CR 86340

FLUIDIC PLASMA DISPLAY STUDY
FINAL REPORT
PHASE III

By Jacq Van Der Heyden

March 1970

Prepared under Contract No. NAS 12-532 by

MARTIN MARIETTA CORPORATION

Orlando, Florida

for

Electronics Research Center
Cambridge, Massachusetts

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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TECHNICAL RESPONSIBILITY

This program is being sponsored by the Electronic Research Center of the National Aeronautics and Space Administration, Cambridge, Massachusetts, under Contract NAS 12-532. 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 (OR 10,634) covers the third phase of this contract through March 1970.

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ILLUSTRATIONS

FLUIDIC PLASMA DISPLAY STUDY

By Jacq Van Der Heyden

Martin Marietta Corporation
Orlando Division
Orlando, Florida

SUMMARY

This final report cites the program objectives and the progress made during Phase III of research contract NAS 12-532.

This study was sponsored by the Electronic Research Center of the National Aeronautics and Space Administration, and covers hybrid fluid plasma display techniques. The program was aimed toward the development of low cost, more reliable plasma display matrices through the use of fluid rather than electronic control systems for such matrices.

This report contains sections covering the background of fluid controlled plasma display systems and the progress made towards the development of a line and column fluid controlled plasma display matrix. Recommendations for further investigations leading to a large scale plasma display matrix are also included in this report.

INTRODUCTION AND BACKGROUND

This section presents the state of the art of plasma display systems, the fluidic control system implementations, and significant accomplishments made prior to this third phase of the contract.

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 . n individual display cells that should be controllable independently of each other to obtain a universally usable display system.

Plasma Display Cells.-- The several forms of plasma display cells are variations of the basic principle of a closed cell constructed from glass, 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; 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.

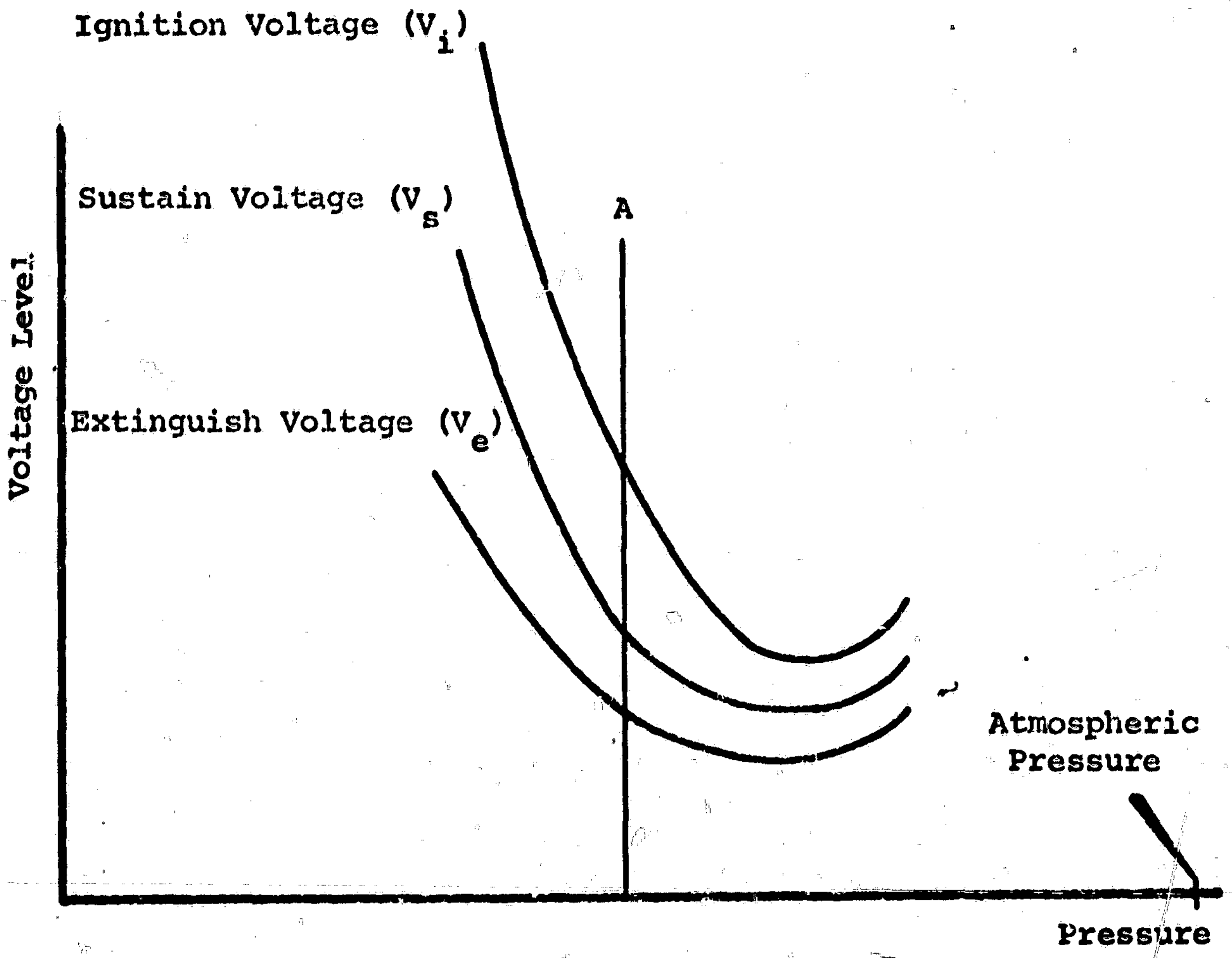


Figure 1. Typical Relationship of Voltage and Internal Cell Pressure

<u>Conventional Plasma Display Control Systems.</u>--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 fluid control system.

Fluid Control Systems

Some problems in crossed grid control systems for plasma displays can be solved by fluid techniques. The main advantage of a fluid 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 fluid control system that controls the internal pressure will be completely independent of the electrical impedance changes encountered in the plasma.

Fluid 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. Fluid 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. Pressure control can be accomplished with fluid-mechanical techniques.

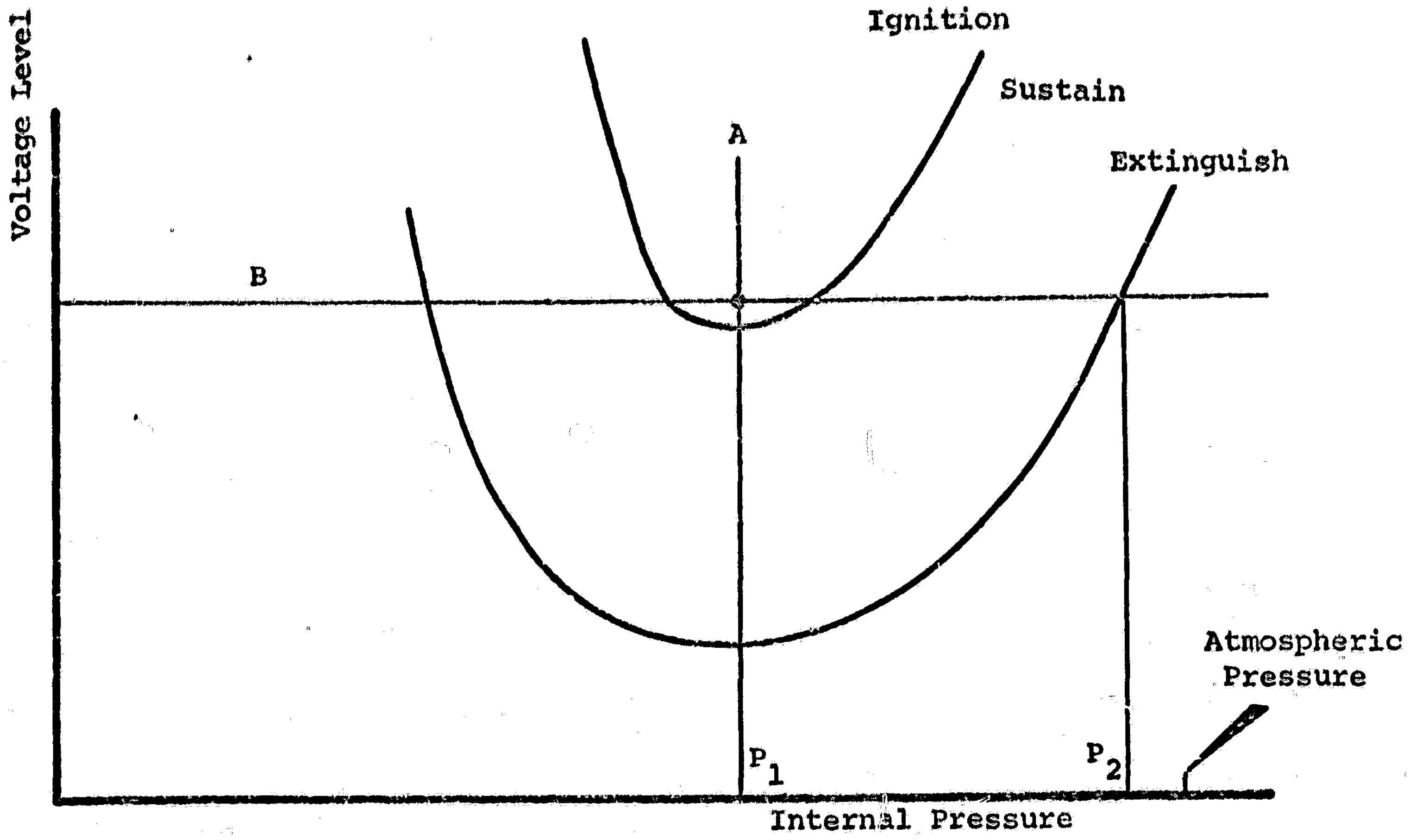


Figure 2. Fluid Control Mechanization

Previous Accomplishments in Fluid Controlled Plasma Display Systems

The feasibility of using fluid control techniques for plasma displays was ascertained during Phase II of this contract. Results of this study are reported in Phase II Final Report, Contract NAS 12-532, "Fluidic Plasma Display Study." This report, dated March 1969, carries Martin Marietta's identification number OR 9930. The most significant problem solved during this effort was the development of plasma display cells that could be operated with pressure signals rather than voltage level signals. Also investigated was the possibility of using fluidic techniques to operate a display matrix control system.

Complete details of the investigation are contained in the above mentioned report and highlights are described in the following section of this report.

Plasma Display Cells.--Since plasma display cells that were previously developed for use with electronic control systems worked at pressure levels which were not compatible with the pressure ranges suitable for fluid control systems, a new family of cells was developed.

To facilitate controlling plasma display cells with varying pressure conditions, it was necessary to construct cells with an external gas connection. The general shape of the gas cells used is shown in Figure 3. These earlier cells were formed by a round hole in the glass cell plate, and the cell plate was 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 and electrodes are deposited on the outsides of cover and bottom plates.

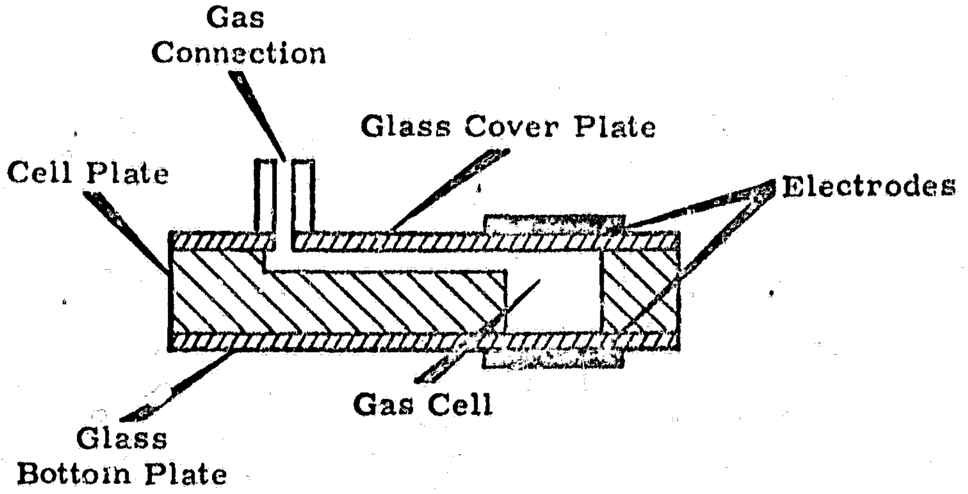


Figure 3. Experimental Cell Construction

The most promising cell configuration developed during this phase of the contract exhibited voltage pressure characteristics as shown in Figure 4. Constant excitation at 500 volts, made it possible to switch the cell on and off with a pressure switching range of 4 inches Hg from -18 to -14 inches Hg. These pressures are readily obtainable with fluidic mechanical or fluidic techniques.

Annular Electrodes.--During the investigations conducted in the previous phase of this contract, several types of vapor deposited electrodes were used in the construction of experimental cells. This method of construction was rather costly and time consuming; therefore, experiments with electrodes etched in solid metal were conducted. These experiments resulted in successful electrode configurations that can be etched from copper or other metal laminates using a manufacturing process similar to that used to obtain printed circuits. The annular or "hollow" electrodes are depicted in Figure 5.

Fluidic Logic Elements.--Advancements made in the field of fluidic control system technology have made the fluidic system a likely candidate for control of a plasma display matrix. To ascertain the feasibility of a fluid

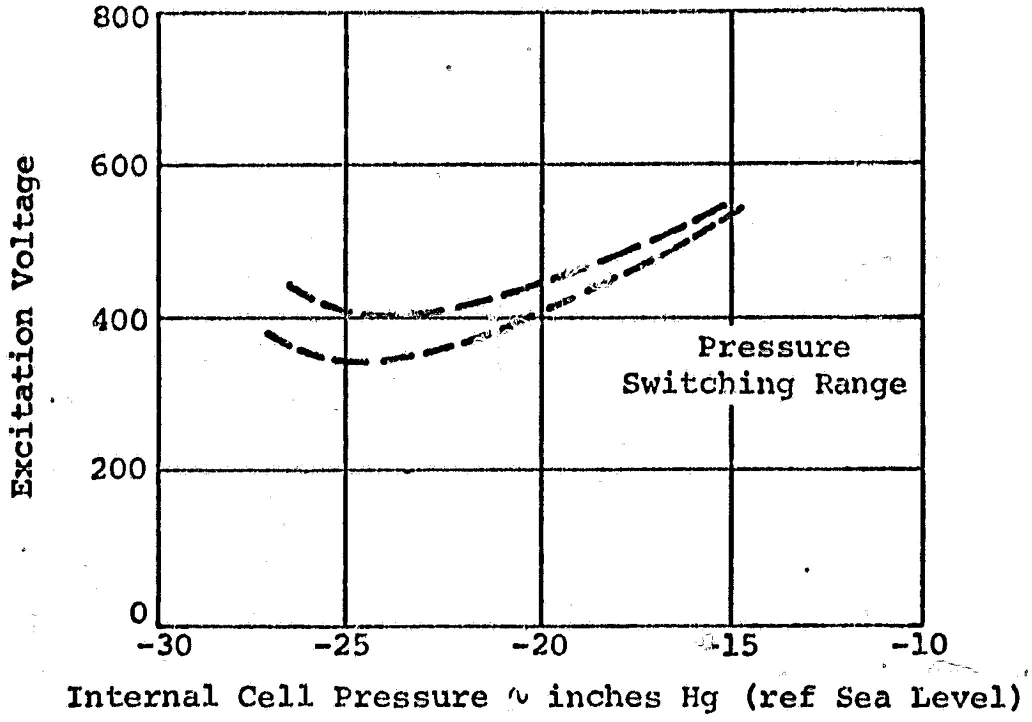


Figure 4. Plasma Cell Test Results

control system for this purpose, an investigation was conducted which tried to match the pressure signals required to operate a density controlled plasma display cell with the output pressure levels obtainable from fluidic logic gates. 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.

