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CROSS-GRID DISPLAY AND COMPUTER INPUT STUDY FINAL REPORT

By D. J. Schott and J. O. Woodward

April 1970

Prepared under Contract No. NAS 12-2115
SPERRY FLIGHT SYSTEMS DIVISION
Phoenix, Arizona

Electronics Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ELECTRONICS RESEARCH CENTER

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FOREWORD

This report presents the results of a program investigating the possibility of using an ac plasma panel as an interactive display device. The work was performed by Mr. D. J. Schott and Mr. J. O. Woodward of Sperry Flight Systems Division, Sperry Rand Corporation, Phoenix, Arizona, during the period from April 1969 to December 1969. This work was performed for the National Aeronautics and Space Administration, Electronics Research Center, under Contract No. NAS 12-2115. The contract was administered by NASA-ERC, with Mr. E. Hilborn as the technical monitor.

ABSTRACT

This report describes an investigation concerning the feasibility of using ac plasma panels as interactive graphic display devices. The use of external voltage probes to selectively write and erase the panel was studied, as were means for computer interrogation of the panel. The feasibility of both of these objectives was established. Of the waveforms considered for probe writing, the most reliable combination was a squarewave-excited ac probe used in conjunction with a sinewave sustained panel. With this waveform combination, probe voltages of 150 volts (0 to peak) or less were effective. A means of electronically interrogating individual cells was proved. These write/erase and interrogate capabilities and the previously demonstrated display characteristics suggest that the image-retention capabilities of the plasma panel may be used for both graphic computer input and output.

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CROSS-GRID DISPLAY AND COMPUTER INPUT STUDY FINAL REPORT

By D. J. Schott and J. O. Woodward

Sperry Flight Systems Division
Phoenix, Arizona

I. INTRODUCTION AND SUMMARY

This program explored the feasibility of using an ac-coupled gas discharge tube, a plasma panel, as a two-way link between a human operator and a computer. The capabilities of the plasma panel as a display have been previously demonstrated. This program considered the panel's feasibility as a data input device.

A. BACKGROUND

The display capabilities of the external-electrode, ac-coupled plasma panel have been aggressively studied since its inception at the University of Illinois* in 1966.

It has been shown that the ac plasma panel combines the properties of memory, display, and high brightness in a simple structure. In addition, the panel incorporates a coincidentally addressed cross-grid, inherently digital. These salient features have prompted continued development work, with emphasis on application as a computer display.

Traditionally, computer-generated symbolic generation has been displayed by cathode ray tubes or plotters. Interaction with CRT display is often desirable and is possible. Analog methods normally use light pens and beam pens; they require analog-to-digital conversion circuitry and often require complex tracking algorithms. Since these methods are used with CRTs, they are incapable of providing the positional accuracy inherent in an all-digital system. Digital methods use a stylus in conjunction with an x-y coordinate system. Devices used to implement these methods (e.g., Rand Tablet, Sylvania Data Tablet, and others) have disadvantages of high cost and small size, and since these devices are not integral to the display, they require the operator to sequentially scan the tablet and the display. Finally, none of these devices possess an inherent memory capability and must therefore be used on-line or require an expensive external storage means.

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*Bitzer, D.L. and Slottow, H.G., "The Plasma Display Panel - A Digital Addressable Display With Inherent Memory", Proceeding of the Fall Joint Computer Conference, San Francisco, California, November 1966.

It seems likely that the plasma panel can overcome these difficulties by its capability to enter digital data directly into the display, at the same accuracy and resolution as that of the display. Furthermore, the panel can act as both a display and tablet at the same time, and can store input data (without a requirement for external memory) until it is required by the computer. Thus, it seems possible that information may be presented, modified, and corrected in an off-line operation.

B. PROGRAM OBJECTIVES

The purpose of this contract was to investigate the possibility of using the plasma panel as a graphic input device. The program consisted of the following elements:

- Analytical study, design, and fabrication of a probe (voltage or light) capable of affecting the panel, in a controlled manner, such that presented information can be directly altered

- Study of optical or electronic techniques that may allow computer determination of stored plasma panel information

C. PROGRAM ACCOMPLISHMENTS

It was found that an ac voltage probe with a squarewave voltage can be used to selectively and reliably write or erase a sinewave-excited, thin-walled ac plasma panel. The write mode can be changed to the erase mode by a simple 180-degree phase shift on the probe. The probe voltage is reasonably low, 150 volts (0 to peak). For effective control, the phasing of these two signals is important. It was found that resolutions as small as 32 lines per inch could be electronically addressed with a voltage probe.

An electronic circuit was tested that discriminates the current pulse from a single lighted cell. This circuit removes the large reactive currents normally present and amplifies the small fast pulse associated with an "on" element. The electronics necessary to interface this to a computer were not considered.

D. REPORT ORGANIZATION

Section II provides some fundamental background information for the subsequent discussion of results. Section III presents physical and functional descriptions of the equipment used. Included is a description of special electronics as well as several test article displays studied. A technical discussion of the experimental results achieved with ac and dc voltage probes is given in Section IV. This section is technically supported by Appendix A, which provides some theoretical background concerning ac plasma panels. Section V concerns electronic interrogation schemes, while Section VI summarizes the results achieved, the deficiencies noted, and the conclusions reached concerning the feasibility of using an ac plasma panel as an interactive device.

II. FUNDAMENTAL CONSIDERATIONS

In order to enter information into the plasma panel via a probe, some external means of controlling the firing of a cell is necessary. Three externally controllable parameters can be employed to initiate plasma breakdown: the applied voltage, the amount of surface charge*, and the production of the first charged particle that initiates the discharge. Externally controlled applied voltage refers to voltage produced by an external, man-controlled source, not a computer-controlled source, such as the plasma panel's crossed-electrode drive lines. Write/erase by control of the first particle that initiates ionization will be an unreliable technique; it is virtually impossible to eliminate all charged particles from the volume of a gas cell since they are constantly being created by natural radiation and by the decay of long-lived, excited gas molecules (metastables). Therefore, two controllable write/erase parameters remain: applied voltage and amount of surface charge. These parameters may be influenced by either optical or voltage probes.

A. OPTICAL PROBES

An optical or light probe may control the surface charge in the cell. The cell charge is composed of two parts: the mirror charges resulting from the application of voltage to the external electrodes, and a fixed charge resulting from the accumulation of charged particles. In normal operation, the combination of these two charges causes a breakdown in the cell. By providing the proper bias on electrode lines in combination with light, photo-produced charged particles can be used to charge or neutralize the cell walls. A light probe could create free charge by either photoemission from the walls or photoionization of the gas atoms.

In photoemission of the glass walls, electron mobility and space charge estimates indicate that the necessary transfer across the cell could be accomplished. However, in order to produce a wall charge of 100 volts (corresponding to a memory of 50 volts) in 30 microseconds, it is estimated that a current density of 10^{-5} ampere per square centimeter is required. This is many orders

*"Surface charge" or "wall voltage" refers to the charge or voltage that is caused by the accumulation of charged particles from the cell volume.

of magnitude higher than the current densities ($\sim 10^{-12}$ ampere per square centimeter) obtained by Rohatgi* by irradiating glass with ultraviolet light. It is apparently necessary to obtain the wall charges by coating the glass walls with photo-emitting materials.

It may also be possible to obtain the necessary wall charges by photo-ionizing the gas. It has been reported** that the breakdown potential for Penning mixtures is increased by irradiation with red-yellow neon light. This presumably is due to a reduction in the density of metastable atoms, which play an important part in the breakdown of Penning mixtures. Such an effect might conceivably be used to write and erase plasma panel cells.

Success of either method depends heavily on the speed at which the charged particles can be released. For panels suitably prepared to permit rapid light-probe-induced charge production, it is critically important that the panel be insensitive to normal room lighting and radiation. The combination of these two requirements may be difficult to achieve.

B. VOLTAGE PROBES

Voltage probes can control either the effective applied voltage appearing across a cell or the amount of surface charge accumulated on the cell walls. In the former approach, the simple constructive or destructive interference of an ac capacitively coupled probe should be considered. In the latter approach, consideration should be given to a dc probe whose voltage provides a field that permits the asymmetric accumulation of free charge on cell walls.

1. Principles of DC Probes

Theoretically, writing with a dc voltage probe might be accomplished in the following manner. Since a cell that is not ignited has little or no surface charge other than that induced by the sustaining signal, the field produced is insufficient to cause plasma breakdown. If a dc probe is brought into the neighborhood of a cell, it induces mirror charges on the walls of the cell envelope. The combination of these mirror charges and the sustaining voltage-induced charge may produce a voltage that exceeds the firing voltage of the cell, thereby causing the gas to ionize. In effect, the probe produces a bias voltage within the cell, similar to the slow-write technique sometimes used to address the display via drive lines.

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*Journal of Applied Physics, Volume 28, 1957, page 951.

**Druyvesteyn and Penning, Reviews of Modern Physics, Volume 12, 1940, page 115.

Erasing with dc voltage probes may be accomplished by placing a probe-induced bias charge on selected cells. If this bias charge magnitude is properly selected, then on alternate half-cycles of the sustaining voltage, the wall charge can be nearly zero as referenced to system ground (Figure 1). If the probe is strobed off on one of these alternate half-cycles, the subsequent electric field applied to a cell is due only to sustaining voltage, and the cell should not re-ignite.

2. Principles of AC Probes

In the ac probe approach, data is entered by supplying sufficient additional voltage via a probe so that the firing voltage is exceeded and the selected matrix elements ionize. To write, the probe supplies an ac signal properly phased to the normally present sustaining voltage [see Figure 2(A)]. To erase, the phase of the probe voltage is reversed, thereby sustracting from the sustaining voltage to an extent that the resultant applied field would drop below the extinguishing voltage. Although this type of erasure may at first seem trivial, it is, in fact, rather subtle. If the voltage probe were abruptly turned on and if its field nullified the sustaining field, the discharge would clearly extinguish; however, the wall charge would remain. Upon removal of the probe, the extinguished cells would immediately refire. If, on the other hand, the nullifying field from the probes were slowly applied, successive discharges would become less and less intense [Figure 2(B)]. The reason for the discharge weakening is related to the rise time (for sinewaves) or overvoltage (for squarewaves) of the applied field while the discharge pulse is occurring. Since the traverse speed for a manually operated probe is slow by comparison to a sustaining frequency of 100 kHz, it is expected that probe fields would be slowly applied.

Since the ignition time required for a cell is very short, generally sub-microsecond, it is conceivable that probe writing may be possible with a single pulse. This technique results in a writing/erasing method that is very similar to a method currently being used in several applications for electronic write via coincident address of electrode lines. Instead of using pulses coupled to the drive lines, the voltage probe applies a voltage spike that is capacitively coupled directly into the cell. The writing or erasing mode is selected simply by controlling the timing of the voltage spike, as shown in Figure 2(C). The voltage spike approach has the advantage, over the simple ac or dc probe, of ultra-high-speed writing and relative safety due to the low energy content of a single spike.

