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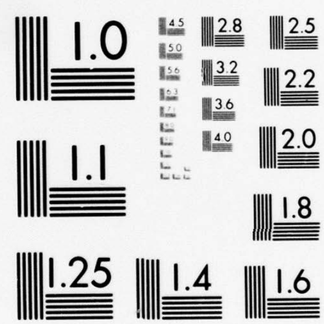

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A SURVEY OF SHUTTERING TECHNIQUES FOR THE RAE HIGH-SPEED TELEVISION RECORDING SYSTEM

by

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A SURVEY OF SHUTTERING TECHNIQUES FOR THE RAE HIGH-SPEED TELEVISION RECORDING SYSTEM

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R. W. Corbin

SUMMARY

Mechanical rotating disc shutters are currently used with the high speed television camera system developed by RAE but a more compact device, capable of exposure times down to 50 microseconds, would be highly desirable. The suitability of electro-optical shuttering devices is discussed for this application and typical performance figures are given. It is concluded that image intensifiers of the electrostatically focused triode or proximity focused diode types, fibre optically coupled to a Plumbicon camera tube, offer sufficient promise to justify further work.

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1 INTRODUCTION

The exposure time of a television camera system is generally taken to be the time for the reading beam to complete one scan of the camera tube format, ie the reciprocal of the frame rate. A 625 line, 50 Hz system is standard in the UK, and one complete frame of video is made up from 2 interlaced fields, giving a frame rate of 25 Hz. However, provided precautions are taken to reduce the effects of picture lag, it is possible to increase the field rate, at the expense of resolution, within the same video bandwidth and also to separate the fields in order to record moving objects. This is the basis of the high-speed television system developed by RAE, which operates at a field rate of 100 Hz. With normal lighting the exposure time per picture is 10 ms, which is too long to prevent blurring in images of fast moving objects, but by using electronic flash, triggered by the field synchronisation pulses, the exposure time can be reduced to as little as 3 μs. Under high ambient illumination levels, where it is impracticable to use electronic flash, a rotating disc shutter, again locked to the field synchronising pulses, is used to reduce the exposure time to about 1 ms. With the prototype equipment this motor driven shutter was placed in front of the lens and made the camera system inconvenient to use in practice, particularly when changing lenses. However, an improvement was effected in later models, developed from the RAE prototype by Messrs J D Jackson Electronics, under contract, in which the shutter was placed behind the zoom lens used to provide variable magnification for ease of setting up. The shutter is still restricted to 1 ms exposures and a compact device capable of providing shorter exposures and, thus, better pictures of fast moving objects would be highly desirable. Ideally, this should also be compatible with automatic exposure control techniques for use over a wide range of light levels.

This report examines the possibilities for improving the shuttering technique and reviews devices which have been considered for this application. The main emphasis is given to principles rather than to details of operation so that the reasoning behind the narrowing of options can be appreciated readily by non-specialists.

2 REQUIREMENTS OF HIGH-SPEED TELEVISION

2.1 Sensitivity

In order to record random, fast moving, events satisfactorily it has been found that the subject should appear in not less than two successive pictures.

Cyclic events also require at least two fields per cycle. Since the basic field rate is 100 Hz, the speed of the subject should ideally not exceed 50 times the camera field of view per second. A 1:1 aspect ratio format is used and the equivalent speed is, therefore, $\frac{625}{2} \times \frac{100}{2}$ or 15625 TV lines/sec. If the system resolution is not to be impaired significantly, the exposure time should restrict image motion to not more than 1 TV line. The exposure should, thus, not exceed 1/15625 or 64 μs.

Experience with the current system using the rotating disc shutter has shown that lens aperture settings up to f/4 are required to cover daylight conditions adequately. Since a reduction in exposure of 20 times is required, larger aperture lenses can only provide a partial solution and the limit is set when the loss in image quality exceeds that due to motion itself. The sensitivity of the Plumbicon tube can be doubled by means of light bias[2] but only at the expense of an increase in noise level. Gain in a new shutter is, therefore, highly desirable and any attenuation of light would be quite unacceptable.

2.2 Resolution

The television camera system has a resolution close to 300 TV lines per picture height and a square format of 11.3 mm side is used in the camera tube. This yields an equivalent resolution of about 13 line pairs per mm and any shutter device should have a significantly higher resolution, since systems cascaded together result in an overall resolution which may be approximated by summing the reciprocal resolutions of the individual components, ie $\frac{1}{R} = \sum_{1}^{n} \frac{1}{R_n}$.

2.3 Shutter ratio

It is important to find a device which has an adequate shutter ratio, that is the ratio of the amount of light passing in the open condition to that in the closed condition, because the cumulative effect of light on a Plumbicon camera tube is such that if the shutter ratio is poor there may be more signal resulting from the unwanted images than the wanted ones. The shutter ratio should be at least two orders better than the mark-space ratio of the shutter. For the 50 μs exposures contemplated, which are in a total field time of 10 ms, the mark-space ratio is 200:1. Therefore we require a shutter ratio of 20,000:1 or better if the unwanted images are to be adequately rejected.

2.4 Lag

The retention of after images due to lag in the camera tube is a serious drawback to high speed recording of moving objects. Lag is the result of incomplete erasure of the signal, stored at the target, by the reading beam and the effect is most noticeable in the highlights where the stored signal is high. In the high speed camera, a Plumbicon camera tube is used because of its low lag characteristics (5% of the image remaining after the third field), and the effects are reduced still further by the incorporation of highlight suppression techniques during the line flyback time within the camera. Any new shutter must not introduce lag which would degrade overall performance in this respect.

2.5 Physical characteristics

The system must be convenient to operate, reasonably portable and as rugged as the basic television camera so that special precautions when transporting it and handling it at trials sites are not required. Any return towards the cumbersome rotating disc, before lens, shutter arrangement used with the prototype would be a retrograde step. It is also important that the system can be operated from a 240 V, 50 Hz mains supply, and bulky driving equipment should be avoided. Since the equipment will be used in the field, interconnecting leads should be kept to a minimum and although high voltages are undesirable, they are acceptable providing features can be included in the design to ensure safety in operation.

3 LIMITATIONS OF THE PRESENT SHUTTER

Minimum exposure times of about 1 ms are achieved at present with a motor driven, 200 mm disc which rotates at 3000 rpm but unless a much larger disc is used, any further significant reduction in exposure is not feasible. Making the disc aperture smaller than the lens diameter only serves to reduce the available light rather than the exposure time. If a larger motor were used, it would be possible to halve the exposure by doubling the disc speed and using only one aperture. However, a limit is reached at this point because the disc would be revolving at a speed equivalent to the field rate of 100 Hz. Contra-rotating discs to provide capping could lead to shorter exposures but only at the expense of mechanical complexity and the use of an even larger motor with appropriate gears. Such an arrangement is unlikely, even then, to provide the required exposure times of about 50 μs.