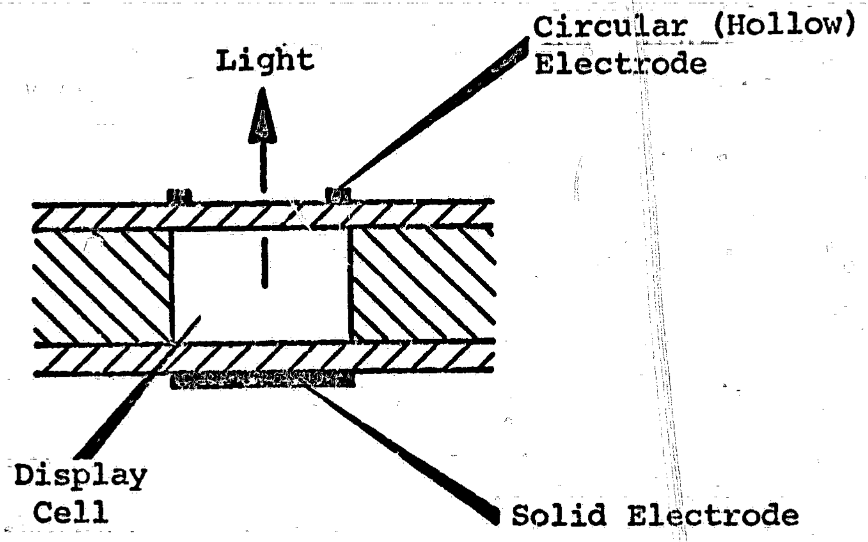


Figure 5. Electrode Configuration

Investigations were conducted to determine the capabilities of Martin Marietta's state of the art fluidic devices to operate under low pressure conditions. Figure 6 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. These capabilities are sufficient to switch plasma display cells. Figure 7 illustrates the control pressure levels and output pressure levels versus supply pressures for nitrogen, neon, argon, and helium. Neon will be used as the primary gas in the display systems.

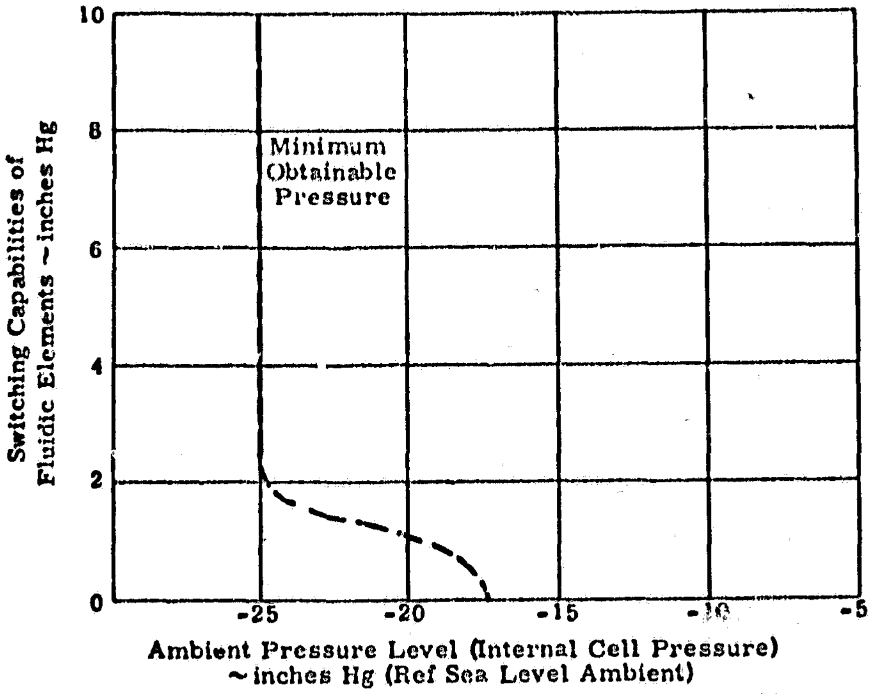


Figure 6. Maximum Switching Capabilities versus Internal Cell Pressure

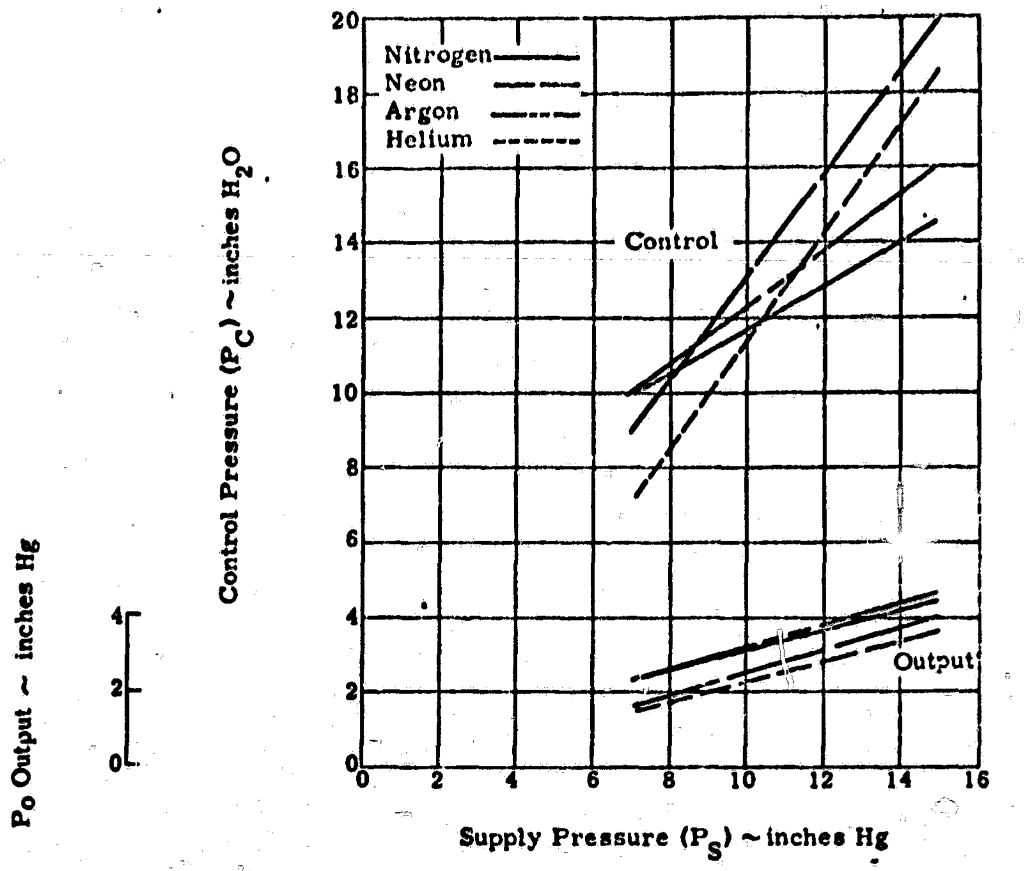


Figure 7. Four Mil OR-NOR Element

PROGRAM OBJECTIVES

During this 9 month program, Martin Marietta continued the investigation of fluidically controlled plasma display devices. Feasibility of control of single plasma display cells with fluidic techniques was proven under phase II of this contract.

The investigation covered the control of multiple display cell arrangement such as matrix display configurations used for computer driven alphanumeric readout matrices. Specifically, the studies and experiments covered the development of cell matrices which can be controlled fluidically. These matrices differ from conventional plasma display arrangements in two ways. The display matrix requires input channels for the fluidic signals and cell firing characteristics should be compatible with the signal levels obtainable from fluidic logic circuits. Efforts were extended in the areas of optimization of display matrix design, design of cells, and interconnecting lines. Also, investigation of crosstalk problems encountered in line and column control systems were conducted. Development of a simple experimental matrix was undertaken to prove feasibility of fluidic line and column type control systems for plasma display matrices.

During the program, study results indicated that certain advantages could be gained by utilizing different control techniques than those possible with a purely fluidic approach to the problem. It was decided to increase the scope of work to include some of these other techniques in the investigation.

PROGRAM PROGRESS

Progress made towards obtaining a fluid controlled plasma display matrix can be divided into four areas: 1) continued development of plasma display cells compatible with fluid control systems, 2) investigation of a fluidic control system that could be used to control a plasma display matrix, 3) utilization of an oscillatory control system, and 4) investigation of fluid control systems other than pure fluidic systems.

The following sections describe the progress made during this contract in each of the above four areas, as well as the experimental hardware built to demonstrate the feasibility of these approaches and used for experiments necessary to verify the analyses of these various approaches.

Plasma Cell Development

Two obvious disadvantages are connected with the display cell design used during the previous phase of this contract. This design (Figure 3) was entirely suitable for the investigations it was intended to support; however, the additional channel used to transmit pressure signals would add cost to the display matrix and would take up a relatively large area of the display matrix, thus decreasing the maximum obtainable cell density of a display matrix. To eliminate these drawbacks, investigations were conducted to ascertain the feasibility of combining the previously developed fluid controlled plasma display cells with the annular electrode investigated during the previous phase of the contract. This new cell configuration, (Figure 8) does not require a large display area since fluid signals now enter directly into the cell through the center of the electrode. Also, elimination of the control signal channel would result in a less costly construction, compared to electronically controlled plasma display matrices.

Experiments subsequently verified that this cell configuration was satisfactory, providing electrode thickness was increased substantially over the electrode depth normally reported as useable with electronically controlled display systems. Utilization of electrodes of small crosssections, such as those necessary to ensure light transmissions, resulted in local separation of the electrodes from the glass cell cover plate. This problem was circumvented by using electrode thicknesses of at least 0.001 inch on the backside of the display cells. The electrodes on the observers

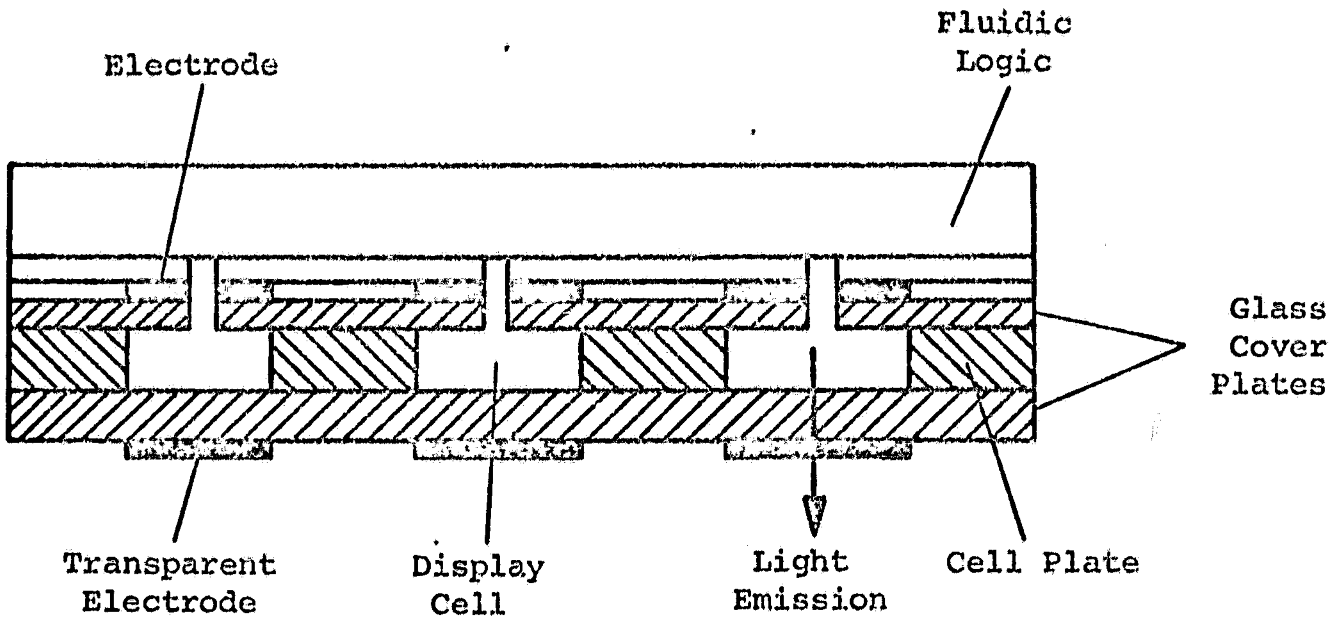


Figure 8. Construction of Display Matrix

or front side of the display matrix can be maintained at the customary thicknesses to ensure sufficient light transmission to the viewer without any detremental effects to the structure of the display cell.

Fluidic Control System

During the previous phase of the contract it was shown that a fluidic control system for cross grid controlled plasma display matrices was feasible. The mechanization of such a fluid system was studied during the course of this contract. Feasibility was determined through a theoretical analysis of the performance of a fluidic system. If simple display cells were individually connected to one line and one column pressure signal channel as shown in Figure 9, five distinct pressure levels would result in the matrix, e.g., assuming that the 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. 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.

