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FLUIDIC PLASMA DISPLAY STUDY

FINAL REPORT (PHASE II)

By Jacq Van Der Heyden

June 1969

Prepared under Contract No. NAS 12-532 by
MARTIN MARIETTA CORPORATION
Orlando, Florida

Electronics Research Center
Cambridge, Massachusetts

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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TECHNICAL RESPONSIBILITY

This program was sponsored by the Electronic Research Center of the National Aeronautics and Space Administration, Cambridge, Massachusetts, under Contract NAS 12-532 (Report No. OR 9930). The NASA monitoring scientist is Mr. E. H. Hilborn. The program manager at Martin Marietta's Orlando Division is Mr. Harold J. Straut. The principal investigator is Mr. Jacq Van Der Heyden.

This report covers the period 10 May 1968 through 21 March 1969. Previous work done under this contract was reported in Martin Marietta's report No. OR 9477, Final Report Phase I, released as NASA-CR-86105 and describing development of a fluidic thermochromic display device.

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ILLUSTRATIONS

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APPENDIX A ILLUSTRATIONS

I. INTRODUCTION AND SUMMARY

This report cites the program objectives and the progress made during Phase II of research contract NAS 12-532. This study, sponsored by the Electronics Research Center of the National Aeronautics and Space Administration, covered fluidic plasma display techniques. The object of the study was to determine the feasibility of using fluidic systems to control matrix type plasma displays.

Utilization of fluidic techniques to control these computer readout display systems was found to have distinct advantages over previously developed electronic methods of control. Switching circuits do not have to transfer high voltage control signals, and erroneous display signals caused by impedance changes in the display matrix can be avoided with fluidic control techniques.

During the program plasma display cells which can be lighted and extinguished with pressure signals act constant. Voltage inputs were investigated and developed. Fluidic elements using neon gas as a working media were successfully tested over the pressure ranges required to switch plasma display cells. Also covered by the investigations were possible pneumatic power supplies for the matrix control system and the preferable locations of the plasma cell electrodes.

Section II describes the program objectives and contains the statement of work for the investigation. Discussions on the technical aspects of the investigations are presented in Section III. Relevant information pertaining to construction of the display cells used in the investigations is contained in Appendix A. A report on new technology as required by the contract is included in Appendix B.

II. PROGRAM SCOPE

This section of the report contains a short discussion of plasma displays and the merits of fluidic control systems for these displays. The statement of work governing the contract is also presented in this section.

A. PLASMA DISPLAY SYSTEMS

Recent progress in display techniques includes the development of plasma displays that appear especially promising both for large tactical display panels and for airborne and portable digitally controlled display systems.

Plasma displays for these applications are usually a matrix type. A display matrix consisting of n rows and m columns contains $m \cdot n$ individual display cells that should be controllable independently of each other to obtain a universally usable display system.

1. Plasma Display Cells

The several forms of plasma display cells are variations on the basic principle of a closed cell constructed from glass and filled with a suitable gas such as neon or a mixture of neon and other gases. Usually the gas cells are formed by laminating a glass honeycomb panel between two sheets of glass. Electrodes are deposited upon the two outer sheets. Two types of cells have been used successfully: those with exterior electrodes and those with interior electrodes. The holes in the honeycomb inner glass laminate are either drilled or etched chemically. Electrodes are generally deposited by state of the art deposition techniques. Generally the gas mixture pressure in the cell is somewhat lower than atmospheric.

When a voltage is applied across two electrodes placed on opposite sides of the enclosed cell, an electrical discharge is caused through the gas mixture. This electrical discharge causes emission of visible light when proper conditions are met. Normally the light emission is directly proportional to the voltage applied across the cell. Recent developments include cells that fire a burst of rapid discharges after reaching a certain voltage. They may exhibit an hysteresis effect in the relationship between the applied voltage and the emitted light. This hysteresis effect can be used to advantage as a memory device in matrix display systems.

Dependent upon the size of the cell, the gas mixture, and the gas pressure, a certain voltage applied across the plasma display cell will ignite the cell. This potential is called the ignition voltage, V_i. After initial ignition is obtained, light emission will continue at a lower voltage level;

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this is called the sustain voltage level, V_s. When the voltage drops below the sustain level, the cell will extinguish. This voltage level is called the extinguish voltage level, V_e. Typically these voltage levels will be a function of the internal pressure of the gas in the cell as shown in Figure 1. Obviously, when a constant pressure is maintained in the cell and the voltage is varied along line A as shown in Figure 1, hysteresis between the input voltage and light emission of the cell will be observed.

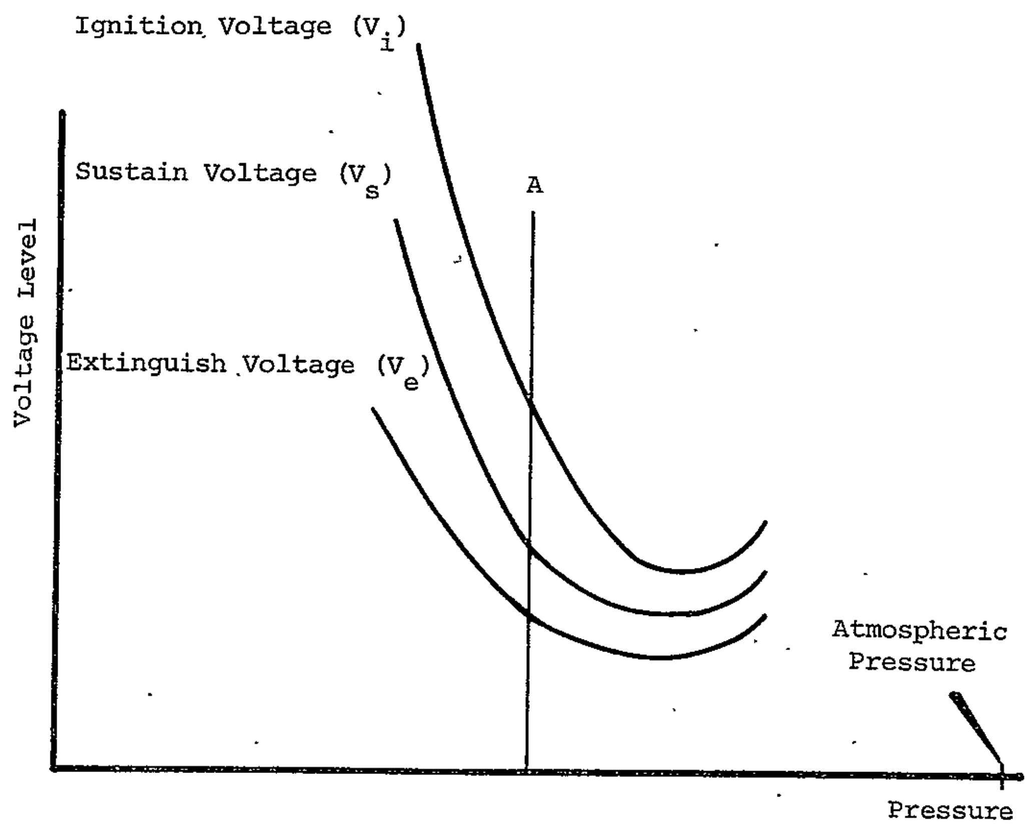

Figure 1. Typical Relationship of Voltage and Internal Cell Pressure

2. Conventional Plasma Display Control Systems

A plasma display matrix can be controlled in either of two ways. In the first system a separate control circuit is used for each cell in the matrix. For large matrices this control system becomes complex and costly, because of the large number of control circuits required. For example, even if only one logic element per cell is required, a 1000 by 1000 cell matrix would require 10^6 logic elements.

An obviously better solution is offered by the second system where a crossed grid array is used. Each column and each row is controlled as an entity. Using one element per column and one per row, a 1000 by 1000 cell matrix will require 2000 control elements, an obvious improvement. The drawback of crossed grid control systems is that, when a complete column is addressed, all cells also having the corresponding line control circuits energized may light up. Conventional electronic control systems circumvent these difficulties by utilizing the inherent hysteresis effect of the cells as a memory, and by sequentially energizing (scanning) the electrodes of selected cells.

Even when utilizing the memory effects combined with the scanning type control system two problems remain to be solved before an electronic control system will be judged feasible; namely:

1. Large scale displays cannot be built economically because of the high cost involved in the control circuits; the reliability of circuits with a large amount of control elements is also unsatisfactory. Since the voltage levels required to control the plasma display cells are substantial, transistorized circuits cannot be counted on to provide low-cost systems. No immediate results can be expected from developments anticipated in microelectronic techniques.

2. The impedance of each plasma display cell basically has two distinct levels. Cells in the activated state exhibit less impedance than those which are extinguished. Consequently, the impedance seen by the excitation signals provided to the display cells will vary depending upon how many cells are fired or extinguished. The impedance changes are sufficient to fire unwanted cells.

Both problems can be solved with a fluidic control system.

B. FLUIDIC CONTROL SYSTEMS

Some problems in crossed grid control systems for plasma displays can be solved by fluidic techniques. The main advantage of a fluidically controlled plasma display system will be in the simplification of the control circuits and the reduction of its failure rate and cost, as compared to electronic control systems.

Since unwanted firings of adjacent cells are at least partly caused by the effects of a change in the impedance of the cell when it converts from the inactive to the active state, a control system that works on the internal cell pressure rather than the applied voltage will be advantageous. A fluidic control system that controls the internal pressure will be completely independent of the electrical impedance changes encountered in the plasma.

Fluidic control, rather than electronic control, can be mechanized as cited here. Figure 2 shows the typical relationship between internal cell pressure and ignition voltage levels as explained earlier. Electronic control of the cell firing is accomplished by varying the voltage level along line A in Figure 2. Fluidic control can be instigated by 1) maintaining the voltage constant on the cell, and 2) varying the internal cell pressure along line B. If the internal pressure is held at the P_1 level, the cell will fire. An increase in pressure to a level anywhere between P_1 and P_2 will still sustain the firing. At pressure level P_2 the cell will extinguish. Since pressure control can be accomplished fluidically, complete fluidic control, combined with a constant voltage supply, is possible.

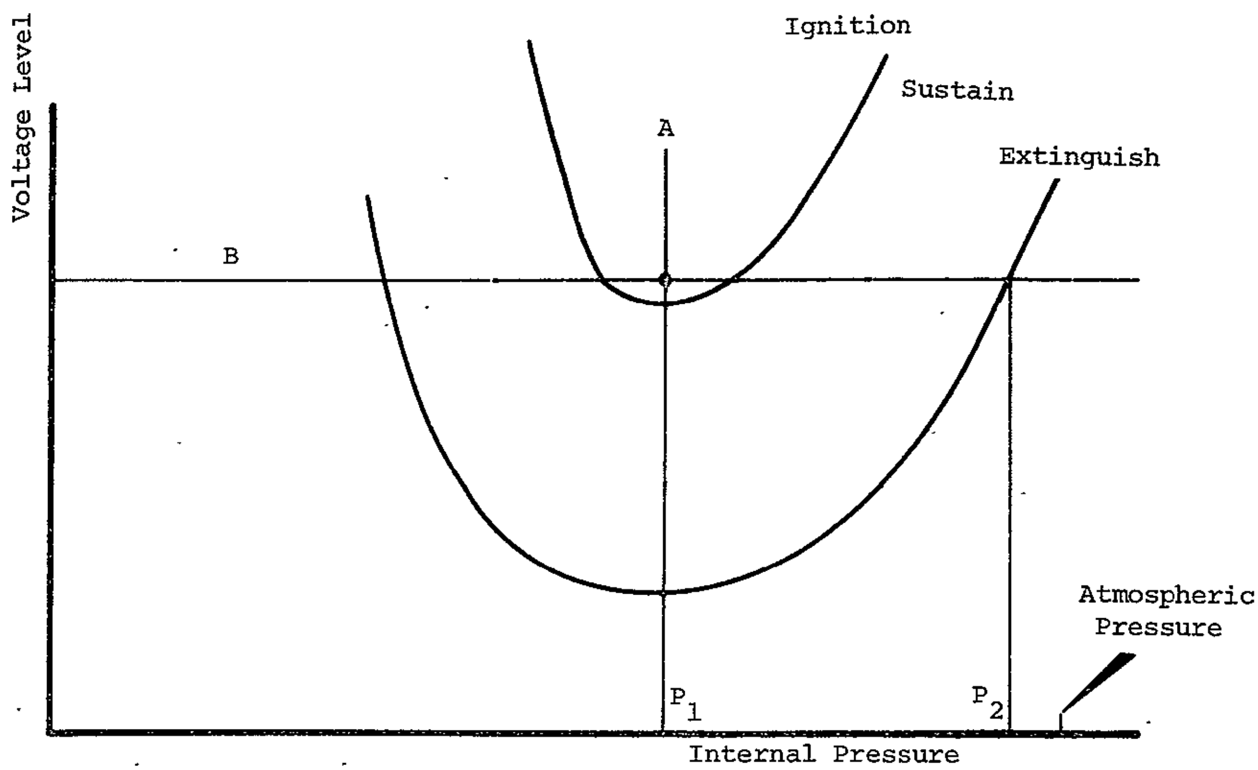

Figure 2. Fluidic Control Mechanization

C. STATEMENT OF WORK

The program consisted of a feasibility study of a fluidically controlled plasma display device. The device studied receives electrical information and translates this information into pneumatic signals. Conversion of these signals can be accomplished by utilizing electro-to-fluid interface devices developed under this contract for application of electronic computer driven fluidic display systems as described in the Phase I report.

The pneumatic signals will be utilized to light and extinguish plasma display cells. Pressure and gas mixture composition were investigated and are compatible with fluidic control systems. Special attention was paid to the performance of a fluidically controlled matrix type plasma display, since most advantages of a fluidically controlled display over a pure electronic display can be used to a distinct advantage in a matrix type display.

Studies establishing the required performance level of fluidic logic elements theoretically were correlated with actual performance on typical gases, such as neon and nitrogen mixtures, used in plasma display units.

Studies leading to an optimum configuration for a pneumatic power supply were performed. Cost and possible toxicity of gases that can be used for a plasma display make a closed loop pneumatic system mandatory.

The statement of work covering this contract reads as follows:

1 Investigate the design and performance requirements of plasma display cells as related to fluidic control of the firing of these cells. Special attention will be paid to compatibility of this design with the performance of fluidic control systems. The investigation includes a literature search and relevant results will be backed up by experiments where necessary;

2 Investigate basic performance of fluidic elements at pressure levels below atmospheric as required for extinguishing, sustaining, and starting plasma light emission. Performance on optimum gas mixture compositions will be established;

3 Investigate fluidic control systems for matrix plasma displays. Special attention will be paid to line and column control rather than control of each individual cell in order to reduce the number of control elements;

4 Study vacuum type power supplies compatible with the requirements dictated by the fluidic control. Where necessary, only closed loop systems will be considered;

5 Investigate the relative merit of electrodes inside the plasma cell versus exterior electrodes;

6 Investigate the deterioration of light transmission with interior electrodes;

7 A feasibility study on large scale fluidically controlled plasma display systems will be included in the task.

III. PROGRAM RESULTS

Previously, control systems for plasma cell matrix displays were based on electronic control of the voltages applied to the display cells. To analyze the possibilities of utilizing fluidic control techniques for plasma displays, two problems were investigated. The first problem was to obtain plasma display cells which have gas pressure compatible with fluidic element pressure levels. The second was to ascertain if fluidic elements, which normally use air or nitrogen as working fluid, can work with gases such as neon normally used in display cells.

Progress made in these two areas of investigation are reported below. Results of the investigations on the pneumatic pressure supply and the study on various electrode configurations are also included in this section.

A. PLASMA DISPLAY CELLS

A search of available literature indicates that plasma display cells thus far investigated by industry generally are optimized for gas pressure levels somewhat lower than desirable for control by fluidic means. Figure 3 illustrates the relationship between voltages across cell electrodes necessary to fire a cell and the internal pressure level of the cell (Reference 2). Also indicated on this graph is the lowest obtainable pressure using state of the art fluidic elements as pressure switching devices. Unfortunately no information was available on the behavior of plasma display cells at pressure levels higher than indicated on the graph, thus necessitating an investigation in this area.

Theoretical considerations show that for any particular cell the general shape of the firing voltage versus internal pressure curve can be represented by Figure 4 (Reference 3). The curve is of the form:

$$V = f_1(p)\ e^{-f_2(p)}$$

where

V = excitation voltage
p = cell internal gas pressure
f_1 and f_2 are functions of cell geometry and the particular gas used.

The preceding equation is a highly simplified representation of the relationship between voltage and pressure, but is adequate to illustrate the interaction of the cell with the fluidic control system.