4 KERR AND POCKELS CELL SHUTTERS

An alternative to the rotating disc is to use a Kerr or Pockels cell shutter. A Kerr cell is a device employing the principle that certain liquids have the property of rotating the plane of polarised light on the application of an electrostatic field. When such a cell is placed between crossed polarisers very little light will pass until the electrostatic field is applied. The combination may thus be used as a shutter or light modulator. The Pockels cell shutter employs a similar principle but uses a crystal instead of a liquid. The Kerr cell shutter is usually employed for submicrosecond exposures, but longer exposures are permissible provided that the temperature rise is not excessive. Pockels cell shutters are more suitable for light modulation techniques than for photographic shutters because their construction allows for only a narrow angle of light acceptance. Kerr cell shutters are better in this respect but their acceptance angle is still limited, owing to their electrode structure.

The Kerr cell, and Pockels cells employing longitudinally energised crystals, require voltages of 10-20 kV for switching. The provision of such high voltage pulses is a serious problem; bulky driving equipment is required, there is a possibility of interference with the camera circuits, and the question of operator safety must be considered. Transverse mode Pockels cells can be made to work at voltages below 1 kV but they have a high ratio of length to diameter, rendering them suitable only for virtually parallel light. On/off ratios of about 10^4 are claimed for Kerr cells, but Pockels cells have on/off ratios of 10^3 or less, which are scarcely adequate for our purpose.

More recently in the USA, a ceramic material, lanthanum modified lead zirconate titanate or "PLZT",[3] made in the form of thin transparent slices, has been found to exhibit light polarising properties when subjected to relatively modest electric fields. This discovery has led to the invention of flash protection goggles and other devices requiring less than 1 kV for switching. The power requirement is very small and on/off ratios of better than 2000:1 are achieved, with an "on" transmission of 20% or more. It seems possible that the same type of material could be used in a photographic shutter suitable for the present application, but results obtained with early samples produced in this country have not been very encouraging. There was a tendency for the material to crack at various points when subjected to rapid switching rates and some stray light was present at the edges of the electrodes when in the "off" condition.

The main disadvantages of these polarised light devices are that they introduce a light loss in the open condition and that they do not cut off light completely when closed. Because they are not perfect shutters, the rotating disc may need to be retained as a backing shutter to prevent unwanted light being integrated by the camera tube during the closed period. Typical performance figures are given in Table 1 and these are based on manufacturers' data, which have not been verified.

5 IMAGE INTENSIFIERS

A more attractive technique is to insert an image intensifier between the lens and the camera tube, thus obtaining an increase in sensitivity and a potentially faster method of shuttering at the same time. An image intensifier consists basically of an evacuated tube with a photocathode at one end and a phosphor screen at the other. A high potential is maintained between the two active surfaces and focusing is achieved either by a magnetic field or an electrostatic lens system, although in some designs the photocathode is placed very close to the phosphor screen, and proximity focusing is employed. A low intensity image focused on the photocathode is transformed into an electron image on the phosphor screen, where the electron kinetic energy is converted into an amplified light image. Shuttering or "gating" may be effected by pulsing the whole energising voltage or, in some designs, by applying suitable voltage pulses to a gating electrode.

As image intensifiers are usually designed to operate at low light levels they may not always be suitable for use at normal daylight levels without some degree of input light attenuation. Such devices would be suitable for use with a polarising shutter, such as a Kerr cell or if better PLZT crystals become available in future. However, the extra complication would not be worthwhile if gating and gain can be accomplished in the basic intensifier with acceptable image quality.

Fibre optic coupling can be employed between the image intensifier screen and the camera tube thus avoiding the serious light loss (50:1 for a f/2.8 lens at a magnification of 1:1) which occurs with transfer lenses. Exposures down to 4 ns have been achieved using one type of intensifier coupled in this way to a vidicon tube[4]. This is a good indication that the light output from an intensifier screen should be more than adequate for the 50 μs exposures required in the present application, assuming that the correct phosphor is employed. A P20 phosphor, with a persistence in the order of 1 ms, is about right for the present application.

The highest gains from a single stage can be achieved with intensifiers[5,6] incorporating a microchannel plate, which comprises an array of hollow glass tubes of very small diameter, internally coated with a conducting, secondary-emission layer. Useful length to diameter ratios are less than 100 and an energising voltage of about 1 kV produces a high axial field so that each photo-emitted electron entering a channel produces a much larger number through multiple collisions of both primary and secondary electrons with the secondary emission layer. Pulsing the channel plate voltage provides an alternative method of gating: the gain may also be varied over a wide range by varying the channel plate voltage, thus automatic gain control is possible. Another advantage is that because of localised saturation of individual channels, with each channel acting independently, a large measure of highlight suppression occurs. Compared with conventional types, channel plate intensifiers are also smaller, lighter and require less voltage to operate for a given gain. However, there are problems and some of these and also those of the more conventional image intensifiers, which affect their suitability for the present application, are discussed in the succeeding sections.

Typical characteristics of the types of intensifiers discussed are included in Table 1.

5.1 Magnetic focus

A basic single-stage magnetically focused image intensifier is shown in Fig 1 (a). Light from the subject, passing through the glass faceplate, falls on the semi-transparent photocathode releasing electrons. The electrons emitted by the photocathode are magnetically focused by the combination of powerful electrostatic and axial magnetic fields between the cathode and the screen. The electrons spiral down the tube under the influence of these parallel fields moving in helical paths, all electrons emitted from one point coming together after each complete cycle of the helix at field strength dependent distances. High resolution can be achieved in the electron image, formed at these nodes, with a flat photocathode but this requires exact adjustment of the fields and, consequently, well regulated supplies. The phosphor screen can be placed at any node, generally the first, and the image always stays erect. The light gain for a single stage can be as much as 100, depending on the field strengths.

Many applications in astronomy and low-light-level photography demand higher gains, so it is usual to cascade two, three or four stages together in one envelope. Early designs used a screen and photocathode separated by a thin transparent membrane at each interface as shown in Fig 1 (b), but more recently a secondary emission technique has been employed. This principle is illustrated in Fig 1 (c). Accelerated electrons from the photocathode entering the first thin film dynode cause the ejection of a large number of secondary electrons from the other side. These are similarly accelerated into the next dynode and so on. The electron image is focused on each dynode and on the screen phosphor, as before, by adjustment of the electrostatic and magnetic fields.