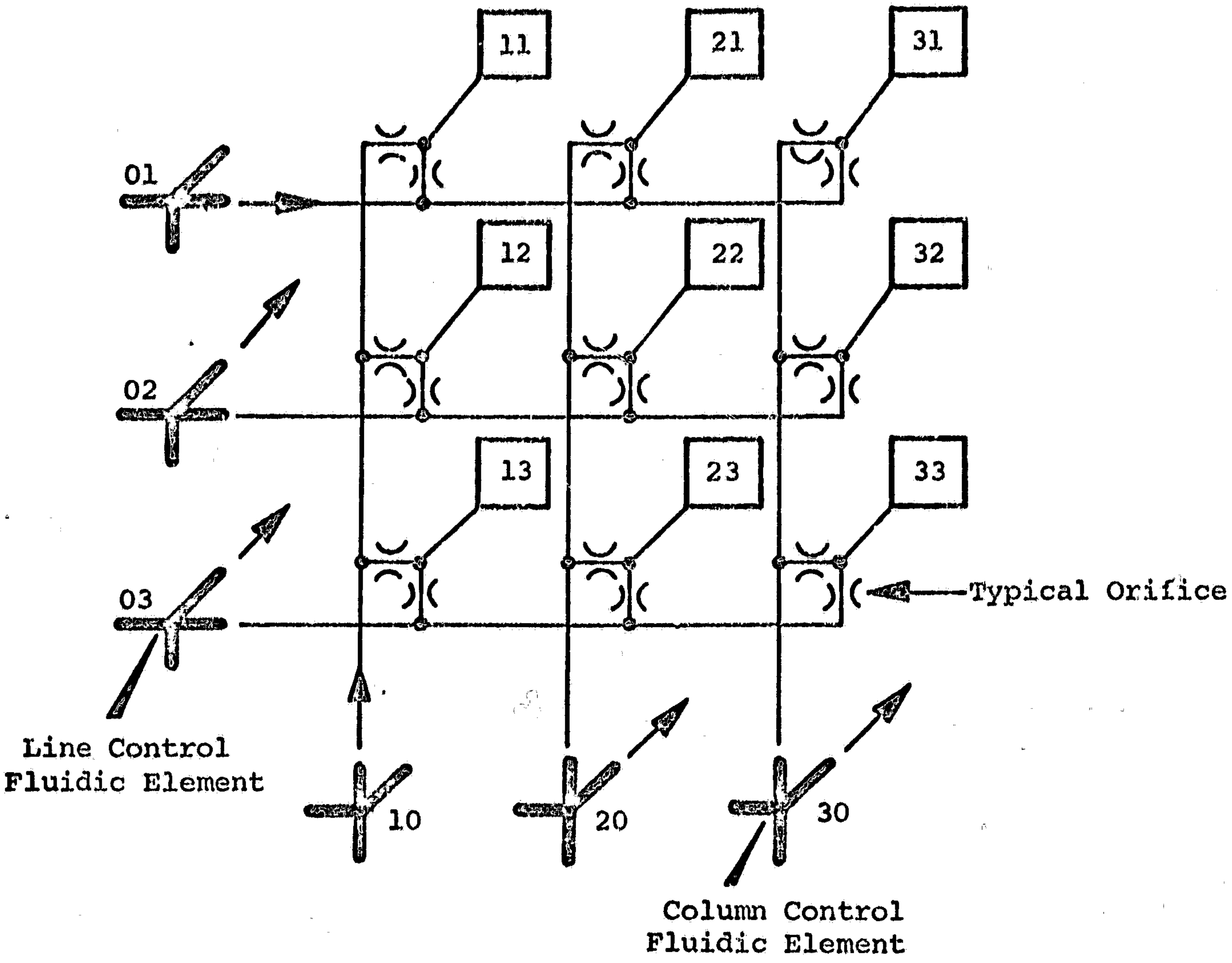


Figure 9. Cross Grid Control System

The fluidic logic system maintains the input pressure to the lines and columns at three distinct levels: P_a, P_q and P_o. This results in five distinct levels that can be present in any of the cells as shown in Figure 10. For proper operation of the system, three pressure levels (P_1, P_q and P_i) should all fall within the plasma cell hysteresis band to prevent unwanted cell firing or extinguishing.

To ascertain the feasibility of this approach experiments were performed on a matrix constructed from metal laminates as shown in Figure 11. Provisions were made to apply pressure to one or more line or column input lines. Some of the simulated plasma cells were connected to pressure transducers in order to monitor pressure changes occurring inside the cell due to control signals applied to line and columns. Figure 12 shows test results obtained with this matrix. Relative levels of input signals and internal cell pressures are shown. The pressure range between pressure levels P_1 and P_i almost covers the complete hysteresis band. No wide margin for variations of individual cell dimensions, which have influence on the ignition and extinguishing levels for each cell, is available, and variation from cell to cell in extinguishing and firing pressure levels

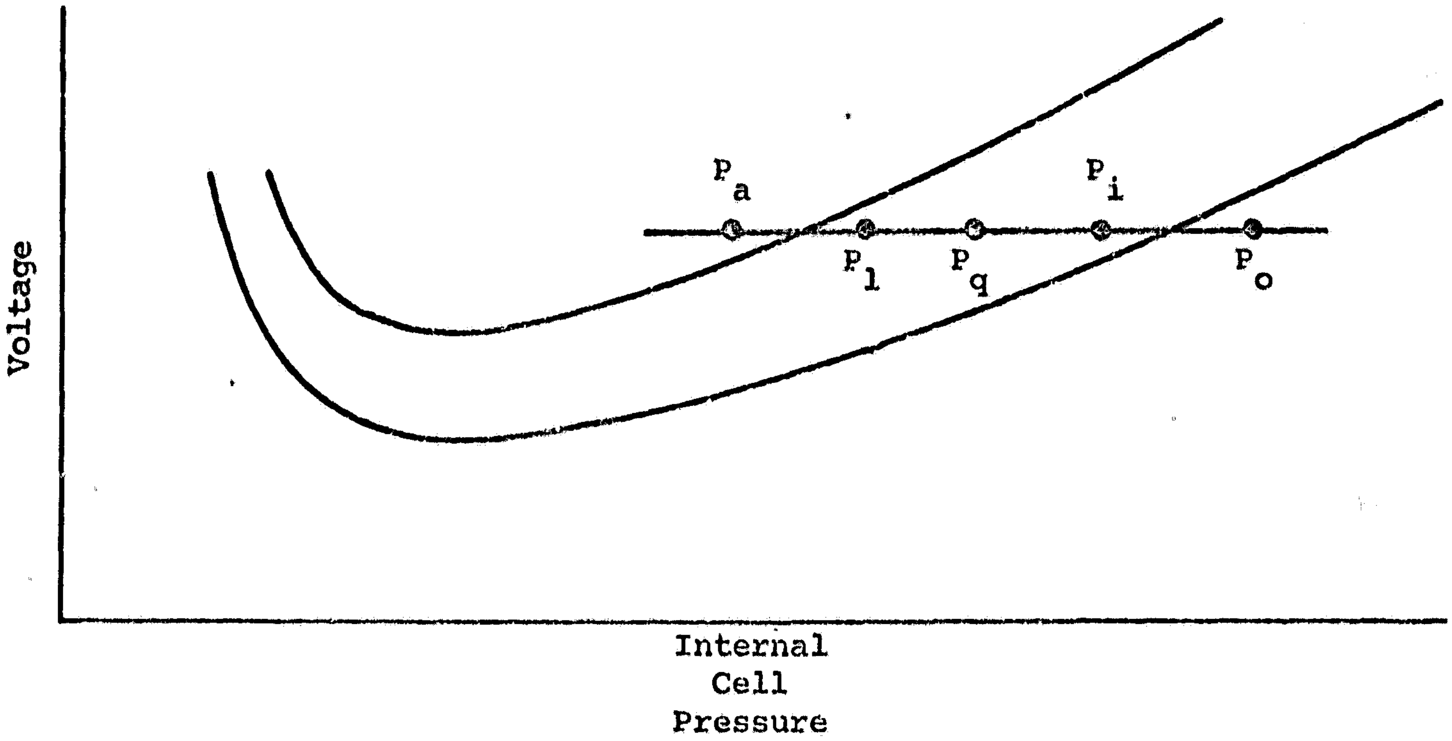


Figure 10. Pressure Levels versus Voltage

has to be kept to an absolute minimum. The margin of operating pressures can be released when the fluidic system is combined with an oscillatory type control system as described in previous section of this report.

A description of the experimental hardware built for this investigation is contained in the Appendix of this report.

Oscillatory Cross Grid Control

It was shown in preceeding paragraphs that if display cells were individually connected to one line and one column pressure signal channel, five distinct pressure levels would result in the matrix. The fluid control system maintains the input pressure to the lines and columns at three distinct levels: P_a, P_q, and P_o. The resulting five distinct levels that can be present in any of the cells as was shown in Figure 12. For proper operation of the system, three pressure levels (P_1, P_q, and P_i) should all fall within the plasma cell hysteresis band to prevent unwanted cell firing or extinguishing.

An improved control system can be obtained by using oscillatory signals as pressure excitation in combination with pneumatic filtering techniques. Figure 13 shows the type of input signals required for this oscillatory control system. The normal output of the control signal into each

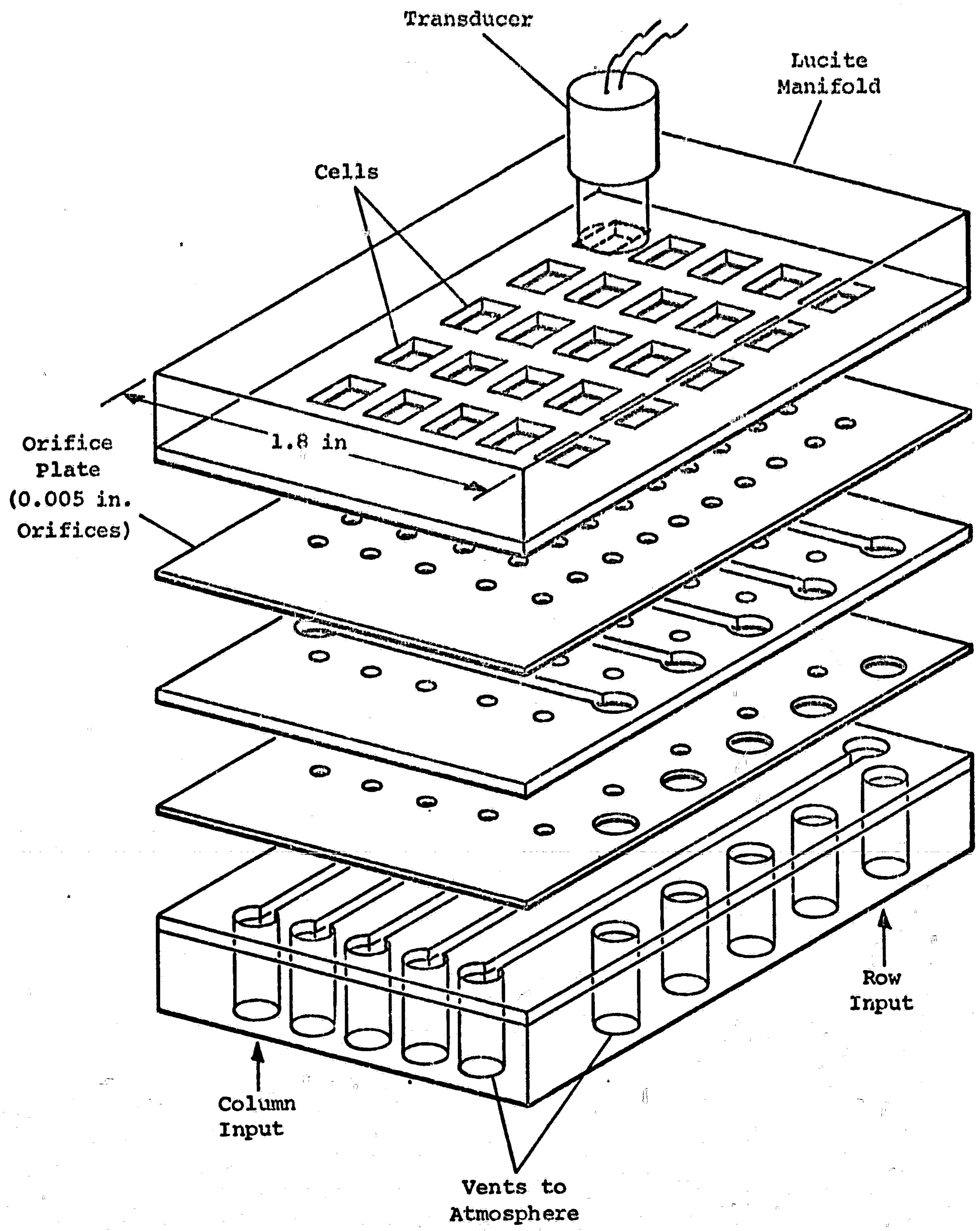


Figure 11. Fluidic Plasma Display [illegible]st Matrix

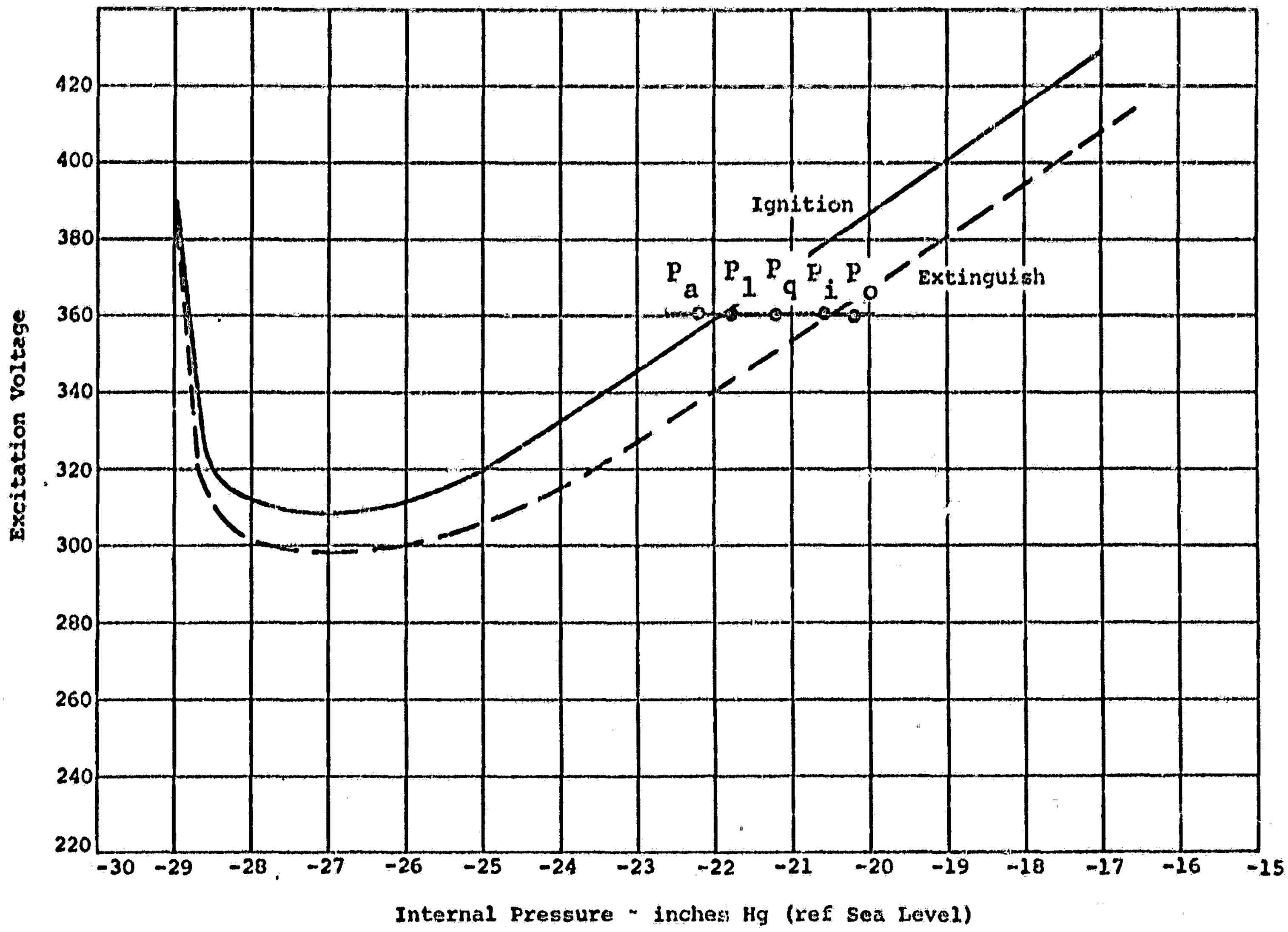


Figure 12. Plasma Cell Pressure Voltage Characteristics

line and column is the steady-state pressure level P_q. The extinguish command is an oscillatory signal with P_o as the highest peak pressure. The ignition command is a pressure oscillation with level P_a as its lowest peak pressure. The extinguish command is an oscillatory signal with P_o as the highest peak pressure. The ignition command is a pressure oscillation with level P_a as its lowest peak pressure.

