

Measurement of Power Development with the
Laser Activated Amphibian Monitor System

by

Steven S. Saliterman

Introduction

A mathematical analysis of frog jumping and the calculation of power development has already been described (1). The Laser Activated Amphibian Monitor System (LAAMS) allows for rapid, economical and reproducible measurement of the frog's acceleration and flight times, and of the jump range. This data along with a center of mass-determining photographic exercise (described earlier) allows for calculation of power development.

Principle of Operation

The frog is made to jump in a long, tall and narrow plexa-glass tank. As the frog hurdles its body through acceleration, flight and deceleration, planes of laser light are interrupted producing signals that indicate when and how long an event is occurring.

The tank temperature and lighting are controlled. Optional control of air composition, humidity and noise levels are forthcoming.

Several jumps (one after another) can be made by the frog and the data instantly recorded on an oscilloscope and strip

chart recorder. After each jump the frog is automatically returned to the starting line by a treadmill.

Figure 1 shows the various phases of a frog's jump. The acceleration time t_a , flight time t_f and range R are measured electronically. Points, a, b, c, d and e are locations of the center of mass at rest, start of flight, summit, start of deceleration, and at rest again respectively. V_0 and θ_0 are the initial velocity and angle of trajectory of the jump. The labeled segments are dealt with later in calculation of power development.

Mechanics of Operation

The system consists of three main units (see Figure 2). The plexaglass jumping tank is 85 cm high x 10 cm wide x 140 cm long. It rests on a top of a platform that also contains the treadmill system, He-Ne laser, beam splitter, reflecting mirrors, and photodiode sensors. The photodiode signals are immediately amplified, encoded, and sent via a signal cable to an instrument rack (see Figure 3). This rack contains a photodiode decoder device, treadmill control system, oscilloscope and camera, strip chart recorder, power supply, and power switches, indicators and breakers. The third main unit is a temperature controller. This houses an air conditioner and heating unit that maintain tank temperature to the nearest degree (anywhere between ten and fifty degrees centigrade).

According to the experiment requirements, a frog is selected and the tank's temperature and lighting are appropriately

adjusted. The frog is placed inside at one end of the tank through a resealable hatch.

The laser provides two planes of light that are planar with the platform. One is located even with the tread and is normally blocked or "off" when the frog is at rest. The other plane is located just above the frog's head (it is adjustable) and is normally "on" when the frog is at rest. The planes are in reality each composed of a continuous laser beam that is bounced back and forth on end mirrors, giving in effect "planes" of light. A top and side view of this arrangement is shown in Figure 4. The two starting beams for each plane are derived by splitting a single He-Ne laser beam. The beams, after being bounced back and forth on the mirrors, land on their own photodiode. Therefore, any interruption of the "planes" causes a corresponding loss of illumination of the corresponding photodiode. The lower photodiode is labeled DA, the upper photodiode DB. In addition to these two light receivers, a third photodiode (DC) is located at the starting line at tread level, and is illuminated by a source shining perpendicular to the direction of tread travel. Table 1 shows the activity of the frog as it relates to the state of the individual light sensors.

<u>Activity</u>	<u>Photodiode</u>			<u>Photodecoder Voltage</u>
	<u>DA</u>	<u>DB</u>	<u>DC</u>	
at rest	off	on	off	1 volt
accelerating	off	off	on/off	3 volts
in flight	on	off/on	on	4 volts
decelerating	off	off	on	3 volts
being returned	off	on	on	2 volts

Table 1. eg. When the frog is accelerating, both planes are blocked and photodiodes A, B, and C are "off." The output voltage of the photodecoder is 3 volts. When the frog first begins to accelerate its head rises and blocks beam DB. When acceleration ends and flight begins, DA is instantly turned on again. (DB may be either on or off during the flight phase.) Deceleration begins and flight ends when the frog first touches the tread again. This is detected by DA suddenly switching off. Deceleration ends when the frog is at rest and DB is once again on. When at rest away from the starting line, DC is on, and the tread is automatically activated bringing the frog back to the starting line.

