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The Hot-Wire Anemometer for Turbulence Measurements

Part II

by

B. Wise, M.A., and D. R. Stewart, D.Phil.

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The Hot-wire Anemometer for Turbulence Measurements

Part II

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B. Wise, M.A. and D. R. Stewart, D.Phil.

Oxford University Engineering Laboratory
O.U.E.L. 54

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SUMMARY

An account is given of some experimental work undertaken to test the theory of operation of a hot-wire anemometer with radio-frequency heating, which has been given in a previous paper (Ref.1)

1. Introduction

In a previous paper (Ref.1) an analysis has been given of the operation of a hot-wire anemometer both with direct-current heating and radio-frequency current heating. The improvement in the response to high-frequency velocity variations obtained by positive feedback was described, and in particular it was suggested that a tuned-anode oscillator with mutual-inductance feedback would provide a suitable embodiment of the theory. Some details of experiments which have been carried out along these lines are given in Section 2, together with some of the results obtained. A comparison

of/

of this system with the conventional constant-current system is given in Section 3. In Section 4 the possibility of using two types of heating, originally considered in Section 5 of the previous paper, is again referred to.

2. A description of the apparatus employed, and some results obtained

2.1. The simple oscillator with inductive feedback

The simplest circuit which has been used for heating the wire is shown in Fig. 1, where R_1 represents the hot wire. The tuning capacity C was 300 pF, and various values of L_1 and L_2 were tried.

An audio input signal was obtained from a beat-frequency oscillator, and fed into the hot wire through a resistance of 1,000 ohms. A diode demodulator was coupled to the tuned circuit, and the demodulated signal amplified. As was shown in Ref. 1, the demodulated response is at twice the input frequency. A Marconi wave-analyser was used to pick out and measure the amplitude of the response over a range of frequencies. It was shown in Ref. 1 that this response varies with frequency in the same way as the response of the wire to variations in air velocity. A typical response curve is shown in Fig. 2. For this wire, $R_a = 9.5$ ohms, $R_1 = 14$ ohms, and the time-constant in constant-current operation was 0.5 m sec. Referring to the equivalent circuit of Fig. 11 in Ref. 1, these values give $R_b = 13.3$ ohms and $C = 37.6\ \mu F$. L was equal to 49 μH, so that a peak is to be expected at a frequency of about 2,600 c/s, compared with the observed value of 3,000 c/s. The gain at the peak over the zero-frequency response was found to vary considerably with the mutual inductance employed, i.e. with the degree of feedback. It was shown in Ref. 1 (See Fig. 12 and the associated calculations) that a very small change in R_c produced a large change in the amplitude of the peak response. It is assumed therefore that in practice the effective value of R_c is not necessarily quite equal to R_1, and as a result the damping of the response varies with M. Another variable circuit parameter which was found useful was a resistance in the cathode circuit, not shown in Fig. 1, which was by-passed at radio frequencies by a condenser.

The effect of different values of the inductance is shown in Fig. 3, where L was 100 μH for curve 1 and 49 μH for curve 2.

The circuit was found to behave in a similar manner with various other types of valve.

2.1.1. Square-wave monitoring

In order to provide rapid means of adjusting the circuit for the best response, a square-wave input was employed, and the response observed on a cathode-ray oscillograph. This input voltage was arranged to vary between zero and some positive voltage, and as it was obtained from the beat-frequency oscillator, its frequency was known, and it could be varied. By this means it was found an easy matter to adjust the mutual inductance and cathode resistance to give the most faithful response, and this was found to correspond with a slight peaking of the response curve as measured with a sinusoidal input voltage. To illustrate this, Fig. 4 shows four photographs, taken with a 400 c/s square wave, for a wire under similar conditions to those which gave rise to curve 1 of Fig. 3. Here the feedback was gradually increased from (a) to (d). The most satisfactory response would be given by curve (b). The poor shape of the comparison wave in these photographs is due to distortion in the oscillograph amplifier, which was inferior to the amplifier used for the actual signal.

Fig. 5 shows some similar photographs taken with the wire in a turbulent stream of air.

2.1.2. An audio oscillation

It has sometimes been found possible to adjust the circuit so that the response becomes infinite at some frequency, i.e. the radio-frequency voltage is modulated at an audio frequency with no input signal. When this happens the modulation envelope is sinusoidal, so that there is no question of its being a relaxation oscillation. The occurrence of this phenomenon can be explained, on the basis of the equivalent circuit of Fig. 11, (Ref. 1) if it is assumed that the effective value of R_c is in these circumstances somewhat greater than R_1. Since C in Fig. 11 (Ref. 1) depends on the mean velocity, the frequency of this audio oscillation varies with mean velocity, and this might provide a useful device for the measurement of velocity, as the relation between frequency and velocity, for any given circuit, is found to be stable with time. An experimental curve is given in Fig. 6, and from this it will be seen that the variation is most rapid at low velocities.

As is mentioned later, in Section 4, an audio oscillation can easily be induced if direct-current heating is used as well as radio-frequency current heating.

2.2. The transitron oscillator

Theory indicates that the smaller the value of the tuned-circuit inductance the greater will be the response band-width, but it was found difficult to use small inductances with the simple circuit of Fig. 1. In consequence, a transitron type of oscillator was tried, with an inductance of 4.8 μH, and a tuning capacity of 60 pF, giving a frequency of about 9 Mc/s. The circuit is shown in Fig. 7 and typical responses in Fig. 8. The amplitude of radio-frequency oscillation could be controlled by means of the suppressor-grid voltage, and it was found that the response became more peaked as the oscillation amplitude fell, until with 24 volts bias on the suppressor grid an audio oscillation occurred at 10,400 c/s. It will be seen from Fig. 8 that a reasonably flat response was here obtained up to 20,000 c/s, which is the best achieved so far. It was found necessary, however, with this circuit, greatly to exceed the allowable screen dissipation of an EF50, so that for this reason it is not considered really practicable. The CV116, 6J7 and 6K7 types of valve were also tried as transitrons without success.

2.3. Push-pull oscillator

The most successful oscillator employed so far was of a push-pull type, as shown in Fig. 9, the frequency of oscillation being 8 Mc/s. The amplitude was varied by means of the control-grid bias. A typical response is shown in Fig. 10.