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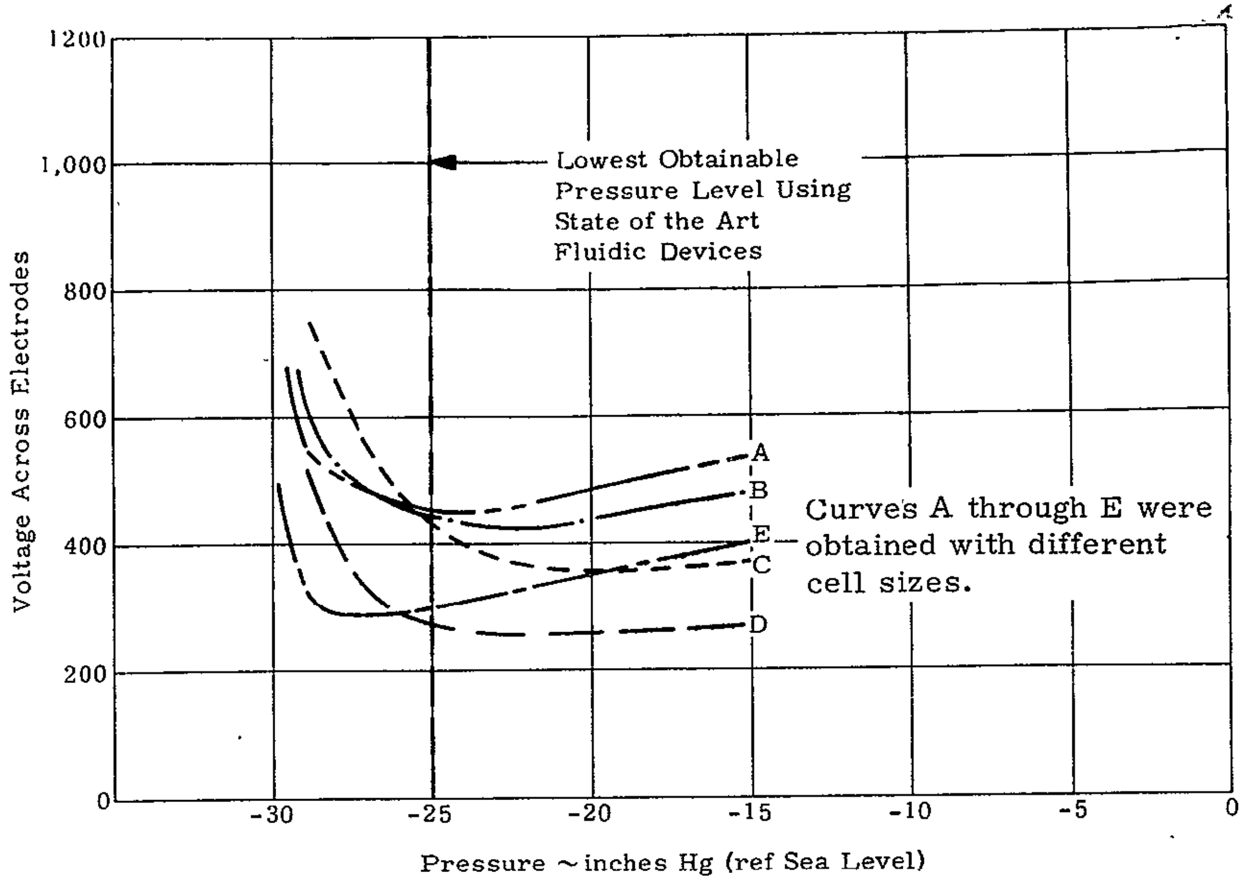


Figure 3. Plasma Display Cell Voltage and Gas Pressure

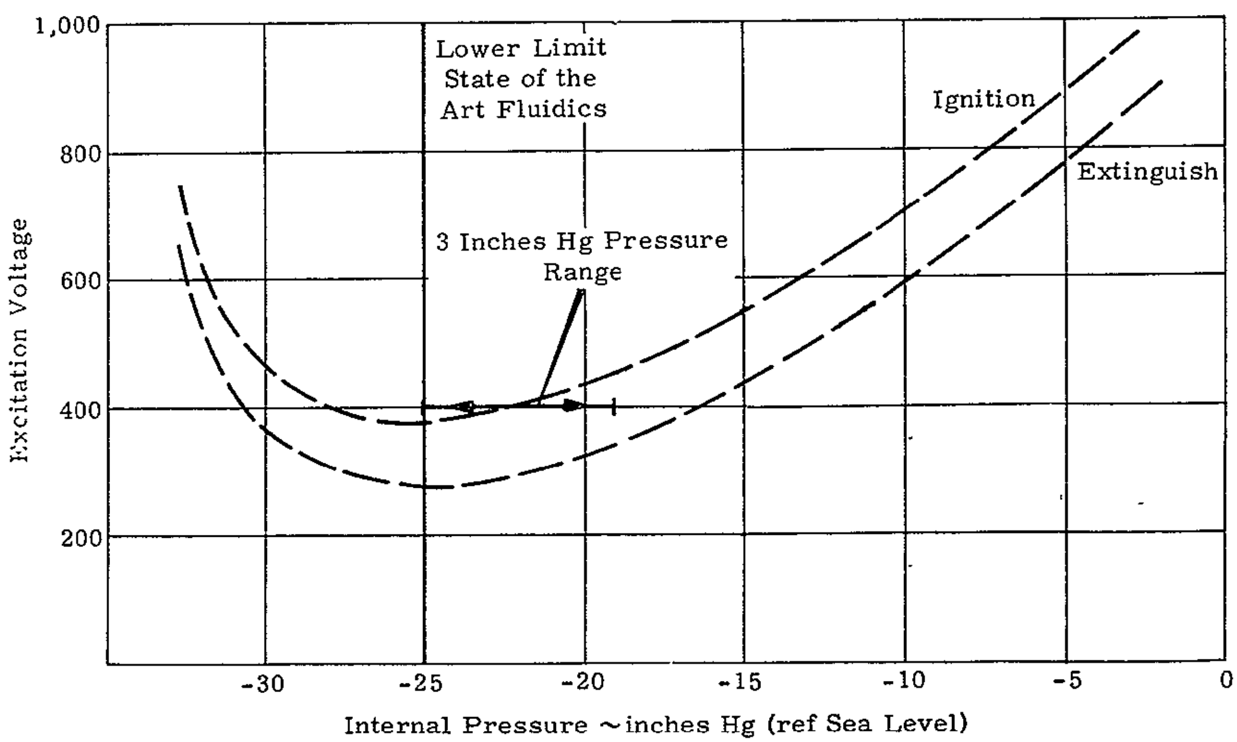


Figure 4. Excitation Voltage versus Internal Pressure

The minimum excitation voltage can be expected to be somewhat less than 400 volts. This minimum voltage point occurs at a pressure of approximately -25 inches of mercury (Hg) differential from ambient or around 5 inches mercury absolute pressure. The lowest obtainable pressure level which can be expected from state of the art fluidic devices is approximately the same -25 inches Hg. This is discussed later. At this pressure level the amount of change in pressure which can be effected by the fluidic control system is approximately 3 inches Hg or a switch from -25 to -22 inches of mercury. As indicated by Figure 4, difficulties are encountered at this point. There is too much difference between the ignition and extinguish pressures of the cell. The traversed pressure range is too small to go from the ignition to the extinguishing stage and vice versa.

Three obvious solutions to the problem exist:

1 Narrow the band between firing and extinguishing voltage levels

2 Increase pressure range of the fluidic control elements

3 Work at higher pressure levels where the factor dV/dp is relatively large.

Solution 1 required plasma cell improvements over the reported cell characteristics. Solution 2 could be obtained by using present state of the art fluidics at higher pressure levels, such as -15 inches of mercury. Solution 3 required higher pressure levels disregarding the area below -25 inches Hg where state of the art fluidics cannot operate. The disadvantages of both solution 2 and 3 are the higher voltage levels necessary to operate the plasma cell.

To obtain a solution to the fluidic-plasma display interaction problem, several plasma cell experiments were conducted to obtain optimum cell configurations compatible with fluidic control systems.

B. FLUIDIC CONTROL SYSTEM

As previously discussed, the advantages of the line and column type control systems over systems that need individual control elements for each cell are lower cost and a simpler control system. The advantages of a fluidic control system over an electronic system are again concentrated in the area of cost and in operating reliability. Line and column control can be implemented fluidically two different ways. Each of these two systems has certain advantages and disadvantages. The two systems and some variations and their relative merits are discussed in the following paragraphs.

1. Crossed Grid Control Systems

Figure 5 shows schematically a crossed grid control system utilizing outputs of fluidic elements as line and column control signals to the display cell matrix. The system shown in Figure 5 has nine display cells numbered 11, 12, 13, 21, 22, 23, 31, 32, and 33. Three line control elements, each consisting of two fluidic logic gates, designated 01, 02, and 03 and three column control elements numbered 10, 20, and 30. Figure 5 shows a matrix of nine cells for clarity. However, the discussion is applicable to matrices of a larger number of cells.

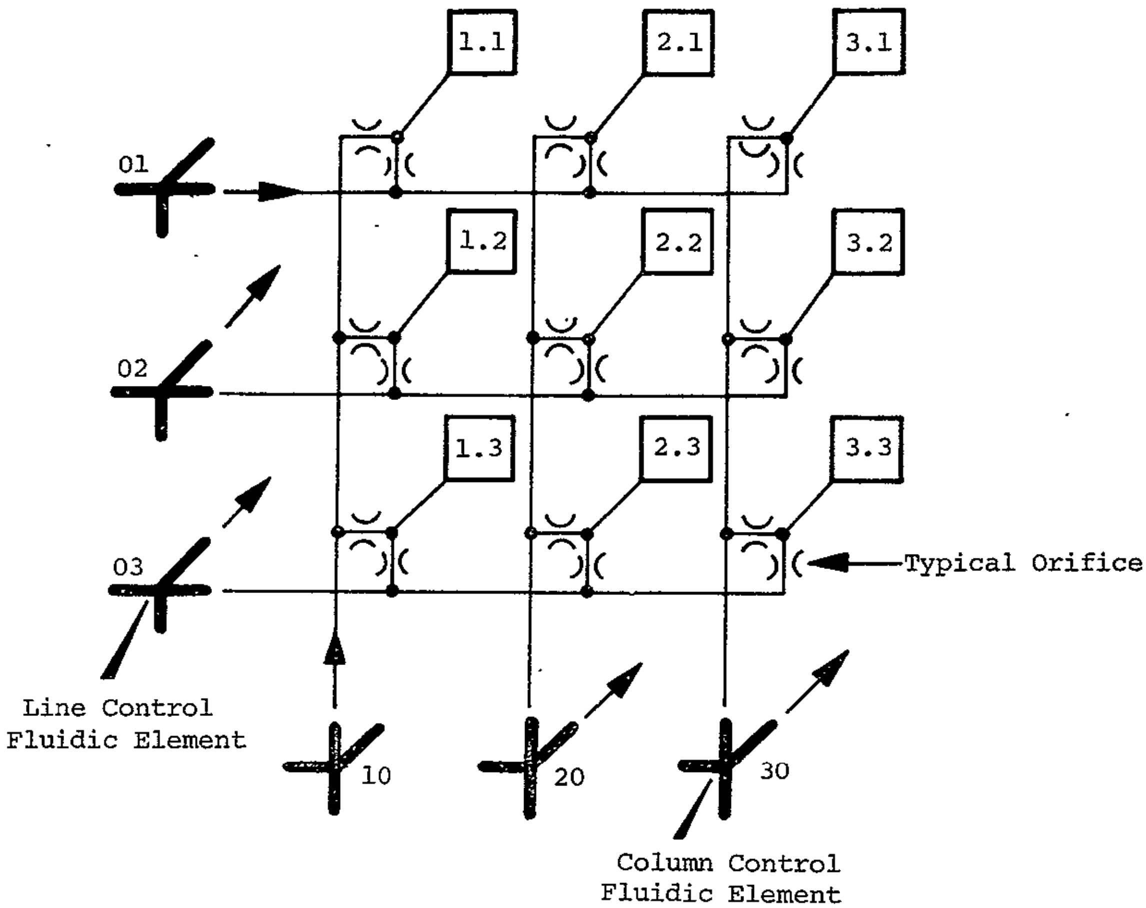


Figure 5. Cross Grid Control System

The display cell matrix used in this system can be of simple construction. Conventional display cell matrices, as presently used with electronic control systems, can be used. Designs having interior or exterior electrodes can be used. The only additional requirement is that each cell has an opening to allow gas to be admitted to the cell's interior. As noted previously nonuniform electrodes having an access hole in the center have been successfully tested. This makes it possible to connect the cells to the fluidic control system as shown in Figure 6.

The advantage of the system shown in Figure 5 is that common, state of the art display cells are used. A possible disadvantage is the problem of crosstalk which may occur between the fluidic elements constituting the line and column signal inputs. Possible crosstalk channels can be

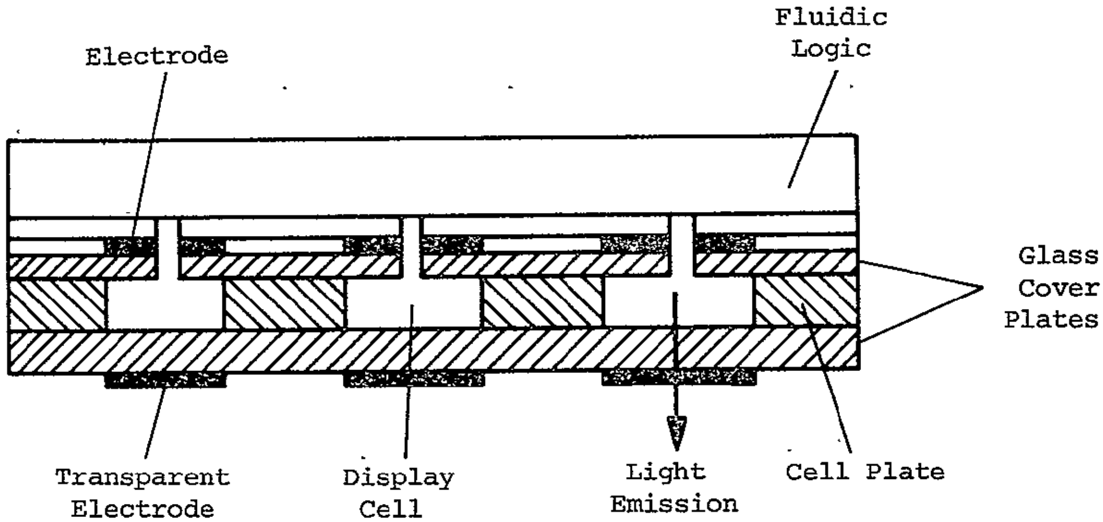


Figure 6. Construction of Display Matrix

traced (Figure 5). For instance, when fluidic elements 01 and 10 are turned on to light cell 11, part of the output flow from element 01 will reach elements 20 and 30 through the network feeding cells 21 and 31.

To analyze the severity of this crosstalk problem, the system shown in Figure 5 has been rearranged as shown in Figure 7. Assuming that the

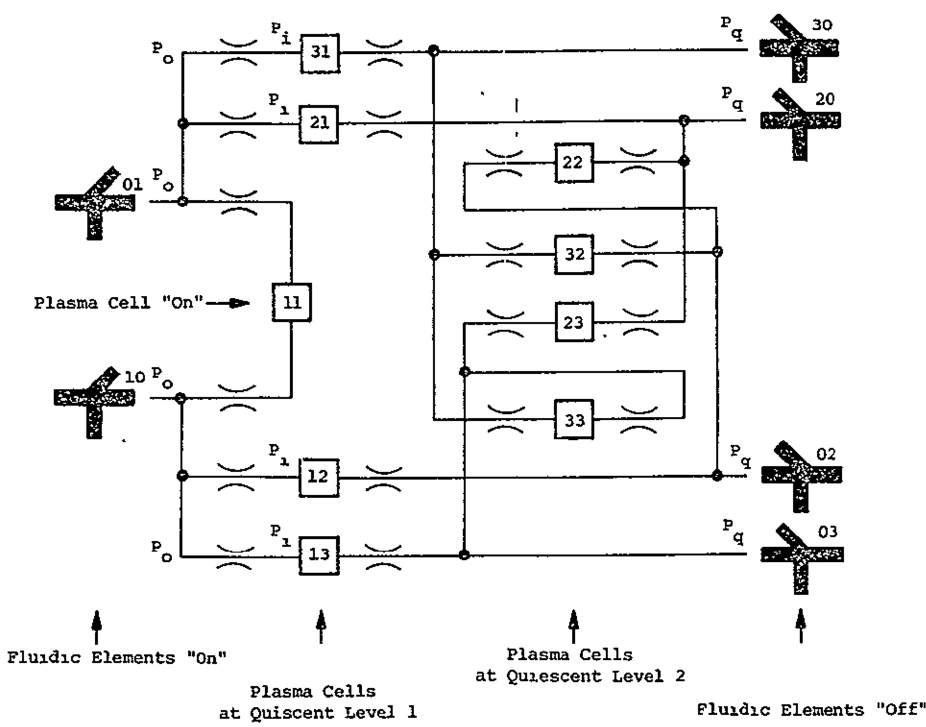


Figure 7. Line and Column Control Schematic

internal pressure of cell 11 was to be increased to obtain the desired action in this cell, the fluidic elements 01 and 10 which are the line and column control elements of cell 11 are turned on. Output pressure levels of these elements are then P_o psi as noted in Figure 7. The remaining control elements 02, 03, 20, and 30 are at the quiescent pressure level P_q. Cell 11, which is connected through two orifices to two lines in which a pressure of P_o is maintained, will be at pressure level P_o. The same reasoning holds for cells 22, 23, 32, and 33. They are connected on both sides to a pressure level P_q and will therefore be at pressure level P_q. Cells 12, 13, 21, and 31 are connected to a level P_o on one side and a level P_q on the opposite side. Since $P_o > P_q$, flow will occur and the pressure level of cells 12, 13, 21, and 31 will be at some intermediate pressure level P_i.