Excellent resolution, low distortion, and uniform response over the active area are obtained with these magnetically focused intensifiers but for our purposes there are many disadvantages. The focus solenoid is very large and heavy. It requires air or water cooling and a continuously variable current stabilised power supply of 0.5 - 1 kw. There is a complicated starting and shut-down procedure. Adjustment is critical and gating can be achieved only by pulsing the whole energising voltage, or that of one stage in multi-stage devices. The provision of such facilities requires quite heavy ancillary equipment, therefore this type of intensifier is not suitable for portable use. It is possible to employ a permanent magnet instead of a solenoid to achieve greater portability, but a suitable magnet tends to be even larger and heavier than the solenoid it replaces, and the fixed field limits the gain variation obtainable.

At the time when the review was made, a magnetically focused triode intensifier with a gating grid, requiring only about a 200 volt swing to achieve cut-off, had recently made its apperance in the USA[7], but full information was not available and it was, therefore, not considered.

5.2 Electrostatic focus

Some image intensifiers make use of electrostatic lenses for focusing. This principle is illustrated in Fig 2 (a). Electrons from the illuminated photocathode are drawn towards a conical shaped anode which has the same high potential as the screen phosphor. The intensifier geometry is such that electrons passing through the anode aperture form an inverted image on the phosphor. One or more focus electrodes are usually incorporated between the photocathode and the anode cone. Electrostatic lenses suffer from serious aberrations, including field curvature and distortion, and it has only been possible to design systems giving good images with a curved photocathode and screen. Externally flat, but internally concave fibre optic faceplates are employed for both photocathode and screen, for this purpose and to facilitate efficient coupling to a camera tube or other intensifier stages. The internal concave shape ensures that all electron paths are of the same length which makes for uniform screen area brightness.

The sharpness of focus tends to fall off slightly towards the edge of the active screen area, but in the centre the resolution can be as good as that of a magnetically focused image intensifier. The light gain is approximately proportional to the photocathode-screen potential, and in a single stage intensifier the gain may be varied over a useful range extending from about 50 to 300. Some distortion is inevitable but with careful design it can be reduced to negligible proportions.

Gating may be achieved either by switching the whole energising voltage on and off or by suitably biasing the focus electrodes. Several recent designs have concentrated on the gating aspect with electrodes especially shaped for this purpose. It is necessary to switch rapidly from the off to the on state or vice versa in order to avoid deterioration of the image focus during the switching period and this entails fairly high-powered circuitry.

Three-stage intensifiers, as shown in Fig 2 (b) with a light gain of about 10^5 are available for low light level work, but the image quality suffers as the number of stages is increased. Comparing a typical three-stage intensifier with its single-stage equivalent, the distortion is increased by a factor of 3 and the limiting resolution halved.

Another approach is to incorporate a channel plate between the photocathode and screen phosphor in a single-stage intensifier as shown in Fig 2 (c), thus greatly increasing its light gain and incidentally obtaining a number of other advantages as mentioned earlier, without significantly increasing its dimensions. One problem is that focusing the electron image onto the flat surface of a channel plate instead of a concave fibre-optic screen surface causes appreciable pin-cushion distortion, which can be cured only externally by some form of cancelling technique. Another problem is that the angle of entry of the electrons into the channel plate varies from the centre to the edge, resulting in an area of low gain in the centre seen as a dark spot in the intensified image, but this has been largely overcome by coating the channel plate input surface with a thin film of aluminium which scatters the electrons and gives a more even distribution of penetration that is virtually independent of their angle of incidence. The aluminium film also prevents ion bombardment of the photocathode thus reducing noise and considerably increasing the life of the intensifier.

This device has been successfully employed for night vision goggles and other low-light-level applications where its small dimensions and weight are an advantage, but for our purposes these channel-plate intensifiers are more attractive for their gating, automatic gain control and highlight suppression capabilities than their high gain, most of which would have to be thrown away for daylight operation. Their image quality is not as good as that of the more conventional single-stage electrostatically focused intensifiers, and they tend to have a higher noise level. Therefore the conventional type with special gating electrodes is probably the better alternative.

5.3 Proximity focus

In proximity focusing the screen and photocathode are placed close together and a high potential is maintained between them so that electrons emitted from each point on the photocathode follow narrow parabolic paths to the screen. A biplanar diode image intensifier employing this principle is shown schematically in Fig 3 (a). The two active surfaces are rather less than 1 mm apart and the potential between them is about 5 kV. The light gain is between 50 and 100 depending on the energising voltage, and a limiting resolution in excess of 30 line pairs/mm is achievable in a 25 mm active diameter. The resolution deteriorates near the edge of the active area for a distance approximately equal to the electrode spacing, but there is no distortion or variation in image brightness over the remainder. There is no image magnification or inversion, but these are of no consequence in the present application, whereas the compact design made possible by this focus method is a big advantage.

Owing to the intense electric field at the photocathode some electron emission occurs in the absence of light, resulting in a high background radiation, but recent figures quoted by manufacturers of these devices are comparable with those for other types of intensifier, which suggests that this problem has been overcome.

The method of gating is to switch the whole energising voltage, but this is lower than that of either the magnetically or electrostatically focused intensifiers.

Two or three of these proximity focused diodes can be cascaded to obtain higher gain, but the consequent loss of resolution is rather serious owing to the relatively poor resolution of each individual intensifier.

An alternative method of achieving higher gain is offered by a proximity focused intensifier incorporating a channel plate as shown in Fig 3 (b). The main problem with this device is that adequate resolution is maintained only if the spacing between the photocathode and the channel plate is restricted to about 0.1 mm. This limits the voltage between them to about 300 V ruling out the use of an aluminium film on the channel plate surface since most of the electrons would be unable to penetrate it. Thus ion bombardment of the photocathode causes a high noise level and shortens the life of the device. For this reason the proximity focused channel plate intensifier has been less successful than the electrostatically focused channel plate intensifier described in para 5.2.

6 CAMERA TUBES

There are a number of camera tubes with a built-in image intensifier section. Their main advantage is that instead of converting the electron image back to a light image at the intensifier screen it is possible for the electron image to impinge directly onto the scanned target of the tube, thus providing a direct video output. Several different targets are available, some of which greatly increase the overall sensitivity of the tube when used in this way. Development of such tubes has largely been stimulated by military requirements for low-light-level surveillance and reconnaissance purposes but for high speed television a high sensitivity is of less importance than the need for a minimum of decay lag. None of the intensifier camera tubes has less decay lag than a Plumbicon, but some of them have been designed for range-gating work, and their gating facilities are of interest in the present study.

Range-gating is a technique in which a pulsed illuminator is employed. The camera tube intensifier stage is gated "on" for the brief duration of each light pulse with an appropriate delay so that only light returning from the subject, and not that from any intervening medium, is received by the tube. A considerable reduction of foreground back-scatter is achieved by this method, enabling clearer pictures of the subject to be obtained in conditions of poor visibility. Gating is usually achieved by pulsing the whole intensifier section energising voltage or by applying a lower voltage to a gating electrode.

