A SURVEILLANCE SYSTEM USING INFRA-RED RAYS

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Summary. Description of a surveillance system with infra red alternating light intensity, which works over a distance of 425 metres. In addition to the light source a foto-electric cell and a two valves amplifier is used.

Introduction

At the present time it is becoming increasingly the practice to entrust the protection and surveillance of rooms containing valuable objects no longer to human attendants, but to automatic alarm systems which become actuated immediately an unauthorised person enters the protection area. The advantage of an arrangement of this type is that surveillance is continuous and that if required the competent public authorities, such as the police, can be directly warned of any intrusion, etc. The close surveillance offered by these systems is particularly useful and desirable, for instance, on strong rooms of banks, valuable collections in museums, shop premises, etc.

A reliable and efficiently alarm system must satisfy the following requirements:

1) It must not be capable of being easily rendered inoperative.

2) It must give an alarm on any interference with its normal state of preparedness (e.g. a failure of the current supply).

3) It must not be recognised as an alarm system.

4) It must not be subject to interference or put out of action by normal activities and operations in the vicinity.

Various mechanical protective arrangements, such as door contacts or step contacts, are naturally quite practicable, but important advantages are offered by a method using invisible rays which on being intercepted in any way release an alarm system. Fundamentally the method depends on the operation of a photo-electric cell, which furnishes a current as long as infra-red radiation falls on it. After amplification this very weak current can be used for controlling an alarm system.

In the simplest form of such a system the photo-electric current is used directly for energising a relay. The current generated is however only of the order of a few micro-amperes, as may be gathered from the following example. If a glowlamp of say 25 candles is used as a light source, the total luminous flux radiated will be about 250 lumens. When a photo-electric cell with a window opening of e.g. 20 sq. cm is placed about 1 m from the lamp, the light falling on the cell will be:

\[
\frac{20}{4\pi100^2} 250 \approx 0.04 \text{ lumen.}
\]

A vacuum cell is employed which for white light has a sensitivity of approx. 25 micro-amps per lumen so that a current of about 1 micro-amp is generated. This extremely weak current can be intensified by inserting a lens between the light source and the photo-electric cell (fig. 1). If for this purpose a lens of 25 cm focal length and 10 cm diameter is used and the distance between the cell and the light source is made only so great that the image of the incandescent coil still falls completely within the cell window, then the whole of the light collected by the lens will fall on the cell.
The coil covers roughly a square of 2 mm side, while the cell window is a circle of 5 cm diameter. The filament must then be placed 26 cm in front of the lens, and the image is produced 460 cm behind the lens, so that a space of 4 m wide can be readily kept under surveillance.

Although the lens throws a much greater portion of the spherically-radiated light on the photo-electric cell than would be incident thereon without a lens, even with this arrangement only 2.32 lumens of the 250 lumens radiated will reach the cell, the absorption losses in the lens being still left out of account. The photo-current is then 58 microamperes. It is not a simple matter to construct a relay responding to this small current, while moreover the space of 41/2 m wide controlled is not particularly large. If in place of a vacuum cell a gasfilled cell is used which is six times as sensitive, but also critical in adjustment, the electric current generated is 350 microamps, which is still too small. We are employing visible light in this example, which therefore does not satisfy condition 3) above.

Since the photo-electric cell under consideration is however fairly sensitive to infra-red rays, the light beam can be rendered invisible by passing it through a glass plate which allows only the infra-red rays to pass through (infra-red filter). This adaptation reduces the photo-current to about a third. In order to be able to operate a relay it has thus been found necessary to amplify the photo-current.

The Amplifier

A simple circuit for amplifying the photo-electric current is shown in fig. 2.

The current generated in the photo-electric cell C by illumination is passed through a resistance R, which is connected to the grid and cathode of the amplifying valve L, so that the voltage of the grid is negative with respect to the cathode. The method of operation is then as follows: No current passes through the resistance R when no illumination falls on the cell. The grid of the valve L is then at the same potential as the cathode, and a definite anode current is circulating which maintains the attraction of the armature of the relay A. When the cell is illuminated the grid becomes negative, and as a result the anode current diminishes, thus releasing the relay armature. In this position the whole system is therefore in the “safe” setting. If the beam of light is interrupted, the current through the relay rises, the armature is attracted and an “alarm” arrangement can be operated.
This method of operation obviously does not satisfy the second condition enumerated above. Any failure or interference in the amplifier remains undetected, since the relay current is then zero and the armature is hence not attracted. This shortcoming can however be readily overcome by using the circuit shown in fig. 3, where the grid of the amplifying valve \( L \) has a negative grid bias, so that a small feed current flows through the relay \( A \) which does not actuate the latter. Since the photo-electric cell is connected in the opposite way to that shown in fig. 2, the current through \( R \) and may cause the attraction of the armature.

