Plasma display panels have come of age

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This paper discusses the present situation for plasma display panels, their principles and characteristics. Work being conducted in a c plasma technology at Thomson-CSF is described in detail.

Keywords: display devices (computers); gas discharge lamps; electron tubes.

A recent study concludes that the market for industrial displays will expand rapidly over the next five years, that the growth rate for industrial displays will indeed outpace the overall industrial electronics market itself by about 30 per cent, and that the 'crossing' of the costs of plasma panels and CRTs will occur about 1985[1]. At the forefront, with 142% growth predicted, one finds the gas discharge or plasma display panel (PDP).

What are the reasons for this success? Plasma display panels have gained acceptance and popularity because of their characteristics, advantageous from three points of view:

Physical:
compact size;
large active display area;
high display capacity;
robustness;
perfectly flat screen.

Operational:
relatively low operating voltages;
direct access to x and y conductors by digital signals;
inherent panel memory, eliminating refresh requirements (a c panels).

User-oriented:
absence of geometrical distortion;
uniform luminance (no vignetting);
high contrast (in high ambient light, low contrast in dark environments for self-scan);
extremely wide viewing angle;
flicker free (a c panels);
easy to read;
possibility of rear access.

This acceptance is principally due, without doubt, to the high quality of the display itself and, for a c plasma panels, to the high degree of image stability and screen transparency. In addition, the compact nature of the panel and the associated electronics meets a growing demand, for example, in the case of word processors and banking terminals. In comparison with CRTs, the PDP is directly addressable in binary x, y address and the operating voltages are low – important considerations to be borne in mind. Finally, the robust nature of a c panels, their simple nature and wide operating range have earmarked them for demanding industrial and military environments. In addition, the transparent nature of the screen also makes it possible to superimpose the plasma panel on a background map chart.

CLASSIFICATION

The generic term 'plasma display panel' encompasses a wide range of devices, covering several fields of display. These may be classified by dividing the products into five groups:

1. Seven-segment or 5 x 7 font or alphanumeric matrix addressed displays of one to several rows.
2. Alphanumeric matrix addressed displays having capacities of up to several hundred characters, some having simple graphic capability.
3. High-resolution matrix addressed displays having from 10^5 to 4×10^6 pixels for full graphic capability.
4. Matrix addressed displays with half-tones for imaging and television.
5. Matrix addressed dispalys with half-tones and colour capability for imaging and television.

Table 1 compares these five categories of plasma displays. It is certain that PDPs have made great inroads into the second and third categories.

A plasma display panel is an electro-optical transformer converting electrical signals into information which is accessible to the human eye. The electrical signals can be either digital, as in alphanumeric devices, or analogue, as in video television signals. Display devices may be classified into two families – light emitters and modulators, depending on their operating principle. Light emitters, which convert electrical energy into light, are power-consuming, since the efficiency of such

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effects is very low. In general, less than 10% (cathodoluminescence 20%), and in most cases less than 1%, conversion is achieved. The plasma display panel is found in this class together with electroluminescent, cathodoluminescent and vacuum fluorescent displays. Light modulators, on the other hand, modulate the light intensity in accordance with the drive signals. They include, for example, electrochromic, electrophoretic and liquid crystals (twisted nematic, dynamic scattering nematic, or tunable birefringence nematic and smectic) devices.

Although differing widely in structure, plasma panels all are based on a common operating principle, namely the use of the luminescence produced by a gas discharge, or more accurately, disruptive discharge in rare gases between cold electrodes[2,3], to display information. Figure 1 illustrates the morphology of the gas discharge. Electrons are released from the cathode by positive ion and ultra-violet bombardment, a sheath of positive ions near the cathode being produced by the build-up of discharge. Electrons under a typical potential of 150 V are accelerated across this gap which gives them sufficient energy to ionize the gas molecules. This ionization produces the cathode glow. At the end of the cathode glow is a relatively dark volume, the Faraday

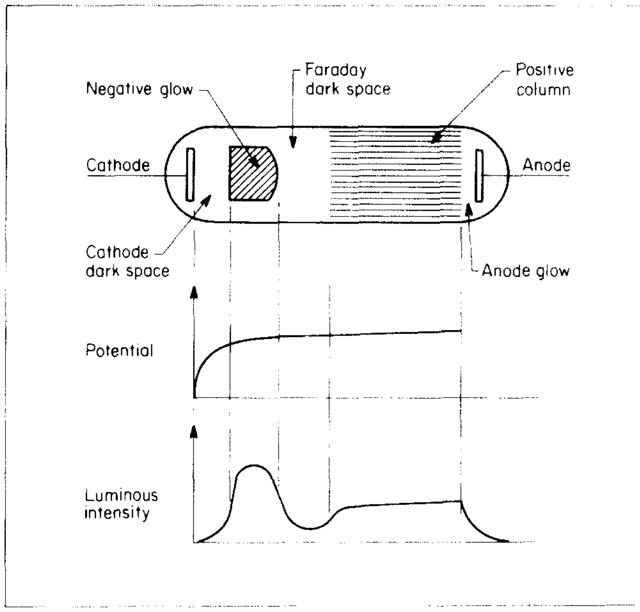

Fig. 1 Morphology of the discharge. In most display applications the cathode dark space is very small. The negative glow is the principal one

Table 1. Comparison of plasma display panels

	Technology	Employment	Alternative devices	Present market position	Future forecast	Format (typical)	Applications	Remarks
Linear array	d c	Widespread	LCD VFD LED	Very good	Stable	1 x 8 to 4 x 32 characters	Digital displays: cash registers, measuring instruments, shop and workshop data handling, etc	Fixed characters
Matrix addressed screens (several hundred characters)	Largely d c with some a c	Common	LCD VFD CRT EL	Very good	Rising	1 or 2 x 80, 4 x 32 to 8 x 40 characters	Alphanumeric terminals; electronic typewriters, telematics, sales points, automobiles, etc	Mainly fixed position VFD is the main competitor
Graphic screens ($\geqslant 10^5$ points)	Exclusively a c	Limited	CRT	Good; very good for demanding environments, eg military	Rising	32 x 256 to 2 000 x 2 000 dots	Computer terminals, word processing, civil, industrial and military applications, alphanumeric and graphic	Alphanumeric and full graphics Adjustable luminance (limited) Generally no fixed pattern
Screens for imaging	Largely d c with some a c	–	EL CRT	Only in laboratory	Unknown	256 x 256 and up	Television and telematics	Drive-related problems
Screens for imaging	Largely d c with some a c	–	CRT	Early research stage	Promising if successful		Professional and domestic television	Minimum 200 000 colour trios and eight luminance levels The possible goal for the future?

dark space which is followed by the positive column, composed essentially of neutral, slightly ionized plasma. The positive column can be of infinite length and may even be non-existent, if the anode is located in or near the Faraday dark space.

The host gas emits radiation at visible wavelengths, the gas discharge emitting light from the negative glow and the positive column. Plasma display panels have been made in which the positive column in mercury is used to produce ultra-violet light, which excites phosphors. To date, however, no commercial displays using this principle exist. A list of references concerning gas discharges is given in the bibliography[4-9].

Figure 2 illustrates the current-voltage characteristics of the gaseous discharge; it is seen that the self-sustaining voltage stems from the breakdown voltage V_B. The self-sustaining voltage is due to the establishment of a space discharge and a sharp potential gradient in the region of the cathode. The characteristic curve shows a zone of negative resistance, within which the discharge current is only limited by the series resistance. The discharge is maintained by a voltage across the cell that is lower than the voltage V_B and greater than the minimum sustaining voltage V_s (extinction threshold).

Plasma panels as display devices

What are the characteristics of gas discharges that make them suitable for the display of information? The answers are an emission of visible light (with an energy efficiency of 0.5 lm W^{-1} for neon), emission of ultra-violet radiation for luminophore excitation – yielding a display of colours, the existence of threshold phenomena (of great interest for matrix addressing), inherent storage capability (eliminating the need for refresh and all its inherent problems; for example, flicker), and the possibility of priming. It is worth while at this point to examine in further detail these characteristics, one by one.