A range gated system could be used for high speed television recording with very few modifications, provided the lag were sufficiently unobtrusive.

Some examples of television camera tubes incorporating internal gain mechanisms are briefly described below and typical characteristics are given in Table 1.

6.1 Image Orthicon and Image Isocon

The Image Orthicon, shown schematically in Fig 4(a) is a broadcast quality camera tube which has been in use for many years. It has a magnetically focused intensifier section in which the electron image from the photocathode is focused onto the scanned target. Secondary emission from the target results in more or less positively charged areas. The scanning electron beam loses some electrons to the more positively charged areas and the remainder return to an electron multiplier surrounding the electron gun. The video signal is derived from the anode current of the electron multiplier.

The Image Isocon, Fig 4 (b), is a modification of the Image Orthicon in which use is made of the scattered electrons returning from the target instead of the reflected beam. The net result of this modification is that a beam-noise problem inherent in the Image Orthicon has been largely eliminated and a superior performance at low light levels is achieved.

Gating of the image intensifier section of these tubes is feasible by switching the whole energising voltage, which is much lower than in most other image intensifiers but apart from this there are no particular advantages in adopting either of them for high-speed television. Their large dimensions and complicated adjustments would be an embarrassment, while their excellent resolution would be to some extent wasted, with the limited bandwidth of the video recorders used.

The Image Isocon has a very low decay lag, comparable with the Plumbicon, but it is difficult to find any good reason why it should be used in preference to an image intensifier-Plumbicon combination, except for very low-light-level work.

6.2 Ebsicon silicon diode array tubes

Some camera tubes use an array of silicon diodes as a target in a compact vidicon-type scanning and read-out system, as shown in Fig 5 (a) and (b). This technique has several advantages. In particular such tubes can be exposed for short periods to extremely high overload light levels without target damage. They also have a high resistance to image burn-in and comet-tail effects. In an intensifier tube a gain of 1000 or more is achieved in the target so that only at the very lowest light levels is a further intensifier stage required. Good resolution is achieved by having a large number of diodes in the array, and modern manufacturing techniques have eliminated the high proportion of tubes formerly rejected for target blemishes, bringing down the cost.

The intensifier section has been designed for range-gating applications in many of these tubes and a number of manufacturers are making cameras embodying it. However, although the dimensions of the intensified tube are comparable to those of an intensifier - Plumbicon combination, and it has the advantages mentioned above, the decay lag appears to be higher by about a factor of 2, which is unsatisfactory.

6.3 SEC Vidicon

In the SEC Vidicon, Fig 5 (c), the target consists of a supporting layer of aluminium oxide Al_2O_3, a layer of aluminium Al, and a low density layer of potassium chloride KCl, mounted on a metal ring. Any of the standard techniques may be used for the image intensifier section.

Electrons from the photocathode penetrate the Al_2O_3 and Al layers causing secondary emission to occur in the KCl. The secondary electrons are collected by the aluminium signal plate and when the KCl layer reaches a sufficiently high potential electrons also flow to the suppressor grid. The KCl thus becomes highly charged. The scanning beam discharges the KCl layer, returning its potential to earth, the discharge current providing a video signal across the load resistor R_L.

The SEC vidicon has a high gain, good resolution and a capability of integrating signals for long periods of time without appreciable image spread. It also has the advantage of a very low decay lag, comparable with a Plumbicon and no build-up lag, which increases its sensitivity to brief exposures. However it is not as sensitive as the silicon diode array tube and the target can be damaged by light overload[8].

The dimensions depend on the type of intensifier stage employed but would be roughly comparable with an image intensifier-Plumbicon combination.

7 CONCLUSIONS

The performance of the existing high speed television system could be improved by new shuttering techniques aimed at achieving exposures in the vicinity of 50 μs. As indicated, the present simple rotating disc shutter is not capable of this degree of improvement, without a large increase in size and power; and that even if such short exposures were made possible by a more sophisticated mechanical device, the camera sensitivity would be barely sufficient for the normal range of daylight illumination and quite inadequate for overcast conditions. The alternative of using a Kerr cell shutter would worsen the sensitivity problem owing to the light loss in the open condition, and this would apply equally to Pockels cell or PLZT shutters. The sensitivity could be increased by about a factor of two by means of light bias in the camera tube but only at the expense of an increase in noise level.

An image intensifier between the lens and the camera tube offers a better solution because of its increased sensitivity and shuttering facility, although there may be problems in matching the low light input requirements of some intensifiers to daylight conditions. Of the various types considered, the most promising are the electrostatically focused triode and proximity focused diode intensifiers. Both of these are capable of providing sufficient gain with an adequate variation for exposure control purposes and may be shuttered or gated with relatively modest voltages. The electrostatically focused triode has a superior performance in most respects but the proximity focused diode is attractive for its smaller dimensions and weight. Highlight suppression and better automatic gain control can be obtained with the channel plate versions of these devices but their high gain would be mostly wasted in the present application. Their image quality is less satisfactory than that of the more conventional types, and they tend to have a shorter life.

Of the various intensified camera tubes only the Image Isocon and the SEC vidicon have a sufficiently low decay lag but the Image Isocon is too large and complicated for a portable camera, and the SEC vidicon does not appear to have any particular advantages over an image intensifier-Plumbicon combination. However it has been used for range-gated low-light-level television systems and the alternative approach of obtaining such a system, modified to suit the needs of high-speed television, is worth serious consideration.

The more rugged silicon diode array tube has about twice the decay lag of a Plumbicon but it is still under development and may eventually supersede the SEC vidicon for this purpose.

8 RECOMMENDATIONS

A 25 mm proximity focused diode image intensifier should be obtained to assess its performance in the context of high speed television recording. Since the review was made, work has started on an intensifier of this type for high speed aerial photography and it will be specifically tailored to operating in a shuttered mode. This is covered by a DCVD contract with English Electric Valve Co Ltd, specifically for a device with a 75 mm active area. However, it is hoped that the development will yield results which can be applied to smaller devices if significant gains are possible compared with quasi dc operation in the context of direct view and low-light-level television applications.

If the proximity diode intensifier's performance proves to be disappointing, the electrostatically focused triode should be considered. It would also be well worthwhile trying out the channel plate versions of these intensifiers even though they will inevitably be more expensive and may have a shorter life.

