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EXPERIMENTS ON THE USE OF A LASER BEAM FOR FIRE DETECTION

PART 1. HEAT DETECTION

by

E. F. O'Sullivan, B. K. Ghosh and J. Turner

October 1970

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ABSTRACT

This note described an experimental investigation of the response to fire of a novel fire detection system. This system consists essentially of a focused laser beam, projected beneath the ceiling of a compartment, and a photocell receiver whose area is just large enough to contain the incident spot of laser light under no-fire conditions. When turbulent hot combustion gases from a fire intercept the path of the beam, the laser spot is randomly deflected on and off the photocell.

Frequency analyses have been made of the photocell's output under normal ambient conditions and in response to fires of different powers. It was found that fire can best be discriminated from ambient heat sources by selecting that part of the photocell's output which is in the range 40-80 Hz.

It is shown that a fire of less than 140 kW, at any position in a building 12 m high, 15 m x 41 m, can be detected in less than 45 s. This performance compares very favourably with the estimated performance of a point heat-sensitive detector of maximum permitted sensitivity.

KEY WORDS: Detector, fire, heat, laser, investigation, circuitry.

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MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

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INTRODUCTION

The work to be described was undertaken in order to provide data for the design of a practical fire detection system using a low-power laser, a corner-cube reflector and a 'chequer-board' photocell[1,2]. The principle of this system is that the collimated beam of laser light is intercepted by the turbulent flow of hot combustion gases from a fire; this causes random deflections of the laser spot about its mean position on the photocell, and the alternating signal from the photocell may be used to detect the presence of fire in a compartment.

Deflections of the laser beam are caused by thermal gradients, so that the system is basically a heat detector. As such it will respond to any source of heat which produces thermal air currents near the ceiling of the compartment being protected. In order to determine the conditions for optimum discrimination of fire from other perturbing influences, frequency analyses have been made of the photocell's output under normal ambient conditions in a large building and when fire was present there.

EXPERIMENTAL

The 0.5 mW beam from a helium-neon laser was focused by a telescope and projected, at a distance of approximately 0.8 m ($2\frac{1}{2}$ ft) beneath the ceiling, along the length of a large laboratory of dimensions 12 m high, 15 m wide, 41 m long (40 x 50 x 135 ft). The beam passed below the ceiling joists which were 4.6 m (15 ft) apart and 0.6 m (2 ft) deep. The beam was returned to the laser end of the laboratory by a corner cube reflector. The returned beam, 15 cm (6 in) above the outgoing beam, fell on a selenium photo-voltaic cell which was covered by a narrow band interference filter to exclude extraneous illumination. The area of the photocell was just large enough to contain the unperturbed laser spot.

The output from the photocell was amplified and passed through a tunable electrical filter (Q = 70). Frequency analyses were made of the photocell's output for a 71 cm (28 in) diameter tray of burning methylated spirits placed at the positions shown in Fig.1. The signal under ambient conditions was recorded before each fire. Some measurements were also made of the response to 46 cm (18 in), 56 cm (22 in) and 92 cm (36 in) diameter trays of burning methylated spirits. The convective heat output of these fires range from 50 kW for the 46 cm diameter tray to 250 kW for the 92 cm tray[3].

RESULTS

Typical curves are shown in Figs 2 and 3 in which the signals measured under fire and under ambient conditions are plotted against frequency for the case of a 140 kW (71 cm diameter) fire at position F or position J. The fire to ambient signal ratio, $^F/A$, is shown in Figs 4 and 5 for fires of different powers at these two positions. The $^F/A$ ratio is defined as the ratio of the photocell's output voltage at a particular frequency when fire was present to the same quantity under ambient conditions. The signal voltage at any one frequency was not steady and the values recorded were averaged by eye, the maximum values of fire and ambient signals being approximately twice the average values.

For fires in any of the positions in Fig.1, the $^F/A$ ratio almost invariably had a maximum value in the frequency range 40–80 Hz. Position F, directly under the laser beam in the centre of the laboratory was one of the most favourable positions for discriminating fire from ambient disturbances (Fig.4). Positions I and J, both 6 m (20 ft) away from the laser beam at either end of the laboratory were the most unfavourable, position J being the worst of the two (Fig 5). The $^F/A$ ratio for a 140 kW fire in any position other than J exceeded 7.5 at 40 Hz and 60 Hz; a similar fire in position J gave an $^F/A$ ratio greater than 4 at these frequencies.

All ambient signals, recorded in the course of 21 experiments on 5 different days, are plotted against frequency in Fig.6. The main contribution to the ambient signal came from the action of 10 turbo-heaters (approx. 10 kW each), spaced, 5 m (16 ft) above ground level, around the walls of the laboratory. The turbo-heaters were operated continuously and the temperature near the laser was of the order 5–8°C. It is seen from Fig.6 that the highest ambient signal recorded at 40 Hz was 1.5 mV; at 60 Hz the highest ambient signal was estimated as 1.1 mV. (Both values refer to the level at the output of the filter which had a voltage gain of 70). Using these two values and the measured fire signals, a worst-case $^F/A$ was calculated for the experiments and the results are tabulated in Tables 1 and 2. These tables show that, for a 140 kW fire, the worst-case $^F/A$ was at least 4 at 60 Hz and at least 3.5 at at 40 Hz.

Table 1

Worst-case fire signal/ambient signal ratio for 140 kW (71 cm diameter) meths. fires

Fire	Horizontal distance of fire		F/A ratio at	
	From laser end of laboratory (m)	From laser beam (m)	40 Hz	60 Hz
G	2.7	0	(17 (14	(8.5 (16.5
F	24	0	(5 (8	(5.7 (10.5
C	38	0	4	4.5
H	2.7	3	7	6.8
E	24	3	6	6.7
B	38	3	7.5	5.4
I	2.7	6	(8 (3.5	(4.5 (4.5
D	24	6	4.5	5.4
J	38	6	4	4.1

Table 2

Worst-case fire signal/ambient signal ratio for fires of different convective heat outputs

Heat output (kW) and diameter (cm) of fire	F/A Ratio at 60 Hz	
	Horizontal distance of fire from laser beam (m)	
	0	6
50 kW (46 cm)	4.8 (F)	1.4(J) 3.2(I)
70 kW (56 cm)		2.5(J) 3.6(I)
140 kW (71 cm)	6.3 (F)	4.1(J) 4.5(I)
250 kW (92 cm)	16 (F)	4.5(J) 6.8(I)

The time to detect a fire in any position was taken as the time from ignition to when the laser spot on the detector became visibly agitated. Tables 3 and 4 give these detection times.