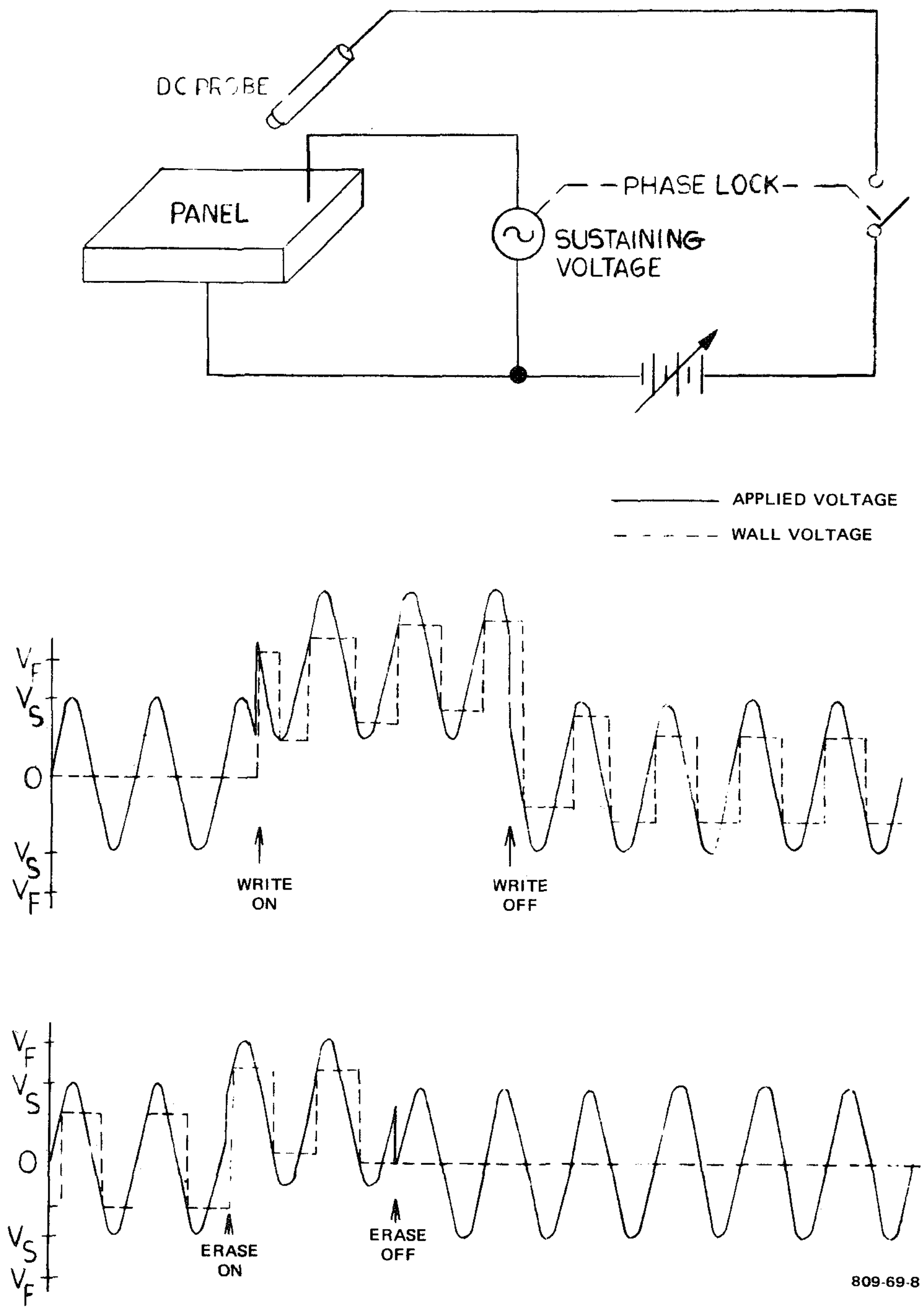


Figure 1. DC Write/Erase Waveforms.
A dc writing and erasing technique involves locally polarizing the glass envelope with a dc probe. Writing (top) is accomplished if the polarization voltage plus sustaining voltage exceed the breakdown voltage. Erasing (bottom) removes the polarizing voltage when wall charge is zero.

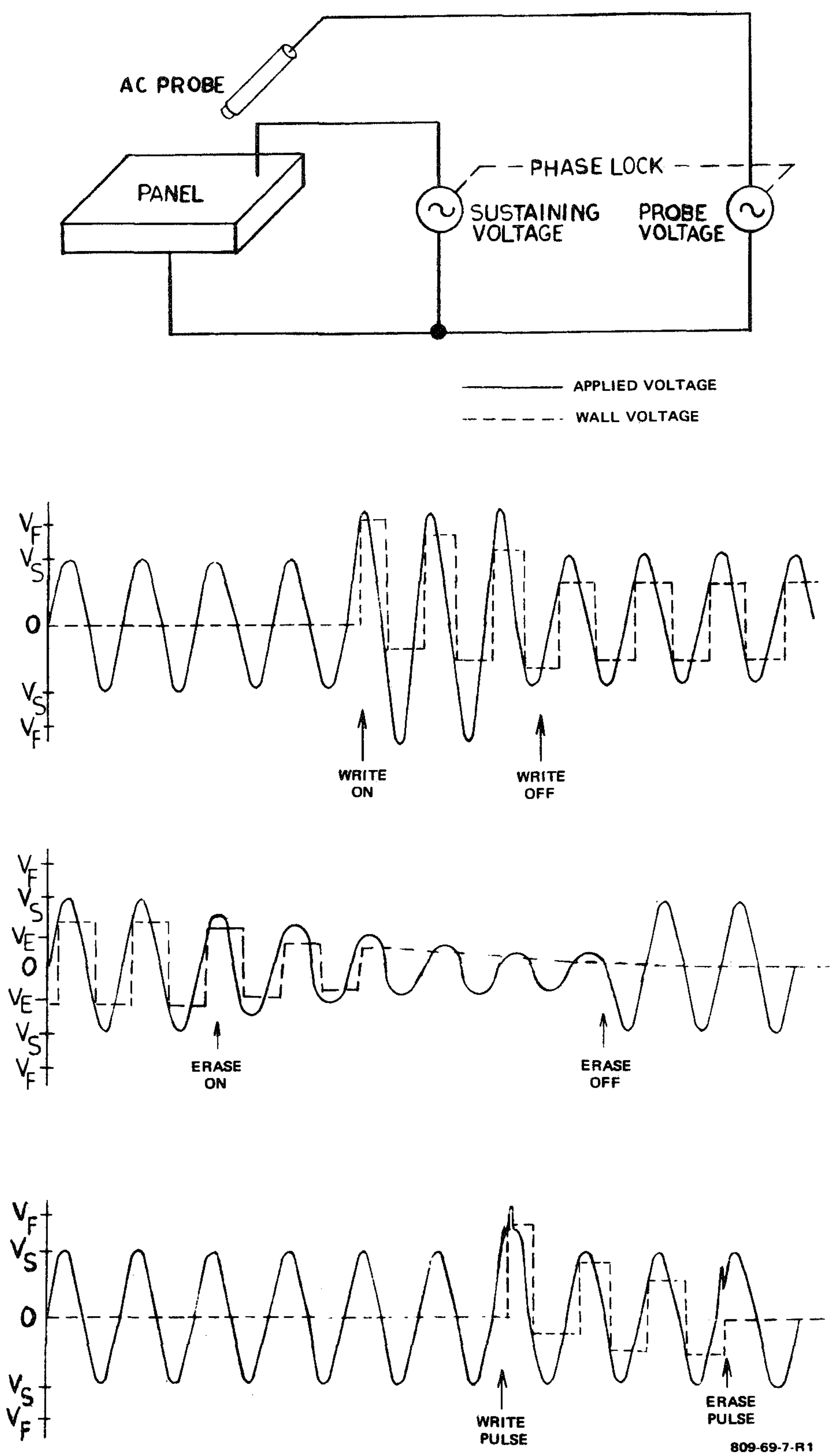


Figure 2. AC Write/Erase Waveforms.
Writing (A) or erasing (B) with ac probes is possible by simply adding a properly phased component to the normal ac sustaining voltage. A fast writing scheme involving the application of a voltage pulse via a capacitively coupled probe may also be possible.

3. <u>General Voltage Probe Considerations</u>

Three factors (other than the actual drive circuit used) may have a pronounced influence on the effectiveness of voltage probes:

- Dispersion of the probe's electric field in the dielectric panel assembly

- Voltage division among the several effective series capacitances of the panel

- Electrostatic shielding effect of the panel electrodes

a. Electric Field Dispersion and Resolution

Voltage probe electric field dispersion can be demonstrated simply by examining the field produced in a dielectric by a static point charge (simulating, for example, a sharply pointed probe). Consider a piece of glass 1/4-inch thick (like a DIGIVUE* panel wall) with a point charge placed on one side. The field due to this charge, produced on the opposite side of the glass, varies as shown in Figure 3, assuming a spherically symmetric field distribution in the glass. In a panel structure, this field distribution is modified somewhat by induced charges on other nearby dielectric surfaces and by the conductive electrodes. The induced charge effect is most significant in regions somewhat removed from the axis of symmetry and is evidenced by a turning-down of the ends of the lines of force in the dielectric toward the surface opposite that containing the point charge. In the vicinity of the axis of symmetry, little perturbation is observed. The field strength at a diameter of approximately 0.09 inch from the axis of symmetry remains at over 85 percent of the maximum. An 0.09-inch circle is large enough to cover roughly four intersections in a 32-line-per-inch grid. This greatly restricts the resolution with which a panel constructed of 1/4-inch glass can be written or erased by a voltage probe. If the point charge is removed a short distance from the surface, the dispersion is further increased, as shown in Figure 4.

*DIGIVUE: registered trademark of Owens-Illinois.

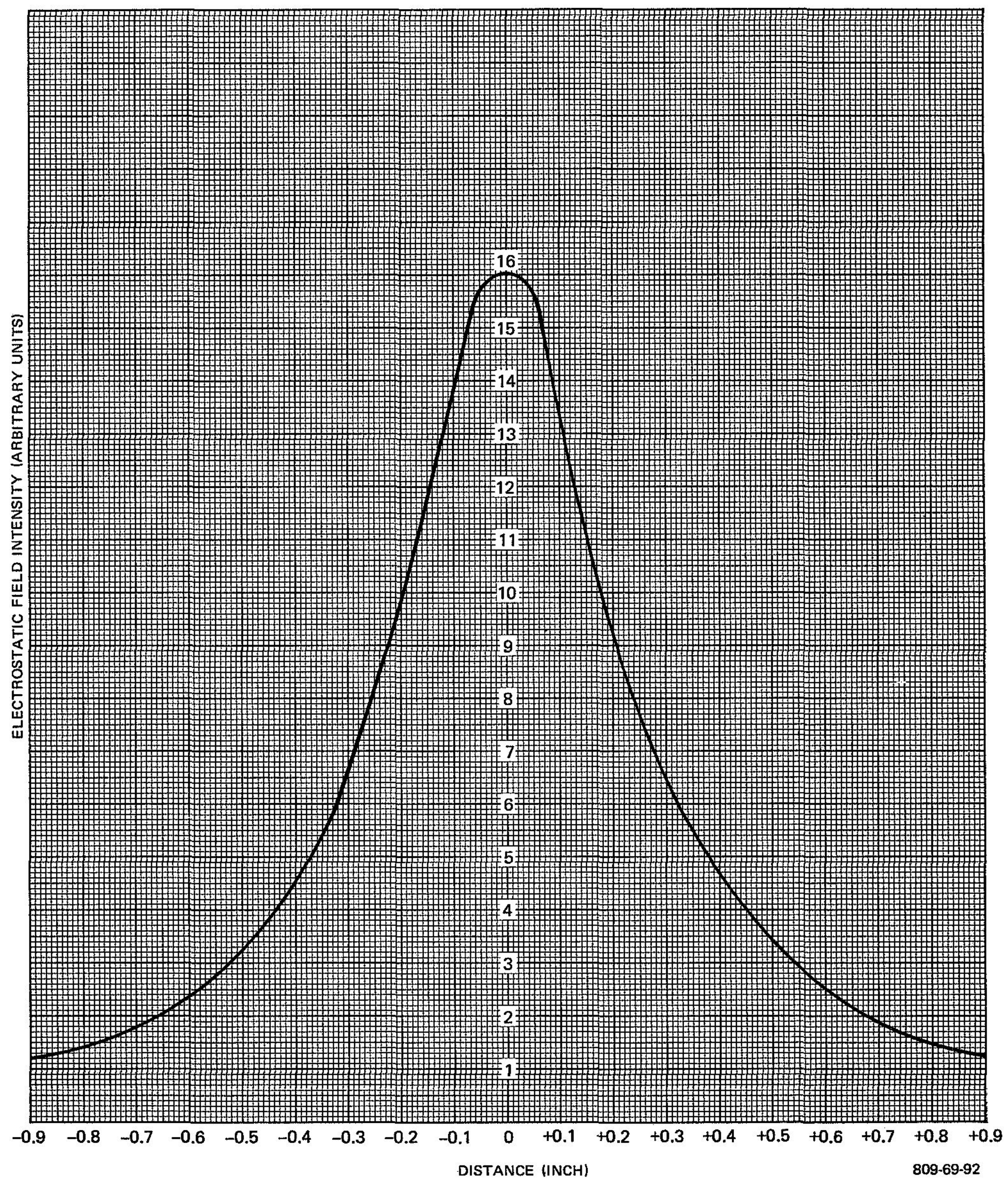


Figure 3. Field Strength Due to a Point Charge Through a 1/4-Inch-Thick Glass Plate

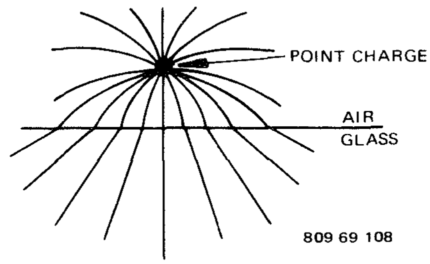


Figure 4. Electrostatic Lines of Force for Point Charge Slightly Removed From a Dielectric Circuit

To further illustrate the problem of dispersion, assume that by some means it is possible to produce a collimiated beam of energy radiating at the panel operating frequency and to bring it incident upon a selected spot on a plasma panel. The distance (D) that the beam would continue to travel in an essentially parallel beam can be calculated from the antenna theory formula

$$D = \frac{d^2}{4\lambda}$$

where d is the diameter of the entering beam and λ is the wavelength of interest. The divergence angle (θ) of the beam in the dielectric can be calculated from the relation

$$\theta = \frac{\lambda}{d}$$

If, for this example, the beam diameter is 0.02 mil and the frequency is 500 kHz, the beam penetrates the dielectric medium approximately 1 angstrom before diverging at an extremely large angle, the value of which is calculated to be on the order of 10^6 radians. This absurd value simply indicates that the point of entry of the beam serves effectively as a spot source with an associated quasi-spherical symmetry. Therefore, nothing would be gained by attempting to collimate the probe's electric field in this frequency range. Collimiated beams are possible, of course, at much higher frequencies (e.g., optical frequencies), but at these frequencies an entirely different interaction exists between probe and cell. Obviously, much thinner front walls must be considered with voltage probes if high-resolution probe writing is to be obtained.

b. Voltage Division

The basic plasma panel may be considered as three capacitors in series, with the insulated voltage probe adding a fourth. The panel drive circuitry, if connected, constitutes a fifth shunt capacitance. Thus, the amount of probe voltage appearing across the interior of a display element is divided capacitively by the various insulators that make up the panel (Figure 5).