3. A comparison with the compensated constant-current system

One of the advantages of any hot-wire system, such as is described here, which attempts to approximate to the ideal constant-temperature condition, appears to lie in the fact that the signal-to-noise ratio is far higher at high audio frequencies than in the conventional compensated constant-current system. In this latter system the signal obtained from the wire, due to any given amplitude of turbulence, falls continuously according to a simple time-constant law, i.e. at the rate of 6 dB per octave, and this is compensated for by an equal time-constant in the amplifier. The noise which is significant is that produced in the first stage of the amplifier, and the signal-to-noise ratio over any frequency band is fixed by this noise and the amplitude of signal produced. Thus the signal-to-noise ratio is much poorer for high-frequency turbulence than for low frequencies, owing to the fall in signal amplitude. This consideration is especially serious by virtue of the fact that the signal due to random turbulence is of the same

nature/

nature as noise. In our feedback system, however, the signal does not fall off until a frequency of the order of 10 kc/s is reached, so that for measuring small amplitudes of high-frequency turbulence it would appear to be far superior to the compensated constant-current method.

Another advantage of the radio-frequency system is that the response curve changes very little with mean velocity, whereas in the compensated constant-current system the compensating circuit required depends on the velocity. To illustrate this, curves are given in Fig. 11 showing the variation of the response curve with velocity for a wire in the push-pull oscillatory circuit of Fig. 9.

4. Negative feedback

It was suggested in Ref. 1 that, when two types of heating are employed, the possibility of broadening the response band-width arises by the use of negative feedback. The theory of this has been further developed, and some experiments have been made. The two types of heating may be direct-current and radio-frequency current or two radio-frequency currents of different frequency. Of these, the former was found the easier to implement in practice, and a typical circuit is shown in Fig. 12.

It can easily be shown that the simple feedback employed in this circuit has the effect of raising the frequency of the peak response but also of raising its magnitude, so that an audio-frequency oscillation may be produced with quite a small amount of feedback. This phenomenon is referred to in Section 2.1.2. To avoid this, the response before application of feedback must be over-damped. This can be done by reducing the radio-frequency feedback until the circuit ceases to be self-oscillatory, and then introducing a voltage into it from another oscillator. This ensures that, in Fig. 11 (Ref. 1), R_c is definitely less than R_1. Another way of reducing the peak amplitude is to feed back additionally a differentiated signal. The possibility of feedback with a doubly-differential signal has also been considered. Detailed theory will be given if practical results appear to justify it.

The broadening of the band-width which results from negative feedback is necessarily accompanied by a decrease in the actual signal level for any given turbulence amplitude, and it would appear therefore that no improvement in the signal-to-noise ratio is effected. It is possible that for some applications the high-frequency turbulence level may be sufficiently high to make this consideration irrelevant, and it is intended to carry the investigation further in this direction.

5. Conclusion

Some embodiments of the theory of radio-frequency heating of a hot-wire anemometer, as given in Ref. 1 have been described, and the results indicate that the system should be useful in the measurement of high-frequency turbulence.

Since this paper was written, our attention has been drawn to two papers (Refs. 2, 3) describing work in which radio-frequency heating of hot wires has been employed. There appears, however, to be little similarity between this work and the systems described here.

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References

1. The hot-wire anemometer for turbulence measurements.
Part I.- B. Wise. O.U.E.L. 52. Presented by Prof. A. Thom.
C.P.273. February, 1951.

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3. Sur l'utilisation des courants de haute fréquence pour le chauffage des anémomètres à fil chaud.- M. Tournier, P. Laurenceau, J. - J. Heubès et Seigneurin. L'O.N.E.R.A. Janvier-Fevrier, 1951.

GMW

FIGS, 1 & 2.

FIG.1.

