NASA Technical Memorandum 78752

A FAIL SAFE LASER ACTIVATED SWITCH USED AS AN EMERGENCY CONTROL LINK AT THE LANGLEY VORTEX RESEARCH FACILITY

(NASA-TM-78752) A FAIL SAFE LASER ACTIVATED SWITCH USED AS AN EMERGENCY CONTROL LINK AT THE LANGLEY VORTEX RESEARCH FACILITY (NASA) 15 p HC A02/MF A01 CSCL 20E
N78-27403
Unclas
G3/36 25220

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JUNE 1978

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SUMMARY

A fail safe light activated switch was used as an emergency control link at the Langley Vortex Research Facility. In this facility aircraft models were towed through a still air test chamber by a gasoline powered vehicle which was launched from one end of a 427-meter track and attained velocities to 31 m/sec in the test chamber. A 5 mW HeNe laser with a mechanical chopper provided a connecting link with the moving tow vehicle on which a silicon photodiode receiver with a specially designed amplifier provided a fail safe switching action. This system provided an emergency means of stopping the vehicle by turning off the laser to interrupt the power to the vehicle ignition and brake release systems.

INTRODUCTION

Since the earliest days of aviation the wind tunnel has been used to study aerodynamic phenomenon. In most studies the emphasis has been on the forces acting on the aircraft with little interest in what was happening in the air behind the aircraft. Today, however, there is increased interest in the flow patterns that are found in the aircraft wake, especially the rotational flow known as the trailing vortex. Because of increasing air traffic the trailing vortex is recognized as a hazard near air terminals and the problem is exacerbated by the diversity in aircraft size and type. Unfortunately wind tunnels can be used to study aircraft wakes for only short distances behind the aircraft while the trailing vortex may extend for miles.

At NASA's Langley Research Center a special facility is being used to study trailing vortices (ref. 1). In this facility an aircraft model is towed through a test section of still air and the vortex studied from a still air frame of reference. Or, by towing a second model at a fixed distance behind the first, the effects of the vortex can be studied from the aircraft frame of reference. This second model can also be used as a vortex probe by varying its position relative to the vortex producing model. In either case the unique feature of this facility is that the air is still and the model is towed through the test section.

In the Langley Trailing Vortex Facility the tow vehicle, a modified gasoline powered car, runs on a track above the test section. The track extends outward on either side of the test section and has a total length of about 417 meters. In a typical test the tow vehicle is launched from an end of the track preprogramed to go through an acceleration phase, a cruise phase through the test section, and a braking phase to the other end of the track. In such a test, the tow vehicle may reach velocities of 31 m/sec.

The tow vehicle, after launch, has no trolleys or other connectors for power or signal transmissions. Mechanical devices attached to the rails have not had the reliability needed for emergency stops and did not provide for emergency test abort at the operator's command. An emergency abort system which utilizes a laser beam as a connecting link to the tow vehicle for the full length of its travel has been developed. This paper describes the photoelectric subsystem of the emergency abort system. This subsystem consists of the following; a laser with optional collimator, a disc chopper, a photodetector with optional collector lens, and a special design amplifier. The photoelectric subsystem activates the emergency abort system through a relay which is an interface element and not considered a part of this subsystem. Emergency stops can be initiated from three stations along the track.

SYSTEM DESIGN

The primary concern in the design of the photoelectric subsystem was that it be fail safe thus the design goals were as follows:

1. Fail safe operation (the only effect of a malfunction or component failure would be to remove power from the relay)

2. Minimum response time for turn off operation

3. Power from 12-volt battery with negative grounds

4. System should operate without adjustment

These design goals were met by using a controlling light beam which was 100 percent modulated at a frequency of 540 Hz. The detector and associated circuitry were designed to utilize the modulation of the control light beam by allowing the vehicle to run only when the light beam is continually switched off and on. The circuit's operating bandwidth included 540 Hz but rejected 120 Hz to avoid problems with flicker from fluorescent room lights.

The detector circuit was also designed to operate without the benefit of the laser collimator or the collector lens at the detector. These optics were considered optional but can be used to improve performance and reliability of the system. The collimator, by expanding the laser beam diameter and by decreasing its divergence, would decrease the flux density on the detector at close range and maintain constant total flux to a greater range. The collector lens, by giving the detector a greater effective area, would simplify alinement problems and increase signal strengths at long range.

SYSTEM DESCRIPTION

The control light beam was 100 percent modulated at 540 Hz by placing a disc chopper at the output of the laser (fig. 1). The chopper motor was a fractional horsepower synchronous type that turns at 1800 rpm. A 22.8-cm-diameter, 0.79-mm bakelite disc was as large as the motor could turn without slowing. Because the chopper disc had to be located after the laser collimator where the beam is 1.59 cm in diameter, only 18 holes could be used. Thus the modulation frequency was fixed at 540 Hz.