The advantages of this scheme are illustrated in Figure 14. When a cell has to be activated, the oscillatory pressure signal is applied to both line and column signal ports of the cell. At low frequencies no signal attenuation is experienced and the equivalent electrical circuit that describes the fluidic action is a shorted capacitor.

Figure 14 shows the amount of crosstalk experienced in a cell when one of the cell inputs is activated and the opposite inlet port is held at pressure P_q. The equivalent electrical circuit shows that the cell now acts as a capacitor to ground, causing attenuation of the excitation signal at higher frequencies.

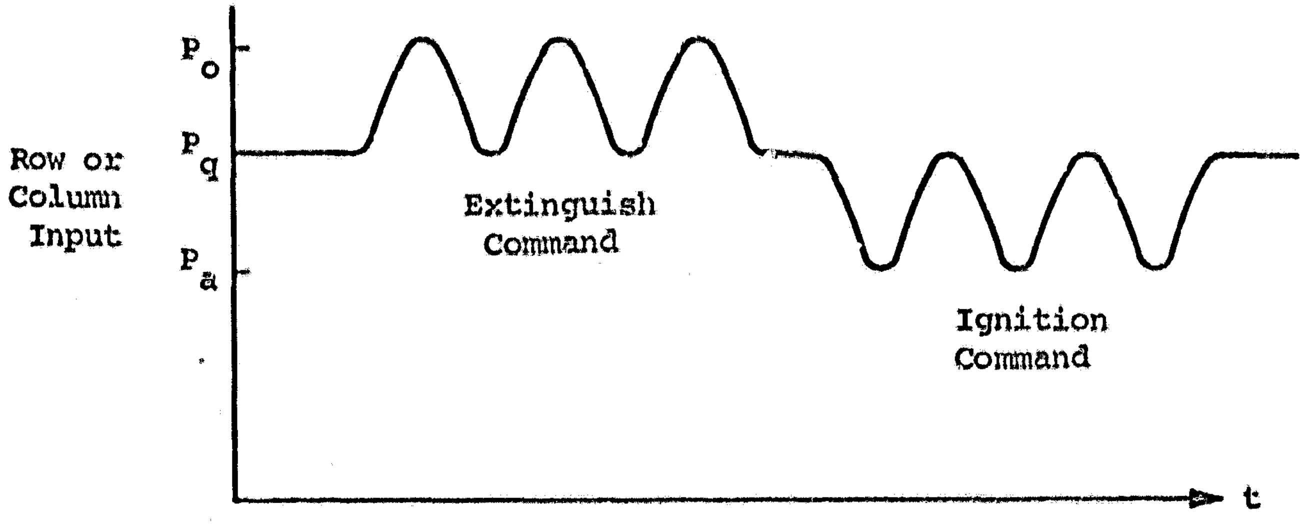
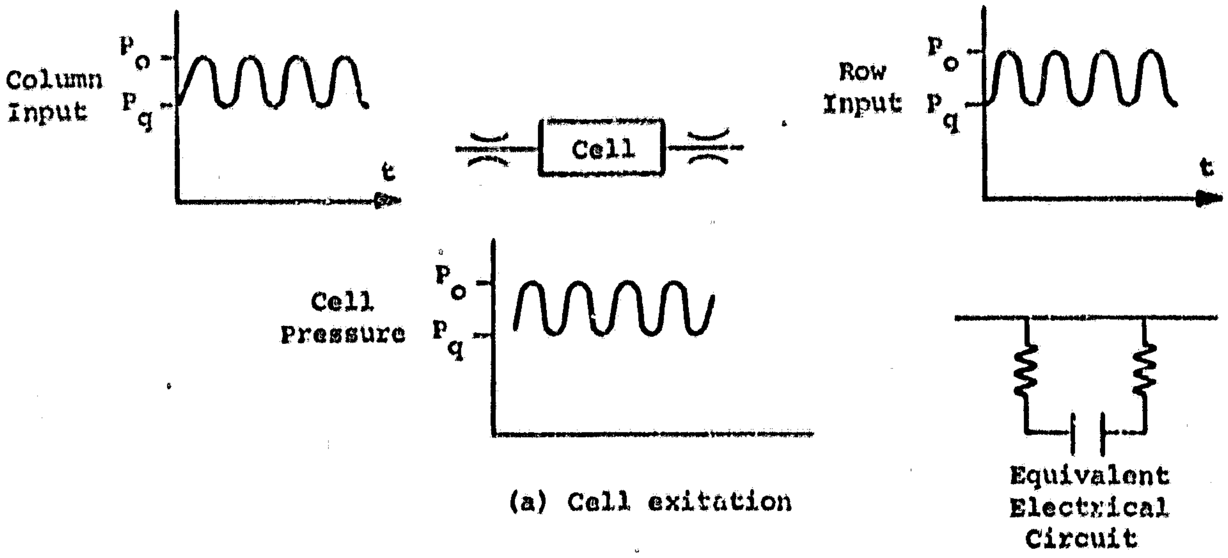


Figure 13. Oscillatory Control

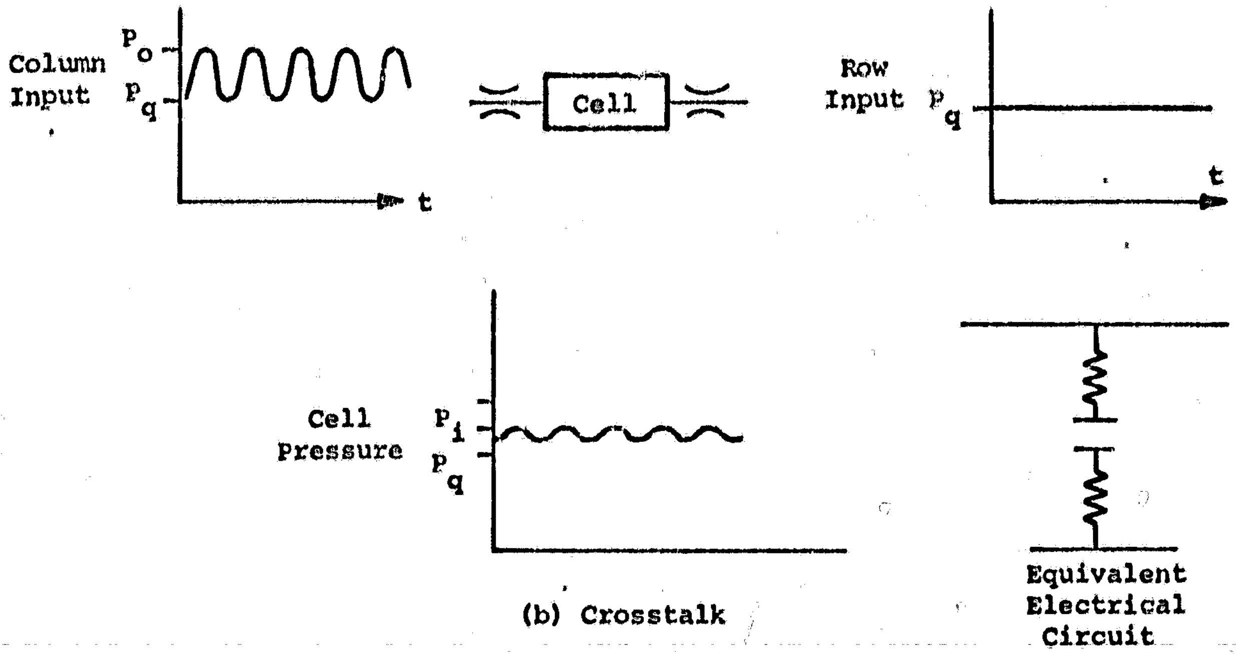
Careful selection of the orifice size that connects the plasma display cell with the row or column signal channel will make it possible to select a signal frequency at which no appreciable attenuation of the pressure signal will be present when both line and column are excited. Considerable attenuation is experienced at that same frequency when only one port is excited. Figure 15 shows the test results obtained with one orifice size selected for experiments. Figure 16 shows that the crosstalk, when plotted against the allowable band formed by the hysteresis of the plasma cell, is within the allowable tolerances.

Since the oscillatory control system scheme depends upon signal filtering action caused by the combination of the size of the inlet orifices which connect the fluid control system with the plasma cell (the pneumatic resistance) and the volumetric effects of the plasma cell itself (the pneumatic capacitance) an analysis can be performed.

As previously explained five distinct pressure levels will be experienced in each cell at some point of the matrix fire and extinguish control cycle. Looking only at the extinguish cycle, the neutral pressure level will be the sustain pressure P_q. Extinguish pressure P_o will be seen in the cell when both line and column corresponding to the cell are activated. Activation of either line or column but not both will result in pressure level P_i. In the oscillatory control system, the pressure levels P_i and P_o will fluctuate in an oscillatory manner. These oscillatory pressure levels can be described mathematically using the following analysis.



(a) Cell exitation



(b) Crosstalk

Figure 14. Pressure Excitation and Crosstalk

Assuming subsonic gas flow conditions are present, the 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