If a voltage probe is brought into contact with a plasma panel, some minimum voltage is necessary to induce a desired resultant potential in the cell beneath the probe. Using thin-walled ac plasma panels and a thin probe insulator, the applied voltage theoretically required to produce a 50-volt potential in a cell may be a small voltage on the order of 70 volts. However, for thick-walled panels, the capacitance values result in a less favorable division of the probe voltage. For a 1/4-inch-thick wall, the probe voltage required to produce 50 volts in a cell is approximately 400 volts.

With the panel disconnected from external circuitry, except for the probe voltage (V_p), the voltage (V_3) across the gas cell is related to the V_p by the equation

$$V_p = V_3 \left(1 + \frac{C_3}{C_1} + \frac{C_3}{C_2} + \frac{C_3}{C_4} \right)$$

where the C's are the capacitance of the respective panel layers (see Figure 5). To maximize the value of V_3 across the gas cell, the expression in the parentheses must be minimized. This implies minimizing the capacitance C_3 of the gas cell and maximizing the capacitances C_1, C_2, and C_4. The dielectric constant of the glass is presumed constant; therefore, the various capacitances can be calculated using the simple capacitance model,

$$C = \frac{\epsilon A}{d}$$

where

ϵ = relative dielectric permittivity

A = area of the capacitor

d = thickness of the capacitor

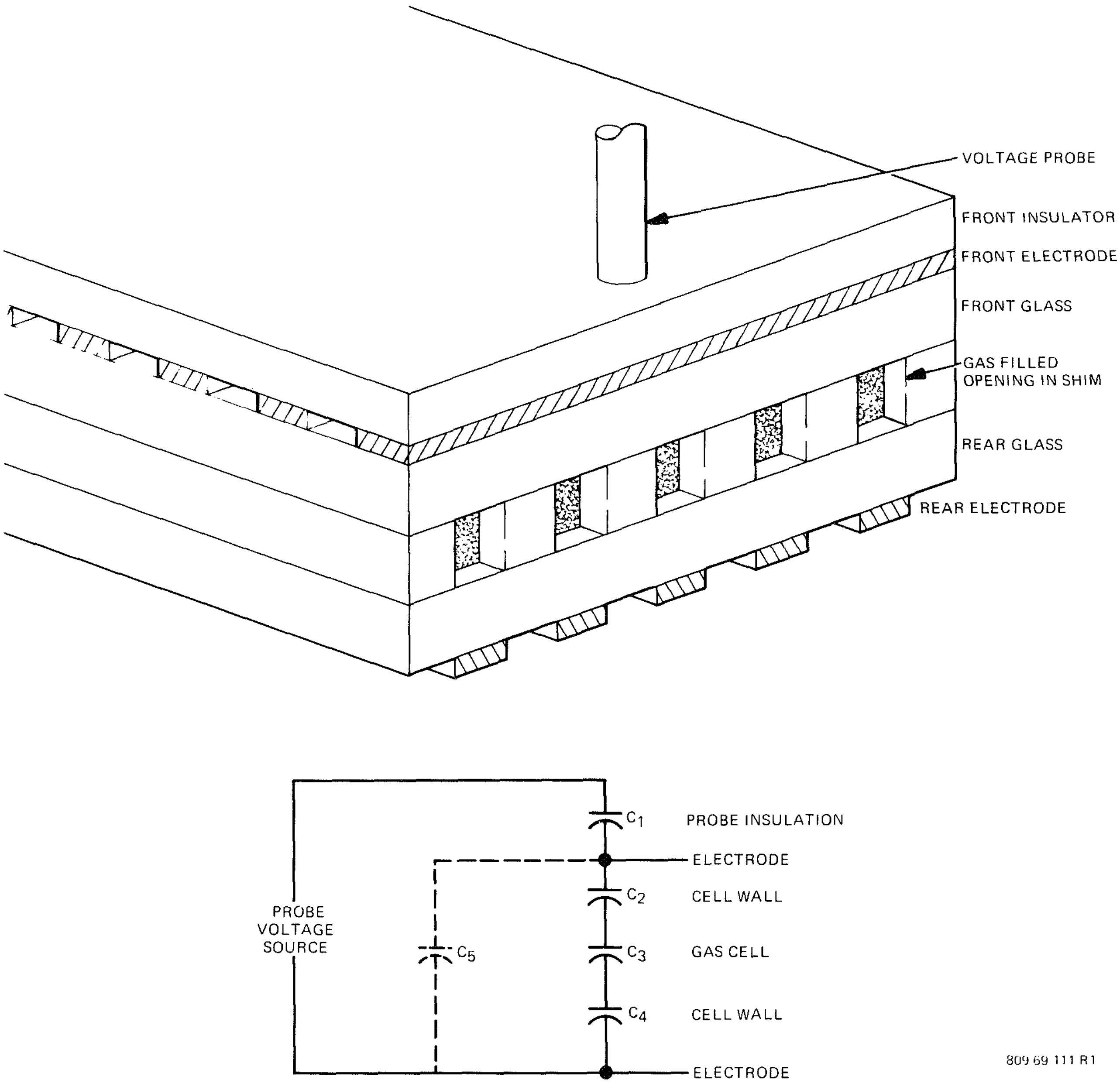


Figure 5. Typical Panel Construction with Equivalent Capacitor Circuit

The following guidelines should be applied in designing a voltage probe write/erase panel for optimal probe and voltage division:

- Use the largest internal cell gap spacing compatible with other design constraints
- Minimize the front wall thickness and stiffening layer thicknesses as much as strength considerations permit
- Design the probe insulator with the thinnest layer of the highest dielectric constant possible possessing sufficient dielectric and wear strength for the probe voltages anticipated

c. Circuit Capacitance

The presence of the metallic electrodes in the plasma panel sandwich and its associated circuitry causes an operational panel to deviate from the simple model used in the previous discussion. The electrodes in the panel, even with the external driving circuitry disconnected, introduce shielding of the gas-filled portion of the panel and a significant shunt capacitance across the panel. If the shunt capacitance (C_5) of the circuit (leads, etc) is now included in a static analysis similar to that previously performed, the gas cell voltage (V_3) is related to the probe voltage by the equation

$$V_p = V_3 \left(1 + \frac{C_3}{C_1} + \frac{C_3}{C_2} + \frac{C_3}{C_4} + \frac{C_5}{C_1}\right)$$

This equation differs from the unshunted case only by the additional term inside the parentheses. The circuit capacitance must also be minimized for favorable probe-voltage division. The shunt capacitance can play a significant role in reducing the cell voltage by comparing, for example, the 10-picofarad crossed electrode capacitance measurable on a Digivue panel to similar values of stray circuit capacitance commonly encountered.

d. Electrode Effects

With the power supply connected, the outer electrodes of a plasma display panel form a kind of Faraday shield for the remainder of the panel layers. It appears that this shield could be quite an effective barrier against externally applied fields, depending on

- Electrode spacing
- Electrode resistance
- Electrode width (for resistive electrodes)
- Electrode-to-cell spacing

Each of the influences on voltage probe writing reduces the proportion of probe voltage that is applied to the cell interior. In each case, reduction of the panel outer-wall thickness aids in reducing the inhibiting effect on the voltage.

C. INTERROGATION

It should be possible to computer-interrogate a plasma panel in at least two ways: optically and electrically. The state of a cell can be determined by the presence of light emission. This light emission could be detected with a photocell behind the panel, a feature possible since the panel's information may be viewed simultaneously from either side. Alternatively, the state of a cell may be determined by the unusual waveform associated with lit cells.

Two methods are possible for an optical scan. In one method, a single photocell would view the entire panel. To read information, the computer would interrupt the sustaining signal and, in sequence, scan appropriate cells by selectively applying, via coincident address, a sustaining signal to each. This requires approximately one-half the sustaining voltage to be applied to each of the orthogonal electrodes that intersect the cell. When this sustaining signal is applied, the cell will light only if it was previously lit. This provides a nondestructive readout that will return the original image when the panel sustaining signal is reapplied.

A raster scan technique might alternatively be used to speed up this scan, at the cost of increased complexity. A line-at-a-time scheme could be used by employing a photocell for each line orthogonal to the lines being scanned (series parallel data). In this case, a shadow mask, lenticular lens, or internally fabricated photocells would be required. Similarly, the panel could be divided into modular groups, each group being sensed by an individual photocell. Individual cells in modules would be serially addressed.

The state of a cell may also be detected electrically. The gas cells and the cell walls have appreciable capacitances, and therefore present a relatively low impedance to the ac sustaining voltage. Therefore, with a sustaining signal applied to the ac plasma panel, a large reactive current is always present. It is not sufficient to merely sense current flow as a measure of the state of a cell; it is necessary to differentiate between the current flow for a lit element and that for an unlit element.

When a cell lights in the plasma panel, charge particles flow rapidly within the cell volume, attempting to neutralize the field produced by the applied voltage. For purposes of formulating an equivalent circuit of this process, Dr. R. Willson* suggested that a cell may be pictured as a capacitor in parallel with a spark gap. AC current that flows through the cell interior then has two components: one associated with the capacitive reactance and the other associated with the spark gap (or the cell in the "on" state). It has been empirically determined that gases which have the best memory characteristics have very rapid and strong breakdown characteristics. Specifically, in the previous analogy, the spark has a very short duration (approximately 100 nanoseconds) compared to the period of the applied sustaining voltage (approximately 10 microseconds).

Several circuits are possible that can discriminate the current pulse from the normal reactive current. Techniques for implementing this type of interrogation would be similar to those described in the optical discussion. Again, either element-at-a-time, line-at-a-time, or modular address of cells by coincident sustaining level signals would permit serial or series-parallel interrogation of plasma panel cells.

*Willson, R. H., A Capacitively Coupled Bistable Gas Discharge Gas Cell for Computer Controlled Displays, Report R-303, Coordinated Science Laboratory, University of Illinois, June 1966.

III. EXPERIMENTAL APPARATUS

A. TEST PANELS

Tests were performed on a variety of panels that fall into two categories:

- Thick-Walled Panels. An Owens-Illinois Digivue was used. This panel has 32-line-per-inch resolution, is cell-less in construction, and uses thin opaque electrodes.

- Thin-Walled Panels. These are cellular in construction, requiring a honeycomb shim to prevent panel collapse during evacuation. Two cross-grid electrode structures were used:

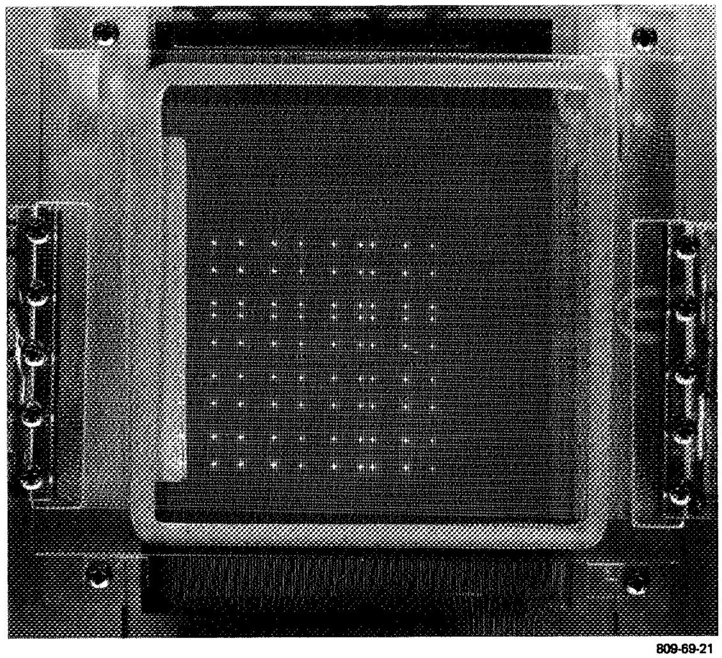
  (1) 32 lines per inch - transparent - vacuum-deposited electrodes

  (2) varied resolution - transparent front electrodes, opaque back electrodes - both vacuum-deposited

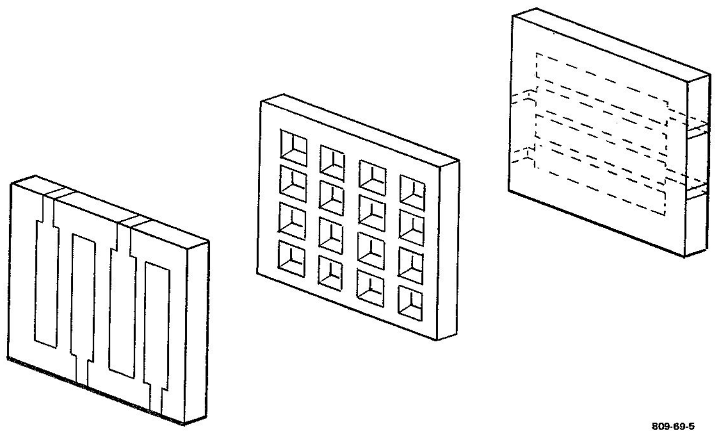
Initial testing was performed on the Digivue panel as it is commercially available. With sinewave signals, the firing voltage for the panel is 200 volts (0 to peak), with 30 volts* of memory. The term memory is used throughout this report to define the difference between the firing voltage (V_f) and the extinguishing voltage (V_e). Figure 6 (A) shows the Digivue panel in operation.