The collector lens and detector circuit were housed in a tube on the side of the vehicle (fig. 2A and 2B). The photodetector and circuitry (fig. 3A and 3B) were positioned beyond the focal length of the collector lens to fully utilize the photodetector's active area and not have the laser beam sharply focused on it.

DETECTOR CIRCUIT DESCRIPTION

The detector circuit (fig. 4) consists of three parts: (1) The photodetector, (2) an amplifier, and (3) a rectifier. The photodetector, a silicon photodiode with an active area of 6.5 cm^2, is operated in the reversed biased mode. At maximum range, without benefit of either collimator or collecting lens, the photodiode intercepts about 1/2 percent (25 μW) of the laser output to produce a photocurrent of about 1.5 μA. This light level and resulting photocurrent is the maximum required for normal operation of the system and represents a signal-to-noise ratio of three as the photodiode dark current is approximately 0.5 μA.

The three-transistor amplifier (Q1, Q2, Q3) is designed to utilize certain features of the control light beam. The output of the amplifier is basically a square wave which follows the light beam, that is, high when the beam is "on" and low when it is "off." This simple operation is modified by the coupling between stages so that the output goes low and stays low if the background light level rises above about four times the noise equivalent level. The output also goes low if the controlling light beam stays on longer than 0.5 msec. Finally, the output coupling is such that as signal frequency increases output power decreases. All these features combine to make a circuit that has a maximum response to a control light beam which is a 100 percent modulated square wave at about 2 kHz. Any change in modulation, duty cycle, or frequency will result in lower power output.

The rectifier circuit, a voltage tripler which consists of six capacitors (C6 through C11) and six diodes (D5 through D10), converts the square wave output of the amplifier into a direct current source of power for the relay. This signal generated power source has a negative polarity to distinguish it from the primary power source, a 12-volt storage battery with negative ground.

To conclude this description of the circuit, there is interface circuitry between the rectifier and the relay. A mode selection switch allows a resistor to be connected in parallel with the relay and a normally closed pushbutton is used for a reset operation.

CIRCUIT OPERATION

The circuit was built and tested to determine and evaluate the operating characteristics. For these tests a 16K ohm, 12-volt relay was used as a load and the controlling light beam was simulated with a light emitting diode driven by a signal generator.

The result of this test is presented (fig. 5) as a plot of power delivered to the relay as a function of beam modulation frequency and battery supply voltage. This graph is not a typical power versus frequency response curve because the frequency is that of a square wave. For the same reason the power to the relay is labeled maximum average power. When the modulation wave form was other than a square wave the power to the relay was reduced.

The operating characteristics of the relay are indicated on the graph by the two horizontal dashed lines. The relay is always open when the power is less than 2.3 mW and always closed when greater than 6.8 mW. The important dynamic characteristic of the relay is its dropout time or time required to switch from the closed to open state. This switching time is dependent on the power input to the relay and varies from 0.15 second when held on by 9 mW power to 0.07 second when held on by 3 mW. To complete figure 5 the chopper frequency is indicated by the vertical dashed line at 540 cycles.

From figure 5 it can be seen that the power supply (battery) voltage has a significant effect on the operation of the photoactivated relay at the chopper frequency. If the supply voltage is less than 12 volts there is not enough power to close the relay, and if the supply voltage is much above 12 volts the dropout time for the relay is longer than desired. Both of these difficulties can be eliminated by proper operation of the reset and mode select switches (S1 and S2 on fig. 4). The reset switch provides a means of closing the relay when the controlling light beam is on and the mode select switch provides a means of reducing the power delivered to the relay to insure a minimum (less than 0.1 second) dropout time when the light beam is interrupted.

A simple checkout procedure can be used prior to operation of the vehicle to insure that the mode select switch is in the proper position to provide minimum response time. This check consists of momentarily blocking the controlling light beam and observing the action of the relay through the indicating lamp. There are three possibilities: First, the relay resets automatically when the beam returns; second, the relay is reset only after activating the reset switch; and third, the relay does not reset when the reset switch is activated. These observations and the conditions they indicate are summarized in table I which can be used to determine the correct switch position. Proper operation of the system, that is a reset accomplished with the reset switch, is slightly different for the two modes. In the optimum mode reset occurs while the reset switch is depressed, but in the normal mode reset does not occur until the switch is released.

EXPERIENCES AND RECOMMENDATIONS

The emergency abort system at the Langley Research Center's Trailing Vortex Facility has been in operation for about 2 years and has demonstrated excellent reliability. During this time, two minor modifications of the original design have been made. First, when the system was installed on the vehicle the coil resistance of the relay used was 12K ohm rather than the designed 16K ohm. The second modification was made after the system was in operation for a few months when it became clear that the alinement of the laser beam with the car could only be maintained by frequent readjustments. This alinement difficulty was easily eliminated by removing the collimator thus allowing the laser beam to expand as dictated by the normal beam divergence.

The operation of the system has been satisfactory with all design goals essentially met, however, some improvements could be made. The most obvious improvement would be to make the system insensitive to changes in power supply voltage and thus eliminate the mode selection switch. Since the laser collimator is not used, this improvement could be implemented by changing the chopper disc to increase the modulation frequency to 2160 Hz and then adding a simple shunt regulator (zener diode) to the output.

