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GAS DISCHARGE DISPLAYS

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Gas discharge display devices have appropriate characteristics to compete with other technologies for seven-bar digital output. The larger dot-matrix panels represent the main challenge to the cathode ray tube in the production of alphanumeric or graphical displays

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The display by electronic devices of information from test and control equipment, computers and the like, is part of the present day electronic scene. Yet it was only 20 years ago with the growth of digital circuit technology that the first digital displays came on to the market. In the development of display devices and expansion of their application over the last 20 years, gas discharge devices have played a prominent part. The most successful device of the early days was the gas discharge numerical indicator tube, widely known under the Burroughs' trade name of the Nixie tube. The Nixie tube reigned supreme for over a decade and glow discharge technology still holds its own today in the very competitive market of numerical display with the newer seven-bar matrix designs.

In the more sophisticated display area of several registers of alphanumerics or even graphics, the gas discharge 'plasma panel' presents the main challenge to the highly developed cathode ray tube. Furthermore, the technical success of such panels has encouraged research on the incorporation of halftones and colour with the ultimate goal of the large screen picture-on-the-wall television which is the television engineers' dream for the future. Gas discharge devices used for such display applications use the light output of a cold cathode discharge emanating from excitation of the gas atoms or molecules under electron bombardment. This process is relatively efficient, especially in neon where the characteristic orange emission has an output efficiency of up to $0{\cdot}5\,\mathrm{lm\,W^{-1}}$. However, the main asset of the gas discharge for display devices is its threshold electrical characteristics.

If a voltage is applied across two electrodes in a gas, then as the voltage is increased the current builds up, due to ionisation in the gas and secondary emission processes at the cathode, until an ignition threshold V_{ig} is reached. At the ignition threshold there is a large increase in current, producing space charge which results in an actual reduction in the potential drop across the electrodes until a minimum is reached. At the minimum the potential remains substantially constant over a wide current range and the physical characteristics of a glow discharge are observed. In this region the discharge can be considered essentially as a constant voltage device requiring an external impedance to control the current. The brightness of the discharge is nominally proportional to the current. Lowering the voltage below the minimum extinguishes the discharge giving a second threshold, the extinction voltage V_e. If the discharge display device is held at a potential between V_{ig} and V_e the discharge can be switched on by applying a pulse which will temporarily raise the potential above V_{ig}, and switched off by a pulse lowering the potential below V_e. Thus the display has the potentiality of 'storage' or memory of information. It also has good contrast, as no light is visible on extinction. Although requiring a supply voltage greater than 100 V, the thresholds are such that the discharge can be switched on or off by voltages and currents compatible with solid state circuit technology.

The glow discharge has other attributes. For example, it can be positively located by the electrodes and in general the display devices can be simple in structure and therefore inexpensive. Also, the devices are reliable, with operational lives of tens of thousands of hours. There are, of course, disadvantages, the major one being the time taken for the establishment of a discharge and for its decay. This limits its switching speed to several microseconds, and also affects the voltage requirements under pulse or AC conditions. In general, the shorter the pulse the higher is the amplitude required to initiate the discharge. On the other hand, the cell can be 'primed' by the presence of charged particles in the vicinity, in which case the required pulse amplitude and/or width will be reduced. The priming may be provided by an adjacent discharge or as a result of incomplete de-ionisation, resulting from a previous discharge in the same region. The significance of these gas discharge characteristics will become apparent when display devices are discussed in the following sections.

The numerical indicator

The main glowing region of the cold cathode discharge follows faithfully the cathode contours, surrounding it in a glowing sheath. This property was exploited in the first type of gas discharge display device, the numerical indicator tube, mentioned above. This device consists of (typically) ten cathode electrodes each formed into the shape of a numeral 0 to 9. The electrodes are stacked one behind another on insulating rods so that they are electrically isolated and are surrounded by a mesh which provides a common anode. The assembly is sealed into a glass envelope containing inert gas at a low pressure.

To operate the tube the anode is held above the ignition voltage and the cathodes positively biased so that little or no current passes to them. The required character is selected by switching the appropriate cathode to earth. A bias, and therefore switching voltage, of 40–60 V is required; this is within the capabilities of integrated circuits and no pattern encoder is needed. The numerical indicator tube represented therefore a very cheap and easy to drive device for numeric display.