Later experiments were performed on panels that differed considerably from the Digivue unit. These panels were of a cellular design, using a shim which contains a pattern of small holes positioned at the electrode line intersections. The shim and cell walls were constructed from Corning microsheet glass, 0.006-inch thick. As shown in Figure 6 (B), electrodes were vacuum-deposited on the outside surfaces of the panel. This type panel provided firing voltages of 210 volts when filled with pure neon, but with little memory (about 5 volts). A small amount of nitrogen added to the neon increased the memory but also increased the firing voltages. It was found that a gas mixture of 1/2 to 1 percent nitrogen in neon was a good compromise, giving 50 volts of memory with a firing voltage of 400 volts.

*Unless otherwise noted, all voltages (in the case of memory, voltage differences) are 0 to peak.



(A) DIGIVUE Panel in Operation



(B) Construction of Thin-Walled AC Panels. Transparent electrodes are vacuum-deposited on the outside of the glass walls, with a honeycomb shim sandwiched between.

Figure 6. Test Panels

In order to determine the selective write/erase resolution capabilities of probes, a panel was designed containing areas of various resolutions. Figure 7 (A) shows the cell design for this panel, with the resolution test pattern clearly evident. The smallest matrix (3x3 group) had square cells 0.016 inch per side at 32-line-per-inch spacing. Each succeeding matrix had the spacing doubled and the line width held constant. This gave spacings of about 20 lines per inch, 12 lines per inch, and 7 lines per inch. The more widely spaced cells had shim openings 0.025 inch per side, primarily to simplify assembly alignment. Opaque rear electrodes were used to provide maximum reflection of light and minimum electrical resistance. Thin, semi-transparent front electrodes were used. These electrodes were more resistive (2.5 kilo-ohm end to end) than the back electrodes, but possessed a transmission of approximately 50 percent. Electrodes in both sets had widths of 0.016 inch. Figure 7 (B) shows this panel in operation. The panel was sealed with vacuum epoxy. The method of attaching the fill tube is clearly seen at the top of the photograph.

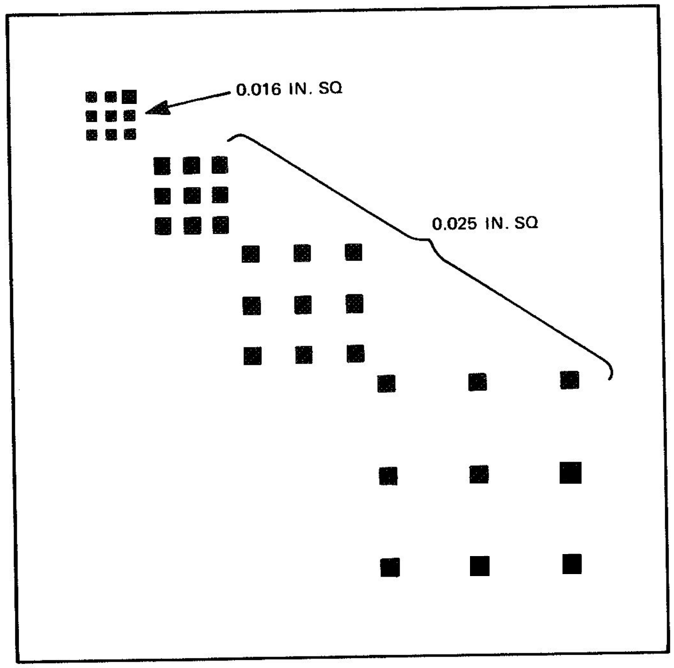
B. DRIVE ELECTRONICS

The two circuits diagrammed in Figure 8 show the sustaining signal power supplies used to provide the panel drive. The top circuit is more complex but also more versatile. Circuit power is provided by a 7094 beam power tube operated class A. This circuit is capable of providing either sinewaves or squarewaves at frequencies from near dc to nearly 500 kHz. However, this circuit is limited by the vacuum tube and the power supplies to an output amplitude of 1000 volts (peak to peak). The panel can be connected with either the front or back electrodes grounded.

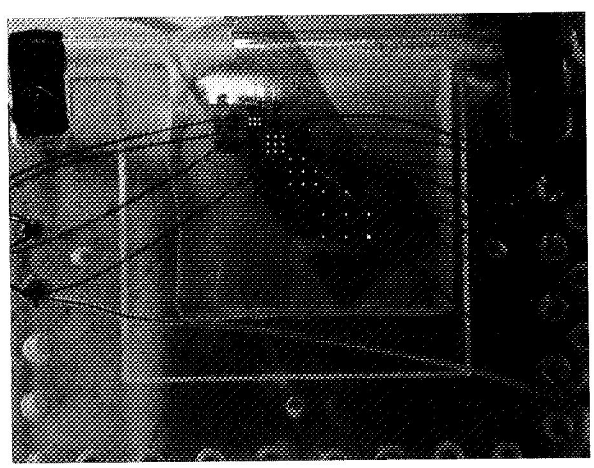
The bottom power supply circuit in Figure 8 was also used. Although it is limited to sinewaves, its possible output voltage is nearly double that of the vacuum tube amplifier. The output voltage is frequency dependent, corresponding to the resonant frequency determined by the step-up transformer inductance and the panel capacitance. Resonance frequency was approximately 100 kHz.

One additional circuit was used to provide drive signals for some of the tests. This circuit employs a simple transistor switch controlled by a squarewave generator. It provides squarewaves up to 500 volts (peak to peak) in amplitude. This voltage limitation prevented extensive use of the circuit.

These power supplies were also used for the voltage probe drive signals. In the voltage probe studies, the two Wavetek signal generators were phase-locked together. The slaved Wavetek could be phase shifted by variable amounts relative to the master, or it could be phase shifted discretely by 180 degrees.

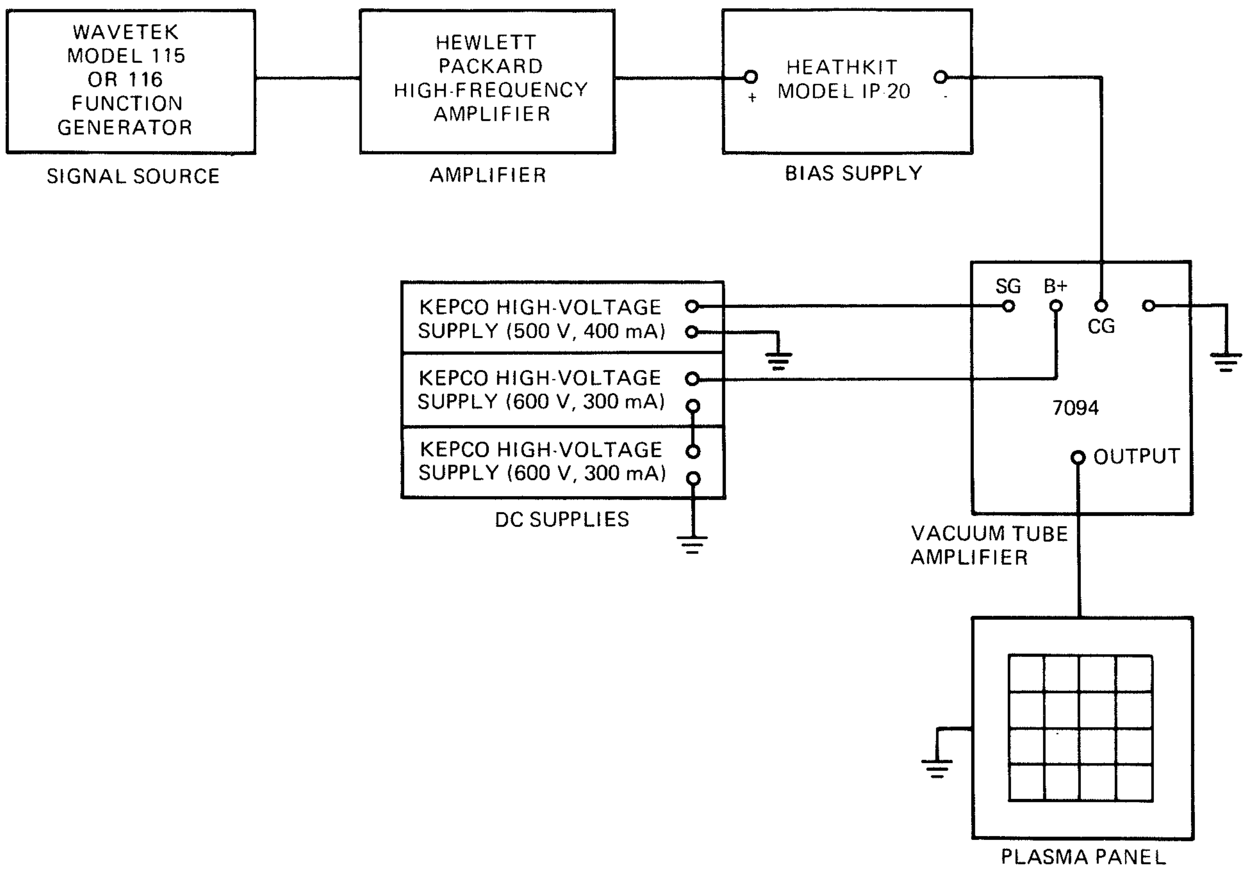


(A) Cell Configuration for Varied-Resolution Display

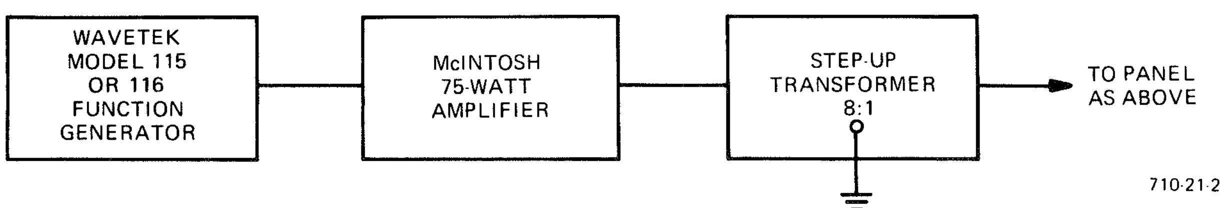


(B) Varied-Resolution Panel in Operation
Showing Method of Construction

Figure 7. Test Panel of Various Resolutions



Functional block diagram of electronics used to drive plasma panel. This system can drive sinewaves or squarewaves up to approximately 500 kHz. Maximum voltage is approximately 1000 volts (peak to peak).

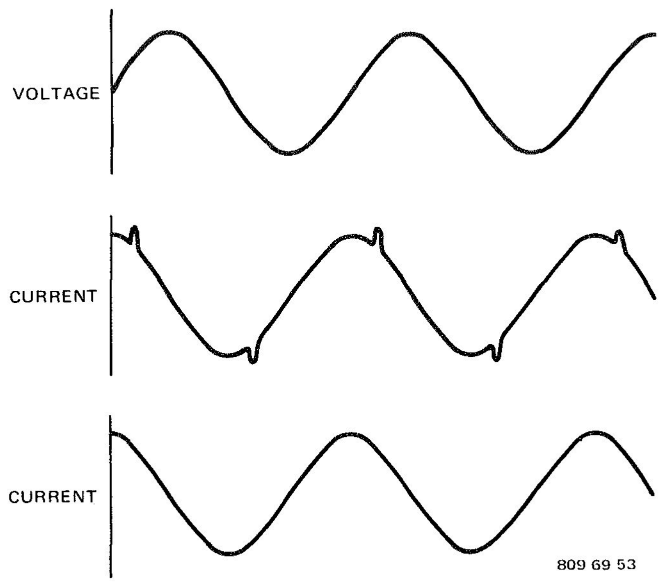


Alternate drive system used can drive the plasma panel with sinewaves. The most efficient frequency (approximately 100 kHz) is determined by capacitive load. This system is capable of 2000 volts (peak to peak).

