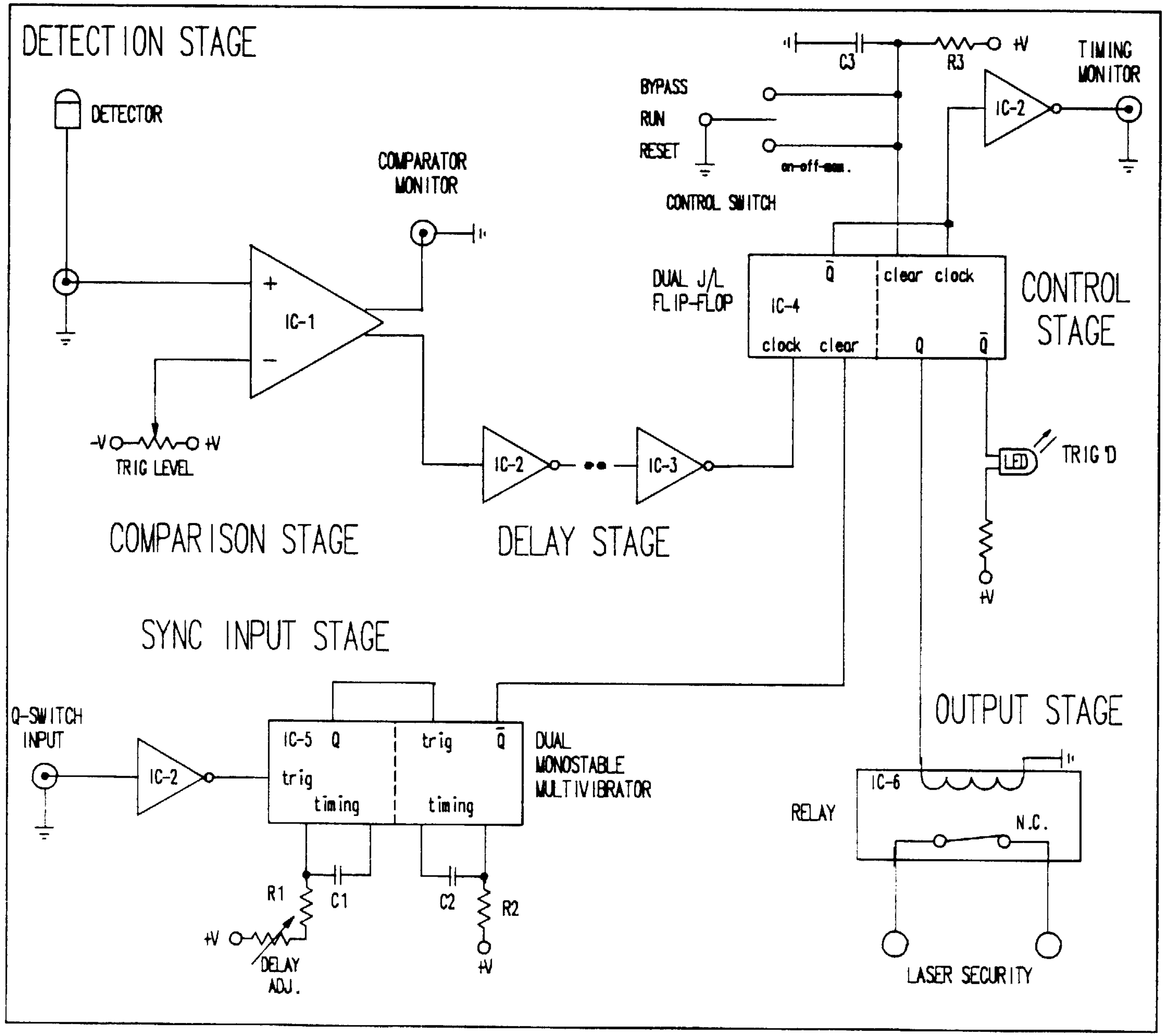

Figure 1: Simplified Circuit Diagram