The subsonic flow of gas through an orifice is governed by the equation:

$$W = \left\{ \frac{P_u}{\sqrt{T_u}} \left(\frac{P_d}{P_u}\right)^{\frac{1}{k}} \sqrt{1 - \left(\frac{P_d}{P_u}\right)^{\frac{k-1}{k}}} \right\} C_1 C_D A \qquad (1)$$

where

W = Weight flow in lb/s
P_u = Upstream stagnation pressure psia
T_u = Upstream stagnation temperature °R
P_d = Downstream pressure psia
k = Ratio of specific heats c_p/c_v
C_D = Discharge coefficient
A = Area of orifice in square inches

$$C_1 = g\sqrt{\frac{2k}{R(k-1)}} \qquad (2)$$

g = Acceleration of gravity
R = Gas constant $in^2/s°R$.

A good approximation to equation (1) can be obtained from

$$W = \frac{C_D C_G A \sqrt{P_d \left(P_u - P_d\right)}}{\sqrt{T}} \qquad (3)$$

where

W = Weight flow of gas in lb/s
C_G = Constant depending on gas
T = Absolute temperature.

Since the areas of both orifices controlling each cell are identical and no gas is stored in the cell under steady state conditions, the weight flow into the cell will equal the flow from the cell. Using Equation (3) and dropping all factors that are identical for both sides, the following is obtained:

from which:

$$\sqrt{P_i \left(P_o - P_i\right)} = \sqrt{P_q \left(P_i - P_q\right)} \tag{4}$$

$$P_i = \frac{P_o - P_q \pm \sqrt{\left(P_o - P_q\right)^2 + 4 P_q^2}}{2} \tag{5}$$

The following reasonable values for P_o and P_q may be selected:

$P_q = 4$ psia
$P_o = 6$ psia

These values substituted into Equation (5) will result in $P_i \approx 5.1$ psia. Figure 8 shows the location of these pressure points with respect to the firing and extinguishing lines of a plasma display cell. Also shown in Figure 8 are the pressure points P_a and P_1 which be obtained when control elements 01 and 10 are at the lowest possible level of P_a psi. Cell 11 will then be at a level of P_a psi and cells 12, 13, 21, and 31 will be at a level P_1 where $P_q > P_1 > P_a$. Cells 22, 23, 32, and 33 will remain at pressure P_q as shown in Figure 5. From Figure 8, note that changes in pressure levels from P_1 to P_q to P_i will not have an effect on the state of the cell. Switching to a level P_o will result in extinguishing the cell. A switch to the P_a level will turn the cell on.

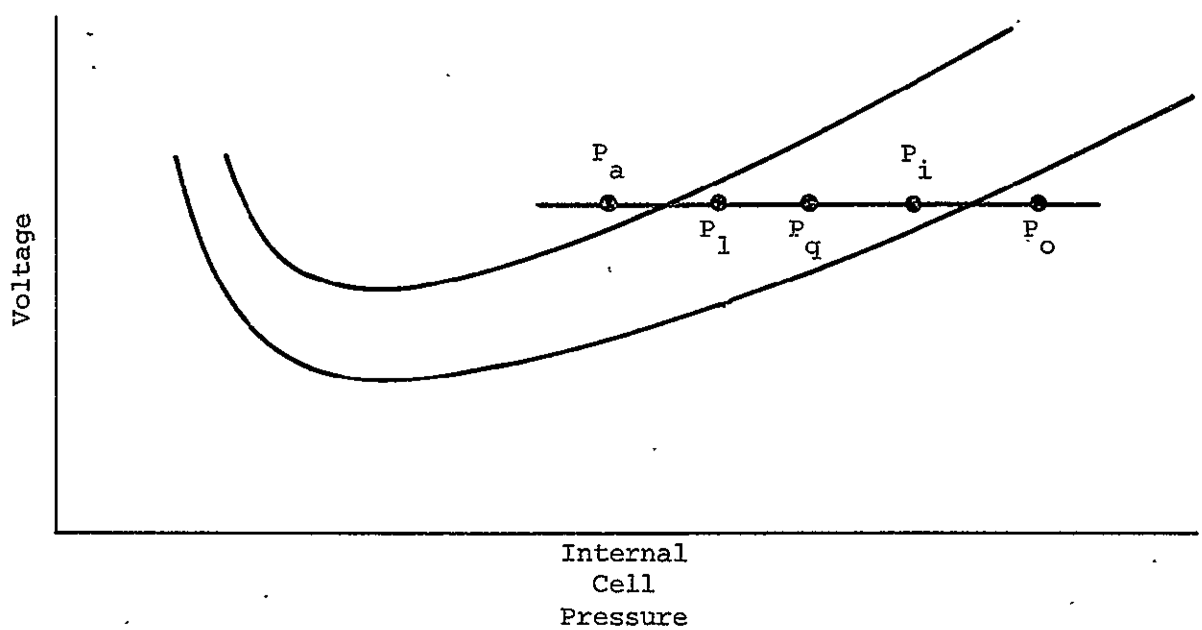
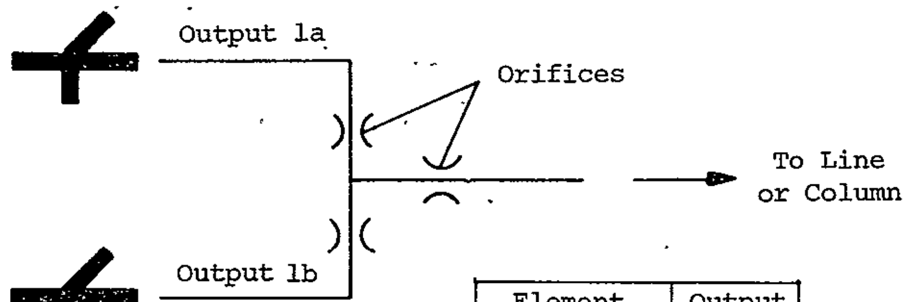


Figure 8. Pressure Levels versus Voltage

The fluidic logic elements maintain the input pressure to the lines and columns at three distinct levels: P_a, P_q, and P_o. These pressure levels are obtained by using a fluidic element of double construction as schematically shown in Figure 9. The highest output level is reached when both elements are on. When one element is off, part of the output flow of the on element will be diverted into the element that was turned



Element		Output
1a	1b	Level
Off	Off	Pa
Off	On	Pq
On	On	Po
On	Off	Pq

Figure 9. Double Element Network

off, thus dropping the output pressure to level P_q. With both elements off this will result in a level P_a, the lowest level obtainable.

2. Serial Cell System

A second approach to line and column control of a matrix type plasma display system with fluidic techniques is a serial cell system. In the serial cell system the individual plasma display cells are constructed as two cells back to back as shown in Figure 10. Various combinations of interior and exterior electrodes together with a center electrode are possible. Figure 10 shows two of these possibilities.

In principle, a double cell arrangement will fire or extinguish only when conditions in both halves of the cell are right. Since complete pneumatic isolation of the two cell halves is accomplished (there is no connection between halves) it is possible to avoid pneumatic crosstalk. This can be accomplished by controlling conditions in one part of the double cell with the line control system while utilizing the column control system to change conditions in the adjacent part of the double cell. A typical multiple cell array using this principle is schematically shown in Figure 11.

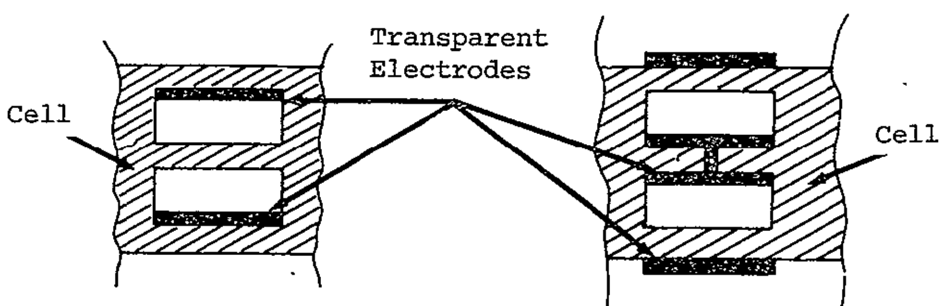


Figure 10. Possible Double Plasma Cells

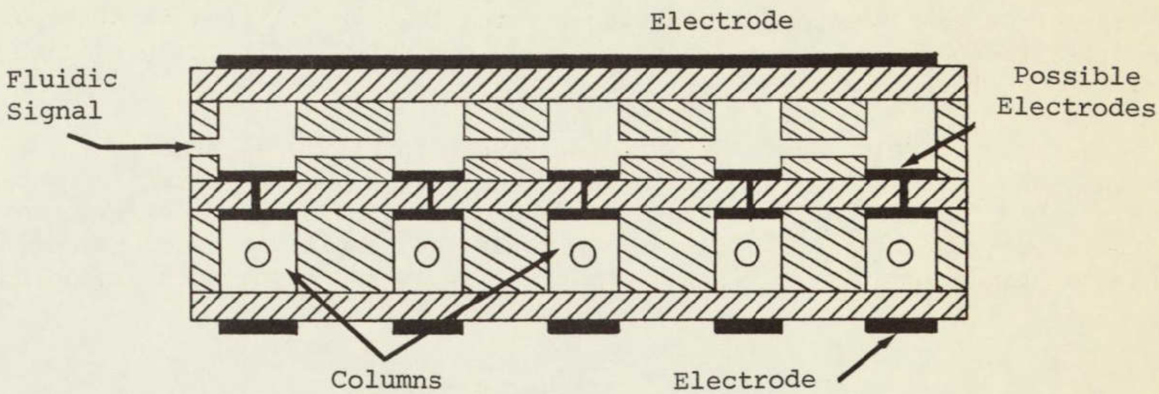


Figure 11. Multiple Cell Array

Variations on the serial cell type system may be implemented by replacing one of the cell halves with another discharge type cell that works as a switch supplying electrons to a display cell. In the cell illustrated in Figure 10, both cell halves will emit light. However, light emission from only one cell section is required, thus making it possible to replace the second cell section with a discharge device that does not emit visible light.

3. System Comparison

The two systems and their variations described in the preceding paragraphs have unique advantages and disadvantages. The cross grid array system utilizes plasma display matrices that are simple in construction. However, a careful match of the fluidic control system with the input requirements of the display cells is necessary to obtain a proper working display. The serial cell arrangement requires a more complicated cell structure, but performance requirements of the fluidic control system can be relaxed. These studies indicated that both systems are feasible. Proper working of the crossed grid array system depends partly upon the size of the matix and is considered more applicable to the smaller display matrices. The performance of the serial cell system is governed by the operating characteristics of these serial cells described later in this report.

4. Fluidic Logic Elements

Following the development of plasma cells having suitable pressure characteristics attention was paid to the fluidic elements to be used in the fluidic control systems postulated for this application. The fluidic elements to be used in the plasma display system deviate mainly in two aspects from conventional fluidic system elements:

1 Working pressure levels are lower than normally encountered in fluidic systems;

2 Fluid media used are neon or a mixture of gases rather than air or nitrogen which are the gases normally used.

Investigations were conducted to determine the capabilities of state of the art fluidic devices to operate under low pressure conditions using nitrogen.

Previously developed fluidic elements shown in Figure 12 exhibit pressure-flow characteristics (using nitrogen as the working fluid) as shown in Figure 13. An investigation was conducted to establish the performance characteristics of these logic elements under the conditions encountered in a plasma display system; e.g., low pressure levels and using neon as the working fluid.

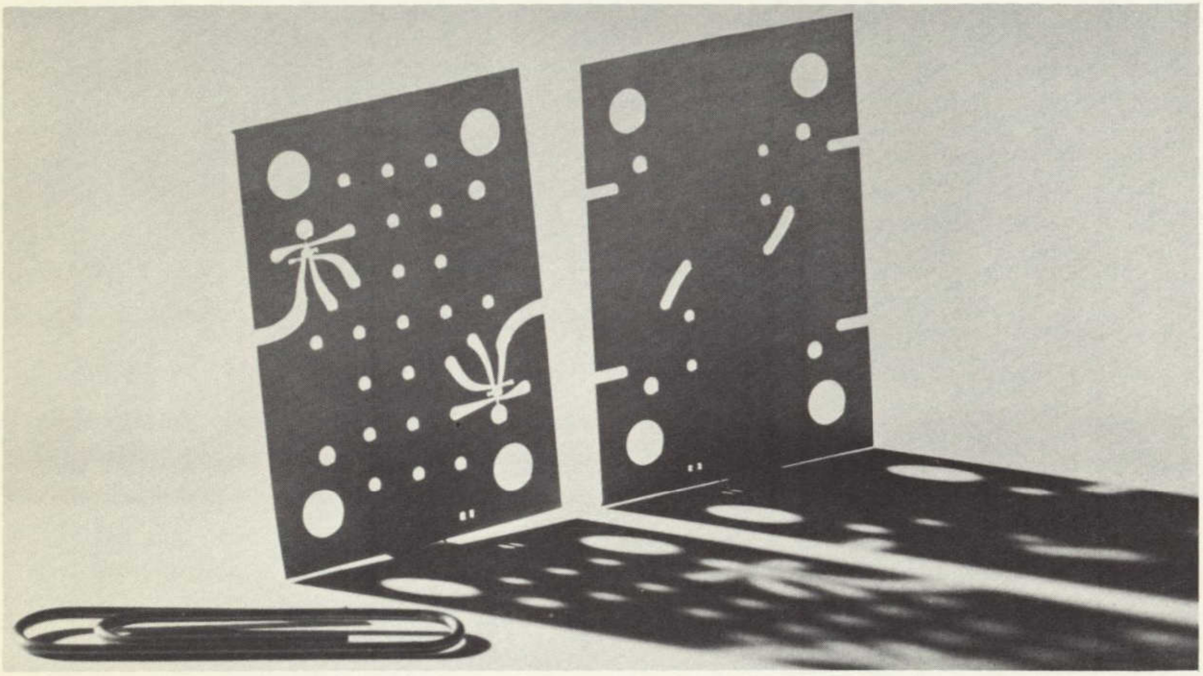


Figure 12. Previously Developed Fluidic Elements

Figure 14 shows the maximum switching capabilities of miniature fluidic elements operating on nitrogen. The graph illustrates the relationship between the maximum switching capability of the fluidic element with respect to the supply pressure to the power nozzle of the element. Different switching capability ranges are obtained for varying ΔP levels.

Figure 15 shows the maximum pressure level changes obtainable at various internal cell pressures. The lowest internal pressure obtainable with fluidic elements is approximately -25 inches Hg vacuum or approximately 5 inches Hg absolute. As previously stated, these capabilities are sufficient to switch plasma display cells.

An investigation was conducted to determine the performance of fluidic elements using other gases as operating media. Figure 16 illustrates the control pressure levels and output pressure levels versus supply pressures for nitrogen, neon, argon, and helium. Although these gases will not necessarily be used in a plasma display system, tests were conducted withthese gases to obtain a sufficiently wide range of gas densities and viscosities.

Their operating characteristics are somewhat different as was expected, since fluidic element performance is affected by gas density and viscosity. However, for application to plasma display cells, the operating characteristics do not vary sufficiently to jeopardize the feasibility of controlling a plasma display with state of the art fluidic elements.