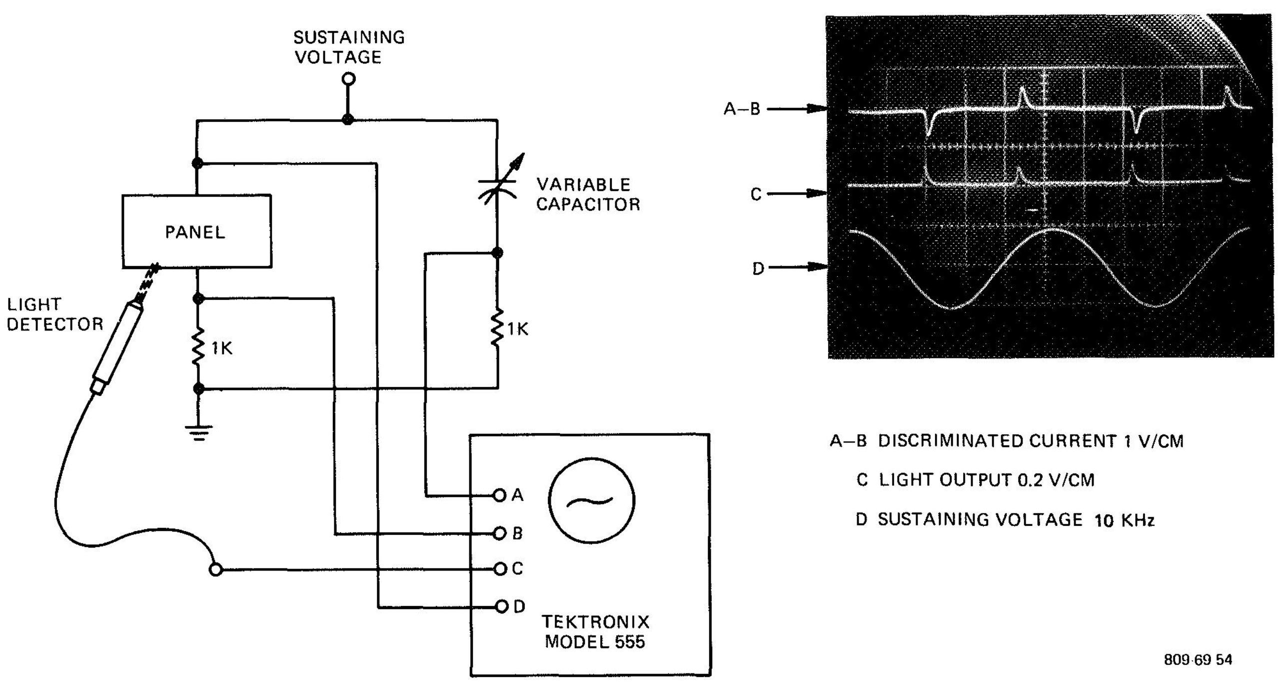
Figure 8. Block Diagrams of Drive Electronics

C. SPECIAL CIRCUITS

As mentioned previously, phasing of the probe and sustaining signals was important, and in some cases, very critical. In order to obtain the correct phasing, it was necessary to know the firing point of the cell. The current pulses from the lit cells on the panel were sensed by the circuit shown in Figure 9. This circuit was used to remove the normally present reactive circulating current and to discriminate the current pulse from a partially lit 10x10 array. The variable capacitor was used to phase the two signals (A and B) by balancing the capacitance of the panel. The two signals were adjusted in magnitude by the oscilloscope gain. The differential input on the oscilloscope was used to obtain the abnormal current spike associated with an "on" element. This technique was not sensitive enough, however, to discriminate the pulse from an individual cell.



A cell in the on-state exhibits a current spike (middle). In the off-state, the current spikes do not appear (bottom).



The oscillogram shows the way in which current and light spikes from lit cells may be discriminated with the above circuit. The photograph was taken with a DIGIVUE panel driven by a 10-KHz sine wave.

Figure 9. Bridge Used to Sense Current of Several Lit Cells

IV. PROBE WRITING RESULTS

A. DC VOLTAGE PROBES

Although selective probe writing was not achieved, the dc voltage probe experiments proved to be informative, as they provided a demonstration of interaction between a low-voltage probe and a plasma panel. Controlled erasure was achieved using the thin-walled, 32-line-per-inch panel. Non-pure neon was used (apparently caused by incomplete purging of the vacuum manifold), giving a firing voltage (V_f) of 425 volts and memory of 45 volts. Other conditions in effect were:

- Drive lines on rear of panel at ground potential
- Drive lines on front of panel driven with 100-kHz sinewaves
- Panel fully lit
- Sustaining voltage, V_s ($\sim$385 volts), set just above extinguishing voltage, V_e
- A layer of Kapton, 1 mil thick, over the face of the panel to serve as electrical insulation from the probe
- DC probe connected as shown in Figure 1

The memory margin was adequate to allow tests over a reasonably large range of voltages.

Initially, experiments were conducted with an unswitched probe. As the sustaining voltage was lowered to near the extinguishing voltage, it was found that application of the dc probe caused erasure, often affecting more than one cell and occasionally erasing an entire line. With V_s raised slightly, the cell would only be dimmed and not extinguished.

In further experimentation it was found that the polarity and magnitude of the probe voltage had no substantial effect on erasure reliability. Voltages in the range from -250 to +500 volts dc were tested, with a grounded probe proving just as effective. It was not possible to cause erasure if the front lines were grounded and the rear lines were high. This evidence suggests that the dc probe was interacting with the drive lines and/or sustaining voltage level rather than directly with the cell. However, this explanation is at best only partially correct since selective erasure of individual cells was possible.

Throughout these experiments, it was never possible to write a cell with the dc probe. It seems possible to write a cell in a manner analogous to the slow-write technique originally suggested by the University of Illinois.* The combination of the dc probe produced mirror charges and the sustaining voltage induced charge should produce a voltage that exceeds the firing voltage of the cell, thereby causing the gas to ionize. However, voltages to 500 volts for thin-walled panels and to 2000 volts for the Digivue panel were tried with no success. A higher voltage may have produced writing, but this possibility was not investigated. Since both probe writing and erasure were possible with the ac-driven probe technique, the remainder of the voltage probe effort was directed toward ac probes.

B. AC VOLTAGE PROBES

Initial experiments indicated that the phase relationship between the sustaining signal and the probe was more critical than expected and that the optimal phase relationship was not what had been anticipated. The basic circuit for these experiments was shown in Figure 2. The circuit conditions were:

- V_s approximately midway between V_f and V_e
- The probe signal phase-locked to the sustaining frequency
- A layer of 1-mil Kapton insulating material placed between the probe and the front face of the panel
- Thin-walled, 32-line-per-inch, varied-resolution panel used; filled to 730 torr with neon plus approximately 1 percent nitrogen

In early experiments, the sustaining voltage proved to be a critical factor. The most desirable operating voltage for general use was considered to be near the midpoint of the sustaining region. However, it was found that unless the sustaining voltage was near one extreme or the other, probe writing or erasure was very unreliable. As the various factors involved became better understood, it was possible to reliably write and erase the panel at a set sustaining voltage simply by switching the phase of the probe signal.

1. <u>Sustaining Voltage/Probe Voltage Phasing</u>

In order to achieve reliable probe writing and erasure, proper phasing of the ac probe and sustaining voltage was essential. In one circuit configuration which resulted in the lowest probe voltage, the front electrodes were grounded. The entire sustaining signal, referenced to ground, was coupled to the rear

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*Bitzer, D. L., Slottow, H. G., The Plasma Display Panel - A Digitally Addressable Display with Inherent Memory, Proceedings of Fall Joint Computer Conference, 1966.

electrodes. This arrangement is the safest for thin-walled panels since the panel itself acts as protection against the high voltage applied to the rear drive electrodes.

When the sustaining and probe signals were applied in phase using this configuration, reliable erasure could not be achieved. However, if the probe signal were phase shifted while still frequency-locked with the sustaining signal, as shown in Figure 10, reliable write was obtained with minimal probe voltage. Under this optimum write condition, the probe signal changed polarity at the normal firing point of the cell, as evidenced in the lower trace, which presents the current pulses from the lit cells.

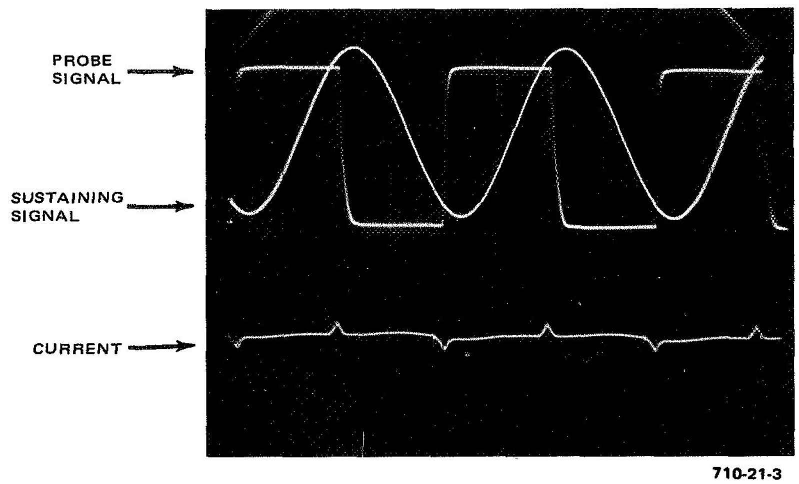


Figure 10. Phasing Used for AC Probe Writing with Squarewave Probe Signal and Sinewave Sustaining Signal

In this photo, all of the panel's lit cells are collectively sensed and contribute to the current trace. The current spikes represent the normal firing point of a lit cell with only the sustaining signal applied; they do not represent the forced firing of the probe-addressed cell. Thus, it appears that for the condition discussed, optimal write is achieved if the probe signal reverses (in the direction of the sustaining voltage*) at the normal firing position.

As previously mentioned, effective erasure was obtained simply by reversing the phase of the probe voltage. With this phase reversal, the sustaining and probe signals oppose each other.

*Because the probe signal is applied to the grounded side of the panel, a negative-going transition constructively adds to a positive-going sustaining signal.

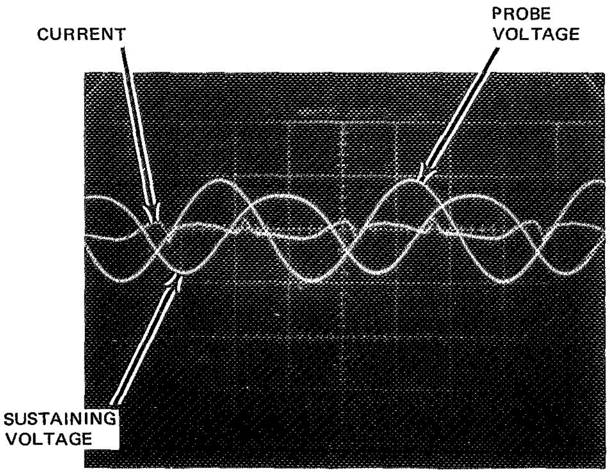
2. <u>Effect of Wave Shape</u>

As might be expected, the phase relationships of the probe and sustaining signals, as well as the voltage amplitude required by the probe to accomplish reliable write/erase, depend on the waveforms used. For this reason, all combinations of sinewaves and squarewaves were investigated, including:

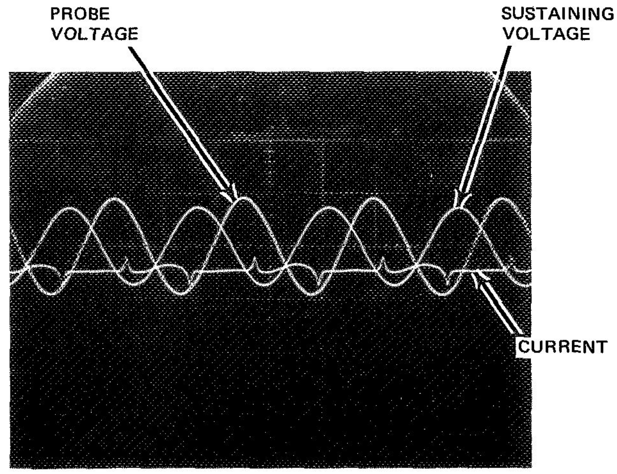
- Sinewave sustaining signal
  Sinewave probe voltage
- Sinewave sustaining signal
  Squarewave probe voltage
- Squarewave sustaining signal
  Sinewave probe voltage
- Squarewave sustaining signal
  Squarewave probe voltage
- Squarewave sustaining signal
  Pulsed probe voltage

The first three cases are illustrated in Figure 11. The sinewave-sinewave combination proved difficult to obtain the proper phase relation for reliable operation. Figure 11(A) shows the phasing for the write mode, while Figure 11(B) shows the erase phasing. These photographs were taken at different times and at different frequencies as noted; they demonstrate, however, that correct phase angle is independent of applied frequency.