The three photodiodes signals enter (via amplifiers) a photocell decoder device. This device translates the binary type code word of the three photodiodes into four discrete output channels -- each representing a given activity of the frog. (Acceleration and deceleration activate the same channel.) These channels (if desired) may each be connected to an individual electronic timer that will record the length of time each channel is "activated." The timers can then be connected via a memory unit to a teletype output device. The method currently being used is to voltage divide the 4 volt "activated" signal of each channel so that each channel produces a different voltage (see Table 1). These outputs are then tied together and fed into an oscilloscope and paper recorder (Figure 3). The output voltage

will with time produce the graph seen in Figure 5. The oscilloscope sweep rate is set so that it can record the acceleration time, flight time and deceleration time in a single sweep. The recorder measures the return time. Several scope traces can be recorded on a single picture by slightly advancing the horizontal adjust after each jump.

Test runs have shown that the frog can be made to jump by a mild current-limited electric shock. When external lights are off and the inside of the tank illuminated with a blue light, the frog will jump down the length of the tank without hitting the sides. The preference for blue light by frogs has been demonstrated by Muntz (2) and Torelle (3).

Data Management

The data necessary for future calculations is obtained in the following way. Time of flight and acceleration are read off of the photographs from the oscilloscope camera. The return time is determined by the length of the trace on the paper recorder. This time is then multiplied by the tread's velocity so that range, R, is obtained. The tread is activated by a rapid start motor and little time is lost in coming to uniform velocity.

$$R = \text{Return Time} \times \text{Tread Velocity}$$

The frog may jump before being fully returned as well as jump so far that it hits the end wall. In either case data from that jump must be discarded and indication of the "bad"

data should be made on the paper recorder.

Calculation of Power Development

It has already been shown (1) that initial velocity V_0 , and angle of trajectory θ_0 , can be determined by solving for the root of the following nonlinear simultaneous equations (see Figure 1):

$$\begin{aligned} \text{I. } 0 &= t_f V_0 \cos \theta_0 + H \cos \theta_0 + M \cos (|\theta_w|) - D - R \\ \text{II. } 0 &= H \sin \theta_0 - t_f V_0 \sin \theta_0 + 0.5 g t_f^2 - M \sin (|\theta_w|) \end{aligned}$$

$$\text{Where } \theta_w = \arctan ((V_0 \sin \theta_0 - g t_f) / (V_0 \cos \theta_0))$$

This task is accomplished with the nonlinear equation root-finder computer program of Kenneth M. Brown (4).

Power development (p.d.) is defined as the total energy expended by the leg extensor muscles as they contract, divided by the product of the time over which this energy was expended (the acceleration time, t_a) and the mass of the extensor muscle groups, M_m .

$$\text{p.d.} = \text{total energy expended} / (t_a \times M_m)$$

A complete discussion of calculation of power development with the data developed here is given in the "Mathematical Analysis of Frog Jumping and Calculation of Power Development" by this author.

Summary

With the development of LAAMS it is now possible to use p.d. as an indice of neuromuscular condition. Frogs can be tested pre and post exposure to an experimental variable. For

example, a change in diet, increased exercise, or even exposure to certain drugs may be expected to alter p.d. The advantages of using frogs are that they are small, easy to care for, inexpensive, and can be readily dissected. If significant differences in p.d. are found between experimental and control groups, serological and histological studies can be readily performed for verification and/or explanation of the results.

Acknowledgements

I am sincerely grateful to Drs. H. Mead Cavert, Frank D. Hirschbach, Warren E. Ibele, John A. Johnson, Walter H. Johnson, Richard McGehee, Robert L. Sorenson and Donald B. Wetlaufer of the University of Minnesota for their encouragement and criticism of this project since its conception in 1971. I am equally grateful to Richard Stish, Richard C. Peterson and Bruce Eaton for their suggestions on the development of the instrumentation.

Financial assistance has come from the University of Minnesota Honors Department, and the University of Minnesota Division of Health Computer Sciences.

References

1. Saliterman, Steven S. (1973) "Measurement of Power Development with the Laser Activated Amphibian Monitor System (LAAMS)." B.A. Thesis, University of Minnesota.
2. Muntz, W.R.A. (1964) Scientific American, 210, pp. 110-119.
3. Torelle, Ellen (1903) American Journal of Physiology, 9, pp. 466-488.
4. Brown, Kenneth M. "Nonlinear Equation System Root-finder." Available on the University of Minnesota CDC 6000/7000/CYBER Series Machines.