In discussing systems that pertain to safety, every effort should be made to insure that even fail safe systems are operated properly. In this spirit it must be emphasized that the reset feature of this system is not part of the fail safe design and should not be relied upon to maintain the relay open with the laser beam on. To insure safe operation of this system the laser must not be turned back on, once it is turned off, until the vehicle is completely stopped.

REFERENCES

1. Patterson, James C., Jr.: Vortex Attenuation Obtained in the Langley Vortex Research Facility, J. Aircraft, Vol. 12, No. 3, Sept. 1975, pp. 745-749.

Table I.- Diagnostic chart for determining the proper position for the mode select switch.

Observed Action	Mode Switch Position	Indicated Conditions	Correct Mode Switch Position
Automatic reset	Optimum	Circuit malfunction (S1, S2, or R10 open circuit)	-
	Normal	High supply voltage	Optimum
Reset occurs when "reset" is depressed then released (correct operation)	Optimum	High supply voltage	Optimum
	Normal	Low supply voltage	Normal
No reset	Optimum	Low supply voltage	Normal
	Normal	Circuit malfunction (any component failure)	-

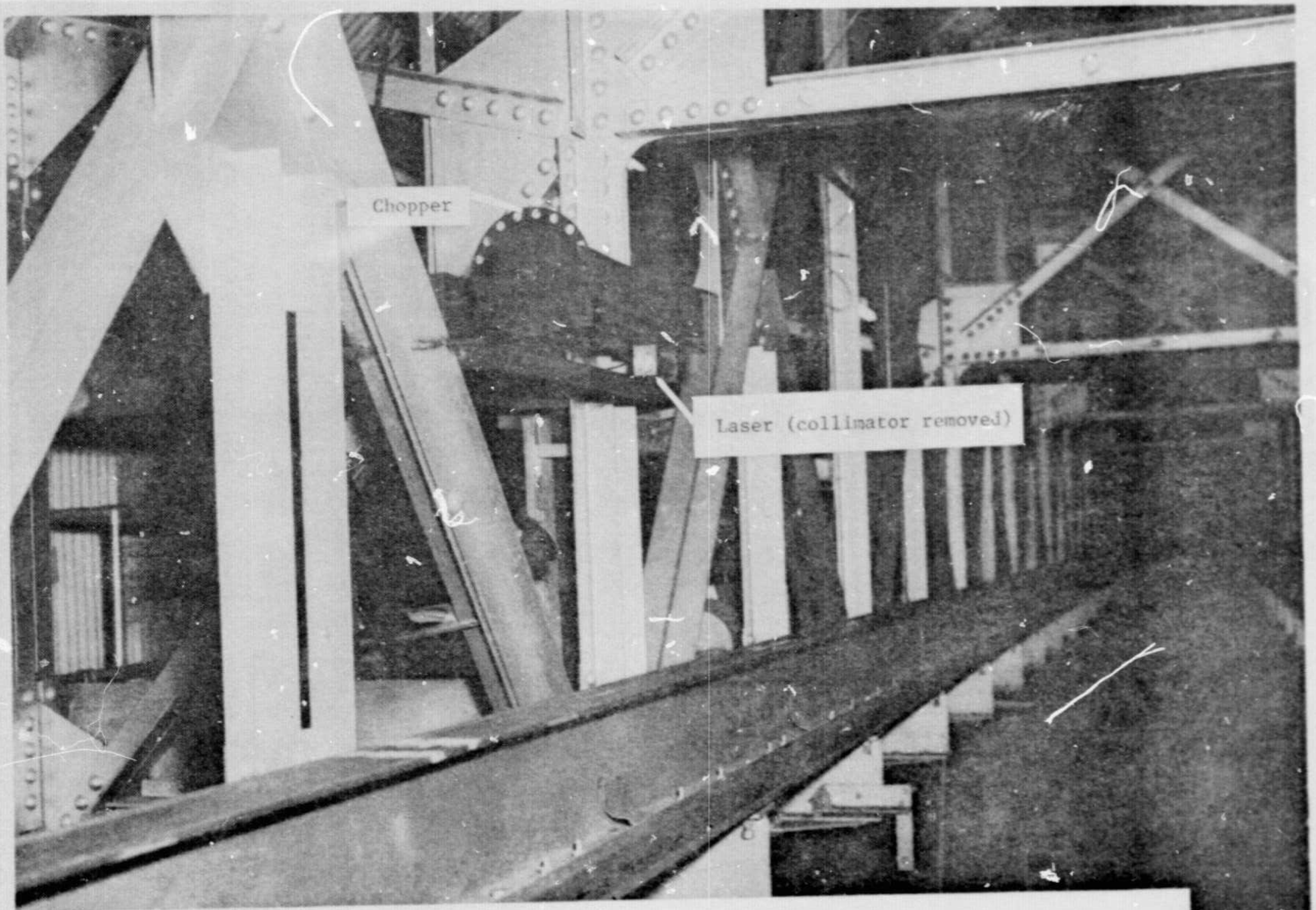

Figure 1. Laser and Chopper Disc at Launch End of Track in the Vortex Research Facility