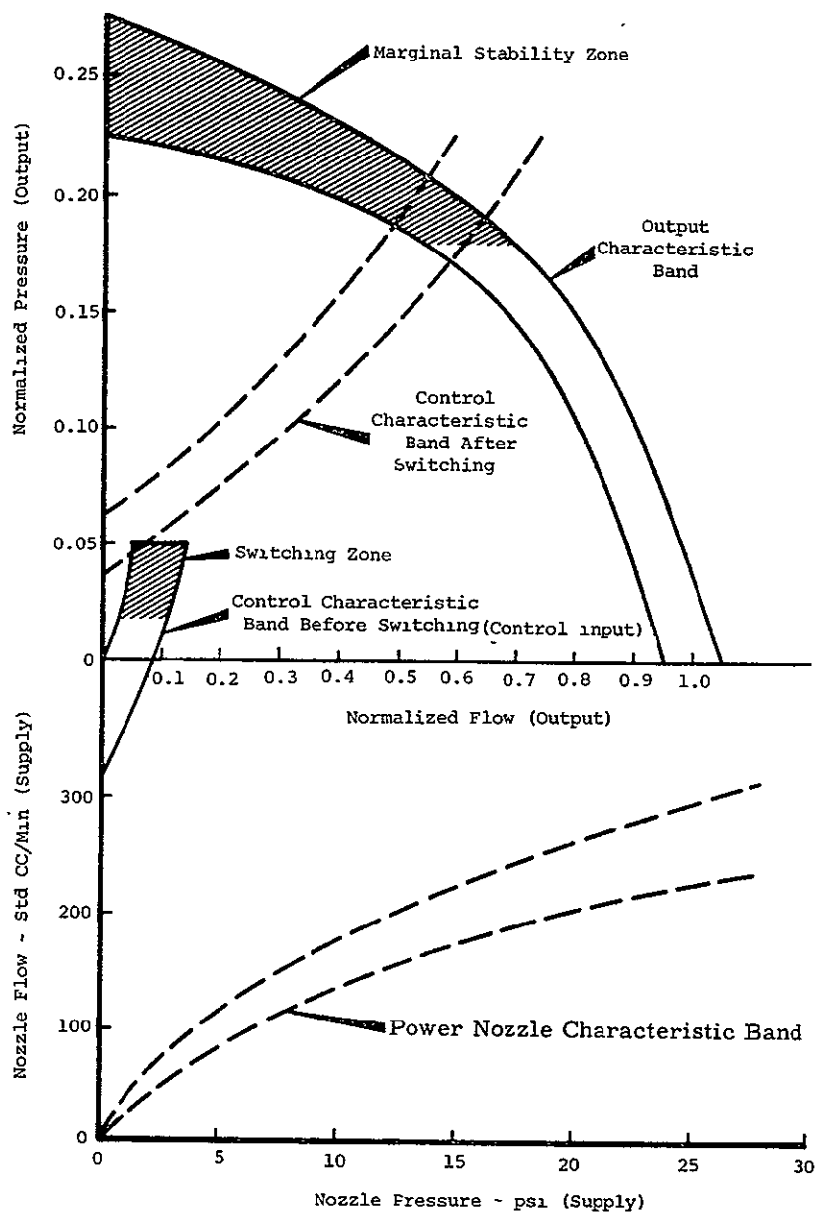


Figure 13. Performance Specification of Fluidic Flip-Flop

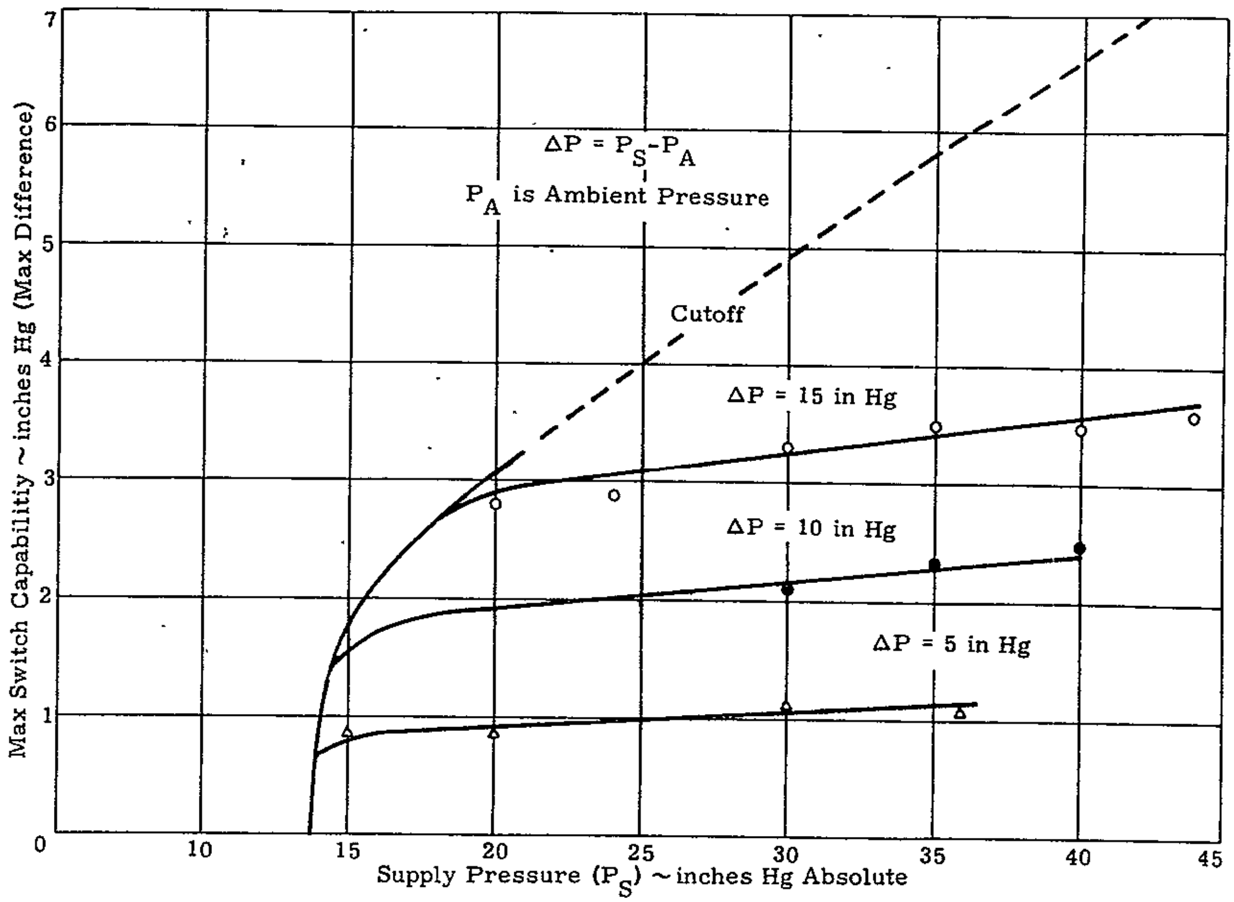


Figure 14. Performance in Partial Vacuum

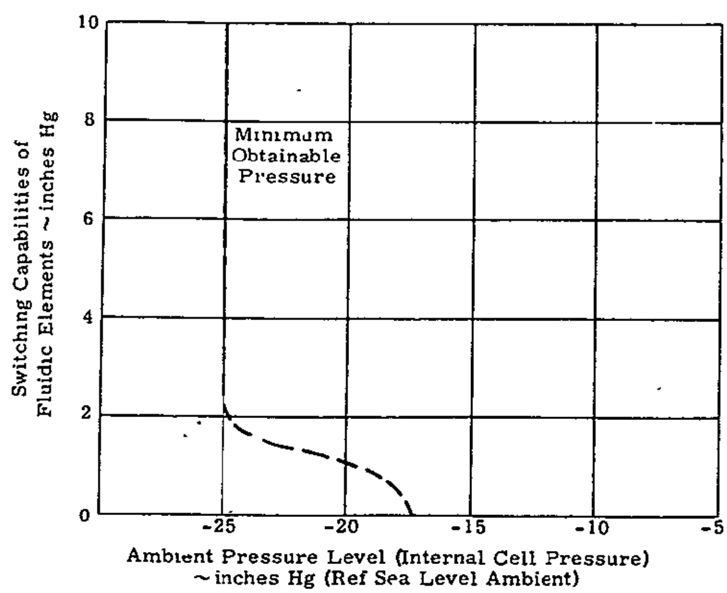


Figure 15. Maximum Switching Capabilities versus Internal Cell Pressure

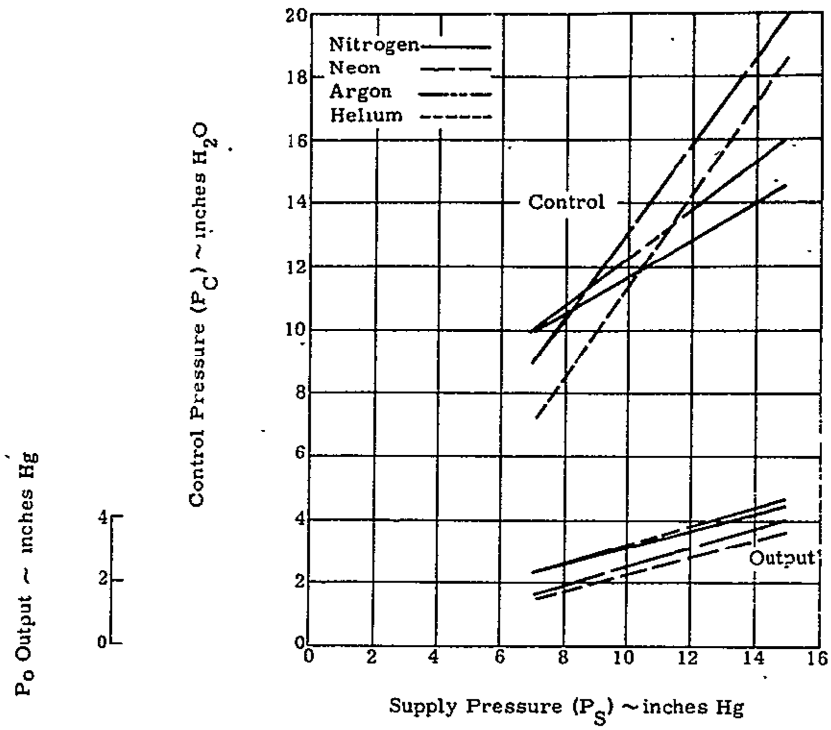


Figure 16. Four MIL OR-NOR Element

C. PLASMA CELL EXPERIMENTS

1. Test Setup

To facilitate experiments with plasma display cells under varying pressure conditions, it was necessary to construct cells with external gas connection. The general shape of the gas cells used is shown in Figure 17. The cell is formed by a round hole in the glass cell plate. The cell plate is grooved to connect the cell cavity with the hole in the glass cover plate. The cover plate and bottom plate are cemented to the cell plate. An external gas connection is cemented to the top plate. Electrodes are deposited on the outsides of cover and bottom plates.

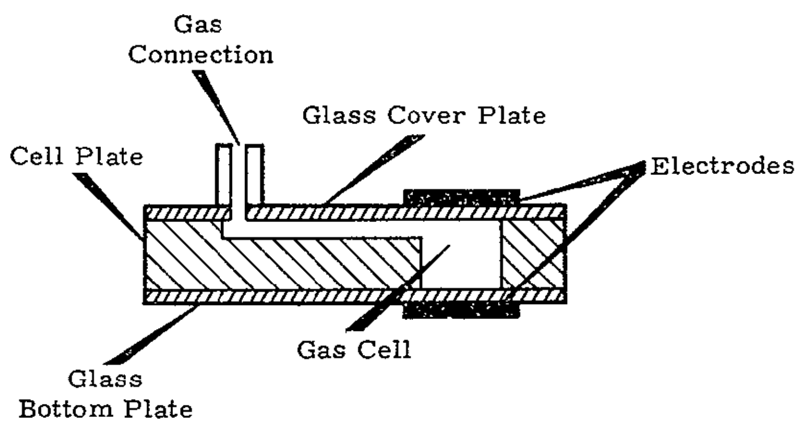


Figure 17. Experimental Cell Construction

To vary the pressure inside the cell during experiments, a variable pressure test setup was constructed (Figure 18). The cell to be tested is connected to a vacuum pump, two fill lines, a manometer, and a mercury filled reservoir. The system can provide pressures over a range from above atmospheric pressure down to the capabilities of the vacuum pump (Figure 19).

For rough tests, the cell is filled with the selected combination of gases when the system has been evacuated by the vacuum pump. After the right mixture of gases is introduced, the internal pressure can be varied by increasing or decreasing the total volume of the system which can be changed by controlling the amount of mercury in the mercury reservoir. This is done by moving the relative position of a second mercury reservoir connected with a hose to the first reservoir. The second reservoir, the mercury motoring bottle, can be positioned any place along a vertical track.

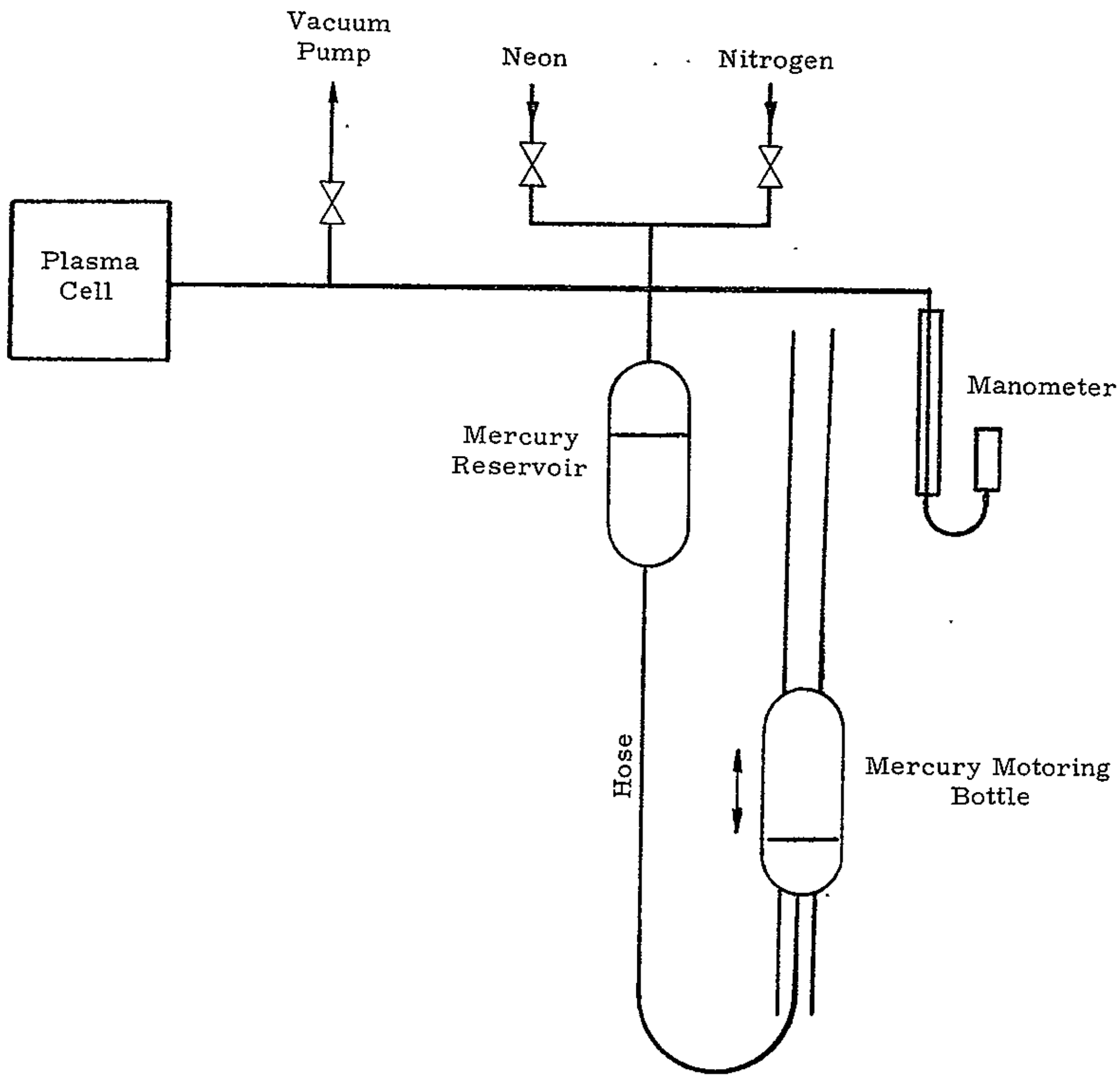


Figure 18. Schematic of Variable Pressure Test Setup

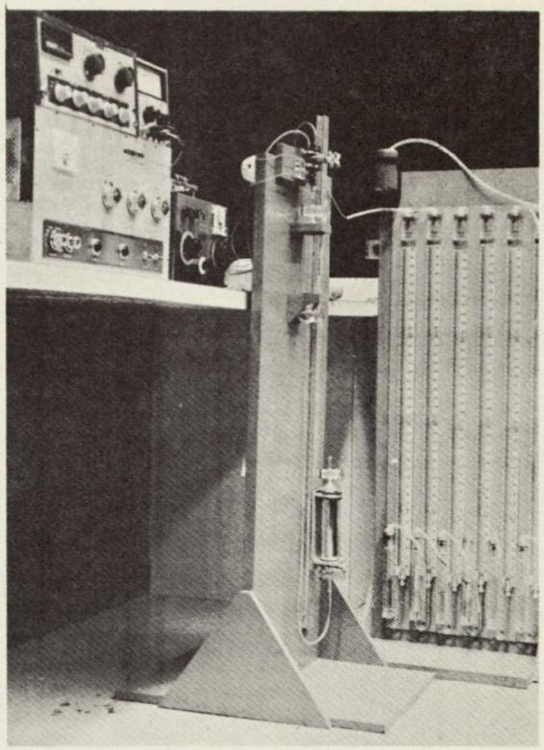


Figure 19. Variable Pressure Experiment

For more precise tests the system was modified to keep contamination of the gases down to a minimum. The modified system is shown in Figure 20. The cell is connected to four valves in parallel. One valve connects the cell to a vacuum gauge to enable pressure measurements to be made. A second valve connects the system to the vacuum pump. Operation of the vacuum pump when this valve is opened will result in a lower system pressure. To raise the system pressure one or both of the fill line valves were opened. It was found that this testing method was more satisfactory as far as contamination problems of the cell gases were concerned.

