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THE ATDL LIDAR PROGRAM

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ABSTRACT

A comparatively inexpensive LIDAR system is described. It employs a neodymium type pulsed laser, simple optical system, and sensitive photomultiplier detector. Preliminary results of returns from the plume of the Bull Run (TVA) stack plume are described.

I. SITE LOCATION

The 950 kw Bull Run electricity generating plant of the Tennessee Valley Authority, located just across the Clinch River from the City of Oak Ridge, emits the residual products resulting from the combustion of 5 tons of coal per minute from an 800-foot stack. Highly efficient electrostatic precipitators limit the amount of fly ash to the smaller particles, but their size and amount are sufficient to permit a good return from a high-energy pulsed laser beam. Moreover, the stack is isolated; no other major industrial or urban source exists within a five mile radius. This combination of circumstances encouraged the Air Resources Atmospheric Turbulence and Diffusion Laboratory to develop a laser capable of studying the effluent from the Bull Run plant. This device is based for the most part on existing technology, as described by Johnson (1) of Stanford Research Institute, and Barrett (2) of NOAA, but incorporated several features by means of which the total cost of the apparatus was kept to a relatively low figure. This report describes the equipment and reports some preliminary results of its operation.

II. THE EQUIPMENT

An orderly procedure for describing the LIDAR system is to describe the equipment along the path of the signal and the following paragraphs will follow this procedure as far as possible.

A. The laser and its mount

The laser is manufactured by the Holobeam Company. It is a neodymium--doped glass type of 5 Joule output, "Q switched" by Pockels cell. The pulse length is 20 nanoseconds, peak power is 250 megawatts, and repetition rate is 12 firings per minute. (In practice the laser is conservatively fired at about 3 Joules.) The Pockels cell has an oscilloscope triggering output, which synchronizes the firing of the laser to the single sweep electronics of an oscilloscope. This feature of the Holobeam Pockels cell is quite advantageous compared to other systems reported in the literature, which use "light pipes" and visual sensors to trigger the oscilloscope.

The mount chosen is an Edmunds (No. 85, 134) equatorial telescope mount with a pedestal base (No. 85, 145). The major advantages of equatorial mounts are that they are rugged and counterweighted. If proper balancing is performed the entire assembly, laser, telescope and photomultiplier, can easily be moved to any angle without gears or cranks, and will remain in that position without locking. Furthermore they are inexpensive. This particular mount is equipped with "setting circles" which are useful for determining the co-ordinates of each firing.

The laser, telescope and photomultiplier are assembled on an aluminum plate 48" x 24" x 3/8" (Figures 1 and 2). The plate is stiffened on the long ends by L shaped "channel bars," and the entire assembly is rigid enough to maintain optical alignment at any angle the equatorial amount assumes.

Cost of laser - $9500.00
Cost of mount - 150.00
Aluminum etc. - 10.00
Laser and mount $9660.00

B. The telescope and photomultiplier assembly

The receiving optics are extremely simple, consisting of an inexpensive, home-made refractor telescope. The objective lens is a simple convex lens, 129 mm diameter, focal length 235 mm. The "eye lens" or secondary ocular is 28 mm in diameter, focal length 47 mm. The objective lens was fitted into a retaining ring made from hard plastic and then recessed into a tube of appropriate diameter. The inside and outside of the tube were painted flat black and a few "light traps" were inserted in the tube.

Since only light of the wavelength of the neodymium pulse (1.06 microns) is to be detected on the photomultiplier tube, a 100 angstrom bandpass filter is included in the optical train. A separate cell containing the "field stop," eye lens, and bandpass filter was made so that the latter can easily be removed for visual alignment (see below). The "field stop" is merely an opaque plate with a 1/8" hole in its center, inserted at the focal plane of the objective lens. This limits the field to approximately 1° and easily accomodates the 5' divergence of the laser beam. The "eye lens" does double duty, by providing an "infinity" focus for the human eye as well as the optimum parallel light rays into the bandpass filter.