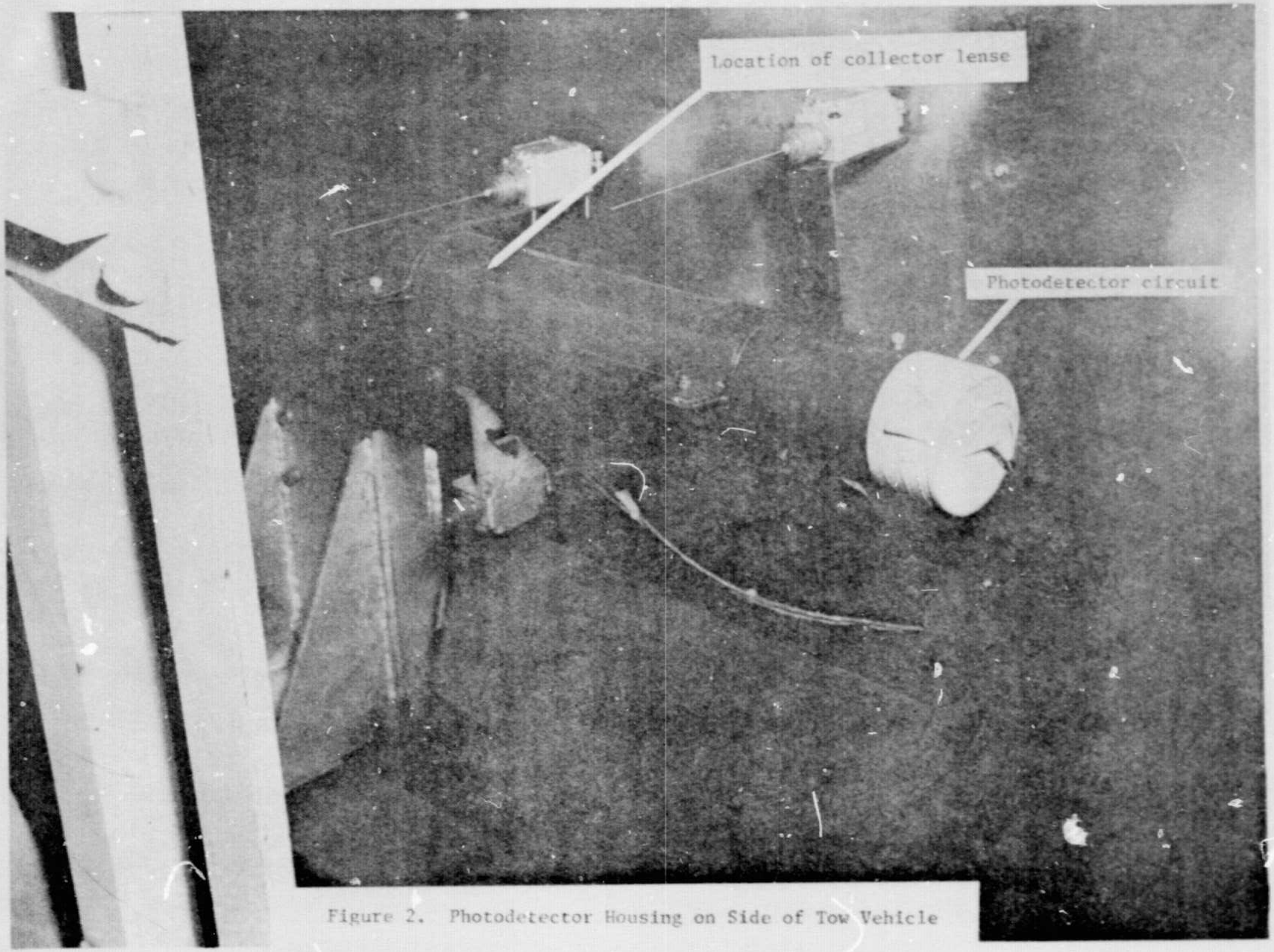

Figure 2. Photodetector Housing on Side of Tow Vehicle

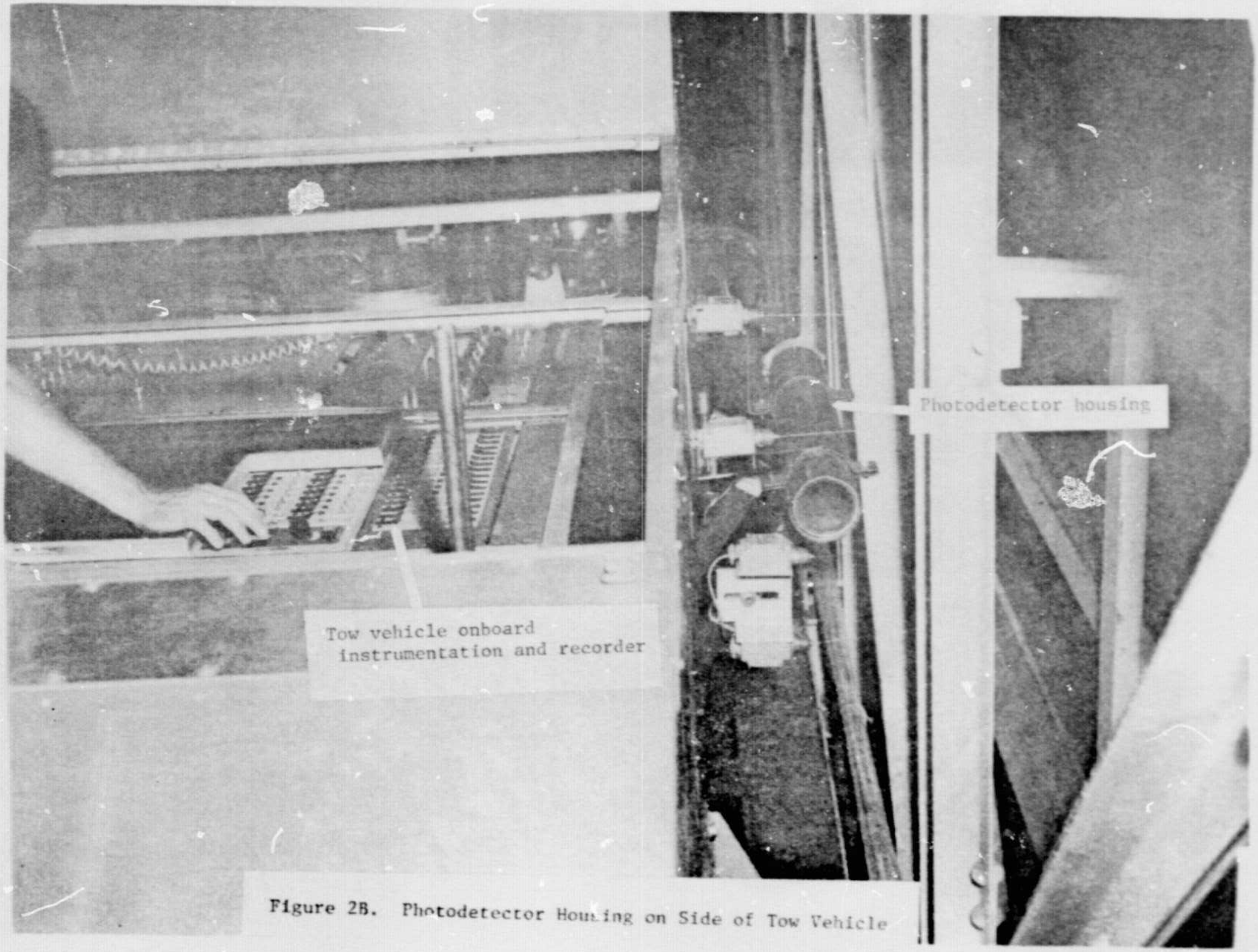