The luminescence produced by a gas discharge is attributable to the transitions between different excited atom states, these excited states resulting from inelastic collisions

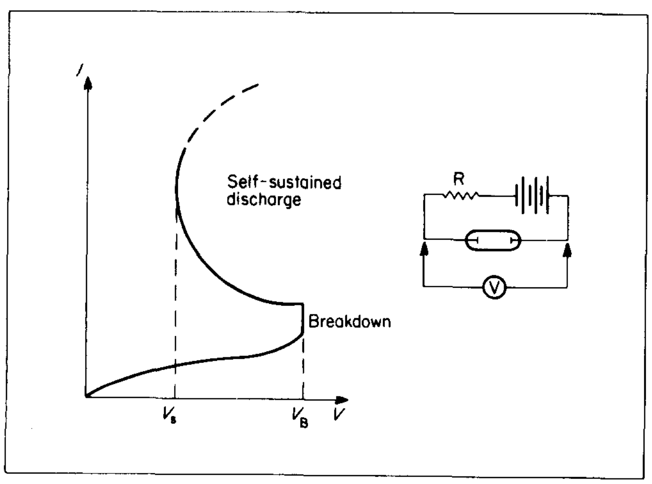

Fig. 2 $I = f(V)$ characteristics of the gaseous discharge

between free electrons and gas atoms – principally in the negative glow region. Other transitions take place between states where the energy difference is greater, resulting in a higher frequency of radiation, generally situated in the ultra-violet.

The threshold capability makes possible x, y row and column drive. Only the addressed point at the intersection of the x and y electrodes is addressed and spurious addressing by half selection is eliminated. In a large array of cells, it is prohibitively costly in terms of drivers and connections, individually to drive each cell. Interconnecting the electrodes in a matrix array very effectively reduces the number of drivers and interconnections and hence the cost.

Storage capability can be understood by referring to Fig. 2. As the voltage increases, breakdown is reached, ie a discharge is produced. The discharge is maintained with a lowering of the voltage until the threshold point is reached. Thus the gas discharge point remains on after having been addressed. In addition, the effects of flicker, inherent in the techniques of refresh in the case of non-storage operation, are not felt. The direct utilization of this technique is not, however, without its drawbacks, and requires one series resistance per cell. This poses technological problems and explains the use of line-by-line addressing, which only requires one series resistance per column, but strongly reduces the luminance. Storage capability has been most efficiently used with a c plasma panels[10]. The pulse drive technique[11] is another operating mode yielding signal storage.

Discharge does not begin immediately upon application of the firing voltage – one electron or ion must be present in the gap, to be accelerated and to produce the first of the ionizing events necessary for breakdown. Priming, the introduction of the necessary electrons or ions into the gap between electrodes from a nearby discharge, reduces both the firing voltage and the time lag. The requirement for initiating particles leads to a statistical time lag in breakdown and, in addition, there is a formative time lag (a few microseconds) during which the breakdown process proceeds to the self-sustaining state. If the priming is sufficiently intense, the firing voltage can be almost the same as the sustaining voltage and the firing delay reduced[12]. Priming is used in a c displays to lower and render more uniform the firing voltage[13]. It is related to the density of the charged particles and to the excited metastable states in the gas, the density being a function of the time and space in the interior of the plasma panel. In particular, priming depends directly upon the activity of neighbouring cells[14]. If, for example, a non-active cell is in the neighbourhood of an active cell, the density of the charged particles will be high and the non-active cell will have its firing potential strongly reduced. Cells further away on the other hand, will have, a potential V_B that increases with distance (Fig. 3). This effect can be exploited to bring about a shift of the discharge[15-17]. Figure 3 shows that it is possible to displace the discharge, step by step, towards the right with a simple three-phase drive. This effect is employed in d c panels such as Burroughs Self-Scan, the more recent device of Philips[18] or even in a c panels, such as Fujitsu's Self-Shift.

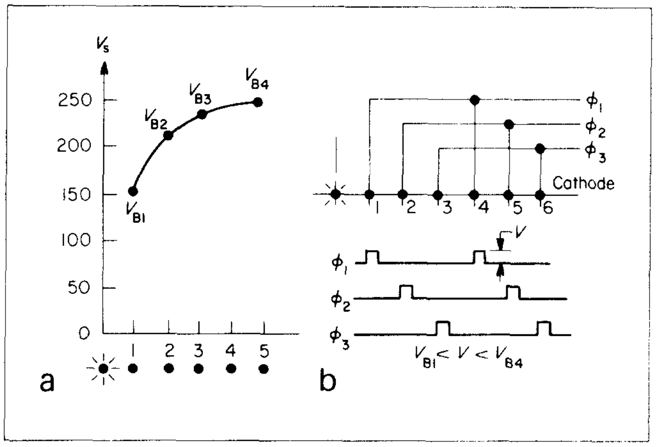

Fig. 3 Mechanisms for : a – priming; b – shift

Two technologies

Two different basic technologies have been developed and commercialized, giving rise to what are known as d c driven plasma panels and a c driven plasma panels. In d c plasma displays, the electrodes or resistive extensions of these are immersed in the gas. A C operation would be possible, but discharge currents are almost always unidirectional. In a c plasma panels, a dielectric surface isolates the electrodes from the gas with which they only have electrostatic coupling. Only a c operation is possible. Both types of panel can be operated in a storage or non-storage mode where storage means that the memory is inherent to the display device. In the non-storage or cyclic mode, the memory is external to the display and the image information is transferred to the display device sequentially and refreshed frequently enough to avoid flicker. Thus the difference between the two panel types is not simply structural, but also impacts the operating characteristics. Table 2 gives a short comparison of the two technologies.

It is evident from Table 2 that the optical characteristics are very similar for the two technologies. A C plasma panels however, do not suffer from flicker, a particularly disagreeable phenomenon for the operator under prolonged observation, and offer a wide viewing angle. These are important characteristics to bear in mind where scanning is employed. D C plasma panels are suited to the linear display of several digits. Many of the commercially available d c plasma panels are employed in seven-segment displays. Examples are the Burrough's Panaplex, the Beckman Planar and National Electronic's Plasmac. They are also suitable for the alphanumeric display of several hundred characters, of which the best-known example is the Burrough's Self-Scan. This uses the shift mechanism previously mentioned, a simplified presentation of which is given in Fig. 4. These panels are well adapted to the display of several rows of characters, but due to their technical complexity they do not have the high-resolution graphic capability of a c plasma panels. A new memory panel being developed by Burroughs marries the advantages of the two technologies by associating d c and a c operation.

Electronic problems with gas discharge

In matrix addressed screens of all types, the drive electronics represent a considerable, if not preponderant part of the device, whether from the standpoint of volume, cost, or

Table 2. Comparison of d c driven and a c driven plasma display panels

Parameter	Panel type: a c driven	Panel type: d c driven
Colour	Equivalent	Equivalent
Luminance	Equivalent	Equivalent
Contrast	Very good	Good
Flicker	None	Under certain conditions
Viewing angle	Very wide	Limited
Resolution	High	Limited
Number of cells	High	Limited
Compactness	Equivalent	Equivalent
Connections	Complex	Simple
Drive electronics	Complex	Medium complexity
Panel technology	Simple	Complex
External memory	Not required	Required
Power consumption	Equivalent	Equivalent

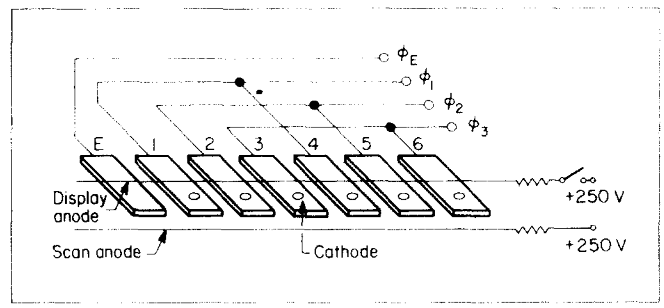

Fig. 4 Self-scan schematic structure

impact on performance. The search has been to simplify the electronics, the main efforts being concentrated in the following areas:

1. Development of a structure utilizing the previously described shift mechanism in order to reduce the number of screen outputs (sometimes considerable) and consequently the number of drive amplifiers necessary. This solution has met with a certain success, especially for d c panels of medium capacity.
2. For high-capacity a c panels, realization of multiplexing, associating to each electrode a network of two diodes and a resistance, allowing the realization of AND logic, as is done, for example, in the addressing of magnetic memories.
3. Finally, more recently, the development of special integrated circuitry, to reduce the volume occupied, and with integration of series-parallel conversion and decoding logic to improve the speed of access to the screen. This last point certainly represents the most important innovation in plasma panel technology for a long time.

