An Infra-Red Image-Converter Tube

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ABSTRACT. A simple infra-red image-converter tube developed for military applications during the war is described. The basic design consists of a silver-caesium oxide photo-cathode deposited on a plane-glass surface with an anode in the form of a Willemite screen parallel to it. An indication is given of possible commercial and academic applications.

INTRODUCTION

In 1938, the Admiralty became interested in the image-converter tube for use in a special telescope capable of detecting infra-red radiation from, for example, a screened homing beacon. The outbreak of war and the urgency of the requirement resulted in the simplest possible design being chosen, and in 1940, Electrical and Musical Instruments Ltd. were asked to undertake the development of a tube based on the system first proposed by Holst(1). Within less than 6 months a group working in the firm produced prototype tubes, and after service trials large-scale production of tubes and receivers was commenced in 1942 by The Gramophone Co. Ltd. The tube was used in a large number of service applications, and although initially intended only for observing infra-red beacons, was subsequently used in picture-forming equipment to view scenes illuminated with infra-red radiation.

DESCRIPTION OF TUBE

There is nothing novel in the principle of the image-converter tube which is, in effect, a form of photocell in which the anode is replaced by a fluorescent screen. Several forms have been described in the past both in periodicals(1-7) and text-books(8). During the war the main advance was in the direction of production design and technique. Figs. 1 and 2 show the simple design developed for British service applications. The tube envelope consists of an evacuated cylinder of Pyrex glass about 5 cm. in diameter and 4 cm. in length, with plane end-windows 2 mm. in thickness. A semi-transparent silver-caesium oxide photo-cathode, with photo-emissive sensitivity out to about 1·3μ, is deposited on one end-window by a technique similar to that employed in standard photocell activation. A Willemite screen deposited on a thin plane glass plate is mounted parallel to the cathode and separated from it by 5 mm. The screen may be viewed through the window remote from that carrying the cathode.

A full description of the processes involved in the manufacture of the tube will be given elsewhere by the E.M.I. workers.

OPERATION

Infra-red radiation falling on the cathode will release electrons which may be accelerated, by application of a high voltage, to the anode where they will form a fluorescent (green) image corresponding to the initial infra-red image. The brightness of any element of the fluorescent screen will depend upon the number of electrons impinging on that element of the screen, so that gradations in the intensity of infra-red radiation falling on the cathode will be reproduced in the fluorescent image. Thus, if the image of a distant infra-red beacon is focused on to the cathode by a suitable objective lens, the electron emission at this point will cause a bright spot to appear at the corresponding point on the anode. In the same way, if the image focused on the cathode is that of a scene illuminated with infra-red, then the green fluorescent image on the screen will correspond to the original scene, or, more correctly, to the variations in infra-red reflectivity in the original scene.

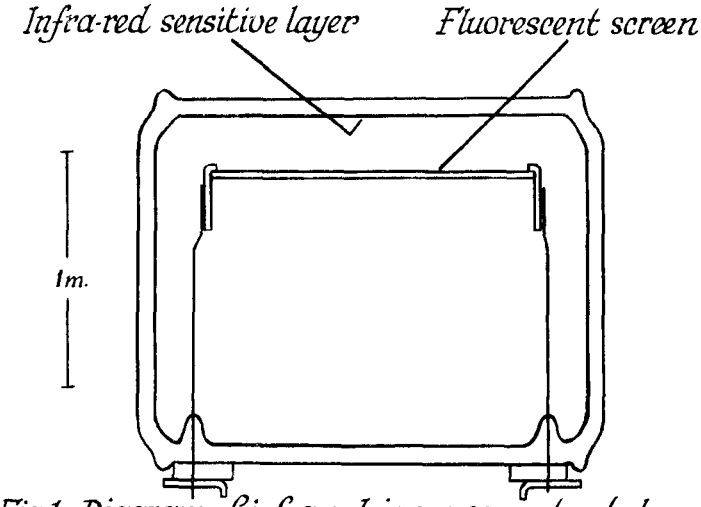

Fig 1. Diagram of infra-red image-converter tube

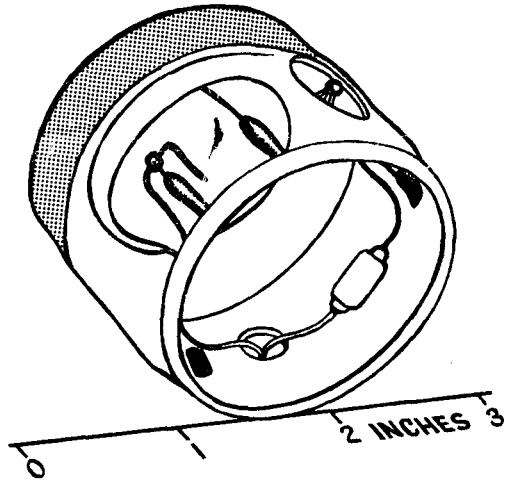

Fig 2. Infra-red image-converter tube

PERFORMANCE

The applications of the image-converter tube fall into two general categories, those in which the detection of a point source is involved and those in which the device is used to view an extended target. In connexion with the former application the sensitivity of the average tube is such that, using an f/2·9 objective lens of 4 in. focal length and a 22-dioptre eyepiece, a tungsten point source (2800° K.) of conspicuity 10-mile candles, screened with Wratten 87 filter, is visible to a dark-adapted observer. Spectacle lens quality optical components are adequate in this type of use and an applied voltage of 3 kV. is sufficient. With the optical system

described the image is, of course, inverted and reversed, but, in general, erection is only required in the picture-forming systems. Where the latter applications are concerned and maximum brightness and definition is required, a voltage of up to 6·5 kV. is applied to the tube, which has to be selected to withstand this high voltage. A resolution of up to 350 lines/in. (black plus white) on the cathode can be obtained. A typical optical system is a four-component f/1.9, 1½ in. focal length, projection lens, 4 in. focal length erector (cemented doublet) and 1 in. Ramsden eyepiece. It is sometimes convenient to include a Wratten 87 filter in the objective system to reduce the effects of stray illumination such as moonlight.