Table 1

PERFORMANCE OF SHUTTERING DEVICES

MECHANICAL AND POLARISED LIGHT DEVICES

Shutter device and useful diameter	Wt (kg)	dia (mm)	lgth (mm)	Shutter ratio	Min. exp. (s)	Light gain	Limiting resolution lp/mm	Limiting resolution lp/PH	Distortion %	Lag (s)(1)	Switching volts (kV)	Weight of driving equipment (kg)	Main source of data given	Remarks
Motor driven rotating disc used in front of 50mm diameter lens	2.5	200	150		10^{-3}	1.0	-	-	nil	nil	nil	7.5	RAE	Bulky; inconvenient for lens changing; minimum exposure too long.
23mm Kerr cell	0.5	55	25	10^{4}	10^{-10}	0.1	30	500	1.0	nil	14-20	5.0	Barr and Stroud	Light loss; very high switching voltage; brief exposures only.
19mm Pockels cell	0.5	55	75	10^{3}	10^{-8}	0.2	20	270	1.0	nil	5-15	5.0	Electro-Optics Developments Ltd	Light loss; high switching voltage; poor shutter ratio; narrow angle.
25mm PLZT shutter	0.1	50	10	2×10^{3}	10^{-4}	0.2	50	900	1.0	nil	0.5-1.2	2.0	Plessey	Light loss; very low bulk; not yet available commercially.

IMAGE INTENSIFIERS

Intensifier type and useful photocathode/screen diameter	Wt (kg)	dia (mm)	lgth (mm)	Shutter ratio	Min. exp. (s)(2)	Light gain per stage	Output image limiting resolution lp/mm	Output image limiting resolution lp/PH	Distortion %	Lag (s)(1)	Switching volts (kV)	Weight of driving equipment (kg)	Main source of data given	Remarks
48 mm magnetic focus 2 stage diode (with focus coil)	32	229	470	10^{5}	10^{-6}	50-100	50	1700	2.0	10^{-3}	10-20	100	EMI	Very bulky; needs air or water cooling; high power; high switching voltage.
40 mm magnetic focus 1-stage triode	no data			10^{5}	10^{-7}	50-200	70	2000	2.0	10^{-3}	0.2-1.0	no data	ITT (USA)	Bulky; high power; not available commercially.
25 mm electrostatic focus 1-stage diode	0.15	50	60	10^{5}	10^{-6}	50-300	30	550	2.0	10^{-3}	10-20	10.0	Mullard	Very high switching voltage; otherwise satisfactory.
40/25 mm electrostatic focus 1-stage triode	0.6	100	140		10^{-7}	50-300	30	550	2.0	10^{-3}	0.2-1.0	5.0	Westinghouse (USA)	Moderately bulky; otherwise satisfactory.
18 mm electrostatic focus 1-stage with channel plate	0.1	45	44	10^{6}	10^{-7}	0-50K	30	400	14.0	10^{-3}	0.1-1.0	1.0	Mullard	Pin-cushion distortion; non uniform light gain?
25 mm proximity focus 1-stage diode	0.05	50	14	10^{5}	10^{-6}	10-70	25	450	nil	10^{-3}	3.0-10	5.0	English Electric Bendix (USA)	Moderate resolution; high switching voltage; very low bulk.
25 mm proximity focus 1-stage with channel plate	0.05	50	14	10^{6}	10^{-8}	0-20K	20	350	nil	10^{-3}	0.2-1.0	1.0	Bendix (USA) ITT (USA)	Ion feedback may cause short life; moderate resolution; very low bulk.

CAMERA TUBES

Camera tube type and photocathode diameter	Wt (kg)	dia (mm)	lgth (mm)	Shutter ratio	Min. exp. (s)(2)	Lowest light level for normal use lux	Limiting resolution (TV lines/PH)	Distortion %	Lag % 3rd field signal(3)	Switching volts (kV)	Weight of driving equipment (kg)(4)	Main source of data given	Remarks
30mm Plumbicon with proximity focus diode intensifier	0.15	50	234	10^{5}	10^{-6}	1.0	300	2.0	5.0	3.0-10	5.0	Plumbicon: Mullard Intensifier: Bendix (USA)	Existing camera tube can be used for initial experiments.
35 mm Image Isocon	0.57	78	432	10^{5}	10^{-6}	10-1	600-800	1.0	5.0	0.5	2.0	English Electric	Too large for portable camera; complicated adjustments.
40mm SEC tube	0.3	75	240	10^{5}	10^{-6}	10-1	600-800	2.0	5.0	5.0-10	5.0	Westinghouse (USA)	Compares well with Plumbicon plus intensifier.
40mm Intensified silicon diode array tube	0.3	77	214	10^{5}	10^{-6}	10^{-2}	600-800	2.0	10.0	1.5	2.0	RCA (USA)	Decay lag worse than Plumbicon. Still under development.

Notes: (1) Lag refers to retention of 'frozen' image. Small lag is better than no lag. (See Para 2.4)

(2) Minimum exposure time depends mainly on gating electronics.

(3) Lag in camera tube is dependent on light level. Figures are very approximate.

(4) Weight of driving equipment refers to electronics needed for gating the camera tube and is a rough estimate only.