The photomultiplier unit is reworked EG and G Model 585-63 system. Photomultiplier tubes capable of detecting 1.06 micron wavelengths have appreciably lower sensitivities than other tubes and much higher "dark currents." For example an Amperex XP1005 tube at room temperature and maximum sensitivity will produce 20 microampere signal in the absence of ambient light. Since 30 microamperes is the maximum allowable continuous current, some alteration must be made. By the addition of a solid state (Peltier effect) cooling unit, the dark current is reduced by over two orders of magnitude. In addition the optical diffuser that came with the photomultiplier assembly was removed, thereby adding a factor of ten to the sensitivity, and the final dynode state was rewired, adding another factor of ten. An additional power supply capable of delivering 1500 to 1800 volts, which adds one or two more orders of magnitude of sensitivity, was also provided. Not all of this increased sensitivity can be used, particularly in daylight when the phenomenon of "shot noise" is most apparent, but the option is available to the operator for his judgement in trading tube life for rise time, scope noise vs. phototube noise, etc.

Cost of telescope	$ 15.00
Cost of bandpass filter	125.00
Cost of photomultiplier	3,735.00
Total cost of optical train	$ 3,875.00

C. The electronics

1. The Emitter Follower

Since the output of a photomultiplier tube is a pure current source, it would seem that additional voltage amplification between the photomultiplier and oscilloscope would be unnecessary. A sky background may produce 10^{-7} amperes of current from the anode of the photomultiplier tube operating at a 1000 volt supply voltage. Most oscilloscopes have an input impedance of 10^6 ohms which means a voltage of 0.1 volt is displayed on the oscilloscope screen. Unfortunately, the long cables required from the photomultiplier to the scope, some 20 feet or more, produces an RC time constant (integration time) of 3×10^{-4} seconds. Timing requirements of the LIDAR necessitiate an RC time of 10^{-8} sconds or less, obviating a direct PM to oscilloscope link. One obvious answer is to use a 50 to 100 ohm resistor across the photomultiplier which matches the cable impedance and reduces the RC time to acceptable levels, but this sacrifices several orders of voltage magnitude.

Instead we chose to use an impedance transformer of the emitter follower type. This permits use of either a short cable from the photomultiplier tube to a 1000 ohm (or higher) resistor, or a logarithmic diode, as the "load" on the PM tube. The impedance is then lowered to 50 ohms for matching to the long connecting cables. The emitter follower is based on a design by J. T. Lorenzo (3) of Oak Ridge National Laboratory. The frequency bandpass of this device will exceed our requirements. However it is a capacitive input device. This has the minor disadvantage that the sky background is not available directly since any steady current is blocked by the capacitor.

2. The Oscilloscope

The Tektronix RM 547 oscilloscope was employed, because of its combination of fast rise time, delayed sweep capability, and flexibility. The delayed sweep feature permits a higher sweep speed and greater resolution "on target" than a simple sweep from the initial triggering pulse.

The oscilloscope trace is photographed with a Graflex "Super Graphic" camera equipped with a Polaroid roll film back (Fig. 3). The f4.5 lens is sufficient for sweeps of 1 microsecond/cm or slower with Polaroid 10,000 speed flim. If faster sweeps become desirable, conventional scope cameras with their faster lenses will be required. The flash contacts of the camera are wired in series with a 5 volt battery and the remote trigger of the laser. This arrangement has been found to synchronize laser, oscilloscope, and camera perfectly.

Cost of scope	$2,600.00
Cost of camera	400.00
Total	$3,000.00

III ALIGNMENT

Collimating two optical trains to 1° or less in field operations would seem to be a difficult problem. Fortunately, the laser's optics are transparent to visual light, and a target can be clearly seen by sighting down the optical system. The receiving telescope has been designed to permit visual sighting of the target. In operation a simple coupling between the telescope and photomultiplier is removed, the 1.06 micron filter is also removed, and the observer can bring the laser target (fixed) into the telescope's view (adjustable). This system has proved more satisfactory than use of an auxiliary finder telescope.

IV MISCELLANEOUS

In addition to the optical train and hardware, several other items are necessary; these include:

Protective goggles (3 pairs)	\$ 135.00
Field housing for the remote site	170.00
Autocollimator for aligning the optical train	665.00
	\$ 970.00

The total cost of this LIDAR system is thus \$17.605.00.

V. THE RESEARCH PROGRAM

The LIDAR is located some 2000 meters from the Bull Run plant's stack. The effluent of the stack consists principally of SO_2 and filtered fly ash. The fly ash particles with their small terminal velocity (one foot/minute) and great abundance, provide an excellent tracer for examining the behavior of the emerging plume cross-section. The program is to be continued at least through one calendar year to observe the plume's behavior (height of rise, spread, bifurcation, etc.) through the seasons.