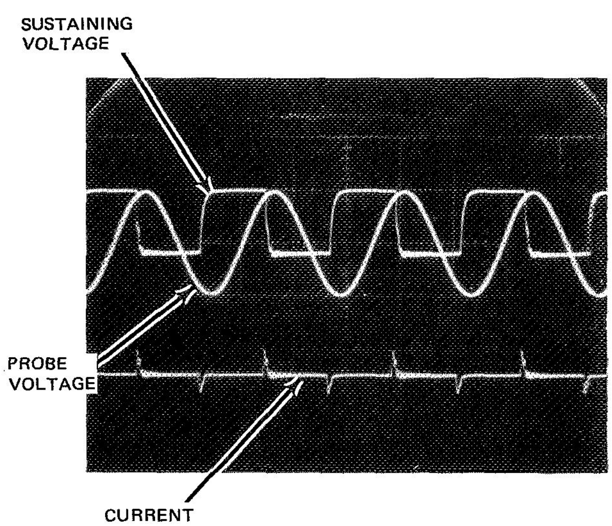
Figure 11(C) shows a squarewave sustaining signal used in conjunction with a sinewave-driven voltage probe. In this case, the phasing was much less critical and the probe voltage was lower than that necessary for sinewave-sinewave operation. This may be explained as follows. There is a fundamental delay in the formation of the discharge - the formative time delay - that is reasonably fixed. For a squarewave signal, the discharge should occur at the time of the squarewave transition plus the formative timelag. For lowest probe voltage requirements, the probe voltage should be near its peak at that point, as shown in the figure. Because of the relatively broad sinewave peak, the phasing is not too critical. The case pictured here does not reflect the reduced probe voltage, but it was observed that the voltage could be reduced to 300 volts without jeopardizing reliability. This is in direct contrast to the previous case, where the reliability was poorer. With two sinewaves trying to influence the cell, there is no sharp transition to trigger the discharge; in fact, the field produced by the probe may itself cause a phase of the normal firing position relative to the sustaining signal.



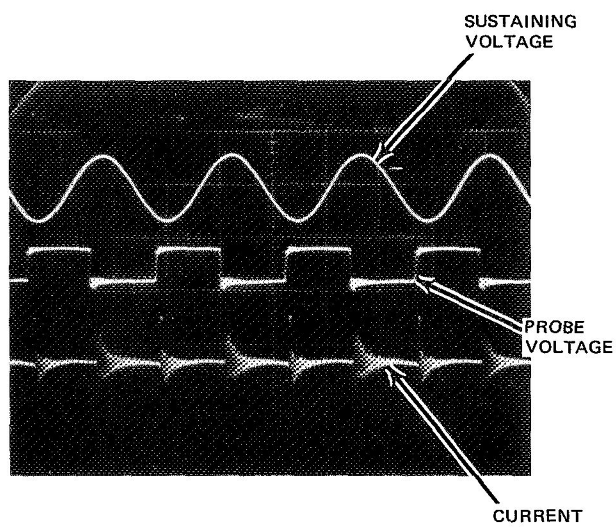
(A) Phasing for Write
140 kHz, 500 v/cm
on voltage traces.



(B) Phasing for Erase
80 kHz, 500 v/cm
on voltage trances.
Note 180° phase reversal.



(C) Phasing for Write
80 kHz, 500 v/cm
on voltage traces.



(D) Phasing for Write
80 kHz, 500 v/cm
on voltage traces.

710-21-4

Figure 11. Optimum Probe and Sustaining Signal Phasing for Various Combinations of Signal Waveforms

The most favorable waveform combination studied is shown in Figure 11(D). The phasing of the sinewave sustaining signal in combination with the squarewave probe signal, while still important, covered a much broader acceptable range than did the other combinations. The probe voltage could be reduced to as low as 150 volts peak, maintaining good reliability in writing and erasing the panel. No quantitative measurement was made of writing speed but it was reasonably fast; near-normal writing speed could be used. Only momentary alignment of each cell with the probe caused a change of cell state.

With the sinewave sustaining signal and squarewave probe voltage at fixed voltage settings, it was possible to write and erase all spacings on the varied-resolution panel except the 32-line-per-inch grid. In this case, it was necessary to slightly increase both the sustaining and probe voltages. This increased work is expected* and is due to the smaller area of the cells in the 32-line-per-inch matrix, 0.256×10^{-3} inch^2 compared to 0.625×10^{-3} inch^2. With voltages raised, however, single cells could be resolved in the 32-line-per-inch matrix.

Two additional waveform combinations were investigated with minimal success. With squarewaves on both the sustaining signal and the voltage probe, it was nearly impossible to obtain the proper phase relationship between the two signals. It is felt that this phasing difficulty was due to insufficiently precise phase locking, required for the rapid rise and fall time associated with squarewaves. Other circuit combinations may overcome this difficulty.

If the squarewaves are narrowed to pulses, the reliability becomes even less. The pulse generator used was limited to pulses of a given polarity. Thus, the probe is influential only once each cycle rather than twice, as with the other waveforms. Since the pulse technique was only tried with a squarewave sustaining signal, it may be possible that this technique would work with other sustaining signal waveforms.

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*<u>Plasma Display Technical Study, Final Report</u>, Sperry Flight Systems Division, Sperry Rand Corp, for Air Force Flight Dynamics Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, February 1970.

Goede, W. F., <u>Effect of Hole Diameter, Electrode Width, and Glass Thickness on Properties of the Plasma Display Cell</u>, Coordinated Science Laboratory, University of Illinois, Urbana, Illinois, July 1968.

V. ELECTRICAL INTERROGATION

When the current bridge described on page 24 is used to discriminate the single-cell current pulses, the signal-to-noise ratio is so low as to preclude positive sensing. Since it is necessary to detect the pulse from a single cell, another circuit was developed (Figure 12) to discriminate and amplify the current pulses for a single lit cell. Coupling to the discriminator is provided by the pulse transformer, which also provides isolation from the large sustaining voltage. A simple high-pass filter, the two capacitors and inductor, along with the low magnetizing inductance of the small transformer reject the drive frequency and pass the discharge current component. The differential amplifier removes any remaining drive signal and amplifies the current pulses.

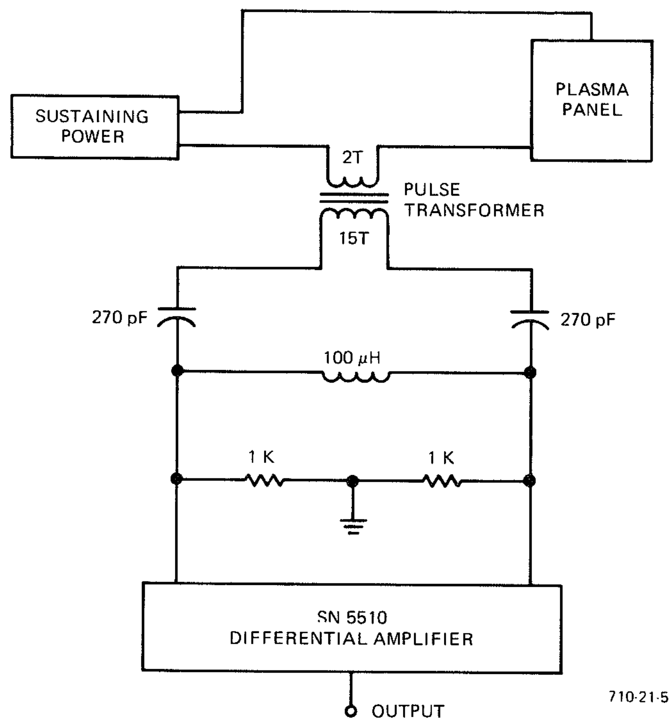


Figure 12. Diagram of Circuit Used to Discriminate and Amplify Single-Cell Current Spikes

In the figure below, the drive frequency is 100 kHz at 500 volts. The current spikes are 0.5 volt in amplitude. Amplification and/or wave shaping is readily possible to provide for direct computer input.

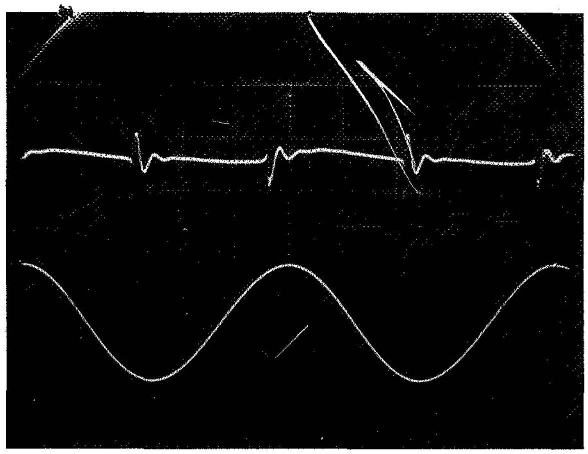


Figure 13. Sustaining Voltage Waveform and Current Spikes from Single Lit Cell

Since interrogation can be performed element-at-a-time or line-at-a-time as described on page 12, it is important to consider the interrogation time available, that is, the time constant for non-volatile information storage. In an effort to determine the time available for interrogating the panel without loss of information, the following experiment was performed.

The varied-resolution panel (Figure 7) was filled with a 1-percent nitrogen in neon mixture at a total pressure of 610 torr. A gated sustaining signal was applied whose voltage was midway between the firing and extinguishing voltages (340 and 300 volts, respectively). With a given set of information entered into the panel under cw operation, the duty cycle was decreased (for given on time) until the stored information was destroyed (that is, the panel began to spontaneously erase).

Figure 13a shows that over the majority of the test range, the maximum off time for non-volatile information storage depends on the previous on time. For very short on times (less than 8 pulses), there appears to be a lack of total information of the wall charge, as evidenced by a break from linearity on the plot. At longer on and off times, it might be expected that the maximum off time for non-volatile information storage would stabilize due to the finite leakage time of the wall charge. It is seen that usable off times at least as long as 0.8 second can be achieved. The measured available time should allow for computer interrogation by the proposed schemes without any difficulty.

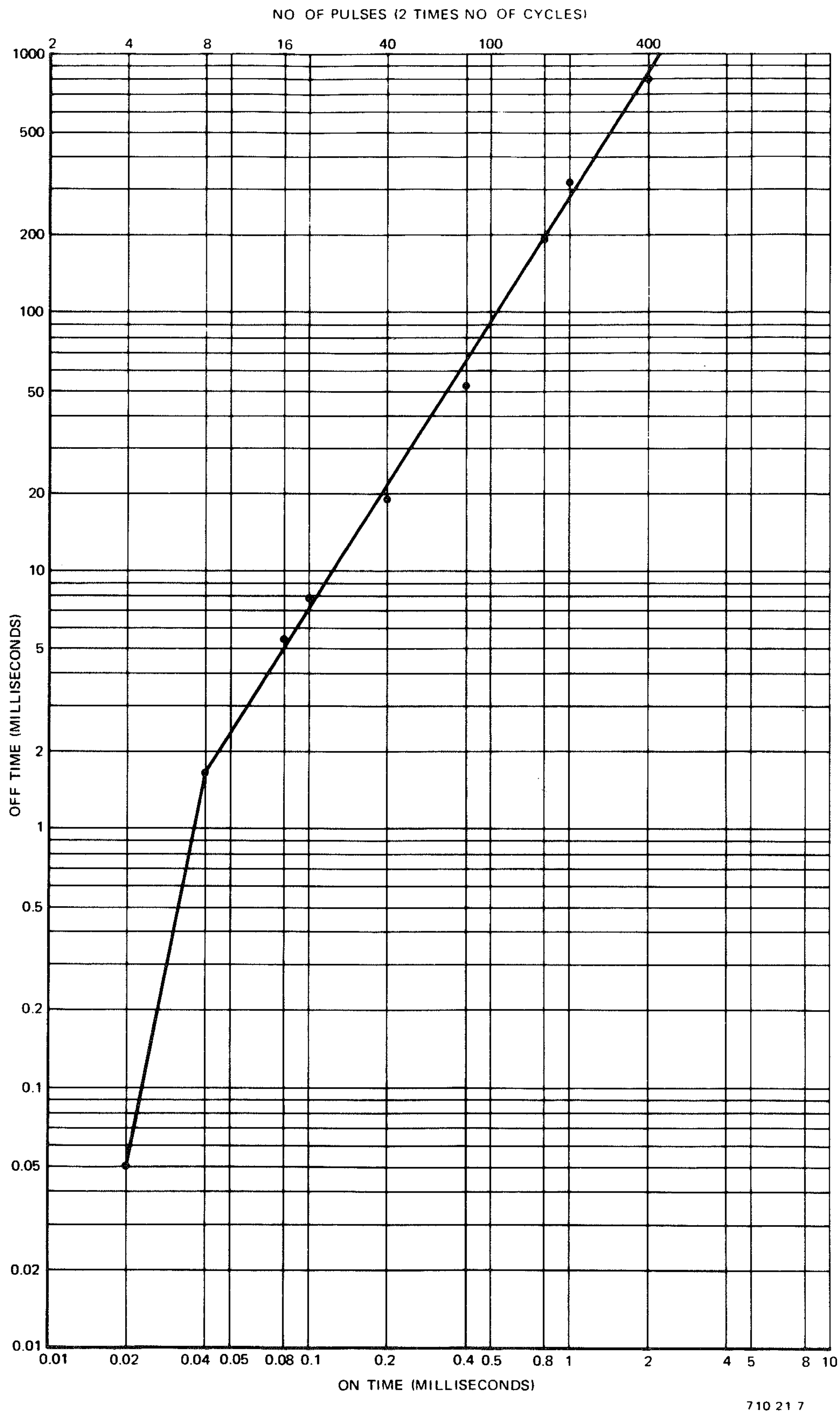


Figure 13a. Maximum Off Time for Non-Volatile Information Storage

VI. SUMMARY AND CONCLUSIONS

The purpose of this contract was to investigate the possibility of using an ac plasma panel display as a computer input device. As a result of this work, the following conclusions are drawn.