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Fig 15

Figure 15. Experimental Cell Pressures Using Oscillatory Signal

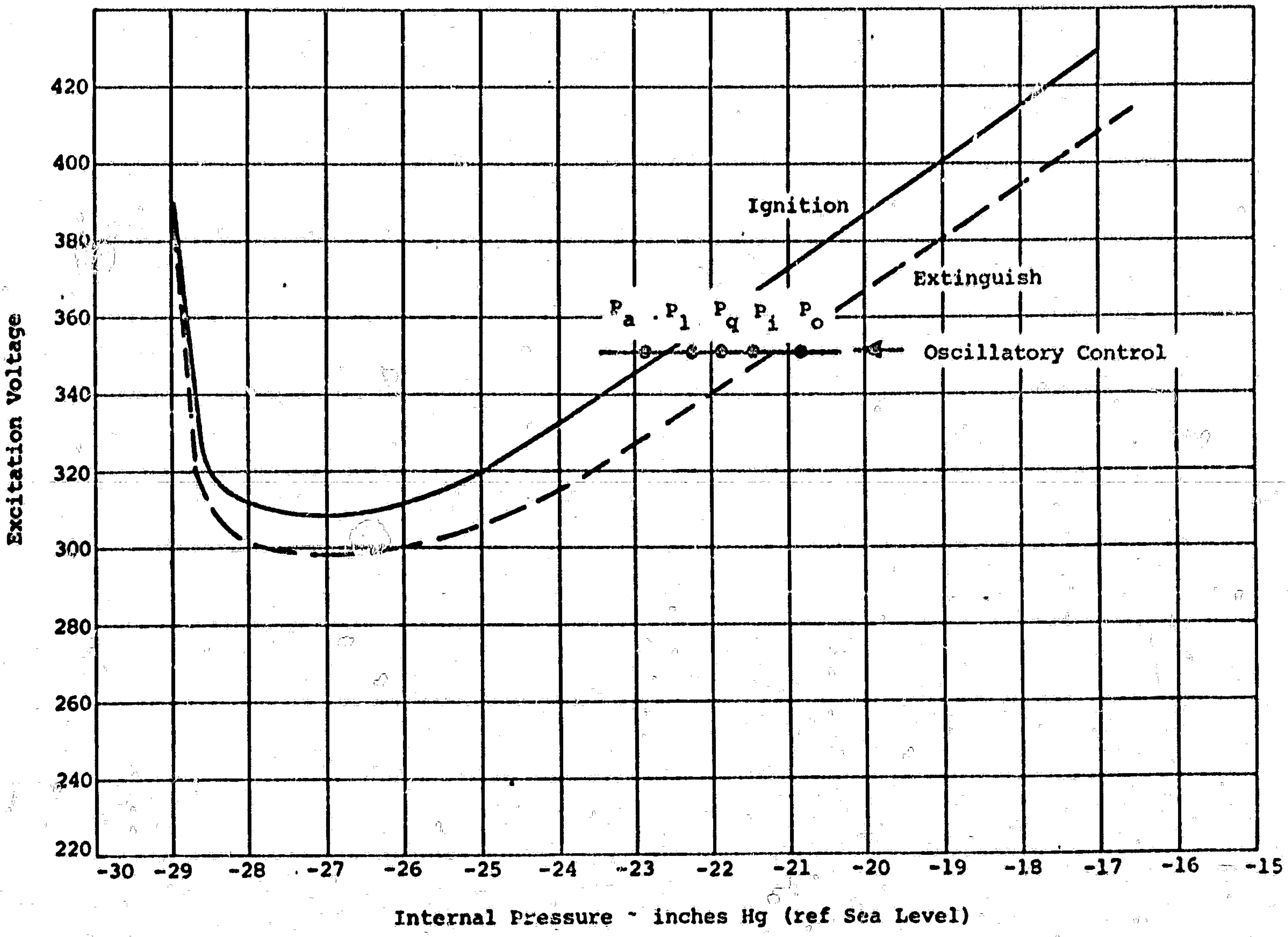

Figure 16. Plasma Cell Pressure Voltage Characteristics

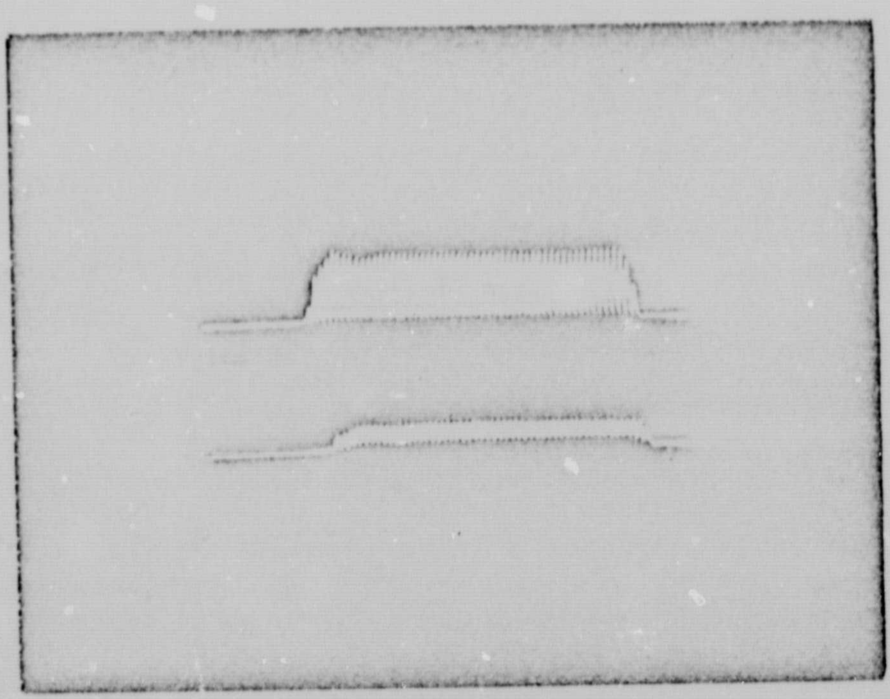

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FIGURE 15 REDUCTION S/S

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

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

g = acceleration of gravity
R = gas constant $in^2/s°R$.

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

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

where

W = weight flow of gas in lb/s
C_G = constant depending on gas
T = absolute temperature.

When cells are addressed by only one line or column signal Figure 17 represents the RC network formed by the cell volume and the two orifices.

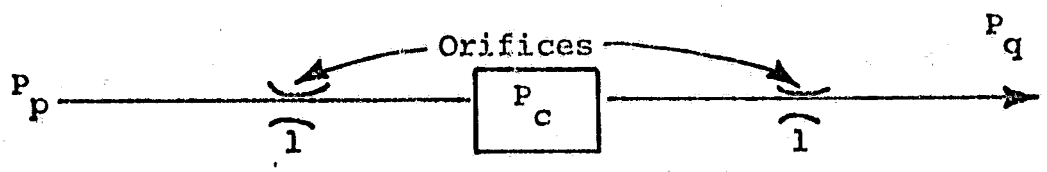

Figure 17. Cell Addressing Network

The oscillatory excitation pressure P_p causes fluctuations in the cell pressure P_c through the inlet orifice. The cell is connected through the second orifice to the quiescent pressure P_q. Utilizing equation (3) to obtain expressions for the flow through each of the two orifices we find

$$W_1 = \frac{C_D\ C_G\ A\sqrt{P_c\quad (P_p - P_c)}}{\sqrt{T}} \tag{4}$$

and

$$W_2 = \frac{C_D\ C_G\ A\sqrt{P_q\quad (P_c - P_q)}}{\sqrt{T}} \tag{5}$$

The rate of change of flow through the first orifice with respect to time will now be:

$$\frac{dW_1}{dt} = \frac{C_G\ A\ C_D\ P_c}{2\sqrt{T}\sqrt{P_c\left(P_p - P_c\right)}}\ \frac{\partial P_p}{\partial t} + \frac{C_G\ A\ C_D\ \left(P_p - 2P_c\right)}{2\sqrt{T}\sqrt{P_c\ \left(P_p - P_c\right)}}\ \frac{\partial P_c}{\partial t} \tag{6}$$

or

$$\frac{dW_1}{dt} = C_1 \frac{\partial P_p}{\partial t} + C_2 \frac{\partial P_c}{\partial t} \quad \text{lb/s}^2 \tag{7}$$

where

$$C_1 = \frac{C_G\ A\ C_D\ P_c}{2\sqrt{T\ P_c\ \left(P_p - P_c\right)}} \tag{8}$$

and

$$C_2 = \frac{C_G\ A\ C_D\ \left(P_p - 2P_c\right)}{2\sqrt{T\ P_c\ \left(P_p - P_c\right)}} \tag{9}$$

Similarly, the rate of change of the flow through the second orifice is represented by

$$\frac{dW_2}{dt} = C_3 \frac{\partial P_c}{\partial t} \quad \text{lb/s}^2 \tag{10}$$

where

$$C_3 = \frac{C_G\ A\ C_D\ P_q}{2\sqrt{T\ P_q\ \left(P_c - P_q\right)}} \tag{11}$$

The net rate of change of the flow through orifices 1 and 2 should be equal to the change of the mass of the gas accumulated inside the cell.

The gas inside the cell is governed by the universal gas law

$$P_c\ V = MRT \tag{12}$$

where

V = cell volume
M = mass of gas

Since volume and temperature can be considered constants the rate of change of the gas mass inside the cell can be described by

$$\frac{dM}{dt} = \frac{V}{RT}\frac{dP_c}{dt} \text{ lb/s} \tag{13}$$

The rate of change of the above quantity should be equal to the net flow into the cell or

$$\frac{d}{dt}\left(\frac{V}{RT}\frac{dP_c}{dt}\right) = \frac{dW_1}{dt} - \frac{dW_2}{dt} \tag{14}$$

Using the Laplace operator s to define differentiation

$$\frac{Vs}{RT}\frac{dP_c}{dt} = C_1\frac{dP_p}{dt} + C_2\frac{dP_c}{dt} - C_3\frac{dP_c}{dt}$$

or after rearranging

$$\frac{dP_c}{dP_p} = \frac{\dfrac{C_1}{C_3 - C_2}}{1 + \dfrac{V}{RT\left(C_3 - C_2\right)}S} \tag{15}$$

is obtained as a relationship between cell pressure P_c and excitation pressure P_p.

This relationship is of the form

$$\frac{dP_c}{dP_p} = \frac{K}{1 + \tau s}$$

where K is the gain of the signal transmission and τ is the time constant. Substituting the original values

$$K = \frac{1}{\left(\dfrac{P_q}{P_c}\right)^2 + 1} \tag{16}$$

$$\tau = \frac{V\, C_G\, C_D \left(\dfrac{P_q}{P_c}\right)\sqrt{\dfrac{P_c}{P_q} - 1}}{2R\sqrt{T}\, A\left(\dfrac{P_q}{P_c}\right)^2 + 1} \tag{17}$$

Typical values for the plasma display cells previously developed under this contract are:

V for a 1 mm diameter cell of 1 mm thickness is 0.5×10^{-4} in ^{3}.

C_G for neon $= \sqrt{\frac{2g}{R}} = \frac{64.4}{76.5} = 0.842$

$C_D = 0.8$

R for neon = 76.5 ft lb/lb - R

T = room temperature in °R = 530

$A = \frac{\pi}{4} 0.008^2 = 0.5 \times 10^{-4} \text{ in}^2$

$P_q = 9$ psia

$P_c = 10$ psia

Substituting these values into equation (17) will result in $\tau = 3.15 \times 10^{-4}$ seconds which is equivalent to a 500 Hz frequency.

At zero frequency or steady state no net mass of gas is accumulated in the cell, thus $W_1 = W_2$. Equating previously established relationships (Equations (4) and (5)) will result in

$$P_c (P_p - P_c) = P_q (P_c - P_q) \qquad (18)$$

using $P_c = 10$ psia and $P_q = 9$ psia we find $P_p = 10.9$ psia.

Figure 18 shows the percentage of the magnitude of the oscillatory signal still admitted to the cell when the cells are constructed with the dimensions shown previously. At a frequency of 3000 Hz, only 20 percent of the oscillatory frequency is admitted to the cell when only one signal (either line or column) is present.

When both line and column control signals are oscillating in phase, it is expected that at least 90 percent of the amplitude of the signals will be transmitted to the cell. Figure 19 indicates the relative pressure levels which will be obtained with an oscillatory control system as described. The illustration also shows the pressure levels required for normal fluid control systems.

As shown in Figure 19, the extinguish and fire levels of a typical pressure controlled display cell may be 8 and 10 psia respectively. This means that a pressure level below 8 psia will cause the cell to fire, and a pressure level exceeding 10 psia will extinguish the cell. Typically, a safety margin to account for variations in different cells is required, thus necessitating a firing pressure level of approximately 7.75 psia (F_2) and an extinguish level of 10.25 psia (E_2). The construction of the pneumatic circuit will also cause a change in pressure level from the quiescent cell level (Q) when only one signal (either line or column) is sent to the cell. Since

