A Carbon-Dioxide Laser System

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INTRODUCTION

Lasers have always fascinated me, even before I was in a position to understand them. Unfortunately I never saw one until 1970, by which time I was over fourteen years of age. It is certain that students and experimenters of the future will be exposed to them much earlier, as lasers of all kinds have proliferated everywhere; since 1970 I have seen hundreds.

Most everyone interested in lasers has thought, at one time or another, of building one. The devices are demanding, as a rule, both in terms of materials and workmanship. Even the experts have found it difficult to make them perform. This fact frightened me, but I enjoy a challenge--and when I first viewed a carbon-dioxide laser (only a year ago), I knew I had to try it.

The carbon-dioxide laser is substantially easier to construct than the atomic-gas lasers, and for this reason I found it an excellent "first" laser. From it, I learned much of what I need to attempt other types, and in the process I gained a valuable and useful laboratory tool.

GENERAL DESIGN CONSIDERATIONS

First, I wanted a laser small enough to be convenient on a lab table and small enough to be easily moved, yet large enough to produce a useful power output. With these factors in mind, I arbitrarily set a cavity length of about one meter.

The next choice involved the cavity mirrors. One popular arrangement, often used in low-cost applications, is to use a half-symmetric cavity in which both the flat and concave mirrors are totally reflective; the output is extracted through a hole in the flat mirror. I did not know how this would effect mode structure and beam divergence, so I chose to use the more conventional method of coupling the output through a partially-reflective dielectric coated mirror. I was fortunate that a friend had some fragments of an accidentally-broken mirror made of germanium. He sold one to me, along with a spherical glass mirror coated with gold, for a very reasonable price. This same friend, adept at glass-working, made the coaxial water-cooled laser tube which forms the heart of my system.

Many tight-budget laser users operate their carbon-dioxide laser on a mixture of carbon-dioxide and air. I wished to get the maximum possible efficiency, so I opted instead to use the more conventional mixture of carbon-dioxide, nitrogen, and helium. I purchased the mixture from a local supplier of specialty gases; the proportions are 14% carbon-dioxide, 14% nitrogen, and 72% helium.

Since I lacked the materials to construct a direct-current power supply at the time I first began the design, I wished for the laser to be operable from either direct or alternating current. For this reason, both electrodes were to be identical, to permit either to function as a "cathode."

The direct-current supply, when finally constructed, would have to provide around 8 kilovolts, adjustable from 0 to about 70 milliamperes. I desired monitoring for both of these parameters, as well as controls and connectors for the laser and all accessories.

THE LASER OSCILLATOR

The laser tube is 117 centimeters in length, and is mounted, for mechanical stability, on a 5-foot length of rigid aluminum extrusion (see Fig. 1). Mounting plates, milled from .5-inch aluminum stock, hold the tube at each end. Two more plates, at the ends of the extrusion, complete the assembly. This arrangement is designed to be fitted with a protective cover but this has not yet been assembled.

The electrodes are cut from brass tubing, and are mounted coaxially with the bore of the laser tube. The water jacket covers them along with the bore to maintain a low temperature during operation of the unit. The leads pass out through the gas ports on the tube and are brought out of the unit through the hollow base.

The mirror mounts are turned from aluminum stock, and are mounted directly on the ends of the tube with epoxy. O-ring seals secure the mirrors, which can be removed and replaced without disturbing system alignment (see Fig. 2). Other O-rings, in grooves just deep enough to hold them in place, are compressed by three 10-32 screws and provide ample angular adjustment for each mirror.

The mirrors are spaced 115.5 centimeters apart. The output coupler is flat and is 90% reflective. The total reflector is spherical and has a radius of curvature of 200 centimeters. The bore of the tube measures .75 centimeters in diameter and represents the smallest aperture within the cavity; this results in the tube having a Fresnel number of 1.15. The discharge path is 77 centimeters long. Using the graphical procedure devised by Theodore S. Fahlen[1], I estimate an output power (TEM_{00}) of around 25 watts with a divergence (full-angle) of 2 milliradians.