A few selected LIDAR returns from the Bull Run stack plume are shown to illustrate results to date. The plume oscillates vertically and horizontally and exhibits pronounced bifurcation. Figure 4a shows a return from the plume about 12.5 to 14 microseconds after the laser was pulsed. At 12.8 microseconds (1920 meters) the return is very strong, then drops to a minimum at 13.2 microseconds (1980 meters) and then has a secondary maximum at 13.5 microseconds (2030 meters), trailing to zero at about 14 microseconds. From this the appearance of the cross section of the plume can easily be inferred. A similar scope photograph, Figure 4b, shows a double hump centered about 15 microseconds (2250 meters).

For detailed study of the plume's cross-section, the trace may be enlarged using electronic delaying procedures, so as to display only the target (plume) portion. Figures 4c and 4d show multiple exposures of the plume during a relatively steady interval, only slight (about .1 microsecond or 15 meters) meandering being evident. A few minutes later, the three exposures shifting of the plume's geometry. Figures 4e and 4f illustrate a similar effect.

Acknowledgements

The authors would be remiss not to express their debt and appreciation to Messrs. Duane Turner and William Brooks whose practical knowledge of construction and physical toil transformed a chaotic assortment of parts into a precision tool.

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Figure 1: Observer positioning the LIDAR on target.

Figure 2: The laser and mount. The vertical stand and clamps hold a portable autocollimator.

Figure 3: The firing station

Figure 4a: Return from the Bull Run stack plume. Sweep rate is 2 microseconds per centimeter; duration of sweep is 20 microseconds.

Figure 4b: Return from the Bull Run stack plume. Sweep rate is 2 microseconds per centimeter, duration of sweep is 20 microseconds.

Figure 4c: Return from the Bull Run stack plume. Multiple exposure, delayed sweep. Total delay, 12 microseconds, sweep rate is 0.2 microseconds per. cm. Duration of sweep shown is 2 microseconds.

Figure 4d. Return from the Bull Run stack plume. Multiple exposure, delayed sweep. Total delay, 12 microseconds. Sweep rate 0.2 microseconds per cm. Duration of sweep shown is 2 microseconds.

Figure 4e. Return from the Bull Run stack plume. Multiple exposure, delayed sweep. Total delay 10.8 seconds. Sweep rate is 0.2 microseconds per cm. Duration of sweep shown is 2 microseconds.

Figure 4f. Return from the Bull Run stack plume. Multiple exposure, delayed sweep. Total delay is 10.6 seconds. Sweep rate is 0.2 microseconds per cm. Duration of sweep shown is 2 microseconds.

References

1. Warren B. Johnson, Jr., Lidar Study of Stack Plumes: Preliminary Data Analysis, Stanford Research Institute Contract No. PH 22-68-33 (1968).

2. Earl W. Barrett and Oded Ben-Dov, Application of the Lidar to Air Pollution Measurements, Reprinted from Journal of Applied Meteorology, 6, No. 3, June 1967, pp. 500-515