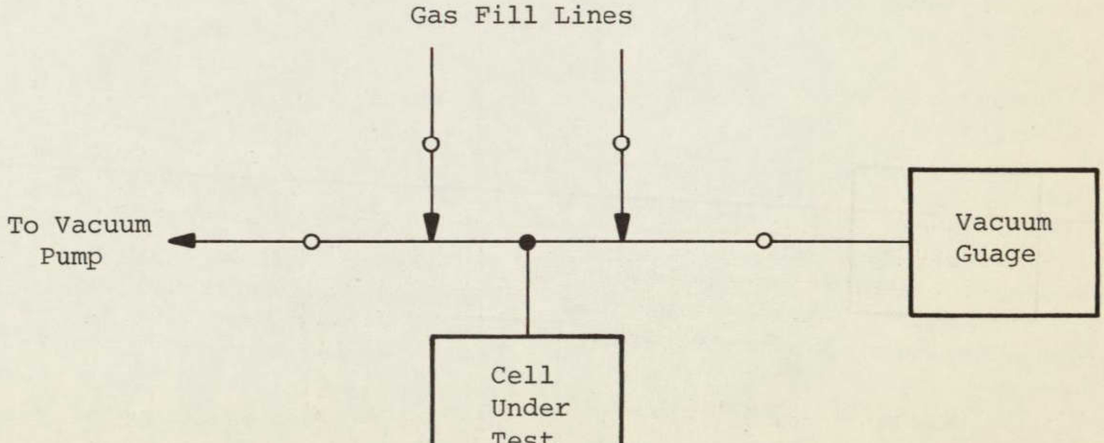


Figure 20. Modified Display Cell Test Setup

2. Test Results

Several experiments were conducted on plasma display cells constructed as shown in Figure 17. The most promising configurations thus far evolved exhibited voltage pressure characteristics as shown in Figures 21 and 22. These particular cell configurations had reasonable dV/dp factors at fairly high pressure levels.

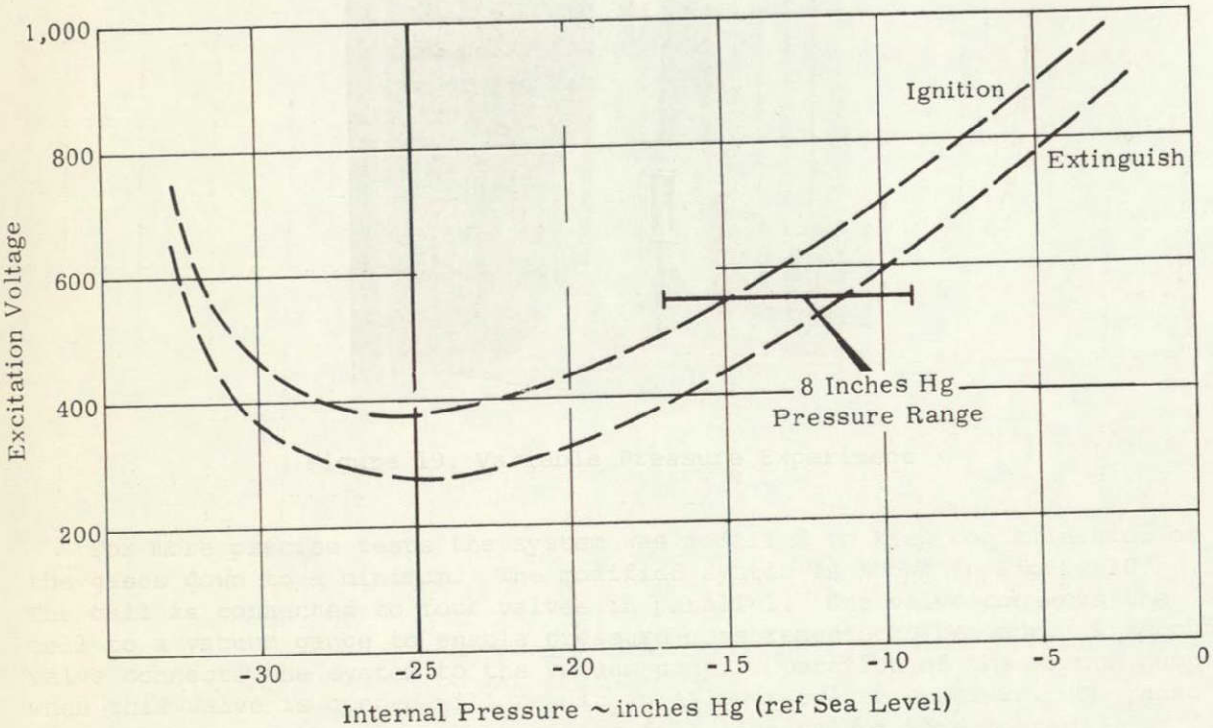


Figure 21. Excitation Voltage versus Internal Pressure

The physical dimensions of the most successful cells are shown in Appendix A of this report. The cell data shown in Figure 21 show this type of cell is usable with fluidic control systems.

Constant excitation at 500 volts, for instance, will make it possible to switch the cell on and off with a pressure switching range of 4 inches Hg from -18 to -14 inches Hg. As will be shown in the section of this report describing the fluidic control system, these pressures are obtainable with present state of the art fluidic techniques. The cell exhibiting the characteristics shown in Figure 22 runs at somewhat lower voltage levels. The differences between cells having the characteristics shown in Figure 21 and 22 are, namely, the physical size of the cell. Appendix A lists the various dimensions used for these cells.

The cells used to obtain the test data shown in these figures exhibit characteristics favorable to utilization of fluidic systems for control of the firing and extinguishing cycles. No further development of these single cells is necessary at this time. The development program on single cells has thus been completed.

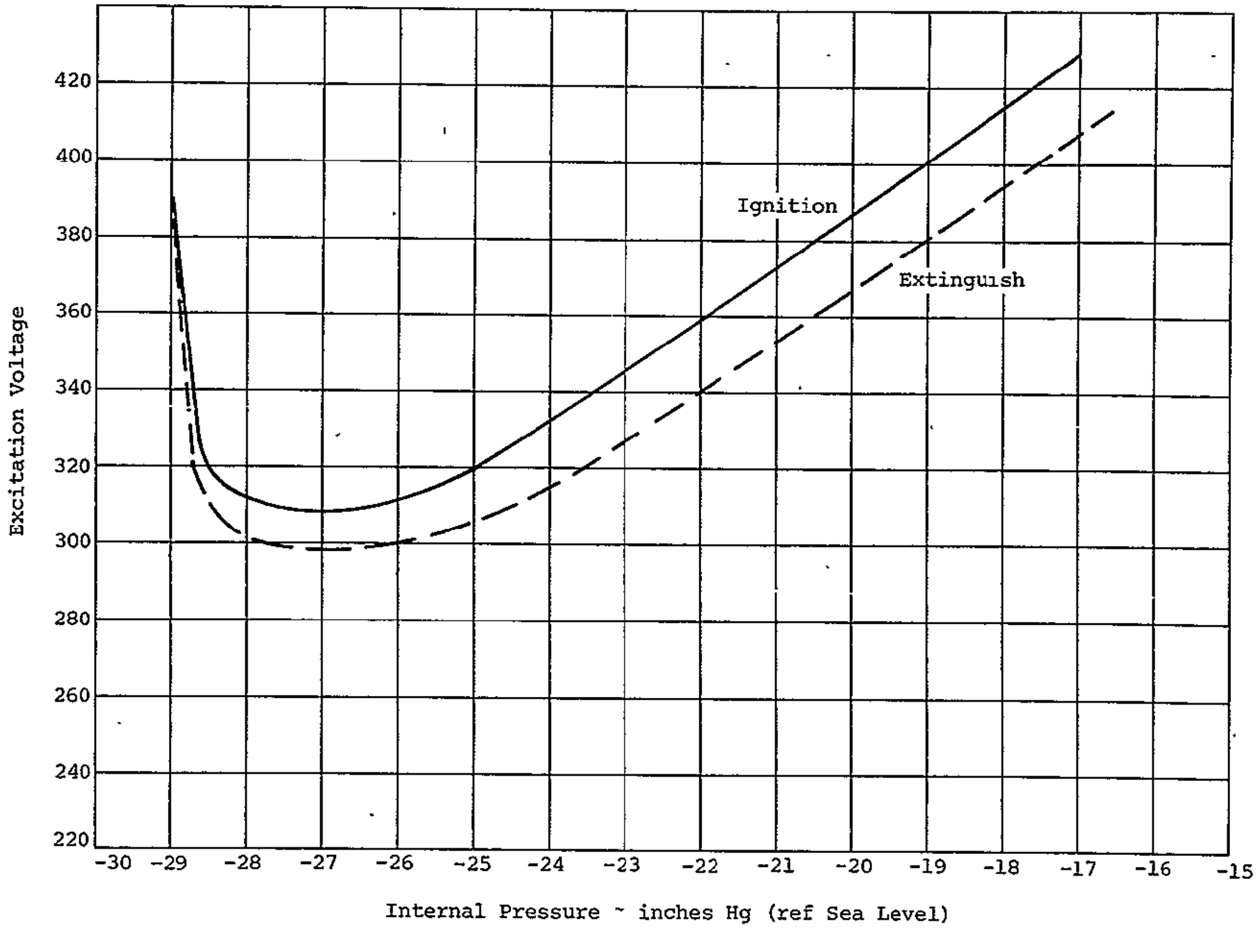


Figure 22. Plasma Cell Pressure Voltage Characteristics

D. EXPERIMENTS WITH DOUBLE DISPLAY CELLS

As pointed out in Section IIIB, a completely isolated row and column control system can be implemented when serially connected display cells are used. Since such a system has distinct advantages, it was decided that performance characteristics for double cells should be established.

Schematics of two types of double cells used during the experiments are shown in Figure 23. Exact dimensions of these cells are shown in Appendix A of this report.

The double cell works on the principle that pressure voltage conditions in each of the two cell halves should be at the required levels before ignition occurs. Since the impedance of an extinguished cell is different from the impedance presented by a lighted cell, it was expected that firing and extinguishing of double cells would not follow the exact same pattern as that found for single cells. This can be explained with the help of Figure 24. This illustration shows the equivalent electrical schematic of double display cell. The glass plates used as cover plates and also the glass separator plane in between the two cell halves are represented by the capacitors C_G. The extinguished cell halves can be represented by the capacitors C_C. The effect of firing of a cell can be represented by a short circuit around the cell capacitance C_C.

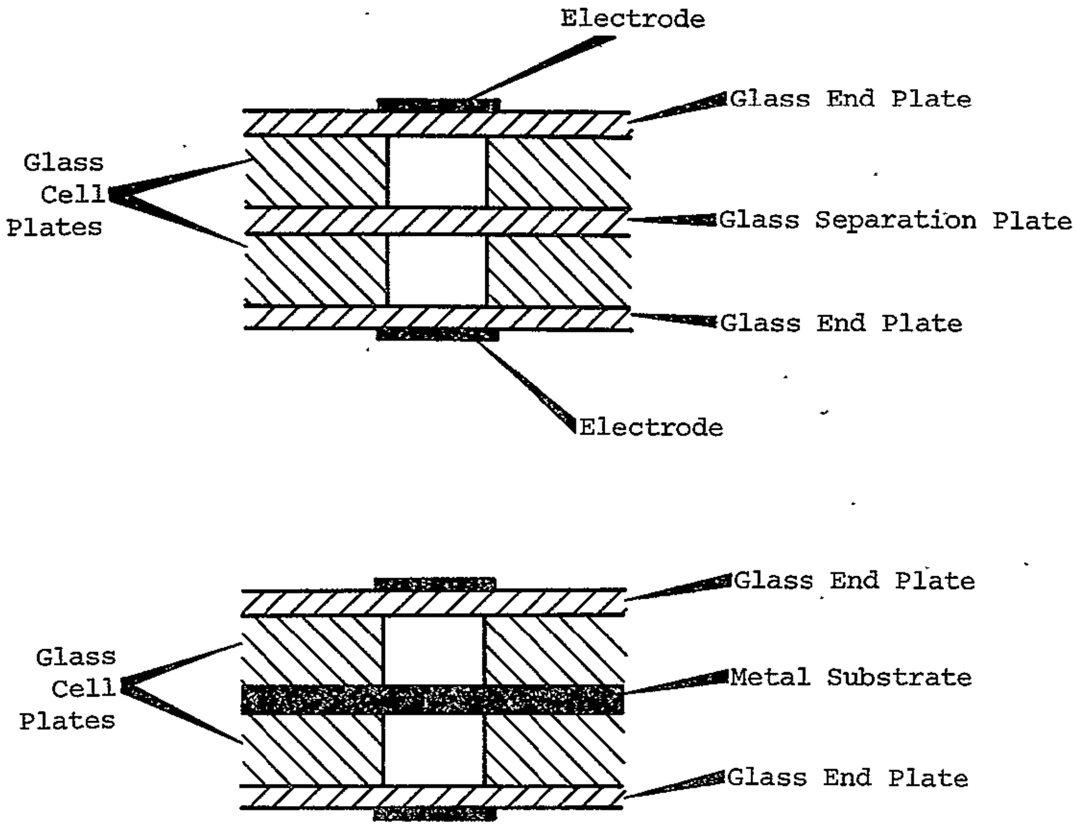


Figure 23. Double Display Cell Schematics

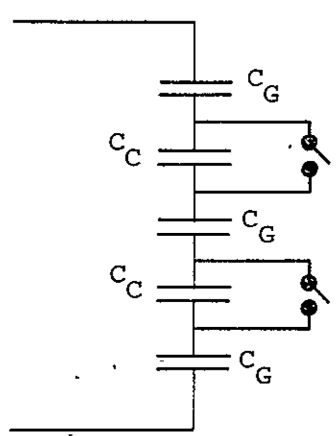


Figure 24. Equivalent Electrical Schematic

When both cell halves are extinguished, roughly half of the excitation voltage is across each cell half.

When conditions for firing are right in one cell, this cell will fire. The capacitor C_c representing this cell will then be shorted and a higher voltage will be presented to the second cell half. Since both pressure and voltage changes will affect the firing, it was expected and found that much larger pressure fluctuations were necessary in each of the cell halves to instigate firing and extinguish the cells.

Limited experiments with the double cell, built according to the construction shown in Figure 23(a), shows that this cell could be made to light. Considerable pressure excursions were necessary to change the state of the cell. Unfortunately, the test cell was destroyed due to local heating problems before actual measurements could be secured.

In order to analyze the action of each cell half independently, another double cell was constructed. In this cell a metal substrate was used to separate the two cell halves. It was expected that, since the capacitance C_G of the glass separator used in the first cell was replaced by a metal conductor, the excitation voltage levels for this cell would be somewhat less than those required for the cell built completely from glass parts.

Figure 25 and 26 show the pressure voltage relationships of each of the two cell halves. As can be determined from the figures a total excitation voltage of more than 700 volts is needed to activate both cells. The electronic equipment presently used to provide the AC power for the cells is not capable at present to generate this high voltage.