The actual output power is unknown, as I have been unable to measure it directly. It is sufficient to ignite wood almost instantly, and it heats the surface of a fire-brick to incandescence. The divergence is measured to be 2.3 milliradians, 15% higher than my estimate. I do not know how reliable my measurement is, as it relied on the relative sizes of char spots on a piece of wood!

The laser operates well with a gas pressure of between 10 and 15 torr. The vacuum pump evacuates the tube continuously while the mixture seeps in through a needle valve. At a pressure of 10 torr the optimum current is 35 milliamperes.

THE POWER SUPPLY

The direct-current source is relatively simple, being unregulated. A plate transformer, driven from a variable voltage, has its output rectified in a bridge and then filtered by a circuit consisting of two oil-filled capacitors and a large inductor (see Fig. 3). There is a large, fan-cooled ballast resistor in series with the laser tube. At any given pressure, the laser discharge drops a constant voltage, so the current may be adjusted simply by varying the voltage across the laser-ballast resistor combination.

The voltages across the tube and the non-adjustable portion of the ballast resistor are measured with the circuit of Fig. 4.

Voltage dividers feed voltage-followers consisting of U1-U4. The zener diode pairs protect the delicate op-amps from excessive voltages. The voltage-followers deliver their outputs to a pair of differential amplifiers, in which the actual voltage measurement is performed. Transconductance amplifiers, U6 and U8, convert these voltages into currents for driving the front-panel meters directly. Since the voltage across the ballast resistor is directly proportional to the current through the laser, this meter is calibrated directly in milliamperes.

Built into the power supply cabinet are controls for the vacuum pump and two auxiliary devices. All high-current circuits are relay-controlled and all externally-accessable circuits are fused. The rear apron contains electrical outlets for the accessories and connectors for hooking up the laser.

[1]Theodore S. Fahlen, "CO_2 Laser Design Procedure," <u>Applied Optics</u> vol 12, no. 10 (October 1973), p. 2381

CONCLUSIONS

I do not know if I met the first design goal or not. The system is not easily moved--the power supply alone requires two people to lift it! The power output is impressive, though. I have yet to see a more powerful laser, though I undoubtedly will sometime in the future.

Possible applications for the device include atmospheric communications and light materials processing. One use to which I hope to put it is to excite a far infrared (millimeter-wave) laser of the type recently invented.

Many modifications are possible. The germanium mirror absorbs considerable amounts (around 5%) of the laser's output, and soon becomes excessively hot. It would be desirable to replace the fragment with a good mirror made of a less absorptive material. A Brewster window would be a desirable addition, as it would provide an open cavity and polarized output. This would necessitate moving the output mirror to the front plate on the enclosure, but this would be simple to do. The power supply could be current-regulated for greater stability, and modulation could be performed.

It seems that there are an infinity of things that are possible with this laser! Therein lies perhaps the greatest advantage of such a project--since the work never ends, neither does the satisfaction.