The realization of these integrated circuits are not however, without their constraints. Take, for example, the gas discharge. A high voltage (100 V minimum, and up to 200 or 300 V, depending on the device) has to be applied to the electrodes and the current required is of the pulsed type – very brief but of high amplitude, eg 10 A for a panel of 512 x 512 points. Obviously these two points do not make the work of LSI circuit design engineers any easier as they

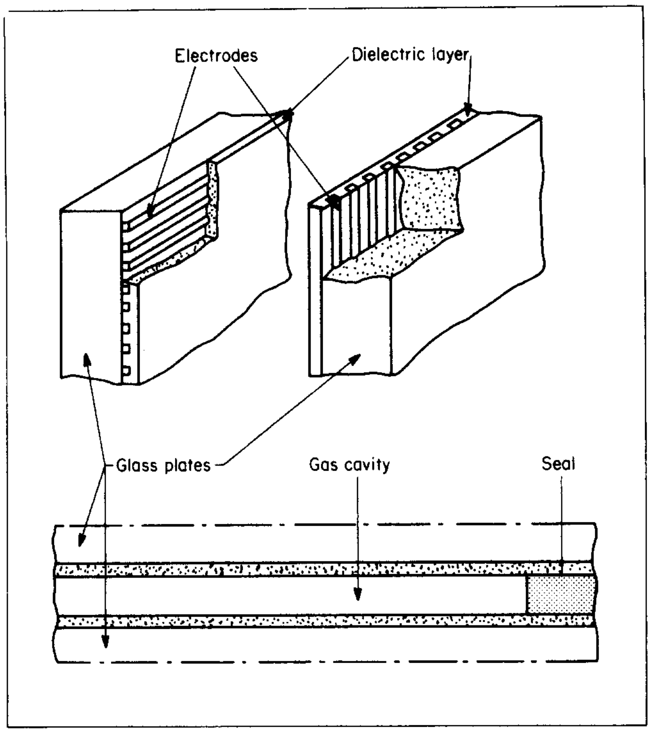

Fig. 5 Cut-away views of an a c plasma panel

are used to voltages of 5 and 12 V. The difficulties are on their way to being surmounted by Texas Instruments, Dyonics, Supertex, Sharp and Thomson-CSF.

A C DRIVEN PLASMA DISPLAY PANELS

Description

An a c plasma panel intended to display a large number of characters or elaborate graphics is shown in Fig. 5. The panel consists of two identical glass plates enclosing a cavity filled with gas at low pressure. Each plate has a parallel array of conducting electrodes on its inner face, and a dielectric layer, which isolates the electrodes from the gas. The dielectric is made of materials satisfying specific requirements such as resistance to sputtering by ionic bombardment and high secondary emission for lowering the firing voltage. The glass plates are positioned such that the linear electrode arrays are orthogonal to each other. The two plates are joined by a precision seal, leaving a thin and uniform gap between them. This gap is evacuated and filled with a rare gas mixture, the essential component of which is neon. Neon was chosen for its high luminescence in the visible spectrum.

Theory of operation

The panel appears as a juxtaposition of individual gas cells, each cell being the crossing point of two sets of conductors, x (lines) and y (columns). Figure 6a shows the construction of an elementary cell with two electrodes x and y and the two dielectric layers on which charges are stored.

Figure 6b gives the equivalent electrical diagram of this cell. Between the two external electrodes x and y are two capacitors C_d representing the two dielectric layers and a capacitor C_o representing the cell itself. A current generator at the terminals of the capacitor C_o represents the current generated I_m at the time of gas discharge. The potential difference at the cell terminals is the sum of the voltage induced by the external voltage $V_x - V_y$ and the voltage V_m induced by the charges stored in the capacitor C_o. This voltage V_m is called the internal or memory voltage. It follows that:

$$V = (V_x - V_y)\,\frac{C_d}{2C_o + C_d} + V_m,$$

ie that $V = a\,(V_x - V_y) + V_m$

The coefficient a is related the geometric characteristics of the cell and has a value close to unity (0.95). Thus:

$$V \approx (V_x - V_y) + V_m$$

The bistable or memory mode of operation is the most common operating mode for a c plasma panels. In this mode there are two levels of cell luminance, a bright 'on' level and an 'off' level, the level of luminance being determined by the intersection of the dynamic load line and the characteristics of the plasma discharge.

Fundamentally, the principle of operation is related to the presence of the dielectric layer covering the electrodes. By storing the charges created at ionization, it gives the panel an intrinsic 'memory'. This is illustrated in Fig. 7 which represents, as a function of time, the external voltage applied to the panel electrodes and the internal or memory voltage due to the charges stocked on the dielectric. A charge cell will be fixed at each transition of the sustaining voltage and will be kept on by this simple signal. A cell in the off state remains off.

A continuous a c square wave voltage, $V_x - V_y$, the sustaining voltage, is continuously applied to all x and y electrodes. Its value is such that electric field is insufficient to cause discharge of the gas, ie it is less than the firing voltage. In the absence of any other signal the panel is in the off condition (initial state). A cell can be selectively addressed by apply-

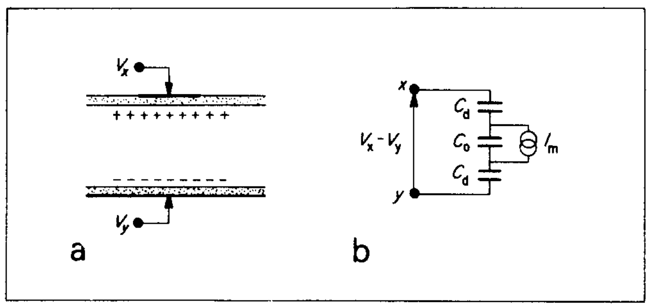

Fig. 6a – Elementary cell; b – equivalent electrical diagram

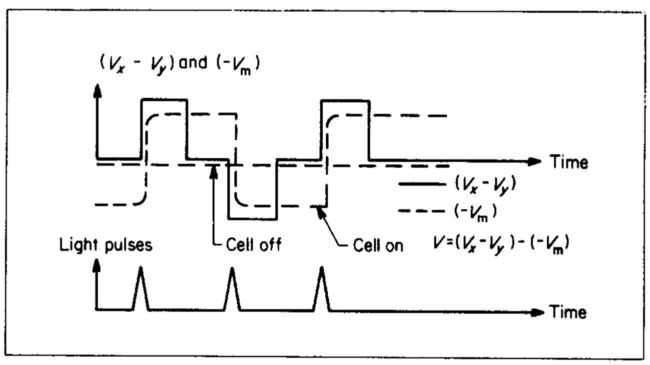

Fig. 7 Memory voltage in an a c plasma panel

ing between the x and y electrodes a writing signal in the form of an auxiliary instantaneous voltage whose amplitude exceeds the firing voltage (Fig. 8). The ions and electrons generated by this discharge build up on the two sides of the dielectric, creating an internal voltage V_m of opposite polarity to the sustaining voltage. The discharge is subsequently rapidly quenched.

In the following half-cycle of the sustaining voltage, the internal voltage V_m no longer opposes, but adds to, the sustaining voltage. The addition of these two voltages exceeds the firing voltage of the cell. A new discharge occurs with corresponding electron and ion deposit followed by extinction; in this way, the addressed point will fire once every half-cycle of the sustaining voltage.