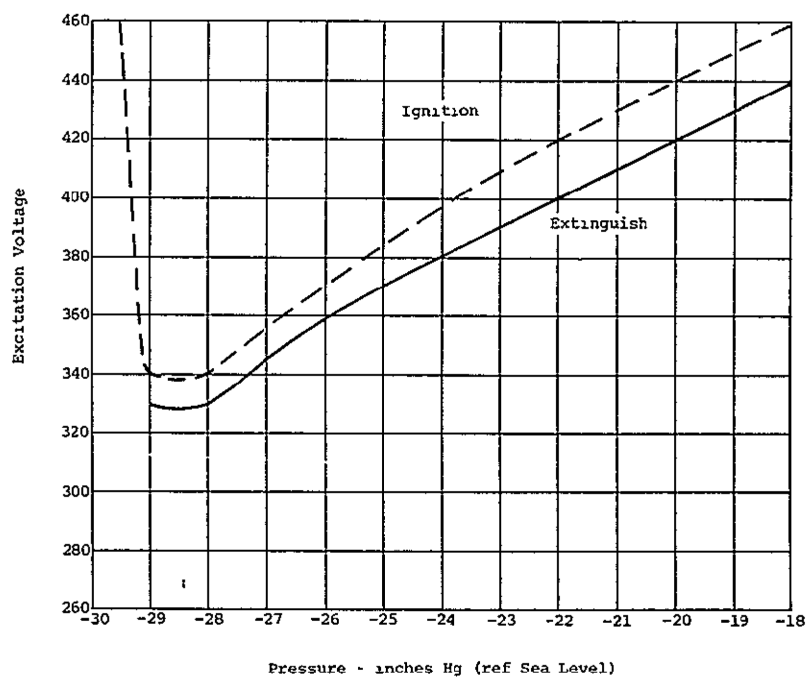


Figure 25. Pressure Voltage Relationships of Double Cell Half

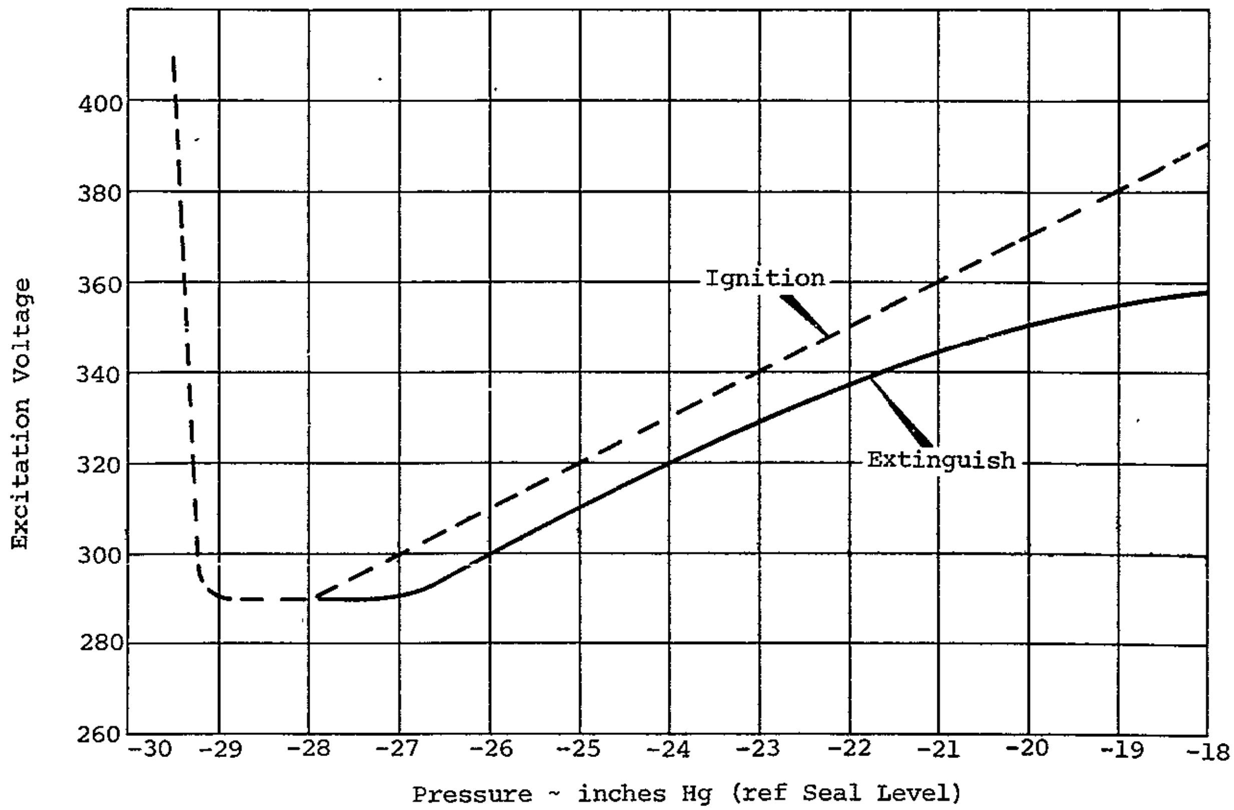


Figure 26. Pressure Voltage Relationships of Double Cell Half

E. PRESSURE SUPPLY

A fluidic control system for a matrix type plasma display can be built from fluidic elements described earlier. The fluidic elements require a certain flow which has to be maintained at least during part of the operating time of the fluidic switching logic; thus a pressure supply is needed. Since neon or a mixture of primarily neon and some other gases will in all probability be used as the working media for at least part of the fluidic control system and the display matrix, a closed loop system seems in order due to high cost of the gases involved.

Two systems are possible. In the first, gas is stored at high pressure in a pressure vessel. The gas flows upon demand, regulated by a valve, to the fluidic logic and the display matrix. The gas is accumulated at low pressure in a second pressure vessel. At a point in time where pressure in the supply bottle falls to a minimum level, the gas collected at the low pressure level can be compressed and transferred to the high pressure bottle to replenish the supply.

A second, and possibly more attractive, system for large displays is schematically depicted in Figure 27. The high pressure generated by the pump is used by the fluidic logic system. Part of the gases used by the fluidic logic system are transmitted to the display matrix. Overflow from the display matrix, as well as the gas utilized by the fluidic logic gates but not used in signal transfer to the display matrix, is accumulated. The pump draws gas from the accumulator.

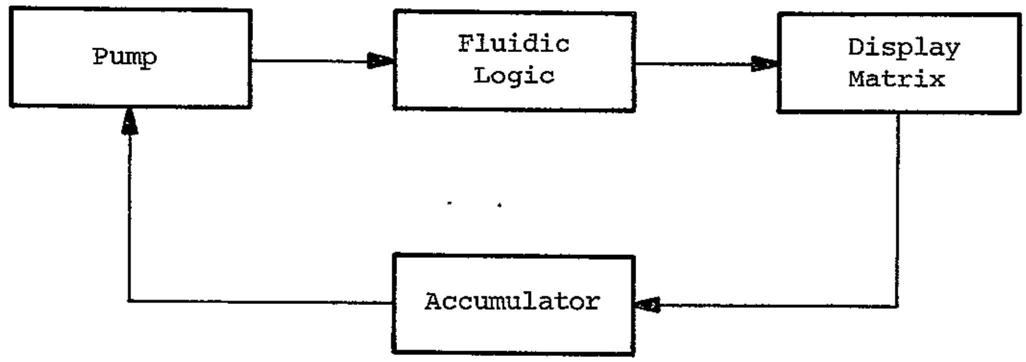


Figure 27. Schematic of Closed Loop System

In order to determine the size of the pump needed, a display matrix of 500x400 cells was considered. A matrix of this size would be approximately equivalent to commercial CRT's as far as definition of the display is concerned. For line and column control 900 logic elements would be necessary for control of this matrix. The equivalent air flow through these logic elements at the particular pressures necessary to operate a display matrix would be 75 cc/min per element for a total flow of 67 liters/min. Compared to commercially available air pumps, the power requirements for this matrix will be approximately 0.2 HP. A pump of this capacity is not of unreasonable size.

Commercially available pumps of this capacity are, however, not suitable as presently constructed for the application to fluidically controlled plasma display systems. The reason for this is the contamination of the neon caused by the pump. During the experiments conducted at Martin Marietta, it became obvious at an early stage that plasma cell performance was greatly dependent upon the amount of impurities in the neon gas. Even short length pneumatic lines and connections eventually contributed sufficient impurities to change the firing and extinguishing characteristics of the display cells. These impurities were found to be mainly outgassing products of the materials used in the construction of the experimental set up. In subsequent experiments care was taken to avoid materials with a large amount of outgassing products.

Table I* gives relative figures of merit (R) for contamination caused by various plastic materials. The value R = 1, indicates no contamination will be generated during the experiments. Values higher than 1 indicate graduations of the amount of contamination to be expected.

From Table I it is obvious that pump parts constructed from teflon would be the best choice for this application. Pumps specifically constructed for pumping neon gas are not commercially available. However, modifications could be made to existing compressors to obtain a unit suitable for this application.

*Vacuum Deposition of Thin Films, L. Holland, Chapman and Hall Ltd., 1966.

TABLE I

Vacuum Properties of Several Plastics
Selected from the Results of Hogg and Duckworth**

Plastic	Manufacturer	R(70 min)
Teflon	Dupont de Nemours Co	1•0
Polystyrene	Plax Corporation	1•1
Acetate cellulose butyrate	Plax Corporation	1•1
Mycalex	Mycalex Corporation	1•1
Polythene	Dupont de Nemours Co	1•2
Amphenol	American Phenolic Corporation	1•3
Etho cellulose	Plax Corporation	1•4
Polyethylene	Plax Corporation	1•6
Cellulose acetate	Plax Corporation	3•9
Lucite	Plax Corporation	5•1
Nylon	Dupont de Nemours Co	Large

F. Cell Brightness

During the experiments conducted with the pressure activated display cell, it was noticed that the cells used in these experiments were generally brighter than those previously observed. One reason for this may be that excitation voltages with frequencies of around 7.2 mc were used as opposed to the normally used frequencies of at least one order of magnitude lower.

The cell brightness of one cell was measured with a Pritchard Spectra Photometer, manufactured by the Photo Research Corporation of Hollywood, Florida. Figure 28 depicts the brightness of the display cell as a function of the internal gas pressure. A lighted cell has a brightness of 1300 foot-lamberts at a working pressure of -25 inches Hg with a excitation voltage of 360 volts.

Brightness drops to around 930 foot-Lamberts before the cell extinguishes. After extinguishing the cell exhibits a faint glow at a level of 60 foot-Lamberts or less up to a pressure of -8 inches Hg.

Figure 29 depicts the change in brightness of the same cell when internal cell pressure is held constant at 25 inches Hg below sea level reference and voltage is varied from 270 to 400 volts. The lowest observed brightness level is 800 foot-Lamberts for the lighted cell. Brightness increases almost linearly with voltage up to 1000 foot-Lamberts at 400 volts as expected. Again, a faint flow up to about 100 foot-Lamberts was noted when the unlighted cell was brought close to the conditions necessary to fire the cell.

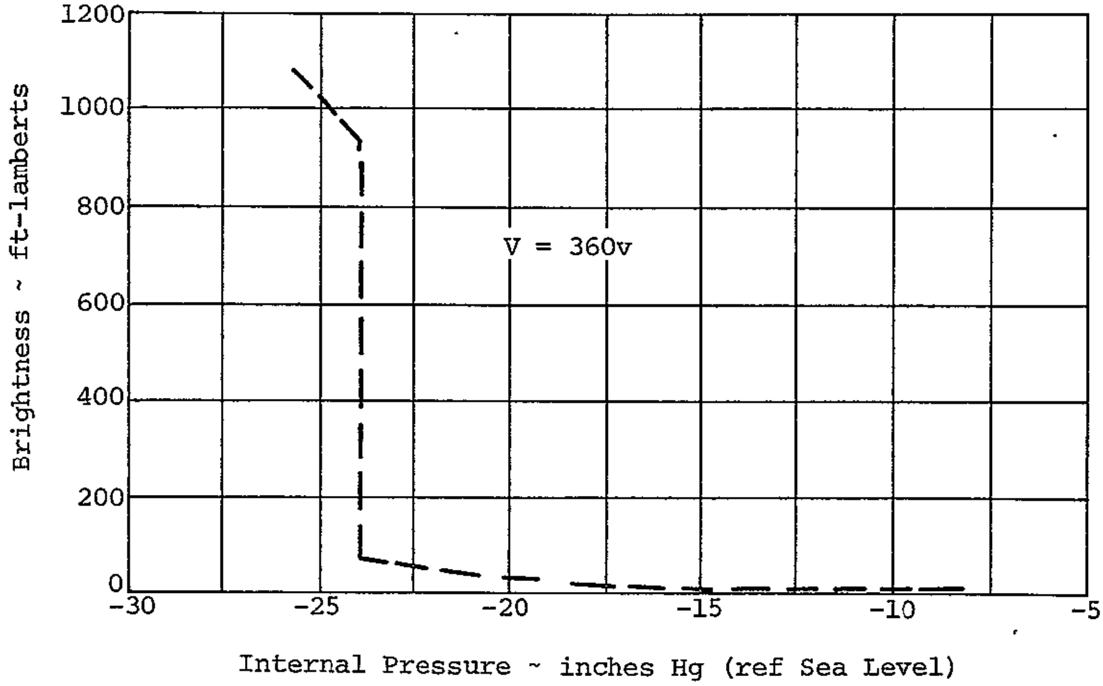


Figure 28. Plasma Cell Brightness versus Internal Pressure of Neon

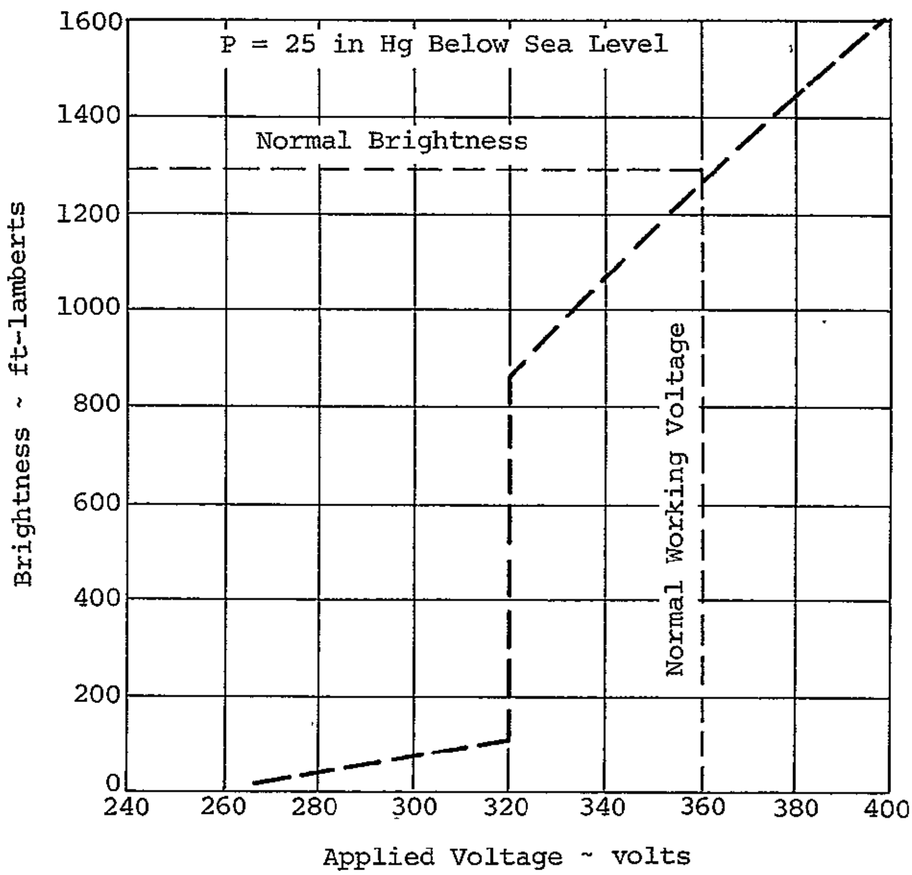


Figure 29. Plasma Cell Brightness versus Applied RF Voltage

G. ELECTRODES

1. Construction of Electrodes for Plasma Display Cells

During investigations of plasma display cells several types of vapor deposited electrodes were used in the construction of the experimental cells. This method of construction was rather costly and time consuming; therefore, experiments with electrodes etched from solid metal were conducted. These experiments resulted in successful electrode configurations which can be etched from copper or other metal laminates using a process similar to the process used in manufacturing printed circuit boards. The two external electrodes to be used with each display cell are depicted in Figure 30. As shown in this illustration one of the electrodes is hollow to permit light to be transmitted from the cell. The exact design of these electrodes is described in Appendix A of this report.

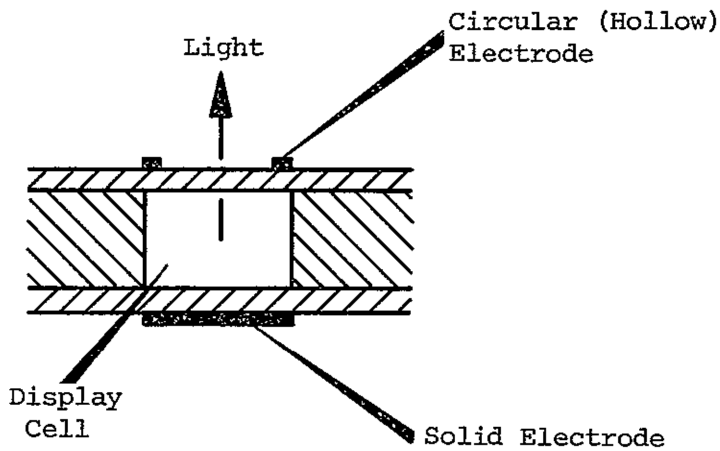


Figure 30. Electrode Configurations

2. Lifetime of Internal Electrodes

Internal electrodes in plasma cells deteriorate through a process called sputtering. In this process atoms are liberated from the cathode by the accelerated positive gas ions. The sputtered atoms may condense on the cell walls, collide with gas molecules and return to the cathode, or deposit on the opposite electrode.

The sputtering rate is dependent on the following parameters:

1 Type of gas used;

2 Temperature of cathode;

3 Cell geometry;

4 Internal gas pressure;

5 Voltage between electrodes;

6 Cell current

Sputtering increases with the atomic weight of the gas. Also, in a mixture of gases a small percentage of one gas may have a marked effect on the sputtering rate of the second gas. For plane, parallel electrodes, the distance between electrodes is the governing factor as far as cell geometry is concerned. Increasing this distance reduces sputtering. Pressure, voltage, and current are the most important parameters. The sputtering rate increases with voltage and current and decreases with pressure, but the relative influence of these parameters varies greatly with the operating point.

To obtain an estimate of the lifetime of an electrode, parameters 1, 2, and 3 above will be considered constant. Takatsu* has shown that below about 30 ma

$$Q = f(i^{\alpha}, p^{-\beta}) \qquad \begin{matrix} 2.5 < \alpha < 5.0 \\ 2.2 < \beta < 4.5 \end{matrix}$$

Q = sputtering rate
i = current
α, β are constants dependent upon gas and cell
p = gas pressure.

Some experimental results obtained by Rockwood** are shown in Figures 31 and 32. Rockwood's experimental curve follows the equation $Q = Ki^{\alpha}$ (where $\alpha \approx 4.0$) below 30 ma and shows that above this current level the rate of change of Q with i decreases.

Holland*** demonstrated that for reasonable changes in voltages when currents were in the high milliamp or amp range,

$$Q = K_3 \frac{V-V_c}{P}$$

where:

V = voltage

V_c = critical voltage

P = pressure

K_3 = constant

For almost all metals and conditions the critical voltage is above 300-400 volts.