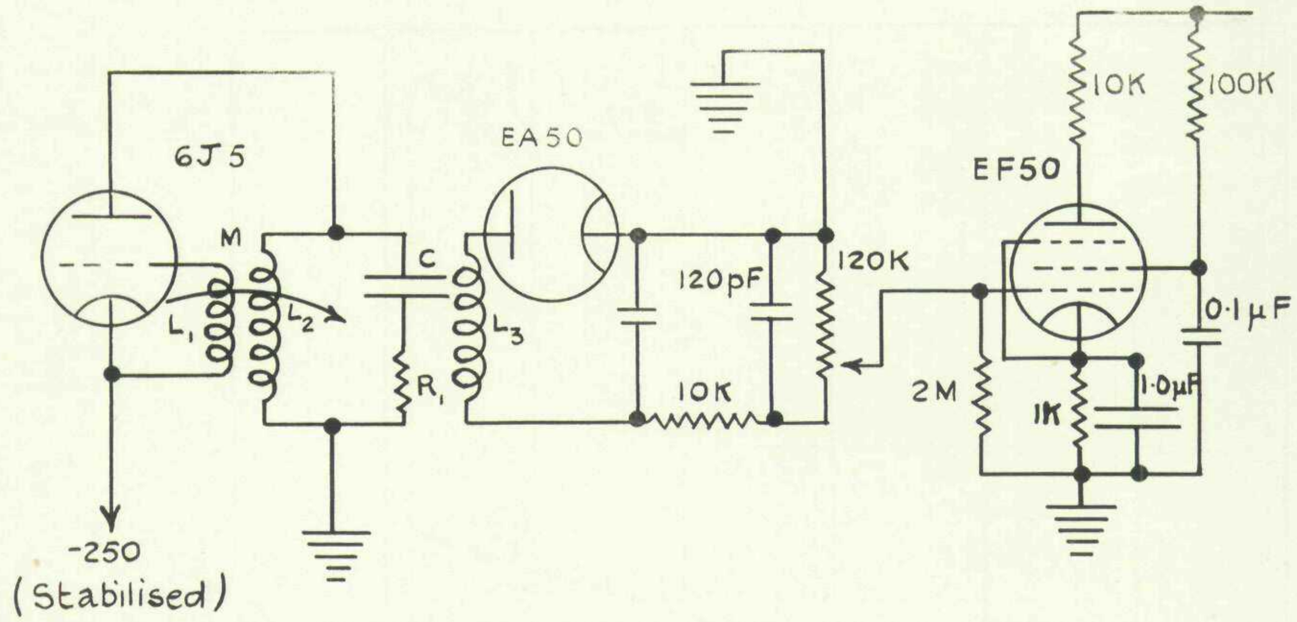
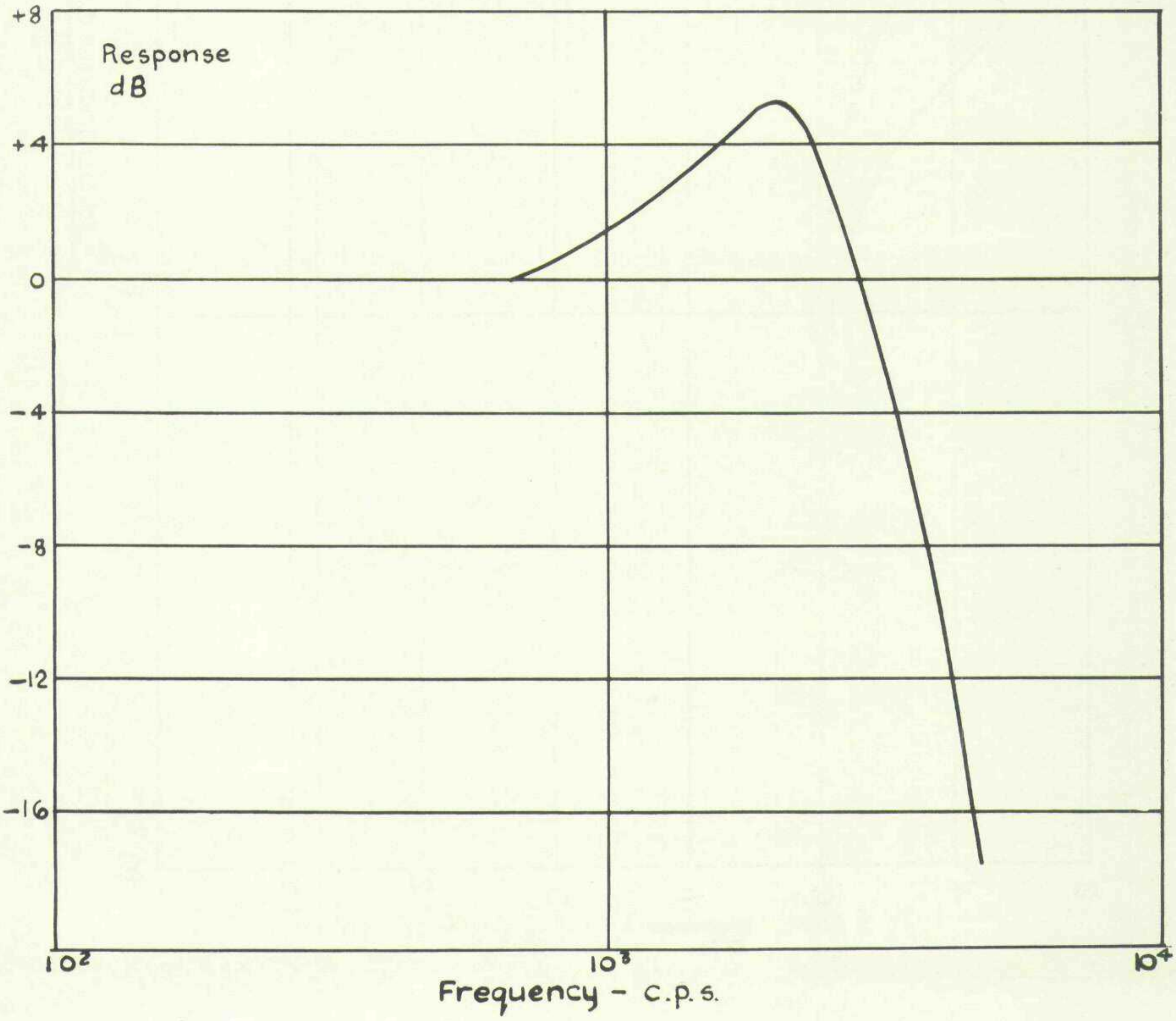


FIG. 2.



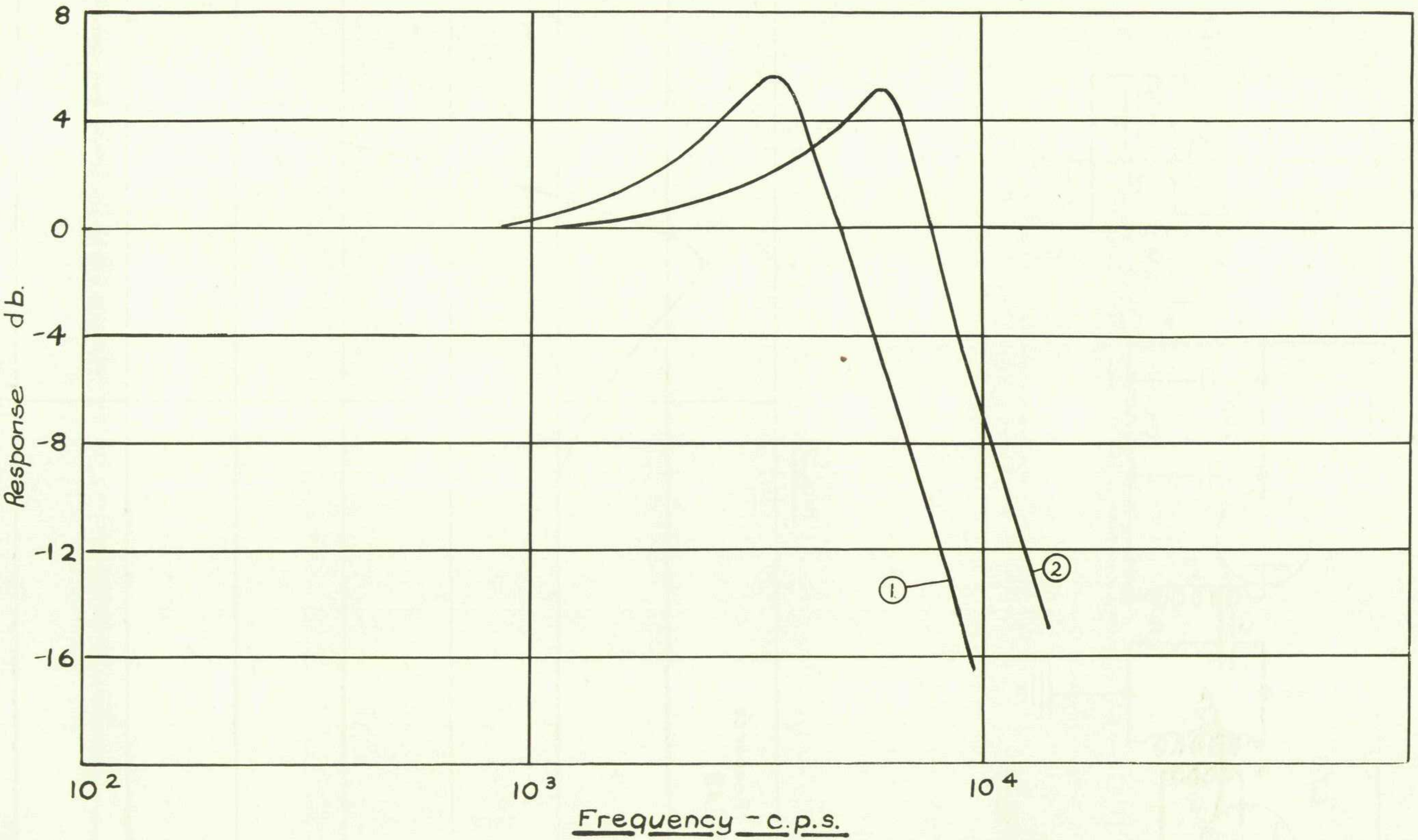
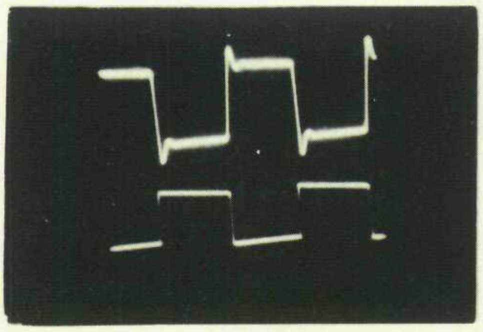
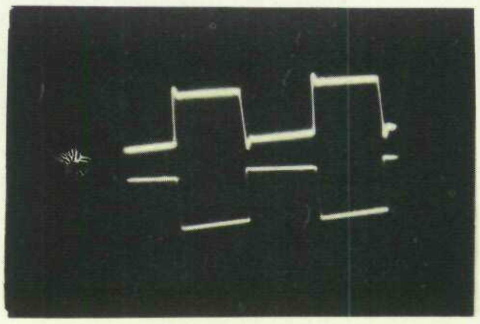