(1) A thin-walled panel can be successfully written and erased using an ac voltage probe. For the most favorable waveforms, the panel could be written and erased with a moderately low probe voltage (150 volts). Still lower probe voltages seem possible with alternate electrode configurations.

(2) While either sinewaves or squarewaves can be used as a sustaining signal for the panel and as a signal for the voltage probe, one combination - a sinewave sustaining voltage and a squarewave probe voltage - gave the best reliability, the lowest probe voltage, and the least critical phasing. Writing by this technique was reasonably fast.

(3) The phasing between the sustaining signal and the probe signal is very important. For reliable operation, it was necessary for the probe voltage to be near a peak, or making a transition, at the normal firing point of the cell.

(4) AC voltage probes do not appear to be a feasible means of writing and erasing thick-walled panels. In the course of the study, it was not possible to affect a Digivue panel with probe voltages as high as 2000 volts, peak to peak.

(5) Using the ac voltage probe, it was possible to resolve individual cells in a 32-line-per-inch matrix. Higher resolution may be possible but was not studied.

(6) The active phenomenon responsible for voltage probe writing is not thoroughly understood. Two possibilities immediately suggest themselves: first, the probe may interact with the sustaining electronics via the drive electrodes, and second, the probe may affect energy transfer directly into the gas volume of the cell. Interaction with the drive lines does not seem likely, however, as a reaction should be observed on all cells downstream of the probe signal on single-ended drive lines. This phenomenon was not evident; unique address of individual cells occurred. Therefore, the evidence suggests that the probe interacts simply by constructively or destructively adding to the normally present sustaining signal within the cell.

(7) The demonstrated moderately low voltage requirements of ac-driven probes and the potential for further substantial voltage reduction with altered electrode configuration suggest that operator safety consideration should be compatible with voltage probes. In addition, selective address by a grounded dc probe was achieved. However at present, only the erasure mode of the dc probe has been demonstrated.

(8) Due to the rapid ignition time of a plasma cell, generally sub-microsecond, it is conceivable that voltage probe writing may be possible with a single pulse. The waveform combination necessary to prove this was not achieved. Potential advantages of this technique are safety and power considerations associated with the low energy content of a single, narrow voltage spike.

(9) Light probes may have a major advantage over voltage probes in that they are applicable to thick-walled, high-resolution panels as well as thin-walled panels, and they are completely safe. However, panels that are suitable for use with light probes may be vulnerable to ambient lighting and/or the light generated by lit cells within the panel. In addition, proposed techniques suitable for probe writing are more difficult to implement, and writing speed may be limited.

(10) A reasonably simple electronic circuit was studied that can easily discriminate the current pulse from a single lit cell. With level adjustment and/or signal shaping, the signal produced should be suitable for computer usage and could be used to interrogate information stored on a plasma panel.

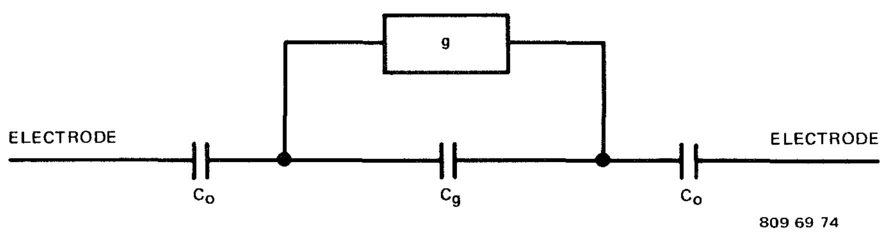
(11) The time available to non-destructively interrogate the panel by coincident application of sustaining level signals appears compatible with various interrogation scan methods. Other methods seem possible, where signals of non-sustaining frequency, amplitude, and/or phase are selectively applied without interruption of the normally present sustaining signal.

APPENDIX A

DISCHARGE AND MEMORY EFFECTS IN AC PLASMA PANELS

A discussion of ac plasma panel discharge and memory behavior is important in understanding electronic write/erase techniques, either via coincident line address or via probe address.

Because the plasma panel is a three-layer sandwich structure of gas-between-glass between the plasma panel electrodes, the structure represents a multi-dielectric capacitor (in the "off" state). Therefore, the potential applied to the gas is less than the applied voltage on the electrodes. In the simple equivalent circuit shown below, the box labelled g represents the additional complicated circuit of the gas-filled gap present when a discharge occurs or is forming (it is of near-infinite impedance when the discharge is absent).



C_o represents the capacitance of the glass wall (both walls are assumed identical) and C_g the capacitance of the gas-filled gap.

If V' is the potential applied to the electrodes and V_A is the resulting potential across the unfired gas-filled gap, the impressed voltage on the gas cell is

$$V_A = \frac{C_o}{C_o + 2C_g} V'$$

Knowing this relationship, the distributional effect of the cell structure will be ignored, and the applied or impressed voltage referred to will be assumed to be the voltage applied to the gas-filled gap between the glass walls not including the effect of any electrical charge residing on the wall (wall charge).

The following symbols will be used throughout:

V_A = the voltage applied to the inner wall surfaces neglecting surface charge

V_w = the potential between wall surfaces due only to surface charge

V_R = the result voltage, $V_A + V_w$

V_f = firing voltage of the plasma panel (or given electrode intersection)

V_e = extinguishing voltage of the plasma (or electrode intersection)

V_s = sustaining voltage of the plasma panel

At point f, $V_A - V_w = V_f$ and the panel or intersection fires

At point e, $V_A - V_w = V_e$ and the panel or intersection extinguishes

The breakdown of the gas in a plasma panel is governed by the electric field applied to the gas-filled gap between the panel inner surfaces. When the potential across the gap reaches the firing voltage of the panel, the gas breaks down electrically by ionizing, allowing charge to flow through the ionized gas (plasma). The charge flows to reduce the impressed field until the resultant potential drops below the extinguishing voltage of the plasma, at which time the plasma quenches. The charge accumulated on the cell wall is

$$Q_w = V_w C_g$$

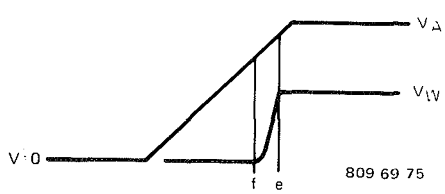


Figure 14

Assume that the impressed voltage on a cell (panel intersection) rises at a moderate rate to a finite value V such that $V_f < V < 2V_f$, as shown in Figure 14. At $V = V_f$, the gas discharge forms, permitting charge to be transported until $V_a - V_w = V_e$, when the discharge extinguishes. This results in a single discharge that occurs between points f and e.

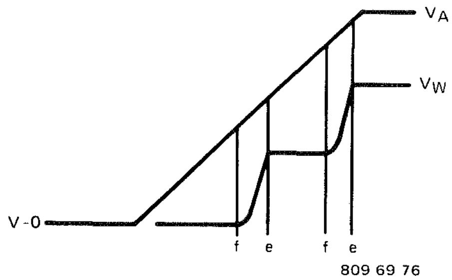


Figure 15

Other circumstances can also be induced. Assume that the impressed voltage rises as before, but to a higher final value (Figure 15). After the initial discharge extinguishes as in the first case, the value of $V_A - V_w$ again becomes equal to V_f, and the discharge forms a second time, extinguishing again at $V_A - V_w = V_e$. The result is a multiple-discharge effect, the discharges again occurring in the time periods represented between points f and e.

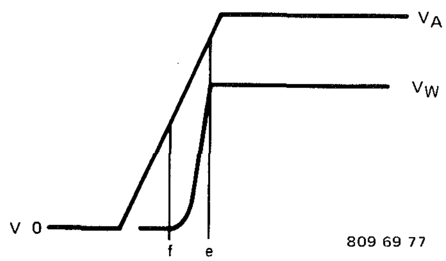


Figure 16

The multiple-discharge effect may not occur if the rise time of the applied voltage is sufficiently high. Assume now that the applied voltage rises from zero to the same value as in Figure 15, but with a faster rise time (Figure 16). The finite charge transfer rate through the discharge (determined primarily by the gas employed) results in a stronger single discharge extending over a longer period of time, rather than multiple discharges. (This longer discharge duration results directly in a larger light output.)

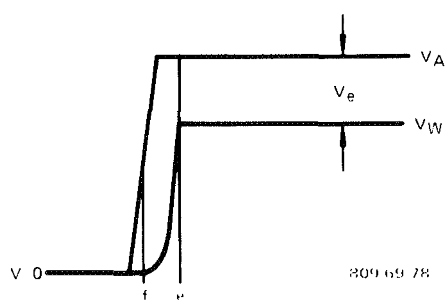


Figure 17

If the rise time is increased still further, as shown in Figure 17, the peak applied voltage will be reached before the plasma extinguishes. Thus, the discharge duration and strength is directly dependent only on pulse height. The wall voltage rises to within V_e of the applied voltage peak ($V_A > V_f$).

A repetitive light pulse output may be obtained by cycling the impressed voltage between zero and a voltage V such that $V > (V_e + V_f)$, illustrated in Figure 18.

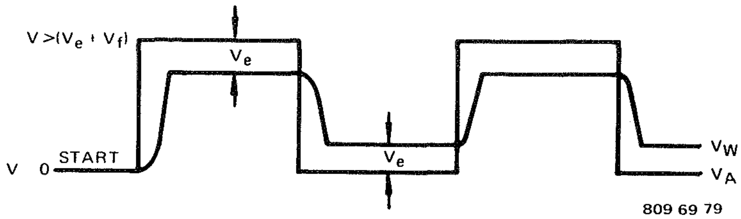


Figure 18

Plasma panels are normally driven with an applied voltage of alternating polarity (which amounts to shifting the zero voltage reference in Figure 18).

For memory mode operation, both the upper and lower limits on the impressed voltage are important. Recall that when a cell fires, a charge will accumulate on the cell wall.

$$Q_w = V_w C_g$$

On the opposite cycle of the applied potential, the charge Q_w remains, at least initially, on the cell wall. The resultant voltage, V_R, across the gas cell is

$$V_R = V_A + V_w$$

A discharge will occur when the voltage across the cell reaches the firing voltage of the cell, $V_R = V_f$. If the discharge in the cell is to be maintained solely by the voltage impressed on the cell, the impressed sustaining voltage, V_s, must equal or exceed the firing voltage.

$$V_s = V_A \geq V_f$$

If, however, the wall is charged to some V_w by a previous cycle, the sustaining voltage is reduced.

$$V_s = V_f - V_w$$

This lower V_s is the voltage required to keep the cell operating with each polarity reversal of the applied potential after the cell has been fired. It will not sustain the discharge in the absence of wall charge. At voltages between V_f and V_s, the cell is then bi-stable. The "on" or "off" state of the cell is now determined by the presence or absence of the wall charge, as shown in Figures 19 and 20.

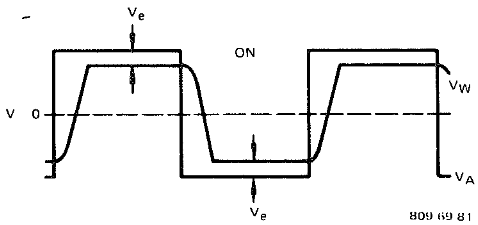


Figure 19

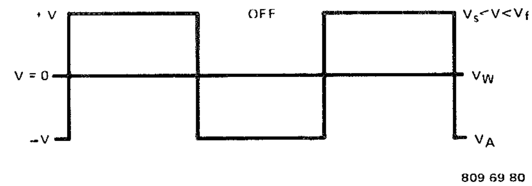


Figure 20

The same set of conditions may be brought about using other than rectangular waveforms. Indeed, the earliest plasma panel drives were largely sinusoidal; only recently has the trend shifted toward rectangular waveshapes. The oscilloscope traces (Figure 21) of applied voltage and light output provide examples of square- and sinusoidal-driven ac plasma panel outputs. The waveforms for the "on" and "off" conditions using a sinusoidal sustaining voltage are shown in Figures 22 and 23.