Figure 1. The Frog Jump Model. Points a,b,c,d and e are locations of the center of mass at rest, start of flight, summit, start of deceleration, and at rest again respectively. Pts. h and j are the tips of the toes, and pts. i and k are the tips of the fingers (as measured in the ZY-plane). The distance between pts. f and g is equal to the distance between i and k, and is represented by the segment R. D is the distance between the tips of the toes and the tips of the fingers. Segments H and M are measured by a c.o.m.-determining photographic exercise described in (1). The initial velocity V_0 , and angle of trajectory θ_0 , are found by solving two nonlinear simultaneous equations derived by manipulation (also (1)) of segments I, J, L, A, E, D, N and R.

I is a vertical segment from pt. b to the distance axis. J is a vertical segment from pt. m to d. L is vertical segment from pt. d to the distance axis. Segment groups H,I,A and L,M, N each form right triangles. E is the horizontal displacement of c.o.m. during flight, and S (pt. c to e) plus I is the maximum height obtained.

Figure 2. The Laser Activated Amphibian Monitor System.

Figure 3. Electronic schematic for the light sensing circuit, decoder, indicator display, tread control, simulators and overrides, and outputs to the oscilloscope and strip chart recorder.

Parts list:

A1-3	Fairchild A741 operation amplifiers
C1-2	500 pf. silva mica capacitors
D1-15	IN4383 diodes
G1-8,10,12-15	Fairchild 9935 DTL Inverters
G5	Fairchild 9946 DTL NAND gate
G9,10	Fairchild 9962 DTL NAND gates
L1-4	GE 348 miniture indicators
P1-3	5K ohm potentiometers
P4-6	10K ohm potentiometers
PD1-3	T I H11 photodiodes
Q1,3,5,7	2N3393
Q2,4,6,8	2N3416
R1-6	20K (all resistors 1/4 watt, 10%)
R7-9	2 meg
R10-12	15 meg
R13,19	10K
R14,20	20K
R15,17	40K
R16,18	30K
R21,23,25,27,29-31	39K
R22,24,26,28	1K
RL1-3	HG1004 (Hg wetted relay contacts)
S1-5	SPST momentary push buttons, 5A, 110 VAC

Figure 4. Position of the upper and lower "planes" of laser light. The lower beam is blocked by the frog while the

upper beam (positioned just above the head) is unobstructed. Photodiode DA is "off" while photodiode DB is "on." A third beam crosses the tread at the starting line. When the frog is at rest at the starting line photodiode DC is off. When the frog accelerates both DA and DB are off (DC is ignored). Flight is indicated when DA goes on (DB is ignored), and terminated when DA goes off. During deceleration both DA and DB are off. When the frog is again at rest DA is off while DB and DC are on. This combination causes the tread to automatically start. The tread stops when the frog is back at the starting line and DC is off.

Figure 5. Output signal of the photodiode decoder. A different voltage corresponds with each activity of the frog.