The 'on' or written state is initiated by a short pulse of the right phase which has momentarily increased the applied voltage. The sustaining voltage cannot produce firing without the aid of the wall voltage, so erasure of a selected 'written' point is achieved with a low amplitude of the applied a c wave form. This short pulse cannot produce enough wall voltage to sustain the subsequent firings.

Panel technology

In general a c plasma panels are made by sealing two substrates together in such a way that a uniform and narrow gap is left between them. This cavity is then evacuated, filled with a mixture of rare gases and sealed off. The substrate is soda-lime silicate (ordinary window glass) which serves as a rigid support for the electrode networks. The plates must be as flat as possible and able to withstand the successive thermal shocks originating from gas discharges.

Forming the electrode network on each glass plate is an exacting operation calling for great precision. This, of course, increases in difficulty as the number of cells increases, since the distance between cells must be less. Suppose we have a square panel composed of n^2 cells of pitch p. On each plate, a network of n electrodes must be deposited, of length $> np$ and width $< p/5$. This width limitation is determined by cell-to-cell interaction and by luminance considerations, as increasing electrode width strongly reduces the luminance. Uniformity of electrode width on the substrate is extremely important, since it directly affects both the uniformity of luminance and a weak scattering of the cell voltage characteristics.

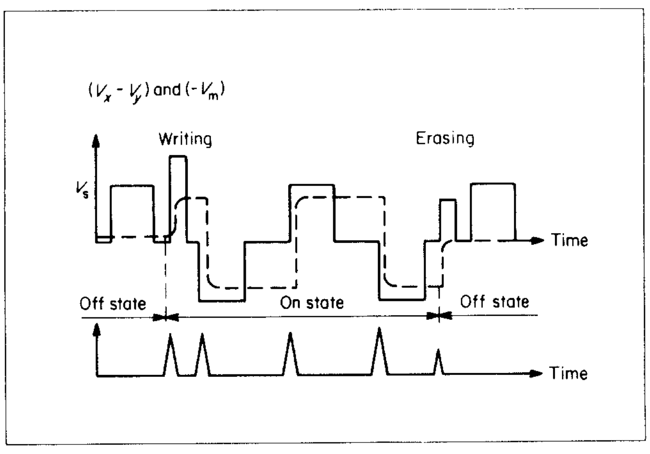

Fig. 8 Writing and erasing mechanism

Deposition of the electrode networks on the substrate require good adhesion of the electrodes to the substrate, passivity with respect to the subsequent processing steps, small tolerances of conductor dimensions, no opens, shorts or other defects in the final conductor pattern, and high conductivity. This last point is of extreme importance. The peak current in a cell is approximately $I = 50\,\mu A$. This peak current becomes $n \times I$ when the n cells are linked to one 'on' electrode. In this case, if R is the electrode's resistance and taking into account the current distribution in the electrode, then the end voltage drop is equal to $[(n+1)R]I/2$. If a maximum voltage drop of 0.5 V is tolerated, this gives a value of R less than or equal to $(0.5 \times 2)/(n+1)I$. For high-resolution panels, the electrode networks are deposited by the photoengraving of a metallic layer under vacuum. For relatively low-resolution panels, serigraphy is used (gold paste), this technique being particularly well adapted to automated means of production. Both methods call for extremely high-purity environmental conditions which are achieved by climatically controlled clean air zones ('clean rooms').

The dielectric layer provides the capacitive coupling between the electrode network and the gas in the cavity. The peak current drawn by the cell, and hence its luminance, and the amplitude of the voltages required to operate the cell are directly determined by the value of the capacitance. Uniformity of dielectric thickness and dielectric constant over the whole substrate is necessary for optimized performance. In addition, the dielectric must be transparent in order not to absorb the emitted light. This also enables back-projection. The dielectric is deposited by serigraphy of an enamel paste with a low fusion point. After vitrification, the dielectric layer is around 25 μm. The capacitance (C_d) of the dielectric layer is related to α, the ratio of the voltage applied to the gas and the external voltage, by the expression $\alpha = C_d/(2C_o - C_d)$. The value of C_d determines the quantity of charge transferred at each discharge ΔQ. To a first approximation $\Delta Q = C_d V_m$ and represents the integral of the discharge current as a function of time during the whole discharge, a quantity proportional to the luminance emitted during a discharge. It is evident that for a given value of V_m, increasing C_d increases ΔQ.

Sealing the panel consists of joining the two glass substrates together to leave a uniform gap (100 to 200 μm) between them. Homogeneity of cavity thickness is all important, since it directly affects the cell's characteristics. Paschen's law states that the firing voltage is a function of the product pd, where p is the pressure of the gas and d the thickness of the cavity. For a given gas, pd is at a minimum for a gas pressure of 10 torr cm. In addition, the thinner the cavity, the more localized is the discharge with respect to the electrode which directly affects uniformity of luminance.

Sealing is effected by placing a glass paste around the circumference of the panel. The glass seals are cured and the panel 'baked out' to remove contaminants, filled with a gas mixture at the desired pressure, and the panel fill tube sealed off. The gas is essentially composed of neon with a small percentage of argon. This Penning mixture reduces the ionization potential by the action of metastable neon atoms on the argon atoms:

$$Ne^* + A \rightleftharpoons A^+ + e^- + Ne$$

The gas is introduced to give an internal pressure of between 300 and 200 torr at ambient temperature. Because of the relatively large seal area to gas volume ratio (compared to a CRT), it is necessary for the rim seal to have a very low leak rate to ensure long device life.

Drive electronics

The drive electronics includes all the circuits necessary for the generation and application of all voltages to the panel electrodes for correct operation. The block diagram is given in Fig. 9.

The drive electronics consists of a multiplexing network of diodes and resistors, addressing transistors and decoding logic circuits (permitting address decoding and the driving of the addressing transistors) for each group of electrodes x (columns) and y (rows). Each group contains in addition, two sustaining power amplifiers, one for setting at logic state 1 (V_1) and the other for logic state 0 (0 V). The two less powerful amplifiers are reserved for the priming electrodes.

An internal clock assures signal generation and the ordering of the different orders and addresses, and includes only logic circuits. The d c power supply voltages necessary for operating this electronic circuitry are + 5 V for the TTL logic circuits, + 12 V for driving the transistors, V_1 (+ 100 V approximately) and V_2 (- 100 V approximately) for sustaining and addressing signals.

The addressing signals are the different voltages applied to the rows and columns electrodes for the operations of writing, 'memory' and erasing. These signals are of two types: bulk or sustaining signals, which are applied to all electrodes; and selective signals, which are applied only to electrodes addressed (writing and selective erasure). Figure 10 represents these different signals schematically.

For a cell, C represents the column voltage and L the row voltage. The difference, C - L represents the voltage at the cell terminals. The a c plasma panel is best sustained by square waveforms that have a rise and fall transition of less than 1.0 μs. The sustaining signals are applied in parallel to all the electrodes and ensure the display of the information received.

The alternative signals of amplitude V_1 are made up of column pulses, amplitude V_1 and width T_{E1}, and are immediately followed by identical line signals of width T_{E2}. The difference C - L (Fig. 10) represents an alternative signal of amplitude V_1, applied at the cell terminals, which provokes two firings for a previously written cell. Each sustaining cycle (T_{E1} + T_{E2}) is separated from the one following by time T_3. Thus, the total period of the cycle can be regulated, directly affecting the panel luminance level.

The writing signals provoke the firing of addressed cells. In Fig. 10b four cells are represented by A_1, A_2, A_3 and A_4. Assuming that cell A_1 has been selected, the electrodes C_1 and L_1 will receive a writing signal, activating A_1. This signal must not of course activate A_2 and A_3 which have a line and column in common. The column signal for the written point (C_1) is of amplitude V_1 and of duration T_{E1} + T_1, and for the unwritten point (C_2), V_1 and T_{E1} respectively. The line signal for the written point (L_1) is of amplitude V_1 and duration T_{E2} (it is preceded by a negative writing signal of amplitude V_2 (lower than V_1) and duration T_1), and for the unwritten point (L_2), V_1 and T_{E2} respectively. The resultant of this combination of signals is represented by $C_1 - L_1$, $C_1 - L_2$, $C_2 - L_1$ and $C_2 - L_2$. It is evident from the Figure that the $C_1 - L_1$ signal is of amplitude $V_1 + V_2$, necessary for the firing of the selected A_1 cell, while all the other signals are less than V_1.