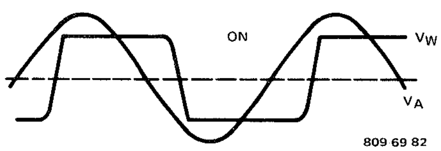


Figure 22

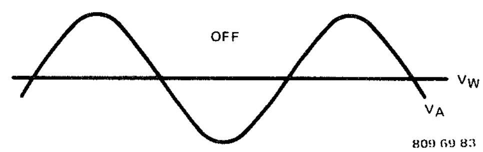


Figure 23

In the case of sinusoidal sustaining voltages, the voltage rise time plays a substantial role in the actual output brightness by influencing the discharge duration. Comparing Figures 24, 25, and 26, it can be seen that the discharge duration (t_d) may be influenced by changing either sustaining voltage amplitude or repetition frequency. The effect in both cases is traceable to the change in the rise time of the impressed sustaining voltage waveform.

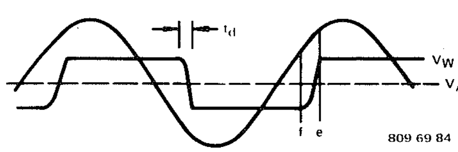


Figure 24

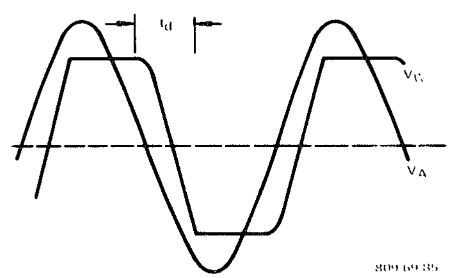


Figure 25

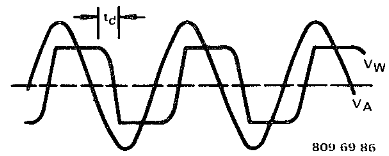


Figure 26

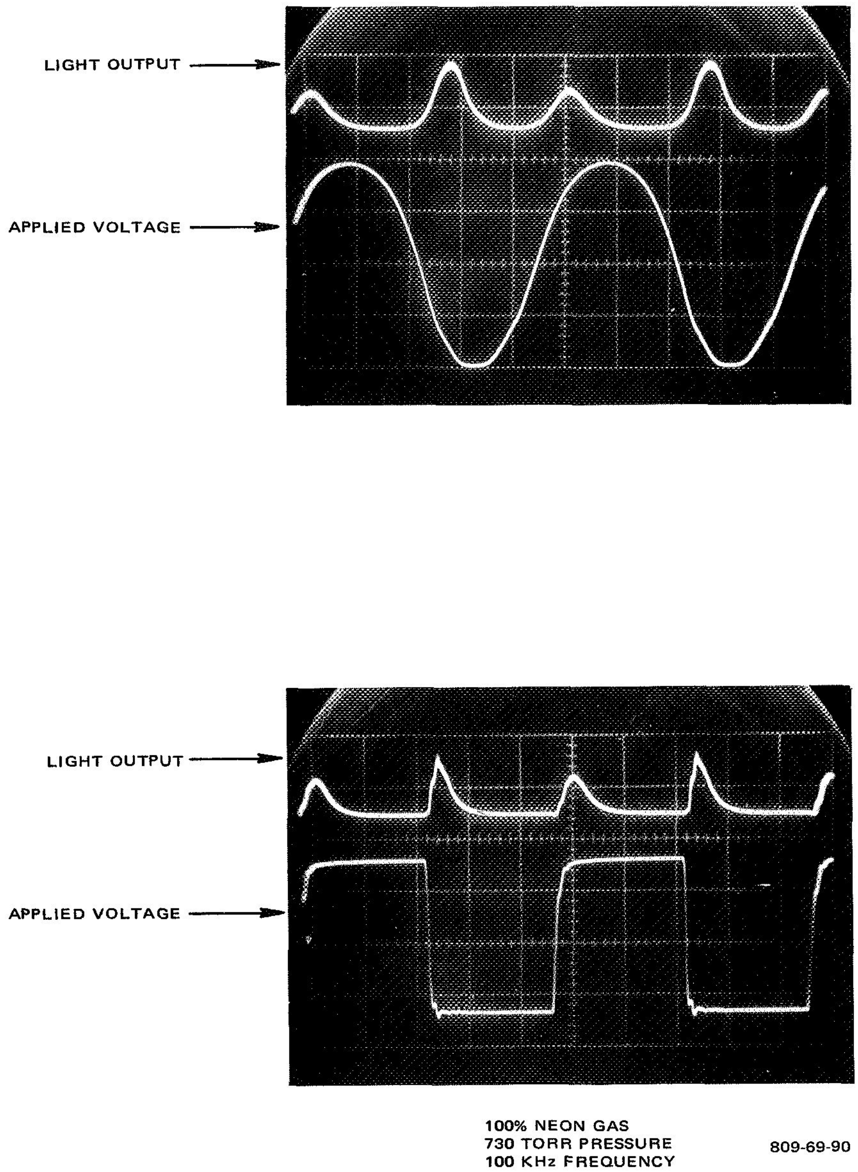


Figure 21. Signal Rise Time Effect on Discharge Pulse Shape. A discharge occurs with each polarity reversal of the driving potential. The change in shape of the light outputs reflects the changes in the discharge brought about by differences in driving signal rise times at the time of the discharge.

The oscilloscope traces below show the rise time effect accompaning operation of a plasma panel at three different frequencies. Although the applied voltages are equal for the three frequencies, the output brightness varies considerably, the waveforms with the highest rise times producing the greatest light output. The effect is most striking in the 100 KHz trace where the waveform asymmetry has a pronounced influence on the light output pulses. The panel used contains 100 percent Neon at 730 torr pressure.

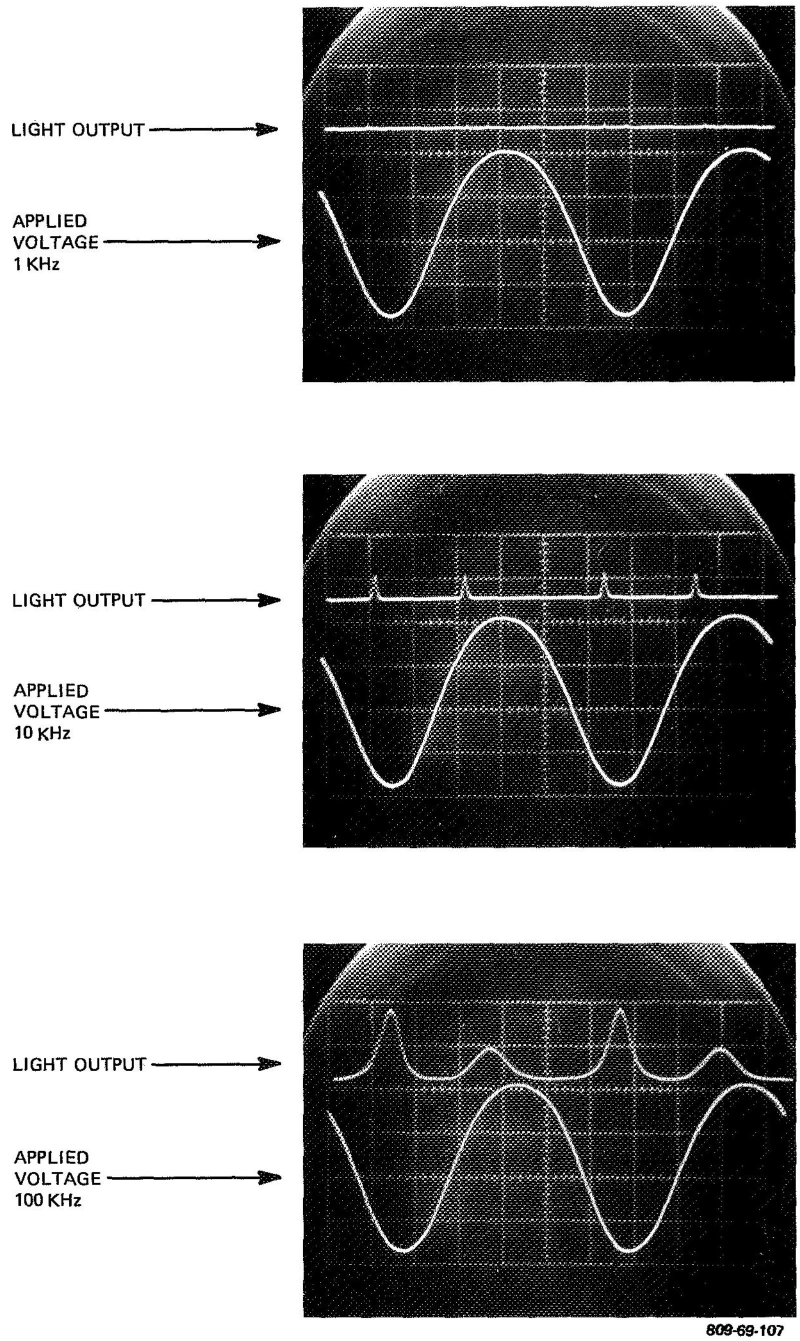


Figure 27. Signal Frequency (Rise-Time) Effect on Discharge Pulse Strength

To change from the "off" condition to the "on" condition simply requires that the difference between the wall voltage and the applied voltage be forced to exceed the firing voltage of the cell for a period of time sufficient for the plasma discharge to form and enough charge be transported to raise the wall voltage to at least half the firing voltage. This may be done by summing a positive pulse of the proper magnitude, duration, and phase relation with the sustaining voltage (Figure 28).

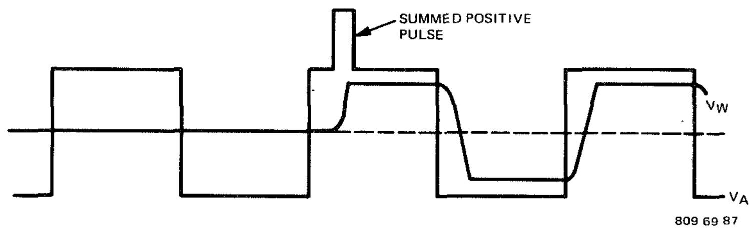


Figure 28

The inverse operation, that of changing from the "on" condition to the "off" condition, is the inverse of the one just described but is not quite as simple to implement. Basically, the wall voltage must be reduced to zero. In most cases, this means that the charge transport during a discharge, and hence the discharge itself, must terminate when the wall voltage is zero or very near zero. In Figure 29, this is accomplished by summing a negative pulse, again of the proper magnitude, duration, and phase relation, with the sustaining voltage. Any means, however, which accomplishes the same zero or near-zero wall voltage will result in an extinguished plasma panel cell.

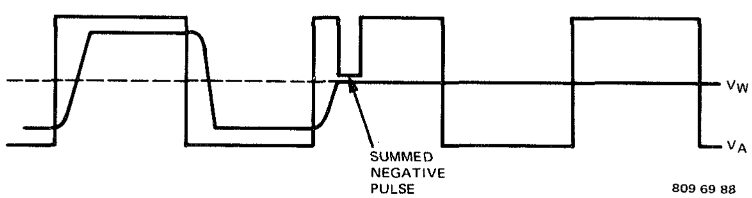


Figure 29

APPENDIX B

NEW TECHNOLOGY APPENDIX

The following potentially new concepts were developed in the course of work on this contract:

(1) Method of using ac-driven probes to write and erase an ac plasma panel.

	Page
Theoretical Discussion	7
Experimental Results	28 to 32

(2) Method of using dc-driven probes to erase an ac plasma panel.

Theoretical Discussion	6
Experimental Results	27 and 28

(3) Method of electrical interrogation of an ac plasma panel.

Theoretical Discussion	16 and 17
Experimental Results	33 to 35

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13. ABSTRACT

This report describes an investigation concerning the feasibility of using ac plasma panels as interactive graphic display devices. The use of external voltage probes to selectively write and erase the panel was studied, as were means for computer interrogation of the panel. The feasibility of both of these objectives was established. Of the waveforms considered for probe writing, the most reliable combination was a squarewave-excited ac probe used in conjunction with a sinewave sustained panel. With this waveform combination, probe voltages of 150 volts (0 to peak) or less were effective. A means of electronically interrogating individual cells was proved. These write/erase and interrogate capabilities and the previously demonstrated display characteristics suggest that the image-retention capabilities of the plasma panel may be used for both graphic computer input and output.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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