Figure 2B. Photodetector Housing on Side of Tow Vehicle

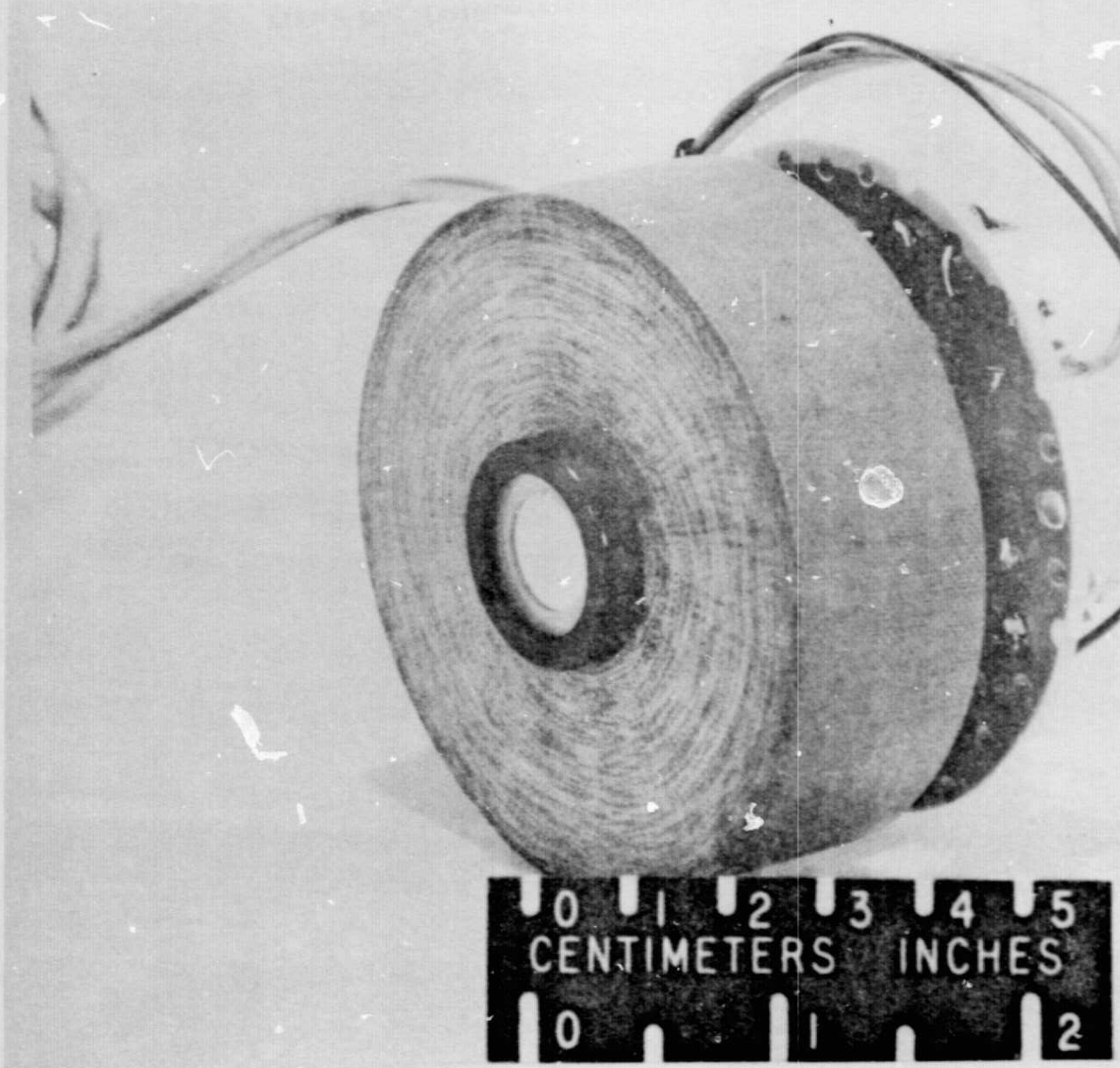