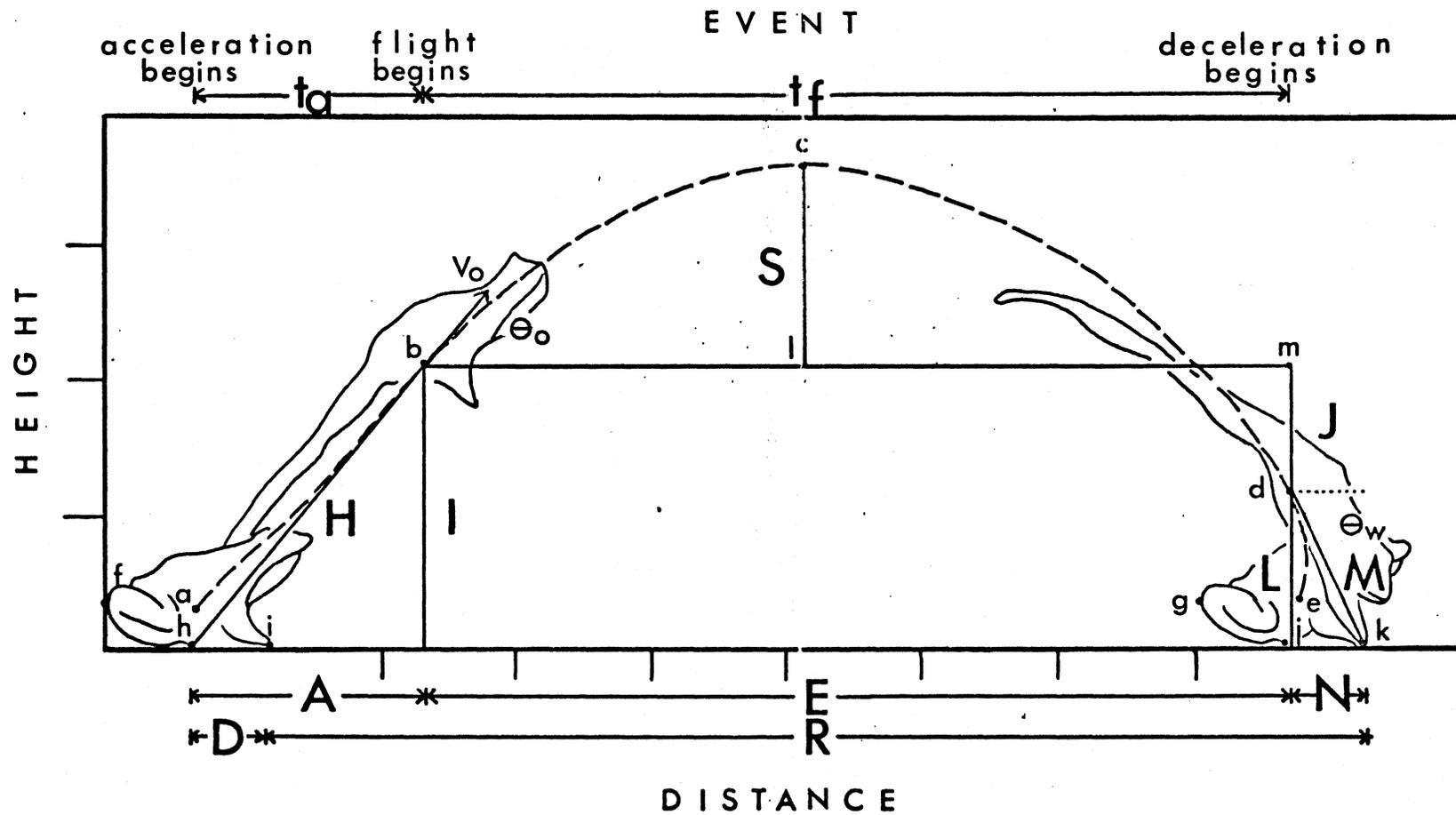


Fig. 1.