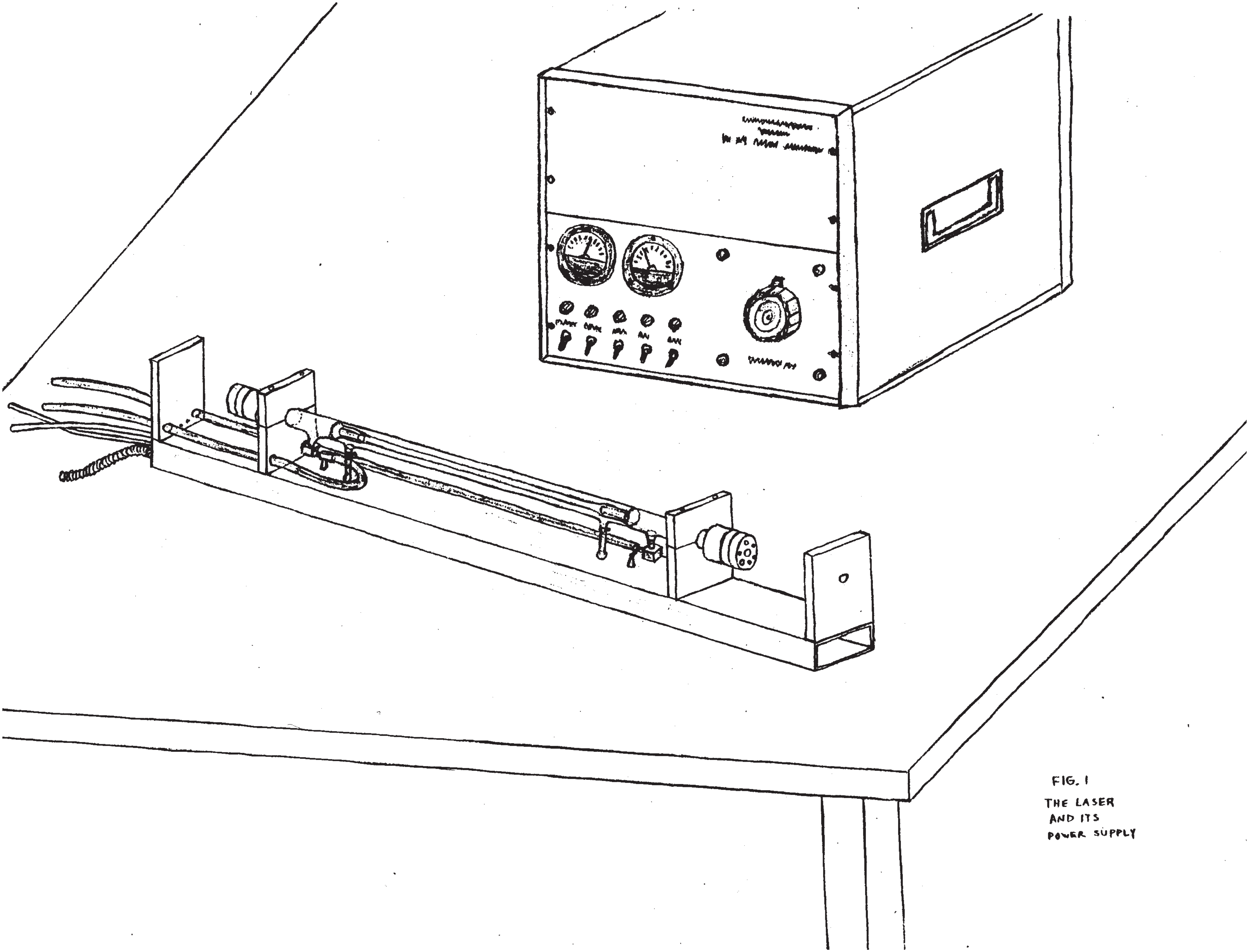


FIG. 1
THE LASER
AND ITS
POWER SUPPLY

FIG. 2

OUTPUT
MIRROR CELL
DETAIL (ACTUAL SIZE)

TOTAL REFLECTOR, AT OPPOSITE END
OF TUBE, IS MOUNTED SIMILARLY.