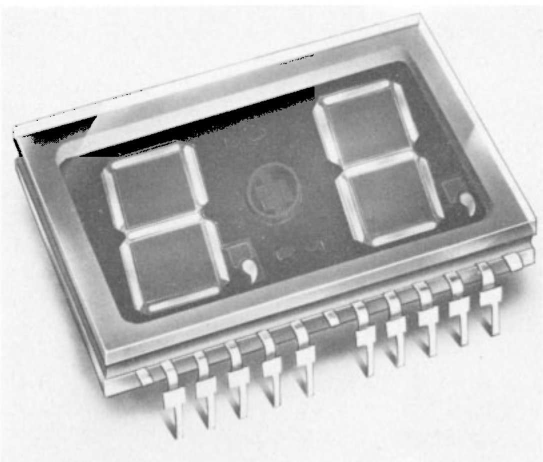
The stacked cathode array has disadvantages from the subjective point of view. The viewing angle is restricted, the digits in a register are not strictly on the same plane and the nonselected electrodes together with the rather fuzzy glow outline give a 'cluttered' appearance. The modern trend is towards planar seven-bar matrix displays for numerals, the rather square format becoming not just acceptable but fashionable. Fortunately gas discharge technology is readily adapted to this format, with seven cathode bars and a common anode. It offers the same flat package as other technologies and the threshold characteristics make it particularly suitable for multiplexing.

In the multiplex arrangement, tubes in a multinumeral array are addressed sequentially by applying a positive pulse to the anode of each tube in turn, at a switching rate fast enough to present a stationary display, > 50 Hz. As the pulse is applied to each anode, negative potentials are applied to the required cathodes to form the number. The corresponding cathode bars of each tube can be interconnected and a single pattern encoder is time-shared between all the tubes. This arrangement allows multiple digit tubes to be assembled with up to 16 numerals packaged in one envelope.

Such display tubes can be constructed with metal electrodes mounted on a lead frame with mica insulation as shown in the example of a two-digit tube in figure 1. Alternatively, the electrodes and connections may be deposited on the glass envelope by a silk screen printing technique developed for hybrid circuits. By printing four or five layers of alternately conductor and insulating patterns, the complete electrode pattern with crossover points, etc, can be printed on the rear plate of the envelope. Most of the commercial tubes are filled with a neon gas mixture giving the characteristic orange glow, but in the case of the tube shown in figure 1 a blue mercury glow tube is offered as an alternative. Brightness levels around $700\,\mathrm{cd\,m^{-2}}$ are quoted for such devices.

Although 15-bar star-burst pattern arrays have been made in gas discharge technology for alphanumeric displays on a similar basis, the gas discharge lends

Figure 1 *Two-digit glow discharge numerical indicator ZM1550 from Philips*



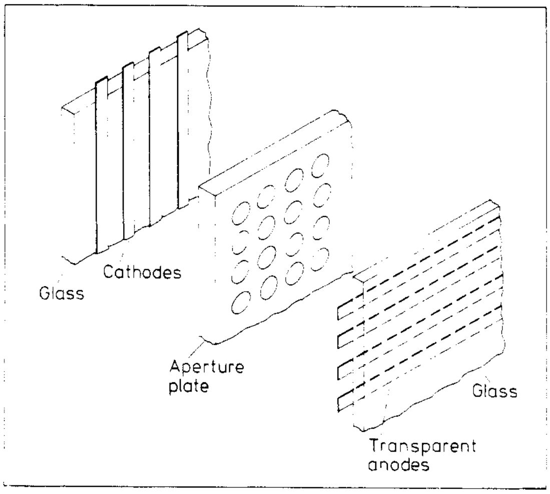


Figure 2 *Exploded view of a* DC *plasma panel*

itself to a dot-matrix array which can be cross-bar addressed for such applications. The main development in gas discharge displays over the past decade has been the exploitation of such dot-matrix arrays for displaying up to 3000 characters or graphics, the so called plasma panels.