Table 3
Detection times for
140 kW (71 cm diameter) meths. fire

Fire	Horizontal distance of fire: From laser and of laboratory (m)	Horizontal distance of fire: From laser beam (m)	Detection time (s)
G	2.7	0	10, 11, 9
F	24	0	8, 10
C	38	0	10
H	2.7	3	15, 16
E	24	3	15, 15
B	38	3	15, 16
I	2.7	6	19, 14, 18
D	24	6	16, 20
J	38	6	23, 17, 20, 23

Table 4
Detection times for fires of different
convective heat outputs

Heat output (kW) and diameter (cm)	Detection time (s): Horizontal distance of fire from laser beam (m): 0	6
50 kW (46 cm)	15-30	23, 15-30
70 kW (56 cm)		20, 20-30
140 kW (71 cm)	9 (average)	19 (average)
250 kW (92 cm)	10	20, 15-20

A further 15 s, would, in practice, be added to the detection times in Tables 3 and 4, since it has been found that delaying the alarm indication until the fire signal has persisted for about 15 s will provide protection against possible false alarms due to transient vibrations of the laser mounting etc.

DISCUSSION OF RESULTS

If an $^F/A$ ratio of at least 4 is required for good discrimination of fire from ambient, then Tables 1 and 2 show that a 71 cm diameter methylated spirits fire (140 kW) anywhere in the laboratory could be detected. In the most favourable circumstance, i.e. the fire nearly directly beneath the laser beam, a fire of only 50 kW (46 cm diameter) would be required for detection. If a worst-case $^F/A$ of 2.5 were acceptable, a 70 kW fire (96 cm diameter) anywhere in the laboratory could be detected. The time required to detect these fires would be in the range 25 to 45 s, including the delay time referred to above.

These sizes of fire may be compared with the size of fire required to operate point-type heat sensitive detectors. The latter size of fire depends on the rate of development of the fire[4]. A heat detector of maximum sensitivity permitted by BS.3116 requires, for operation, a fire of between 50 and 500 kW if the detector is on a 12 m high ceiling and directly above the fire (see Appendix 1). If the same detector is at a distance of 4.6 m (15 ft) or more from the fire axis, the sizes of fire required for an alarm are increased by a factor of about 2. The time from ignition of the fire to its detection can range from 25 s to 34 min. At the other extreme, a detector with the lowest sensitivity specified for a Grade I detector requires a fire of at least 760 kW, assuming the detector is on a 12 m high ceiling. In practice, heat-sensitive detectors are set at a sensitivity approximately midway between the highest and lowest sensitivity specified in the Standard.

It is seen, therefore, that, in general, the sensitivity of a laser beam fire detection system is better than that of the most sensitive practical heat detector. Furthermore, it has been estimated by Lawson[2] that the decrease of sensitivity with ceiling height is less rapid with the laser beam system than with other types of heat-sensitive detectors. In addition, the laser beam system can be readily adapted to act simultaneously as a smoke detector[2].

The data from the present experiments has been used in designing an electronic circuit for an experimental laser beam fire detection system. This circuit is described in Appendix 2.

SUMMARY AND CONCLUSIONS

The sensitivity to fire of a laser beam fire detection system has been studied. In this system, fire is detected by means of the time-varying deflections of the laser beam which are caused by the hot combustion gases in turbulent flow beneath the ceiling. Frequency analyses of the output from the photocell on which the laser beam is incident have shown that fire can be best discriminated from other heat sources by selecting that part of the photocell's output which is in the range 40-80 Hz.

Allowing a safe margin for the avoidance of false alarms, a 140 kW fire at any position in a building 12 m high, 15 m x 41 m long, can be detected in less than 45 s. This performance compares very favourably with that of a rate of rise heat detector of the maximum sensitivity specified in BS 3116.

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(1) LAWSON, D. I. United Kingdom Patent 1189297/70.

(2) LAWSON, D. I. A Laser Beam Fire Detection System. Fire Research Note No. 824, April 1970.

(3) PICKARD, R. W., BIGMORE, R. H. and HIRD, D. Gas Temperatures Beneath Ceilings. Inst. Fire Engng. Q. 24 (55), 230-59, 1964.

(4) British Standard 3116 : Part 1 : 1970. Automatic Fire Alarm Systems in Buildings. Part 1. Heat Sensitive (Point) Detectors.

APPENDIX I

SIZE OF FIRE REQUIRED FOR DETECTION BY (POINT) HEAT-DETECTORS

With a detector having the highest sensitivity permitted by BS.3116, the minimum size of fire that can be detected is a fire which gives a rate of temperature rise at ceiling level of about 10°C/min. (The temperature is assumed to rise linearly with time). The fire will be detected when this rate of temperature rise has persisted for 30 s, that is, when the temperature at ceiling level has risen by 5°C. The size of fire at detection may be calculated from Pickard's[1] approximation of Yih's equation[2]

$$Q = \frac{4.18\,\theta_c^{3/2}\,(h + 1.3\,d)^{5/2}}{10^3\,(2 \times 10^3)^{3/2}} \qquad (1)$$

in which Q = size of fire, kW

θ_c = temperature rise above fire, °C

h = ceiling height, cm

d = fire diameter, cm (1.3 d assumed 50 cm)

However, Yih's equation applies to sources producing heat at a constant rate. For a developing fire, the time taken for the combustion products to travel from fire to ceiling must be taken into account. For a 12 m high ceiling, this time is about 15 s (Tables 3 and 4). Thus, although the fire is detected when the ceiling temperature has risen 5°C, the heat output of the fire at detection is that corresponding to a steady source of heat which gives a temperature rise on the ceiling of 7.5°C. Substituting $\theta_c = 7.5$°C into equation (1) gives $Q = 52$ kW for a 12 m high ceiling. For the same detector situated more than 4.6 m horizontal distance from the fire axis, a fire 2.2 times as great is required for an alarm[1].