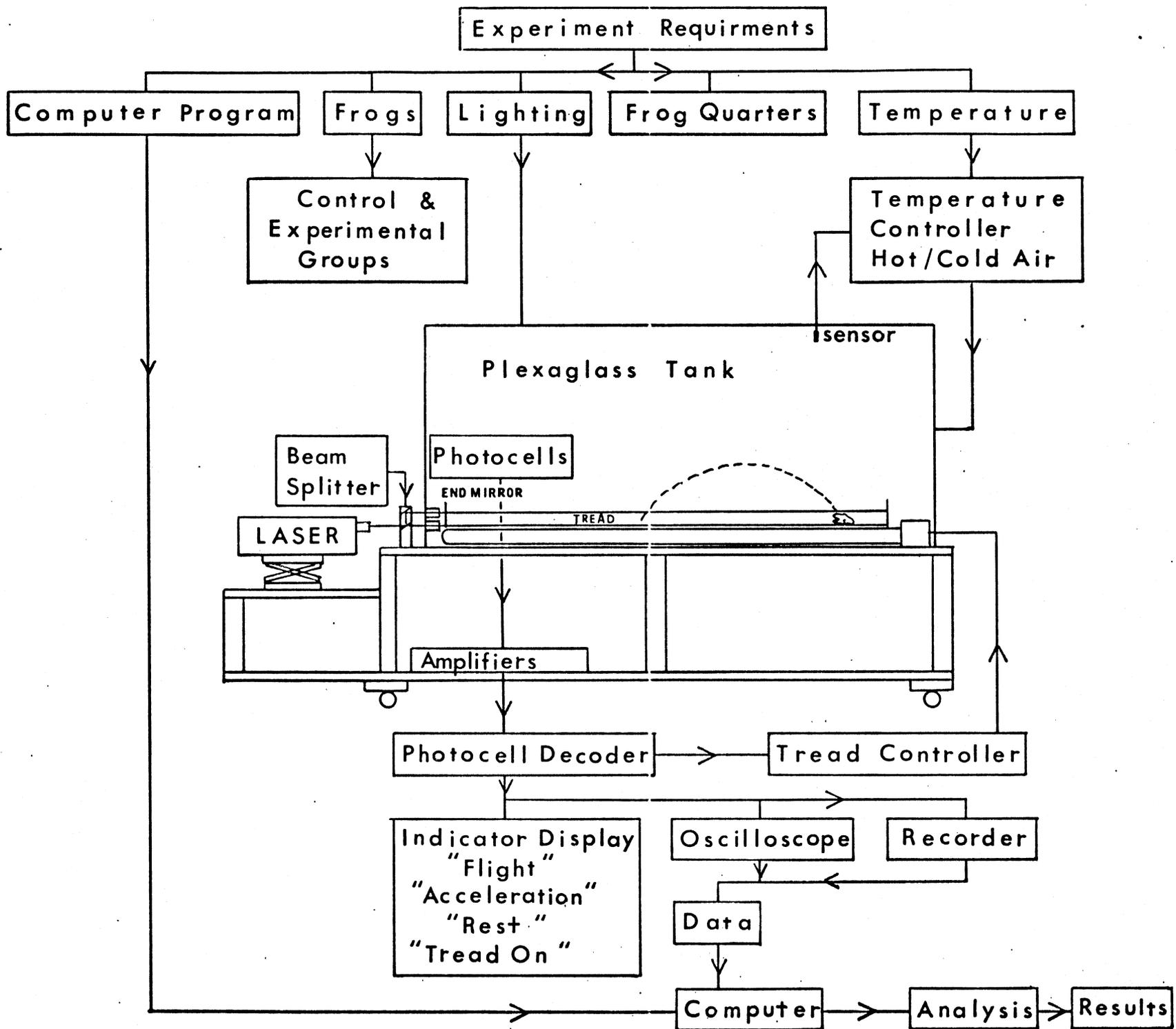


Fig. 2.