The plasma panel

Basically the plasma panel consists of a two-dimensional array of discrete gas discharges which can be selectively addressed by cross-bar electrodes. In many designs the discharges are confined in separate cells formed by apertures in an insulating plate which is placed between two glass plates on which the orthogonal system of electrodes are mounted. An exploded view of such a panel is shown in figure 2. The three plates are sealed together round the edges and filled with a gas mixture which is predominantly neon at a reduced pressure of $1-3 \times 10^4$ Pa. The panels may be operated under AC conditions in which each set of electrodes acts alternately as anodes or cathodes, or under DC conditions in which one set of electrodes always acts as cathodes and the other as anodes. Both methods of operation are exploited in commercial designs. In the AC operation the electrodes need not be in contact with the gas and indeed are normally isolated from it by an insulating layer.

To ignite a required cell without unwanted cells igniting, coincident pulses are applied to the appropriate row and column, such that the combined amplitude of the two pulses is sufficient to ignite the cell but a single pulse amplitude is not. Since two cells in different rows and columns cannot be addressed simultaneously without coincident pulses also appearing on other cells, the panel must be addressed either a dot at a time or a row at a time (line dumping). Two drive modes may be distinguished, 'cyclic'– in which each cell is illuminated only during the addressing period– and 'storage'–in which a cell, having been addressed, remains lit until it is erased some time later. Once lit, the current through the cell must be limited by a series impedance.

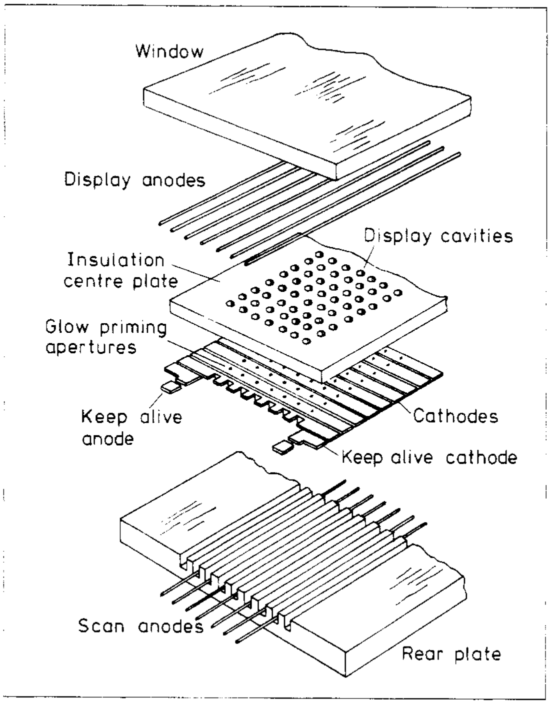


Figure 3 *Exploded view of Burroughs Self-Scan panel*

In the cyclic mode the cells are biased below the extinction voltage, and the current limiting impedance can be placed outside the panel in series with one set of electrodes. It is then time-shared between all the cells along the electrode to which it is connected. In the storage mode the cells are biased to a voltage between V_{ig} and V_e. Time sharing of the impedance is not possible and a series impedance is required for each cell. In the AC panel the insulating layer provides a capacitive impedance to each cell and the panel therefore has inherent storage.

Incorporating storage in a DC panel is more difficult and although panels have been designed with thick or thin film resistors deposited at each cell position, practical large area DC panels with storage have not reached commercial development. The DC operated panel is therefore essentially a cyclic panel and as such is limited in character capacity. This is partly due to the switching time and partly due to the brightness. The brightness of the panel is determined by the product of the duty ratio and the peak current. The latter is limited since high peak currents can cause erosion of the cathode by sputtering and shorten the operational life. In practice the duty ratio is limited to about 1:250 when the brightness would be of the order of $100\,\mathrm{cd\,m^{-2}}$ for neon.

Design of plasma panels

Early DC panels were based on the construction shown in figure 2 with the aperture plate fabricated by etching holes in a photosensitive glass which was later fired to an opaque state. More recent designs have employed silk screen printing techniques, building up the cellular structure or discharge barriers with several layers of insulating prints. The cellular structure is necessary to locate the discharge and prevent crosstalk. Such panels are simple and economic to construct and suitable for displaying up to 1000 alphanumeric characters. However, they require a transistor driver for each row and column which makes their circuit cost high compared with a CRT.

A panel which reduces the circuit cost and has been especially successful for limited size displays is the Self-Scan panel marketed by Burroughs. An exploded view of its first design of panel is shown in figure 3. The panel can be considered as having two sections: (i) the glow scan section, which consists of the scan anodes and the rear side of the cathode conductors: and (ii) the display section consisting of the display anodes and the front side of the cathodes with an insulating aperture plate in between, similar to the conventional DC panel (figure 2). The two sections are linked via the small glow priming apertures in the cathodes.