Fig. 3. If no light falls on \( C \) a very weak current flows through \( A \) which causes no other component to operate. If \( C \) is illuminated then, contrary to fig. 2, the grid of \( L \) becomes more positive, since here the current from \( C \) flows through \( R \) in the opposite direction; the current through \( A \) increases and may cause the attraction of the armature.

The fluctuating light is generated in the following way: A steel spring is substituted for the armature in a magnetised coil (such as that from a loud-speaker) which is energised by alternating current. A small disk is attached to the spring at its free end.

Fig. 4. The intermittent illumination system. Light of fluctuating intensity falls on the photo-electric cell \( C \), *inter alia*, an alternating voltage is thus generated across \( R \). This voltage is amplified by \( L_1 \) and is then applied to \( L_2 \), whereupon the current through the relay \( A \) increases, as shown in fig. 6.

The fundamental circuit of the apparatus evolved in this Laboratory is reproduced in fig. 4. It will be seen that a condenser has been inserted between the photo-electric cell and the grid of the first amplifying valve. This has been done for the following reason: The circuits in figs. 2 and 3 are fundamentally those for D.C. amplifiers. It is, however, difficult without complicated precautions to obtain a D.C. amplifier with more than one stage, while on the other hand the construction of a multi-stage amplifier for A.C. is very simple. Fig. 4 is thus a circuit for an A.C. amplifier, so that it is necessary to furnish the cell with A.C. also.

Two methods can be used for generating alternating current:

1) Alternating voltage can be passed to the anode of the cell.

2) The cell can be illuminated with an intermittent or fluctuating light.

The second method is naturally the more advantageous. The apparatus no longer responds to a continuous beam of light, so that one cannot walk through the beam and direct a beam from a pocket lamp on to the cell as a substitute for the screened light. For this reason the second method was selected.
end. On connecting the coil to the A.C. mains supply the disk will vibrate with a frequency of 50 times per second (fig. 5). This arrangement is set up in the beam between the glowlamp and the lens in such a way that the disk, when at rest, just bisects the beam of light falling on the lens. In this way the beam can be entirely cut off or given a free passage by a minimum deflection of the spring. One might be inclined to employ resonance phenomena, i.e. make the natural frequency of the spring equal to the A.C. frequency, in order to obtain a large deflection with a small power. This method cannot however be used satisfactorily since then a small variation in frequency will immediately result in a marked diminution of the deflection. The natural frequency must exceed the frequency superposed on it, as otherwise the spring would vibrate about a node.

In this way the photo-electric cell receives an intermittent beam of light so that on a voltage drop in $R$ an alternating voltage is obtained at the grid of the first amplifying valve. After amplification this voltage is impressed on the grid of the second valve, which acts as an anode rectifier and whose anode current therefore increases with increasing (alternating) voltage at the grid. The grid of $L_2$ has a negative bias of such a value that a very weak anode current flows (fig. 6). If alternating voltage is now applied to the grid the anode current as shown in the figure will become pulsating; the pulsations are not however registered if measured by a moving coil instrument which at a sufficiently high frequency of pulsation indicates the mean current. This anode current is employed for actuating the alarm relay.

The currents at which the relay attracts or releases the armature are determined by the dimensions. From the characteristic of the rectifier, i.e. from the variation of the anode current as a function of the grid alternatting voltage, the voltage required at the grid can be found so that the relay attracts its armature. The rest current which flows when no alternating voltage is present, i.e. when the light beam is cut off, must therefore be a little smaller than the current at which the armature is released (see fig. 7).

![Fig. 6. In the absence of alternating voltage at the grid the amplifying valve operates at the point $P$ of the characteristic (current intensity $i_1$). If an alternating voltage is applied to the grid a pulsating anode current with an average value of $i_2$ is obtained.](image)

![Fig. 7. Characteristic of the rectifier, i.e. anode current of the rectifier (which therefore flows through the relay $A$) as a function of the alternating voltage at the resistance $R$ of fig. 4. At the current $i_b$ the relay armature is attracted; at $i_a$ it is released.](image)
Sensitivity of the system

The sensitivity of the system is mainly determined by the current sensitivity of the relay, which in its turn is governed *inter alia* by the windings on the relay core. The power of a relay is determined solely by the product of the current intensity and the number of turns, so that up to a point the sensitivity of the relay can be raised by increasing the number of turns and reducing the diameter of the wire. Since the photo-electric cell must generate such a current that the amplifier can furnish the difference between the currents at which the relay armature is attracted and released, it is evident that these currents will preferably be made small since the ratio between them is constant.