If the fire is slowly developing so that the rate of temperature rise at the ceiling is 1°C/min, the fire will be detected (by a detector having the maximum permitted sensitivity) when the ceiling temperature has risen 34°C. This corresponds to a fire of 500 kW beneath a 12 m high ceiling.

For a grade I detector having the minimum specified sensitivity, a temperature rise at ceiling level of about 45°C is required for an alarm, and this is nearly independent of the rate of fire development. The corresponding fire size is 760 kW, assuming a 12 m ceiling.

REFERENCES

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APPENDIX 2

CIRCUIT FOR EXPERIMENTAL LASER BEAM FIRE DETECTION SYSTEM

by

B. K. Ghosh

The circuit of Fig.7 is a tuned amplifier whose output triggers an alarm-indicator via an SCR. A time-delay is incorporated so that the required signal level for alarm must persist for about 15 s.

Details of the circuit are as follows. The photocell signal is fed to a low-noise pre-amplifier, having a gain of about 200, formed by transistors TR1 and TR2. The load of TR2 is a potentiometer which is used to control the output available to the next stage. The output of the pre-amplifier is fed to a filter-amplifier formed by TR3 and TR4. The filter is a band pass type with a centre frequency of 70 Hz and 3 db points at 60 and 80 Hz. This stage has a gain of 5.

The output of the filter is further amplified (X20) by TR5 and then rectified. The rectified signal is applied to a time-delay network (comprising the 220μF capacitor and the 68kΩ resistor) and then to an SCR which switches the alarm indicator L1. The delay depends not only on the time constant RC but also on the amplitude of the signal so that the time delay is reduced in the case of a larger fire. A UJT (TR9) monostable circuit resets the alarm after one minute.