The four signal combinations have one characteristic in common, namely a leading edge of amplitude V_1 at the beginning of the cycle (start of T_{E1}) and a trailing edge of amplitude - V_1 at the start of T_{E2}. This means that no matter which of the four signals is applied to the already

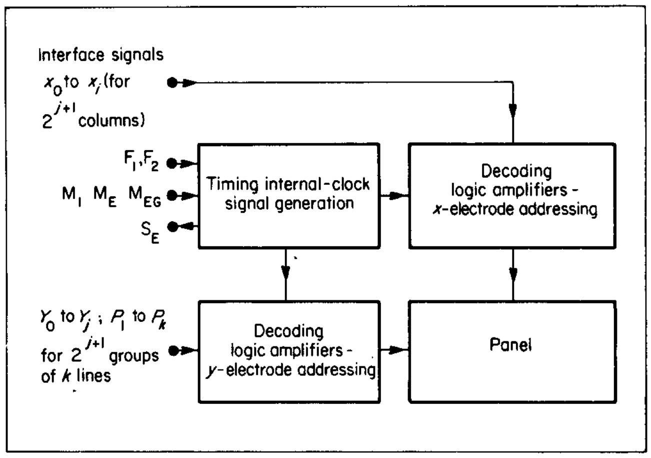

Fig. 9 Block diagram of the drive electronics

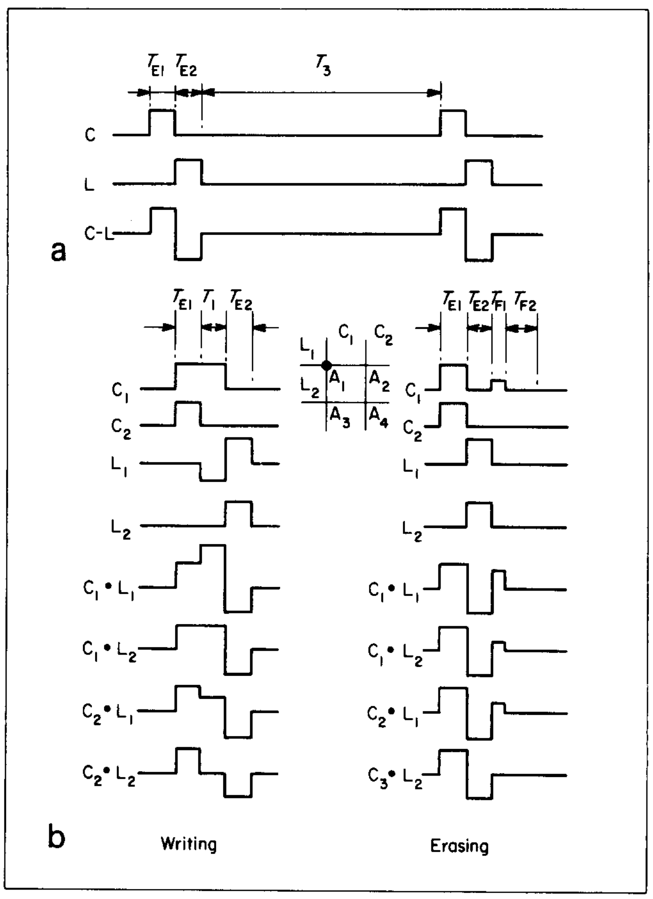

Fig. 10 Drive signals for: a – sustaining; b – writing and erasing

written cell, this cell will go through a sustaining cycle. This is very important because this allows keeping written cells fired without the insertion of standard cycles, even when there are numerous successive writing operations. In addition, the leading and trailing edges are simultaneous whatever the signal, and can therefore be applied in parallel to all the electrodes by the same circuit that provided the sustaining signals.

The function of the selection erase signals is to erase the cells that have been addressed. This is achieved by the use of a weak pulse that cannot produce enough wall voltage to sustain subsequent firings, ie it is insufficient to permit discharge in the following sustaining cycle. The erase pulse is made up of two pulses, which appear on the electrodes C_1 and L_1, the sum of which gives a signal of sufficient amplitude (signal $C_1 - L_1$). Figure 10b shows that the erasing cycle is made up of four periods, $T_{E1} + T_{E2}$ which is a normal sustaining cycle time, T_{F1} which is the erasing pulse time, and T_{F2} which is a neutralization time during which the cell receives no signal. The function of T_{F2} is to avoid the occurrence of a pulse after T_{F2} which could refire a cell which had just been just turned off. Figure 11 shows that the selective erasing signals have the same advantages as the writing signals, ie the pressure of a sustaining cycle on each written or non-written cell. Bulk erasing is achieved simply by applying a sustaining cycle in which the line pulse T_{E2} has been reduced in amplitude.

Drive circuits

As has just been mentioned, the electrode signals required are of two types: the bulk signals are simultaneously applied to the assembly of electrodes, while the selective writing and erasing signals are applied to one addressed electrode or to a group of addressed electrodes. The difficulty to overcome is addressing one electrode amongst many, which necessitates a number of drivers and amplifiers equal in number to the electrodes. This can be handled by multiplexing provided that one knows how to realize the electrode level decoding circuits, and how to address a single electrode, or simultaneously a group of electrodes. For n electrodes, where n is a power of two ($n = 2^x$), multiplexing allows addressing one, and only one, electrode amongst n with a number of drivers equal to x. For example, if $n = 256$, then $x = 8$, and a great reduction in the necessary number of drives and amplifiers is achieved.

At this point, an example of an multiplexing circuit will be given, which allows one electrode amongst sixteen to be addressed. We will assume that C_1 and C_2 represent the column writing signals (C_1 an addressed electrode and C_2 a non-addressed electrode) (see Fig. 10). The electrode addressed must be at V_1 (logic state 1) during the time that the other fifteen electrodes are at logic state 0. Figure 11 represents the block diagram for the sixteen electrodes with the elementary cell at the bottom of the Figure.

The sustaining signal is applied to the electrode by diode 1 (for setting at high state V_1) and by diode 2 (for resetting to state 0) by means of the two power amplifiers, H and B. This is the only function of diode 1 and it takes no part in addressing. The AND function is assured by the resistance and diode 2 and for the electrode to be addressed (set at V_1), it is required that the resistance be carried to V_1 AND and that diode 2 not be grounded. This can be readily done with the addressing transistors. Suppose we want to address electrode number 7, we will have to order A_3 to become conducting leading to A_3 becoming saturated and hence A_1, A_2 and A_4 being cut off. We will have ordered B_1, B_3 and B_4 to become conducting and hence saturated leading to B_2 being cut off. One sees that in this example, addressing 16 electrodes is achieved with eight transistors instead of 16. A second multiplexing network of diodes permits taking this number down to four ($\log_2 16$).