FIG. 3.

FIG. 4.



(a)



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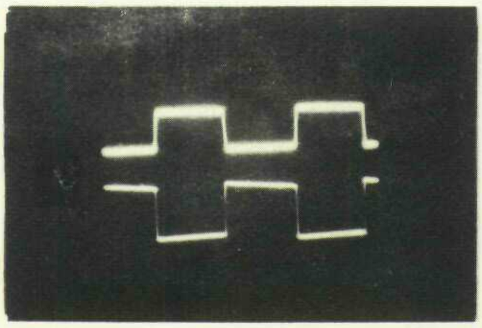
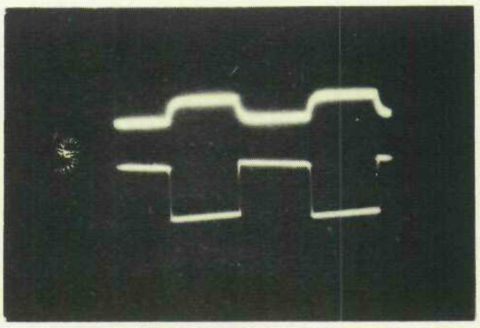
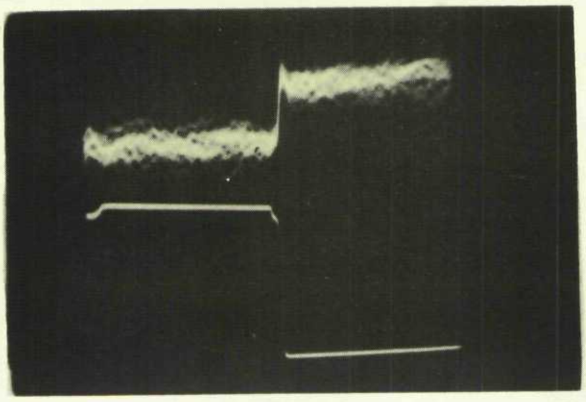


(c)

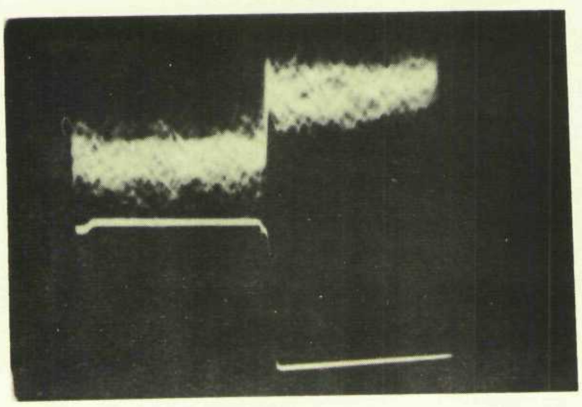


(d)

FIG. 5.



(a)