*Takatsu, K., and Toda, T. "Cathodic Sputtering During Glow Discharge," Electrical Engineering in Japan, Vol 86, No. 10, Oct 1966.
**Rockwood, G. H., Trans Amer Inst Elect Engrs, 60, 901, 1941.
***Holland, L. Vacuum Deposition of Thin Films, London: Chapman and Hall Ltd, 1966.

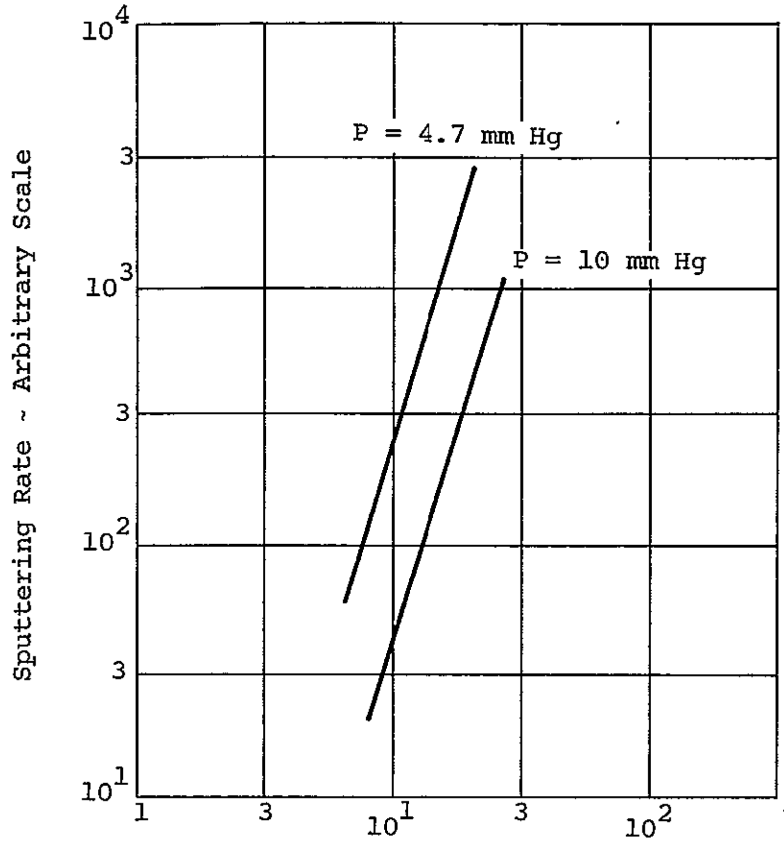


Figure 31. Current Dependence of Sputtering in Neon

Sputtering below V_c is insignificant. Interpolation of data in the three above mentioned references imply mass rates of sputtering of about 0.5×10^{-6} q/hr for typical electrodes of the type used in matrix display systems at pressures of 0.4 mm Hg. Takatsu's derived relationships indicate that at normal operating pressures for a fluidically controlled plasma display matrix this sputtering rate will be less than 1 percent of the rate of 0.4 mm Hq. Therefore, for a typical 1 mm diameter electrode used for plasma cells having a total mass of 6×10^{-6} grams, the lifetime will be

$$\frac{6 \times 10^{-6} \times 10^{2}}{0.5 \times 10^{-6}} = 1200 \text{ hr}$$

These lifetime calculations are, of course, dependent upon the duty cycle of the display cell. The calculated lifetime is for a continuously energized cell.

Since sputtering rates decrease with increased internal cell pressure, internal electrodes will have a longer lifetime in fluidically controlled matrices which of necessity run at higher pressure levels than conventional plasma display systems. It would be desirable to verify experimentally the derived relationships shown above.

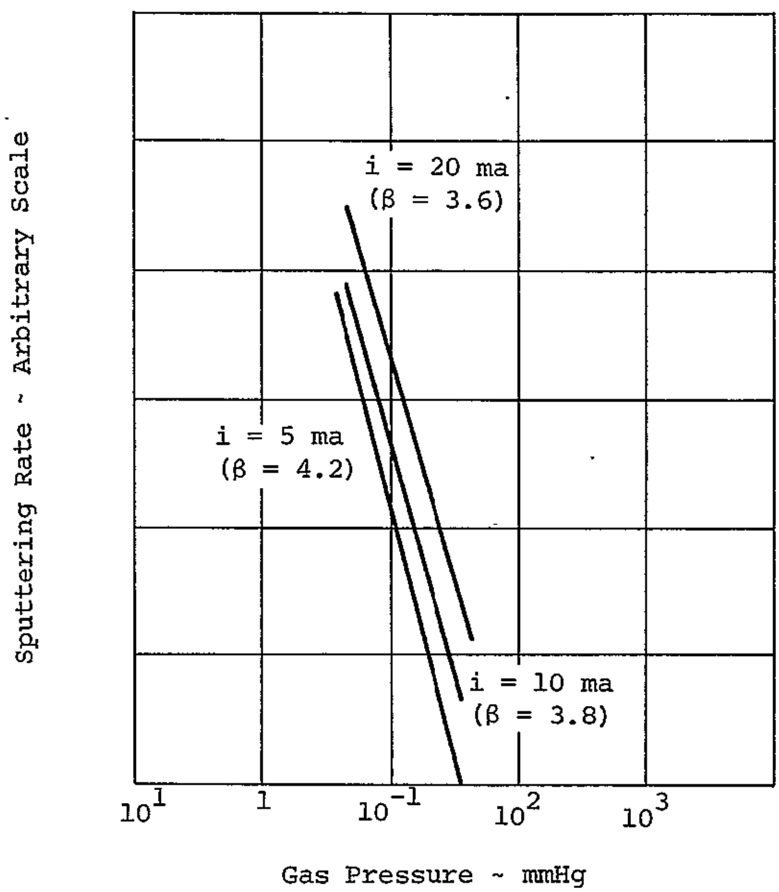


Figure 32. Pressure Dependence of Sputtering in Neon

APPENDIX A

CELL CONSTRUCTION

This appendix contains the dimensions of the experimental cells which proved to be the most desirable from a standpoint of performance. Also contained in this appendix are some helpful notes on construction methods of the experimental plasma display cells. These construction methods proved satisfactory for this purpose. However, for Mass-produced larger display matrices other methods may have to be found.

1. Description and Fabrication of Single Display Cells

To facilitate experiments with plasma cells under varying pressure conditions, it was necessary to construct cells with external gas connection. The typical gas cell used throughout the program is shown in Figure A-1.

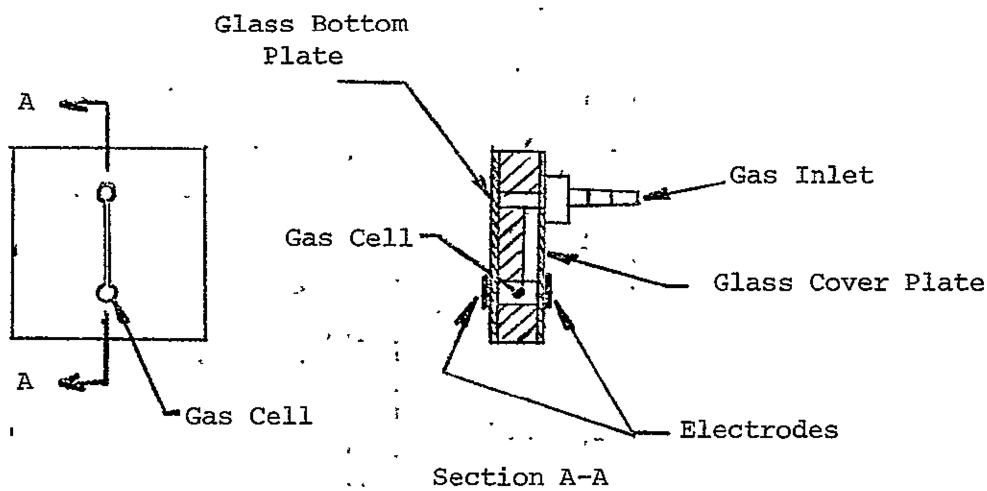


Figure A-1. Experimental Single Cell Construction

Although various substrate materials were considered such as quartz, pyrex, and Fotoceram, it was felt that the ultimate goals could just as easily be achieved with the more readily available and less expensive soft glasses. Since transparency rather than optical quality was required, soft glass would suffice. Furthermore, in the event that the assemblies would be sealed with frit, the soft glasses would ideally match the temperature coefficient of the glass frit.

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The inherent difficulties in machining glass were overcome by the use of diamond tipped drill bits and an S. S. White Industrial Abrasive Unit. For greater accuracy and uniformity, the Raytheon Ultrasonic Impact Grinder provides excellent results. It must be pointed out here, that while these methods are suitable for single cells, or displays of several cells, a 100 x 100 matrix, for example, would of necessity require an etched glass, or a glass ceramic such as Corning's Fotoceram, eliminating the need for extensive drilling or expensive tools, dies, and jigs.

Several materials were used to seal the glass substrates such as Eastman 910, apiazon wax and grease, and Fisher Scientific's "Permount". The application of an adhesive or sealing agent between the glass layers proved undesirable, since the material was either drawn into the cells during operation and caused excessive separation of the plates, or the cell could not be hermetically sealed.

The most expeditious method of sealing the assembly was found in the use of a two part epoxy, such as Ren RP-1125A applied along the edges and allowed to cure. Since the glass plates were tightly clamped, the outgassing problem was also minimized.

The inlet connection was a modified clipped brass hose fitting from which the external threads were removed. Attaching the fitting to the glass cover plate was accomplished with apiazon wax, an effective hermetic seal.

Early in the program an effort was directed toward vapor deposition of electrodes. The bottom plate was chosen as the transparent viewing side of the cell thus requiring a transparent electrode as a matter of convenience in the test setup. The cover plate could be covered with a solid electrode. (See Figure A-1)

Construction of the transparent electrode was achieved by first evaporating nichrome over one face of the glass followed by a film of gold outside the area of the cells. The choice of nichrome as a thin interfacial layer is based on its excellent adhesion to glass as compared to other conveniently evaporated metals. A film of approximately 100 Angstroms resulted in 40 percent to 60 percent light transmission. A final layer of 3000 Angstroms of gold over the area outside of the cell increased the conductivity as well as facilitated the attachment of external connecting wires.

The cover plate was constructed in an identical fashion except for the omission of a transparent viewing area.

The high resistance of nichrome as an electrode resulted in the disintegration of some films during operation. To overcome this difficulty, the decision to use separately etched copper electrodes fastened to the glass, proved helpful. The electrode configuration could readily be altered and damaged electrodes could easily be replaced without destroying the cell. (See Figure A-2).

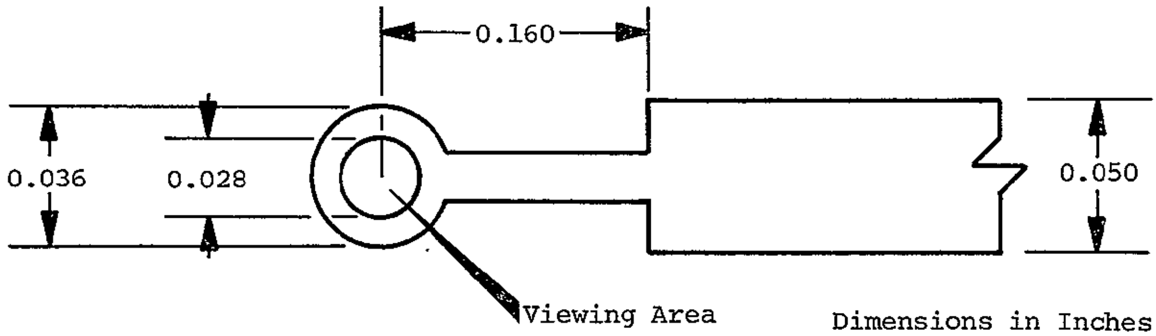


Figure A-2. Electrode Configuration Typical Dimensions

After some trial and error the optimum configuration for a hollow electrode was established. The hole in the center of the electrode made it possible to view thy performance of the cell without the use of transparent electrodes. Typical dimensions of the single cells used for the experiments are shown in Figure A-3.

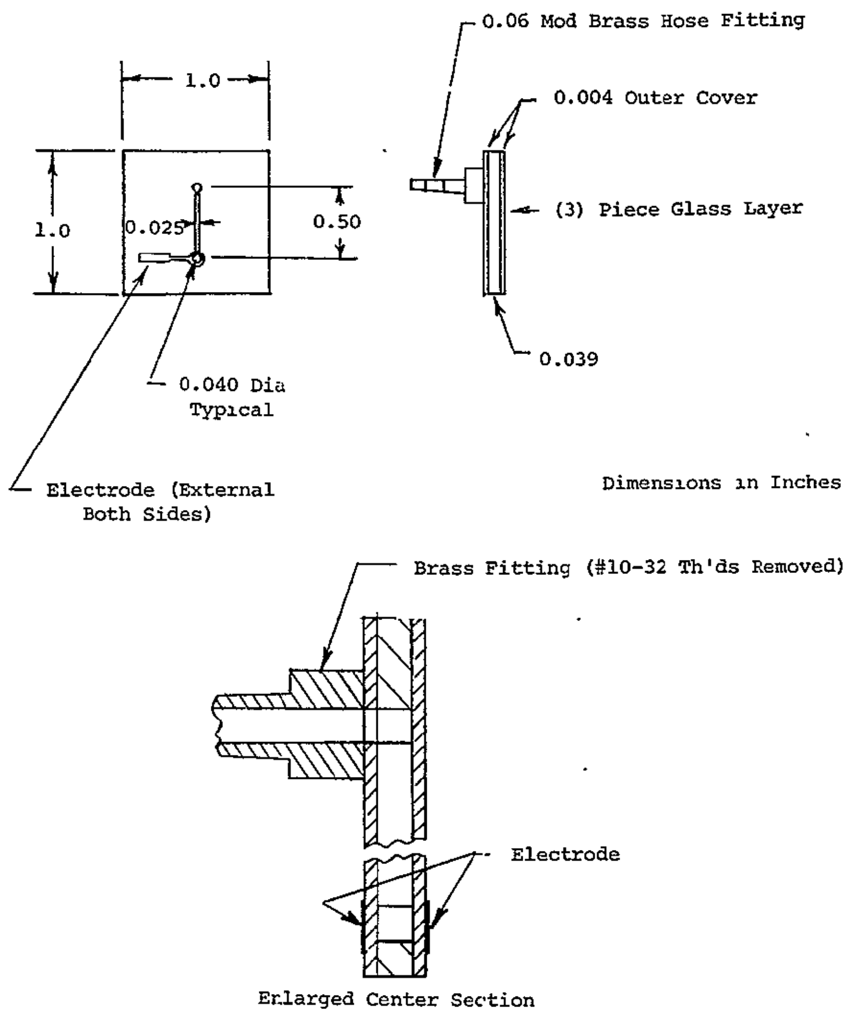


Figure A-3. Typical Dimensions of Single Plasma Cell

2. Double Plasma Display Cells

The double cell is essentially two single cells back to back. In constructing such a cell, a separator, either glass or metal, divides the cell in half, resulting in two distinct and independent cells, each equivalent to a single cell. (See Figure A-4).

An inlet is provided to each cell. Electrodes are positioned as in the single cells, and fabrication methods are identical to that of the single cell.

Figure A-5 shows typical dimensions of the double plasma display cell.

Figure A-6 shows the dimensions of internal electrodes used with some of the experimental cells. Figure A-7 depicts the dimensions of the vapor deposited electrodes while Figure A-8 shows the attachment of the external gas connection to the cell. Figure A-9 is an illustration of the sealing methods used in manufacturing the cells.