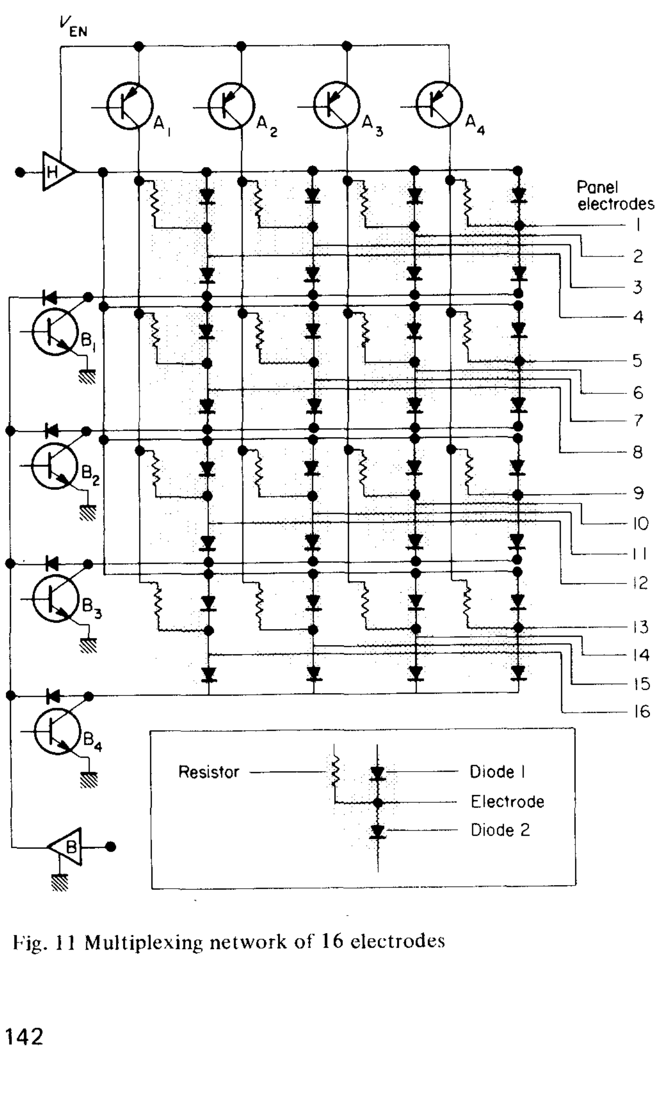

Fig. 11 Multiplexing network of 16 electrodes

THOMSON–CSF A C PANELS AND ACCESSORIES

The panels

Thomson-CSF has been actively working in the a c plasma panel field since 1967[19,20] and has developed a full range of products (Table 3 and Figs. 12–16).

These panels are based on the luminescence produced when electrical discharge occurs in neon gas. They give a red-orange colour which is bright and yet soft, giving a comfortable display for both short and extended viewing. Set against a black background, these panels give contrast which is typically > 25 under low-level illumination and > 10 under 1 000 lx ambient illumination (Table 4). The viewing angle being extremely wide (160°), the viewer can take almost any position in front of the screen, which offers a very wide angle of full readability.

These panels are extremely compact, thin and light in weight, and can thus be readily integrated into consoles. With today's explosive development in computer and micropro-

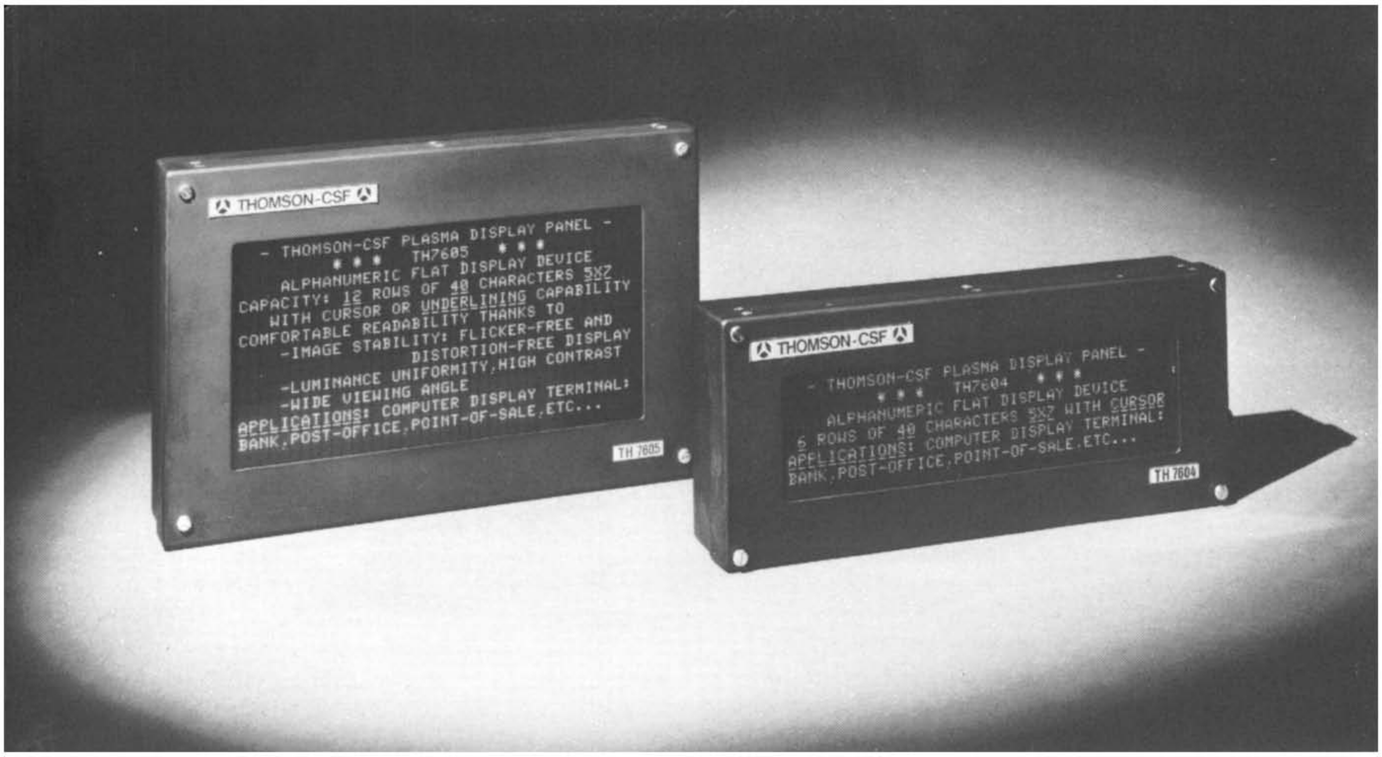

Fig. 12 Plasma panels (TH 7605 and TH 7604)

Table 3. Thomson-CSF range of a c plasma display panels

Type	Number of cells	Pitch between cells (mm)	Dimensions (mm)	Capacity: Alphanumeric	Capacity: Graphic
TH 7604	48 x 200	0.82	294 x 125 x 57	6 rows of 40 characters (5 x 7) 7 rows plus cursor per character	No
TH 7605	96 x 200	0.82	300 x 195 x 59	12 rows of 40 characters (5 x 7) 7 rows plus cursor per character	No
TH 7607 (rugged version)	128 x 256	0.64	270 x 200 x 120	16 rows of 42 characters (5 x 7) 8 rows of 32 characters (7 x 9) 8 or 16 electrodes per character	All points addressable
TH 7603A*	256 x 256	0.64	260 x 260 x 60	32 rows of 42 characters (5 x 7) 16 rows of 32 characters (7 x 9) 8 or 16 electrodes per character	All points addressable
TH 7606	512 x 512	0.46	335 x 335 x 85	64 rows of 85 characters (5 x 7) 32 rows of 64 characters (7 x 9) 8 or 16 electrodes per character	All points addressable

* A version of this panel with an extended operating temperature range (-15°C to +55°C) is designated TH 7613

Table 4. Optical, electrical and mechanical characteristics of Thomson-CSF plasma display panels

Typical optical characteristics	
Red-orange colour of neon spectrum	$\lambda_{avge} = 600$ nm
Viewing angle	160°
Contrast:	
– under low-level illumination*	> 25
– under 1 000 lx ambient illumination*	> 10
Maximum luminance†	150 cd m^{-2}
Typical electrical characteristics	
Input	TTL logic levels
Writing time – one point	20 μs
Writing time – one 5 x 7 character	100 μs
Bulk erasure time (full screen erasure)	20 μs
Selective erasure time – one point	20 μs
Selective erasure time – one 5 x 7 character	100 μs
Environmental characteristics‡	
Operating temperature for alphanumeric panels	-15°C to +55°C
Storage temperature	-25°C to +70°C
Humid heat	+40°C at 90 % AR
Vibration resistance (10 Hz to 500 Hz)	2 Gs

* Values measured using a glazed filter (60% attenuation).
† Measurement made without filter. The luminance can be adjusted by TTL logic commands (F_1, F_2) to one of four factory-set levels.
‡ A special series of ruggedized panels, able to withstand more rigorous environments, is for military use.

cessor-aided human functions, there is more and more call for a flat-screen man-machine interface, and it is here that these plasma display panels score over the cumbersome CRT. The simple technology allows the design of large high-capacity display panels. Display capacity starts at 6 rows of 40 characters (5 x 7) rising to 64 rows of 85 characters (5 x 7), with or without full graphic capability. Since each point of the useful area can be individually addressed, the user can select the type of arrangement he desires. There is thus a free choice of character format, spacing between characters, underlining, cursor, tabulations, etc.