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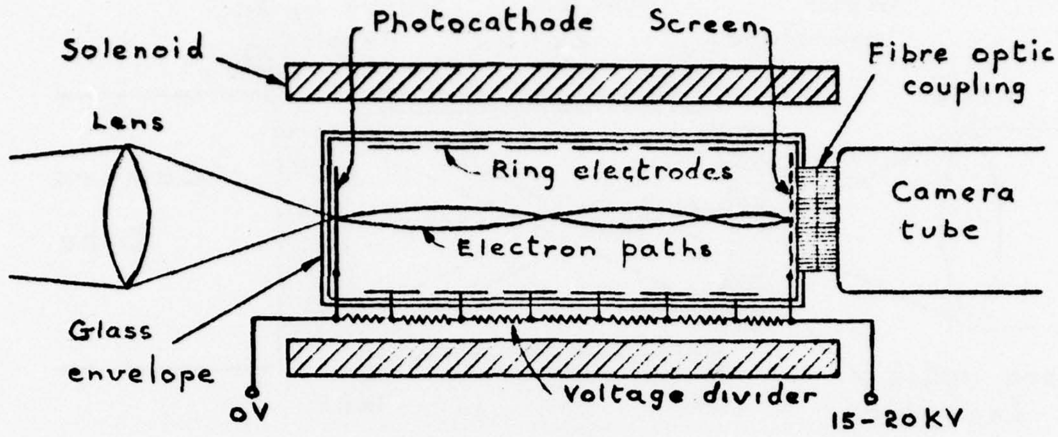
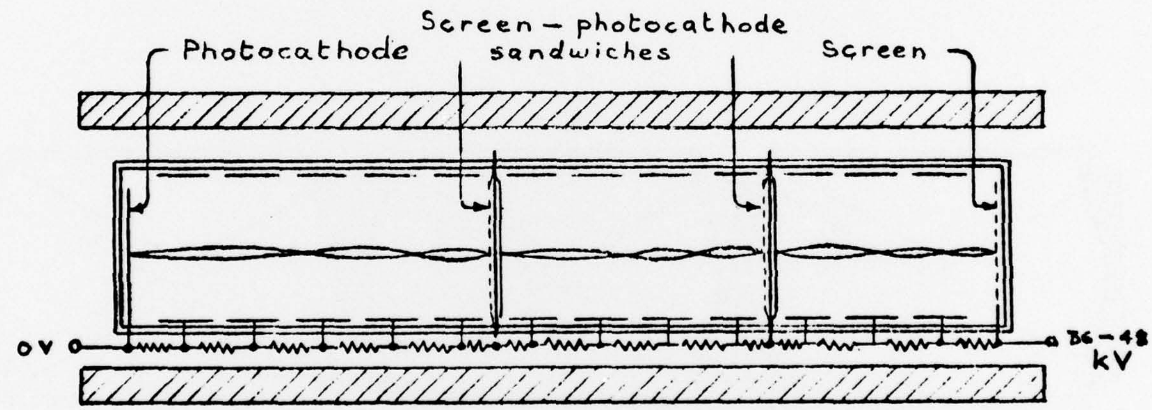
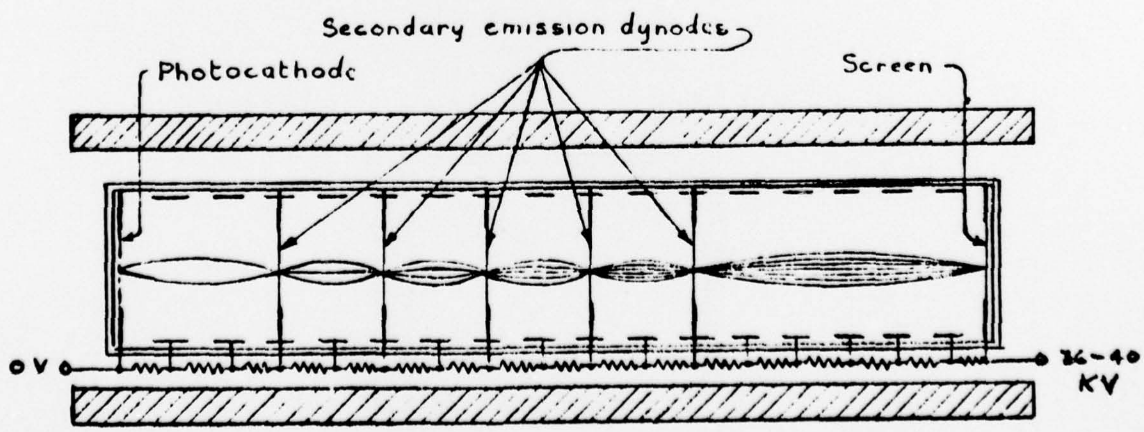


(a) Basic single-stage intensifier

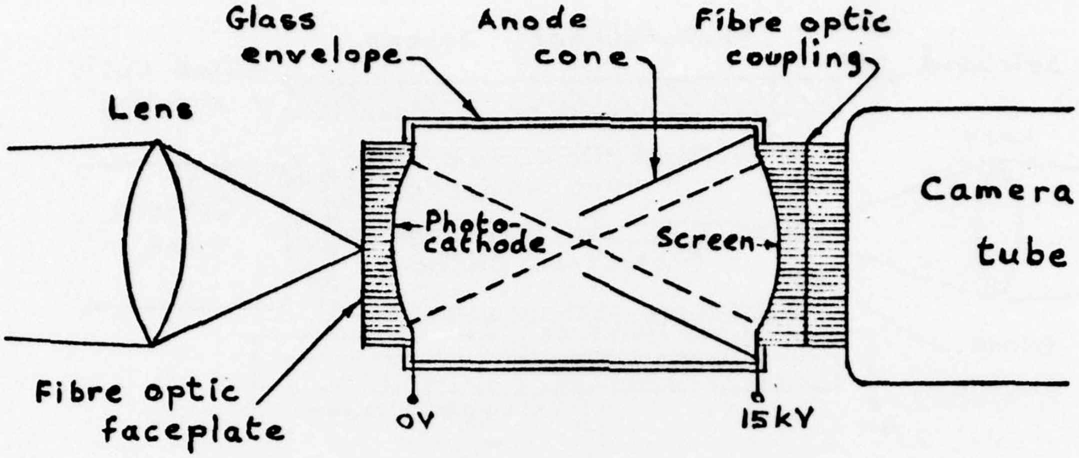


(b) Multistage version of basic design

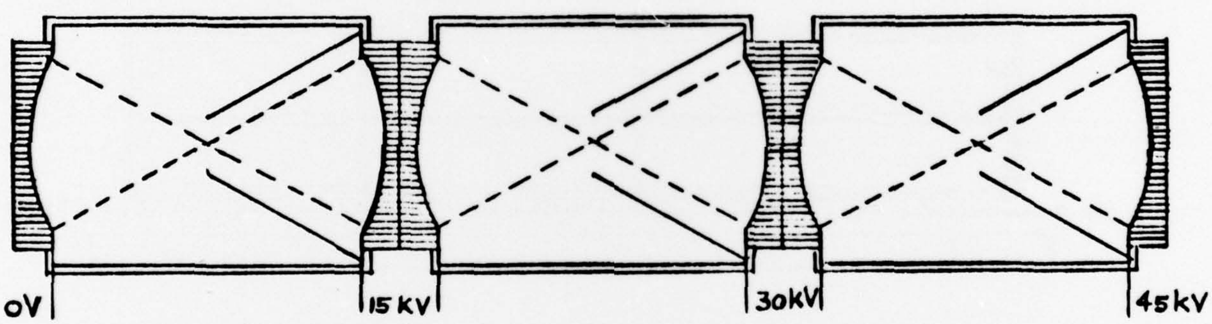


(c) Transmission secondary emission Intensifier.