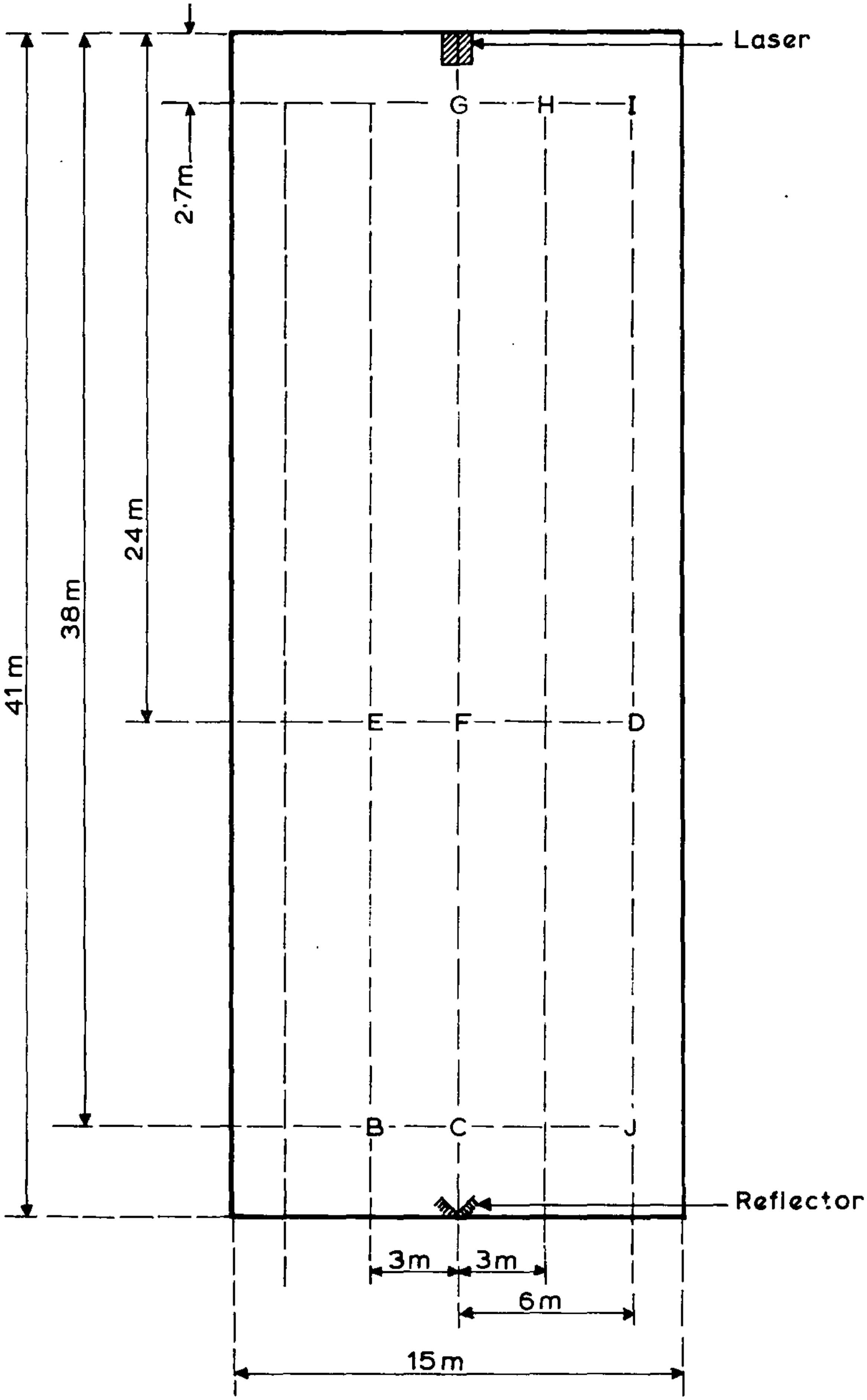


FIG. 1. POSITIONS OF FIRES ON GROUND IN 12m HIGH LABORATORY

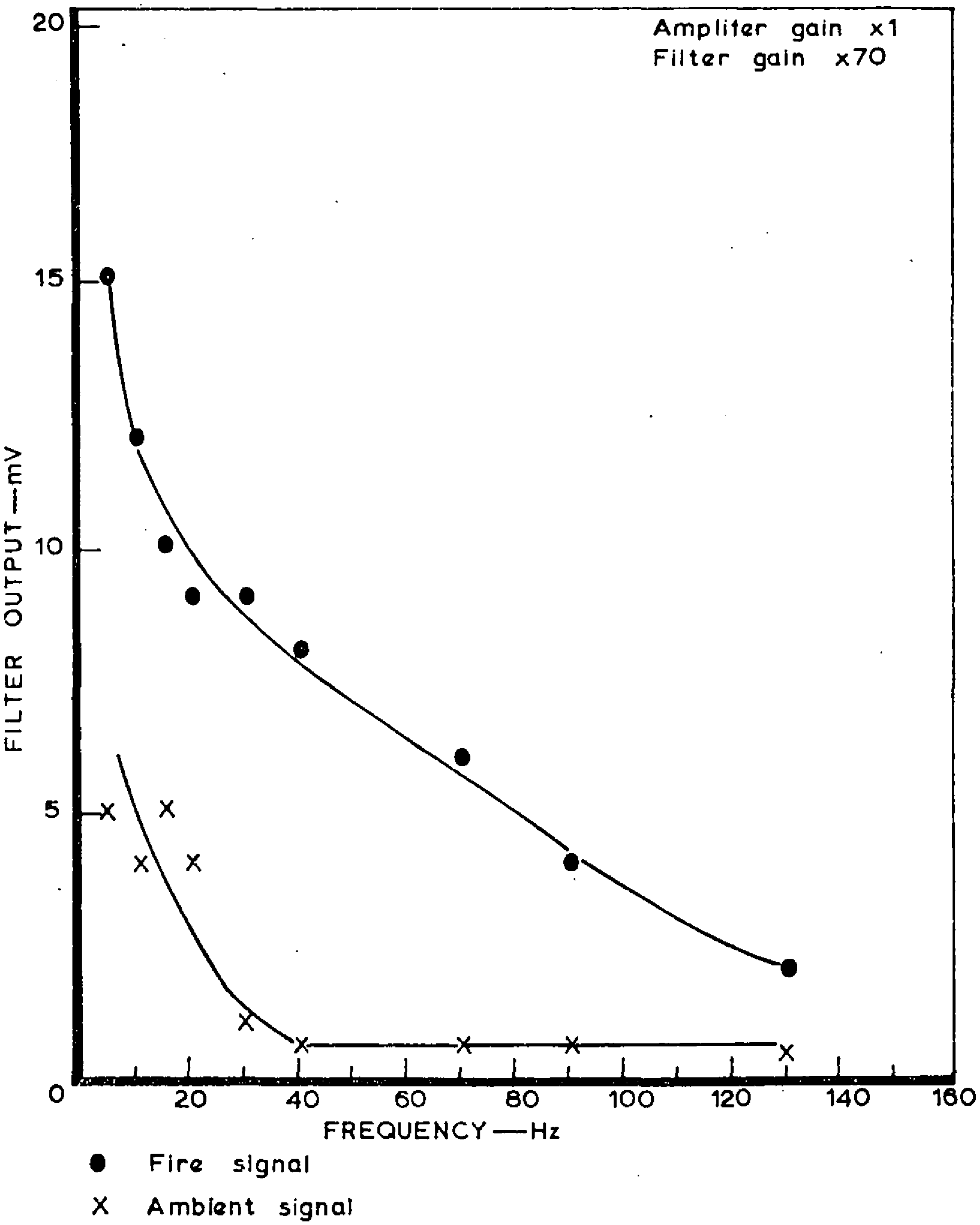


FIG. 2. FREQUENCY ANALYSES OF