Thomson-CSF has also gone into the manufacture of militarized plasma display panels, where operation under extreme environmental conditions is a way of life. The full range of PDPs has thus been able to benefit from this experience, making high reliability a norm, rather than an exceptional accomplishment. These panels offer several advantages over the conventional CRT, which can be crucially important:

1. Absence of flicker and freedom from geometrical distortion. Both of these display defects are extremely irritating for the observer over prolonged periods. When using CRTs, one is always confronted with the problems of sway, distortion and flicker.
2. Inherent memory. Once the information is displayed, the display remains unfaded and the image does not require repeated refresh, as is necessary with the CRT.
3. Selective writing and erasure of the displayed image can be accomplished more easily than with CRT-based displays.
4. No risk of implosion.

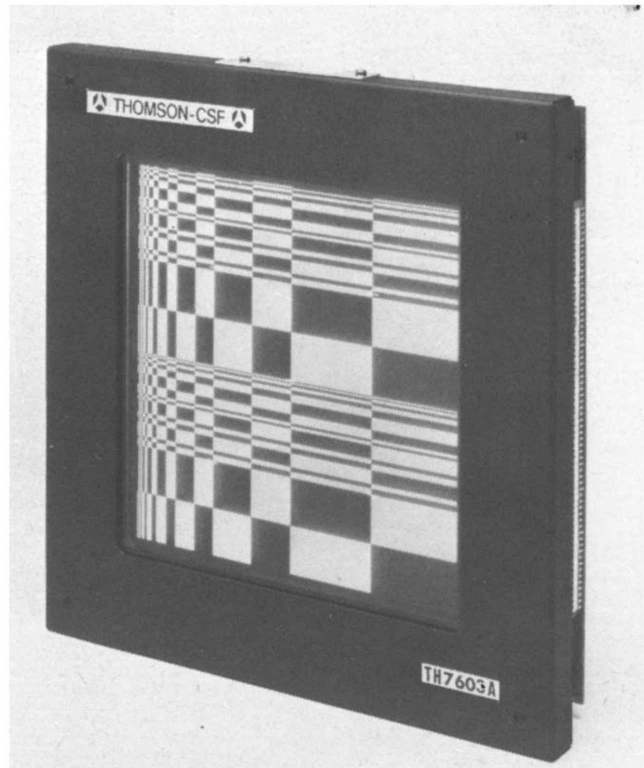

Fig. 13 Plasma panel (TH 7603A) area graphics

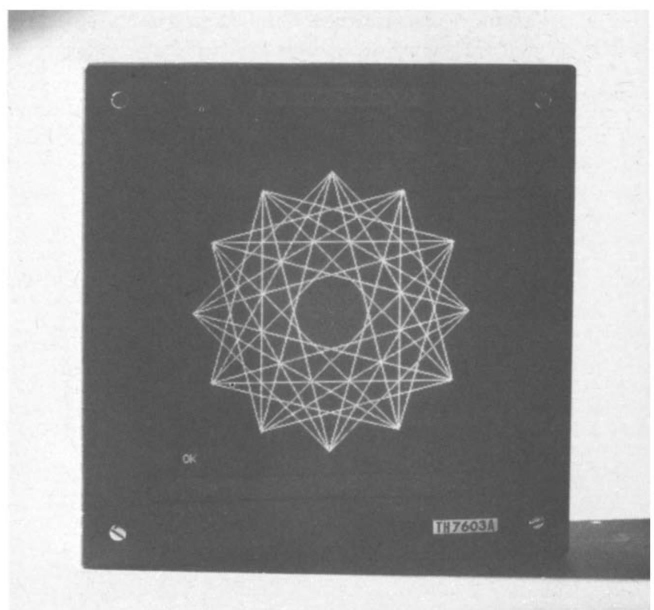

Fig. 14 Plasma panel (TH 7603A) line graphics

These characteristics explain the success of a c plasma display panels for high-quality displays. They have achieved notable success in demanding environments, both military and civil.

The qualities of these plasma display panels make them highly suitable for a wide variety of applications. Besides constituting ideal replacements for CRTs in graphic display consoles, these a c plasma panels are also ideal for point-of-sale consoles, banking and post office terminals, and computer-controlled machine tool displays. Certain especially robust panels find applications in mobile terrestrial, maritime and airborne systems, both civil and military.

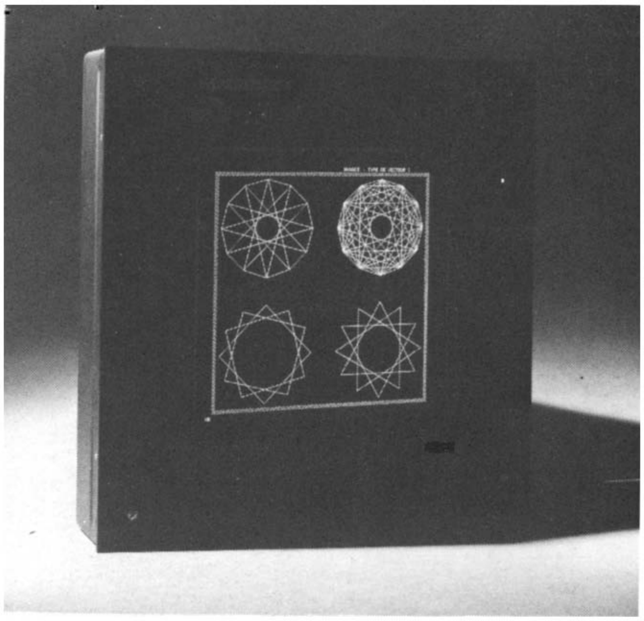

Fig. 15 Plasma panel (TH 7606) line graphics

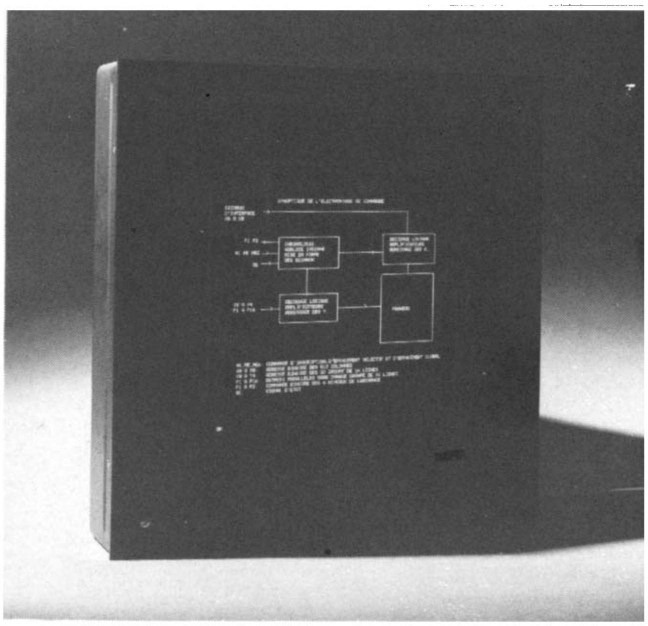

Fig. 16 Plasma panel (TH 7606) alphanumerics

Interface board

Thomson-CSF manufactures the TH 7514 interface board (Table 5), which has been designed to simplify the use of Thomson-CSF plasma display panels in alphanumeric display consoles. Using an SFF 96802 microprocessor, this board can be readily connected to most computer systems, using either serial or asynchronous access (RS 232/CV24 or 20 mA current loop) or parallel access. The TH 7514 utilizes the ASCII code.

This interface board contains an input buffer memory of 700 character capacity (700 bytes), which permits synchronizing the date input rate with the microprocessor's speed. The microprocessor can process 300 characters per second and the buffer memory can accept an input data rate of up to 3 000 characters per second. The capacity of the buffer memory is nevertheless sufficient to ensure the complete display on the associated panel in most instances.

