The Scophony Television Receiver

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THE Scophony television receiver is an optico-mechanical system and possesses the advantages over the purely electric systems employing a cathode ray tube that (1) larger pictures are possible without great expense; (2) high voltages are not necessary—the voltage of a radio set is sufficient; (3) there is lower power consumption for a given picture size. It is scarcely necessary to add that the Scophony receiver works on the B.B.C. transmission.

The essential parts of an optico-mechanical television receiver are: (1) optical elements for producing an illuminated area on the screen; (2) means for moving the illuminated area over the screen; this is at present done by giving it two components of uniform motion in two directions at right angles, one horizontally and one vertically; (3) means for modulating the intensity of the illumination in accordance with that of corresponding areas of the picture to be reproduced. The modulated signals are received in the form of electro-magnetic waves and are converted into variations in voltage in an electrically tuned circuit; these have to be converted into variations in light intensity. The difficulty of this conversion arises from the high frequency of the signals, which is 5×10^6. (The picture is divided up into approximately 500×400 elements and scanned 25 times a second.) In sound recording, the highest frequency is of the order of 10^4; television has then an increase of 500 times. It is thus easily understandable that mechanical light valves are out of the question, nor is it possible to apply the electrical variations directly to a lighting circuit, because a sufficiently brilliant source cannot be extinguished from its condition of maximum illumination in one five millionth of a second. The Kerr effect was formerly employed, and is still used in the telegraphic transmission of pictures, but the light flux that the Kerr cell can handle is too small for high definition television. (It has other disadvantages such as high capacity, causing time lag.)

The Scophony Light Control, invented by J. H. Jeffree[1], employs a cell which may be 10 cm. × 2 cm. in area and allowing ample light flux; its action is based on the diffraction of light by compressional waves generated in liquid which act as a grating. Electrodes connected to the electric circuit excited by the radio waves are attached to a quartz plate of which the thickness is such that the natural period of vibration under electric oscillations is 10 megacycles. A parallel beam of light is sent through the cell and (in order to separate the diffracted from the undiffracted light) brought to a focus by means of a lens. An opaque shield cuts off the light of zero order (undiffracted light) and the diffracted light (three orders of spectrum are used) passes to the screen. The amplitude of the oscillation in the crystal, and of the compressional waves produced in the liquid at any time, is proportional to that of the electrical oscillations, which in turn is proportional to the light received at the instant from the element of the picture which is being scanned. As the supersonic wave travels along the cell, it is 'followed' by a rotating mirror of a mirror drum so that the small beam of diffracted light from it to the mirror is reflected in a fixed direction in space (compare the action of the heliostat mirror in following the sun's motion). A lens forms an image of the cell on the screen, so that the amount of light reaching a point on the screen is proportional to that of the corresponding point on the picture, but—and this explains the increased optical efficiency of this light control—the point is illuminated, not for one five millionth of a second but for the time the wave takes to travel along the cell. If we take the cell as 10 cm. long, this time, since the average speed of the waves at the frequency specified is about 1,000 m. per sec., amounts to one thousandth of a second—a 500-fold increase.

We have been considering the 'line scan'. The number of traverses the illuminated area makes per picture is called the number of lines (the B.B.C. standard is 405) and so the illuminated area, which in one direction may be equal to the width of the picture, must be limited in a perpendicular direction to a line width or 1/405 part of the picture height. This means that the image of the light cell on the screen must be compressed; to do this cylindrical lenses are required. Moreover, to reduce the length of the scanning drum so as to keep its inertia small, in order that the power required to drive and synchronize it may not be excessive, the light beam is still further compressed in this direction. This is the principal of the 'split focus' invented by G. W. Walton[2]; it is only by this reduction in size that it is possible to drive and synchronize the high-speed drum at 30,000 r.p.m. The drum is driven by an asynchronous motor and synchronized by means of a phonic wheel to which the synchronizing pulses of the transmission are applied. At the high speed used, glass would fly to pieces, so stainless steel is used, which metal is necessary in order to obtain optically polished mirror faces. The amount of steel is kept at a minimum, and the drum is in fact a steel annulus with an aluminium core. The inertia can thus be brought down to 137 gram. cm.^{2}. The slow-speed drum to provide the scanning in the other direction has to change the picture (or 'frame') 50 times a second and moves only 1/202·5 times as fast as the high-speed drum, for the same number of faces, and there does not arise the same need to reduce size.