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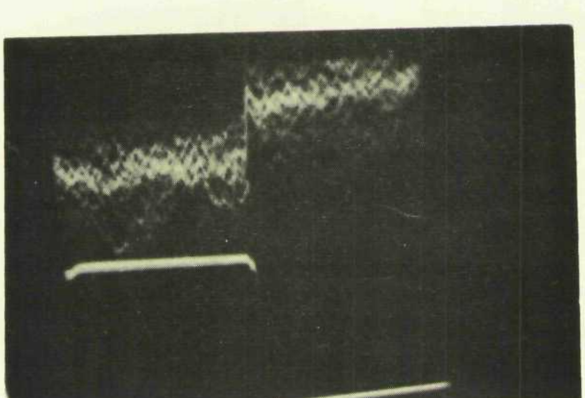
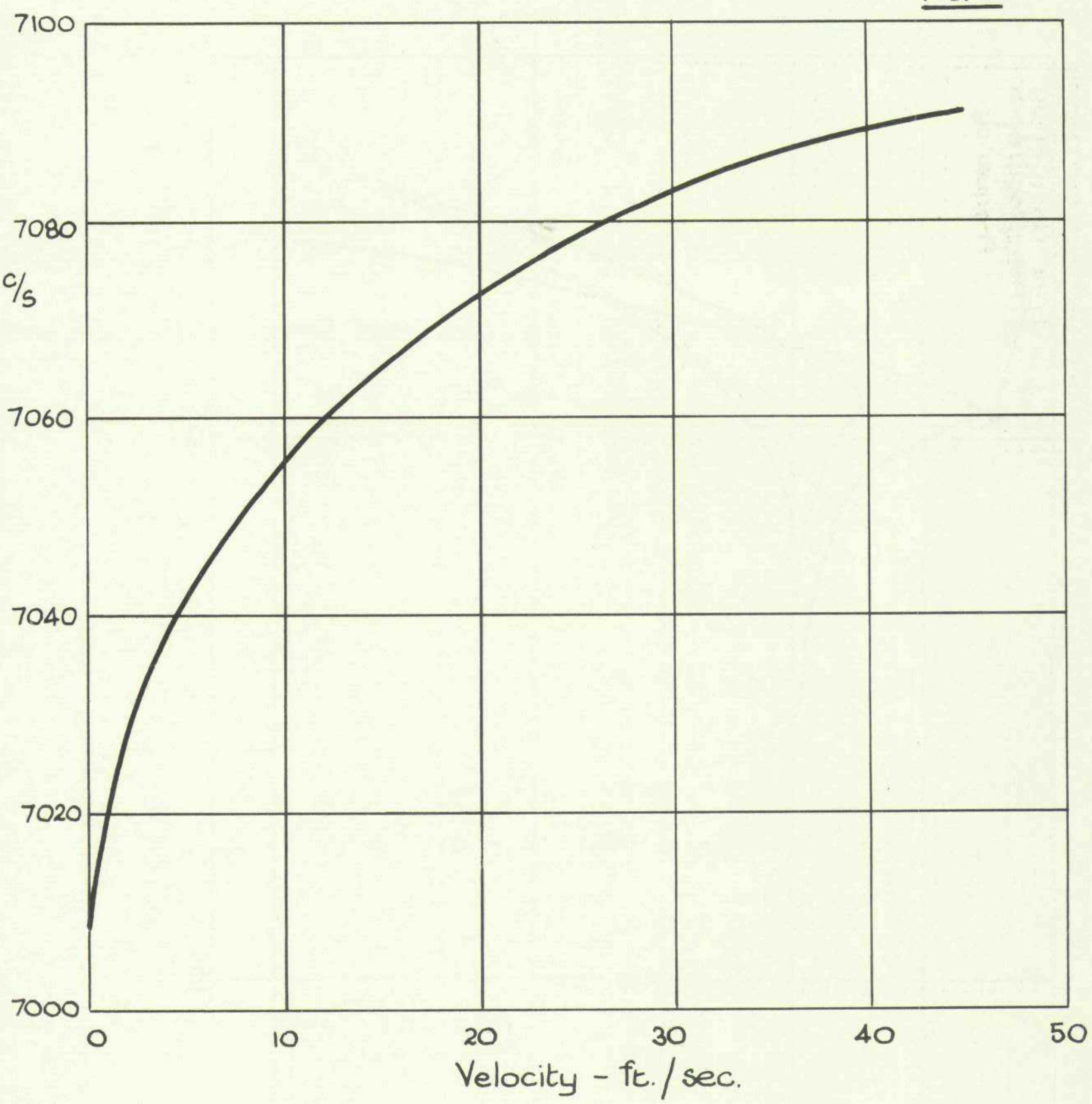


(c)

FIGS 6, 7.

FIG. 6.



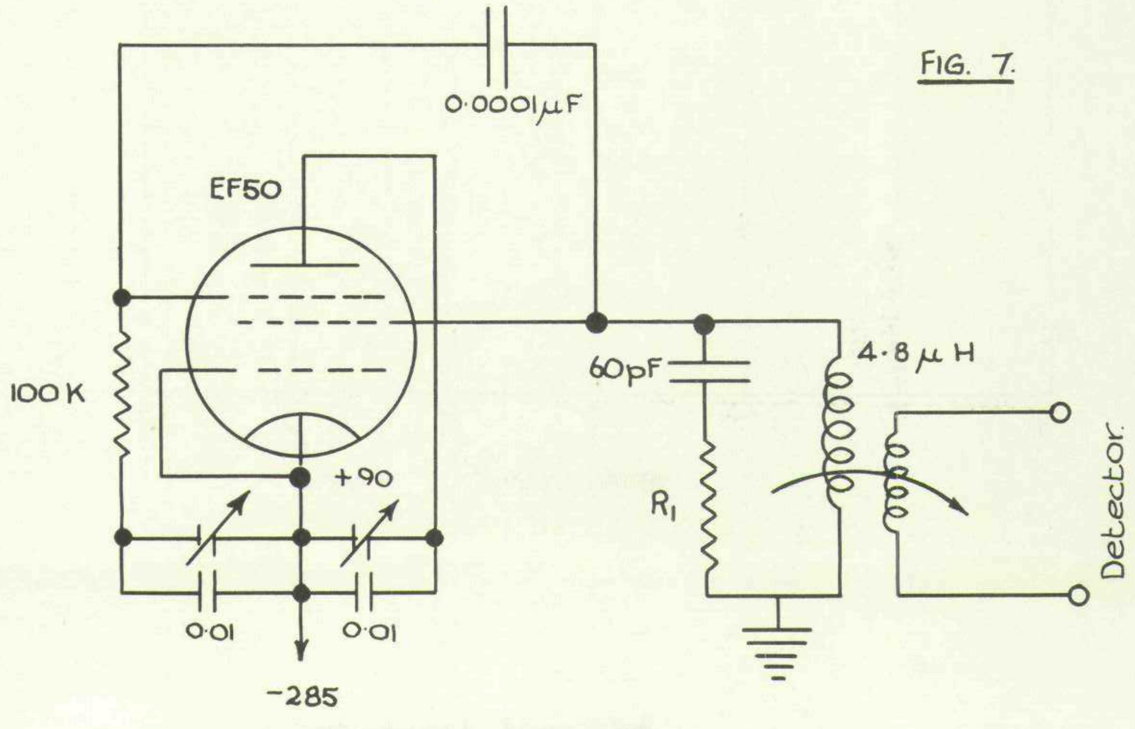


FIG. 7.