Figure 3A. Photodetector and Associated Circuitry

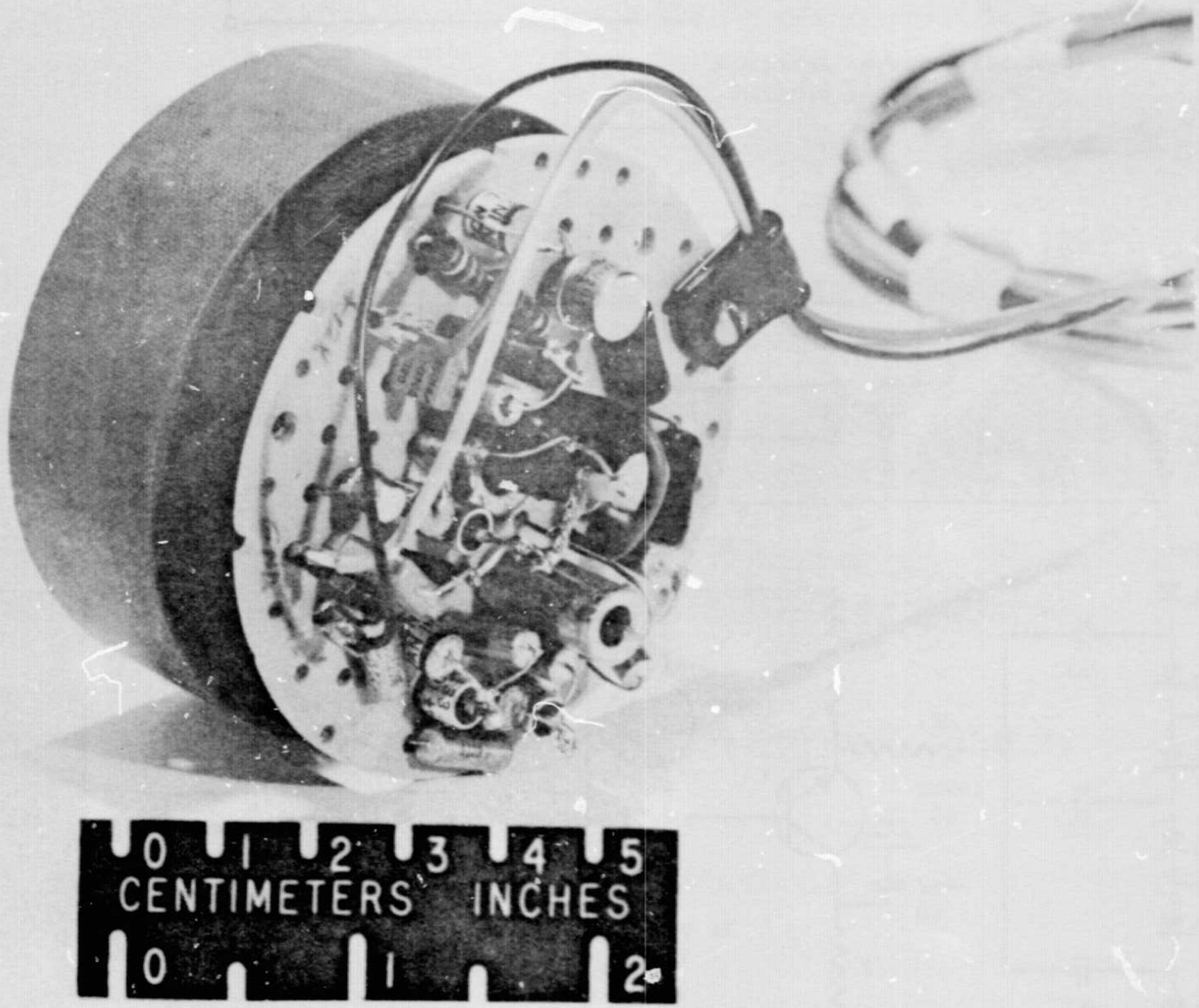

Figure 3B. Photodetector and Associated Circuitry