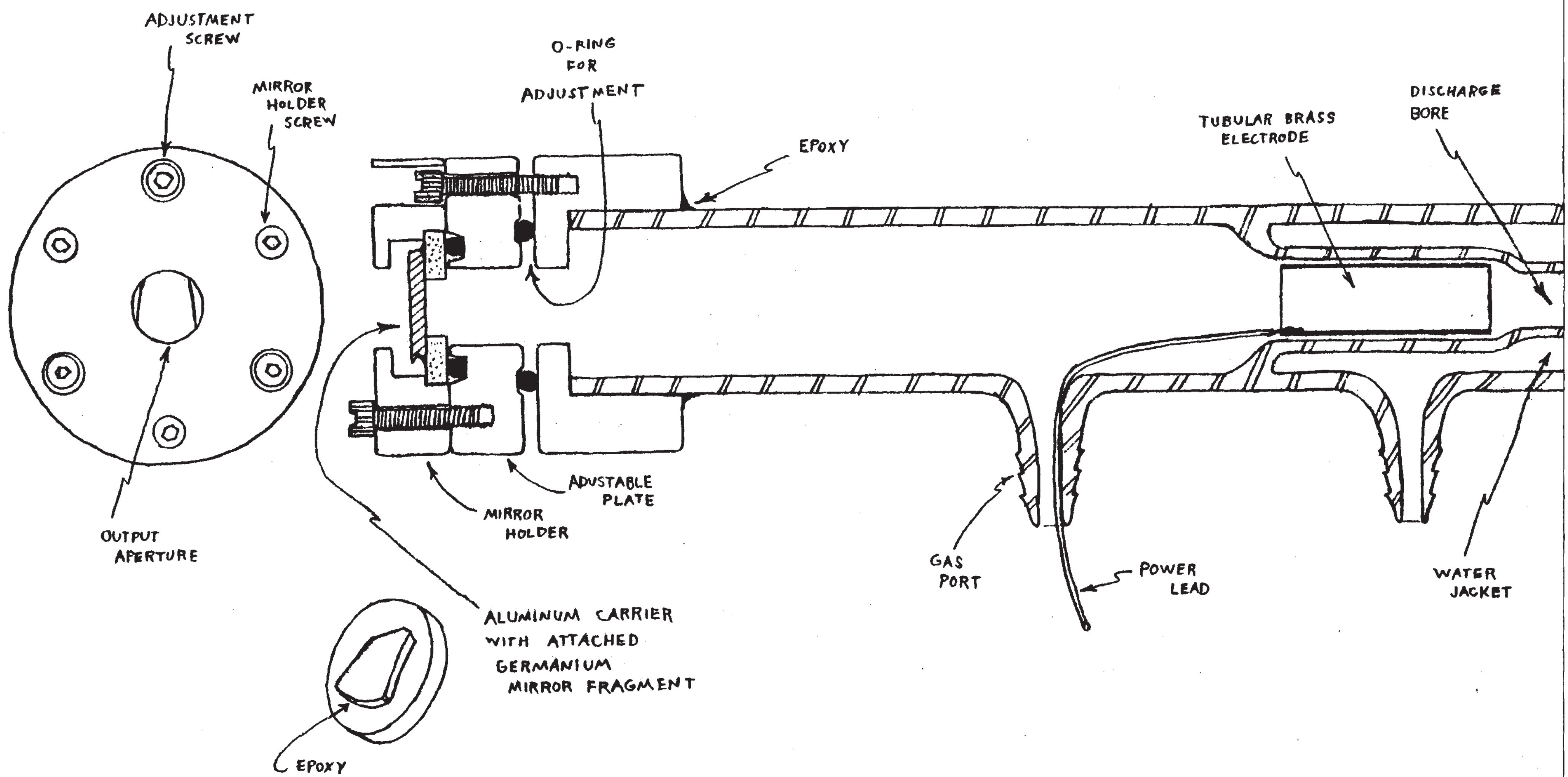