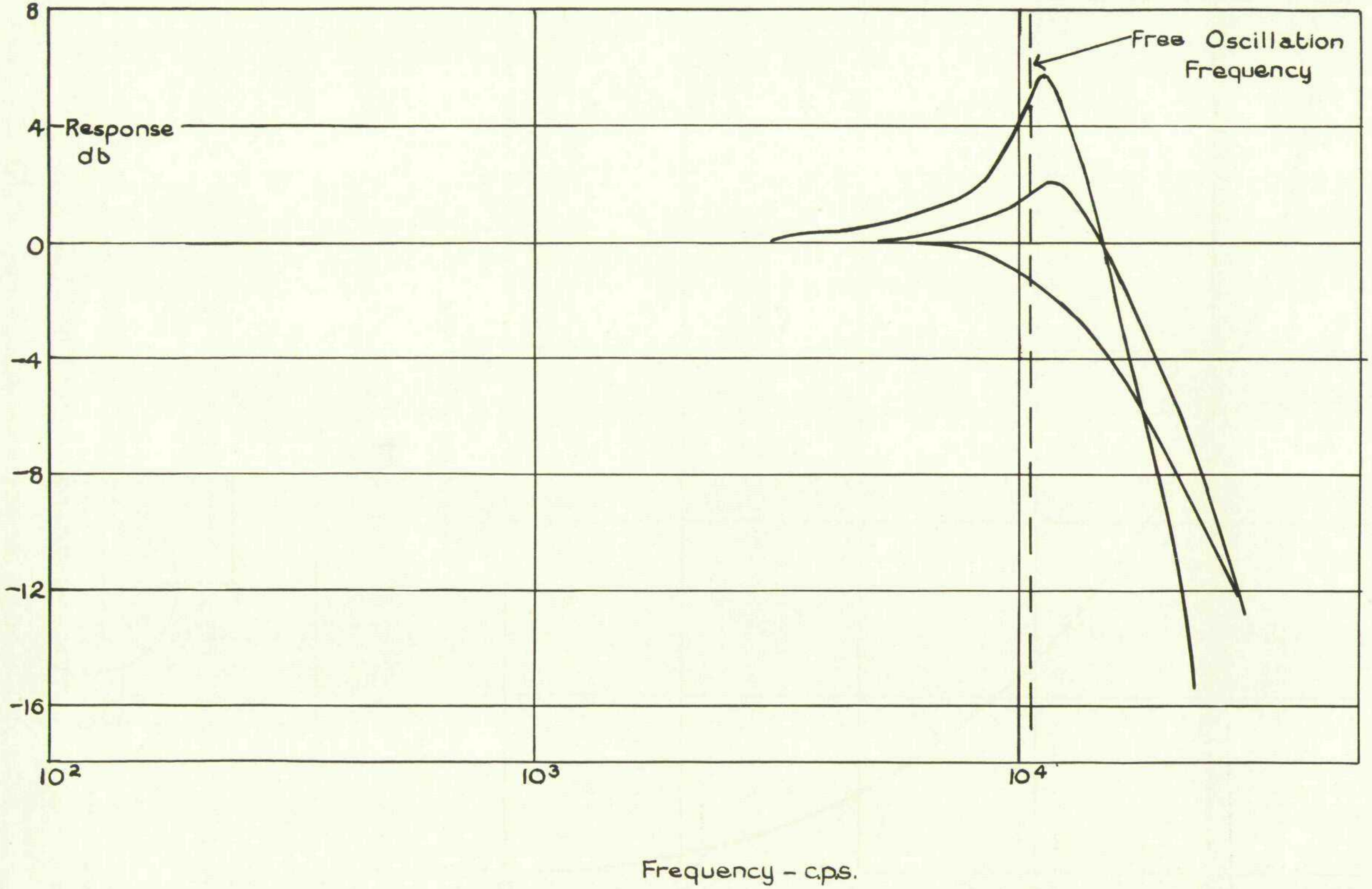
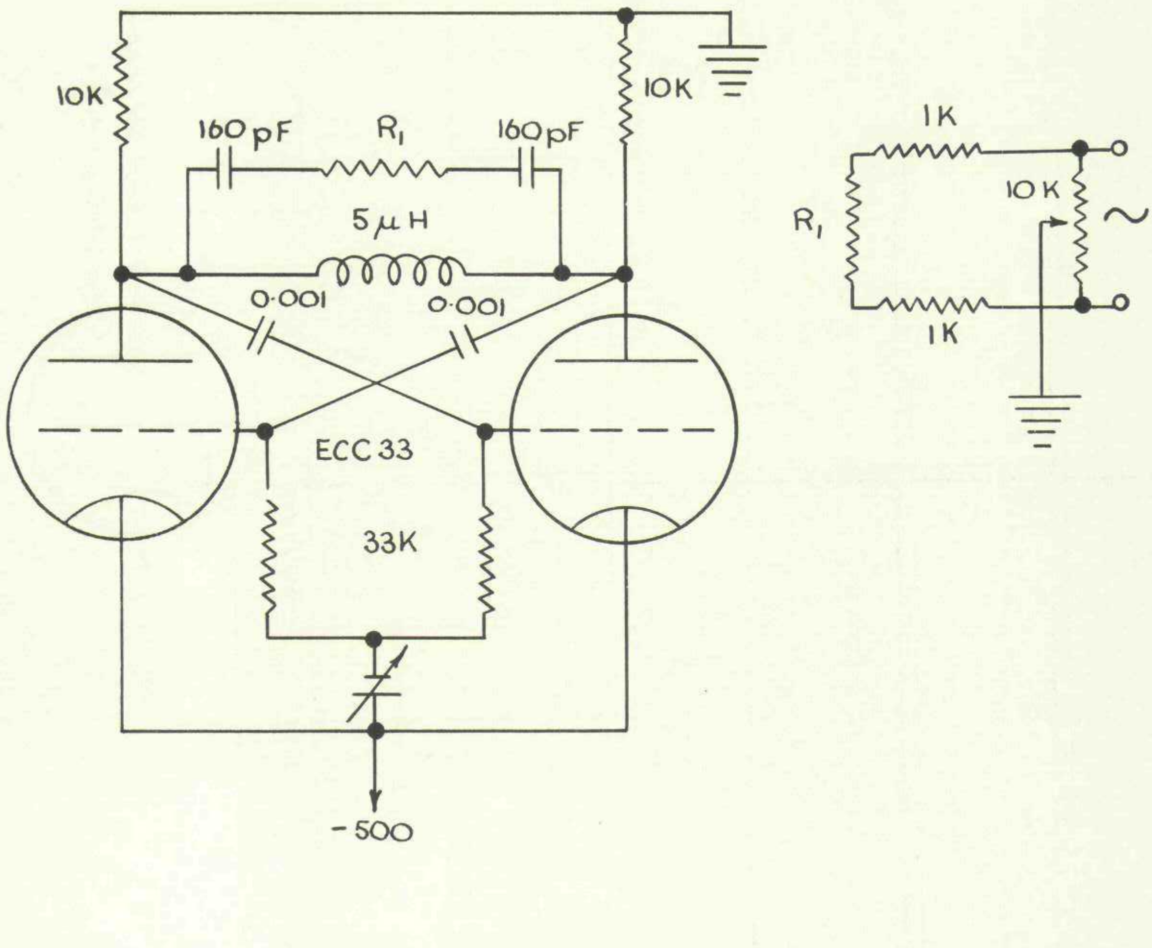