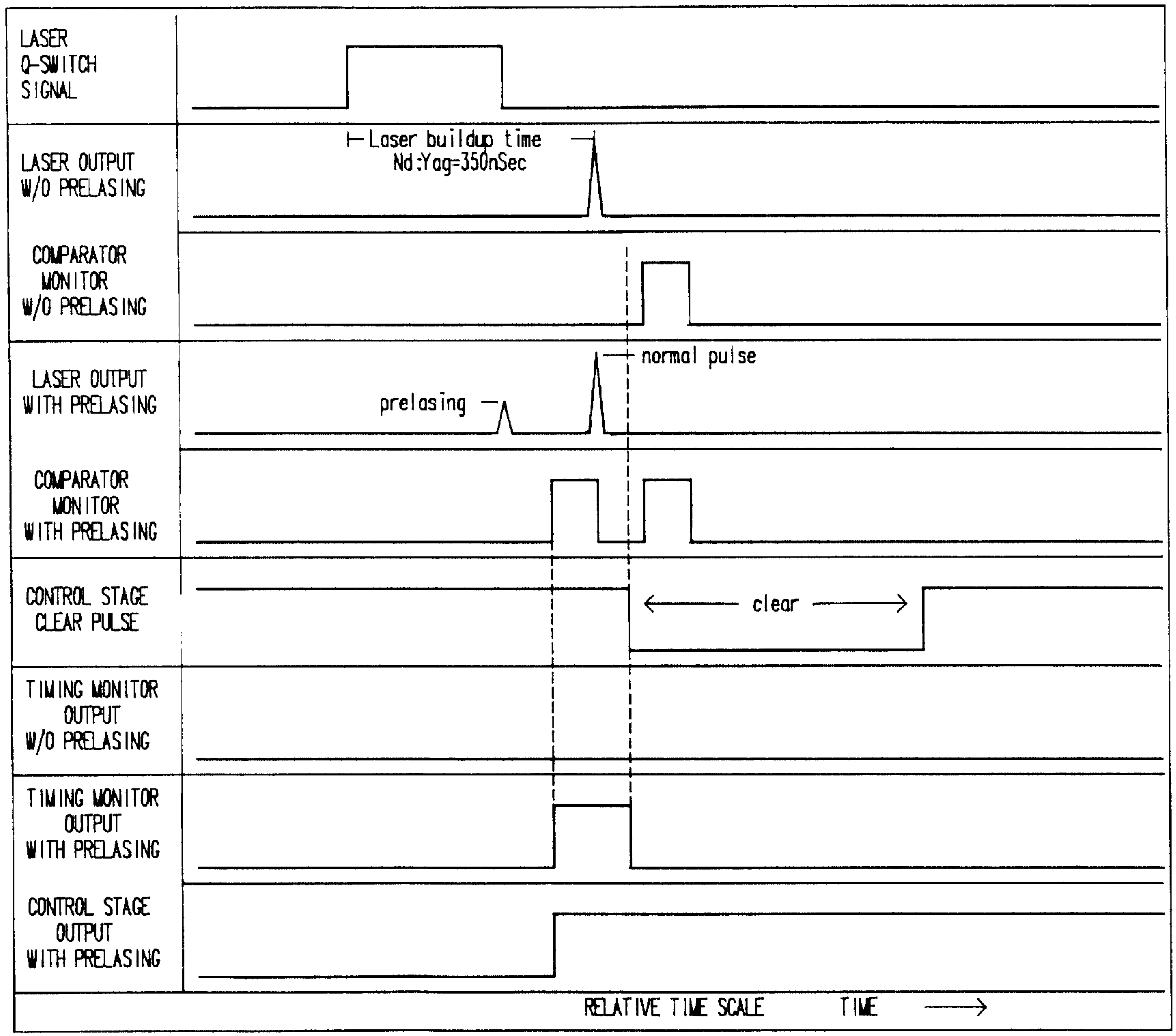

Figure 2: Timing Diagram