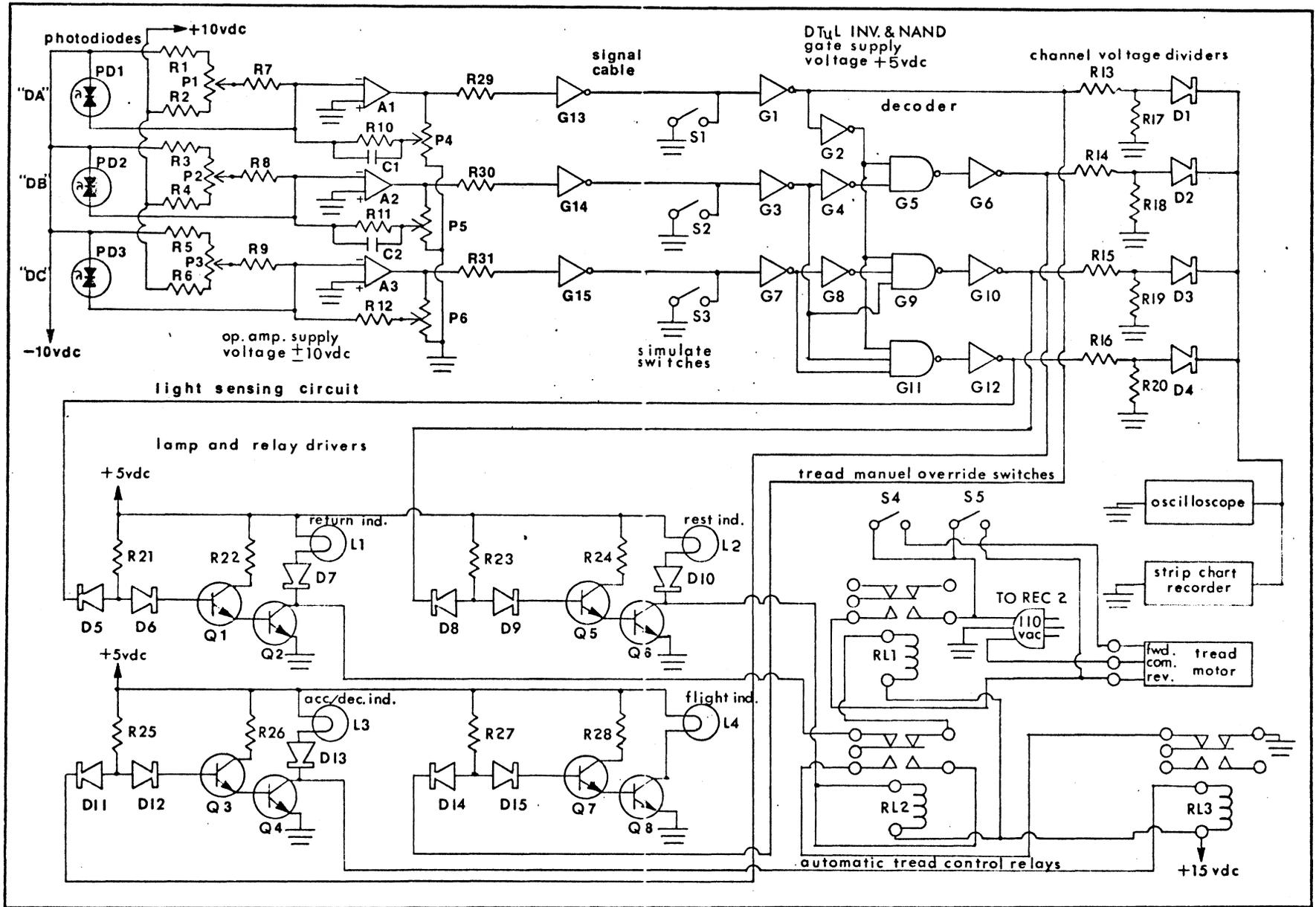


Fig. 3.