Free Oscillation Frequency
Response db
8
4
0
-4
-8
-12
-16
10²
10³
10⁴
Frequency – c.p.s.

FIG 8

FIG. 9.



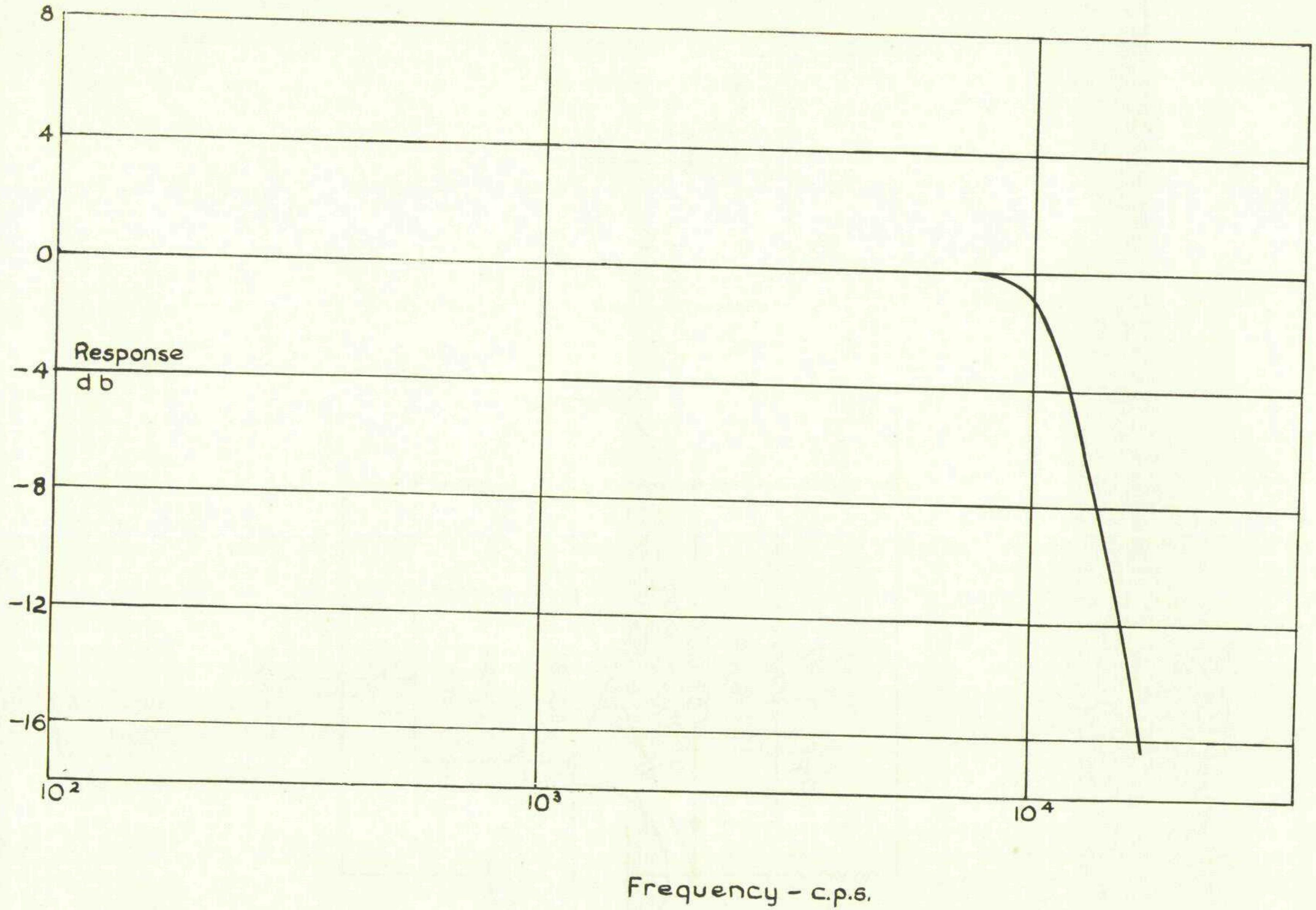


FIG 10

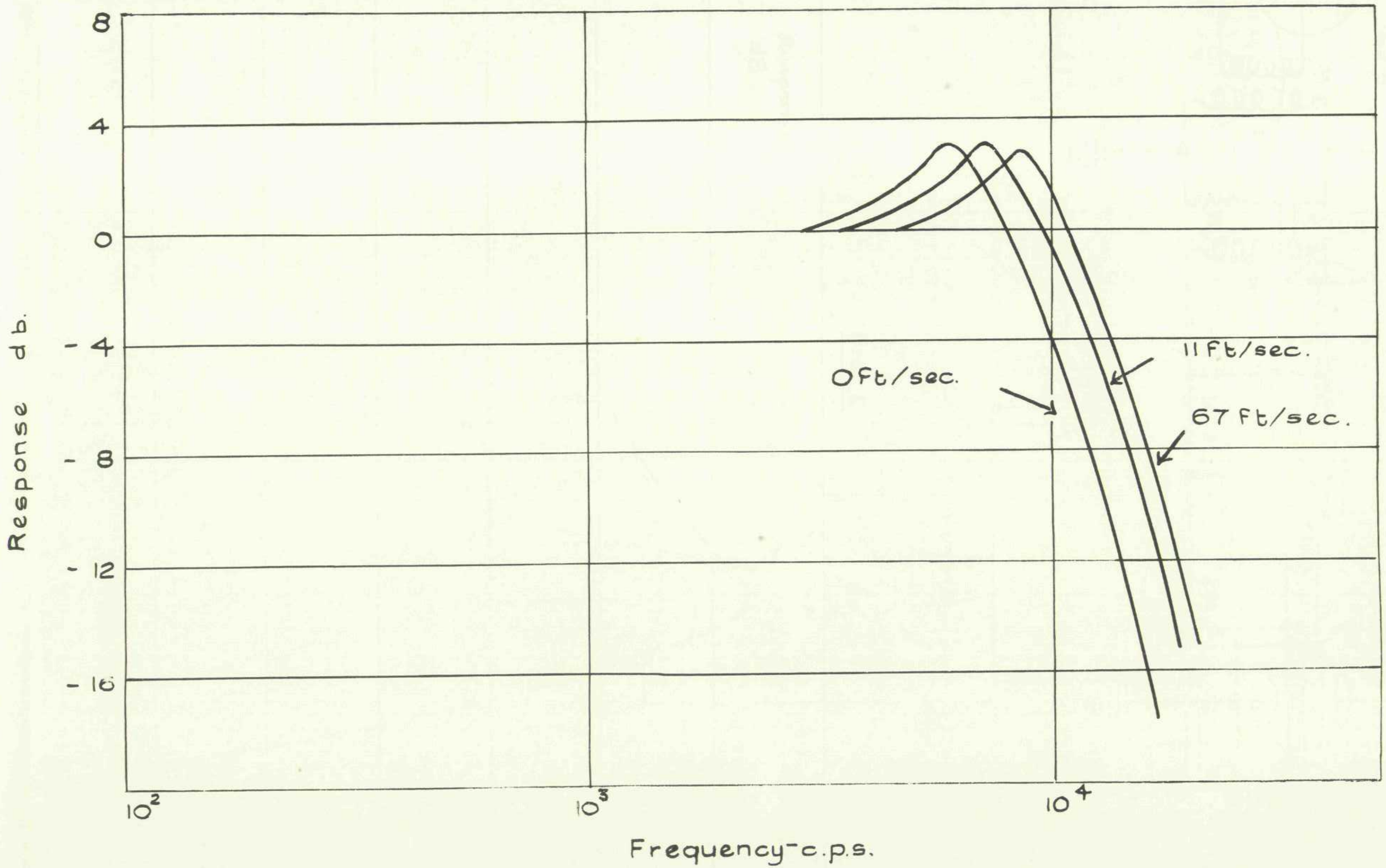

8
4
0
- 4
- 8
- 12
- 16
Response d.b.
10^2
10^3
10^4