In operation, a glow is transferred down the length of the panel at the rear of each cathode at a field rate of approximately 60 Hz. It is hardly visible from the front as the cathode apertures are very small, but it primes the display cells in front of the glow, reducing significantly their ignition voltage. If, therefore, an anode pulse is applied at the appropriate time of such an amplitude that it will ignite a primed cell but not an umprimed cell, then a visible glow will occur at the designated crosspoint. Thus by parallel addressing the anodes in synchronism with the glow transfer, the desired data can be displayed.

The transfer of the glow along the back of the cathodes is effected by connecting every sixth cathode in parallel and applying voltage pulses of the order of 100 V in sequence to the six bus-bars so formed. The amplitude of the pulses is such that they will only ignite the heavily primed cathode adjacent to the previously lit cathode, so that the correct sequence is ensured. Thus only six drivers are required in the column direction. The same company has recently introduced a second design aimed at reducing the panel cost. The glow is transferred along the front of the panel between the display cells hidden from view by a wide transfer anode strip. Being coplanar, the cathodes and insulating barriers can be silk screen printed on one plate and the glow transfer and display anodes on the other with an aperture plate between. A larger dot pitch has to be used, however, to accommodate the glow transfer sections. Clearly the brightness depends on the duty ratio and therefore on the number of characters per line. For 40 characters a brightness around $100\,\mathrm{cd\,m^{-2}}$ was achieved which means the panel is visible in a normally lit room.

For a capability of 1000 or more characters and graphics, storage in the panel is required because of the switching time and also to improve the brightness. It is in this area that the AC panel comes into its own. Pioneered by Bitzer and Slottow at Illinois University, AC panels have been the subject of considerable investigation and are now commercially exploited by several companies.

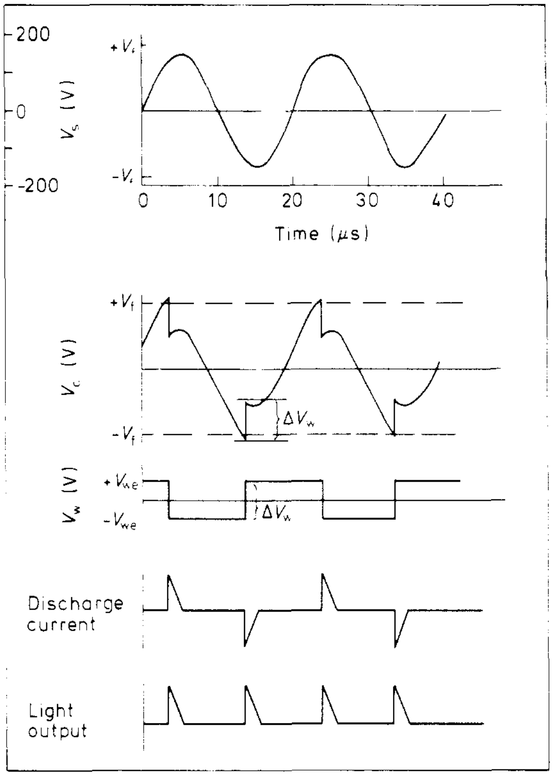


Figure 4 *The sustainer voltage V_s, tube voltage V_c and wall voltage V_w for a typical AC plasma panel together with current and light output waveforms*

Constructionally, AC panels are similar to the DC panels shown in figure 2, except that the electrodes are coated with a glass dielectric layer. The mechanism, however, is rather different. Consider an AC signal applied across the electrodes, of an amplitude V_f such that a gas discharge breakdown can occur on each half-cycle. The establishment of the discharge on say the positive half-cycle will result in the build-up of charge on the dielectric surface in front of the cathode which will set up a voltage V_{we} in opposition to the applied voltage. These wall charges have two effects: first, they can reduce the voltage during the half-cycle to a value below the extinction voltage and extinguish the discharge (which can happen in less than a microsecond) and second, on reversal of the polarity, the wall charge voltage V_{we} adds to the applied voltage to allow breakdown at a lower applied potential (i.e. $V_f - V_{we}$). At any voltage between V_f and $V_f - V_{we}$ the cell has a bistable characteristic: a cell initially ignited will re-ignite each half-cycle, but an off cell will never be ignited.