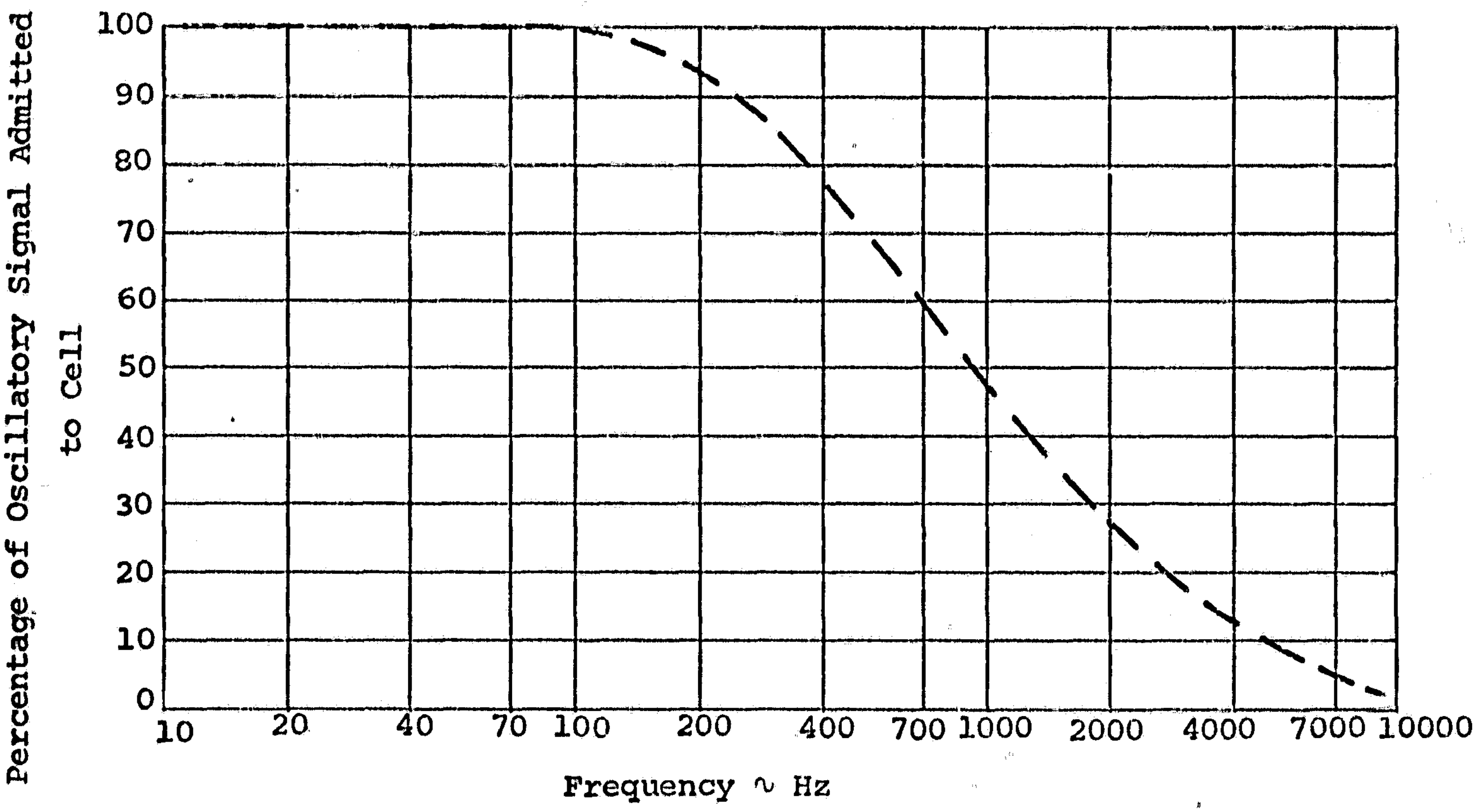

Figure 18. Control Signal Levels

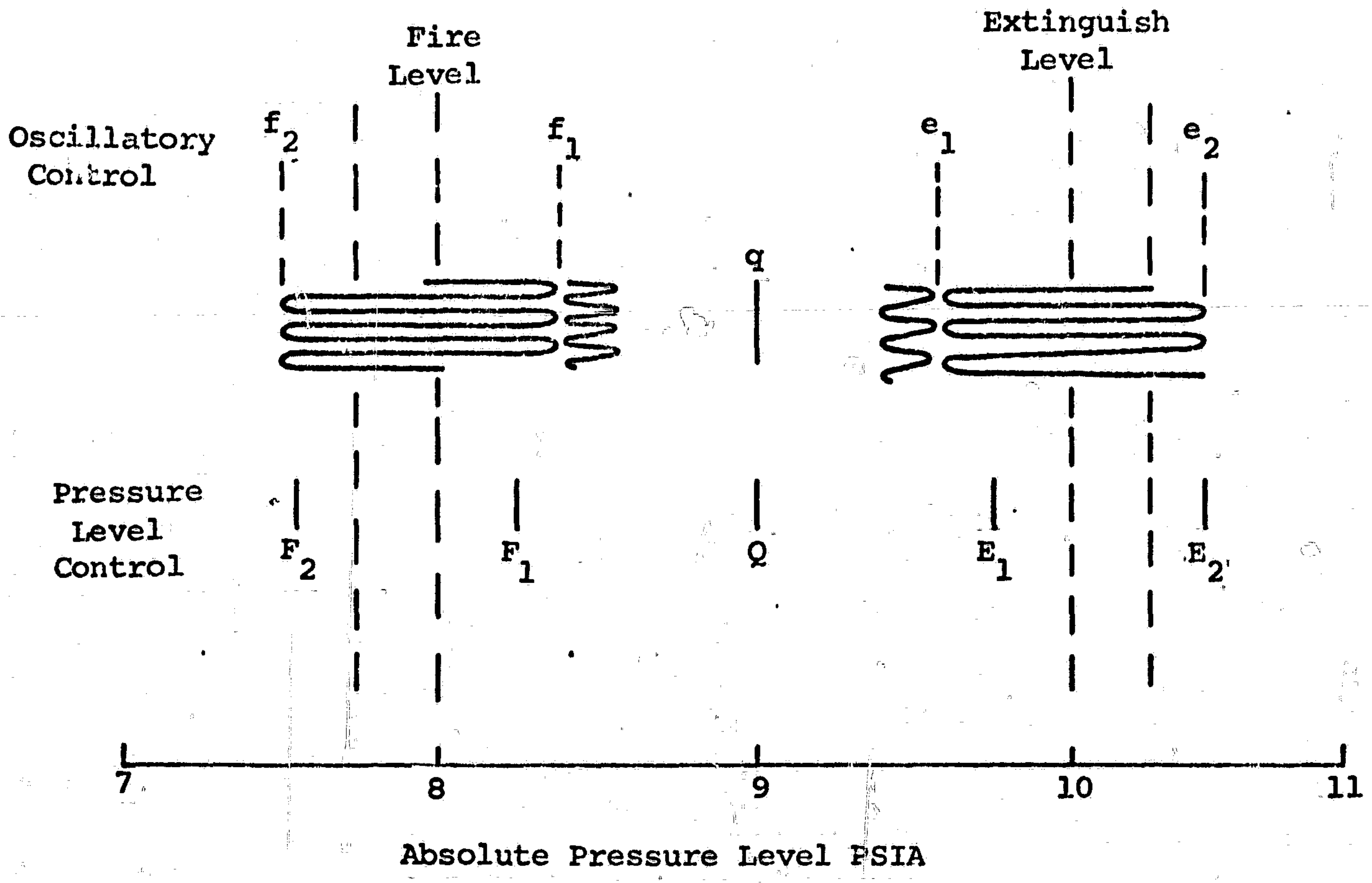

Figure 19. Cell Control Pressure Levels

a signal originating from only one source (line or column) should not change the state of that cell, these pressure levels, F_1 (one fire command) and E_1 (one extinguish command), should fall between the fire and extinguish levels. As can be seen in Figure 15, a safety margin of 0.25 psi is available. When oscillatory control is used, the sinusoidal peaks causing extinguishing and firing of the cell (at levels F_2 and E_2 respectively) are still of the same magnitude as used in the pressure level control system (F_2 and E_2). However the sinusoidal pressure peaks caused in the cell when either line or column command signals alone are received are at least 60 percent farther away from the fire and extinguish levels obeyed by the cell. The margin of safety, now increased to 0.4 psi, makes it possible to loosen tolerances on cell dimensions and electrode construction to a much wider range than previously allowable. The oscillatory control system method can be used in conjunction with the fluidic plasma control system as well as with some other pressure control systems described in the following paragraphs.

Pressure Control Systems

During the course of this contract, it was decided to include investigations on line and column control systems other than those driven by fluidic logic networks. Such systems, when feasible, could be built without a pneumatic power supply, thus reducing the complexity of the control system. The elimination of the small gas compressor will also reduce the amount of contamination of the neon gas, which in turn affects the useful lifetime of a display system.

Several mechanizations of direct pressure control without the utilization of a fluidic logic network to provide the extinguish and fire pressures are possible. Figure 20 shows in principle the basic mechanization of this control system. Two possible electrode locations are shown. In principle, the pressure control system will extinguish or fire a display cell when the flexible diaphragm is moved. Movement of the diaphragm will change the volume of the pressure cavity. The change in volume will cause a change in gas pressure in the pressure cavity. The pressure change in the pressure cavity will in turn result in pressure changes in the display cell cavity since the two cavities are in communication through a connecting orifice. The flexible diaphragm can be mechanized with metal bellows or resilient materials. Movement of the diaphragm can be instigated with piezoelectric crystals or by electromechanical actuators which can utilize the low voltage signals available from a computer when the display is used as a computer readout device.

Line and column control is mechanized by connecting the cells to a common pressure cavity as shown in Figure 21. This illustration shows the display cells connected to a common pressure cavity. A second cavity located perpendicular to this cavity will constitute the second part of a complete line and column control system.

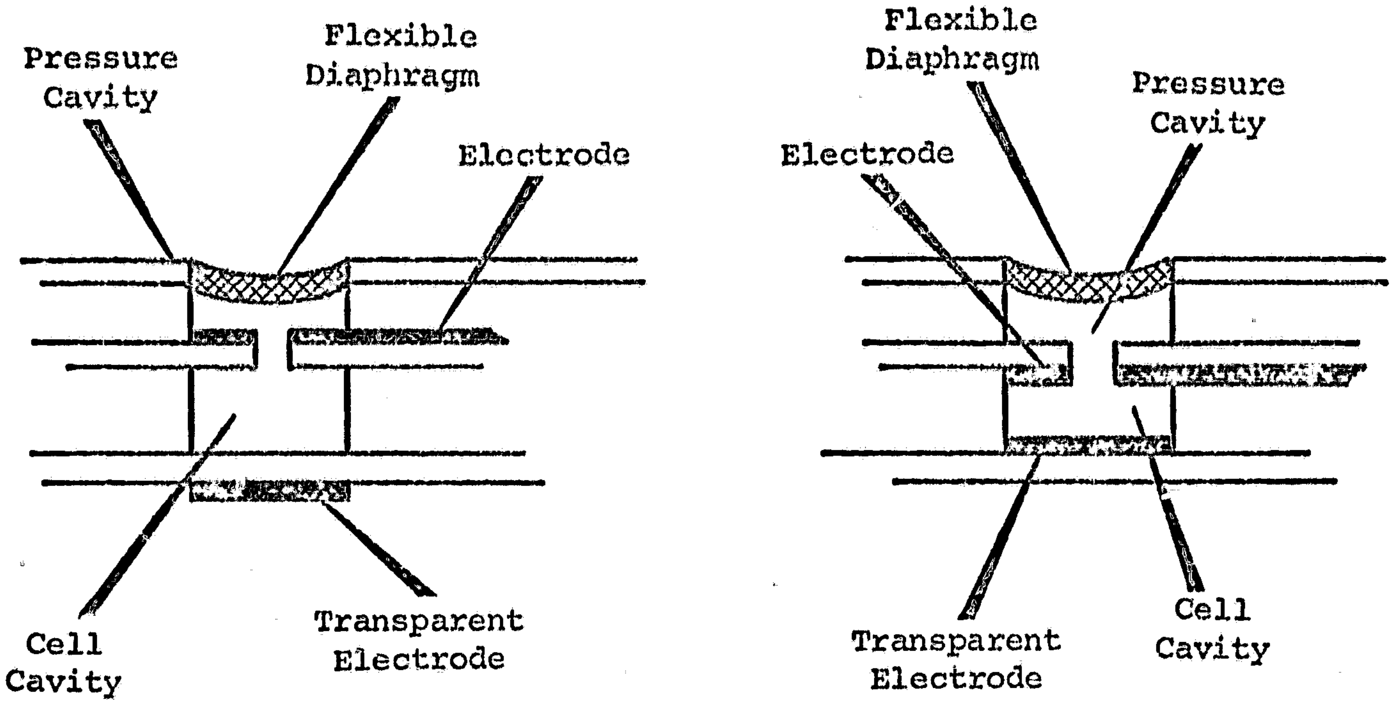

Figure 20. Pressure Controlled Plasma Display Cells

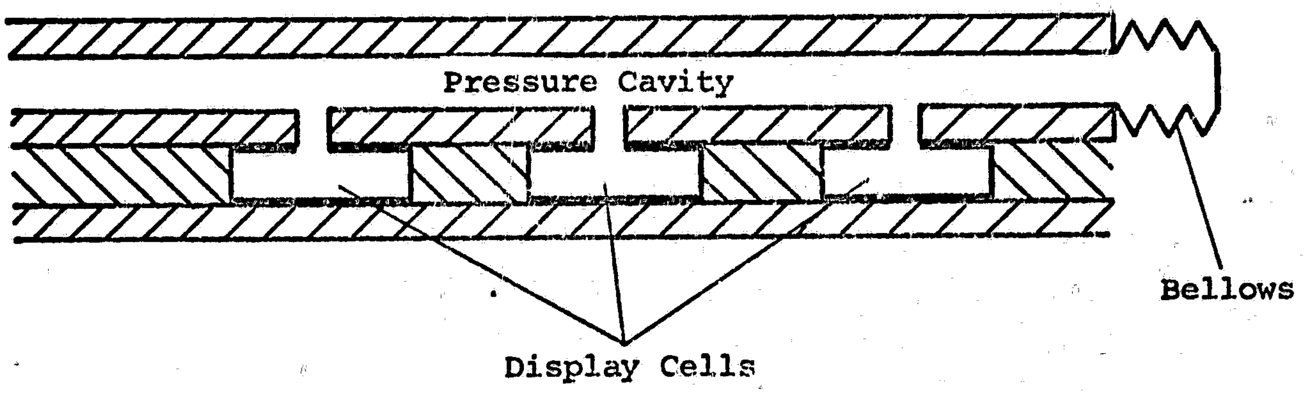

Figure 21. Line and Column Control Mechanization

Figure 22 is a photograph of the experimental 4 cell matrix built to ascertain feasibility of this approach to line and column pressure control systems for plasma display matrices. The complete system is shown schematically in Figure 23. This system is filled with neon gas at a pressure level which is centered in the hysteresis band of the particular display cells for a preset sustaining voltage across the electrodes. Simultaneous actuation of a line and a column bellows will cause a change in pressure level in the corresponding cell which is sufficient to change the state of this cell. With proper design, actuation of only the line or the column bellows will not cause sufficient changes in the cell pressure level to change the status of the cells in that particular line or column. When necessary, this system can be combined with the oscillatory type control system previously described.

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Fig 22

Figure 22. Experimental Hardware Plasma Display

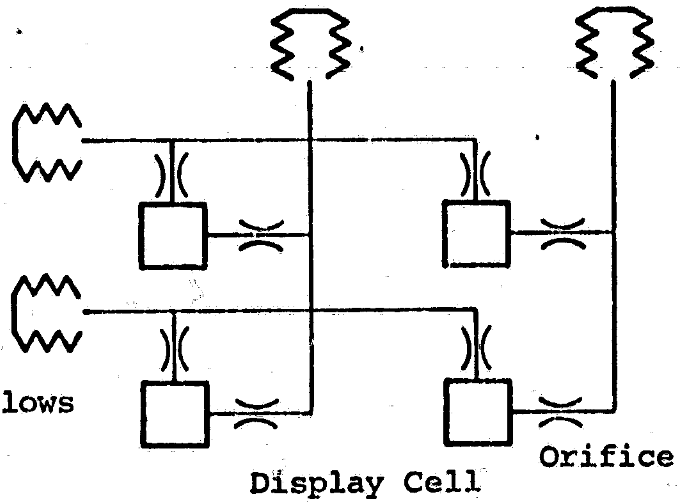

Figure 23. Schematic of Pressure Control System

Experimental and demonstration hardware built during this contract is described in the Appendix of this report.

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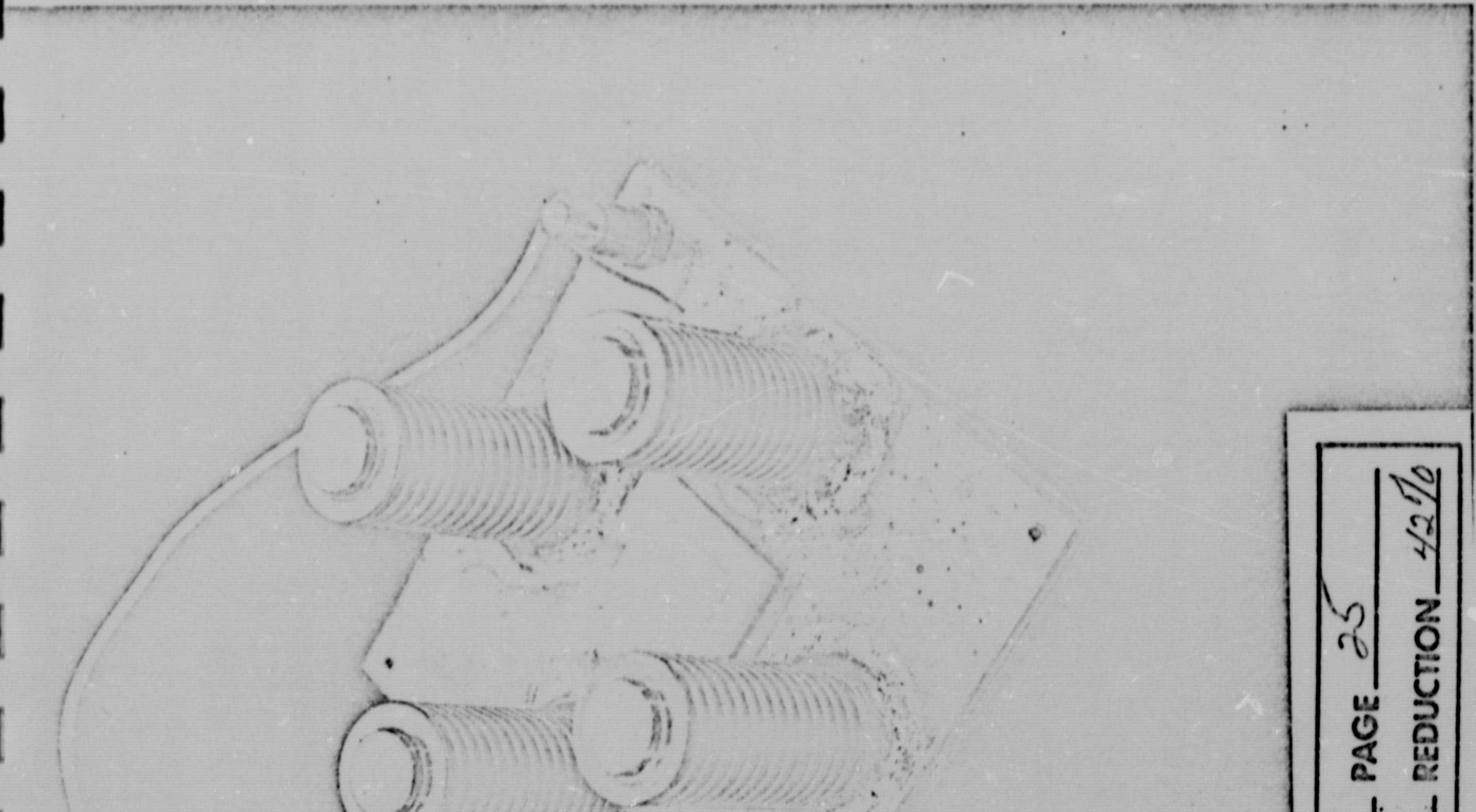

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FIGURE 22 REDUCTION 42%

Fig 22

CONCLUSIONS AND RECOMMENDATIONS

Analysis and experiments have shown conclusively that fluidic control systems for plasma display systems are feasible. The main advantage of such a system over electronically controlled systems would be an increase in reliability. The disadvantage of this system is presently the lack of adequate compressors that can provide the required pneumatic power to drive such a display system. Presently available compressors do not have the required pressure and flow level in combination with a design which keeps the circulating neon gas at a reasonably low contamination level.