FIRE AND AMBIENT SIGNALS: 140 kW FIRE AT POSITION F

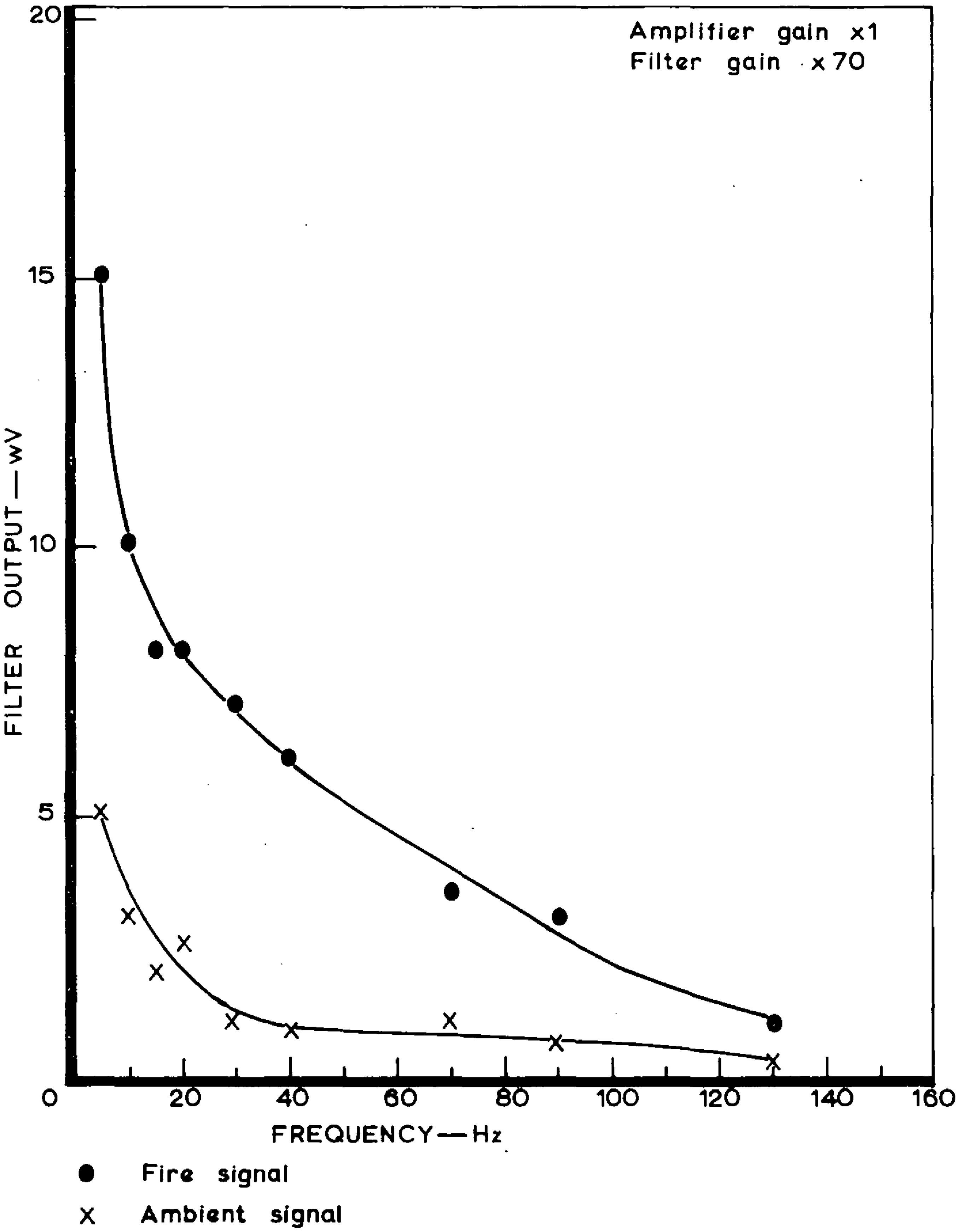
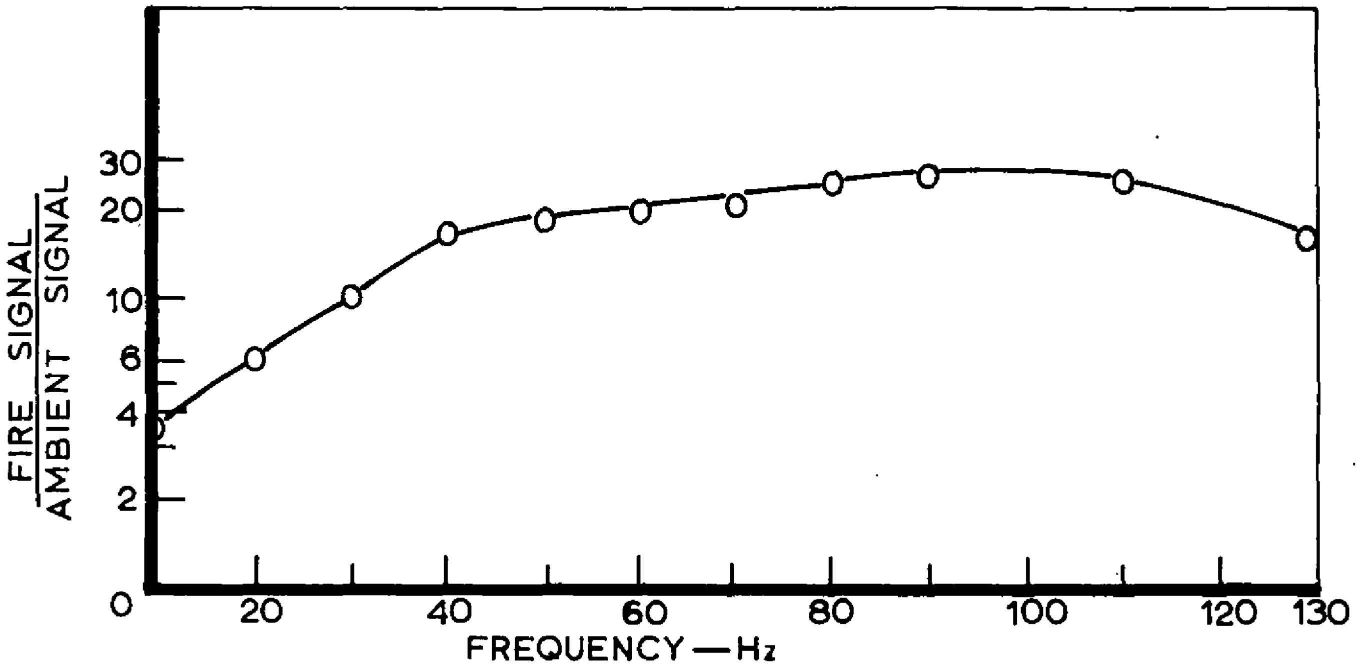
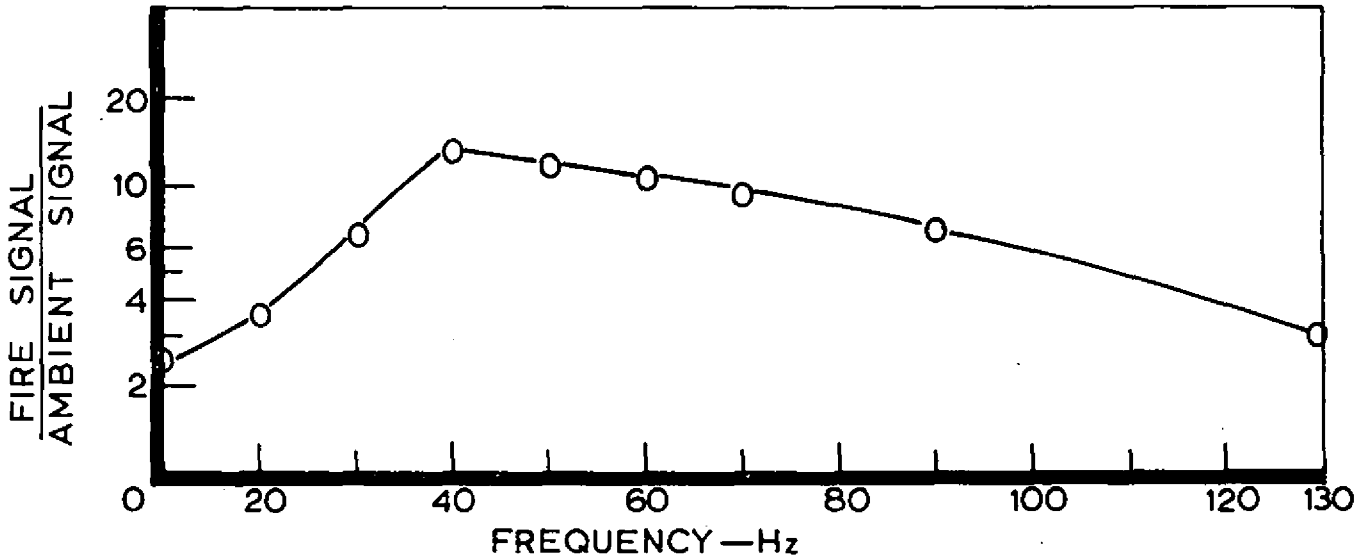