The operation of the panel is illustrated in figure 4 which shows the sustainer voltage waveform V_s, the voltage across cell V_c and the wall voltage V_w, for a typical panel, together with the current and light output. The output pulse is of the order of a few microseconds, and therefore the brightness depends on

Figure 5 *Graphic display on a 21·6 cm (8·5 in) Owen-Illinois* AC *panel having 512 × 512 lines with a resolution of 24 lines/cm (60 lines/inch)*

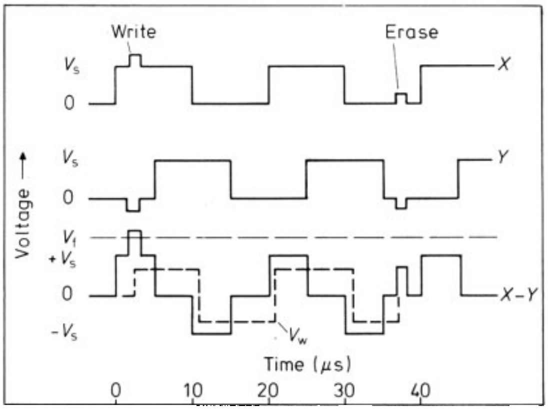


Figure 6 *Address pulses and sustainer waveform for operating an* AC *plasma panel*

frequency. There is however a maximum frequency of 100 kHz set by the de-ionisation time, giving a duty ratio of 1 in 100.

In the AC panel the discharge is restricted to the wall charge area in front of the electrodes and there is no need for the cellular structure between the electrodes. Thus the panel consists of two plates placed parallel so the electrodes form a cross grid, the narrow space between the plates being filled with gas and sealed round the edges with glass enamel. Because of the simplicity of the structure which has no geometric registration restrictions, a resolution up to 24 lines/cm (60 lines/inch) is obtainable, as opposed to 16 lines/cm (40 lines/inch) achieved by DC panels. Panels having 512 × 512 lines are commercially available and an example is shown in figure 5.

To change the state of an AC cell it is necessary to alter its wall voltage, i.e. from zero for the 'off' cell to a finite value V_w for an 'on' cell. This is normally achieved by superimposing addressing pulses of the order of 2 μs duration on the sustainer voltage suitably timed relative to the sustainer waveform. Typical drive waveforms are shown in figure 6. The square-wave sustainer is preferred and has now superseded the sine-wave drive for AC panels. Panels are filled with a neon–argon mixture to give low voltages and a recent development has been to coat the dielectric layer with MgO to reduce the values further. Typical driving pulses are 100 V sustaining (200 peak to peak) with switching voltages less than 150 V. The inherent memory of the panel allows random write, and random erase, but it is more complex to drive than a cyclic panel.

It still requires a driver for each column and row and schemes to reduce the number of electrode connections are being actively investigated. They mainly involve a self-shifting arrangement whereby the information is fed into the panel at one corner and transferred to other parts by applying successive pulses to two transfer electrodes interposed between each display cell, in a similar manner to the Self-Scan system. Because of the extra electrodes this system reduces the resolution by a factor of three. Recently Fujitsu described a self-shift system in the horizontal direction only, whereby one of the shift electrodes was between the anodes and the other between the cathodes which were interdigitally connected in the anode direction. A cell pitch of 0·5 mm was attained by this technique. Although twice as many rows are required, only two connections are required for the columns with seven addressing electrodes for 7 × 5 dot characters. Another scheme involves pairs of electrodes on both walls associated with each glow position. The electrodes at each cell act as four AND gates and matrixing of the electrodes is possible.

AC panels are beginning to make their impact on the alphanumeric market, although the pioneer, Owen-Illinois, has now dropped out of the arena. Although capable of large capacity display they compete with the Self-Scan panel for the medium size displays of 300–500 characters. The total cost of the panel and the drive circuit constitutes the main barrier to the commercial exploitation of larger displays, where compared to the CRT they are uneconomic.