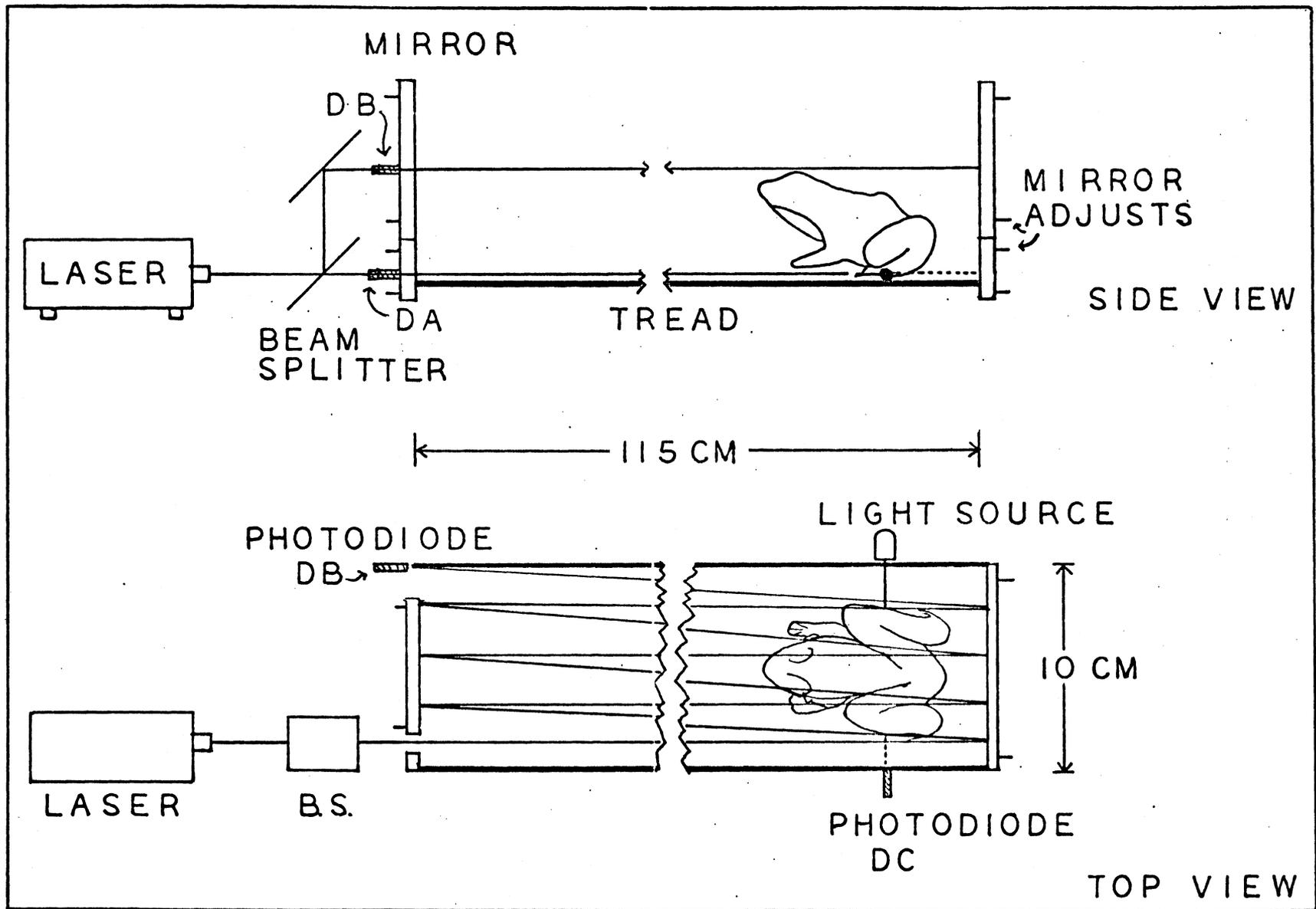


Fig. 4.

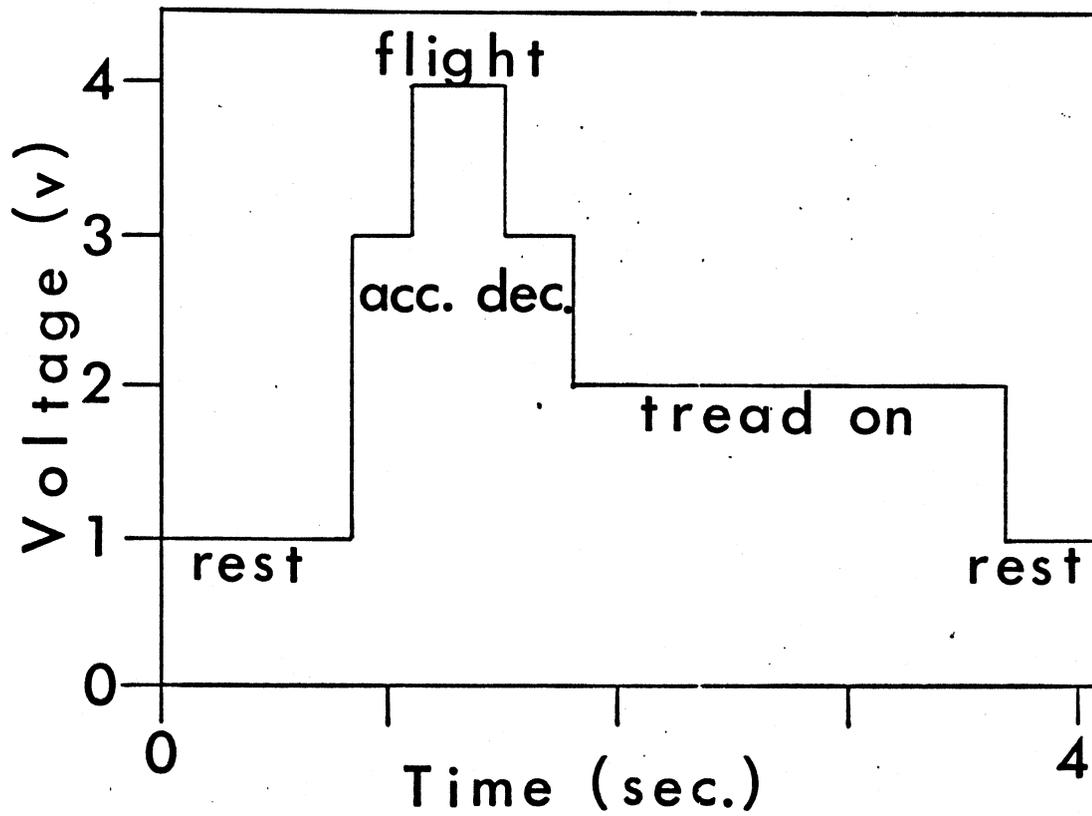


Fig. 5