It has been found possible to wind a relay having a "response current" of 0.6 mA and a "release current" of 0.2 mA. To obtain this current difference a grid alternating voltage of 0.015 volt is required at the first amplifying valve. The photo-electric cell must therefore furnish 0.015 \( \mu \)A (through an impedance of 1 megohm). This is the effective value, the peak value is \( \sqrt{2} \) times greater. The light however fluctuates from zero to a maximum, and the curve of the intermittent light must be compared with the "zero line" as shown in fig. 8. This indicates that the peak value of the current which the cell must furnish is:

\[
2 \cdot 0.015 \cdot \sqrt{2} = 0.042 \ \mu \text{A}.
\]

When using a gas-filled photo-electric cell whose sensitivity for white light is approx. 150 \( \mu \)A per lumen, the 0.042 \( \mu \)A required would need an intensity of 0.00028 lumen of white light. With infra-red rays the sensitivity is however three times smaller, so that then 0.00084 lumen (expressed as white light) must impinge on the photo-electric cell.

Distance of Surveillance

To calculate the length of beam corresponding to an intensity of 0.00084 lumen at the cell window, it must be remembered that over this great distance the whole of the light emerging from the lens no longer falls on the photo-electric cell; the size of the image of the lamp coil is on the other hand a multiple of the cell window (fig. 9). In this case the amount of incident light is inversely proportional to the square full distance of the light source. Since the focal length \( f \), the size \( V \) of the lamp coil and the quantity of light \( L \) falling on the lens are fixed, and also the amount of light \( l \) required for illuminating the cell cannot be improved in the particular construction adopted, the length of the beam \( b \) between the lens and the cell can only be increased by enlarging the surface \( A^2 \) of the cell. The photo-electric cell must receive a minimum of

\[
l = \frac{A^2}{B^2} \cdot L = \frac{A^2 f}{V^2 l}.
\]

which gives for the permissible distance of the photo-electric cell:

\[
b = \frac{f}{V} \cdot \sqrt{\frac{A^2 L}{l}}.
\]

The magnitude \( A^2 \), the operative area of the cell, can in fact be further increased. For if the cell is placed at the focus of a parabolic mirror, the effective surface of the cell will be equal to that of the mirror.

The above-mentioned magnitudes have the following values in our apparatus:

\[
\begin{align*}
f &= 25 \text{ cm}, \\
V &= 0.2 \text{ cm}, \\
A^2 &= 200 \text{ sq cm}, \\
L &= 2.32 \text{ lm (see above)}, \\
l &= 0.00084 \text{ lm}
\end{align*}
\]

so that for infra-red light the distance of surveillance can be:

\[
b = \frac{0.2}{25} \sqrt{\frac{200 \cdot 2.32}{0.00168}} = 93000 \text{ cm}
\]
In practice the attainable length of beam is smaller since absorption losses must also be taken in consideration. A more comprehensive system of surveillance with rays will in fact require a larger number of mirrors, e.g. for reflecting the beam of light to and fro. The lens and the parabolic mirror referred to above also absorb light. If five plane mirrors are used and each optical unit absorbs 20 per cent of the light incident on it, then the quantity of light $L$ must be multiplied by a factor $(0.8)^5 = 0.21$.

The maximum path of surveillance is then:

$$b' = 93000 \times 0.21 \approx 42500 \text{ cm}.$$  

The apparatus could therefore be used for surveillance over a distance of 425 m.

Advantages and Disadvantages

One disadvantage of all systems run from alternating current mains is that any failure in the supply immediately causes a false alarm to be given. The apparatus will also give an alarm when a failure or defect develops in one of the components; yet, according to the point of view, this can also be regarded as an advantage.

The principal advantage of the system is the fact that the beam of light is itself a fluctuating magnitude. A second and less important advantage is that, owing to the provision of the parabolic mirror which concentrates all incident rays at its focus, a screen with a small hole can be placed at this level at the focus itself. Extraneous light rays impinging at an angle, emanating from the general illumination or from passing light sources and concentrated next to the actual focus, do not then reach the photo-electric cell which is therefore screened against these rays. This renders interference with the apparatus by means of a light source with the same characteristics extremely difficult, since the direction of incidence of the rays has also to be very accurately adjusted.

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Fig. 9. Layout of a surveillance system in which the window $A$ of the photo-electric cell is considerably smaller than the image $B$ of the lamp coil.