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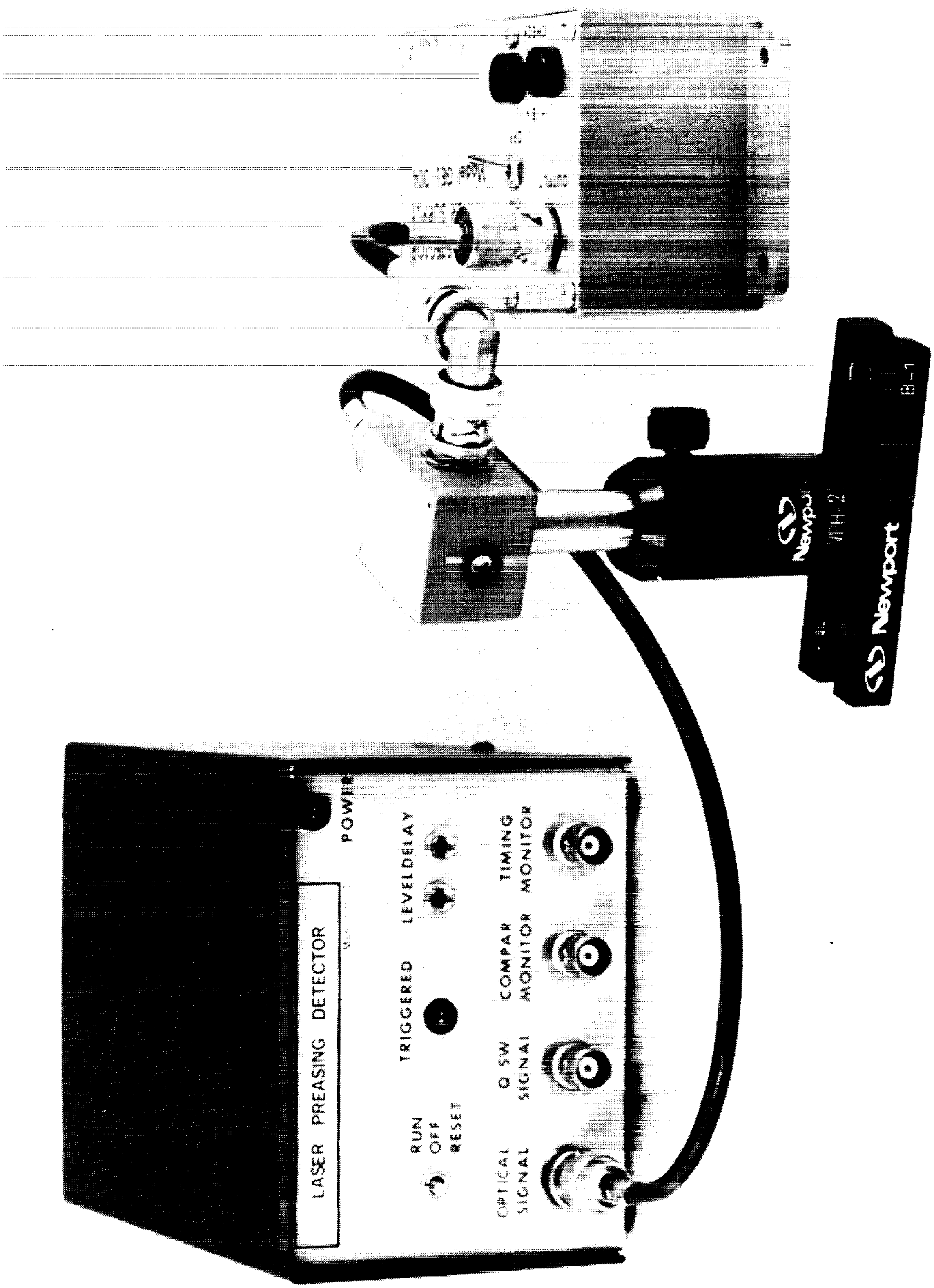