Considerable improvement over pure fluidic control systems can be obtained with other pressure level control systems as described in this report. These pressure level control systems do not require a circulating compressor, thus eliminating a source of contamination of the neon gas or other gases used in the system. In addition, no power to drive the compressor is necessary, and elimination of the compressor will also result in a reduced volumetric requirement of the complete display system.

Further development of pressure controlled plasma display systems will result in a potentially more reliable display system at considerable lower cost than present day electronically controlled system. This development will require the following areas of investigation:

<u>1</u> A survey of better manufacturing methods of display cell matrices resulting in more uniform cell configurations. (As reported elsewhere this problem also plagues electronically controlled systems.)

<u>2</u> A study determining the optimum interface between the computer and the pressure cavities of the display systems. (Electromechanical devices or piezoelectric crystal are two mechanisms which should be considered in this study.)

APPENDIX

EXPERIMENTAL HARDWARE

Three different types of experimental hardware were designed and built under this contract. The fluidic control system concept was investigated with the help of an experimental 4-cell matrix and a fluidic control system complete with compressor and valving system to simulate computer input signals. The oscillatory control system was tested with a matrix built on a larger scale and the pressure control system was analyzed with several 4-cell matrices. Each one of these experimental setups is described in detail below.

Fluidic Control System.--After several attempts to obtain a four cell matrix failed, due to inadequate sealing of the glass cells to their cover plates, the matrix was redesigned. Leakage paths developed from cell to cell due to adhesive shrinkage. These leakage paths caused changes in the pressure levels of some cells when adjacent cells were subjected to commanded pressure fluctuations.

The problem was solved by using one glass plate which contained the cell cavities in conjunction with individual glass covers for each cell. A liberal amount of epoxy around each cover ensured complete isolation from cell to cell. Indications are that presently used methods to manufacture electronically manipulated plasma display matrices may not be entirely useful for pressure operated displays, because of the cross leakage from cell to cell. In electronically operated displays a constant internal cell pressure is maintained so that leakage paths from cell to cell will not affect the working of the electronic device.

It is recommended that during succeeding development stages of the pressure operated plasma display, attention be paid to this problem. For research and exploratory development efforts, however, present methods of manufacturing are adequate.

The final design of the four-cell matrix used for further experiments is shown in Figure 24. The first series of experiments done with this matrix resulted in fire-extinguish pressure levels which varied considerably from cell to cell. These variations were mainly due to differences in cell dimensions. Experiments were conducted with various etched electrode geometries to determine whether cell-to-cell variations in operating characteristics could be adjusted for by varying electrode geometry and location. The results proved that such an adjustment was possible, but not completely satisfactory. Figure 25 shows the voltage versus pressure traces after final adjustments of the electrodes.

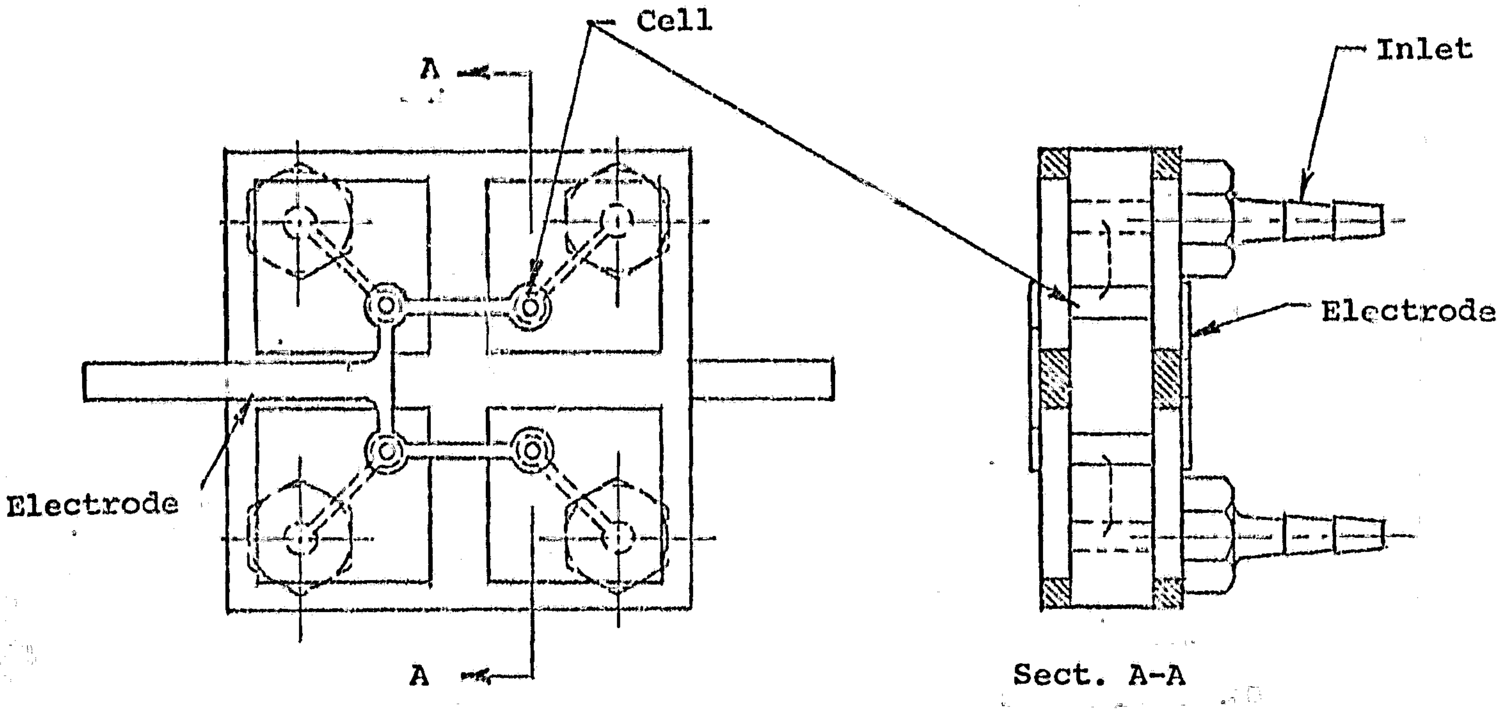

Figure 24. Four Cell Plasma Matrix

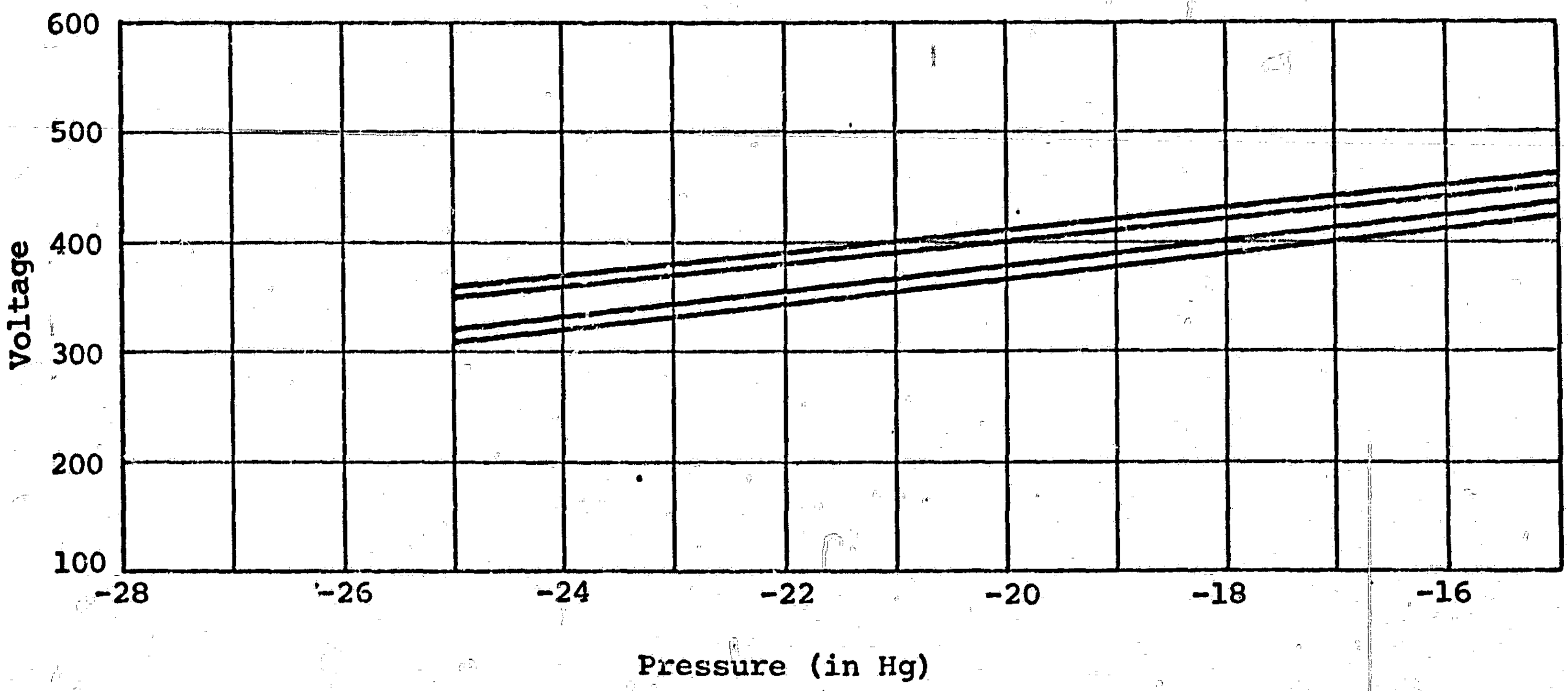

Figure 25. Cell Voltage-Pressure Relationship

The fluidic control systems designed for these experiments are shown in Figure 26. A schematic of the control module is shown in Figure 27. Each line and column is addressed by two fluidic logic gates to obtain the three pressure levels necessary to fire, sustain or extinguish the display matrix cells.