3. Photo Cell Amplifier by J. T. Delorenzo, Oak Ridge National Laboratory Drawing No. Q-2251-1, July 15, 1965.

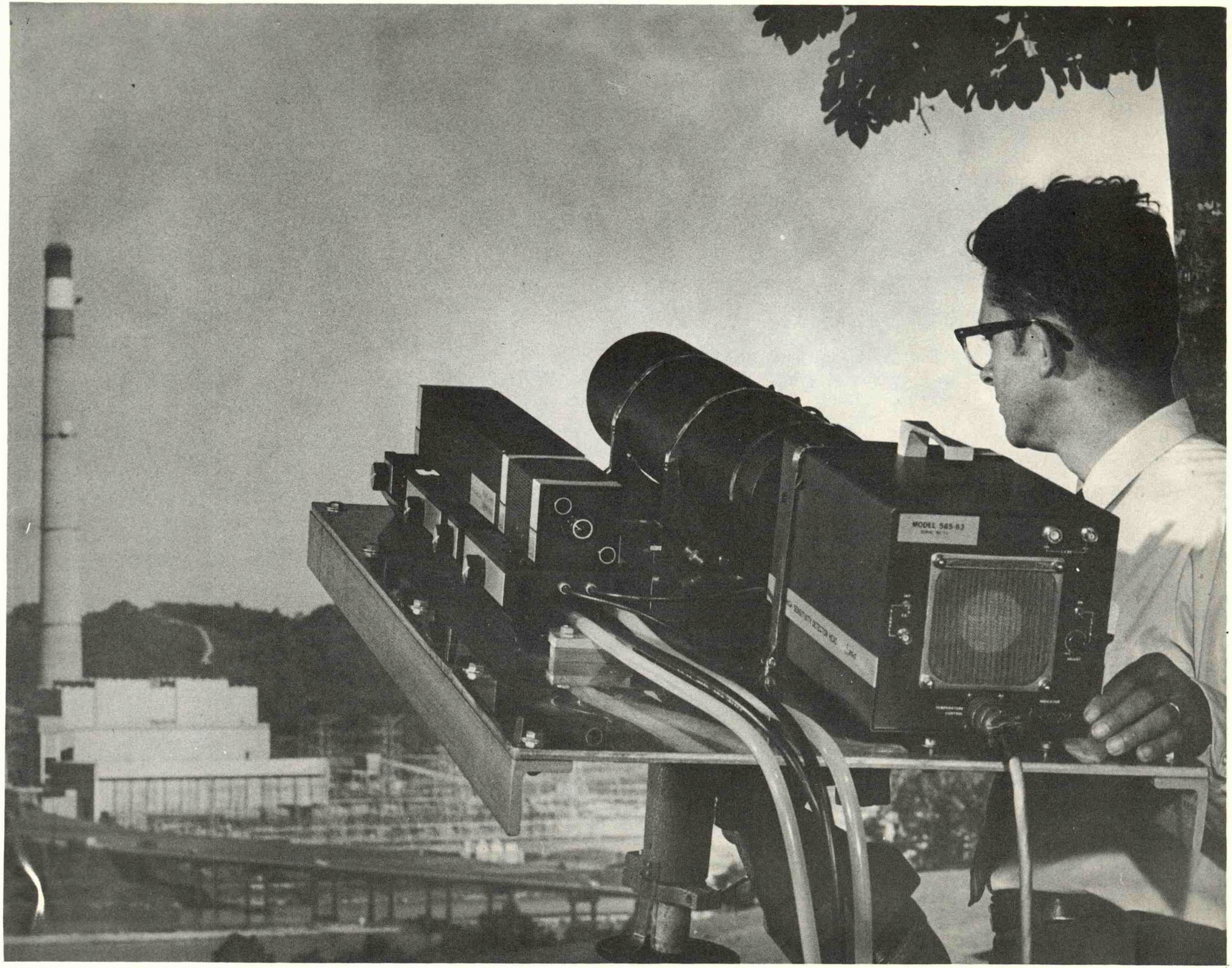

Figure 1

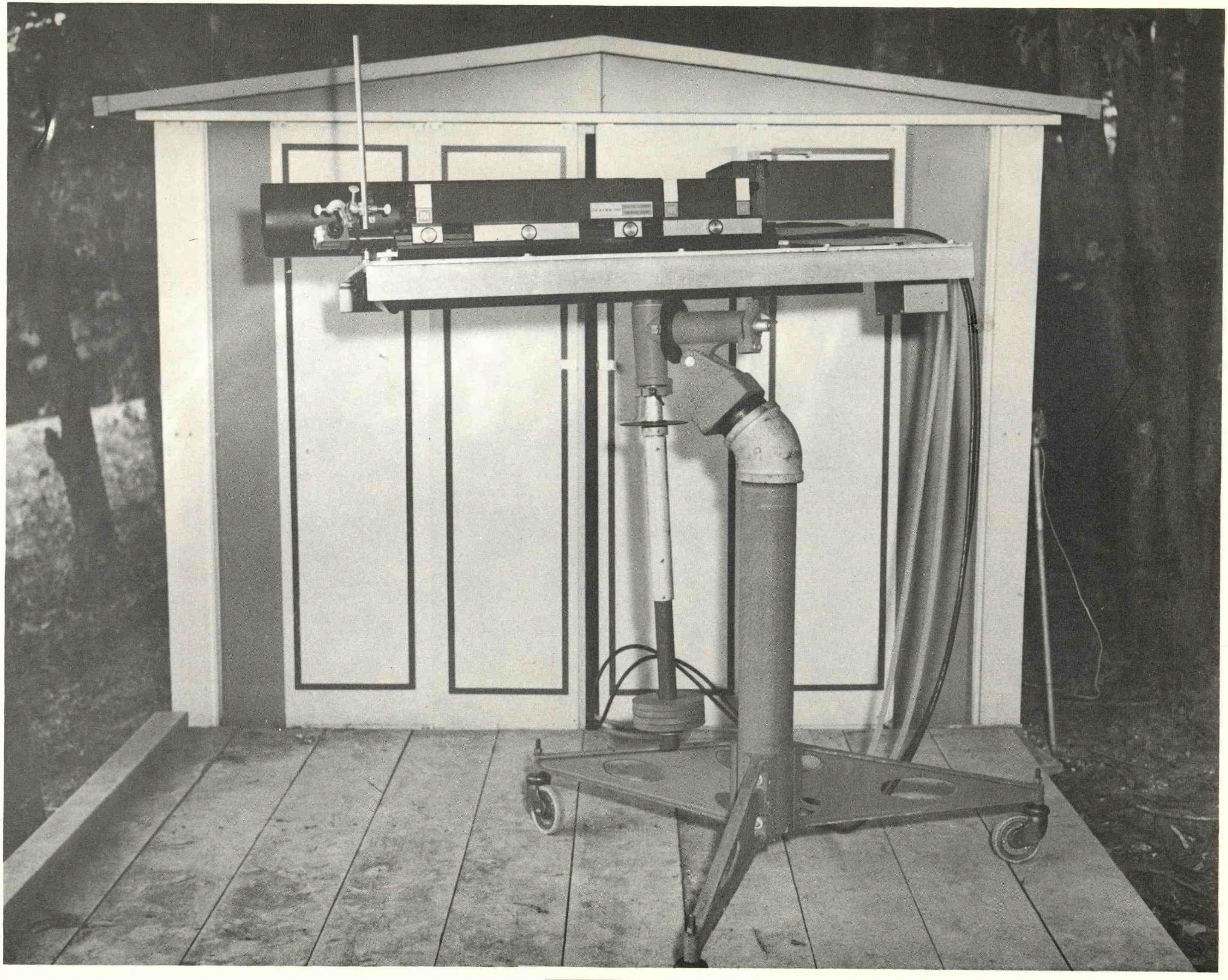

Figure 2

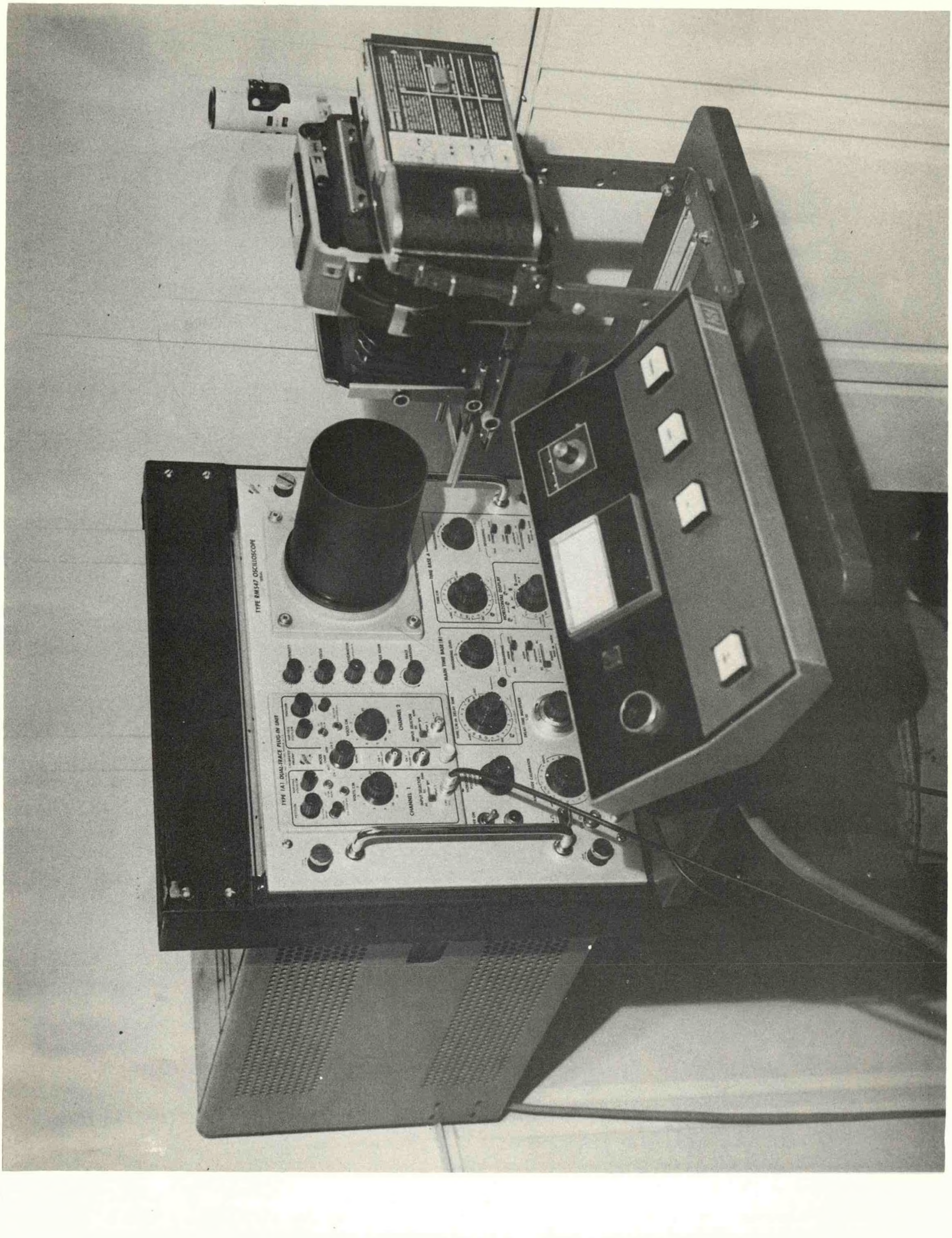
TYPE RM547 OSCILLOSCOPE
TYPE 1A1 DUAL-TRACE PLUG-IN UNIT
CHANNEL 1
CHANNEL 2
MAIN TIME BASE (B)
TIME BASE A
HORIZONTAL DISPLAY