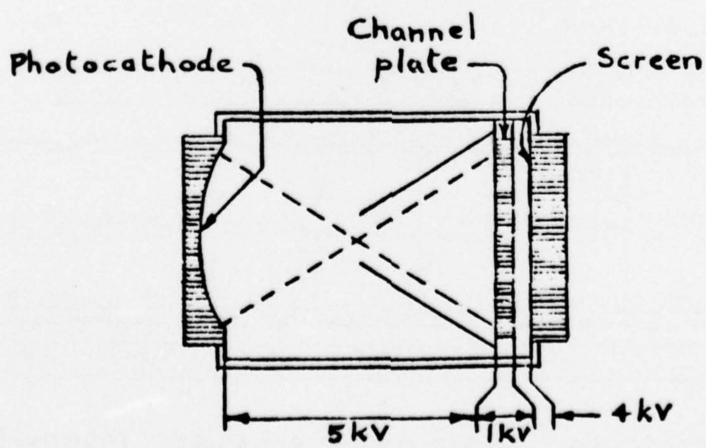
Fig 1 Magnetically focused image intensifiers



(a) Basic single-stage intensifier

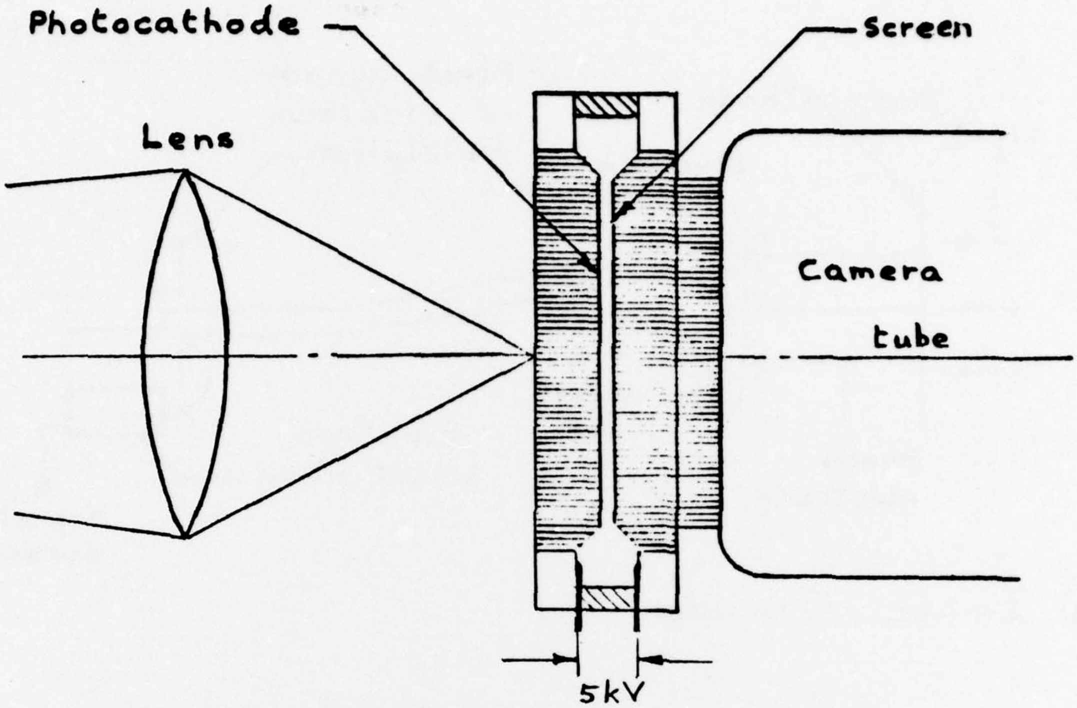


(b) Multi-stage version of basic design.

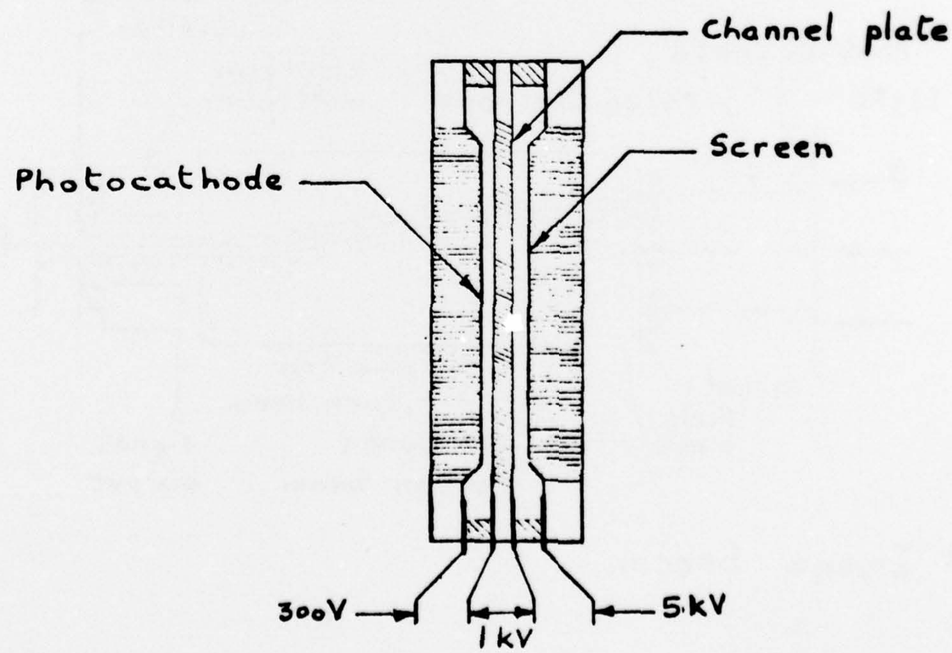


(c) Channel plate version.