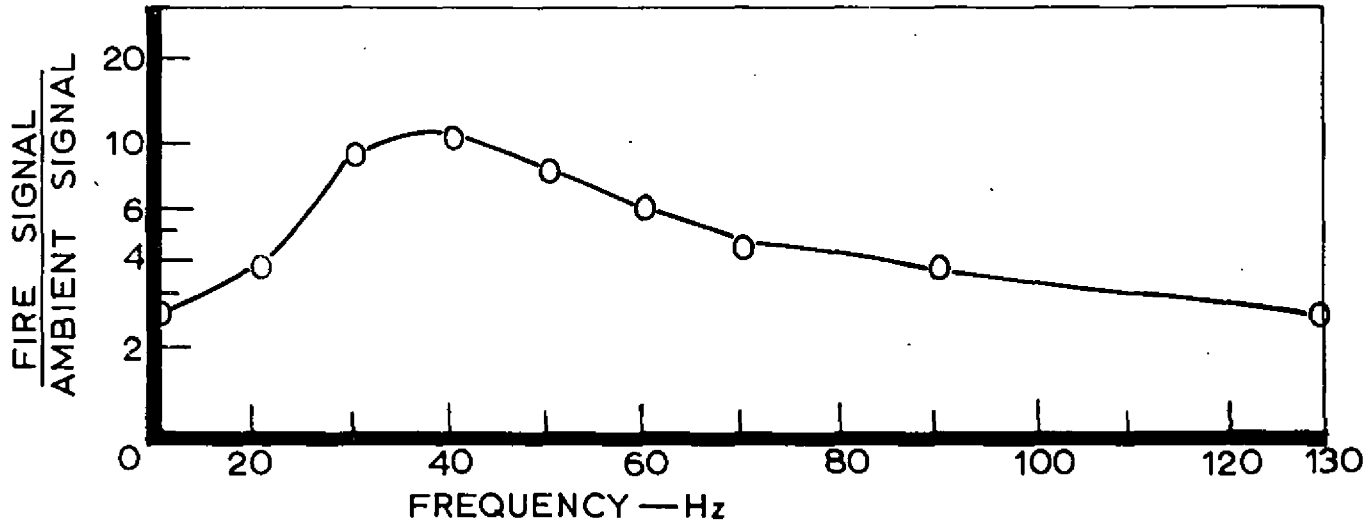
FIG. 3. FREQUENCY ANALYSES OF FIRE AND AMBIENT SIGNALS : 140 kW FIRE AT POSITION J