Figure 3

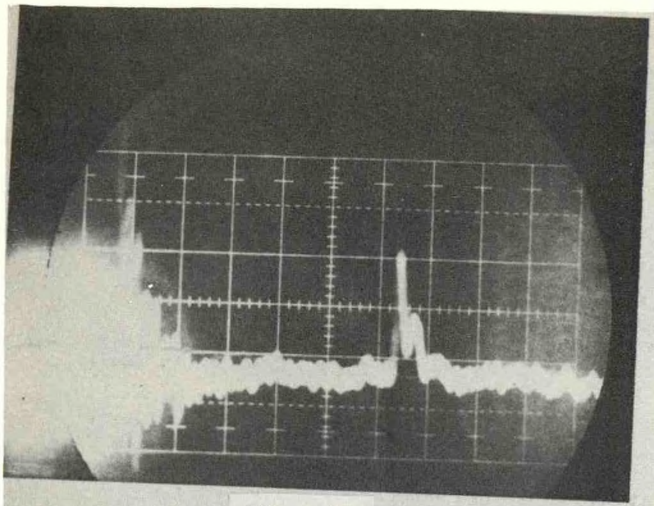

Fig. 4a

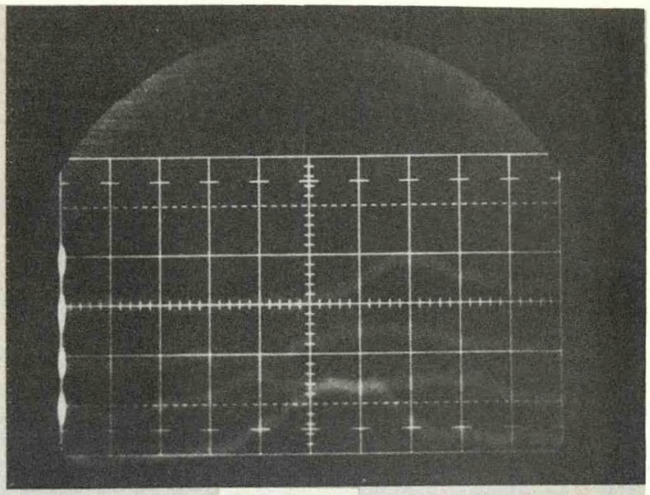

Fig. 4d

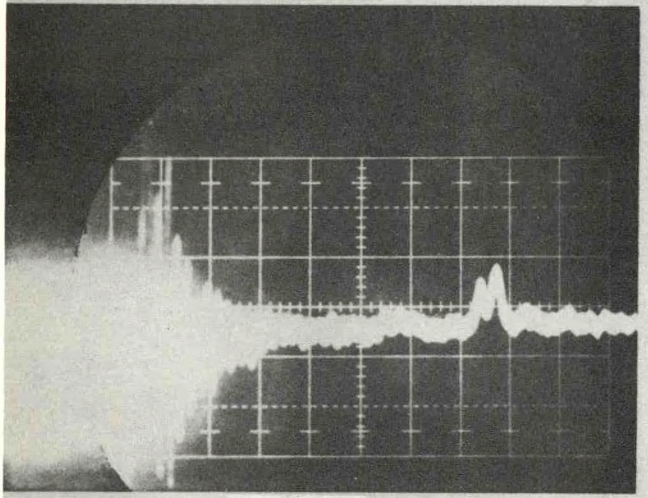

Fig. 4b

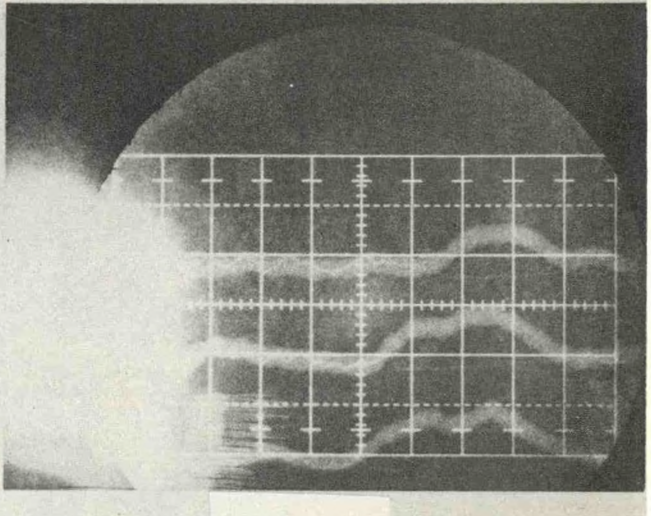

Fig. 4e

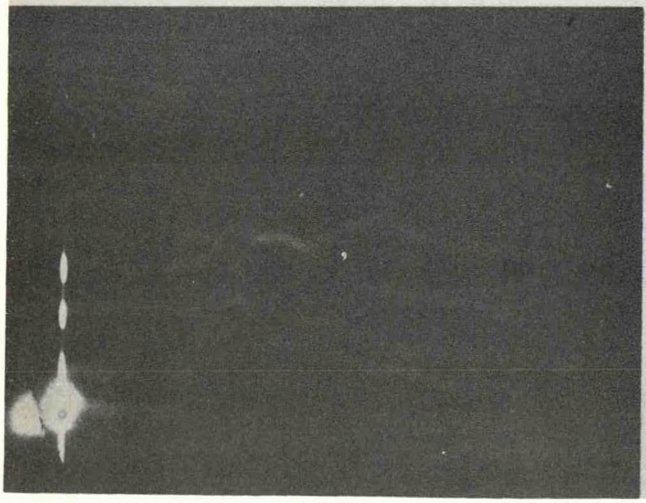

Fig. 4c

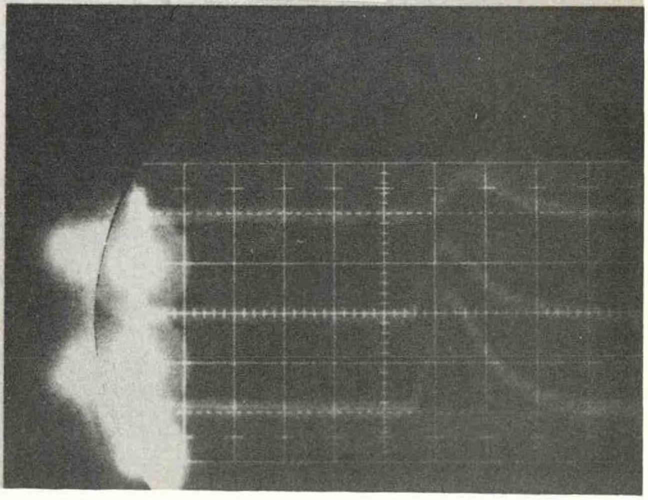

Fig. 4f