Fig 2 Electrostatically focused image intensifiers

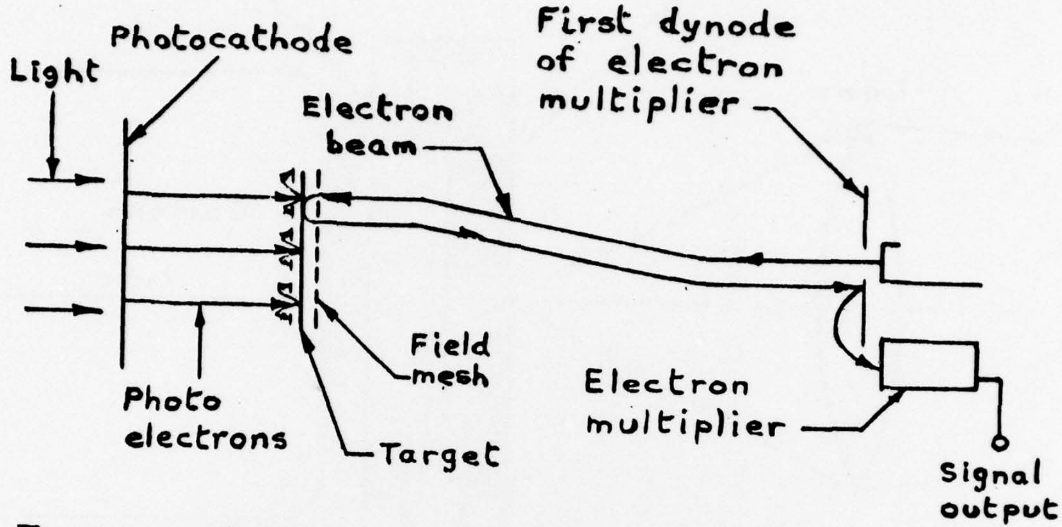


(a) Biplanar diode intensifier

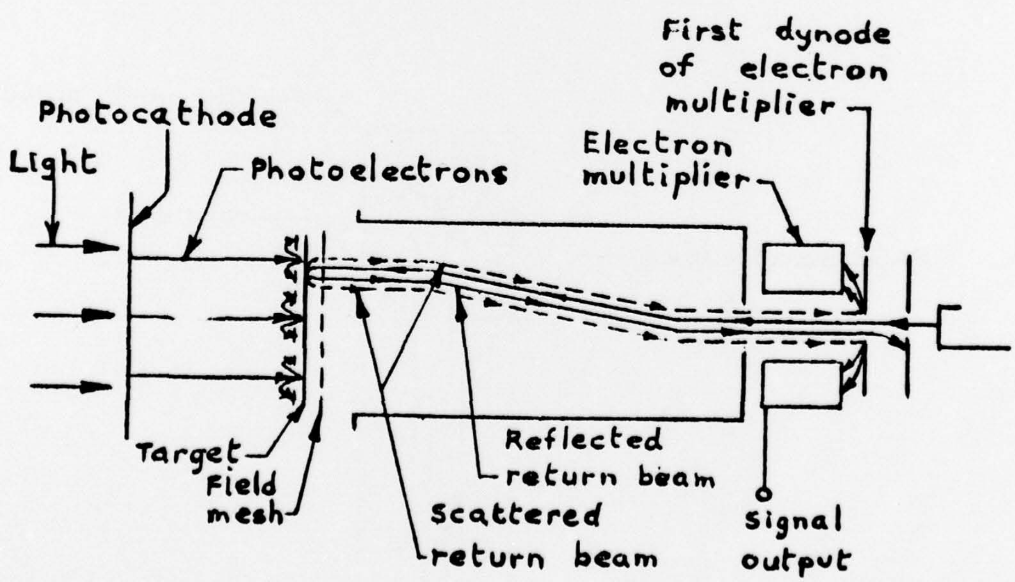


(b) Channel plate version

Fig 3 Proximity focused image intensifiers



(a) Image Orthicon



(b) Image Isocon

Fig 4 Image orthicon and image isocon schematics

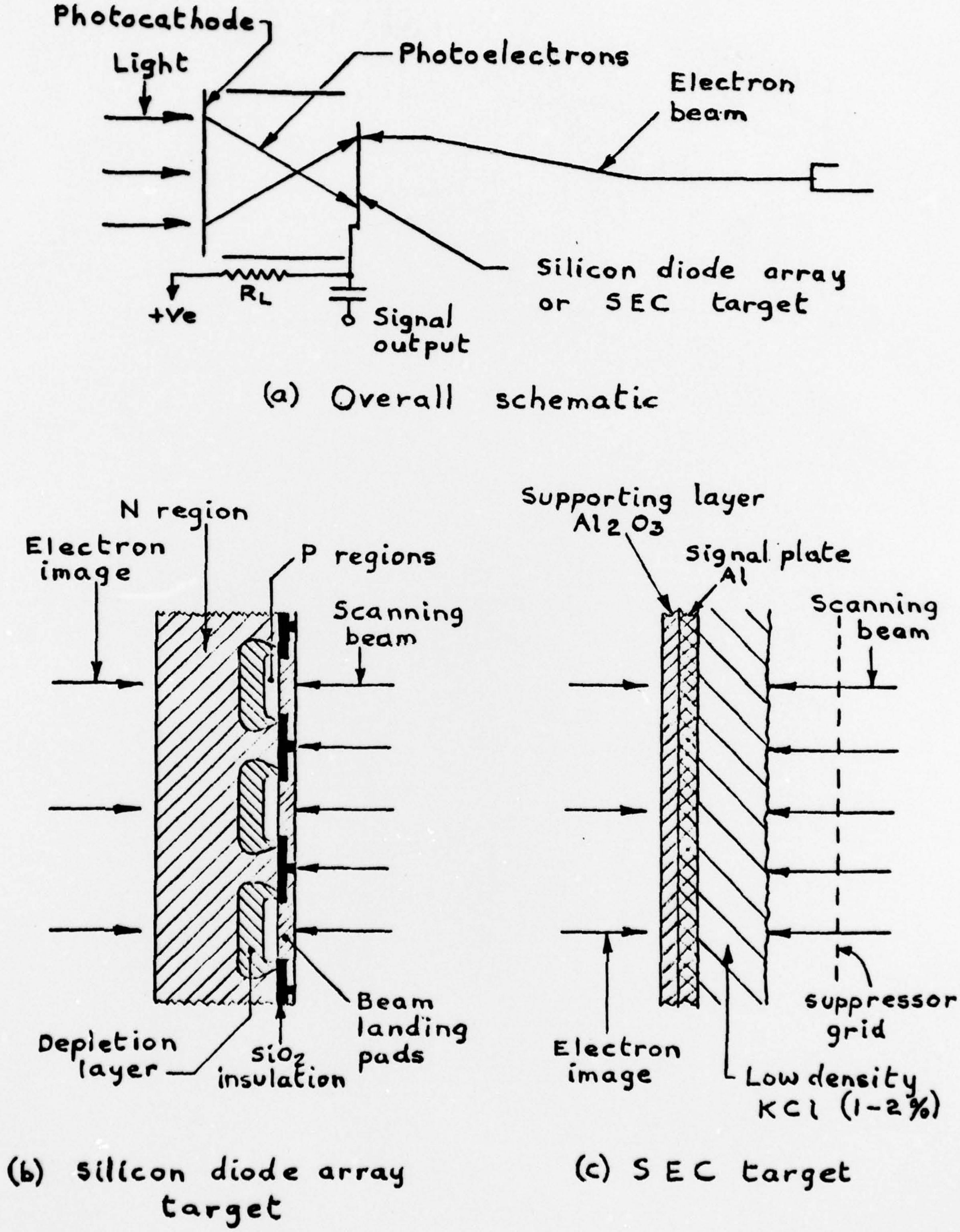


Fig 5 Intensified target vidicons

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17. Abstract

Mechanical rotating disc shutters are currently used with the high speed television camera system developed by RAE but a more compact device, capable of exposure times down to 50 microseconds, would be highly desirable. The suitability of electro-optical shuttering devices is discussed for this application and typical performance figures are given. It is concluded that image intensifiers of the electrostatically focused triode or proximity focused diode types, fibre optically coupled to a Plumbicon camera tube, offer sufficient promise to justify further work.

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