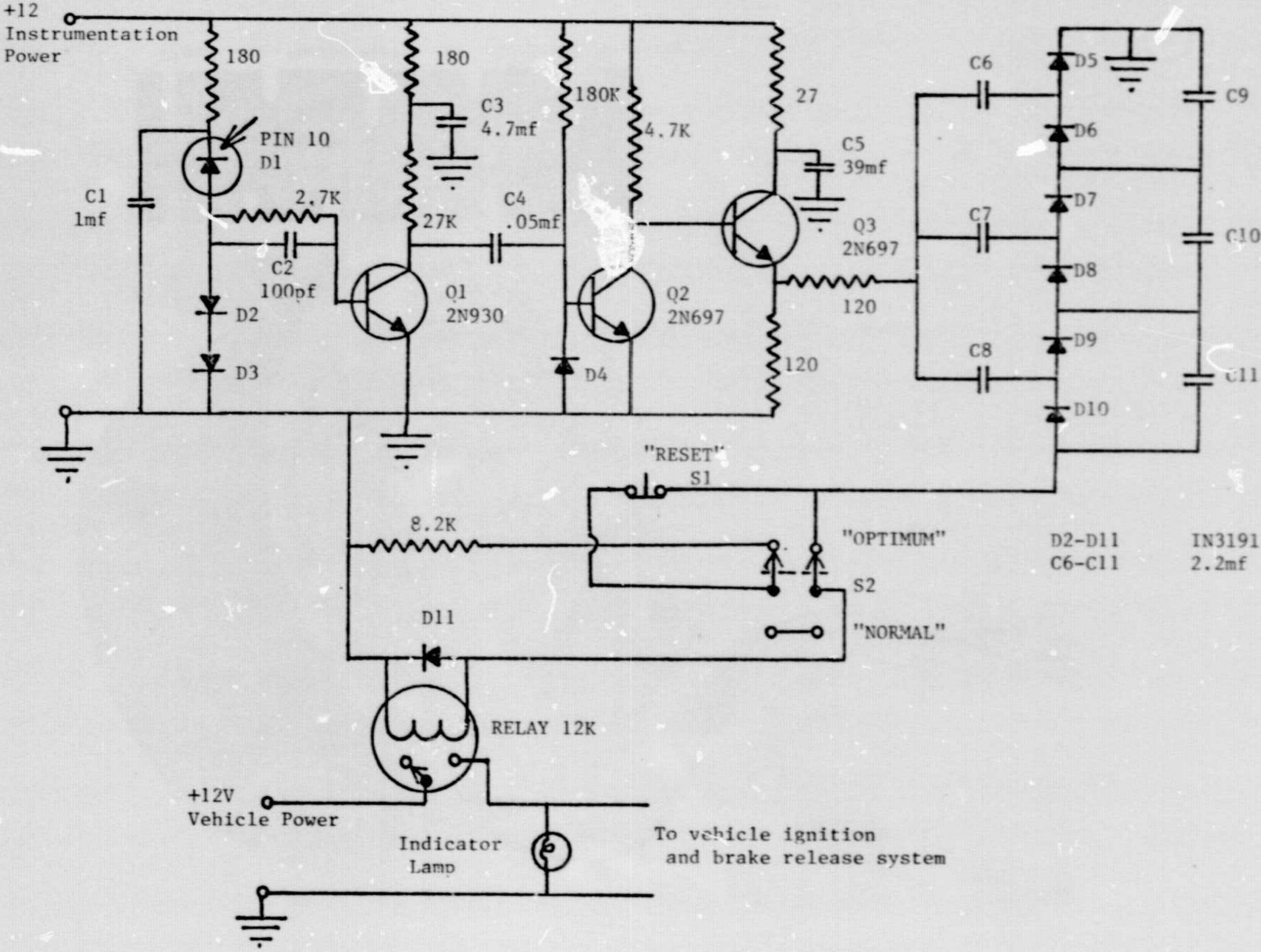

Figure 4. Circuit Diagram of Photo-operated Relay for Emergency Fail Safe Control