Auxiliary equipment

Some form of power unit is, of course, required to supply the accelerating voltage to the tube. In many service applications it was possible, in view of the high insulation of the tube and the low current involved (10^{-9} A.), to make use of dry piles (Zamboni piles) as source of voltage. However, the high internal resistance of such piles ($10^{10}\ \Omega$) necessitates the complete sealing of the instrument, and for many commercial applications a vibrator power unit is more suitable. Fig. 3 shows a typical circuit diagram for the latter. In any case it essential that the tube be mounted in a well-insulated holder of a material such as Keramot, Distrene, or Perspex. Where a source of radiation is required, a tungsten filament lamp running at normal colour temperature (say 2800° K.) is used. Such a lamp is, of course, more efficient as a source of near infra-red in the 1μ region than of visible radiation and is admirably suited, in conjunction with an infra-red filter, for use with the silver-caesium oxide photo-cathode. The normal filter consists of a plastic base incorporation a dye absorbing visible radiation below about 0·8μ and transmitting the longer wave-lengths. A typical filter might have a visible transmission of 3% of Wratten 87, with an infra-red transmission (to a caesium photo-surface) of 65% of Wratten 87.

Applications

The war time service applications were connected with homing operations, recognition and identification, and vehicle driving, at night. Typical of these applications that should be useful in peacetime problems are observation of animal behaviour in the dark (in connexion with infra-red sensitization of the retina), and the direct measurement of refractive indices at wave-lengths of about 1μ, using a receiver fitted on the telescope of a spectrometer (in connexion with the design of optical systems for infra-red receivers). A further application is in pyrometry, to extend the range of optical pyrometric methods to lower temperatures, since the spectral response of the image-converter tube enables the radiation from hot surfaces at temperatures lower than visible to be detected. Again, in the control of operations that have, of necessity, to be carried out in the dark (e.g. processing of panchromatic film) the image-converter tube will meet a requirement of long standing.

In order that equipment may be available for applications in research and industry, arrangements will be made shortly for a quantity of surplus tubes to be released for disposal by auction through the Ministry of Supply.

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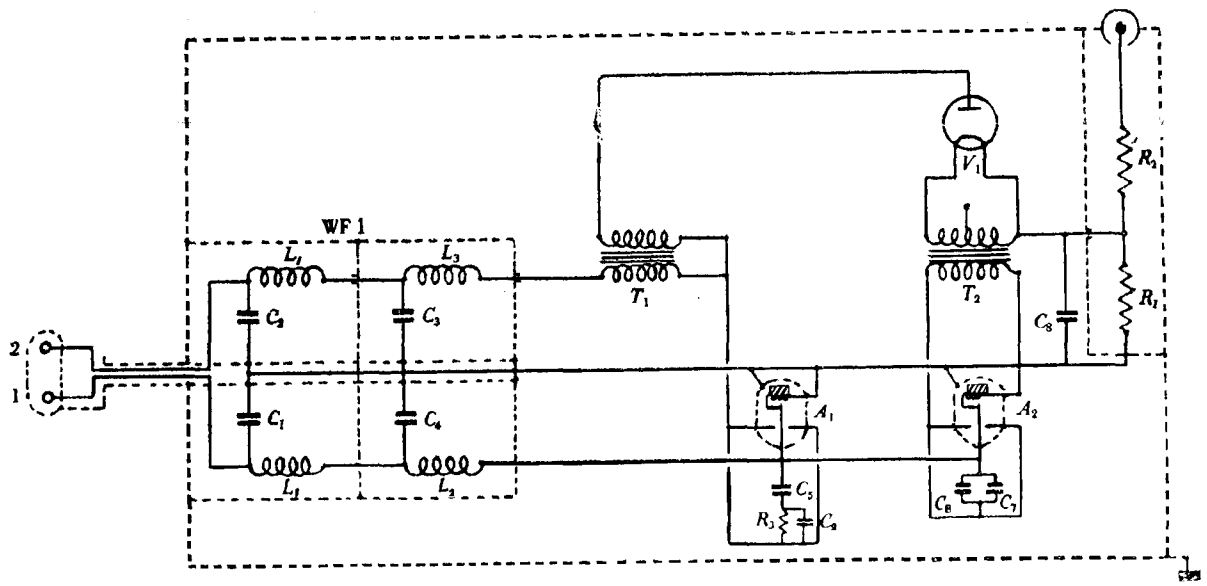

Fig. 3. Circuit of vibrator power unit for use with infra-red image-converter tube. R_1, 200 MΩ; R_2, 100 MΩ; R_3, 68 Ω 5W.; C_5, 0·5 μF.; C_6, 1·0 μF.; C_7, 0·75 μF.; C_8, 0·1 μF.; C_9, 100 μμF.; T_1, Lucas 12 V. car ignition coil; T_2, filament supply transformer; A_1, A_2, Weare and Wright vibrators NS/12; V_1, Mullard HV1; WF1, radio-interference suppressor

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