(a) 250 kW (92 cm diameter) fire

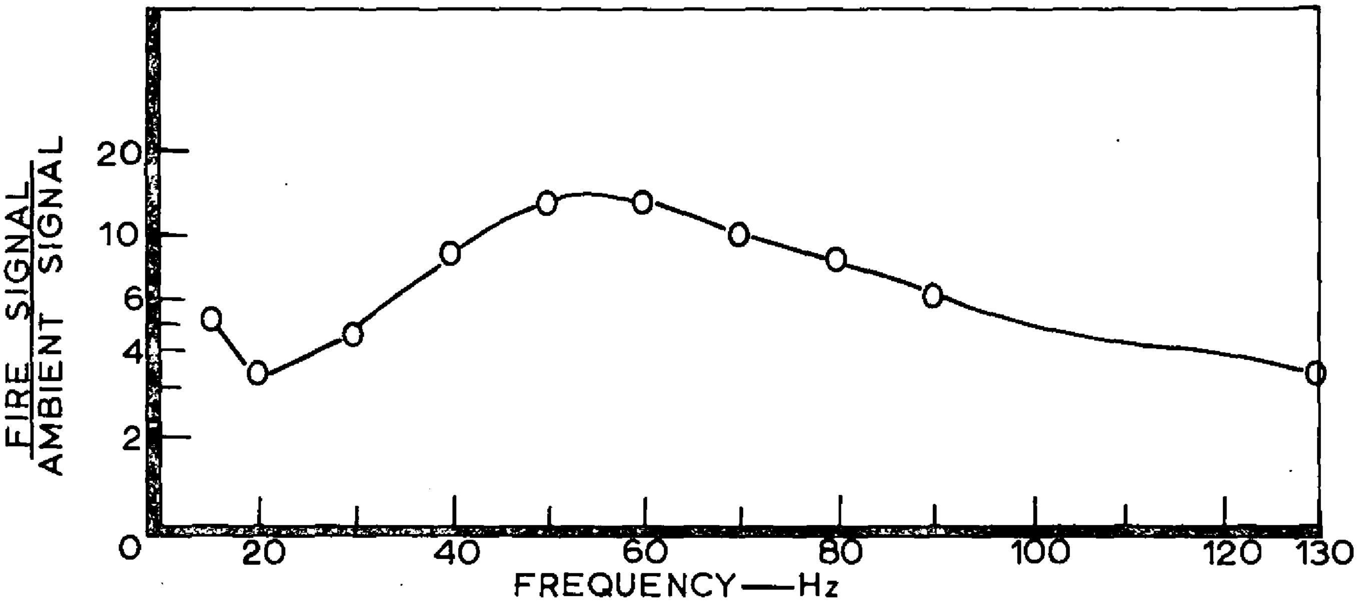


(b) 140 kW (71 cm diameter) fire

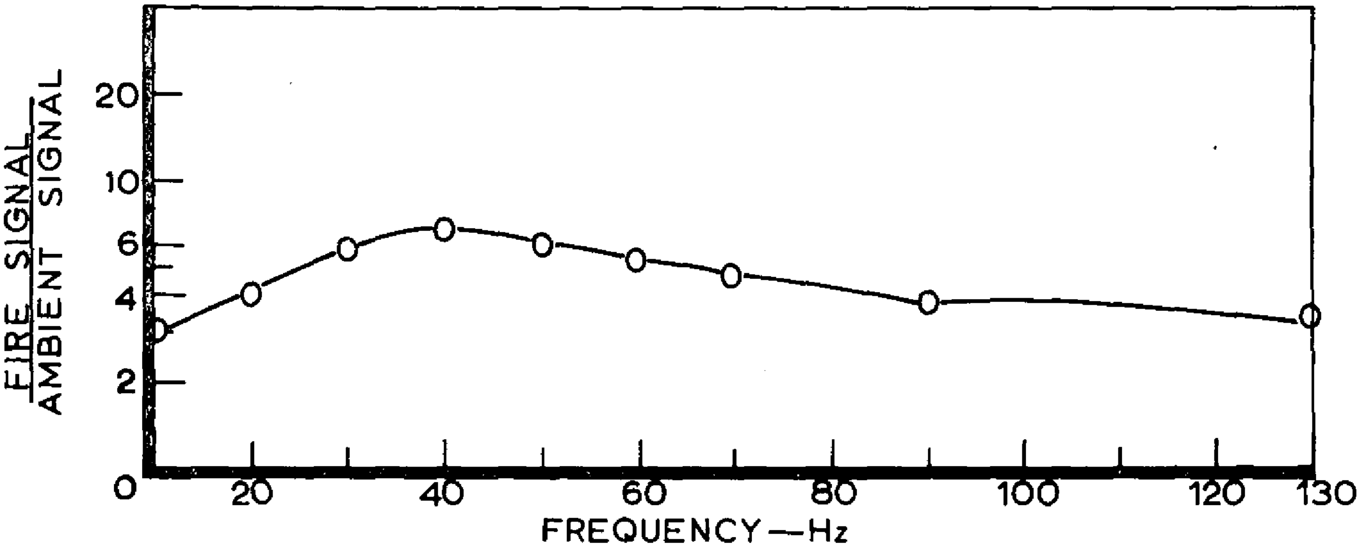


(c) 50 kW (46 cm diameter) fire

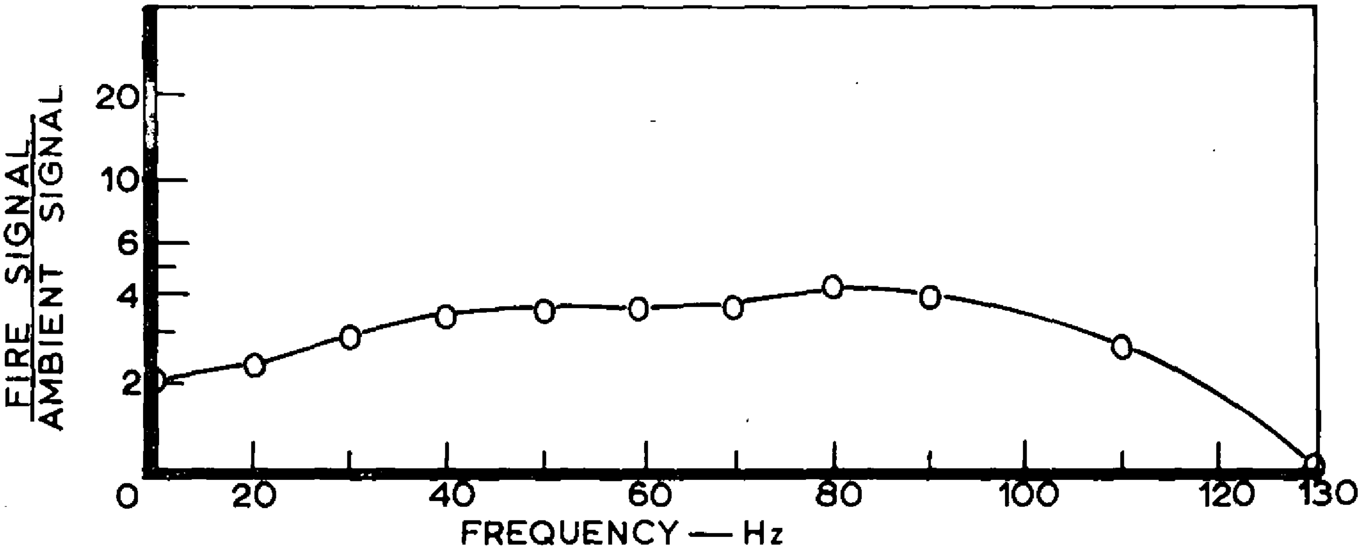
FIG. 4. RATIO OF FIRE AND AMBIENT SIGNALS AS A FUNCTION OF FREQUENCY FOR FIRES AT POSITION F