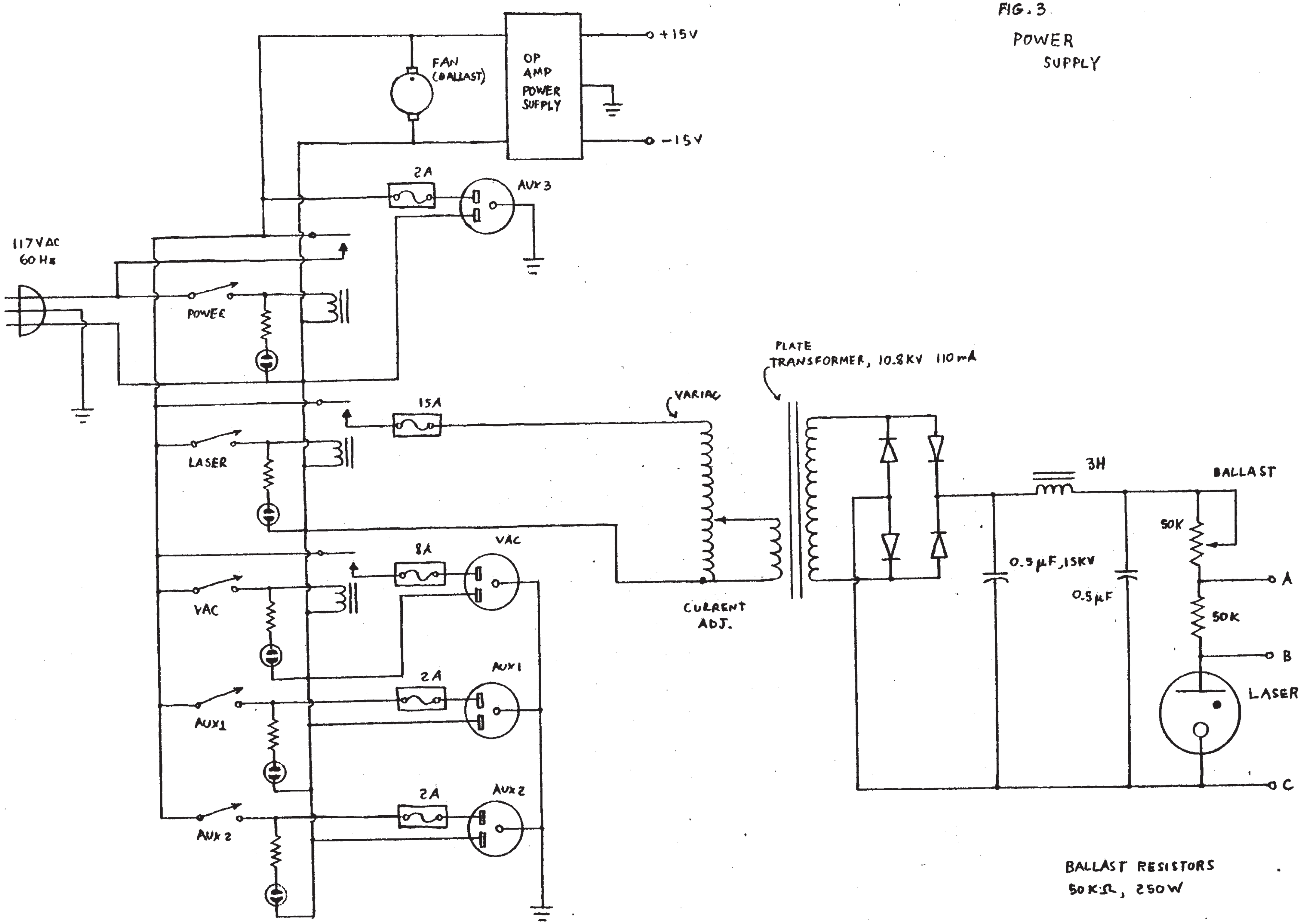