Fig. 1 shows the lay-out of the system, but in order to show the optical arrangement, conventional sections made in two planes at right angles through the axis are shown (Fig. 2). Here the scanners are only indicated and for the sake of clearness the rays are shown undeviated by reflection at the scanners.

The lenses B_2 and C have a two-fold function. Inasmuch as C images the supersonic waves in the cell on to the screen, B_2 may be regarded as a field lens to C, reducing its size. On the other hand, the lenses B_2 and C have to form a well-defined image (of the light source) on the opaque shield, and furthermore they have to fulfil a condition which is peculiar to the Scophony optical system. A ray parallel to the axis impinging on the supersonic wave field at P at a distance h from the axis is brought to a focus at the shield at an angle θ to the axis. Now P travels with uniform linear speed along the cell, and the mirror drum rotates with uniform angular velocity; it is therefore seen that the condition h/θ = constant must be fulfilled[3]. (Compare the aplanatic or sine condition, $h/\sin\theta$ = constant.)

The above condition being satisfied, the following relationship must hold:

Equivalent focal length of B_2 and C is equal to the ratio of velocity of the supersonic waves to rotation speed of scanner. Putting the velocity of the supersonic waves at 1,000 m./sec. $= 10^5$ cm./sec. and speed of rotation of drum at 500 r.p.m., we get equivalent focal length $= 50/\pi = 16$ cm. approximately. Now as there are 405 lines to the picture and 25 pictures per second (or 50 pictures of 202·5 lines in the interlaced system), there are 10,125 line changes per second. Therefore the supersonic waves must travel along the cell in 1/10,125 sec., so that the size of the cell is

$$\frac{100{,}000}{10{,}125} = 10 \text{ cm.}$$

approximately.

The aperture ratio of the two lenses B and C is therefore $\frac{10}{16}$ or 1/1·6.

For a cell 10 cm. long, holding 500 elements of the picture (an element being equal to the line width) each element occupies a space 0·02 cm. The wave-length of the supersonic waves is $\frac{10^5}{10^7}$ (frequency $= 10^7$) $=$ 10^{-2} cm., so that an element of the picture is carried by two complete waves. Nomoto has shown that a width of two waves produces the diffraction phenomena.

The equivalent focal length of B_2 and C being 16 cm. and the angle of diffraction being equal to (wave-length of light)/(wave-length of supersonic waves) $= 0{\cdot}55 \times 10^{-4}/10^{-2} = 0{\cdot}0055$ radians for light for which the eye has maximum sensitivity, the centre of the first order diffraction spectrum is displaced $16 \times 0{\cdot}0055 =$ 0·09 cm. from the axis; the centre of the second order diffraction spectrum is displaced $32 \times 0{\cdot}0055 = 0{\cdot}18$ cm. from the axis; and that of the third order spectrum $48 \times 0{\cdot}0055 = 0{\cdot}27$ cm. from the axis. It has been found experimentally that approximately 45 per cent of the light is diverted into the first order (at maximum modulation), 37 per cent into the second, and 8 per cent into the third (with negligible amounts in the higher orders, so that about 10 per cent is lost). Now the amount of light in the zero order is directly proportional to the area of the zero order, that is, the image of the light source formed by undiffracted light; but the amount of light in the diffracted spectra is not proportional to the area unless this is very small, because as the area is increased some of the diffracted light is cut off by the opaque shield, which must be equal in width to the zero order. It can be shown on the basis of the above measurements that the amount of light increases rapidly as the size of zero order is increased to 1·8 mm.