(a) 250 kW (92 cm diameter) fire



(b) 140 kW (71 cm diameter) fire



(c) 70 kW (56 cm diameter) fire

FIG. 5. RATIO OF FIRE AND AMBIENT SIGNALS AS A FUNCTION OF FREQUENCY FOR FIRES AT POSITION J

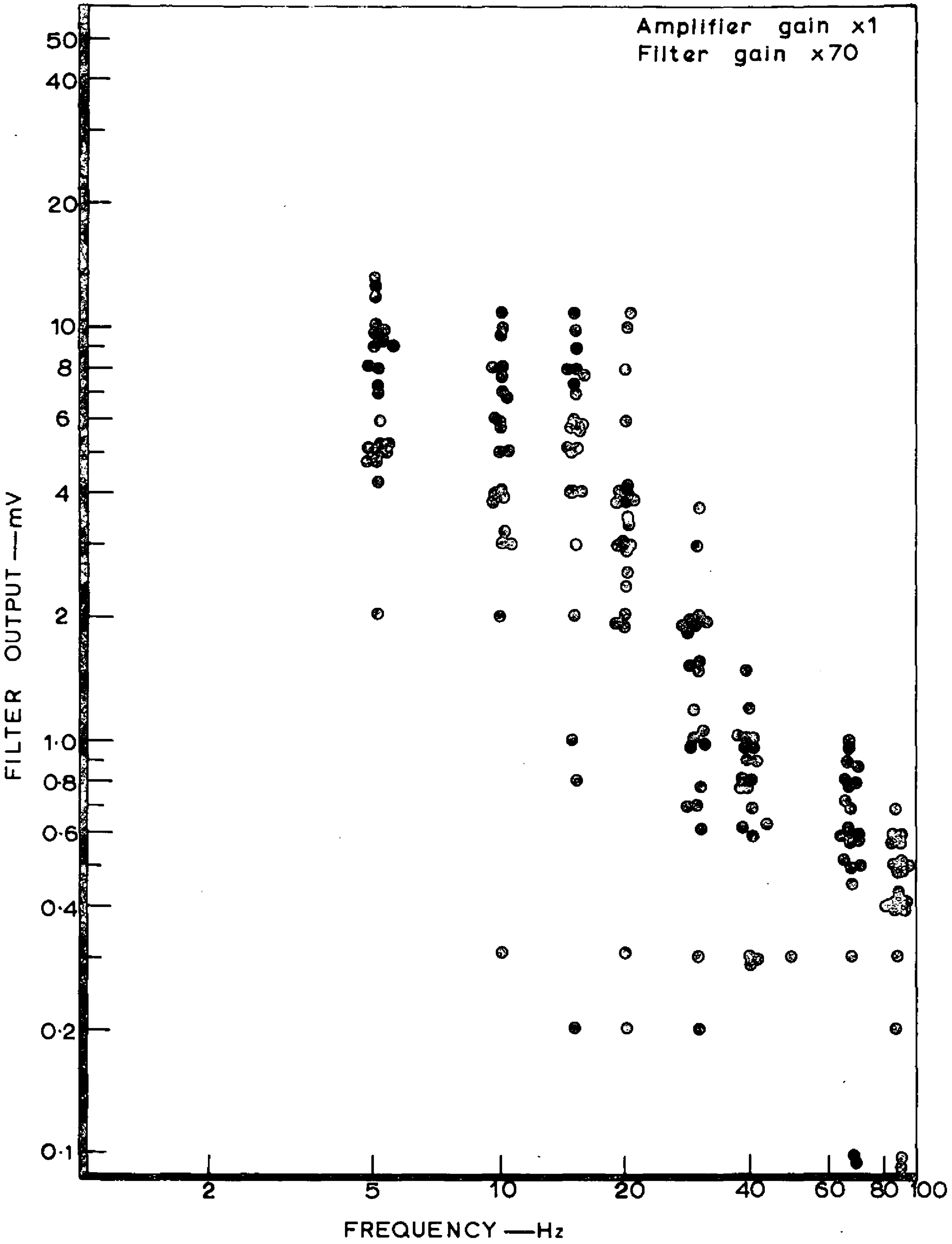


FIG. 6. AMBIENT SIGNALS AS A FUNCTION OF FREQUENCY

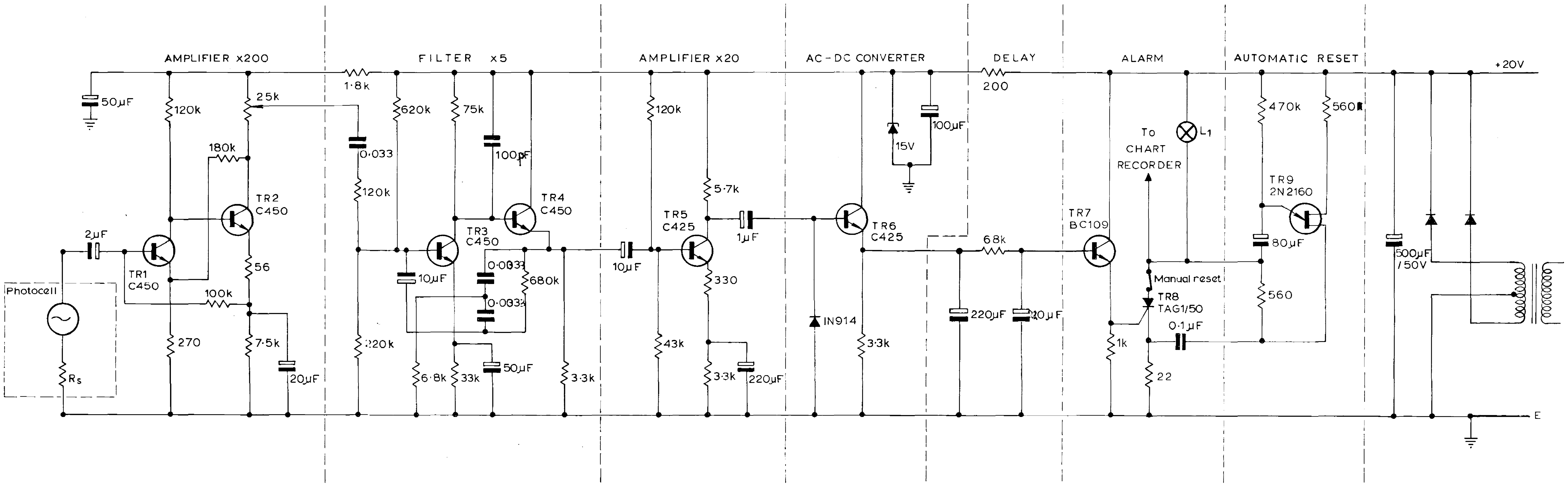


FIG. 7 CIRCUIT FOR USE WITH AN EXPERIMENTAL LASER BEAM FIRE DETECTION SYSTEM

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