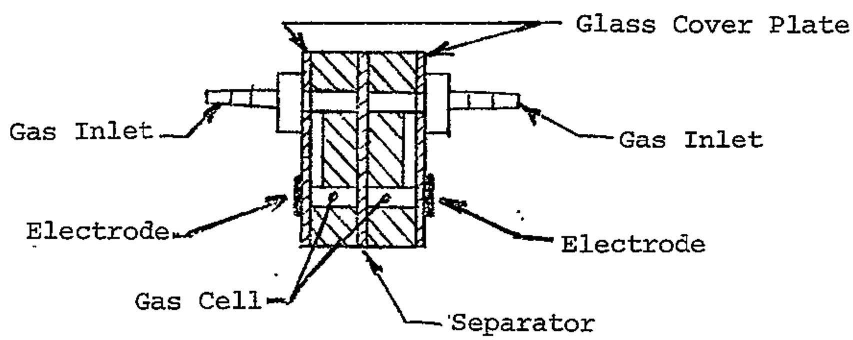


Figure A-4. Experimental Double Cell Construction

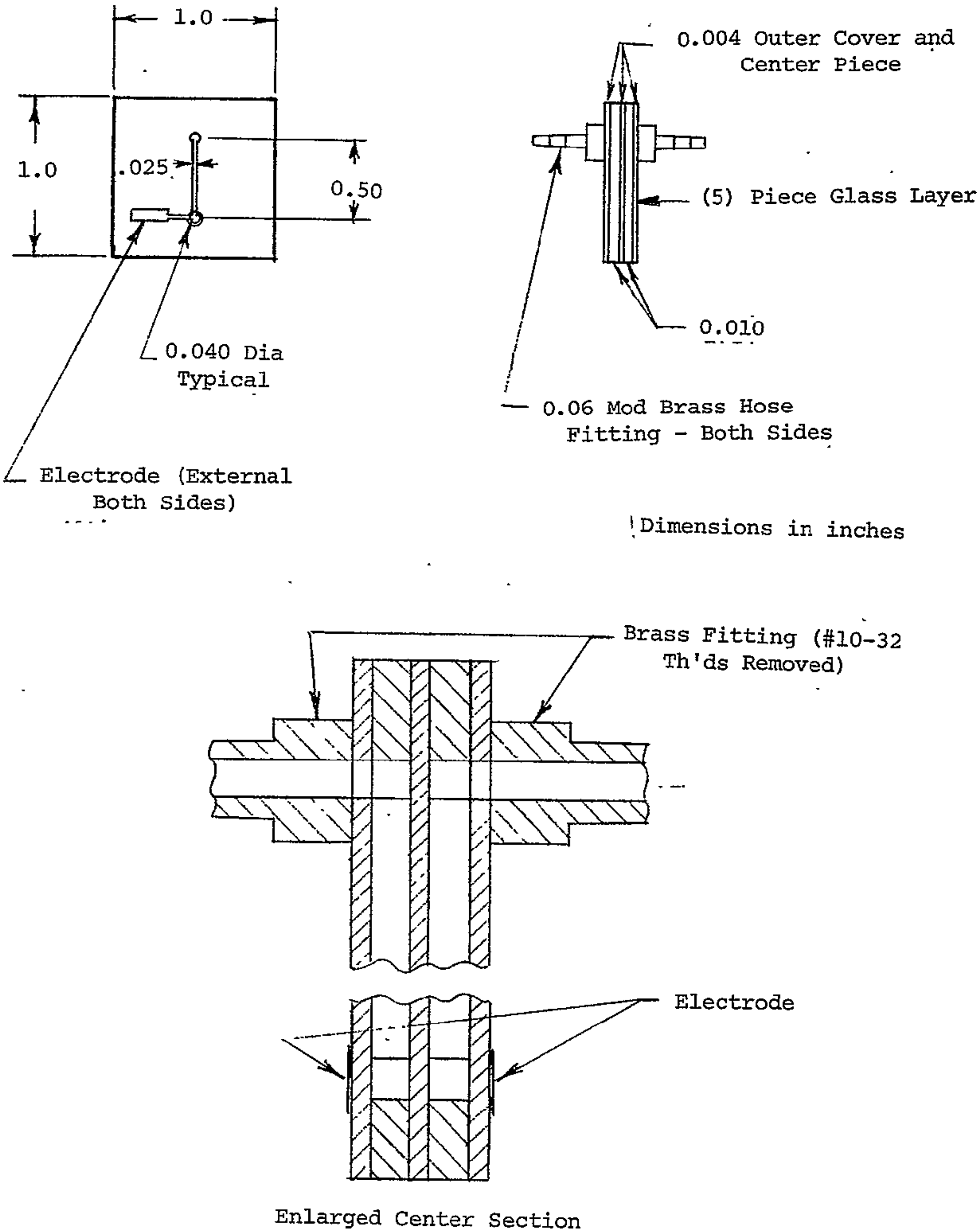
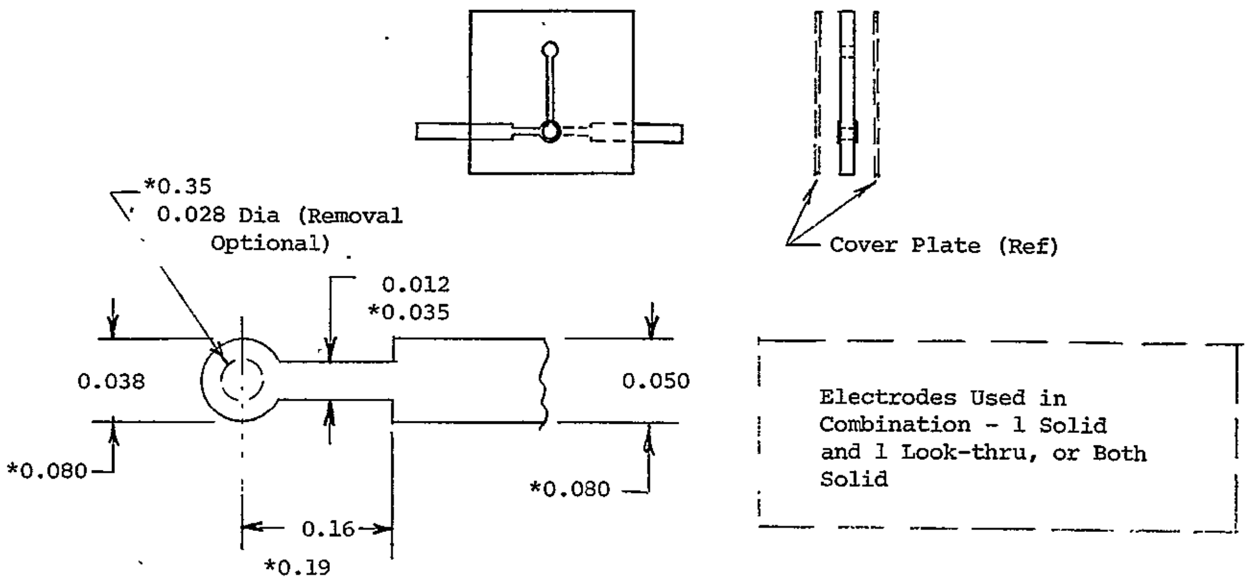
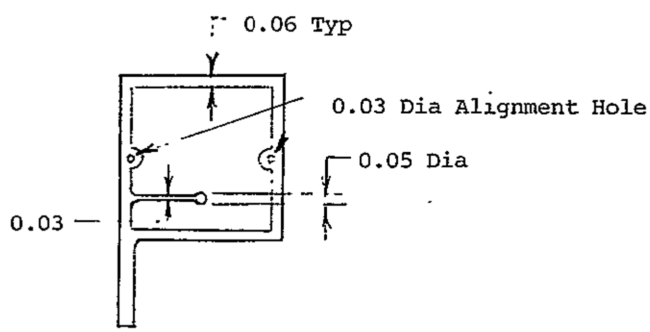


Figure A-5. Double Plasma Cell



Enlarged View of Electrode (*Large Size)
(0.001 Thick Brass Shim Stock)

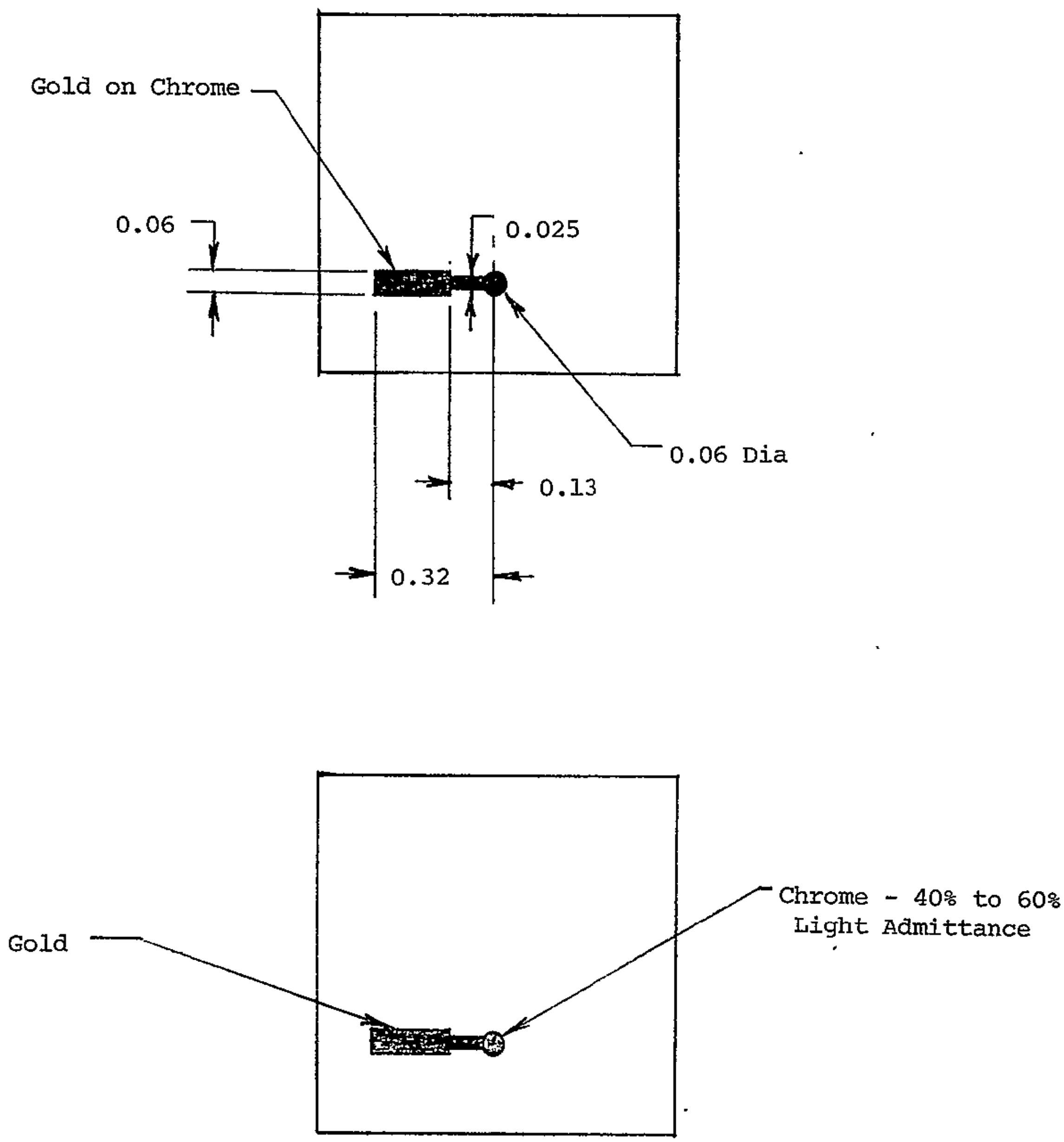
NOTE: External etched electrodes are 0.001 or 0.002 thick copper.



Alternate Electrode
(0.001 Thick Brass Shim Stock)

Dimensions in Inches

Figure A-6. Internal Electrode Construction (Etched)



Dimensions in Inches

Figure A-7. External Electrode - Vapor Deposited

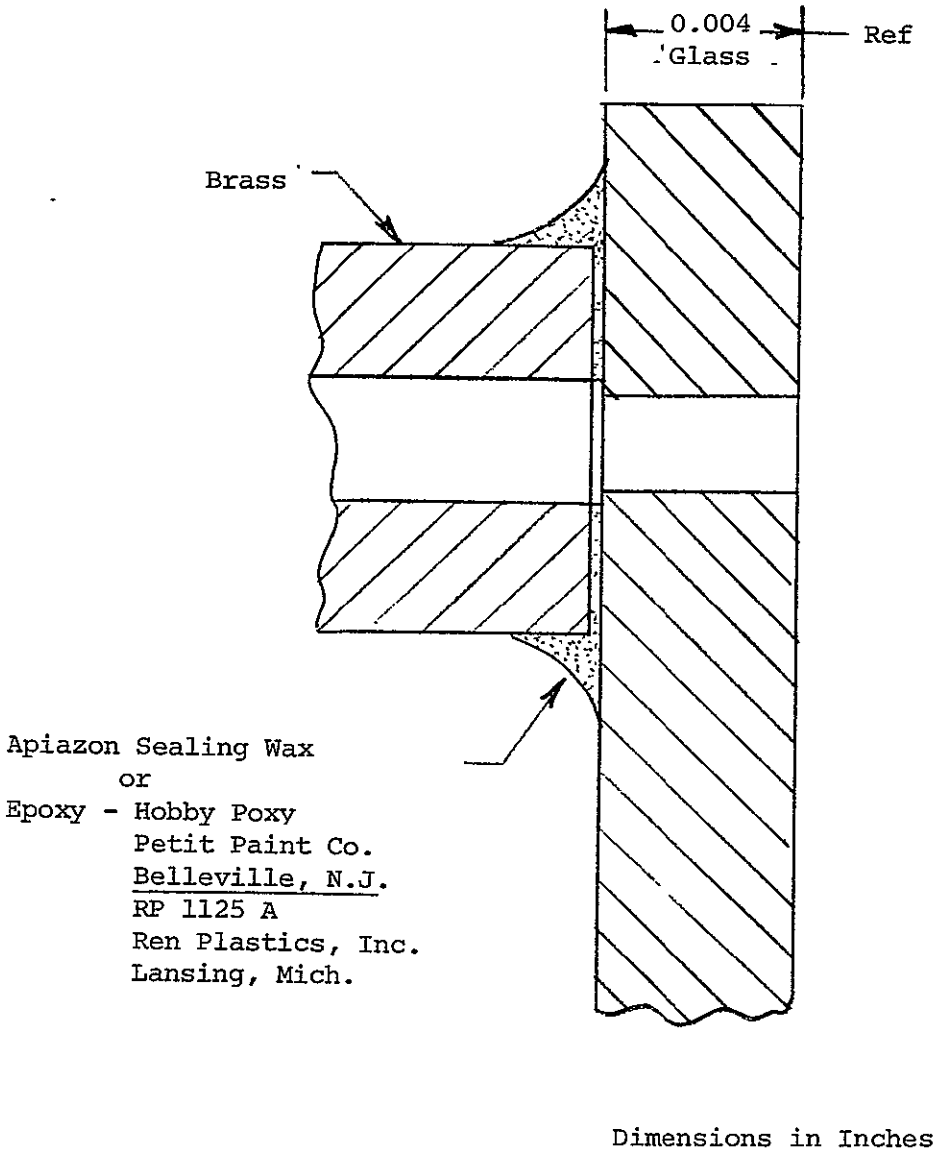
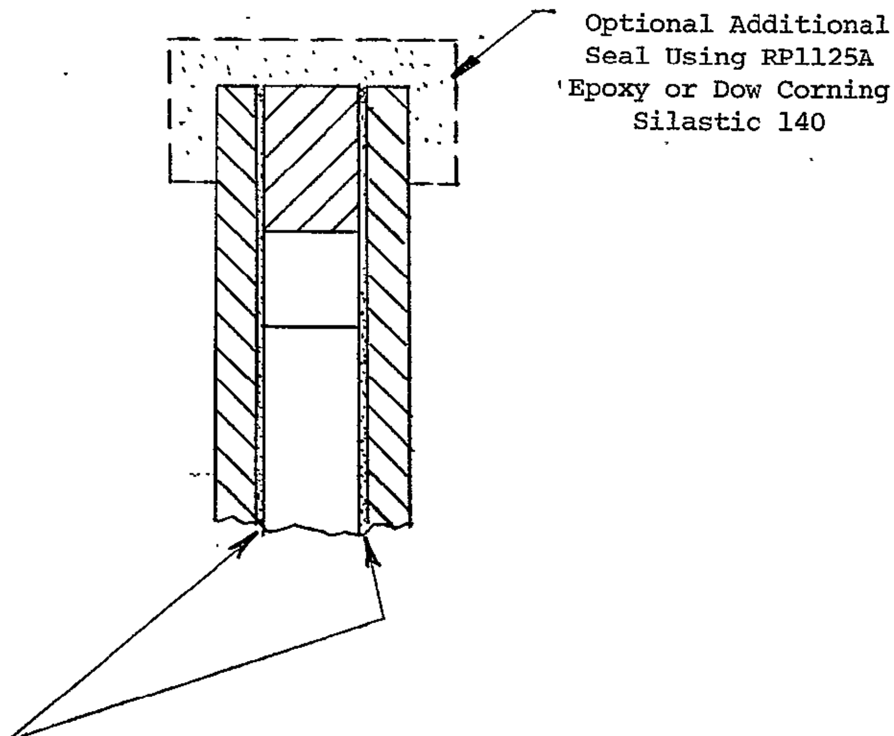


Figure A-8. Attachment of Brass Fitting



(a) Apiazon Sealing Wax or Grease

(b) RP1125A Epoxy (Ren Plastics, Mich.)

(c) Permount (Fisher Scientific, N.Y.)

(d) Eastman 910 (Armstrong Corp., Pa.)

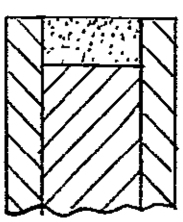


Figure A-9. Bonding Glass Substrates

APPENDIX B

NEW TECHNOLOGY

After a review of the work done under this contract it is felt that the following items should be classified as innovations and improvements.

1 Operation of plasma cells on fluidic control systems rather than with electronic control components;

2 The application of solid electrodes to plasma display cells. These electrodes, which only partially cover the display cells, can be manufactured at reduced cost and improve plasma cell brightness;

3 Double plasma display cells make it possible to provide complete isolation of row and column control systems in a matrix type plasma display system.

These new technology items will be reported to NASA-ERC separately as required under the New Technology Clause of contract NAS12-532.

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