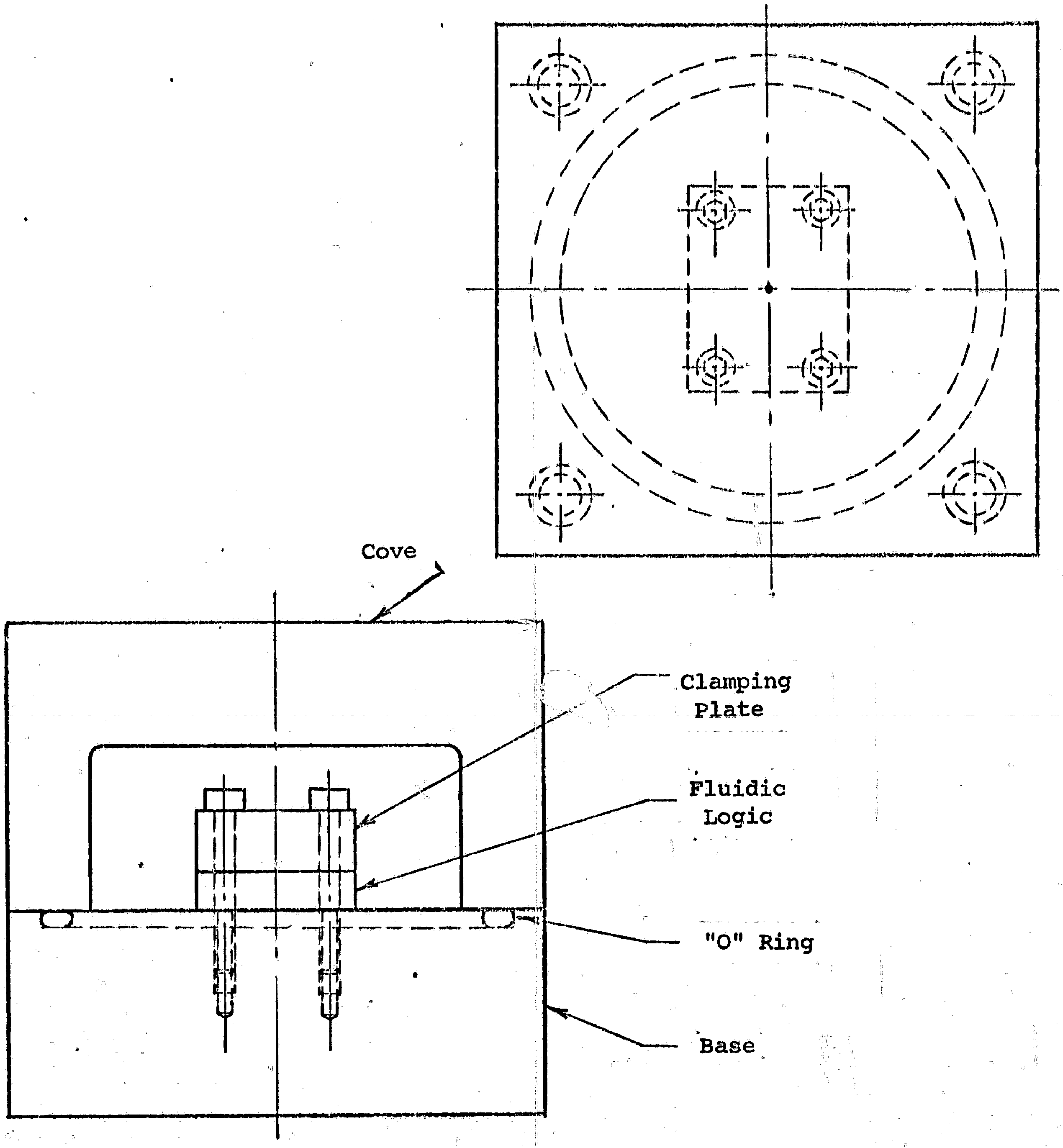

Figure 26. Fluidic Logic and Fixture Assembly

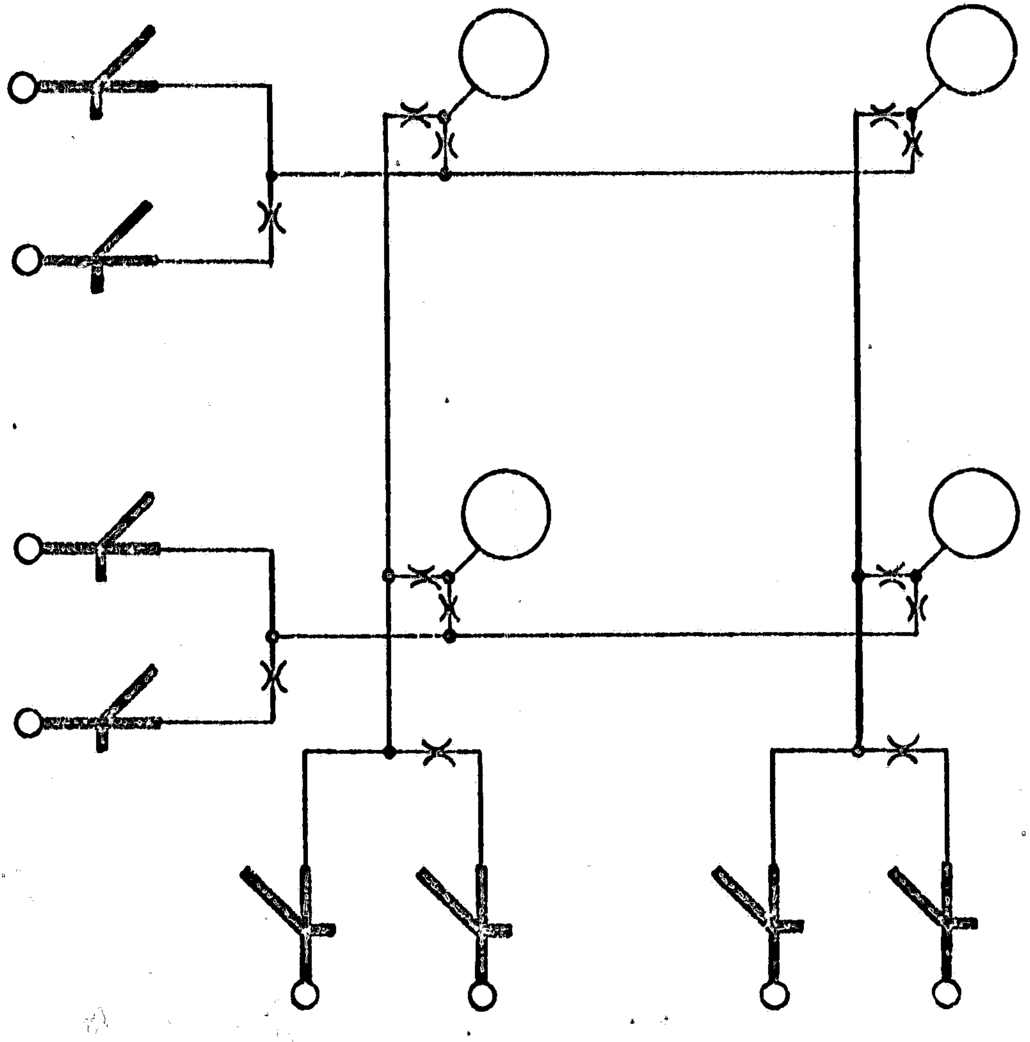

Figure 27. Schematic of Plasma Cells and Control Elements

Power Supply.--A survey has been conducted to determine type, cost and capacity of pumps presently available on the market which are compatible with the requirements for operation of a pressure controlled plasma display matrix.

The survey showed that pumps with output characteristics matching the present scope of work were not available. Most of the units that met the specifications for pressure range and neon gas contamination had a flow capacity which exceeded the requirements by a considerable margin. All pumps surveyed which showed output flow rates compatible with a small plasma display matrix did not meet the specifications for leakage and contamination rates.

The in-house design and fabrication of a pump meeting all requirements has been considered. Cost for a project of that scope however proved beyond the available funding. Consequently, the choice was made to obtain the larger pump. This selection was based partly on the idea that matrices with an increased number of cells could be accommodated.

A Dia-Pump model 08-800-71 from Air Control Incorporated was selected as the unit most desirable for our purposes. This pump was purchased and used to drive the fluidic element's neon supply. The complete system is shown in Figure 28 undergoing test.

Fig. 28
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Figure 28. Fluidic - Plasma Display Setup

Oscillatory Control System.--A schematic of the experimental hardware used to analyze the performance of an oscillatory type control system was shown in Figure 11 and test results were described in previous sections of this report. Of interest is the placement of the pressure transducer in the display cell cavity. To avoid introducing additional filtering of the cell pressure changes through pneumatic instrumentation interconnections the pressure transducer had to be placed directly adjacent to the cell. Figure 29 shows schematically on a much enlarged scale the placement of the transducer.

Pressure Control System.--Figure 30 shows the demonstraion hardware developed to ascertain the feasibility of the pressure control systems. The pressure signals in line and column are generated by movement of the bellows which are part of the test setup. Each of the bellows is connected to a line or column of the control system. The display cells used with this setup are illustrated in Figure 31. The line and column pressure cavities are in direct communications with each of the cells as previously described and as illustrated in Figure 21.

Several display cell constructions have been tried on this setup. Cells manufactured from quartz plates proved the most successful. Repeatability from cell to cell on matrices built from soft glass or aluminum oxide 96 percent pure ceramic leaves something to be desired. Tests conducted with the quartz matrix showed that selective extinguishing of individaul cells by depressing the corresponding line and column bellows can be accomplished.

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FIGURE 29 REDUCTION 44%

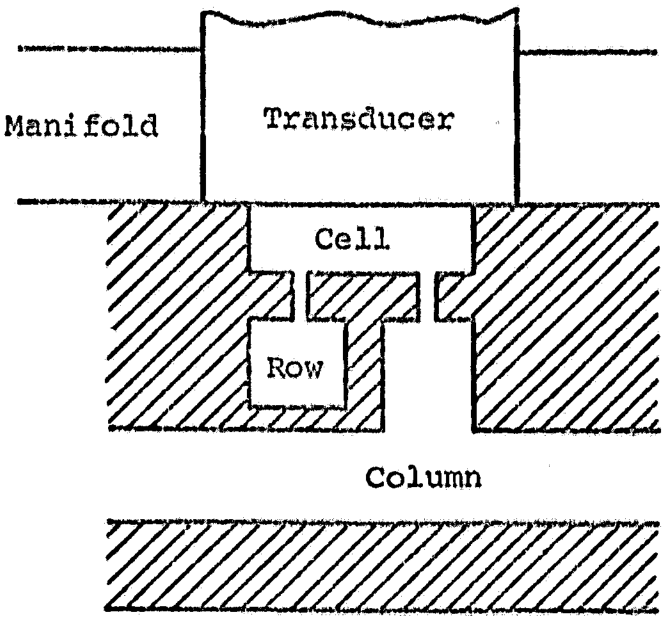

Figure 29. Cross Section of Single Plasma Plasma Cell in Test Matrix

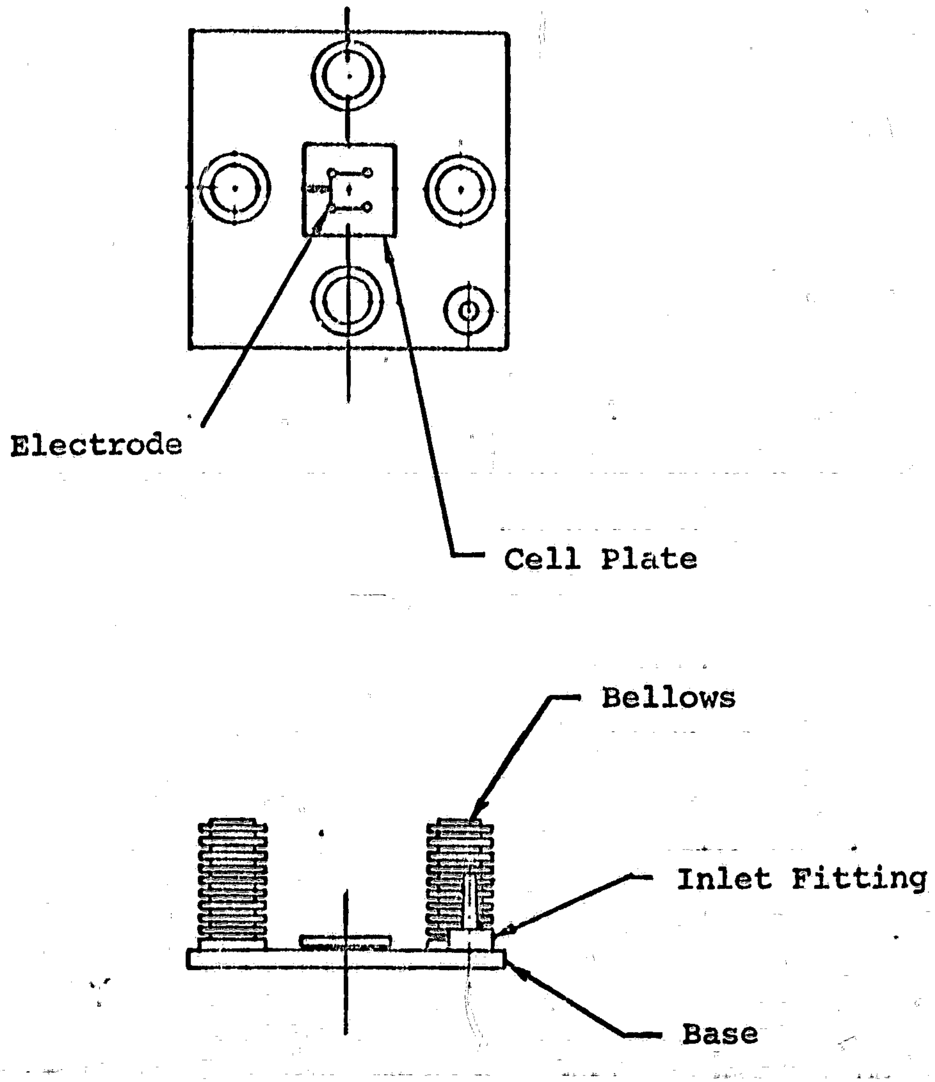

Figure 30. Plasma Matrix Test Setup

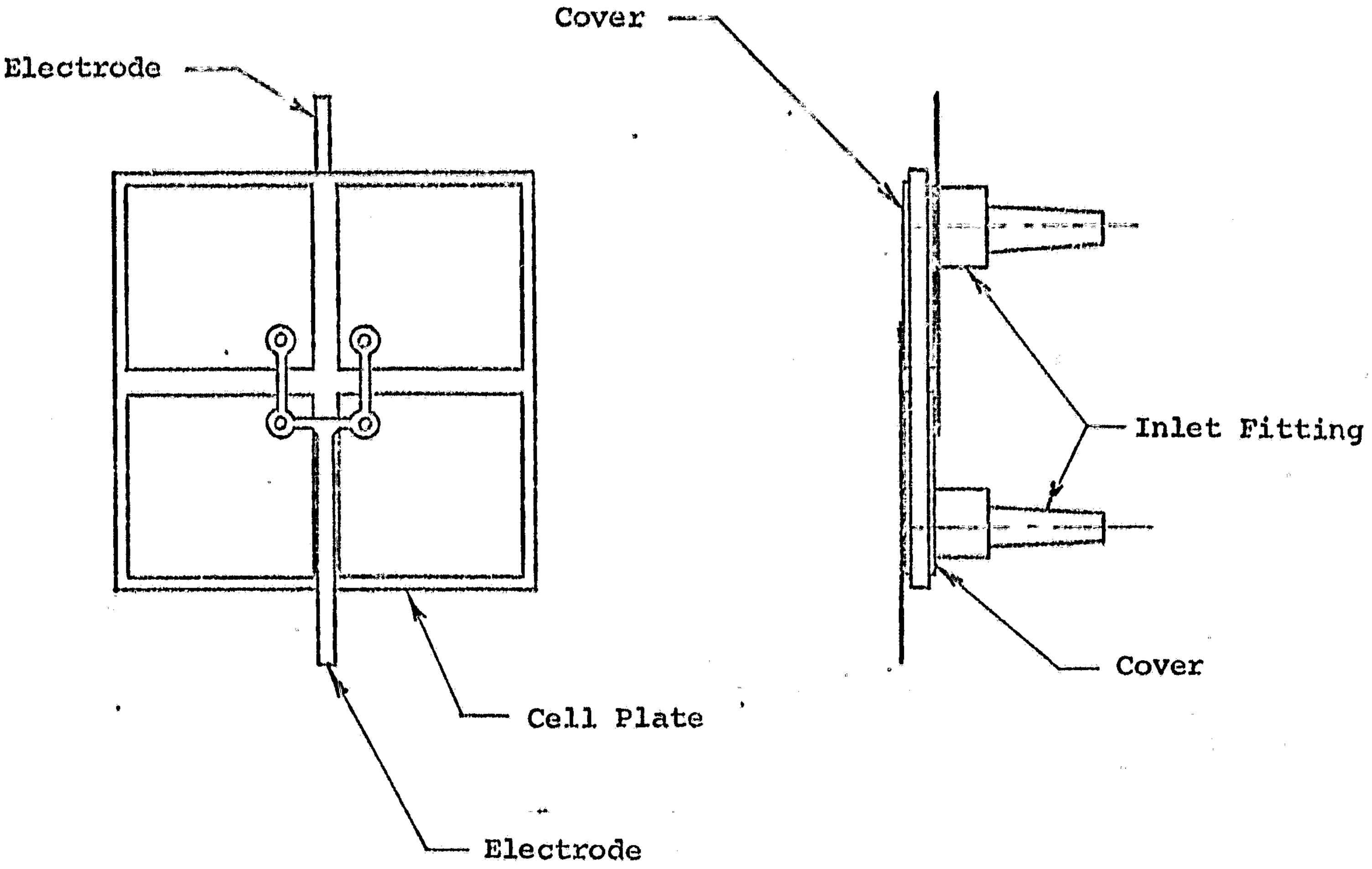

Figure 31. Plasma Cell Matrix

Some voltage adjustment on the individual cells was necessary to compensate for the nonuniformity of the cell characteristics. These nonuniformities were caused by variations in cell dimensions, and thus firing characteristics, caused by the cell manufacturing process used.