Frequency-c.p.s.
O ft/sec.
11 ft/sec.
67 ft/sec.

FIG. 11.

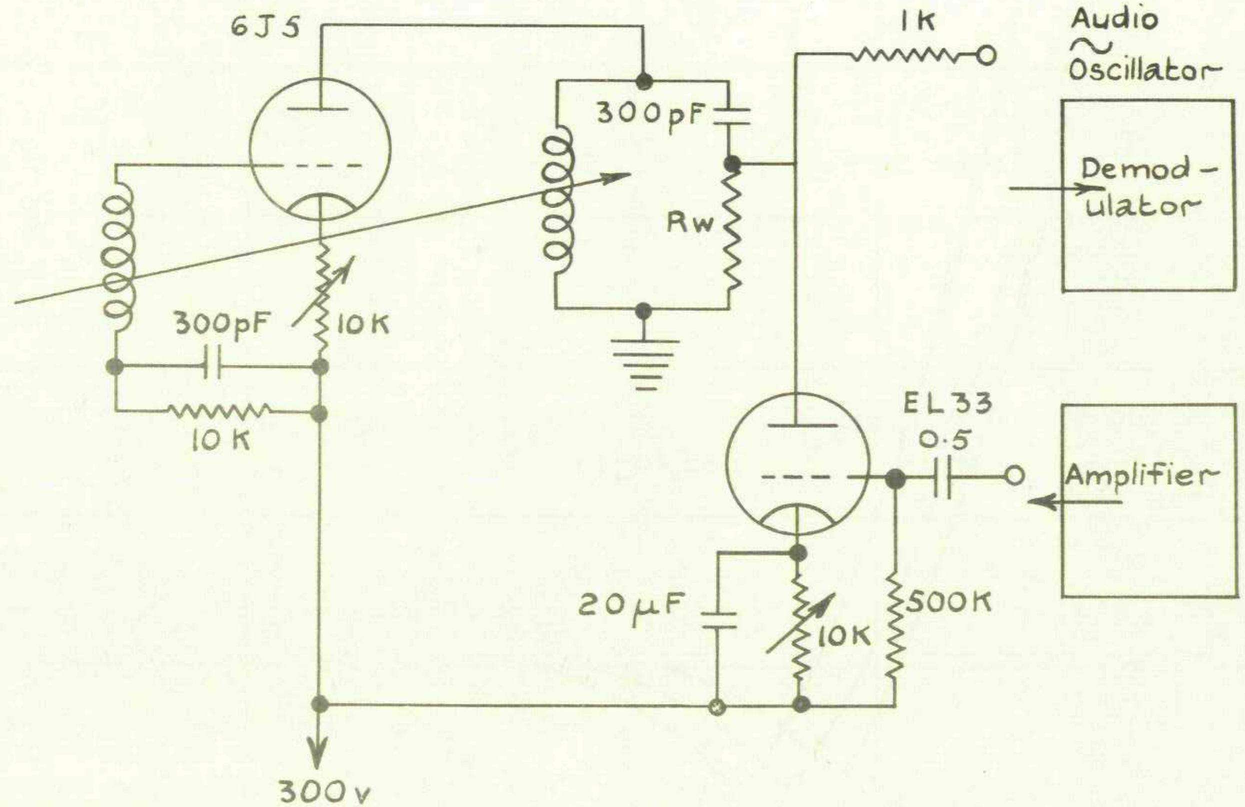

6J5
300pF
Rw
1K
Audio
Oscillator
Demod-
ulator
300pF
10K
10K
EL33
0·5
Amplifier
20μF
10K
500K
300v

Fig. 12.

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