Figure 3: Photo of Detector Instrument and Optical Detector

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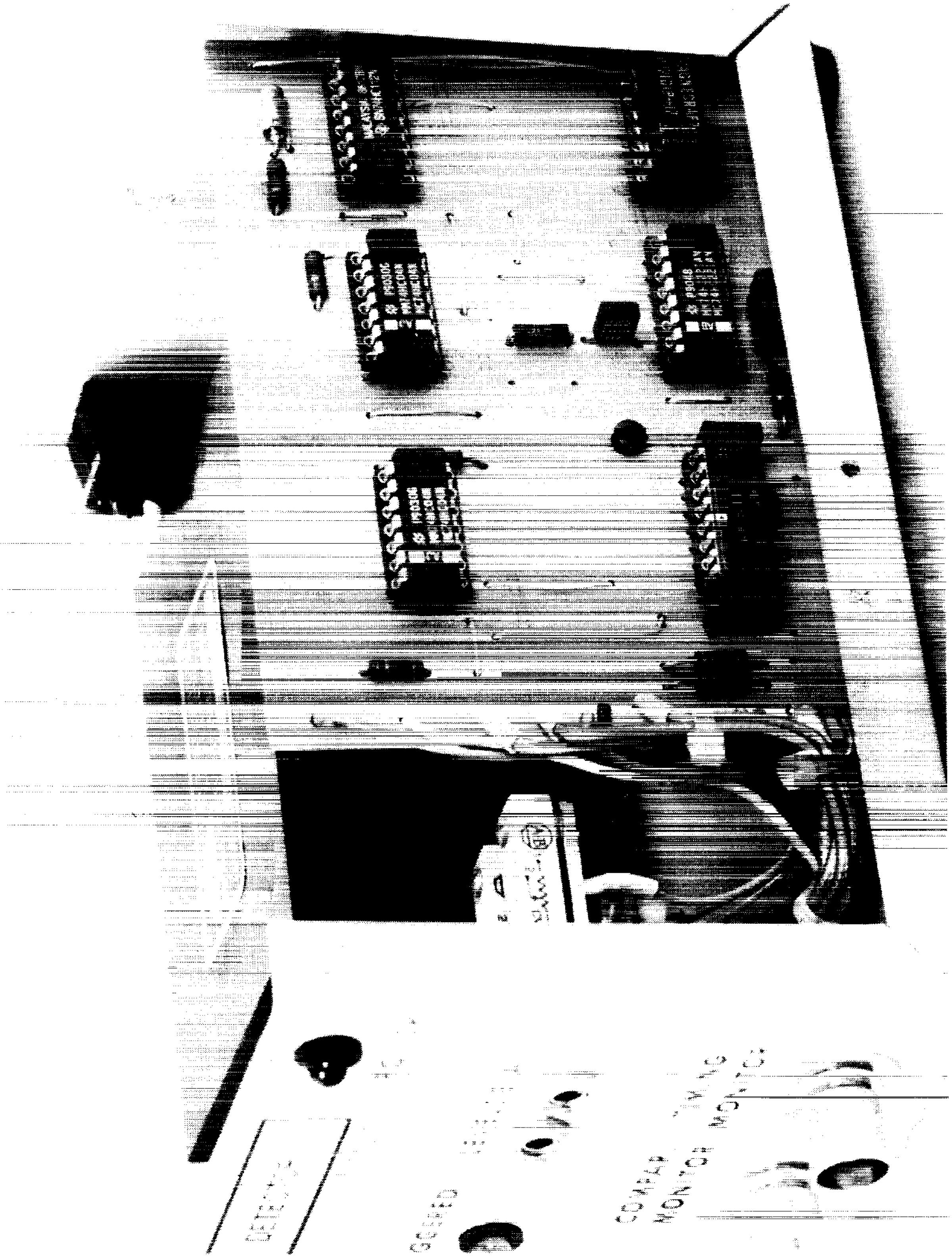