FIG. 3

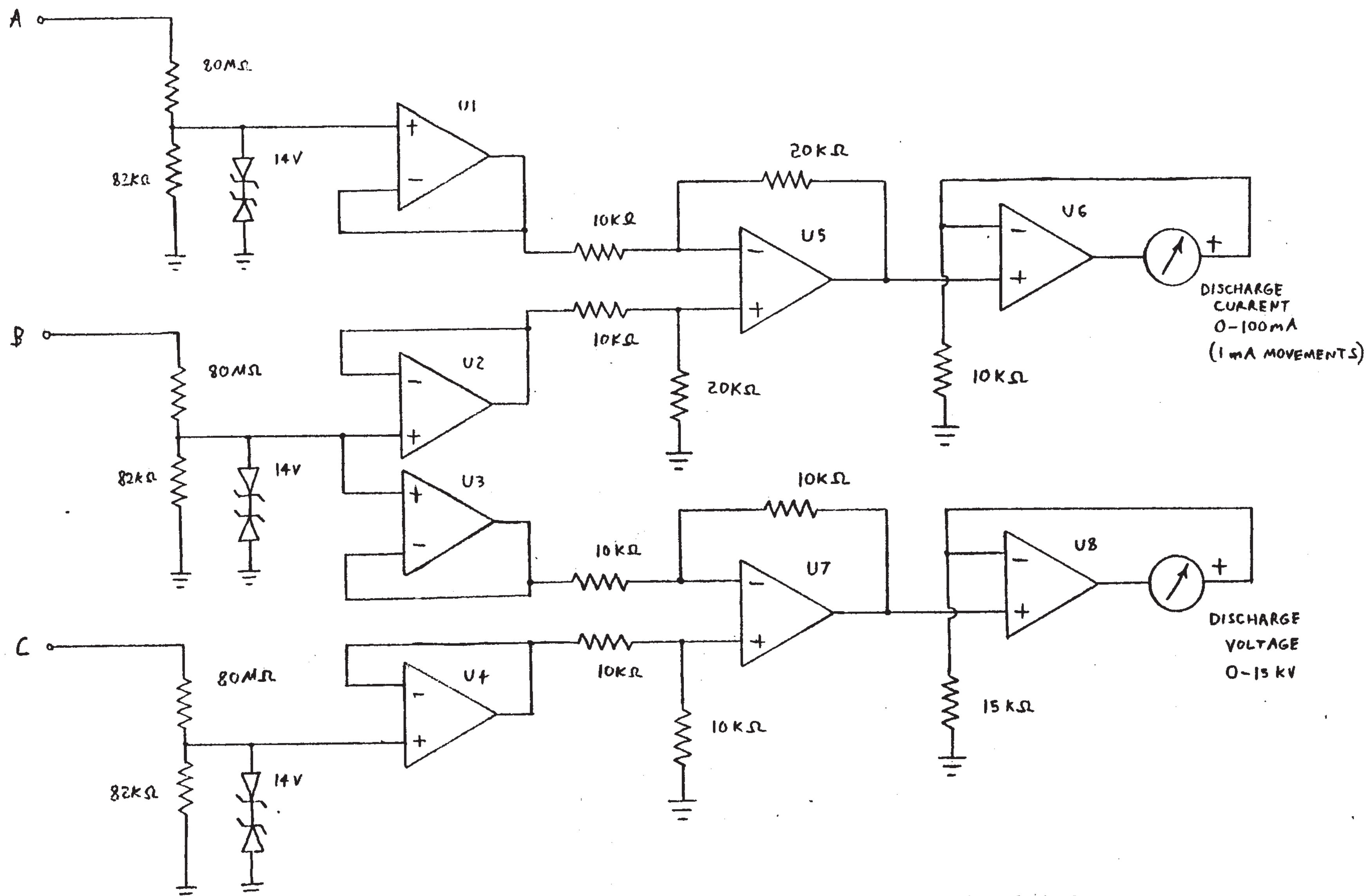
POWER SUPPLY



BALLAST RESISTORS
50KΩ, 250W

FIG. 4

MEASUREMENT CIRCUIT



U1-U8 741 OR EQUIV.

ALL RESISTORS 1/4W, 5% EXCEPT 80MΩ (10%)

ZENER DIODES IN5244 OR EQUIV.