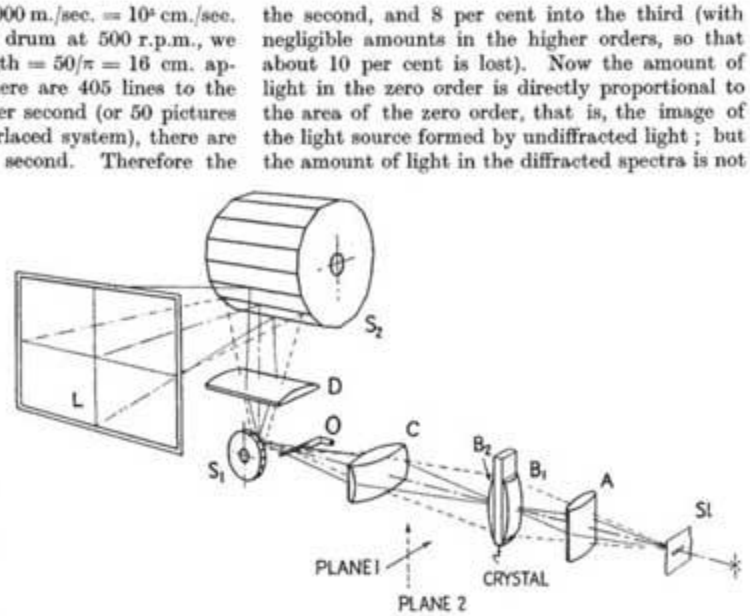

Fig. 1.

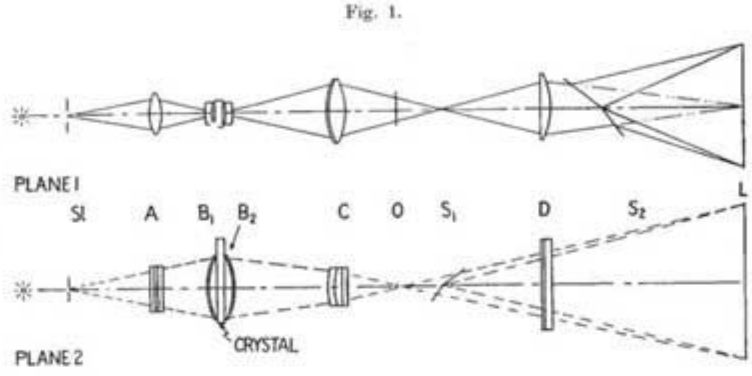

Fig. 2.

Sl IS AN ILLUMINATED SLIT.
A IS A CYLINDRICAL CONDENSER FOCUSING THE SLIT IN THE CELL IN PLANE 1.
B_1 COLLIMATES THE LIGHT FROM Sl, TO PASS THROUGH THE CELL AS A PARALLEL BEAM.
B_2 FOCUSES IT, WITH THE AID OF C, ON THE OPAQUE SHIELD O.
C FORMS AN IMAGE OF THE CELL ON THE SCREEN L IN PLANE 2 AND AN IMAGE OF THE LIGHT SOURCE ON THE SCANNER S_1 IN PLANE 1.
S_1 AND S_2 ARE THE TWO SCANNERS.
D FORMS THE 'LINE IMAGE'.

less rapidly for an increase to 2·6 mm. and thereafter very slowly. These calculations cannot be very accurate as no account is taken of light of different wave-lengths, but experiment is in agreement that a size of 2·5–3 mm. gives optimum results. It is preferable to interchange slit and shield, placing the shield in front of the light source and the slit in front of the scanner[4]; this arrangement gives a solid beam of light, instead of one having a hollow centre, taking up less room on the scanner. The diffracted light from this source can be dealt with very efficiently by a scanner of 5 cm. diameter.

A larger light source could be used by increasing the angle of diffraction by reducing the wave-length of the supersonic waves. To this there are several objections: shorter waves are more rapidly absorbed by the liquid (Nomoto states that no diffraction spectra can be obtained at frequencies of 30 megacycles, so that no great increase of frequency is possible); a larger light source would require a larger scanner, which would increase the difficulties of synchronization and driving; and finally, more power would be required to 'drive' the crystal (this is at present about 6 watts).

A rough idea of the accuracy required in the scanner can be obtained by considering that in the Scophony system a picture line of 500 elements is scanned by a rotation of 18° by the scanner. One element therefore corresponds to about 2 minutes of arc. Each surface of the scanner must therefore be placed accurately to a fraction of a minute of arc.

The present Scophony receivers, although operating by no means at the limit of optical efficiency, give the satisfactory screen brightness of 15 lux. The home receiver gives a picture 2 ft. wide, using a mercury vapour lamp. The public hall receiver gives a picture 6 ft. wide, using a standard cinema arc consuming 100 amperes.

[1] British Patent 439,236.

[2] British Patents 328,286 and 451,132.

[3] Patent applied for lenses fulfilling this condition.

[4] Patent applied for.