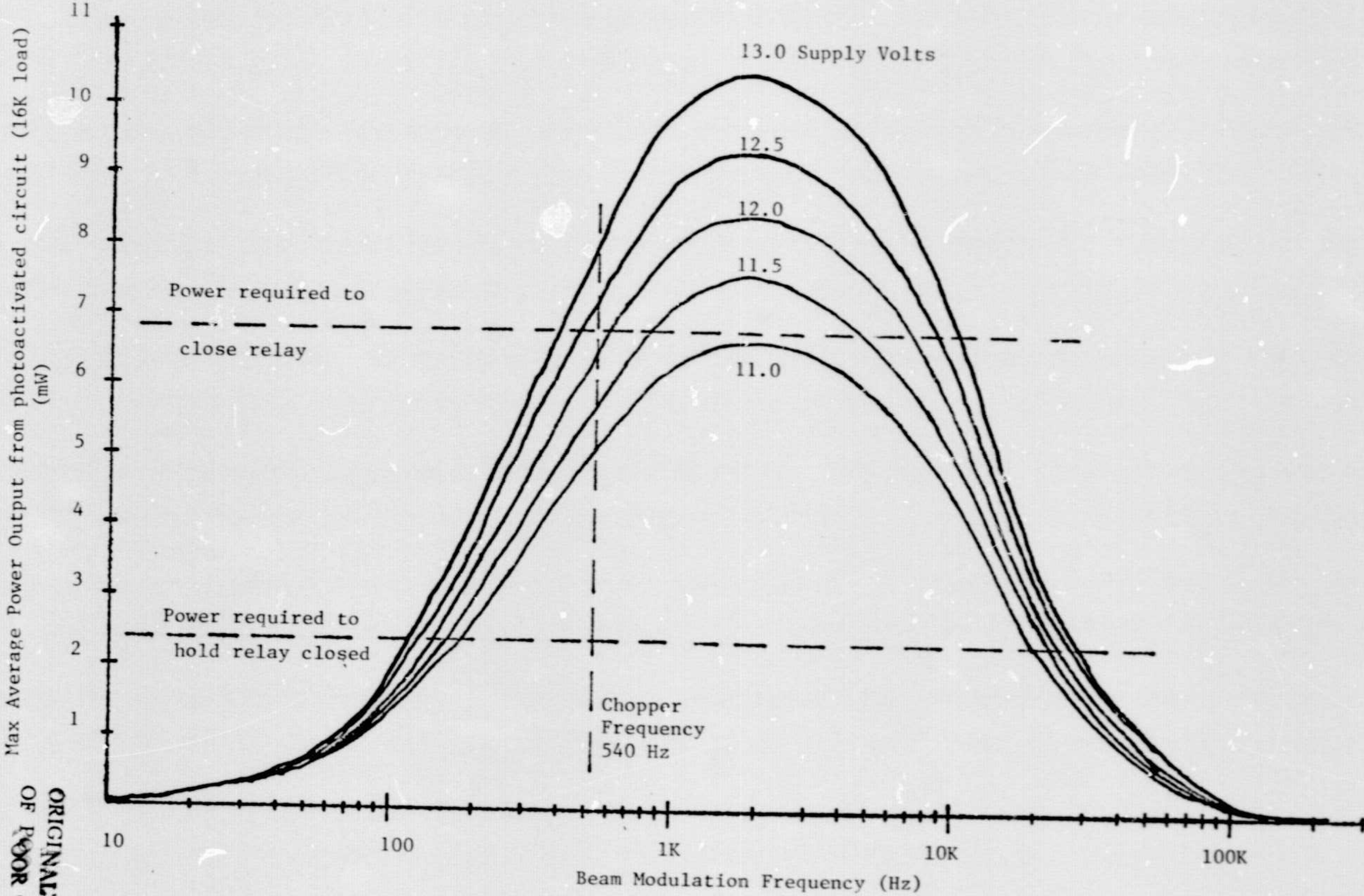

Figure 5, Operating Curve for Photo-operated Relay

1. Report No. NASA TM 78752	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle A Fail Safe Laser Activated Switch Used as an Emergency Control Link at the Langley Vortex Research Facility	5. Report Date June 22, 1978
	6. Performing Organization Code 1277
7. Author(s) Philip C. Kassel, Jr.	8. Performing Organization Report No.
	10. Work Unit No. 514-52-03
9. Performing Organization Name and Address Langley Research Center Hampton, VA 23665	11. Contract or Grant No.
	13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

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17. Key Words (Suggested by Author(s)) Fail safe, Remote control, Laser Activated switch	18. Distribution Statement Unlimited - Unclassified

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 13	22. Price* $3.50

* For sale by the National Technical Information Service, Springfield, Virginia 22161