Table 5. Alphanumeric interface board (TH 7514) ASCII code, 24 V, 20 mA, eight parallel bits. 64 (5 x 7) characters)

Model	Corresponding panel	Text format
TH 7514B	TH 7604	6 rows of 40 characters
TH 7514B	TH 7605	12 rows of 40 characters
TH 7514A	TH 7603A	16 rows of 42 characters
TH 7514C	TH 7603A	25 rows of 42 characters
TH 7514C	TH 7606	51 rows of 35 characters

Power supplies

Thomson-CSF also makes a series of power supplied (Fig 17 and Table 6) designed to meet all the voltages necessary to power its line of plasma panels and interface boards. The power supplies have sufficient power for the continuous display of an image with all points on the panel illuminated at maximum luminance, and for the instantaneous overloads necessary for their writing or erasing. The output voltages include two low voltages, for the panel's logic circuit and for switching circuit bias respectively, and two other voltages for writing, erasing, and sustaining a display image.

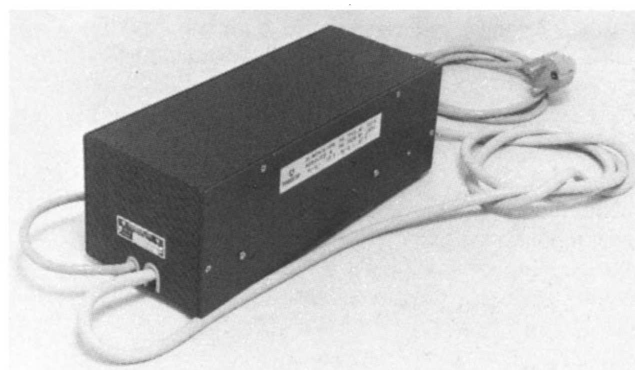

Fig. 17 Power supply (TH 7144) for TH 7604 panels

CONCLUSION

As mentioned at the beginning of this paper, PDPs, and in particular a c PDPs, have in the last few years carved out a large place for themselves in the display market. Looking ahead, Thomson-CSF is committed to a determined and intensive programme of research and development in a c PDP technology to make these devices even more successful. This programme is particularly orientated towards:

1. Realizing the full potential of the natural mechanical and environmental robustness of PDPs by improving their mechanical and electrical design. The assembly of these more robust PDPs and their associated electronic circuitry in a highly compact module will lead to display devices having practically no equal for high reliability under severe environmental conditions.
2. The development of integrated circuits specifically designed for panel drive. In the past, it has been this element that has proven to be a stumbling block to the development of its market. The benefits to result from the introduction of integrated circuits are many: reduced volume of the electronics circuitry; cost of the circuitry and power consumption; improved speed of screen access (simultaneous

Table 6. Plasma panel power supplies made by Thomson-CSF

Type	Corresponding panel	Dimensions (mm)	Input	Outputs			
				$V_1 - V_L$ (adjustable)	$V_2 - V_L$ (adjustable)	$V_L - V_{ground}$	$V_p - V_{ground}$
TH 7144	TH 7604	280 x 115 x 105	220 V ± 10% 50 Hz ± 2 Hz 30 V A	-90 V -110 V (regulation 1%) 0.2 A maximum	+90 V +110 V (regulation 1%) 0.2 A maximum	5 V ± 0.25 V 1.5 A maximum	12 V ± 0.3 V 1 A maximum
TH 7145	TH 7605	280 x 115 x 105	220 V ± 10% 50 Hz ± 2 Hz 30 V A	-90 V -110V set at 1% 0.2 A maximum	+90 V +110 V set at 1% 0.2 A maximum	5 V ± 0.25 V 1.5 A maximum	12 V ± 0.3 V 1 A maximum
TH 7143A	TH 7603A	285 x 120 x 109	220 V ± 10% 50 Hz ± 2 Hz 60 V A	-90 V -110 V set at 1% 0.4 A maximum	+90 V +110 V set at 1% 0.4 A maximum	5 V ± 0.25 V 1.5 A maximum	12 V ± 0.3 V 1 A maximum
TH 7146	TH 7606			Under development			

writing or erasing of several points); simplified interface circuits; and, in the long run, the possibility of implanting the chips on the screen itself, resulting in simplification of the electrical connections. It is for these reasons that the Semiconductor Division of Thomson-CSF is at present developing integrated circuits specifically designed to meet the needs expressed by the Electron Tube Division.

These lines of research and development, together with the already undertaken reduction in cell pitch, will facilitate the development of high-resolution PDPs, eg 1 024 x 1 024 pixels and up. This will enhance their intrinsic characteristics of compact size, robustness, ease of use and good electro-optical performance.

Acknowledgements

Several of the Figures were presented at Eurodisplay '81 in Munich.

References

1 'The industrial display market in the USA' A754 (Frost and Sullivan, 1980); see *Displays* **2** (1981) 218

2 **Hirsh, M.M., Oskam, H.J.** 'Electronic discharges' : Volume 1 of 'Gaseous electronics' (Academic Press, 1978)

3 **Sobel, A.** 'Gas discharges' *IEEE Trans* **24** 7 (1977)

4 **Francis, G.** 'The glow discharge at low pressure', in 'Handbuch der Physik XXII, Gas Discharges, Volume II' (Springer-Verlag, 1956) 53

5 **Jackson, R.N., Johnson, K.E.** 'Gas discharge displays : a critical review' in 'Advances in electronics and electron physics, Volume 35' (Academic, 1974) 191

6 **Weston, G.F.** 'Cold cathode glow discharge tubes' (Iliffe, 1968)

7 **'Plasma panel displays'** *J Phys E : Sci Instrum* **8** (1975) 981; 'Progress in electro-optics' edited by E. Camatini (Plenum, 1975)

8 **Agajanian, A.H.** 'A bibliography on plasma display panels' *Proc Soc Inf Disp* **15** (1974) 170

9 **Chodil, G.** 'Gas discharge displays for flat-panel TV', *IEEE Trans Consumer Electron* **CE-21** (1975) 221

10 **Bitzer, D.L., Slottow, M.** 'The plasma panel. A digitally addressable display with inherent memory' **29** Joint computer conf (San Francisco, 1966)

11 **Holz, G.E.** 'Pulsed gas discharge display with memory' *Soc Inf Disp Dig* (1972) 26

12 **Holz, G.E.** 'The primed gas discharge cell – a cost and capability improvement for gas discharge matrix displays' *Soc Inf Disp Dig* (1970) 30; *Proc Soc Inf Disp* **13** (1972) 2

13 **Ngo, P.D.T.** 'Dynamic keep-alive to improve plasma panel write and sustain margins' *IEEE Trans Electron Devices* **ED-22** (1975) 676

14 **Cola, R.** *et al* 'Gas discharge panels with internal line sequencing' in 'Advance in image pick-up and display. Volume 3' (1977) 83

15 **Weikart, G.S.** 'Indpendent subsection shift and a new simplified write technique for self-shift a c panels' *IEEE Trans Electron Devices* **ED-22** (1975) 663

16 **Ishizaki, H., Yamaguchi, H., Kashiwara, H., Murase, K.** 'Driving technique for self-shift PDP' in *Soc Inf Disp Dig* (1977); **Andoh, S., Oki, K.I., Yoshikawa, K.** 'Meander type self-shift PDP' in *Soc Inf Disp Dig* (1977)

17 **Ngo, P.D.T.** 'A shifting mechanism based on charge spreading for an ordinary a c plasma panel' in *Soc Inf Disp Dig* (1977)

18 **Smith, J.** 'A gas discharge display component for desk-top word processors' Biennal display research conf (1980) 79

19 **Reboul, J.P.** 'Ecrans plats pavane' Colloque int sur les dispositifs et systèmes d'affichages numériques (Paris, 1973)

20 **Deschamps, J.** 'L'affichage de données graphiques et alphanumériques par panneaux à plasma' *Rev Tech Thomson-CSF* **10** 2 (1978)