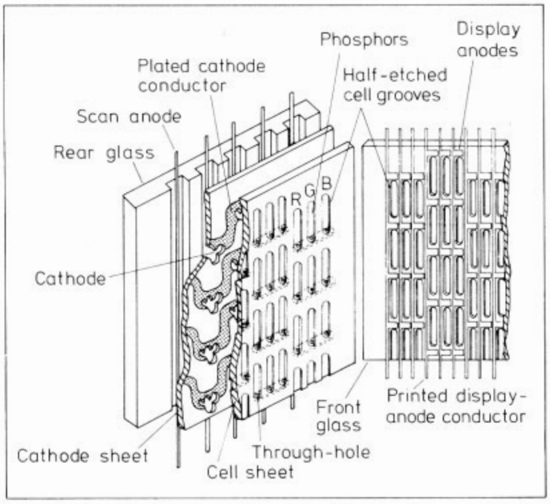
Colour and halftones

The gas discharge panels for alphanumeric applications are normally filled with a neon gas admixture giving the characteristic orange–red glow. It is not surprising, however, that, as a competitor to the CRT, applications to television should also be considered; this entails full colour and halftones. The achievement of colour depends on combining the discharge with phosphors. The phosphor can either be activated by electrons (cathodeluminescence) or by ultraviolet stimulation (photoluminescence). Most of the investigations however have been with photoluminescent phosphors. The gas mixture is selected to give the maximum emission in the ultraviolet region with a minimum in the visible; xenon, krypton or mercury vapour are used, often admixed with other inert gases. The early experiments were carried out with standard panels and TV tube phosphors, the phosphor dots being deposited on the window in front of the cells, or in the case of DC panels on the wall of the cells in the aperture plate. The luminous efficiencies were rather low with losses occurring in the phosphor layers. In the AC panels there were problems of optical cross-coupling and the phosphor affecting the electrical characteristics. Better application of the phosphors with UV absorbing layers between dots has reduced the latter problems. Improvement in the efficiency has been obtained by the choice of the gas mixture and by better matching of the phosphor to the UV radiation. Efficiencies up to $0{\cdot}5\,\mathrm{lm\,W^{-1}}$ comparable with neon values have been obtained with green phosphors. A further improvement can be obtained by using the positive column of the discharge as in fluorescent tubes rather than the cathode glow normally used for display. To make use of this enhancement the discharge must be turned through a right angle so that the column is viewed side on.

In general the introduction of colour into a plasma panel presents complications if an equivalent brightness to the neon panel is to be achieved. Also there is evidence that operational life is reduced. Halftones are mainly of interest to television display but they can offer an extra dimension to alphanumeric panels for some applications.

Halftones are a problem for storage panels where a common sustainer is applied to all the elements. However, because the AC panel is more advanced for large area displays, several techniques have been proposed for incorporating grey scale in such panels. One approach was to use a complex waveform by which the cell is ignited two, four or six times in a given time period depending on when the address pulse is applied. Only four levels of intensity could be obtained. Alternatively the panel can be scanned several times in each frame period, the brightest spots being turned on in the first scan, the next level on the second scan and so on. Because of the slow switching speed, again only a few grey scale levels are obtained. Systems have also been proposed in which the grey scale is attained by spatial distribution of lighted cells, each picture element consisting of several cells which can be on or off. This requires a panel with a high resolution.

For the DC cyclic panel, where the cells are sequentially addressed, the problem is greatly simplified. In a line-dumping system each cell can be current and/or time modulated during the line period. Over 64 grey scale levels have been achieved, and 'black and white' panels of 100×100 elements were demonstrated ten years ago. In the last few years colour displays on similar sized panels have been demonstrated mainly by Japanese companies. The most recent is that by NHK, the Japanese Broadcasting Corporation, using a positive column DC arrangement with Self-Scan. A cut away diagram of the panel is shown in figure 7 together with a photograph of the output. The panel had 95×384 elements on a cell pitch of 0·5 mm and gave a white luminance of $36\,\mathrm{cd\,m^{-2}}$ with a dissipation of 23 W. See also the article by R N Jackson and J Smith in this issue.



a

b

Figure 7 *Experimental Self-Scan colour panel with positive column display constructed by NHK* **a,** *Cut away diagram of the panel construction.* **b,** *Panel output*

No doubt if the application to television succeeds, the price of panels and their drive circuits will come tumbling down and their application to alphanumeric displays will be assured. There is, however, a long way to go with the main barrier being the light efficiency which needs to be at least an order of magnitude better for a practical TV display.

Further reading

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