Figure 4: Photo of Close-up of Circuit Board

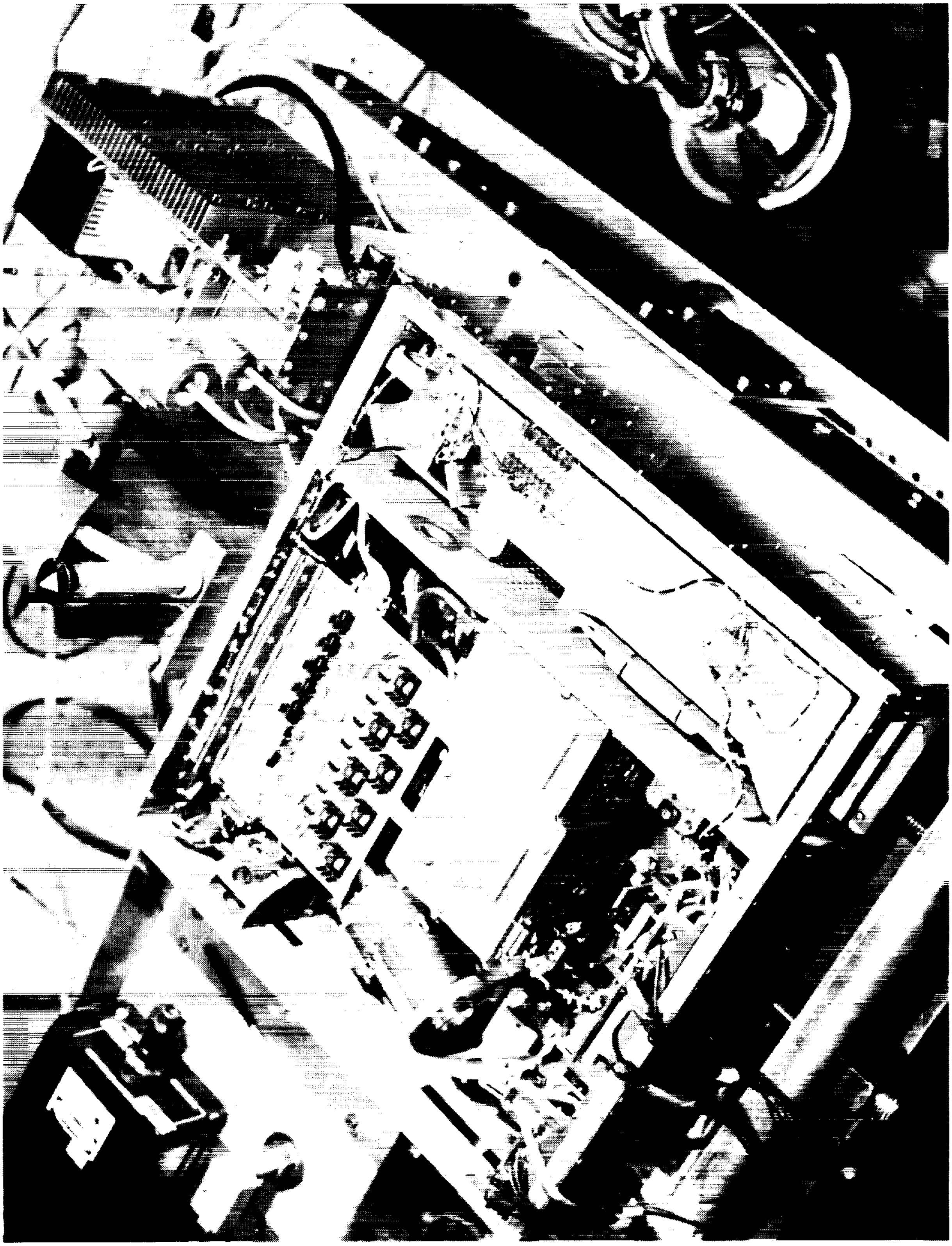

Figure 5: Q-Switched Laser Prelase Detection Circuit